Neutronic Analysis of the 1D and 1E Banks Reflux Detection System

by

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***Samer D. Kahook
Westinghouse Safety Management Solutions, LLC***

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ABSTRACT

Two H Canyon neutron monitoring systems for early detection of postulated abnormal reflux conditions in the Second Uranium Cycle 1E and 1D Mixer-Settler Banks have been designed and built. Monte Carlo neutron transport simulations using the general purpose, general geometry, n-particle MCNP code have been performed to model expected response of the monitoring systems to varying conditions.

The confirmatory studies documented herein conclude that the 1E and 1D neutron monitoring systems are able to achieve adequate neutron count rates for various neutron source and detector configurations, thereby eliminating excessive integration count time. Neutron count rate sensitivity studies are also performed. Conversely, the transport studies concluded that the neutron count rates are statistically insensitive to nitric acid content in the aqueous region and to the transition region length.

These studies conclude that the 1E and 1D neutron monitoring systems are able to predict the postulated reflux conditions for all examined perturbations in the neutron source and detector configurations. In the cases examined, the relative change in the neutron count rates due to postulated transitions from normal ²³⁵U concentration levels to reflux levels remain satisfactory detectable.

TABLE OF CONTENT

NEUTRONIC ANALYSIS OF THE 1D AND THE 1E BANKS REFLUX DETECTION SYSTEM (U)...	I
ABSTRACT.....	IV
TABLE OF CONTENT	V
1.0 INTRODUCTION.....	1
1.1 Summary.....	1
2.0 DESCRIPTION.....	2
2.1 Description of the 1D and 1E Banks	2
2.1.1 Material Description of the 1D and 1E Banks.....	5
2.1.1.1 Aqueous Material.....	5
2.1.1.2 Solvent/Organic Material.....	6
2.1.1.3 Mixing and Transition Regions Material.....	7
2.2 Description of the Extraneous Neutron Source	7
2.2.1 Neutron Source Packages.....	7
2.3 Description of the Neutron Detector.....	10
2.4 Neutron Monitoring Systems.....	12
2.4.1 Stage 11 of the 1E Bank.....	12
2.4.1.1 The 1E Bank Detector Package.....	12
2.4.1.2 The 1E Bank Pu-Be Source Package	13
2.4.2 Stages 5 and 6 of the 1D Bank	13
2.4.2.1 The 1D Bank Detector Package	13
2.4.2.2 The 1D Bank Pu-Be Sources.....	14
3.0 ASSUMPTIONS	15
4.0 METHODOLOGY	16
4.1 Neutron Spectra and Source Strength Model.....	17
4.2 Material Models.....	18
4.2.1 Polyethylene.....	19
4.2.2 Type 304 Stainless Steel.....	19
4.2.3 Tantalum.....	19
4.2.4 Pu-Be.....	20
4.2.5 BF ₃	20
4.2.6 1D and 1E Material S(α,β) Tables.....	20
4.3 Neutron Count Rate	21
4.4 Geometry	22
4.4.1 1E Bank MCNP Model	22
4.4.2 1D Bank MCNP Model.....	22
5.0 RESULTS.....	23
5.1 Results of the 1E Bank Studies.....	23
5.2 Results of the 1D Bank Studies	25
5.3 Comparison of the 1D Bank Results with the 1E Results.....	26
5.4 Benchmark, Verification, and Validation Studies.....	27
5.4.1 Thermal Sensitivity of the BF ₃ Probes.....	27
5.4.2 Benchmark of the 1D Bank Model.....	29
6.0 REFERENCES.....	31
APPENDIX A. NEUTRON SOURCE SPECTRA FROM A ONE CI PU-BE NEUTRON SOURCE	33

APPENDIX B. THE MCNP MODEL FOR THE 1E BANK.....	34
APPENDIX C. THE MCNP MODEL FOR THE 1D BANK.....	39
APPENDIX D. SENSITIVITY STUDIES OF THE 1E BANK NEUTRON MONITORING SYSTEM	46
D.1 SENSITIVITY OF THE DETECTOR POSITION ON THE 1E BANK COUNT RATE AND REFLUX DETECTABILITY	48
D.2 SENSITIVITY OF THE SOURCE POSITION ON THE 1E BANK COUNT RATE AND REFLUX DETECTABILITY	49
D.3 EFFECTS OF SOURCE & DETECTOR POSITION ON THE NEUTRON COUNT RATE AND REFLUX DETECTABILITY	51
D.4 COUNT RATE AND REFLUX DETECTABILITY SENSITIVITY DUE TO THICKNESS OF THE BOTTOM, FRONT, AND BACK PLATES OF THE 1E BANK.....	51
D.5 SENSITIVITY OF THE TRANSITION REGION LENGTH ON THE COUNT RATE AND REFLUX DETECTABILITY	52
D.6 AFFECTS OF THE ERRONEOUS SDEF VALUES ON THE NEUTRON COUNT RATES OF THE 1E BANK.....	53
APPENDIX E. SENSITIVITY STUDIES OF THE 1D BANK NEUTRON MONITORING SYSTEM	55
E.1 SENSITIVITY OF THE DETECTOR POSITION ON THE 1D BANK COUNT RATE AND REFLUX DETECTABILITY	55
E.2 1D BANK COUNT RATE SENSITIVITY DUE TO SOURCE PACKAGE LOCATION.....	57
E.3 EFFECTS OF SOURCE & DETECTOR POSITION ON THE NEUTRON COUNT RATE AND REFLUX DETECTABILITY	57
E.4 SENSITIVITY OF THE TRANSITION REGION LENGTH ON THE COUNT RATE AND REFLUX DETECTABILITY	59
E.5 COUNT RATE AND REFLUX DETECTABILITY SENSITIVITY DUE TO NITRIC ACID IN THE AQUEOUS MATERIAL.....	60
DISTRIBUTION LIST	62

Neutronic Analysis of the 1D and the 1E Banks Reflux Detection System (U)

1.0 INTRODUCTION

The Nuclear Materials Stabilization & Storage Division (NMS&S) of the Westinghouse Savannah River Company (WSRC) has postulated that certain initiating events can lead to abnormal and undesirable reflux conditions in a number of stages¹ of the Second Uranium Cycle 1D and 1E Banks [1]. A reflux condition can cause the uranium concentration in the solvent and/or aqueous regions to rise in certain stages and drop in others.² Although neutron monitor systems³ are installed on the 1D and 1E Banks, most of the affected stages are located far enough away from the installed neutron monitoring systems such that the postulated changes in the uranium levels are not detectable.

Westinghouse Safety Management Solutions, LLC, (WSMS) was tasked by NMS&S to perform neutron transport studies so that Neutron Monitor (NM) systems can be designed for the early detection of the postulated abnormal reflux conditions in the Second Uranium Cycle 1D and 1E Banks [1]. An acceptable design of the neutron monitoring system consists of one that meets the following two conditions:

- ↳ *the monitoring system should be configured such that an adequate neutron count rate (> 50 n/sec is obtained), since low neutron count rates require the integration count time to be excessive and may reduce the amount of time available to correct for the postulated reflux condition; and*
- ↳ *the postulated reflux conditions should cause a minimum of 5% increase in the neutron count rate.*

The aforementioned task was completed by WSMS and documented in Reference [2]. Reference 2 outlines the minimum design requirements of the neutron monitoring system such that the postulated reflux conditions can be detected in its early stages. NMS&S built neutron monitor systems that met the design requirements of Reference 2.

This report documents the neutronic studies performed on the as-built configuration of the neutron monitoring systems. Additionally, neutronic studies performed to test the numerical models are included herein. The normal and abnormal reflux conditions' neutron count rates due to design tolerances are also investigated and documented in this report.

1.1 Summary

Neutron monitoring systems for early detection of postulated abnormal reflux conditions in the Second Uranium Cycle 1E and 1D Mixer-Settler Banks have been designed, built, and tested through the application of numerical modeling. The numerical tests that have been performed in this manner consist of detailed three-dimensional Monte Carlo neutron transport simulations utilizing the general purpose, general geometry, n-particle MCNP Code.

¹ *The reflux conditions are postulated to occur in Stages 10 and 11 of the 1E Bank and in Stages 3 through 8 of the 1D Bank.*

² *The 1D Bank, which is an extraction bank, employs sixteen stages while the 1E Bank, which is a stripper bank, employs twelve stages.*

³ *A neutron monitor system for the referenced 1D and 1E Banks consists of a neutron source, normally a one Ci Pu-Be, and a neutron detector.*

The neutron transport studies concluded that the 1E and 1D neutron monitoring systems are able to achieve adequate neutron count rates for various neutron source and detector configurations, thereby eliminating excessive integration count time. These studies also concluded that the neutron count rate is quite sensitive to the following:

- ↳ the position of the neutron detector package,
- ↳ the position of the neutron source package, and
- ↳ the thickness of the stainless-steel plates of the 1E and 1D Mixer-Settler stages.

Additionally, the neutron transport studies concluded that the neutron count rate is statistically insensitive to the following (statistically indistinguishable, i.e., changes in the neutron count rates are within the statistical uncertainties of the Monte Carlo simulations):

- ↳ Nitric acid content in the aqueous region (and mixing and transition regions).
- ↳ Transition region length.

More importantly, the studies documented herein concluded that the 1E and 1D neutron monitoring systems are able to predict the postulated reflux conditions for all examined perturbations in the neutron source and detector configurations. That is, despite relatively large perturbations in the 1E and 1D neutron monitoring systems configurations (more than twice the as-built tolerances) the relative change in the neutron count rates due to the postulated transitions from normal ^{235}U concentration levels to reflux levels remain sufficiently large enough, i.e., greater than 5%.

2.0 DESCRIPTION

In the sections that follow, the various systems (banks, neutron sources, and neutron detectors), postulated reflux conditions, and relevant input data needed to perform the analyses documented herein are described.

2.1 Description of the 1D and 1E Banks

The 1E and 1D Banks consist of various numbers of counter flow stages used in the stripping or extraction process. Each stage of the 1D and 1E Banks consists of three distinct material regions, as follows:

- ↳ the aqueous region consisting of a homogeneous mixture of light water⁴ and uranium;
- ↳ the solvent/organic region consisting of a homogeneous mixture of 7.5 vol. % TriButyl Phosphate (TBP), 92.5 vol. % n-Paraffin, and uranium; and
- ↳ the mixing and transition⁵ regions, both consisting of a homogeneous mixture of 30 vol. % aqueous and 70 vol. % solvent/organic materials. The fractions provided herein are volume-based fractions.

⁴ Depending on the flow stream/feed-line, the aqueous region would contain HNO_3 at varying concentrations.

⁵ In reality, the transition region would be comprised of a mixture of aqueous and organic materials at varying volume fractions through out its flow path.

Depicted in Figure 1 is a side view schematic of a mixer-settler stage. The different material regions of a mixer-settler and direction of flow within one mixer-settler stage is also shown in Figure 1.

Figure 1. Side View Schematic of a Mixer-Settler

A top view schematic of six⁶ stages in a mixer-settler bank is presented in Figure 2. As depicted in Figures 1 and 2, the organic and aqueous phases flow concurrently from the mixing section through the settling section. In the settling section, the organic and aqueous phases are separated by gravity (Figure 1). At the end part of the settling section, the two distinct phases are directed in a counter-current direction to the next stages (mixing region). Shown in Figure 2 is the counter-current flow of the organic and aqueous phases between adjacent stages and the concurrent flow of the organic and aqueous phases within the settler region of a stage.

The 1D Bank, an extraction bank, employs sixteen mixer-settling stages in its process. The 1E Bank, a stripping bank, employs twelve mixer-settling stages in its process. Both banks are constructed from stainless steel⁷. Presented in Table 1 are dimensional data for the 1E and 1D Banks. Note that the mixing region (shown in Figures 1 and 2) does not in reality consist of a homogeneous mixture throughout its volume. The mixture region consists of distinct regions of solvent and aqueous materials and regions of varying levels of mixtures of solvent and aqueous materials. Additionally, the mixing region contains stainless steel structures such as separator plates, baffles, and impeller blades, which are not shown in Figures 1 and 2.

⁶ The 1D Bank employs sixteen mixer-settler stages while the 1E Bank employs twelve mixer-settler stages. Figure 2 shows six stages for illustration purposes only.

⁷ Modeled as 304 stainless steel in this study.

Figure 2. Top View Schematic of a Six-Stage Mixer-Settler Bank

Table 1. Dimensions of the 1-D and 1-E Banks Stage Regions (inches)

	Extraction Banks (1D)	Stripping Banks (1E)
Number of Stages	16	12
Settling Section ^a (height, width, length)	10 x 8 x 48	12 x 12 x 108
Mixing Section ^a (height ^b , width, length)	8 x 8 x 9	9.5 x 12 x 13.5
False Bottom ^a (height)	2	2
Aqueous Region Height in Settler ^a	3.33	4
Bottom Plate Thickness	0.50	0.50
Top Plate Thickness	0.25	0.25
Side Plate Thickness (between stages)	0.25	0.25
False Bottom Plate Thickness	0.25	0.25
Front & Back Plates Thickness	0.50	0.50

^a Listed dimensions are the Inner dimensions.

^b The height of the mixing region for the 1D and 1E Banks are modeled as 7 3/4" and 9 3/4" in this study. This is not expected to affect the results or conclusions.

2.1.1 Material Description of the 1D and 1E Banks

As indicated in the previous section, the 1D and 1E Banks consist of three distinct material regions, in addition to the stainless steel material that comprises the structural material of the banks. The three distinct bank materials are the aqueous, the solvent, and the transition and mixing materials. Presented in Table 2 are the uranium (^{235}U) concentration levels in these materials⁸ for normal operating conditions and for the postulated abnormal reflux conditions. The uranium is enriched with 65-wt. % ^{235}U , with the balance of uranium modeled as ^{238}U . The uranium concentration levels of Table 2 do not cause any operational limits to be violated or exceeded. It is deemed that if the neutron monitor system is able to detect these levels, sufficient time is available to take corrective actions in order to preclude exceeding any operational limits. A detailed description of the 1D and 1E aqueous, solvent, and mixing region materials are included in the following sections. The "Bank Zero" condition, which appears in Table 2, refers to the operational mode when the solvent and aqueous are uranium free (0 g/L).

Table 2. Bank Zero, Normal, and Abnormal Reflux ^{235}U Concentration Levels in the Second Uranium cycle 1D and 1E Banks

1E Bank Levels (g of ^{235}U /Liter)											
Condition	Stage#10 (g/L)		Stage#11 (g/L)		All other Stages (g/L)		Organic	Aqueous	Organic	Aqueous	Organic
	Organic	Aqueous	Organic	Aqueous	Organic	Aqueous					
Bank Zero	0	0	0	0	0	0	0	0	0	0	0
Normal	0	0	0	0.5	0	0	0	0	0	0	0
Reflux	1	5	4	10	0	0	0	0	0	0	0
1D Bank Levels (g of ^{235}U /Liter)											
Condition	Stage 8		Stage 7		Stage 6		Stage 5		Stage 4		Stage 3
	Organic	Aqueous	Organic	Aqueous	Organic	Aqueous	Organic	Aqueous	Organic	Aqueous	Organic
Bank Zero	0	0	0	0	0	0	0	0	0	0	0
Normal	1.3	0.5	1.3	1.2	1.4	3	1.4	4.6	1.5	5.3	1.5
Low 1DX Flow	8.7	2.5	10	14	9	19	7.6	17	6.5	13	5.5
Low 1DX TBP	4.8	4	4.6	20	3.2	20	2.2	14	1.6	9	1.1
High 1DS' Flow	8.5	3	8	20	4	19	2	10	0.5	4	0.5
High 1DS Flow	12.3	6.5	10.7	20.5	8.3	17.5	6.5	13	5	9.5	3.9

2.1.1.1 Aqueous Material

The aqueous region consists of water, uranium, and nitric acid (HNO_3). The aqueous material regions of the 1E Mixer-Settler Bank contain 0.03M of HNO_3 . However, the aqueous regions of the 1D Mixer-Settler Bank may contain up to $\approx 4\text{M}$ of HNO_3 . For Stage 5 of the 1D Bank, the aqueous region contains about 1M HNO_3 . Due to the low concentration of HNO_3 in the 1E Bank, the aqueous region is modeled as uranium in water. Note that, however, the effects of HNO_3 on the neutron count rates for normal and abnormal reflux conditions in the 1D Bank are investigated. The various aqueous mixtures composition and density (aqueous solution at varying levels of uranium) are calculated based on the uranium levels of Table 2 and physical data of Table 3.

⁸ Since the mixing and transition regions are made-up of a homogenized mixture of 30 vol. % of the aqueous material and 70 vol. % of the solvent material (volume based fractions), the ^{235}U concentration levels in these regions need not be listed.

Table 3. Physical Constants for the Aqueous Region Materials

Parameter	Value	Reference
Atomic Weight of ^{16}O	15.9994 g/mole	14
Atomic Weight of Hydrogen	1.0079 g/mole	14
Density of Water	1.0 g/cm ³	15
^{235}U Enrichment	65 wt. %	1
Density of Uranium Metal	18.9 g/cm ³	15
Density of Nitric Acid, HNO_3	1.5129 g/cm ³	23

2.1.1.2 Solvent/Organic Material

The solvent region consists of a homogeneous mixture of 7.5 vol. % TBP and 92.5 vol. % *n*-Paraffin with uranium. TBP, which is $\text{C}_{12}\text{H}_{27}\text{O}_4\text{P}$, has a density of 0.9727 g/cm³ [16]. Listed in Table 4 are the composition data for TBP.

Table 4. Composition Data for TBP

TBP: TriButyl Phosphate: $\text{C}_{12}\text{H}_{27}\text{O}_4\text{P}$					
Element	Atoms/ Molecule	AW of Element	grams/mole in TBP	MCNP X-Section ID	Mass %
H	27	1.0079	27.2133	1001.60c	10.2248%
C	12	12.0000	144.0000	6012.60c	54.1049%
O	4	15.9994	63.9624	8016.60c	24.0325%
P	1	30.9741	30.9741	15031.60c	11.6378%

Three Alkanes compose *n*-Paraffin: Dodecane, Tridecane, and Tetradecane, at the volume fractions shown in Table 5. Utilizing the data of Table 5, a density of 0.7582 g/cm³ is calculated for *n*-Paraffin. The mass fractions are then calculated utilizing the atomic weights of hydrogen and carbon (Table 4) with hydrogen at 15.31-wt. % and carbon at 84.69 wt. %.

Table 5. Constituents of *n*-Paraffin

Alkane	Chemical Formula	Volume Fraction	Density (g/cm ³)	Molecular Weight (g/mole)	Mass Fraction	
					H	C
Dodecane	$\text{C}_{12}\text{H}_{26}$	20%	0.7490	170.2054	15.396%	84.6037%
Tridecane	$\text{C}_{13}\text{H}_{28}$	40%	0.7570	184.2212	15.319%	84.6808%
Tetradecane	$\text{C}_{14}\text{H}_{30}$	40%	0.7640	198.2370	15.253%	84.7470%

Utilizing the data of Tables 4 and 5, and the fact that the solvent region is composed of 7.5 vol. % TBP and 92.5 vol. % *n*-Paraffin, the composition data for the solvent region is obtained, and is presented in Table 6. Note that the data in Table 6 is for bank zero conditions, i.e., at a uranium concentration of 0 g/L. The various solvent mixtures compositions and densities (solvent solution at varying levels of uranium) are calculated based on the uranium levels of Table 2, the data in Table 6, and a uranium solid density of 18.9 g/cm³ (Table 3).

Table 6. Composition Data for the Solvent Material with Uranium at 0 g/L

Nuclide	Mass Fraction			Nuclide ID
	TBP	n-Paraffin	Solvent	
H	10.2248%	15.3077%	14.8288%	1001.60c
C	54.1049%	84.6923%	81.8104%	6012.60c
O	24.0325%	0.0000%	2.2643%	8016.60c
P	11.6378%	0.0000%	1.0965%	15031.60c
Density	0.9727	0.7582	0.7743	

2.1.1.3 Mixing and Transition Regions Material

As stated earlier, the mixing and transition regions consist of a homogenized mixture of 30% aqueous material and 70% solvent/organic material (volume fraction). Utilizing the composition data in Table 6 and the data in Table 3, the various compositions and densities of the mixing and transition regions materials (for all stages and uranium levels) are determined.

2.2 Description of the Extraneous Neutron Source

Since neutrons generated from the spontaneous fission of uranium isotopes are not adequate to produce a statistically significant count rate, an extraneous neutron source is required. Traditionally, the extraneous neutron source consists of a one Ci Pu-Be source container. The neutron sources utilized for the neutron monitoring systems addressed in this document also consist of one Ci Pu-Be sources⁹. The Pu-Be material is lined with tantalum that is then placed in a stainless steel container (cylindrical container). Details of a typical one Ci Pu-Be neutron source¹⁰ include the following [4,18]:

- ✧ 1.019 g of ²⁴⁰Pu, 14.94 g of ²³⁹Pu, and 7.83 g of ⁹Be;
- ✧ the Pu-Be region is modeled as a cylinder, with a height of 1 5/16" and an ID of 3/4";
- ✧ 1/16" thick tantalum liner is assumed to surround the Pu-Be material; and
- ✧ 1/16" thick type 304 stainless-steel container.

2.2.1 Neutron Source Packages

In order to enhance the neutrons generated in the source and to enhance the effective neutron count rate by increasing the number of neutrons interacting with the fissile regions of the banks, modifications have been employed to the neutron source container. The modifications consist of utilizing a polyethylene block in a stainless steel container. The polyethylene block increases the neutron multiplication factor of the source, thus releasing more neutrons from the fission of the ²³⁹Pu nuclide, and increases the (n,2n) neutrons by reflecting a fraction of neutrons back into the source material to interact with the beryllium. Also, the polyethylene block would provide a scattering media to scatter neutrons toward the banks (neutrons that otherwise would have not interacted with the mixer-settler regions).

⁹ Based on the reported mass of the ²³⁹Pu in the Pu-Be source, the actual activity of the source is 0.927 Ci. However, the 0.927 Ci Pu-Be source is referred to as a one Ci Pu-Be source throughout this document.

¹⁰ The Pu-Be source specifics provided herein are for the Pu-Be neutron source with the M-356 serial number.

Three different neutron source packages have been designed and built for the neutron monitoring systems. One source package is placed under the end of the settling section of Stage 11 of the 1E Bank, schematics of which are shown in Figure 3. The remaining two source packages are for the 1D Bank: one source package is to be placed on the outside of the settling section of Stage 6, schematics of which are shown in Figure 4. The other source package is to be placed on the outside of the mixing section of Stage 5, schematics of which are shown in Figure 5. The differences between these packages are the size of the polyethylene block, the size of the stainless steel housing, and the location of the Pu-Be source within the package. These differences are shown in Figures 3 to 5. The three different sizes were required due to physical restrictions on and near the mixer-settler stages.

Figure 3. Schematic of the Neutron Source Package for Stage 11 of the 1E Bank

Figure 4. Schematic of the Neutron Source Package for Stage 5 of the 1D Bank

Figure 5. Schematic of the Neutron Source Package for Stage 6 of the 1D Bank

2.3 Description of the Neutron Detector

The neutron detector consists of two LND Model 20240 BF₃ probes inserted into a block of polyethylene that is encased in a stainless-steel housing. Details of the neutron detector probes include the following:

- ✦ Filling to a pressure of 200 Torr of BF₃
- ✦ Boron is enriched to 96 a% ¹⁰B (natural Boron contains 20 a% ¹⁰B)¹¹
- ✦ Structural material made of type 304 stainless steel
- ✦ ID 0.96" and OD 1" with an Effective Height of 4.94"

A schematic of the BF₃ probe (LND, model 20240) is presented in Figure 6 [17]. Table 7 presents the manufacturer specifications of the LND, BF₃ probe model 20240 [17]. Top and side view schematics of the neutron detector package (BF₃ probes, polyethylene, and stainless steel housing) are presented in Figures 7 and 8.

Table 7. Specifications of the LND 20240 BF₃ Probe

PARAMETER	Value
Gas Pressure (Torr)	200
Cathode Material	Stainless Steel
Maximum Length (inch/mm)	9.44 / 239.7
Effective Length (inch/mm)	4.94 / 125.4
Maximum Diameter (inch/mm)	1.0 / 25.4
Effective Diameter (inch/mm)	0.96 / 24.38
Operating Temperature Range °C	-50 to +100
Effective Volume (cm ³)	58.57
Thermal Neutron Sensitivity (cps / nv)	1.3
Recommended Operating Voltage (volts)	950
Operating Voltage Range (volts)	850 - 1100
Maximum Resolution (% FWHM)	10
Tube Capacitance (pf)	6.5
Weight (grams)	200

Figure 6. Schematics of the BF₃ Probe

¹¹ The sensitivity studies modeled the BF₃ at a ¹⁰B enrichment of 90 a%. However, due to the low density of the BF₃ in the probes, the conclusions of the sensitivity studies remain to be valid. That is, the low density of BF₃ does not cause significant neutron flux depression in the LND 20240 probes.

Figure 7. Top View Schematic of the Detector Package System

Figure 8. Side View Schematic of the Detector Package System

2.4 Neutron Monitoring Systems

Two neutron-monitoring systems have been designed and built for the early detection of the postulated abnormal reflux conditions. The first consists of a neutron detector package and a neutron source package for the 1E Bank. The second consists of a neutron detector package and two neutron sources for the 1D Bank. Both of these systems are described in the following section.

2.4.1 Stage 11 of the 1E Bank

As indicated previously, the neutron monitoring system for Stage 11 of the 1E Bank consists of one neutron source package and one neutron detector package. The configuration and orientation of the neutron source and detector are described below.

2.4.1.1 The 1E Bank Detector Package

The detector package (Figures 7 and 8) is placed vertically outside the settling region of Stage 11. The center of the package is centered in the middle of Stage 11, as shown in Figure 9. The surface-to-surface separation distance between the outer surface of the back plate of Stage 11 and the outer surface of the detector package is $\frac{1}{4}'' \pm \frac{1}{8}''$. The lowest plane of the BF_3 probe is at $2\frac{1}{4}'' \pm \frac{1}{8}''$ below the aqueous region's bottom surface, as shown in Figure 10.

Figure 9. Top View Schematic of the Detector Package outside the End of the Settling Region of Stage 11 of the 1E Bank

Figure 10. Side View Schematic of the Detector and Pu-Be Source Relative to Stage #11 of the 1E Bank

2.4.1.2 The 1E Bank Pu-Be Source Package

The neutron source consists of a one Ci Pu-Be source packaged in a polyethylene block with the dimensions and configuration of that shown in Figure 3 of this document. The Pu-Be Source is placed directly under Stage 11 with its centerline aligned with midpoint of Stage 11, as shown in Figure 9. The centerline of the source is at $4'' \pm 1/8''$ from the outer surface of the settling region of Stage 11. (Figure 10). The surface-to-surface separation distance between the lower surface of the bottom plate of Stage 11 and the upper surface of the source package is $3/8'' \pm 1/8''$.

Note that the centerline of the Pu-Be source is aligned with the centerline of the neutron detector package.

2.4.2 Stages 5 and 6 of the 1D Bank

The neutron monitoring system for the 1D Bank consists of two neutron source packages and one neutron detector package. The configuration and orientation of the neutron sources and detector are described below.

2.4.2.1 The 1D Bank Detector Package

The detector package (Figures 7 and 8) is placed horizontally under the mixing region of Stage 5, beneath the supporting I-beam. A side view schematic (on the x-z plane) of this configuration is shown in Figure

11. As shown in Figure 11, the surface-to-surface separation distance between the detector package and the I-beam structure is $1/2'' \pm 1/8''$ in both the x- and z-directions.

Presented in Figure 12 is a side view schematic on the y-z plane of the detector package for this bank. The bottom surface of the entire probe is at $10\ 1/8'' \pm 1/8''$ under Stage 5. That is, the distance between the lower surface of the probe and the edge of the mixing region of Stage 5 is at $10\ 1/8'' \pm 1/8''$, as shown in Figure 12.

2.4.2.2 The 1D Bank Pu-Be Sources

Also shown in Figure 11 is the projection of the two neutron source packages: one facing the end of the settling region of Stage 6, and the other facing the end of the mixing region of Stage 5. The surface-to-surface separation distance between the neutron source packages¹² and the outer surface of the 1D Bank stages is $3/8'' \pm 1/8''$.

Figure 11. X-Z Plane Schematic of the Detector System under Stage 5 of the 1D Bank

¹² Unlike the neutron source of the 1E Bank (Figures 9 & 10), these neutron sources are oriented horizontally with the lid of the packages facing the end of the settling region of Stage 6 and facing the mixing region of Stage 5.

Figure 12. Y-Z Plane Schematic of the Detector Region under Stage 5 of the 1D Bank

3.0 ASSUMPTIONS

Assumptions utilized in these studies include the following:

- ✧ The mixing region is modeled as a homogeneous mixture of aqueous and solvent materials. In reality, the mixing region consists of distinct regions of solvent and aqueous materials and regions of varying levels of mixtures of solvent and aqueous materials.
- ✧ The mixing region contains stainless steel structures such as separator plates, baffles, and impeller blades, which are not modeled.
- ✧ The actual transition region's shape and profile is not as depicted in the schematics provided herein. The schematics reflect the shape as modeled in the neutron transport studies. Additionally, in the similar fashion as was done for the mixing region, the transition region is modeled as a homogeneous mixture of the aqueous and solvent materials. In reality, the transition region material would be comprised of a mixture of aqueous and organic materials at varying volume fractions
- ✧ The aqueous material of the 1E Mixer-Settler Bank is modeled as light water with uranium. The effects of the presence of HNO_3 in the aqueous material of the 1D Mixer-Settler Bank on the neutron count rates are investigated in the sensitivity

sections of this study. Other additives that may be present are assumed to have a negligible effect on the neutron count rates.

- ✧ The boron in the BF_3 probes is modeled with an enrichment of 90 a% ^{10}B in the sensitivity parts of this study. The actual enrichment is 96 a% ^{10}B . However, due to the relatively low pressure of the BF_3 gas in the probes, no significant flux depression is expected. Therefore, the calculated neutron count rates in the sensitivity studies can be scaled upwards by a factor of 96/90 (1.06667) to account for this assumption.
- ✧ The heights of the aqueous and solvent phases are assumed to be constant and fixed for bank zero, normal operations, and abnormal reflux conditions.
- ✧ Neutrons produced by the (γ, n) reaction are not accounted for in these studies. That is, the neutron yield from such reactions is relatively small compared with the other sources of neutron production, i.e., (α, n) , spontaneous fission, and induced fission reactions in the Pu-Be source and in the mixer-settlers. This is due to the relatively high threshold energy for such reactions ($E_\gamma > 1.5 \text{ MeV}$).
- ✧ Neutrons generated from the spontaneous fission of uranium are not accounted for in this study. The contribution of these neutrons¹³ to the neutron count rate is negligible, especially when compared to the neutron count rate from the Pu-Be source.
- ✧ The only sources of neutrons are those produced by the Pu-Be sources and induced fission of uranium within the mixer-settler liquid materials. That is, the mixer-settlers and their surrounding are assumed to be free of contamination¹⁴.
- ✧ Jumpers and other support systems and structures¹⁵ are not modeled. These components are assumed to have a negligible effect on neutron interactions, and consequently, the neutron count rates.
- ✧ All air regions are modeled as void.

4.0 METHODOLOGY

The neutron count rate, as observed by the BF_3 probes, is determined by simulating the interactions experienced by neutrons from birth¹⁶ until those neutrons or their secondary neutrons¹⁷ are transported to the detector and absorbed in the BF_3 . The neutron birth-to-detection simulation is performed using the MCNP Code [8-10], a three-dimensional, general purpose, and n-particle Monte Carlo code.

However, for the simulation to be valid, a valid representation of the actual system is needed. That is, all components that significantly affect the neutron birth-to-detection process needs to be defined. For the system at hand, the relevant components are the following:

- ✧ The energy and intensity of the neutrons produced in the Pu-Be source.

¹³ Directly or indirectly by inducing fission and liberating neutrons.

¹⁴ Contamination, as referred to herein, implies fissile contamination or any other type of contamination that would affect the neutron count rates.

¹⁵ Excluding the support I-beam of Stage 5 of the 1D Bank.

¹⁶ Neutrons from the spontaneous fission of plutonium in the Pu-Be source, namely ^{240}Pu , and neutrons from the (α, n) reaction in the Pu-Be source.

¹⁷ Neutrons liberated from inducing fission of plutonium in the Pu-Be source and uranium in the mixer-settler and neutrons produced by the $(n, 2n)$ reactions.

- ✧ The environment affecting the neutron birth-to-detection process. This is the media between and in the vicinity of the Pu-Be generated neutrons and the detector, i.e., all materials and the space these materials occupy.
- ✧ The detection process, which is the absorption of a neutron in the BF_3 probe.

In the sections that follow, the above analytical models are described.

4.1 Neutron Spectra and Source Strength Model

As indicated previously, the extraneous sources utilized in the neutron monitoring systems are one Ci Pu-Be sources. The Pu-Be sources consist of 1.019 g of ^{240}Pu , 14.94 g of ^{239}Pu , and 7.83 g of ^9Be . Neutrons are produced in the Pu-Be source by the following:

- ✧ The (α, n) reaction with beryllium, where α 's are produced by the ^{239}Pu and ^{240}Pu isotopes from spontaneous fission and decay.
- ✧ The spontaneous fission of the ^{240}Pu isotope (≈ 2.2 neutrons/fission [22]).
- ✧ Induced fission (n, f).
- ✧ The (γ, n) reaction with beryllium, where the γ 's are produced by either neutron interactions, spontaneous fission, or induced fission.
- ✧ The $(n, 2n)$ reaction with beryllium, where the incident neutron may have been produced by any of the means listed above

Neutrons produced by induced fission and $n, 2n$ reactions are accounted for in the Monte Carlo simulations within the MCNP code [8-10]. However, (α, n) neutrons and spontaneous fission neutrons and their spectra are determined from the RASTA code [11] and are hardwired into the MCNP models using the "sdef" cards. The RASTA code computes neutron and photon source terms arising from (α, n) events, spontaneous fission, Bremsstrahlung, and decay. Neutrons produced from (γ, n) reactions are not accounted for in this study¹⁸.

Results of the RASTA code are presented in Table A-1 of Appendix A. The results of Table A-1 indicate the following:

- ✧ Spontaneous neutrons contribute less than 0.1% of the source strength. Over 99.9% of the neutrons are produced from the α, n reaction.
- ✧ The average energy per emitted neutron is 4.86 MeV.
- ✧ The total source strength from the Pu-Be source is 1.7×10^6 n/sec

Although not shown, other studies have been performed to examine the time-dependent source strength and spectra. The results of these studies indicated that over a 50-year period, the average energy of the neutron and total neutron source strength remain essentially constant¹⁹.

¹⁸ The (γ, n) neutrons can be accounted for in the Monte Carlo simulation if a γ spectra and source strength are defined (mainly from spontaneous fission). However, the neutron yield from such reactions is relatively small compared with the other sources of neutron production, e.g., (α, n) and spontaneous fission. This is due to the relatively high threshold energy for such reactions ($E_\gamma > 1.5$ MeV).

¹⁹ The average energy of the neutron source decreases by less than 0.01% and the total neutron source strength decreases by less than 0.3% over a 50-year period.

The MCNP cards defining the neutron source model are listed below in Figure 13. These cards represent neutrons emitted from the Pu-Be source of Stage 11 of the 1E Bank. The only differences between this source model and the source model for the 1D Bank are the values for the "pos" and "axs" parameters. The applicable values for the "pos" and "axs" parameters representing the nominal locations of the source packages of the 1D Bank are those shown in Figure 14.

```

sdef      pos=46.99 299.72 -5.15937   erg=d1
          rad d3 ext d2 axs 0 0 1
si1  1    5.00E-08  2.57E-07  6.45E-07  1.37E-06  3.45E-06
          7.87E-06  2.40E-05  6.92E-05  1.58E-04  3.34E-04
          1.02E-03  2.47E-03  5.23E-03  1.11E-02  1.85E-02
          2.31E-02  2.52E-02  2.90E-02  3.64E-02  4.92E-02
          8.42E-02  1.47E-01  2.40E-01  3.33E-01  4.34E-01
          5.53E-01  6.76E-01  7.82E-01  9.11E-01  1.18E+00
          1.50E+00  1.79E+00  2.08E+00  2.29E+00  2.36E+00
          2.42E+00  2.60E+00  2.87E+00  3.35E+00  4.33E+00
          5.52E+00  6.74E+00  8.01E+00  9.31E+00  1.11E+01
          1.32E+01  1.58E+01
sp1      4.63E-15  5.42E-12  5.58E-12  1.25E-11  1.94E-12
          1.00E-14  4.50E-11  1.98E-10  5.52E-10  1.68E-09
          1.63E-08  6.59E-08  3.37E-07  1.50E-06  2.02E-06
          8.06E-07  7.14E-07  2.39E-06  4.59E-06  1.06E-05
          5.11E-05  9.43E-05  3.56E-04  1.07E-03  4.50E-03
          5.82E-03  9.02E-03  5.81E-03  1.33E-02  2.54E-02
          1.66E-02  1.53E-02  2.49E-02  1.08E-02  1.85E-03
          9.50E-03  3.02E-02  5.07E-02  1.44E-01  2.21E-01
          1.02E-01  1.26E-01  1.05E-01  7.12E-02  6.06E-03
          3.31E-08  5.30E-09
si2      1.66688
si3      0 0.9524

```

Figure 13. MCNP Source Definition cards for the Nominal Position of the Pu-Be Source Package for Stage 5 of the 1E Bank²⁰

```

sdef      pos=d4   axs 0 1 0
si4  1    68.2625 -5.1625 13.335
          59.0555 -4.5275 6.0325
sp4      0.5 0.5

```

Figure 14. The "pos" and "axs" Parameters Representing the Nominal Locations of the Source Packages of the 1D Bank

4.2 Material Models

Materials for the aqueous, the solvent/organic, and mixing and transitions regions have been defined previously. However, there are a number of other materials that affect the neutron birth-to-detection process. These materials are defined in the subsections that follow.

²⁰ In the sensitivity studies involving the 1E Bank models, the neutron source was distributed over a height of 2.06 cm, rather than the 1.66688 cm (si2 card,) and distributed over a radius of 1.269 cm, rather than the 0.9524 cm (si3 card). This error causes neutrons to be started outside the by Pu-Be material region. However, the effects of this error are negligible and do not affect the conclusions, as shown in the 1E Bank sensitivity studies section.

4.2.1 Polyethylene

Polyethylene is utilized in the neutron source package and detector package, as described previously. Polyethylene is defined at a density of 0.92 g/cm³ and consists of 14.372 wt. % hydrogen (MCNP ID 1001.60c) and 85.628 wt. % carbon (MCNP ID 6000.60c) [10]. Note that two cards are used in modeling polyethylene. The first card is its material card "*m21*" defining its composition as 14.372-wt. % hydrogen and 85.628-wt. % carbon. The second card is utilized to invoke the $S(\alpha,\beta)$ treatment for thermal neutron scattering with hydrogen in polyethylene. Thermal neutron scattering is more accurately represented with $S(\alpha,\beta)$ tables than the free gas model since $S(\alpha,\beta)$ tables account for the crystalline effects of a particular material. The $S(\alpha,\beta)$ treatment is generally invoked when the neutron's energy falls below 4 eV²¹. The $S(\alpha,\beta)$ card for polyethylene is the "*mt21*" card. Both of these cards are listed below, as follows:

m21	1001.60c -0.14372	6000.60c -0.85628	\$ Polyethylene @ 0.92 g/cc
mt21	poly.01t		

4.2.2 Type 304 Stainless Steel

This material is used to model the following:

- ↳ The structural material of the 1D and 1E Banks.
- ↳ The support I-Beam under Stage 5 of the 1D Bank.
- ↳ The structural material of the BF₃ probes.
- ↳ The structural material of the detector package.
- ↳ The stainless steel container of the Pu-Be sources.
- ↳ The structural material of the neutron source packages.

Type 304 stainless steel is defined at a density of 7.92 g/cm³ and consists of 69.5 wt. % iron, 19.0 wt. % chromium, 2.0 wt. % manganese (MCNP ID 25055.60c), and 9.5% nickel [10]. Four MCNP x-section libraries are used to define iron (MCNP ID's 26054.60c, 26056.60c, 26057.60c, and 26058.60c), five libraries for nickel (MCNP ID's 28060.60c, 28062.60c, 28058.60c, 28061.60c, and 28064.60c), and four libraries for chromium (MCNP ID's 24050.60c, 24053.60c, 24052.60c, and 24054.60c). The material card for stainless steel, as employed herein, is defined to be "*m20*," and is as follows:

m20	26054.60c -0.03962	26056.60c -0.63849	26057.60c -0.01488
	26058.60c -0.00202	25055.60c -0.02000	24050.60c -0.00793
	24053.60c -0.01838	24052.60c -0.15903	24054.60c -0.00466
	28060.60c -0.02532	28062.60c -0.00360	28058.60c -0.06402
	28061.60c -0.00111	28064.60c -0.00094	\$ 304 ss @ 7.92 g/cc

4.2.3 Tantalum

Tantalum is used to model the Pu-Be source container liner. Tantalum is defined at a density of 16.6 g/cm³ [15] and its material card is defined with 100wt. % tantalum (MCNP ID 73181.60c). The material card for tantalum is defined to be "*m30*," and is as follows:

m30	73181.60c -1.00000	\$ Tantalum @ 16.6 g/cc
-----	--------------------	-------------------------

²¹ For neutron energies above 4 eV, the MCNP code utilizes the free gas model for neutron scattering. $S(\alpha,\beta)$ effects are most important when the neutron energy falls below 2 eV [8].

4.2.4 Pu-Be

The Pu-Be region of the neutron source containers is defined with "m40" material card and the "mt40" $S(\alpha, \beta)$ card for thermal neutron scattering with beryllium. The source material consists of 1.019 g of ^{240}Pu , 14.94 g of ^{239}Pu , and 7.83 g of ^9Be , as provided by Reference 18. This material is defined with 32.913 wt. % beryllium (MCNP ID 4009.60c), 62.802 wt. % ^{239}Pu (MCNP ID 94239.60c), and 4.285 wt. % ^{240}Pu (MCNP ID 94240.60c). The density of the Pu-Be material is determined by dividing the total mass of the Pu-Be (23.789 g) by its volume ($H = 1\ 5/16"$ and $D = 3/4"$, volume = 0.5798" or 9.502 cm³). The Pu-Be material density²² is calculated to be 2.5036 g/cm³. The Pu-Be material cards are listed the following:

```
m40 4009.60c -0.32913 94239.60c -0.62802 94240.60c -0.04285 $ Pu-Be @ 2.5036 g/cc
mt40 be.01t
```

4.2.5 BF₃

BF₃ is the material utilized for neutron detection and is defined in this study with the "m22" material card. The simplest way to define the BF₃ material is using relative atom fractions, i.e., 0.96 $^{10}\text{B}^{23}$ (MCNP ID 5010.60c), 0.04 $^{11}\text{B}^{19}$ (MCNP ID) and 3.0 ^{19}F (MCNP ID 9019.60c). However, and to be consistent with all material cards defined herein, the BF₃ material is defined on a mass fraction basis. Using the atomic weights of, 10.01294, 11.00931, and 18.9984 atoms/mole for ^{10}B , ^{11}B , and ^{19}F [14], respectively, the "m22" material card is defined as follows:

```
m22 5010.60c -0.14336624 5011.60c -0.00656801 9019.60c -0.85006575 $ BF3 in Det. 7.33485E-04 g/cc
```

The density of the BF₃ material in g/cm³ is obtained based on its gaseous pressure of 200 Torr. Since one mole of BF₃ at STP (273 K and 760 Torr) occupies 22.4136 liters and has a mass of 67.048 grams, or has a density of (67.0480 g/22,414 cm³) or 2.9913 x 10⁻³ g/cm³. Assuming the detector is maintained at a temperature of 20°C (293 K) and giving that its pressure is 200 Torr yields (200/760) x (273/293) or 24.5196% of the BF₃'s STP density. This implies that the BF₃ in the LND 20240 probe is at a density of 7.33485 x 10⁻⁴ g/cm³ in the probes.

As indicated previously, in the 1E and 1D Banks sensitivity studies, the boron in the BF₃ is modeled to be enriched with 90 a% ^{10}B . The density of the BF₃ at this enrichment is 7.34139 x 10⁻⁴ g/cm³. Additionally, the BF₃ material card, as used in the sensitivity studies, is the following:

```
m22 5010.60c -0.13428612 5011.60c -0.01640541 9019.60c -0.84930848 $ BF3 in Det. 7.33485E-04 g/cc
```

4.2.6 1D and 1E Material $S(\alpha, \beta)$ Tables

The solvent, aqueous, mixing, and transition regions' materials have been described previously. In addition to MCNP material cards being defined for these regions, $S(\alpha, \beta)$ tables are also utilized for

²² The volume occupied by 15.959 g of plutonium is 0.80439 cm³ and that occupied by 7.83 g of beryllium is 4.237 cm³. The combined volume of both elements is 5.0414 cm³. This implies that the Pu-Be region has a void fraction of $\approx 47\%$.

²³ BF₃ is made of three atoms of fluorine and one atom of boron, with boron composed of 96 a% ^{10}B and 4% ^{11}B .

thermal neutron scattering. For the aqueous regions, the "lwtr.01t" table is used to model thermal neutron scattering with hydrogen. For the solvent regions, the "benz.01t" table is used to model thermal neutron scattering with hydrogen and carbon. Note that the "benz.01t" table provides $S(\alpha, \beta)$ values for hydrogen and carbon accounting for the atomic bonds in benzene. Since $S(\alpha, \beta)$ tables for the solvent material (7.5 vol. % TBP and 92.5 vol. % *n*-Paraffin) are not available, the $S(\alpha, \beta)$ table for "benz.01t" is utilized. The selection is based on the following:

- ↗ The only available²⁴ $S(\alpha, \beta)$ table for thermal neutron scattering with both hydrogen and carbon as the scattering nuclides is the "benz.01t" table.
- ↗ The density of the solvent region (without uranium) is 0.7743 g/cm³, which is comparable with the 0.879-g/cm³ density of benzene [16]. Note that the hydrogen's partial density in the solvent is 0.115 g/cm³ while in benzene it is 0.068 g/cm³. The carbon's partial density in the solvent is 0.633 g/cm³ while in benzene its density is 0.811 g/cm³.

Additionally, the $S(\alpha, \beta)$ table for "benz.01t" is utilized for thermal neutron scattering with the mixing and transition regions material, since these regions' materials are homogenized mixtures of 70 vol. % solvent and 30 vol. % aqueous material.

4.3 Neutron Count Rate

The neutron count rate in each of the BF₃ probes²⁵ is calculated by tallying the rate at which neutrons are absorbed by the BF₃. This is accomplished in the MCNP code by use of the flux averaged over a cell tally (tally type 4) in conjunction with the tally multiplier card (*fm* card) with the "*C m (reaction list)*" option. With this approach, the MCNP code calculates the following reaction rate:

$$C \int \varphi(E) R_m(E) dE$$

Where C is a constant multiplier, $\varphi(E)$ is the energy-dependent neutron fluence (n/cm²), and $R_m(E)$ is the energy-dependent "response" function (for the reaction of interest) from the MCNP cross-section libraries for material m .

For the problem at hand, the MCNP reaction list for neutron absorption is "-2" and the defined material number for BF₃ is "22" in this study. Note that the MCNP reaction cross sections are microscopic and are in units of barns. Additionally, since the MCNP results (tallies) are normalized per unit of starting particles, then the MCNP calculated reaction needs to be adjusted to reflect the actual number of particles, or in this case the source intensity. That is, if C is set to one, the MCNP calculated tally would represent the neutron absorption quantity in units of absorptions-bn/cm².

Therefore, the constant multiplier C is used to convert the MCNP normalized values to values that represent the system at hand. The neutron source strength of 1.7×10^6 n/sec is used to convert from per starting particle to per second. Also, the total number of atoms/molecules in each of the BF₃ probes is

²⁴ $S(\alpha, \beta)$ tables for thermal neutron scattering can be generated from a special set of ENDF libraries and processed into a format suitable for use with the MCNP code. The word available is used to denote the libraries that have been released with the MCNP code.

²⁵ Each BF₃ probe in the detector package is used to obtain an independent neutron count rate. That is, the neutron count rate represents the count rate that each probe would experience and not the combined count rate of both probes.

used to convert from barns/cm² to the total observed reactions. The total number of BF₃ molecules in each probe is the BF₃ atomic density (molecules/bn-cm) multiplied by the volume occupied by the BF₃.

The molecular density of the BF₃ (at 200 Torr and 20°C) is 2.63517×10^{-05} molecules/bn-cm while the volume it occupies in each probe is 58.595 cm³. The value of C is $(2.63517 \times 10^{-05} \text{ molecules/bn-cm}) \times (58.595 \text{ cm}^3) \times (1.7 \times 10^6 \text{ n/sec}) = 2,624.93^{26}$. Note that for the 1D Bank, the value for C is twice that derived here since it employs two one-Ci Pu-Be neutron sources, i.e., $C = 5,249.87^{27}$ for the 1D neutron monitoring system.

4.4 Geometry

Two distinct geometry models are developed: one model for the 1E Bank and the second model is for the 1D Bank. Both of these models are discussed in the following sections:

4.4.1 1E Bank MCNP Model

The 1E Bank is modeled with the neutron source package, the neutron detector package, and only four stages, namely Stages 9, 10, 11, and 12. Since Stages 10 and 11 are the only stages that would contain uranium during normal and the postulated abnormal conditions (Table 2), then modeling one stage next to Stage 10, namely Stage 9, and one stage next to Stage 11, namely Stage 12, is more than adequate to model neutron reflection. That is, these stages have high scattering materials (hydrogen and carbon) and are 12" wide, which provide neutrons with infinite reflection. Therefore, stages other than Stages 9 through 12, are not modeled, since the neutron count rate would not be affected.

Each of the modeled stages is modeled with its mixing, transition²⁸, solvent, and aqueous regions, including the stainless steel structures shown in Figures 9 and 10. The 1E Bank MCNP model is presented in Appendix B.

In the model listed in Appendix B, the neutron source package and the detector source package are configured in their nominal positions, as shown in Figures 9 and 10. Additionally, the MCNP file shown in Appendix B is for the 1E Bank under postulated reflux conditions. The MCNP models for the bank zero and normal configuration of the 1E Bank are similar to that shown in Appendix A. The differences are only the material cards (depicting the aqueous, solvent, and mixing and transition regions) and their densities.

4.4.2 1D Bank MCNP Model

The 1D Bank is modeled with the two neutron source packages, the neutron detector package, and only six stages, namely Stages 3 through 8. Since the detector is placed under Stage 5 and the neutron sources

²⁶ In the 1E Bank sensitivity studies, the constant multiplier is set to 2,848.23 rather than the 2,624.93 value shown above. Therefore, results obtained from the MCNP code for the 1E Bank sensitivity need to be multiplied by 0.9216 to obtain the neutron count rate.

²⁷ In the 1D Bank sensitivity studies, the constant multiplier is set to 5,696 rather than the 5,249.87 value shown above. Therefore, results obtained from the MCNP code for the 1D Bank simulations need to be multiplied by 0.9216 to obtain the neutron count rate.

²⁸ Note that the transition region is modeled as having a length of <1 cm. However, the neutron monitoring system sensitivity due to the length of the transition region is investigated in these studies. The results indicate that the length of the transition region has a statistically insignificant effect on the neutron count rates.

are on the settling end of Stages 5 and 6, then modeling two stages next to each of Stages 5 and 6 should be more than adequate to account for neutron reflection and neutronic coupling among the stages.

Each of the modeled stages is modeled with its mixing, transition, solvent, and aqueous regions, including the stainless steel structures shown in Figures 11 and 12. The 1D Bank MCNP model is presented in Appendix C.

In the model listed in Appendix C, the two neutron source packages and the detector source package are configured to their nominal positions, as shown in Figures 11 and 12. Additionally, the MCNP file shown in Appendix C is for the 1D Bank under the *High IDS' Flow* postulated reflux conditions. The MCNP models for the bank zero, normal operation, and other postulated reflux configurations of the 1D Bank are similar to that shown in Appendix B. The differences are only the material cards (depicting the aqueous, solvent, and mixing and transition regions) and their densities.

5.0 RESULTS

Results of the Monte Carlo simulations performed using three-dimensional MCNP models of the 1E and 1D Mixer-Settler Banks are presented and discussed in the Sections 5.1 and 5.2, respectively. Additionally, in each of these sections, results of the sensitivity studies pertaining to perturbing the location of the neutron source package(s) and/or the neutron detector package are summarized. Results of other sensitivity studies, such as the transition region's length and HNO_3 concentrations in the aqueous material of the 1D Bank, are also summarized.

Also included in Section 5.3 are results of various benchmark and validation studies. Results of these studies add validity and substance to the 1E and 1D Bank studies presented herein.

5.1 Results of the 1E Bank Studies

Results of the Monte Carlo simulations using the MCNP code with the 1E Mixer-Settler models are presented in Table 8. Table 8 lists the neutron count rates for various ^{235}U configurations of the 1E Bank (bank zero, normal condition, and reflux) with the neutron source and detector packages configured as shown in Figures 9 and 10.

Table 8. 1E Bank Neutron Count Rate and Reflux Detectability

Description	Cell #300 ^a (n/sec)		Cell #320 ^a (n/sec)		Interacting (n/sec)	% of Normal
Bank Zero	146.3	0.21%	145.0	0.21%	76.7	99.3%
Normal Conditions	147.2	0.20%	146.3	0.20%	77.7	N/A
100% Reflux Conditions	170.4	0.18%	169.7	0.18%	101.0	115.9%
Dead Count	69.3	0.17%	68.7	0.17%	0.0	47.4% ^b

^a Values in these columns with a "%" sign represent the statistical uncertainty (one-sigma) of the calculated Monte Carlo neutron count rate.

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Table 8 lists the neutron count rates for cell #300 and cell #320. These cells represent the active regions of the BF_3 probes inside the detector package. Cell #300 represents the probe closer to Stage 10 while cell #320 represents the probe close to Stage 12. Also shown in Table 8 are the following:

↳ **Interacting.** This column represents the average number of neutrons/sec that interact with the aqueous, the solvent, the transition, and/or the mixing regions of

Stages 9 through 12 and eventually contribute directly or indirectly²⁹ to the neutron count rate.

- ↳ **% of Normal.** Represents the increase or decrease in the neutron count rate from normal operation. However, for the dead count values, this parameter represents the dead count rate divided by the bank zero count rate.
- ↳ **Dead Count.** Represents the rate at which neutrons are directly transported from the Pu-Be source package to the neutron detector and contribute to the count rate without interacting with the stages. In a sense, this parameter represents the noise of the neutron monitoring system. It is independent of the contents of the bank, i.e., bank zero or under reflux conditions.

The results of Table 8 indicate that the nominal configuration of the as-built neutron monitoring system achieves adequate neutron count rates, thereby eliminating excessive integration count times. Note that the count rates listed in Table 8 are directly proportional to the Pu-Be source strength (1.7×10^6 n/sec). The results also indicate that the nominal configuration of the monitoring system is able to predict a $15.9\% \pm 0.22\%$ ³⁰ increase in the neutron count rate when the 1E Bank ²³⁵U levels increase from their normal operation levels to the postulated reflux condition (Table 2).

Sensitivity studies are performed on the 1E Bank neutron monitoring system. These studies are presented in Appendix D of this report. Note that the nominal configuration (reference configuration) of the monitoring system of Appendix D differs slightly from that shown in Figures 9 and 10 and that in which its results are presented in Table 8. The differences between the two nominal configurations are listed in Appendix D. However, despite these differences, conclusions of the sensitivity studies of Appendix D are applicable to system at hand. Results of the sensitivity studies include the following:

- ↳ The neutron count rate is quite sensitive to the following:
 - **Position of the neutron detector package.** The sensitivity studies concluded that the neutron count rate varies by as much as 15% when the detector package is moved ½" from its reference location.
 - **Position of the neutron source package.** The sensitivity studies concluded that the neutron count rate varies by as much as 17% when the source package is moved ½" from its reference location.
 - **Bottom, front, and back steel plate thickness.** The studies concluded that increasing the thickness of these steel plates from ¼" to ½" causes the neutron count rate to drop by as much as 16%.
- ↳ The relative change in the neutron count rate due to the postulated transition from normal ²³⁵U concentration levels to reflux levels is, for all practical purposes, constant for all examined perturbations (within the as-built tolerances). That is, the ability of the 1E neutron monitoring system to predict the postulated reflux condition is virtually unaffected by the following perturbations:
 - **Position of the neutron detector package.** Despite the fact that the detector package location is changed by ½" from its nominal location, the change in the neutron count rate fluctuated between ≈115% to only ≈120%.
 - **Position of the neutron source package.** Despite the fact that the source package location is changed by ½" from its nominal location,

²⁹ Indirectly by inducing fission and liberating neutrons that eventually contribute to the neutron count rate in the BF₃ probes.

³⁰ The "0.22%" value represents one standard deviation due to the statistical uncertainties of the Monte Carlo calculated count rates for the normal and reflux conditions.

the change in the neutron count rate fluctuated between $\approx 115\%$ to only $\approx 120\%$.

- The transition region's length and the thickness of the bank plates had a statistically indistinguishable effect on the system's reflux detectability.

5.2 Results of the 1D Bank Studies

Results of the Monte Carlo simulations using the MCNP code with the 1D Mixer-Settler models are presented in Table 9. Table 9 lists the neutron count rates for various ^{235}U configurations of the 1D Bank (bank zero, normal condition, and the postulated "*High IDS' Flow*" reflux condition) with the neutron source and detector packages configured as shown in Figures 11 and 12. Note that the sensitivity studies performed on the 1D Bank, which are presented in Appendix E, conclude that the "*High IDS' Flow*" scenario produces the least increase in the neutron count rate. Therefore, if the 1D Mixer-Settler Bank is able to detect the "*High IDS' Flow*" reflux scenario, then all other postulated reflux scenarios of Table 2 are detectable as well.

Table 9. 1D Bank Neutron Count Rate and Reflux Detectability

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec) ^a	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
Bank ZERO	110.7	0.32%	129.0	0.30%	95.4%	95.6%	59.9	70.6
Normal Conditions	116.0	0.37%	135.0	0.34%	N/A	N/A	65.3	76.5
High IDS' Flow	127.9	0.37%	150.2	0.35%	110.2%	111.3%	77.1	91.8
Dead Count ^b	50.7	0.32%	58.4	0.30%	45.8%	45.3%	0.0	0.0

^a This value represents the relative inefficiency of the neutron monitoring system as it relates to the normal measurements.

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Results of Table 9 indicate that the nominal configuration of the as-built neutron monitoring system for the 1D Mixer-Settler Bank produces adequate neutron count rates, thereby precluding excessive integration count times. The results also indicate that the 1D neutron monitoring system causes a $10.2\% \pm 0.58\%$ and a $11.3\% \pm 0.54\%$ increase in the neutron count rates in each of the two probes, respectively, when the 1D Bank ^{235}U levels increase from their normal operation levels to the postulated "*High IDS' Flow*" reflux condition (Table 2).

Sensitivity studies are performed on the 1D Bank neutron monitoring system. These studies are presented in Appendix E of this report. Note that the nominal configuration (reference configuration) of the monitoring system of Appendix E differs slightly from that shown in Figures 11 and 12 and that in which its results are presented in Table 9. The differences between the two nominal configurations are listed in Appendix E. However, despite these differences, conclusions of the sensitivity studies of Appendix E are applicable to system at hand. Results of the sensitivity studies include the following:

☞ The neutron count rate is quite sensitive to the following:

- **Position of the neutron detector package.** The sensitivity studies concluded that the normal neutron count rate varies by $\approx 7\%$ when the detector package is moved $\frac{1}{4}$ " from its reference location.
- **Position of the neutron source package.** The sensitivity studies concluded that the neutron count rate varies by as much as 12% when the source package is moved $\frac{1}{4}$ " from its reference location.

☞ The relative change in the neutron count rate due to the postulated transition from normal ^{235}U concentration levels to reflux levels is, for all practical purposes, constant for all examined perturbations (within the as-built tolerances). That is, the

ability of the 1D neutron monitoring system to predict the "High 1DS' Flow" postulated reflux condition is virtually unaffected by the following perturbations:

- **Location of the neutron detector package.** Despite the fact that the detector package location is changed by $\frac{1}{2}$ " from its nominal location, the change in the neutron count rate remains at $\approx 108\%$ and $\approx 109\%$ for each of the two probes.
 - **Location of the neutron source package.** Despite the fact that the source package location is changed by $\frac{1}{4}$ " from its nominal location, the change in the neutron count rate remains at $\approx 108\%$ and $\approx 109\%$ for each of the two probes.
- ✧ The neutron count rates and reflux detectability of the 1D Bank are relatively insensitive (statistically indistinguishable effects) due to the following perturbations:
- nitric acid content in the aqueous material;
 - transition region length; and
 - thickness of the stainless steel plate separating the 4th and 5th Stages.

5.3 Comparison of the 1D Bank Results with the 1E Results

In this section, the results of the MCNP simulations performed on the nominal configuration of the 1E Bank (Table 8) are compared with the nominal configuration results of the 1D Bank (Table 9). The differences between both sets of studies include the following:

First, the 1D Bank's neutron count rates are on the order of $\approx 25\%$ and $\approx 10\%$ lower for the probes represented by cells #300 and #320, respectively, relative to the 1E probes. This result is obtained despite the fact that the 1D Bank utilizes two extraneous neutron sources that have a combined neutron yield that is twice that of the 1E Bank neutron source. The major factors contributing to this observation include the following:

- ✧ **Source-to-Detector Distance.** The center-to-center separation distance between the Pu-Be container to the detector package is ~ 5.8 " for the 1E Bank. On the other hand, for the 1D Bank, this distance is about 8" between the detector and the source of Stage 5 and 6.5" from the detector to the source of Stage 6.
- ✧ **Shielding.** The stainless steel regions of the support I-Beams shield the detector package of the 1D Bank, while the 1E system does not have this shield near the detector or source. Additionally, interacting neutrons due to the source of Stage 6 need to pass through the stainless steel plate between the 5th and 6th stage and the stainless plate due to the false bottom regions of Stage 5.

The second observation is that the neutron count rates in each of the BF_3 probes of the 1D Bank differ by about 15% while the probes of the 1E Bank have about the same neutron count rates. This is due to the following two reasons:

- ✧ **Geometrical Symmetry.** The source and the detector packages of the 1E Bank are arranged in a symmetrical configuration about the midline of Stage 11, which is not the case for the 1D system.
- ✧ **Quasi Symmetry of the ^{235}U Loading.** Another factor, although to a lesser extent, is that the ^{235}U levels in the 1D Bank stages are comparable (excluding Stage 11), while for the 1D Bank the ^{235}U levels differ drastically from one stage to the other.

The third observation is that the relative change in the neutron count rate is significantly lower for the monitoring system of the 1D Bank as it compares with the 1E Bank system when the ^{235}U levels increase from their normal operational levels to the postulated reflux levels. This is due to the following:

- ↳ **Relative Change in ^{235}U Levels.** The total ^{235}U content in Stage 11 of the 1E Bank changes by a factor of ≈ 28 while that of Stage 5 of the 1D Bank changes by less than a factor of 5, when both banks undergo the transition from normal to abnormal reflux levels.

Finally, the transition from bank zero to normal operation causes a higher increase in the neutron count rate of the monitoring system of the 1D Bank as it compares with the 1E Bank system. This is due to the following:

- ↳ **Relative Change in ^{235}U Levels.** The greater ^{235}U levels in Stage 5 of the 1D Bank as compared with the ^{235}U levels in Stage 11 of the 1E Bank. The ^{235}U levels in Stage 5 increase from 0 to 1.4 and to 4.6 g/L in the solvent and aqueous regions, respectively, while for Stage 11 of the 1E Bank, the increase is to 0 and 0.5 g/L in the solvent and aqueous regions, respectively.

5.4 Benchmark, Verification, and Validation Studies

The following sections present results of benchmark studies performed to validate the 1E and 1D MCNP models against known measurements.

5.4.1 Thermal Sensitivity of the BF_3 Probes

Table 7 of this document, which lists technical specifications of the LND 20240 BF_3 probes, indicate that the probe's sensitivity to thermal neutrons is 1.3 n/sec per neutron flux (ν is the neutron flux, $\text{n/cm}^2\text{-sec}$).

In order to determine the thermal sensitivity of the BF_3 probes in the Monte Carlo simulations, the thermal neutron flux and the neutron count rates for the following configurations are examined:

- ↳ Bank zero configuration of the 1E Bank of Table 8, and
- ↳ reflux scenario for the 1E Bank of Table 8.

These configurations are selected since they represent the following types of neutrons:

- ↳ A spectrum of neutrons that directly reach the detector and neutrons that slowed down in the stages regions, without producing secondary fission neutrons within the stages.
- ↳ A spectrum of neutrons interacting with the stages (slowing down), fission neutrons produced within the stages containing relatively high concentrations of ^{235}U , and neutrons that directly reach the detector package without interacting with the fissile regions of the stages.

Presented in Table 10 are the energy-dependent neutron flux³¹ and neutron count rates for the bank zero configuration of the 1E Bank, as determined by the Monte Carlo simulation. Note that Table 10 lists the neutron flux and neutron count rate averaged over both probes of the neutron detector. Also shown in

³¹ The neutron flux values have been multiplied by 1.7×10^6 to re-normalize the results from "per starting neutron" to the total neutron source strength of the Pu-Be source.

Table 10 are the energy-dependent neutron sensitivity values of the BF_3 probes. These values are obtained by dividing the neutron count rate by the neutron flux for each of the energy groups.

Table 10. The BF_3 Probe's Thermal Neutron Sensitivity based on the Bank Zero Simulation of the 1E Bank

Neutron Energy (MeV)		Neutron Flux, ^a		Neutron Count Rate, ^a		Neutron Sensitivity, ^b	
E _{min}	E _{max}	n/cm ² -sec		n/sec		nps/nv	
1.00E-11 ^c	5.00E-08	5.75E+01	0.20%	8.51E+01	0.20%	1.48E+00	0.28%
5.00E-08	6.00E-08	1.24E+01	0.36%	1.20E+01	0.36%	9.68E-01	0.51%
6.00E-08	7.00E-08	9.99E+00	0.40%	8.90E+00	0.40%	8.91E-01	0.57%
7.00E-08	8.00E-08	8.44E+00	0.44%	6.99E+00	0.44%	8.29E-01	0.62%
8.00E-08	9.00E-08	6.95E+00	0.48%	5.41E+00	0.48%	7.78E-01	0.68%
9.00E-08	1.00E-07	5.78E+00	0.53%	4.26E+00	0.53%	7.36E-01	0.75%
1.00E-07	1.00E-06	3.74E+01	0.26%	1.91E+01	0.26%	5.10E-01	0.37%
1.00E-06	3.00E+01	3.09E+02	0.10%	3.92E+00	0.29%	1.27E-02	0.31%
1.00E-11	3.00E+01	4.47E+02	0.09%	1.46E+02	0.16%	3.26E-01	0.18%

^a Values with a proceeded with a "%" sign represent the statistical uncertainty in the Monte Carlo simulation.

^b Values with a proceeded with a "%" sign represent the uncertainty due to dividing the neutron count rate by the neutron flux.

^c The 1E-11 MeV is the lower neutron energy-cutoff in the MCNP simulation.

The results of Table 10 indicate that the neutron sensitivity of the BF_3 probe decreases with increasing neutron energy. The neutron sensitivity is a measure of the "macroscopic"³² absorption cross-section of ^{10}B . Table 10 indicates that the neutron sensitivity of the BF_3 probes varies from about 1.48 nps/nv for neutrons with energies less than 0.05 eV, down to about 0.013 nps/nv for neutrons with energies between 1 eV to 30 MeV. Additionally, the results of Table 10 indicate that the overall sensitivity of the BF_3 probes to neutrons with a spectrum represented by the bank zero configurations of the 1E Bank is 0.326 nps/nv.

To obtain the thermal neutron sensitivity of the BF_3 probe, the total thermal neutron absorption needs to be divided by the total thermal neutron flux. However, to do so, an upper energy-cutoff for thermal neutrons needs to be defined. Usually, thermal neutrons are neutrons with energies less than ~0.1 eV. Then, if the upper neutron energy for thermal neutrons is defined to 0.1 eV, then the calculated thermal neutron sensitivity for the BF_3 tubes is $1.21 \pm 0.21\%$ nps/nv. However, if this upper energy cut-off is defined to be 0.05 eV, then thermal neutron sensitivity for the BF_3 tubes is $1.48 \pm 0.42\%$ nps/sec. Both of these calculated values are in relatively good agreement with the thermal neutron sensitivity provided by the manufacturer of the BF_3 probes, i.e., a thermal neutron sensitivity of 1.3 nps/nv

Presented in Table 11 are the energy-dependent neutron flux³³ and neutron count rates for the reflux configuration of the 1E Bank. The neutron sensitivity results of Table 11 are in excellent agreement with those of Table 10. The overall sensitivity of the BF_3 tubes, when weighted with the spectrum of the reflux condition of the 1E Bank, is $0.335 \pm 0.05\%$ nps/nv. This is slightly higher than that calculated for the bank zero conditions of Table 10, which is $0.326 \pm 0.18\%$ nps/nv. The difference is due to the fact that the neutron spectrum of Table 11 is softer than that of Table 10 because of the following:

³² The microscopic cross-section multiplied by the total number of ^{10}B atoms in the BF_3 probes and weighted over the average energy of the neutron in each energy group.

³³ The neutron flux values have been multiplied by 1.7×10^6 to re-normalize the results from "per starting neutron" to the total neutron source strength of the Pu-Be source.

Table 11. The BF_3 Probe's Thermal Neutron Sensitivity based on the Reflux Condition Simulation of the 1E Bank

Neutron Energy (MeV)		Neutron Flux, ^a		Neutron Count Rate, ^a		Neutron Sensitivity, ^b	
E _{min}	E _{max}	n/cm ² -sec		n/sec		nps/nv	
1.00E-11 ^c	5.00E-08	6.71E+01	0.17%	9.93E+01	0.17%	1.48E+00	0.36%
5.00E-08	6.00E-08	1.44E+01	0.31%	1.40E+01	0.31%	9.68E-01	0.42%
6.00E-08	7.00E-08	1.17E+01	0.34%	1.04E+01	0.34%	8.91E-01	0.43%
7.00E-08	8.00E-08	9.83E+00	0.37%	8.14E+00	0.37%	8.29E-01	0.43%
8.00E-08	9.00E-08	8.12E+00	0.41%	6.31E+00	0.41%	7.78E-01	0.45%
9.00E-08	1.00E-07	6.79E+00	0.45%	5.00E+00	0.45%	7.36E-01	0.47%
1.00E-07	1.00E-06	4.39E+01	0.22%	2.23E+01	0.22%	5.09E-01	0.16%
1.00E-06	3.00E+01	3.46E+02	0.08%	4.60E+00	0.24%	1.33E-02	0.01%
1.00E-11	3.00E+01	5.08E+02	0.07%	1.70E+02	0.13%	3.35E-01	0.05%

^a Values with a proceeded with a "%" sign represent the statistical uncertainty in the Monte Carlo simulation.

^b Values with a proceeded with a "%" sign represent the uncertainty due to dividing the neutron count rate by the neutron flux.

^c The 1E-11 MeV is the lower neutron energy-cutoff in the MCNP simulation.

✧ The neutrons of Table 10 are based on neutrons emitted from the Pu-Be source, which have an average energy of 4.6 MeV. Some of these neutrons reach the detector package directly without interacting with the stages ($\approx 47\%$ of the neutrons being counted did not interact with the stages, as indicated in Table 8).

✧ The neutron spectrum of Table 11 contains neutrons liberated from fission in the 1E Banks (it contains ^{235}U), along with neutrons released from the Pu-Be sources. The average energy of ^{235}U fission neutrons is around 2 MeV [15]. Note also that the fraction of neutrons that directly reached the detectors and caused a count without interacting with the banks is only $\approx 40\%$.

Nevertheless, if the upper neutron energy for thermal neutrons is defined to 0.1 eV, then the calculated thermal neutron sensitivity for the BF_3 tubes is $1.21 \pm 0.18\%$ nps/nv. However, if this upper energy cut-off is defined to be 0.05 eV, then thermal neutron sensitivity for the BF_3 tubes is $1.48 \pm 0.36\%$ nps/sec. Both of these calculated values are equivalent to those calculated for Table 10 and are in relatively good agreement with the thermal neutron sensitivity provided by the manufacturer of the BF_3 probes, i.e., a thermal neutron sensitivity of 1.3 nps/nv.

5.4.2 Benchmark of the 1D Bank Model

Reference 1 describes the current neutron monitoring system installed on Stage 2 of the 1D Mixer-Settler Bank. A schematic of this neutron monitoring system is presented in Figure 15. Note that this detector package is similar to that shown in Figures 11 and 12 with the following exceptions:

- ✧ the detector package is installed under the settling region of Stage 2 rather than Stage 5 of Figures 11 and 12;
- ✧ the neutron source package is installed outside the settling region of Stage 2 rather than outside of Stage 5;
- ✧ the Pu-Be source does not employ a polyethylene block nor does it employ a stainless steel housing for the polyethylene block. The Pu-Be source consists of the Pu-Be region, the tantalum liner, and the stainless steel container, as described in Section 2.2 of this document;

- ↳ there is only one neutron source installed in the neutron monitoring system of Stage 2;
- ↳ the neutron detector of Figure 15 does not utilize a stainless steel liner inside the sleeves, where the BF_3 probes are inserted. Additionally the sleeves utilize conical ends, similar to those examined the sensitivity studies of Appendix D and E. The sleeves inside the detector package are obtained by drilling holes inside the polyethylene block; the diameter is $1\frac{1}{4}$ "; and
- ↳ the end parts of the BF_3 probes are housed in a stainless-steel end cap and a stainless steel spacer [25].

Figure 15. Schematic of the Neutron Monitor System Installed on Stage 2 of the 1D Mixer-Settler Bank

Reference 1 also indicates that the neutron count rates for the bank zero configuration as seen by each of the two probes of the Stage 2 monitor system are ≈ 115 and ≈ 120 n/sec. The difference in the neutron count rate as seen between the two probes may be attributed to different locations for each of the two probes within the detector package.

Nevertheless, the 1D monitor system described in Reference 1 is modeled with the MCNP code. Since the separation distance between the source and detector packages and the 1D Bank are not provided, i.e., values for δx and δz of Figure 15, multiple configurations are examined. Results of the MCNP simulations are presented in Table 12 for various δx and δz values.

Table 12. Neutron Count Rates of the Neutron Monitor System Installed on Stage 2 of the 1D Bank

δz	δx	Count Rate, n/sec	
0 "	0 "	110.82	0.99%
1/2"	0 "	112.75	0.98%
1"	0 "	118.72	0.96%
0 "	1/4"	116.80	0.96%
1/2"	1/4"	121.57	0.94%
1"	1/4"	125.71	0.93%
0 "	1/2"	125.52	0.93%
1/2"	1/2"	129.24	0.91%
1"	1/2"	133.59	0.90%

The results of Table 12 indicates that the MCNP simulations are in excellent agreement with the bank zero measurements. Note that the results of Table 12 reflect the average count rate of both probes, due to the symmetrical configuration of the probes (as modeled in MCNP).

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APPENDIX A. NEUTRON SOURCE SPECTRA FROM A ONE CI PU-BE NEUTRON SOURCE

Table A-1. Energy-Dependent Neutron Source Strength from One Ci of Pu-Be Due to Spontaneous Fission and α, n Neutrons

Group	Neutron Energy (MeV)		neutrons/sec			MeV per sec
	E _{max}	E _{min}	(α, n)	Spontaneous Fission	Both Processes	
1	1.73E+01	1.42E+01	0.00E+00	9.01E-03	9.01E-03	1.42E-01
2	1.42E+01	1.22E+01	0.00E+00	5.63E-02	5.63E-02	7.43E-01
3	1.22E+01	1.00E+01	1.03E+04	4.61E-01	1.03E+04	1.14E+05
4	1.00E+01	8.61E+00	1.21E+05	1.37E+00	1.21E+05	1.13E+06
5	8.61E+00	7.41E+00	1.79E+05	3.67E+00	1.79E+05	1.43E+06
6	7.41E+00	6.07E+00	2.14E+05	1.23E+01	2.14E+05	1.44E+06
7	6.07E+00	4.97E+00	1.73E+05	2.68E+01	1.73E+05	9.56E+05
8	4.97E+00	3.68E+00	3.76E+05	7.91E+01	3.76E+05	1.62E+06
9	3.68E+00	3.01E+00	2.44E+05	7.97E+01	2.44E+05	8.18E+05
10	3.01E+00	2.73E+00	8.61E+04	4.50E+01	8.61E+04	2.47E+05
11	2.73E+00	2.47E+00	5.12E+04	4.91E+01	5.13E+04	1.33E+05
12	2.47E+00	2.37E+00	1.61E+04	2.09E+01	1.62E+04	3.91E+04
13	2.37E+00	2.35E+00	3.14E+03	4.33E+00	3.15E+03	7.42E+03
14	2.35E+00	2.23E+00	1.84E+04	2.70E+01	1.84E+04	4.22E+04
15	2.23E+00	1.92E+00	4.22E+04	7.80E+01	4.23E+04	8.77E+04
16	1.92E+00	1.65E+00	2.59E+04	7.79E+01	2.60E+04	4.64E+04
17	1.65E+00	1.35E+00	2.81E+04	9.71E+01	2.82E+04	4.24E+04
18	1.35E+00	1.00E+00	4.31E+04	1.25E+02	4.32E+04	5.08E+04
19	1.00E+00	8.21E-01	2.26E+04	6.69E+01	2.26E+04	2.06E+04
20	8.21E-01	7.43E-01	9.84E+03	2.93E+01	9.87E+03	7.72E+03
21	7.43E-01	6.08E-01	1.53E+04	5.03E+01	1.53E+04	1.04E+04
22	6.08E-01	4.98E-01	9.86E+03	3.99E+01	9.90E+03	5.47E+03
23	4.98E-01	3.69E-01	7.61E+03	4.43E+01	7.65E+03	3.32E+03
24	3.69E-01	2.97E-01	1.80E+03	2.30E+01	1.82E+03	6.06E+02
25	2.97E-01	1.83E-01	5.73E+02	3.23E+01	6.06E+02	1.45E+02
26	1.83E-01	1.11E-01	1.44E+02	1.68E+01	1.60E+02	2.36E+01
27	1.11E-01	5.74E-02	7.71E+01	9.74E+00	8.68E+01	7.31E+00
28	5.74E-02	4.09E-02	1.57E+01	2.34E+00	1.81E+01	8.88E-01
29	4.09E-02	3.18E-02	6.69E+00	1.12E+00	7.81E+00	2.84E-01
30	3.18E-02	2.61E-02	3.44E+00	6.27E-01	4.07E+00	1.18E-01
31	2.61E-02	2.42E-02	1.02E+00	1.95E-01	1.21E+00	3.05E-02
32	2.42E-02	2.19E-02	1.14E+00	2.27E-01	1.37E+00	3.16E-02
33	2.19E-02	1.50E-02	2.83E+00	6.08E-01	3.44E+00	6.35E-02
34	1.50E-02	7.10E-03	2.01E+00	5.39E-01	2.55E+00	2.82E-02
35	7.10E-03	3.35E-03	3.97E-01	1.76E-01	5.73E-01	2.99E-03
36	3.35E-03	1.58E-03	5.47E-02	5.73E-02	1.12E-01	2.76E-04
37	1.58E-03	4.54E-04	4.44E-03	2.32E-02	2.77E-02	2.81E-05
38	4.54E-04	2.14E-04	0.00E+00	2.86E-03	2.86E-03	9.54E-07
39	2.14E-04	1.01E-04	0.00E+00	9.38E-04	9.38E-04	1.48E-07
40	1.01E-04	3.73E-05	0.00E+00	3.37E-04	3.37E-04	2.33E-08
41	3.73E-05	1.07E-05	0.00E+00	7.65E-05	7.65E-05	1.84E-09
42	1.07E-05	5.04E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	5.04E-06	1.86E-06	0.00E+00	3.30E-06	3.30E-06	1.14E-11
44	1.86E-06	8.76E-07	0.00E+00	2.12E-05	2.12E-05	2.90E-11
45	8.76E-07	4.14E-07	0.00E+00	9.48E-06	9.48E-06	6.12E-12
46	4.14E-07	1.00E-07	0.00E+00	9.21E-06	9.21E-06	2.37E-12
47	1.00E-07	1.00E-11	0.00E+00	7.88E-09	7.88E-09	3.94E-16
Total	1.73E+01	1.00E-11	1.70E+06	1.05E+03	1.70E+06	8.25E+06

APPENDIX B. THE MCNP MODEL FOR THE 1E BANK

The model listed below portrays the 1E Bank under the postulated reflux conditions of Table 2. Additionally, in the model, the neutron detector and neutron source packages are positioned at the nominal values of Figures 9 and 10.

```

El-Stripper Banks SECOND CYLCE W/Pu-Be SRC&N-Detector (Reflux U )
C ----->
C Define Stages 9 thru 12 Bounded in u=19 by:
C 0.0 < X < 125.095, 0.0 < Y < 309.88, 0.0 < Z < 37.465
C ----->
c Define Stripper Bank #12
120 20 -7.92 (-12:16:-22:26:-42: 43) (21 -27 11 -17 41 -44) imp:n=1 $ Outer SS/Bank#12
121 20 -7.92 12 -15 32 -33 42 -43 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#12
122 20 -7.92 13 -14 33 -26 42 -43 imp:n=1 $ Mixer's S.S. Bottom of Bank#12
123 0 12 -13 33 -26 42 -43 imp:n=1 $ Mixer's FALSE Bottom of Bank#12
124 1 -0.774288 15 -16 22 -31 42 -43 imp:n=1 $ Solvent Region/SETTLER of Bank#12
125 2 -1.000000 12 -15 22 -32 42 -43 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#12
126 3 -0.842001 14 -16 33 -26 42 -43 imp:n=1 $ MIXER MATERIAL of Bank#12
127 3 -0.842001 15 -16 31 -33 42 -43 imp:n=1 $ MIXER MATERIAL of Bank#12
c Define Stripper Bank #11
110 20 -7.92 (-12:16:-22:26:-45: 46) (21 -27 11 -17 44 -47) imp:n=1 $ Outer SS/Bank#11
111 20 -7.92 12 -15 23 -24 45 -46 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#11
112 20 -7.92 13 -14 22 -23 45 -46 imp:n=1 $ Mixer's S.S. Bottom of Bank#11
113 0 12 -13 22 -23 45 -46 imp:n=1 $ Mixer's FALSE Bottom of Bank#11
114 4 -0.780441 15 -16 25 -26 45 -46 imp:n=1 $ Solvent Region/SETTLER of Bank#11
115 5 -1.015385 12 -15 24 -26 45 -46 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#11
116 6 -0.850924 14 -16 22 -23 45 -46 imp:n=1 $ MIXER MATERIAL of Bank#11
117 6 -0.850924 15 -16 23 -25 45 -46 imp:n=1 $ MIXER MATERIAL of Bank#11
c Define Stripper Bank #10
100 20 -7.92 (-12:16:-22:26:-48: 49) (21 -27 11 -17 47 -50) imp:n=1 $ Outer SS/Bank#10
101 20 -7.92 12 -15 32 -33 48 -49 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#10
102 20 -7.92 13 -14 33 -26 48 -49 imp:n=1 $ Mixer's S.S. Bottom of Bank#10
103 0 12 -13 33 -26 48 -49 imp:n=1 $ Mixer's FALSE Bottom of Bank#10
104 7 -0.775826 15 -16 22 -31 48 -49 imp:n=1 $ Solvent Region/SETTLER of Bank#10
105 8 -1.007692 12 -15 22 -32 48 -49 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#10
106 9 -0.845386 14 -16 33 -26 48 -49 imp:n=1 $ MIXER MATERIAL of Bank#10
107 9 -0.845386 15 -16 31 -33 48 -49 imp:n=1 $ MIXER MATERIAL of Bank#10
c Define Stripper Bank #9
90 20 -7.92 (-12:16:-22:26:-51: 52) (21 -27 11 -17 50 -53) imp:n=1 $ Outer SS/Bank#9
91 20 -7.92 12 -15 23 -24 51 -52 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#9
92 20 -7.92 13 -14 22 -23 51 -52 imp:n=1 $ Mixer's S.S. Bottom of Bank#9
93 0 12 -13 22 -23 51 -52 imp:n=1 $ Mixer's FALSE Bottom of Bank#9
94 10 -0.774288 15 -16 25 -26 51 -52 imp:n=1 $ Solvent Region/SETTLER of Bank#9
95 11 -1.000000 12 -15 24 -26 51 -52 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#9
96 12 -0.842001 14 -16 22 -23 51 -52 imp:n=1 $ MIXER MATERIAL of Bank#9
97 12 -0.842001 15 -16 23 -25 51 -52 imp:n=1 $ MIXER MATERIAL of Bank#9
C Define PuBe Source in Universe, Bounded in u=20 by :
c R = 0.9525
c -1.666875 < Z < 1.666875 1/2 h= -1.666875
C ----->
800 40 -2.50359 -101 110 -111 u=20 imp:n=1 $ Pu-Be Material
801 30 -16.60 (101:-110:111) -102 112 -113 u=20 imp:n=1 $ Tantalum Container
802 20 -7.92 (102:-112:113) -103 114 -115 u=20 imp:n=1 $ SS 304 Container
803 0 (103:-114:115) -104 114 -116 u=20 imp:n=1 $ Void Between PuBe & its holder
805 0 118 -116 104 130 -131 132 -133 u=20 imp:n=1 $ Void between Poly and its holder
804 21 -0.92 (104:-114:116) 130 -131 132 -133 117 -118 u=20 imp:n=1 $ Poly - Source Holder
811 0 (-130:131:-132:133:-117:116)
140 -141 142 -143 117 -116 u=20 imp:n=1 $ Void around Poly
812 20 -7.92 (-140:141:-142:143:-117:116)
150 -151 152 -153 -116 u=20 imp:n=1 $ SS 304 of holder
807 20 -7.92 (-150:151:-152:153) 120 -116 u=20 imp:n=1 $ SS 304 of holder/Lip Region
808 20 -7.92 116 u=20 imp:n=1 $ SS 304 of Holder's LID
809 0 (-150:151:-152:153) -120 u=20 imp:n=1 $ Void Below Lip Region
810 0 119 -121 160 -161 162 -163
trcl*=( 46.990 300.355 -5.79437) fill=20 imp:n=1 $ ENTIRE SOURCE w/its Holder
C ----->
c Define Detector

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C Define Probe#1 (-X Probe)
300 22 -7.33485E-04 229 -230 -203 u=18 imp:n=1 $ BF3 Region
301 0 228 -231 -203 #300 u=18 imp:n=1 $ Inactive Region Above and Below the BF3
302 20 -7.92 (-228:231:203) 227 -232 -204 u=18 imp:n=1 $ 304 SS surrounding BF3
303 0 225 -227 -201 u=18 imp:n=1 $ Inside Lower Anode Region
304 20 -7.92 224 -227 -202 #303 u=18 imp:n=1 $ SS 304 Cladding of Lower Anode Region
305 0 232 -233 -201 u=18 imp:n=1 $ Inside Upper Anode Region
306 20 -7.92 232 -234 -202 #305 u=18 imp:n=1 $ SS 304 Cladding of Upper Anode Region
309 0 202 -205 224 -227 u=18 imp:n=1 $ Outside Lower Anode Above Cone
310 0 202 -205 232 -234 u=18 imp:n=1 $ Outside Upper Anode Above Cone
311 0 -205 234 -236 u=18 imp:n=1 $ Above Upper Anode
312 0 204 -205 227 -232 u=18 imp:n=1 $ Outside Probe's Center Region
313 20 -7.92 205 -206 224 -236 u=18 imp:n=1 $ SS 304 Cladding of Insert Above Cone Region
314 20 -7.92 -224 222 -206 u=18 imp:n=1 $ SS 304 Cladding of Insert's Conical Region
C
C Define Probe#1 (+X Probe)
320 22 -7.33485E-04 229 -230 -213 u=18 imp:n=1 $ BF3 Region
321 0 228 -231 -213 #320 u=18 imp:n=1 $ Inactive Region Above and Below the BF3
322 20 -7.92 (-228:231:213) 227 -232 -214 u=18 imp:n=1 $ 304 SS surrounding BF3
323 0 225 -227 -211 u=18 imp:n=1 $ Inside Lower Anode Region
324 20 -7.92 224 -227 -212 #323 u=18 imp:n=1 $ SS 304 Cladding of Lower Anode Region
325 0 232 -233 -211 u=18 imp:n=1 $ Inside Upper Anode Region
326 20 -7.92 232 -234 -212 #325 u=18 imp:n=1 $ SS 304 Cladding of Upper Anode Region
329 0 212 -215 224 -227 u=18 imp:n=1 $ Outside Lower Anode Above Cone
330 0 212 -215 232 -234 u=18 imp:n=1 $ Outside Upper Anode Above Cone
331 0 -215 234 -236 u=18 imp:n=1 $ Above Upper Anode
332 0 214 -215 227 -232 u=18 imp:n=1 $ Outside Probe's Center Region
333 20 -7.92 215 -216 224 -236 u=18 imp:n=1 $ SS 304 Cladding of Insert Above Cone Region
334 20 -7.92 -224 222 -216 u=18 imp:n=1 $ SS 304 Cladding of Insert's Conical Region
C ==> Stainless Steel Casing of Detector's Package
340 20 -7.92 220 -221 246 -249 243 -242 u=18 imp:n=1 $ SS 304 of bottom plate (Center
341 20 -7.92 220 -221 246 -249 242 -240 u=18 imp:n=1 $ SS 304 of bottom plate (-X Region)
342 20 -7.92 220 -221 246 -249 -243 -245 u=18 imp:n=1 $ SS 304 of bottom plate (+X Region)
343 20 -7.92 235 -236 246 -249 243 -242 206 216 u=18 imp:n=1 $ SS top plate (Center Region)
344 20 -7.92 235 -236 246 -249 242 -240 206 216 u=18 imp:n=1 $ SS 304 of top plate (-X)
345 20 -7.92 235 -236 246 -249 -243 -245 206 216 u=18 imp:n=1 $ SS top plate (+X Region)
346 20 -7.92 221 -222 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y) below Cone
347 20 -7.92 221 -222 248 -249 243 -242 u=18 imp:n=1 $ SS Poly (Center Region +Y) below Cone
348 20 -7.92 221 -222 -243 244 -245 u=18 imp:n=1 $ SS Poly (-X Region) below Cone
349 20 -7.92 221 -222 242 241 -240 u=18 imp:n=1 $ SS Poly (+X Region) below Cone
350 20 -7.92 222 -226 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y) Outside
351 20 -7.92 222 -226 248 -249 243 -242 u=18 imp:n=1 $ SS Poly (Center Region +Y) Outside
352 20 -7.92 222 -226 -243 244 -245 u=18 imp:n=1 $ SS Poly (-X Region) Outside Cone
353 20 -7.92 222 -226 242 241 -240 u=18 imp:n=1 $ SS Poly (+X Region) Outside Cone
354 20 -7.92 226 -235 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y) Outside
355 20 -7.92 226 -235 248 -249 243 -242 u=18 imp:n=1 $ SS Poly (Center Region +Y) Outside
356 20 -7.92 226 -235 -243 244 -245 u=18 imp:n=1 $ SS Poly (-X Region) Outside Inserts
357 20 -7.92 226 -235 242 241 -240 u=18 imp:n=1 $ SS Poly (+X Region) Outside Inserts
C ==> Polyethylene
360 21 -0.92221 -222 247 -248 243 -242 u=18 imp:n=1 $ Poly (Center Region) Outside Cone
361 21 -0.92221 -222 -243 -244 u=18 imp:n=1 $ Poly (-X Region) Outside Cone
362 21 -0.92221 -222 242 -241 u=18 imp:n=1 $ Poly (+X Region) Outside Cone
366 21 -0.92222 -235 247 -248 243 -242 206 216 u=18 imp:n=1 $ Poly (Center Region) Outside Cone
367 21 -0.92222 -235 -243 -244 206 216 u=18 imp:n=1 $ Poly (-X Region) Outside Cone
368 21 -0.92222 -235 242 -241 206 216 u=18 imp:n=1 $ Poly (+X Region) Outside Cone
369 0 (-220:236:249:-246):(242 240):(-243 245) u=18 imp:n=1 $ Outside the Package
C Squeeze Detector & trcl-it
370 0 250 -251 252 -253 254 -255
trcl*=( 46.990 315.695 -9.78073) fill=18 imp:n=1
C Define everything else within boundaries of problem
400 0 (-21:27:-41:53:-11:17) 20 -28 40 -54 10 -18 #370 #810 imp:n=1
9999 0 -10:18:-40:54:-20:28 imp:n=0 $ Everything Else

40 px -100.000 $ Left-Most X-Plane for Problem Definition
41 px 0.000 $ 12th Tank Left Plate's outer Surface
42 px 0.635 $ 12th Tank Left Plate's inner Surface
43 px 31.115 $ 12th Tank Right Plate's inner Surface
44 px 31.433 $ 12th Tank Right Plate's Outer Surface
45 px 31.750 $ 11th Tank Left Plate's inner Surface
46 px 62.230 $ 11th Tank Right Plate's inner Surface
47 px 62.548 $ 11th Tank Right Plate's Outer Surface
48 px 62.865 $ 10th Tank Left Plate's inner Surface

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49	px	93.345 \$ 10th Tank Right Plate's inner Surface
50	px	93.663 \$ 10th Tank Right Plate's Outer Surface
51	px	93.980 \$ 09th Tank Left Plate's inner Surface
52	px	124.460 \$ 09th Tank Right Plate's inner Surface
53	px	125.095 \$ 09th Tank Right Plate's Outer Surface
54	px	225.095 \$ Right Most X-Plane for Problem Definition
20	py	-100.000 \$ Inner Y-Plane for Problem Definition
21	py	-0.635 \$ ODD/EVEN NUMBERED BANKS Mixing Region Outer Y Surface/Plane
22	py	0.635 \$ ODD/EVEN NUMBERED BANKS Mixing Region Inner Y Surface/Plane
23	py	34.290 \$ ODD NUMBERED BANKS Inner Y-Surface Between Mixing & Settling
24	py	34.925 \$ ODD NUMBERED BANKS Outer Y-Surface Between Mixing & Settling
25	py	35.179 \$ ODD NUMBERED BANKS Plane Defining Outer Boundary of Mixture in Settler
26	py	309.245 \$ ODD/EVEN NUMBERED BANKS Inner Y-Surface/Plane of Settler Region Outer
27	py	310.515 \$ ODD/EVEN NUMBERED BANKS Outer Y-Surface/Plane of Settler Region Outer
28	py	409.880 \$ Outer Y-Plane for Problem definition
31	py	274.701 \$ EVEN NUMBERED BANKS Plane Defining Outer Boundary of Mixture in Settler
32	py	274.955 \$ EVEN NUMBERED BANKS Outer Y-Surface Between Mixing & Settling
33	py	275.590 \$ EVEN NUMBERED BANKS Inner Y-Surface Between Mixing & Settling
10	pz	-100.000 \$ Lower Z-Plane for Problem Definition
11	pz	-0.635 \$ Settling Tanks Lower Bottom Plate/Surface
12	pz	0.635 \$ Settling Tanks Upper Bottom Plate/Surface
13	pz	5.715 \$ Mixing Tanks Lower Bottom Plate/Surface
14	pz	6.350 \$ Mixing Tanks Upper Bottom Plate/Surface
15	pz	10.795 \$ Z-Plane Separating AQUEOUS & Solvent in Settler
16	pz	31.115 \$ Mixing Tanks Lower Top Plate/Surface
17	pz	31.750 \$ Mixing Tanks Upper Top Plate/Surface
18	pz	137.465 \$ Upper Z-Plane for Problem Definition
101	cz	0.95250 \$ Pu-Be Material Region
102	cz	1.11125 \$ Tantalum Liner Around Pu-Be Source
103	cz	1.27000 \$ ss. 304 canister of Pu-Be Source
104	cz	1.58750 \$ Void Betewwen Pu-Be container & Source Holder
106	cz	4.76250 \$ 20-mils region of Cadmium
107	cz	5.08000 \$ ss. 304 canister of Source Holder
108	cz	5.71500 \$ ss. 304 LID of Source Holder
110	pz	-1.66688 \$ -Z of PuBe Region
111	pz	1.66688 \$ +Z of PuBe Region
112	pz	-1.82563 \$ -Z of Tantalum Region
113	pz	1.82563 \$ +Z of Tantalum Region
114	pz	-1.98438 \$ -Z of 304 ss Jacket/Poly +Z Lower
115	pz	1.98436 \$ +Z of 304 ss Jacket
116	pz	4.04812 \$ +Z of Void between Source and its Holder/Poly +Z
117	pz	-5.47688 \$ -Z of Poly
118	pz	3.73062 \$ -Z of Cadmium
119	pz	-5.95313 \$ -Z of Source Holder Stainless Steel Bottom
120	pz	3.41312 \$ +Z of Source Holder Stainless Steel Top
121	pz	4.20687 \$ +Z of Source Holder LID
130	px	-4.365625 \$ -X of Poly
131	px	4.365625 \$ +X of Poly
132	py	-4.365625 \$ -Y of Poly
133	py	4.365625 \$ +Y of Poly
140	px	-4.603750 \$ -X of VOID
141	px	4.603750 \$ +X of VOID
142	py	-4.603750 \$ -Y of VOID
143	py	4.603750 \$ +Y of VOID
150	px	-5.080000 \$ Stainless Steel Side
151	px	5.080000 \$ Stainless Steel Side
152	py	-5.080000 \$ Stainless Steel Side
153	py	5.080000 \$ Stainless Steel Side
160	px	-6.350000 \$ Stainless Steel Side Lid
161	px	6.350000 \$ Stainless Steel Side Lid
162	py	-6.350000 \$ Stainless Steel Side Lid
163	py	6.350000 \$ Stainless Steel Side Lid
201	c/z	2.2225 0.00 0.8763 \$ First Probe's Ri (Void)
202	c/z	2.2225 0.00 0.9271 \$ First Probe's Ro of Voided (304 S.S.)
203	c/z	2.2225 0.00 1.2192 \$ First Probe's Ri (BF3)
204	c/z	2.2225 0.00 1.2700 \$ First Probe's Ro (304 S.S.)
205	c/z	2.2225 0.00 1.5875 \$ First Probe Insert's Inner Radius
206	c/z	2.2225 0.00 1.90500 \$ First Probe Insert's Outer Radius
211	c/z	-2.2225 0.00 0.8763 \$ Second Probe's Ri (Void)
212	c/z	-2.2225 0.00 0.9271 \$ Second Probe's Ro of Voided (304 S.S.)
213	c/z	-2.2225 0.00 1.2192 \$ Second Probe's Ri (BF3)
214	c/z	-2.2225 0.00 1.2700 \$ Second Probe's Ro (304 S.S.)

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215 c/z -2.2225 0.00 1.5875 $ Second Probe Insert's Inner Radius
216 c/z -2.2225 0.00 1.90500 $ Second Probe Insert's Outer Radius
220 pz 0.89073 $ Lower Surface of Package's Bottom Plate (304 ss)
221 pz 1.84323 $ Upper Surface of Package's Bottom Plate (304 ss)
222 pz 4.38323 $ Lower Plane At Outer Cone's Bottom
224 pz 4.70073 $ Lower Plane Probe's Bottom Anode
225 pz 4.75153 $ Upper Plane Probe's Bottom Anode
226 pz 5.56138 $ Top Plane of Probe's Conical Region
227 pz 9.41243 $ Lower Plane Probe's Inactive Region <Bottom>
228 pz 9.46323 $ Upper Plane Probe's Inactive Region <Bottom>
229 pz 10.41573 $ Lower Plane of Probes' Active Region
230 pz 22.96333 $ Upper Plane of Probes' Active Region
231 pz 23.86503 $ Lower Plane Probe's Inactive Region <TOP>
232 pz 23.91583 $ Upper Plane Probe's Inactive Region <TOP>
233 pz 28.62753 $ Lower Plane Probe's Top Anode
234 pz 28.67833 $ Upper Plane Probe's Top Anode
235 pz 35.56000 $ Lower Plane of Package's Top (304 SS)
236 pz 36.19500 $ Upper Plane of Package's Top (304 SS)
240 c/z 2.2225 0.00 4.4450 $ Second Probes's Ro of ss304
241 c/z 2.2225 0.00 4.1275 $ Second Probes's Ri of Poly
242 px 2.22250 $ Artificial Plane
243 px -2.22250 $ Artificial Plane
244 c/z -2.2225 0.00 4.1275 $ First Probes's Ri of Poly
245 c/z -2.2225 0.00 4.4450 $ First Probes's Ro of ss304
246 py -4.44500 $ -y Plane of Poly
247 py -4.12750 $ -y Plane of ss304
248 py 4.12750 $ +y Plane of Poly
249 py 4.44500 $ +y Plane of ss304
250 px -6.76750 $ Plane to Confine Detector Package
251 px 6.76750 $ Plane to Confine Detector Package
252 py -4.54500 $ Plane to Confine Detector Package
253 py 4.54500 $ Plane to Confine Detector Package
254 pz 0.89074 $ Plane to Confine Detector Package
255 pz 36.29500 $ Plane to Confine Detector Package

```

```

mode n
prtmp 2e7 1e6 j 5 j
nps 2e8
totnu no
phys:n 30 1e-09
cut:n 1.0e16 1e-11 -0.50 -0.25
sdef pos=46.990 300.355 -5.79437 erg=d1
rad d3 ext d2 axs 0 0 1
si1 1 5.00E-08 2.57E-07 6.45E-07 1.37E-06 3.45E-06
7.87E-06 2.40E-05 6.92E-05 1.58E-04 3.34E-04
1.02E-03 2.47E-03 5.23E-03 1.11E-02 1.85E-02
2.31E-02 2.52E-02 2.90E-02 3.64E-02 4.915E-02
8.42E-02 1.47E-01 2.40E-01 3.33E-01 4.34E-01
5.53E-01 6.76E-01 7.82E-01 9.11E-01 1.18E+00
1.50E+00 1.79E+00 2.08E+00 2.29E+00 2.36E+00
2.42E+00 2.60E+00 2.87E+00 3.35E+00 4.33E+00
5.52E+00 6.74E+00 8.01E+00 9.31E+00 1.11E+01
1.32E+01 15.575
sp1 4.63E-15 5.42E-12 5.58E-12 1.25E-11 1.94E-12
1.00E-14 4.50E-11 1.98E-10 5.52E-10 1.68E-09
1.63E-08 6.59E-08 3.37E-07 1.50E-06 2.02E-06
8.06E-07 7.14E-07 2.39E-06 4.59E-06 1.06E-05
5.11E-05 9.43E-05 3.56E-04 1.07E-03 4.50E-03
5.82E-03 9.02E-03 5.81E-03 1.33E-02 2.54E-02
1.66E-02 1.53E-02 2.49E-02 1.08E-02 1.85E-03
9.50E-03 3.02E-02 5.07E-02 1.44E-01 2.21E-01
1.02E-01 1.26E-01 1.05E-01 7.12E-02 6.06E-03
3.31E-08 5.30E-09
si2 1.66687
si3 0 0.95249
fq e f
e0 0.5E-07 0.6E-07 0.7E-07 0.8E-07 0.9E-07
0.1e-06 1.0e-06 30
f4:n 300 320 t
f14:n 300 320 t
fm4 1.70e+06
fm14 2.62493e+03 22 -2

```

cf14	124 125 126 127	114 115 116 117
	104 105 106 107	94 95 96 97
cf4	124 125 126 127	114 115 116 117
	104 105 106 107	94 95 96 97
m20	26054.60c -0.03962	26057.60c -0.01488
	24050.60c -0.00793	24053.60c -0.01838
	28058.60c -0.06402	28061.60c -0.00111
	28064.60c -0.00094	26056.60c -0.63849
	26058.60c -0.00202	24052.60c -0.15903
	24054.60c -0.00466	28060.60c -0.02532
	28062.60c -0.00360	25055.60c -0.02000 \$ 304 ss @ 7.92 g/cc
m21	1001.60c -0.14372	6000.60c -0.85628 \$ Polyethelne @ 0.92 g/cc
m22	5010.60c -0.143366239	5011.60c -0.006568014
	9019.60c -0.850065747 \$ BF3 in Detector 7.33485E-04 g/cc	
m30	73181.60c -1.00000 \$ Tantalum @ 16.6 g/cc	
m40	4009.60c -0.32913	94239.60c -0.62802
	94240.60c -0.04285 \$ Pu-Be Material Density @ 1.137448624	
mt1	benz.01t	
mt2	lwtr.01t	
mt3	benz.01t	
mt4	benz.01t	
mt5	lwtr.01t	
mt6	benz.01t	
mt7	benz.01t	
mt8	lwtr.01t	
mt9	benz.01t	
mt10	benz.01t	
mt11	lwtr.01t	
mt12	benz.01t	
mt21	poly.01t	
mt40	be.01t	
m1	1001.60c -1.48288E-01	15031.60c -1.09650E-02
	6000.60c -8.18104E-01	92235.60c -1.00000E-12
	8016.60c -2.26431E-02	92238.60c -1.00000E-12 \$ @ Den=0.77429 g/cc
m2	1001.60c -1.11949E-01	6000.60c -1.00000E-12
	8016.60c -8.88051E-01	15031.60c -1.00000E-12
	92235.60c -1.00000E-12	92238.60c -1.00000E-12 \$ @ Den=1.00000 g/cc
m3	1001.60c -1.35341E-01	6000.60c -5.26618E-01
	8016.60c -3.30983E-01	15031.60c -7.05827E-03
	92235.60c -1.00000E-12	92238.60c -1.00000E-12 \$ @ Den=0.84200 g/cc
m4	1001.60c -1.47119E-01	6000.60c -8.11653E-01
	8016.60c -2.24646E-02	15031.60c -1.08786E-02
	92235.60c -5.12531E-03	92238.60c -2.75978E-03 \$ @ Den=0.78044 g/cc
m5	1001.60c -1.10253E-01	6000.60c -1.00000E-12
	8016.60c -8.74596E-01	15031.60c -1.00000E-12
	92235.60c -9.84848E-03	92238.60c -5.30303E-03 \$ @ Den=1.01538 g/cc
m6	1001.60c -1.33922E-01	6000.60c -5.21096E-01
	8016.60c -3.27512E-01	15031.60c -6.98425E-03
	92235.60c -6.81612E-03	92238.60c -3.67022E-03 \$ @ Den=0.85092 g/cc
m7	1001.60c -1.47994E-01	6000.60c -8.16481E-01
	8016.60c -2.25982E-02	15031.60c -1.09433E-02
	92235.60c -1.28895E-03	92238.60c -6.94049E-04 \$ @ Den=0.77583 g/cc
m8	1001.60c -1.11095E-01	6000.60c -1.00000E-12
	8016.60c -8.81272E-01	15031.60c -1.00000E-12
	92235.60c -4.96183E-03	92238.60c -2.67176E-03 \$ @ Den=1.00769 g/cc
m9	1001.60c -1.34799E-01	6000.60c -5.24510E-01
	8016.60c -3.29658E-01	15031.60c -7.03001E-03
	92235.60c -2.60236E-03	92238.60c -1.40127E-03 \$ @ Den=0.84539 g/cc
m10	1001.60c -1.48288E-01	6000.60c -8.18104E-01
	8016.60c -2.26431E-02	15031.60c -1.09650E-02
	92235.60c -1.00000E-12	92238.60c -1.00000E-12 \$ @ Den=0.77429 g/cc
m11	1001.60c -1.11949E-01	6000.60c -1.00000E-12
	8016.60c -8.88051E-01	15031.60c -1.00000E-12
	92235.60c -1.00000E-12	92238.60c -1.00000E-12 \$ @ Den=1.00000 g/cc
m12	1001.60c -1.35341E-01	6000.60c -5.26618E-01
	8016.60c -3.30983E-01	15031.60c -7.05827E-03
	92235.60c -1.00000E-12	92238.60c -1.00000E-12 \$ @ Den=0.84200 g/cc

APPENDIX C. THE MCNP MODEL FOR THE 1D BANK

The model listed below portrays the 1D Bank under the postulated reflux *High IDS' Flow* condition of Table 2. Additionally, in the model, the neutron detector and neutron source packages are positioned at the nominal values of Figures 11 and 12.

```

1D-Extraction Banks SECOND CYLCE W/Pu-Be Source & Neutron Detector (High IDS' Flow)
C   Define Stages 3 thru      8 Bounded in u=19 by:
C   . 0.0 < X < 84.455, 0.0 < Y < 147.955, 0.0 < Z < 27.305
C   <----->
c   Define Stripper Bank #8
80  20 -7.92 (-12:16:-22:26:-42: 43) (21 -27 11 -17 41 -44) u=9 imp:n=0.323 $ Outer SS-Bank#8
81  20 -7.92 12 -15 32 -33 42 -43 u=9 imp:n=0.359 $ Mixer/Settler S.S. Divider of Bank#8
82  20 -7.92 13 -14 33 -26 42 -43 u=9 imp:n=0.399 $ Mixer's S.S. Bottom of Bank#8
83  0      12 -13 33 -26 42 -43 u=9 imp:n=0.443 $ Mixer's FALSE Bottom of Bank#8
84  1 -0.786829 15 -16 22 -31 42 -43 u=9 imp:n=0.492 $ Solvent Region/SETTLER of Bank#8
85  2 -1.025734 12 -15 22 -32 42 -43 u=9 imp:n=0.547 $ AQUEOUS Region/SETTLER of Bank#8
86  3 -0.858500 14 -16 33 -26 42 -43 u=9 imp:n=0.608 $ MIXER MATERIAL of Bank#8
87  3 -0.858500 15 -16 31 -33 42 -43 u=9 imp:n=0.675 $ MIXER MATERIAL of Bank#8
c   Define Stripper Bank #7
70  20 -7.92 (-12:16:-22:26:-45: 46) (21 -27 11 -17 44 -47) u=9 imp:n=0.750 $ Outer SS-Bank#7
71  20 -7.92 12 -15 23 -24 45 -46 u=9 imp:n=0.750 $ Mixer/Settler S.S. Divider of Bank#7
72  20 -7.92 13 -14 22 -23 45 -46 u=9 imp:n=0.750 $ Mixer's S.S. Bottom of Bank#7
73  0      12 -13 22 -23 45 -46 u=9 imp:n=0.750 $ Mixer's FALSE Bottom of Bank#7
74  4 -0.786091 15 -16 25 -26 45 -46 u=9 imp:n=0.750 $ Solvent Region/SETTLER of Bank#7
75  5 -1.050504 12 -15 24 -26 45 -46 u=9 imp:n=0.750 $ AQUEOUS Region/SETTLER of Bank#7
76  6 -0.865415 14 -16 22 -23 45 -46 u=9 imp:n=0.750 $ MIXER MATERIAL of Bank#7
77  6 -0.865415 15 -16 23 -25 45 -46 u=9 imp:n=0.750 $ MIXER MATERIAL of Bank#7
c   Define Stripper Bank #6
60  20 -7.92 (-12:16:-22:26:-48: 49) (21 -27 11 -17 47 -50) u=9 imp:n=1 $ Outer SS-Bank#6
61  20 -7.92 12 -15 32 -33 48 -49 u=9 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#6
62  20 -7.92 13 -14 33 -26 48 -49 u=9 imp:n=1 $ Mixer's S.S. Bottom of Bank#6
63  0      12 -13 33 -26 48 -49 u=9 imp:n=1 $ Mixer's FALSE Bottom of Bank#6
64  7 -0.779009 15 -16 22 -31 48 -49 u=9 imp:n=1 $ Solvent Region/SETTLER of Bank#6
65  8 -1.050504 12 -15 22 -32 48 -49 u=9 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#6
66  9 -0.860457 14 -16 33 -26 48 -49 u=9 imp:n=1 $ MIXER MATERIAL of Bank#6
67  9 -0.860457 15 -16 31 -33 48 -49 u=9 imp:n=1 $ MIXER MATERIAL of Bank#6
c   Define Stripper Bank #5
50  20 -7.92 (-12:16:-22:26:-51: 52) (21 -27 11 -17 50 -53) u=9 imp:n=1 $ Outer SS-Bank#5
51  20 -7.92 12 -15 23 -24 51 -52 u=9 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#5
52  20 -7.92 13 -14 22 -23 51 -52 u=9 imp:n=1 $ Mixer's S.S. Bottom of Bank#5
53  0      12 -13 22 -23 51 -52 u=9 imp:n=1 $ Mixer's FALSE Bottom of Bank#5
54  10 -0.777533 15 -16 25 -26 51 -52 u=9 imp:n=1 $ Solvent Region/SETTLER of Bank#5
55  11 -1.041761 12 -15 24 -26 51 -52 u=9 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#5
56  12 -0.856802 14 -16 22 -23 51 -52 u=9 imp:n=1 $ MIXER MATERIAL of Bank#5
57  12 -0.856802 15 -16 23 -25 51 -52 u=9 imp:n=1 $ MIXER MATERIAL of Bank#5
c   Define Stripper Bank #4
40  20 -7.92 (-12:16:-22:26:-54: 55) (21 -27 11 -17 53 -56) u=9 imp:n=1 $ Outer SS-Bank#4
41  20 -7.92 12 -15 32 -33 54 -55 u=9 imp:n=1 $ Mixer/Settler S.S. Divider of Bank#4
42  20 -7.92 13 -14 33 -26 54 -55 u=9 imp:n=1 $ Mixer's S.S. Bottom of Bank#4
43  0      12 -13 33 -26 54 -55 u=9 imp:n=1 $ Mixer's FALSE Bottom of Bank#4
44  13 -0.776648 15 -16 22 -31 54 -55 u=9 imp:n=1 $ Solvent Region/SETTLER of Bank#4
45  14 -1.034476 12 -15 22 -32 54 -55 u=9 imp:n=1 $ AQUEOUS Region/SETTLER of Bank#4
46  15 -0.853997 14 -16 33 -26 54 -55 u=9 imp:n=1 $ MIXER MATERIAL of Bank#4
47  15 -0.853997 15 -16 31 -33 54 -55 u=9 imp:n=1 $ MIXER MATERIAL of Bank#4
c   Define Stripper Bank #3
30  20 -7.92 (-12:16:-22:26:-57: 58) (21 -27 11 -17 56 -59) u=9 imp:n=0.750 $ Outer SS-Bank#3
31  20 -7.92 12 -15 23 -24 57 -58 u=9 imp:n=0.750 $ Mixer/Settler S.S. Divider of Bank#3
32  20 -7.92 13 -14 22 -23 57 -58 u=9 imp:n=0.750 $ Mixer's S.S. Bottom of Bank#3
33  0      12 -13 22 -23 57 -58 u=9 imp:n=0.750 $ Mixer's FALSE Bottom of Bank#3
34  16 -0.775910 15 -16 25 -26 57 -58 u=9 imp:n=0.750 $ Solvent Region/SETTLER of Bank#3
35  17 -1.030833 12 -15 24 -26 57 -58 u=9 imp:n=0.750 $ AQUEOUS Region/SETTLER of Bank#3
36  18 -0.852387 14 -16 22 -23 57 -58 u=9 imp:n=0.750 $ MIXER MATERIAL of Bank#3
37  18 -0.852387 15 -16 23 -25 57 -58 u=9 imp:n=0.750 $ MIXER MATERIAL of Bank#3
c   Define Everything Outside Banks in Universe 9
99  0 -41:59:-21:27:-11:17 u=9 imp:n=1 $ Every Thing else in the Stage's Universe
C   <<<<- Pu-Be Source in Modified Source Holder (w/Polyethylene Housing) ->>>>

```

```

C   Source PuBe Region Bounded in u=20 by :
c   R = 0.9525
c   -1.666875 < Z < 1.666875  1/2 h= -1.666875
C   Cells 800 -> 809 define The Pu-Be Source, STAGE #5 SOURCE
800   40 -2.50359 -101 110 -111 u=20 imp:n=1 $ Pu-Be Material
801   30 -16.60 (101:-110:111) -102 112 -113 u=20 imp:n=1 $ Tantalum Container
802   20 -7.92 (102:-112:113) -103 114 -115 u=20 imp:n=1 $ SS 304 Container
803   0 (103:-114:115) -104 114 -116 u=20 imp:n=1 $ Void Between PuBe & its holder
805   0 118 -116 104 130 -131 132 -133 u=20 imp:n=1 $ Void between Poly and its holder
804   21 -0.92 (104:-114:116) 130 -131 132 -133 117 -118 u=20 imp:n=1 $ Poly Source Holder
811   0 (-130:131:-132:133:-117:116)
      140 -141 142 -143 117 -116 u=20 imp:n=1 $ Void arround Poly
812   20 -7.92 (-140:141:-142:143:-117:116)
      150 -151 152 -153 -116 u=20 imp:n=1 $ SS 304 of holder
807   20 -7.92 (-150:151:-152:153) 120 -116 u=20 imp:n=1 $ SS 304 of holder/Lip Region
808   20 -7.92 116 u=20 imp:n=1 $ SS 304 of Holder's LID
809   0 (-150:151:-152:153) -120 u=20 imp:n=1 $ Void Below Lip Region
C   Cells 850 -> 859 define The Pu-Be Source, STAGE #6 SOURCE
850   40 -2.50359 -601 610 -611 u=22 imp:n=1 $ Pu-Be Material
851   30 -16.60 (601:-610:611) -602 612 -613 u=22 imp:n=1 $ Tantalum Container
852   20 -7.92 (602:-612:613) -603 614 -615 u=22 imp:n=1 $ SS 304 Container
853   0 (603:-614:615) -604 614 -616 u=22 imp:n=1 $ Void Between PuBe & its holder
855   0 618 -616 604 630 -631 632 -633 u=22 imp:n=1 $ Void between Poly and its holder
854   21 -0.92 (604:-614:616) 630 -631 632 -633 617 -618 u=22 imp:n=1 $ Poly Source Holder
861   0 (-630:631:-632:633:-617:616)
      640 -641 642 -643 617 -616 u=22 imp:n=1 $ Void arround Poly
862   20 -7.92 (-640:641:-642:643:-617:616)
      650 -651 652 -653 -616 u=22 imp:n=1 $ SS 304 of holder
857   20 -7.92 (-650:651:-652:653) 620 -616 u=22 imp:n=1 $ SS 304 of holder/Lip Region
858   20 -7.92 616 u=22 imp:n=1 $ SS 304 of Holder's LID
859   0 (-650:651:-652:653) -620 u=22 imp:n=1 $ Void Below Lip Region
C   <<<<- BF3 Detector & Its Housing in the I-Beam Lifting Unit ->>>>
C   Define the BF3 Package Centered @ x,y,z => 0.0, 0.0, 0.0
C   Detector Package Bounded in u=18 by :
C   -6.6675 < X < 6.6675
C   -4.445 < Y < 4.445
C   0 < Z < 36.195
C   Define Detector Regions
C   Define Probe#1 (-X Probe)
300   22 -7.33485E-04 229 -230 -203 u=18 imp:n=1 $ BF3 Region
301   0 228 -231 -203 #300 u=18 imp:n=1 $ Inactive Region Above and Below the BF3
302   20 -7.92 (-228:231:203) 227 -232 -204 u=18 imp:n=1 $ 304 SS surrounding BF3
303   0 225 -227 -201 u=18 imp:n=1 $ Inside Lower Anode Region
304   20 -7.92 224 -227 -202 #303 u=18 imp:n=1 $ SS 304 Cladding of Lower Anode Region
305   0 232 -233 -201 u=18 imp:n=1 $ Inside Upper Anode Region
306   20 -7.92 232 -234 -202 #305 u=18 imp:n=1 $ SS 304 Cladding of Upper Anode Region
309   0 202 -205 224 -227 u=18 imp:n=1 $ Outside Lower Anode Above Cone
310   0 202 -205 232 -234 u=18 imp:n=1 $ Outside Upper Anode Above Cone
311   0 -205 234 -236 u=18 imp:n=1 $ Above Upper Anode
312   0 204 -205 227 -232 u=18 imp:n=1 $ Outside Probe's Center Region
313   20 -7.92 205 -206 224 -236 u=18 imp:n=1 $ SS 304 Cladding of Insert Above Cone Region
314   20 -7.92 -224 222 -206 u=18 imp:n=1 $ SS 304 Cladding of Insert's Conical Region
C   Define Probe#1 (+X Probe)
320   22 -7.33485E-04 229 -230 -213 u=18 imp:n=1 $ BF3 Region
321   0 228 -231 -213 #320 u=18 imp:n=1 $ Inactive Region Above and Below the BF3
322   20 -7.92 (-228:231:213) 227 -232 -214 u=18 imp:n=1 $ 304 SS surrounding BF3
323   0 225 -227 -211 u=18 imp:n=1 $ Inside Lower Anode Region
324   20 -7.92 224 -227 -212 #323 u=18 imp:n=1 $ SS 304 Cladding of Lower Anode Region
325   0 232 -233 -211 u=18 imp:n=1 $ Inside Upper Anode Region
326   20 -7.92 232 -234 -212 #325 u=18 imp:n=1 $ SS 304 Cladding of Upper Anode Region
329   0 212 -215 224 -227 u=18 imp:n=1 $ Outside Lower Anode Above Cone
330   0 212 -215 232 -234 u=18 imp:n=1 $ Outside Upper Anode Above Cone
331   0 -215 234 -236 u=18 imp:n=1 $ Above Upper Anode
332   0 214 -215 227 -232 u=18 imp:n=1 $ Outside Probe's Center Region
333   20 -7.92 215 -216 224 -236 u=18 imp:n=1 $ SS 304 Cladding of Insert Above Cone Region
334   20 -7.92 -224 222 -216 u=18 imp:n=1 $ SS 304 Cladding of Insert's Conical Region
C   ==> Stainless Steel Casing of Detector's Package
340   20 -7.92 220 -221 246 -249 243 -242 u=18 imp:n=1 $ SS 304 of bottom plate
341   20 -7.92 220 -221 246 -249 242 -240 u=18 imp:n=1 $ SS 304 of bottom plate (-X Region)
342   20 -7.92 220 -221 246 -249 -243 -245 u=18 imp:n=1 $ SS 304 of bottom plate (+X Region)
343   20 -7.92 235 -236 246 -249 243 -242 206 216 u=18 imp:n=1 $ SS top plate (Center Region)
344   20 -7.92 235 -236 246 -249 242 -240 206 216 u=18 imp:n=1 $ SS top plate (-X Region)

```

```

345 20 -7.92 235 -236 246 -249 -243 -245 206 216 u=18 imp:n=1 $ SS top plate (+X Region)
346 20 -7.92 221 -222 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y)
347 20 -7.92 221 -222 248 -249 243 -242 u=18 imp:n=1 $ SS Poly (Center Region +Y)
348 20 -7.92 221 -222 -243 244 -245 u=18 imp:n=1 $ SS Poly (-X Region)
349 20 -7.92 221 -222 242 241 -240 u=18 imp:n=1 $ SS Poly (+X Region)
350 20 -7.92 222 -226 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y)
351 20 -7.92 222 -226 248 -249 243 -242 u=18 imp:n=1 $ SS Poly (Center Region +Y)
352 20 -7.92 222 -226 -243 244 -245 u=18 imp:n=1 $ SS 304 Around Poly (-X Region)
353 20 -7.92 222 -226 242 241 -240 u=18 imp:n=1 $ SS 304 Around Poly (+X Region)
354 20 -7.92 226 -235 246 -247 243 -242 u=18 imp:n=1 $ SS Poly (Center Region -Y)
355 20 -7.92 226 -235 248 -249 243 -242 u=18 imp:n=1 $ SS 304
356 20 -7.92 226 -235 -243 244 -245 u=18 imp:n=1 $ SS 304
357 20 -7.92 226 -235 242 241 -240 u=18 imp:n=1 $ SS 304
c ==> Polyethylene Regions
360 21 -0.92 221 -222 247 -248 243 -242 u=18 imp:n=1 $ Poly (Center Region)
361 21 -0.92 221 -222 -243 -244 u=18 imp:n=1 $ Poly (-X Region)
362 21 -0.92 221 -222 242 -241 u=18 imp:n=1 $ Poly (+X Region)
366 21 -0.92 222 -235 247 -248 243 -242 206 216 u=18 imp:n=1 $ Poly (Center Region)
367 21 -0.92 222 -235 -243 -244 206 216 u=18 imp:n=1 $ Poly (-X Region)
368 21 -0.92 222 -235 242 -241 206 216 u=18 imp:n=1 $ Poly (+X Region)
c ==> Everything Outside Package in Universe 18
369 0 (-220:236:249:-246):(242 240):(-243 245) u=18 imp:n=1 $ Outside the Package
c Squeeze All stages in Universe that contains sources, Detectors, and all
200 0 1 -2 3 -4 5 -6 fill=9 u=8 imp:n=1
201 0 250 -251 252 -253 254 -255
trcl*=(73.030 30.4725 -7.28 0 90 90 90 0 90 180 90) fill=18 u=8 imp:n=1
202 0 119 -121 160 -161 162 -163
trcl*=(68.2625 -5.1625 13.335 0 90 90 90 90 180 90 0 90)
fill=20 u=8 imp:n=1 $ ENTIRE SOURCE w/its Holder Stage #5 Source
203 0 619 -621 660 -661 662 -663
trcl*=(59.0555 -4.5275 6.0325 0 90 90 90 180 90 0 90)
fill=22 u=8 imp:n=1 $ ENTIRE SOURCE w/its Holder Stage #6 SOURCE
204 0 #200 #201 #202 #203 u=8 imp:n=1
c Define everything else within boundaries of problem Reduce by 0.900
210 0 20 -28 40 -60 10 -18 #98 #97 fill=8 imp:n=1.000
98 20 -7.92 72 -11 70 -71 21 -27 trcl*=(64.691 0 -0.10) imp:n=1 $ Top Part of I-Beam
97 20 -7.92 76 -72 73 -74 21 -27 trcl*=(64.691 0 -0.10) imp:n=1 $ Middle Part of I-Beam
9999 0 -10:18:-40:60:-20:28 imp:n=0 $ Everything else

70 px -12.70 $ I-Beam Surface
71 px 12.70 $ I-Beam Surface
72 pz -1.45 $ I-Beam Surface
73 px -0.40 $ I-Beam Surface
74 px 0.40 $ I-Beam Surface
75 pz -0.001 $ I-Beam Surface
76 pz -50.000 $ I-Beam Surface
40 px -100.000 $ Left-Most X-Plane for Problem Definition
41 px 0.000 $ 8th Tank Left Plate's outer Surface
42 px 0.635 $ 8th Tank Left Plate's inner Surface
43 px 20.955 $ 8th Tank Right Plate's inner Surface
44 px 21.273 $ 8th Tank Right Plate's Outer Surface
45 px 21.590 $ 7th Tank Left Plate's inner Surface
46 px 41.910 $ 7th Tank Right Plate's inner Surface
47 px 42.228 $ 7th Tank Right Plate's Outer Surface
48 px 42.545 $ 6th Tank Left Plate's inner Surface
49 px 62.865 $ 6th Tank Right Plate's inner Surface
50 px 63.183 $ 6th Tank Right Plate's Outer Surface
51 px 63.500 $ 05th Tank Left Plate's inner Surface
52 px 83.820 $ 05th Tank Right Plate's inner Surface
53 px 84.455 $ 05th Tank Right Plate's Outer Surface
54 px 84.456 $ 4th Tank Left Plate's inner Surface
55 px 105.093 $ 4th Tank Right Plate's inner Surface
56 px 105.410 $ 4th Tank Right Plate's Outer Surface
57 px 105.728 $ 03th Tank Left Plate's inner Surface
58 px 126.048 $ 03th Tank Right Plate's inner Surface
59 px 126.683 $ 03th Tank Right Plate's Outer Surface
60 px 226.683 $ Right Most X-Plane for Problem Definition
20 py -20.000 $ Inner Y-Plane for Problem Definition
21 py 0.000 $ ODD/EVEN NUMBERED BANKS Mixing Region Outer Y Surface/Plane
22 py 1.270 $ ODD/EVEN NUMBERED BANKS Mixing Region Inner Y Surface/Plane
23 py 24.130 $ ODD NUMBERED BANKS Inner Y-Surface Between Mixing & Settling Regions
24 py 24.765 $ ODD NUMBERED BANKS Outer Y-Surface Between Mixing & Settling Regions

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25 py 25.019 \$ ODD NUMBERED BANKS Plane Defining Outer Boundary of Mixture in Settle X>
 26 py 146.685 \$ ODD/EVEN NUMBERED BANKS Inner Y-Surface/Plane of Settler Region Outer Plate
 27 py 147.955 \$ ODD/EVEN NUMBERED BANKS Outer Y-Surface/Plane of Settler Region Outer Plate
 28 py 247.955 \$ Outer Y-Plane for Problem definition
 31 py 122.936 \$ EVEN NUMBERED BANKS Plane Defining Outer Boundary of Mixture in Settler
 32 py 123.190 \$ EVEN NUMBERED BANKS Outer Y-Surface Between Mixing & Settling Regions
 33 py 123.825 \$ EVEN NUMBERED BANKS Inner Y-Surface Between Mixing & Settling Regions
 10 pz -100.000 \$ Lower Z-Plane for Problem Definition
 11 pz 0.000 \$ Settling Tanks Lower Bottom Plate/Surface
 12 pz 1.270 \$ Settling Tanks Upper Bottom Plate/Surface
 13 pz 6.350 \$ Mixing Tanks Lower Bottom Plate/Surface
 14 pz 6.985 \$ Mixing Tanks Upper Bottom Plate/Surface
 15 pz 9.737 \$ Z-Plane Separating AQUEOUS & Solvent Regions in Settler
 16 pz 26.670 \$ Mixing Tanks Lower Top Plate/Surface
 17 pz 27.305 \$ Mixing Tanks Upper Top Plate/Surface
 18 pz 127.305 \$ Upper Z-Plane for Problem Definition
 1 px -0.001 \$ -X Plane for Squeezing
 2 px 126.684 \$ +X Plane for Squeezing
 3 py -0.001 \$ -Y Plane for Squeezing
 4 py 147.956 \$ +Y Plane for Squeezing
 5 pz -0.001 \$ -Z Plane for Squeezing
 6 pz 27.306 \$ +Z Plane for Squeezing
 101 cz 0.95250 \$ Pu-Be Material Region
 102 cz 1.11125 \$ Tantalum Liner Around Pu-Be Source
 103 cz 1.27000 \$ ss. 304 canister of Pu-Be Source
 104 cz 1.58750 \$ Void Between Pu-Be container & Source Holder
 106 cz 4.76250 \$ 20-mils region of Cadmium
 107 cz 5.08000 \$ ss. 304 canister of Source Holder
 108 cz 5.71500 \$ ss. 304 LID of Source Holder
 110 pz -1.66688 \$ -Z of PuBe Region
 111 pz 1.66688 \$ +Z of PuBe Region
 112 pz -1.82563 \$ -Z of Tantalum Region
 113 pz 1.82563 \$ +Z of Tantalum Region
 114 pz -1.98438 \$ -Z of 304 ss Jacket/Poly +Z Lower
 115 pz 1.98436 \$ +Z of 304 ss Jacket
 116 pz 4.04812 \$ +Z of Void between Source and its Holder/Poly +Z
 117 pz -5.47688 \$ -Z of Poly
 118 pz 3.73062 \$ -Z of Cadmium
 119 pz -5.95313 \$ -Z of Source Holder Stainless Steel Bottom
 120 pz 3.41312 \$ +Z of Source Holder Stainless Steel Top
 121 pz 4.20687 \$ +Z of Source Holder LID
 130 px -2.063750 \$ -X of Poly
 131 px 6.667500 \$ +X of Poly
 132 py -4.365625 \$ -Y of Poly
 133 py 4.365625 \$ +Y of Poly
 140 px -2.301875 \$ -X of VOID
 141 px 6.905625 \$ +X of VOID
 142 py -4.603750 \$ -Y of VOID
 143 py 4.603750 \$ +Y of VOID
 150 px -2.778125 \$ Stainless Steel Side
 151 px 7.381875 \$ Stainless Steel Side
 152 py -5.080000 \$ Stainless Steel Side
 153 py 5.080000 \$ Stainless Steel Side
 160 px -3.413125 \$ Stainless Steel Side Lid
 161 px 8.016875 \$ Stainless Steel Side Lid
 162 py -6.350000 \$ Stainless Steel Side Lid
 163 py 6.350000 \$ Stainless Steel Side Lid
 601 cz 0.95250 \$ Pu-Be Material Region
 602 cz 1.11125 \$ Tantalum Liner Around Pu-Be Source
 603 cz 1.27000 \$ ss. 304 canister of Pu-Be Source
 604 cz 1.58750 \$ Void Between Pu-Be container & Source Holder
 606 cz 4.76250 \$ 20-mils region of Cadmium
 607 cz 5.08000 \$ ss. 304 canister of Source Holder
 608 cz 5.71500 \$ ss. 304 LID of Source Holder
 610 pz -1.66688 \$ -Z of PuBe Region
 611 pz 1.66688 \$ +Z of PuBe Region
 612 pz -1.82563 \$ -Z of Tantalum Region
 613 pz 1.82563 \$ +Z of Tantalum Region
 614 pz -1.98438 \$ -Z of 304 ss Jacket/Poly +Z Lower
 615 pz 1.98436 \$ +Z of 304 ss Jacket
 616 pz 3.41314 \$ +Z of Void between Source and its Holder/Poly +Z
 617 pz -2.61936 \$ -Z of Poly

```

618 pz      3.09564 $ -Z of Cadmium
619 pz     -3.09561 $ -Z of Source Holder Stainless Steel Bottom
620 pz      2.77814 $ +Z of Source Holder Stainless Steel Top
621 pz      3.57189 $ +Z of Source Holder LID
632 py     -2.060000 $ -Y of Poly
633 py      3.330000 $ +Y of Poly
642 py     -2.063750 $ -Y of VOID
643 py      3.333750 $ +Y of VOID
652 py     -2.540000 $ Stainless Steel Side
653 py      3.810000 $ Stainless Steel Side
662 py     -3.492500 $ Stainless Steel Side Lid
663 py      4.762500 $ Stainless Steel Side Lid
631 px      2.063750 $ -X of Poly
630 px     -14.128750 $ +X of Poly
641 px      2.301875 $ -X of VOID
640 px     -14.366875 $ +X of VOID
651 px      2.778125 $ Stainless Steel Side
650 px     -14.843125 $ Stainless Steel Side
661 px      3.413125 $ Stainless Steel Side Lid
660 px     -15.478125 $ Stainless Steel Side Lid
201 c/z 2.2225 0.00 0.8763 $ First Probe's Ri (Void)
202 c/z 2.2225 0.00 0.9271 $ First Probe's Ro of Voided (304 S.S.)
203 c/z 2.2225 0.00 1.2192 $ First Probe's Ri (BF3)
204 c/z 2.2225 0.00 1.2700 $ First Probe's Ro (304 S.S.)
205 c/z 2.2225 0.00 1.5875 $ First Probe Insert's Inner Radius
206 c/z 2.2225 0.00 1.90500 $ First Probe Insert's Outer Radius
211 c/z -2.2225 0.00 0.8763 $ Second Probe's Ri (Void)
212 c/z -2.2225 0.00 0.9271 $ Second Probe's Ro of Voided (304 S.S.)
213 c/z -2.2225 0.00 1.2192 $ Second Probe's Ri (BF3)
214 c/z -2.2225 0.00 1.2700 $ Second Probe's Ro (304 S.S.)
215 c/z -2.2225 0.00 1.5875 $ Second Probe Insert's Inner Radius
216 c/z -2.2225 0.00 1.90500 $ Second Probe Insert's Outer Radius
220 pz      0.89073 $ Lower Surface of Package's Bottom Plate (304 ss)
221 pz      1.84323 $ Upper Surface of Package's Bottom Plate (304 ss)
222 pz      4.38323 $ Lower Plane At Outer Cone's Bottom
224 pz      4.70073 $ Lower Plane Probe's Bottom Anode
225 pz      4.75153 $ Upper Plane Probe's Bottom Anode
226 pz      5.56138 $ Top Plane of Probe's Conical Region
227 pz      9.41243 $ Lower Plane Probe's Inactive Region <Bottom>
228 pz      9.46323 $ Upper Plane Probe's Inactive Region <Bottom>
229 pz     10.41573 $ Lower Plane of Probes' Active Region
230 pz     22.96333 $ Upper Plane of Probes' Active Region
231 pz     23.86503 $ Lower Plane Probe's Inactive Region <TOP>
232 pz     23.91583 $ Upper Plane Probe's Inactive Region <TOP>
233 pz     28.62753 $ Lower Plane Probe's Top Anode
234 pz     28.67833 $ Upper Plane Probe's Top Anode
235 pz     35.56000 $ Lower Plane of Package's Top (304 SS)
236 pz     36.19500 $ Upper Plane of Package's Top (304 SS)
240 c/z 2.2225 0.00 4.4450 $ Second Probes's Ro of ss304
241 c/z 2.2225 0.00 4.1275 $ Second Probes's Ri of Poly
242 px      2.22250 $ Artificial Plane
243 px     -2.22250 $ Artificial Plane
244 c/z -2.2225 0.00 4.1275 $ First Probes's Ri of Poly
245 c/z -2.2225 0.00 4.4450 $ First Probes's Ro of ss304
246 py     -4.44500 $ -y Plane of Poly
247 py     -4.12750 $ -y Plane of ss304
248 py      4.12750 $ +y Plane of Poly
249 py      4.44500 $ +y Plane of ss304
250 px     -6.76750 $ Plane to Confine Detector Package
251 px      6.76750 $ Plane to Confine Detector Package
252 py     -4.54500 $ Plane to Confine Detector Package
253 py      4.54500 $ Plane to Confine Detector Package
254 pz      0.89074 $ Plane to Confine Detector Package
255 pz     36.29500 $ Plane to Confine Detector Package

```

```

mode n
prtmp 2e7 1e6 j 5 j
nps 2e8
totnu no
phys:n 30 1e-09
cut:n 1.0e16 1e-11 -0.50 -0.25
sdef pos=d4 erg=d1 rad d3 ext d2 axs 0 1 0

```

```

si4 1 68.2625 -5.1625 13.335 59.0555 -4.5275 6.0325
sp4 0.5 0.5
sil 1 5.00E-08 2.57E-07 6.45E-07 1.37E-06 3.45E-06
7.87E-06 2.40E-05 6.92E-05 1.58E-04 3.34E-04
1.02E-03 2.47E-03 5.23E-03 1.11E-02 1.85E-02
2.31E-02 2.52E-02 2.90E-02 3.64E-02 4.915E-02
8.42E-02 1.47E-01 2.40E-01 3.33E-01 4.34E-01
5.53E-01 6.76E-01 7.82E-01 9.11E-01 1.18E+00
1.50E+00 1.79E+00 2.08E+00 2.29E+00 2.36E+00
2.42E+00 2.60E+00 2.87E+00 3.35E+00 4.33E+00
5.52E+00 6.74E+00 8.01E+00 9.31E+00 1.11E+01
1.32E+01 15.575
spl 4.63E-15 5.42E-12 5.58E-12 1.25E-11 1.94E-12
1.00E-14 4.50E-11 1.98E-10 5.52E-10 1.68E-09
1.63E-08 6.59E-08 3.37E-07 1.50E-06 2.02E-06
8.06E-07 7.14E-07 2.39E-06 4.59E-06 1.06E-05
5.11E-05 9.43E-05 3.56E-04 1.07E-03 4.50E-03
5.82E-03 9.02E-03 5.81E-03 1.33E-02 2.54E-02
1.66E-02 1.53E-02 2.49E-02 1.08E-02 1.85E-03
9.50E-03 3.02E-02 5.07E-02 1.44E-01 2.21E-01
1.02E-01 1.26E-01 1.05E-01 7.12E-02 6.06E-03
3.31E-08 5.30E-09
si2 1.66688
si3 0 0.9524
e0 0.5E-07 0.6E-07 0.7E-07 0.8E-07 0.9E-07 0.1E-06 1.0E-06 30
fq e f
f04:n 300 320
fm04 3.4E+06
cf04 84 85 86 87 74 75 76 77 64 65 66 67 54 55 56 57
44 45 46 47 34 35 36 37
f14:n 300 320
fm14 5249.865 22 -2
cf14 84 85 86 87 74 75 76 77 64 65 66 67 54 55 56 57
44 45 46 47 34 35 36 37
m20 26054.60c -0.03962 26057.60c -0.01488
24050.60c -0.00793 24053.60c -0.01838
28058.60c -0.06402 28061.60c -0.00111
28064.60c -0.00094 26056.60c -0.63849
26058.60c -0.00202 24052.60c -0.15903
24054.60c -0.00466 28060.60c -0.02532
28062.60c -0.00360 25055.60c -0.02000 $ 304 ss @ 7.92 g/cc
m21 1001.60c -0.14372 6000.60c -0.85628 $ Polyethelne @ 0.92 g/cc
m22 5010.60c -0.143366239 5011.60c -0.006568014
9019.60c -0.850065747 $ BF3 in Detector 7.33485E-04 g/cc
m30 73181.60c -1.00000 $ Tantulum @ 16.6 g/cc
m40 4009.60c -0.32913 94239.60c -0.62802
94240.60c -0.04285 $ Pu-Be Material Density @ 2.503590623
mt1 benz.01t
mt2 lwtr.01t
mt3 benz.01t
mt4 benz.01t
mt5 lwtr.01t
mt6 benz.01t
mt7 benz.01t
mt8 lwtr.01t
mt9 benz.01t
mt10 benz.01t
mt11 lwtr.01t
mt12 benz.01t
mt13 benz.01t
mt14 lwtr.01t
mt15 benz.01t
mt16 benz.01t
mt17 lwtr.01t
mt18 benz.01t
mt21 poly.01t
mt40 be.01t
m1 1001.60c -1.45823E-01 15031.60c -1.07814E-02
6000.60c -8.04500E-01 7014.60c -1.00000E-12
92235.60c -1.08029E-02
8016.60c -2.22761E-02 92238.60c -5.81692E-03 $ @ Den=0.78683 g/cc
m2 1001.60c -1.05500E-01 15031.60c -1.00000E-12

```

	6000.60c -1.00000E-12	7014.60c -1.36553E-02
	92235.60c -2.92474E-03	
m3	92238.60c -1.57486E-03	8016.60c -8.76345E-01 \$ @ Den=1.02573 g/cc
	1001.60c -1.31369E-01	92235.60c -7.97903E-03
	15031.60c -6.91691E-03	8016.60c -3.28408E-01
	7014.60c -4.89459E-03	
m4	6000.60c -5.16136E-01	92238.60c -4.29640E-03 \$ @ Den=0.85850 g/cc
	1001.60c -1.45965E-01	92235.60c -1.01769E-02
	15031.60c -1.07919E-02	8016.60c -2.22979E-02
	7014.60c -1.00000E-12	
m5	6000.60c -8.05288E-01	92238.60c -5.47989E-03 \$ @ Den=0.78609 g/cc
	1001.60c -1.02865E-01	92235.60c -1.90385E-02
	15031.60c -1.00000E-12	8016.60c -8.54512E-01
	7014.60c -1.33333E-02	
m6	6000.60c -1.00000E-12	92238.60c -1.02515E-02 \$ @ Den=1.05050 g/cc
	1001.60c -1.30270E-01	92235.60c -1.34040E-02
	15031.60c -6.86193E-03	8016.60c -3.25359E-01
	7014.60c -4.85549E-03	
m7	6000.60c -5.12033E-01	92238.60c -7.21753E-03 \$ @ Den=0.86541 g/cc
	1001.60c -1.47350E-01	92235.60c -4.10778E-03
	15031.60c -1.08943E-02	8016.60c -2.25094E-02
	7014.60c -1.00000E-12	
m8	6000.60c -8.12927E-01	92238.60c -2.21188E-03 \$ @ Den=0.77901 g/cc
	1001.60c -1.02865E-01	92235.60c -1.90385E-02
	15031.60c -1.00000E-12	8016.60c -8.54512E-01
	7014.60c -1.33333E-02	
m9	6000.60c -1.00000E-12	92238.60c -1.02515E-02 \$ @ Den=1.05050 g/cc
	1001.60c -1.31057E-01	92235.60c -9.57630E-03
	15031.60c -6.90416E-03	8016.60c -3.27239E-01
	7014.60c -4.88346E-03	
m10	6000.60c -5.15184E-01	92238.60c -5.15647E-03 \$ @ Den=0.86046 g/cc
	1001.60c -1.47642E-01	92235.60c -2.82946E-03
	15031.60c -1.09159E-02	8016.60c -2.25540E-02
	7014.60c -1.00000E-12	
m11	6000.60c -8.14536E-01	92238.60c -1.52356E-03 \$ @ Den=0.77753 g/cc
	1001.60c -1.03780E-01	92235.60c -1.34388E-02
	15031.60c -1.00000E-12	8016.60c -8.62099E-01
	7014.60c -1.34452E-02	
m12	6000.60c -1.00000E-12	92238.60c -7.23627E-03 \$ @ Den=1.04176 g/cc
	1001.60c -1.31643E-01	92235.60c -6.69933E-03
	15031.60c -6.93418E-03	8016.60c -3.28788E-01
	7014.60c -4.90430E-03	
m13	6000.60c -5.17424E-01	92238.60c -3.60733E-03 \$ @ Den=0.85680 g/cc
	1001.60c -1.47817E-01	92235.60c -2.06013E-03
	15031.60c -1.09288E-02	8016.60c -2.25808E-02
	7014.60c -1.00000E-12	
m14	6000.60c -8.15504E-01	92238.60c -1.10930E-03 \$ @ Den=0.77665 g/cc
	1001.60c -1.04555E-01	92235.60c -8.70006E-03
	15031.60c -1.00000E-12	8016.60c -8.68520E-01
	7014.60c -1.35399E-02	
m15	6000.60c -1.00000E-12	92238.60c -4.68465E-03 \$ @ Den=1.03448 g/cc
	1001.60c -1.32096E-01	92235.60c -4.47309E-03
	15031.60c -6.95730E-03	8016.60c -3.29996E-01
	7014.60c -4.92041E-03	
m16	6000.60c -5.19149E-01	92238.60c -2.40858E-03 \$ @ Den=0.85400 g/cc
	1001.60c -1.47964E-01	92235.60c -1.41769E-03
	15031.60c -1.09397E-02	8016.60c -2.26032E-02
	7014.60c -1.00000E-12	
m17	6000.60c -8.16312E-01	92238.60c -7.63371E-04 \$ @ Den=0.77591 g/cc
	1001.60c -1.04947E-01	92235.60c -6.30558E-03
	15031.60c -1.00000E-12	8016.60c -8.71765E-01
	7014.60c -1.35877E-02	
m18	6000.60c -1.00000E-12	92238.60c -3.39531E-03 \$ @ Den=1.03083 g/cc
	1001.60c -1.32357E-01	92235.60c -3.19104E-03
	15031.60c -6.97072E-03	8016.60c -3.30683E-01
	7014.60c -4.92970E-03	
	6000.60c -5.20151E-01	92238.60c -1.71825E-03 \$ @ Den=0.85239 g/cc

APPENDIX D. SENSITIVITY STUDIES OF THE 1E BANK NEUTRON MONITORING SYSTEM

In this appendix, the sensitivity of the 1E Mixer-Settler Bank's neutron monitoring system, i.e., neutrons count rates and reflux detectability, due to the following are investigated:

- ✧ *Perturbations in the position of the detector package.*
- ✧ *Perturbations in the position of the source package.*
- ✧ *Perturbation in the positions of the source and detector package.*
- ✧ *Transition region length.*
- ✧ *Stainless steel plate thickness of the bottom, the front, and the back plates of the mixer-settlers.*
- ✧ *Erroneous sdef values in the si2 and si3 card (neutron source model).*

The reference neutron monitoring system investigated in this study defers slightly from the monitoring system described in Section 2.4.1 and shown in Figures 8 through 10 of this report. The differences between the two systems are the following:

Detector Package and its Configuration

- ✧ *The detector package's stainless steel sleeves, where the BF_3 probes are inserted, utilize conical ends. A side view schematic is presented in Figure D-1 (refer to Figure 8 for the detector package employed in the 1E Bank).*
- ✧ *The polyethylene region below the end of the BF_3 probes is $\approx 1/2$ " thicker than the detector package of Figure 8.*
- ✧ *The BF_3 probes are located $3/4$ " lower than the probes of Figures 8 through 9. That is, the lowest plane of the BF_3 probes are at $1 1/2$ " below the lowest surface of the aqueous region's bottom surface, as shown in Figure D-2.*
- ✧ *The boron in the BF_3 is modeled as 90 a% ^{10}B versus the 96 a% of the actual probes.*

Source Package and its Configuration

- ✧ *The source package is similar to that described in Section 2.4.2.2. However, in the studies presented in this section, neutrons are emitted throughout a volume that is centered in the middle of the Pu-Be regions defined by a height of 2.06 cm, rather than the 1.66688 cm (si2 card,) and distributed over a radius of 1.269 cm, rather than the 0.9524 cm (si3 card). This error causes neutrons to be started outside the by Pu-Be material region. However, the effects of this error are negligible and do not affect the conclusions, as shown in this Appendix.*

Other Differences

- ✧ *The stainless steel thickness of the front, the back, and the bottom plates of the mixer-settlers are erroneously modeled to be $1/4$ " rather than $1/2$ ". However, the effects of this erroneous modeling are investigated in this section.*

Figure D-1. Side View Schematic of the Detector Package System Employed in the Sensitivity Studies

Figure D-2. Side View Schematic of the Detector and Pu-Be Source Relative to Stage

D.1 Sensitivity of the Detector Position on the 1E Bank Count Rate and Reflux Detectability

Results of the Monte Carlo simulations for various 1E Mixer-Settler Bank configurations are presented in Table D-1.³⁴ The results of Table D-1 reflect the nominal configuration of the neutron source package and nominal and perturbed positions of the detector package. The configurations examined in this section represent twice the as-built tolerances in the detector package location. That is, the 1E neutron monitoring system (source and detector) is built with a tolerance of $\pm 1/8$ ", while the configurations examined herein relocate the detector package by $\pm 1/2$ ". In the configurations examined in Table D-1, the neutron source package is fixed at its nominal position, as depicted in Figures D-1 and D-2.

Table D-1. The 1E Bank Neutron Count Rate for Positioning the Detector Package at $1/4$ " Away from its Nominal Position^a

Description	Cell #300 ^b (n/sec)		Cell #320 ^b (n/sec)		Interacting (n/sec)	% of Normal
Nominal Position						
Normal Conditions	126.1	0.30%	125.6	0.31%	82.6	N/A
100% Reflux Conditions	151.8	0.27%	151.6	0.27%	108.4	120.5%
Dead Count ^c	43.3	0.31%	43.3	0.31%	0.0	34.7% ^c
Bank Zero	124.9	0.25%	124.6	0.26%	81.5	99.1%
Detector Moved upwards by ½" from Nominal Position						
Normal Conditions	109.7	0.31%	108.9	0.31%	76.7	N/A
100% Reflux Conditions	135.0	0.27%	133.9	0.27%	101.9	123.1%
Dead Count ^c	32.7	0.58%	32.4	0.58%	0.0	30.1%
Bank Zero	108.6	0.31%	107.7	0.31%	75.5	99.0%
Detector Moved Downwards by ½" from Nominal Position						
Normal Conditions	143.6	0.38%	142.3	0.38%	87.1	N/A
100% Reflux Conditions	169.3	0.24%	168.6	0.24%	113.1	118.2%
Dead Count ^c	56.1	0.44%	55.6	0.44%	0.0	39.4%
Bank Zero	142.2	0.27%	141.4	0.27%	86.0	99.2%
Detector Moved ½" Horizontally Toward Stage 10						
Normal Conditions	121.6	0.29%	128.1	0.29%	81.8	N/A
100% Reflux Conditions	146.8	0.26%	154.0	0.26%	107.3	120.5%
Dead Count ^c	42.1	0.40%	44.1	0.40%	0.0	34.8%
Bank Zero	120.4	0.30%	127.0	0.29%	80.6	99.1%
Detector Moved ½" Horizontally Away from Stage 11						
Normal Conditions	113.4	0.31%	113.0	0.31%	71.1	N/A
100% Reflux Conditions	135.1	0.27%	134.6	0.27%	92.7	119.1%
Dead Count ^c	42.2	0.40%	42.0	0.40%	0.0	37.5%
Bank Zero	112.4	0.31%	112.0	0.31%	70.1	99.1%

^a Neutron source package maintained at its nominal location as shown in Figures 9 and 10.

^b The listed neutron count rates have been adjusted by the 0.9216 factor, as outlined in Section 4.3. Additionally, values in these columns with a "%" sign represent the statistical uncertainty (one-sigma) of the calculated Monte Carlo neutron count rate.

^c This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

³⁴ The MCNP produced neutron count rates have been multiplied by 0.9216 as outlined previously in Section 4.3

Regarding the perturbation of the detector package position, results of Table D-1 indicate the following:

- ✧ *With the exception of moving the detector upwards by $\frac{1}{4}$ ", all other configurations result in the efficiency of the detection system to decrease, as indicated by the increase in the relative dead count rate values (relative to the bank zero count rate).*
- ✧ *Moving the detector downwards and moving the detector away from the stage increases the fraction of non-interacting neutrons, i.e., neutrons that are counted but have not entered in the solvent, aqueous, mixing, or transition regions.*
- ✧ *Moving the detector upwards causes the normal count rate to decrease by about 12%, as it compares with its nominal position. Note that moving the detector package upwards causes both the dead count and the interacting rates to decrease. However, the rate of decrease in the interacting count rate is smaller than the rate of decrease in the dead count rate. The result is an increase in the system's efficiency, and consequently an enhancement of its reflux detectability.*
- ✧ *Moving the detector sideways toward Stage 10 causes the difference between the count rate of each probe to increase. This is due to two factors:*
 - *First, by moving the detector package closer to Stage 10, the probe defined by cell #300 is located at a distance from the source that is greater than the probe defined by cell #320. This will cause the neutron count rate to be higher in the probe of cell #320.*
 - *Second, in this new location, the probe defined by cell #300 is in an area that less affected by changes in Stage 11 than the probe defined by cell #320. That is, the neutron flux due to neutrons exiting the regions of Stage 11 will be higher near the centerline of Stage 11. Since the probe of cell #300 is further away from the centerline³⁵ of Stage 11 than the probe of cell #320, it experiences less of a neutron flux.*
- ✧ *More importantly, the results of Table D-1 indicate that even if the detector package is moved by four times the tolerances of its as-built configuration from its nominal position, adequate neutron count rates are obtained. The lowest observed neutron count rate for normal ^{235}U concentrations, is ≈ 110 neutrons/sec. Additionally, the results indicate that each one of these configurations is able to detect the postulated reflux condition. The lowest observed change is $\approx 18\%$ increase in the neutron count rate when the 1E Bank ^{235}U -concentration levels increase from their normal operation levels to the postulated reflux levels.*

D.2 Sensitivity of the Source Position on the 1E Bank Count Rate and Reflux Detectability

Presented in Table D-2 are the 1E Bank neutron count rates versus the location of the neutron source package. The configurations examined in this section represent four times the as-built tolerances in the location of the source package. That is, the 1E neutron monitoring system, source and detector, are built with location tolerances of $\pm 1/8$ ", while the configurations examined herein relocate the neutron source package by $\pm 1/2$ ". In the configurations of Table D-2, the neutron detector package is fixed at its nominal position, as depicted in Figures D-1 and D-2.

³⁵ The neutron flux is at its maximum near the centerline of Stage 11 due to the fact that the Pu-Be source (in this configuration) is centered in the mid-plane of Stage 11. Note that in the reflux configuration, the maximum location of the neutron flux may be slightly shifted toward Stage 10, due to the presence of ^{235}U in Stage 10.

Table D-2. 1E Bank Neutron Count Rate Versus Neutron Source Package Positions ^a

Description	Cell #300 ^b (n/sec)		Cell #320 ^b (n/sec)		Interacting (n/sec)	% of Normal
Nominal Position						
Normal Conditions	126.1	0.30%	125.6	0.31%	82.6	N/A
100% Reflux Conditions	151.8	0.27%	151.6	0.27%	108.4	120.5%
Dead Count ^c	43.3	0.31%	43.3	0.31%	0.0	34.7% ^c
Bank Zero	124.9	0.25%	124.6	0.26%	81.5	99.1%
Source Package Moved Horizontally Toward Stage 10 by ½"						
Normal Conditions	127.7	0.3%	122.3	0.3%	81.9	N/A
100% Reflux Conditions	153.6	0.3%	147.3	0.3%	107.4	120.4%
Dead Count ^c	44.2	0.4%	42.0	0.4%	0.0	34.8%
Bank Zero	126.4	0.3%	121.0	0.3%	80.6	99.0%
Source Package Moved Downwards by ½" (increasing Surface-to-Surface Separation Distance between it and Stage 11 Bottom)						
Normal Conditions	117.2	0.4%	116.2	0.4%	76.0	N/A
100% Reflux Conditions	139.5	0.4%	138.8	0.4%	98.5	119.2%
Dead Count ^c	41.1	0.4%	40.3	0.4%	0.0	35.1%
Bank Zero	116.3	0.4%	115.2	0.4%	75.1	99.2%
Source Package Moved Inwards by ½" (Package is further under Stage 11 Away from Detector)						
Normal Conditions	107.9	0.3%	108.4	0.3%	71.5	N/A
100% Reflux Conditions	132.2	0.3%	132.3	0.3%	95.6	122.3%
Dead Count ^c	36.7	0.3%	36.6	0.3%	0.0	34.2%
Bank Zero	106.8	0.3%	107.3	0.3%	70.4	99.0%
Source Package Moved Outwards by ½" (Package is moved closer to Detector)						
Normal Conditions	148.0	0.4%	147.2	0.4%	96.0	N/A
100% Reflux Conditions	174.8	0.3%	173.9	0.3%	122.8	118.1%
Dead Count ^c	51.3	0.4%	51.8	0.4%	0.0	35.3%
Bank Zero	146.6	0.4%	145.6	0.4%	94.6	99.0%

^a Neutron detector package maintained at its nominal location as shown in Figures 9 and 10.

^b The listed neutron count rates have been adjusted by the 0.9216 factor, as outlined in Section 4.3. Additionally, values in these columns with a "%" sign represent the statistical uncertainty (one-sigma) of the calculated Monte Carlo neutron count rate.

^c This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Results of Table D-2 indicate the following:

- ✧ With the exception of moving the source inwards (away from detector) by ½", all other configurations result in the efficiency of the detection system to decrease, as it compares with the source at its nominal position.
- ✧ Moving the source downwards and moving it closer to the detector increases the fraction of non-interacting neutrons, i.e., neutrons that are counted but have not entered in the solvent, aqueous, mixing, or transition regions.
- ✧ Moving the source sideways toward Stage 12 causes the difference between the count rate of each probe to increase. That is, by moving the source package closer to Stage 12, the probe defined by cell #320 is located at a distance from the source that is greater than the probe defined by cell #300. This will cause the neutron count rate to be higher in the probe of cell #320.
- ✧ More importantly, the results of Table D-2 indicate that if the source package is moved away from its nominal position by four times its as-built tolerances, adequate neutron count rates are obtained. Additionally, the results also indicate

that the neutron monitoring system retains its ability to detect the postulated reflux condition, even though it is relocated away from its nominal position by as much as $\frac{1}{2}$.

D.3 Effects of Source & Detector Position on the Neutron Count Rate and Reflux Detectability

Presented in Table D-3 are the 1E Bank neutron count rates for the following neutron source and detector configuration:

- ↳ *Neutron Detector Package.* With reference to the detector's nominal position (Figures D-1 and D-2), the detector is moved by $\frac{1}{2}$ " toward Stage 10 (δx), moved away from Stage 11 by $\frac{1}{2}$ " (δy), and lowered $\frac{1}{2}$ " (δz).
- ↳ *Neutron Source Package.* With reference to the source's nominal position (Figures D-1 and D-2), the source package is moved by $\frac{1}{2}$ " toward Stage 12 (δx), moved down by $\frac{1}{2}$ " (δz), and moved $\frac{1}{2}$ " closer to the detector (δy).

Table D-3. The 1E Bank Neutron Count Rate for the Modified Neutron Monitoring System Configuration ^a

Description	Cell #300 ^a (neutrons/sec)		Cell #320 ^a (neutrons/sec)		Interacting (neutrons/sec)	Efficiency	% of Normal
Bank Zero	127.7	0.29%	138.6	0.28%	74.8	56.2%	99.3%
Normal Conditions	128.5	0.29%	139.6	0.28%	75.8	56.5%	N/A
100% Reflux Conditions	147.7	0.28%	159.6	0.27%	95.4	62.1%	114.6%
Inefficiency Count ^b	56.3	0.44%	60.3	0.43%	0.0	N/A	43.8%

^a The listed neutron count rates have been adjusted by the 0.9216 factor, as outlined in Section 4.3. Additionally, values in these columns with a "%" sign represent the statistical uncertainty (one-sigma) of the calculated Monte Carlo neutron count rate

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Table D-3 indicates that, despite the fact that the neutron source and detector packages have been repositioned by 0.866" each from their nominal positions³⁶, the neutron monitoring system retains the ability to produce an adequate neutron count rate and to detect the postulated reflux condition. For the configuration examined in this section, Table D-3 indicates that the neutron count rate increases by an average of $\approx 15\%$ in each probe when the system undergoes the postulated transition from normal to reflux conditions.

D.4 Count Rate and Reflux Detectability Sensitivity due to Thickness of the Bottom, Front, and Back Plates of the 1E Bank

The analysis presented in Sections D.4 through D.6 modeled the thickness of the front, back, and bottom stainless steel plates as $\frac{1}{4}$ " rather than the actual $\frac{1}{2}$ " thickness. Presented in Table D-4 are the results of the MCNP simulations with the corrected plate thickness. The results presented in Table D-4 represent

³⁶ Neutron detector repositioned by $\delta x = +\frac{1}{2}$ ", $\delta y = +\frac{1}{2}$ ", and $\delta z = -\frac{1}{2}$ ", while the neutron source package is repositioned by $\delta x = -\frac{1}{2}$ ", $\delta y = +\frac{1}{2}$ ", and $\delta z = -\frac{1}{2}$ ".

the nominal configuration of the detector and source packages (Figures D-1 and D-2). Also presented in Table D-4 are the results of the bank with the erroneous plate thickness.

The results of Table D-4 indicate that when the actual thickness are employed, the neutron count rates decrease by $\approx 16\%$. This is mainly due to increased neutron reflection from the bottom plate, thereby reducing the fraction of neutrons interacting with the fissile regions of the mixer-settler stages. More importantly, the results of Table D-4 indicate that the neutron count rate remains adequately high, thereby not requiring the integration count rate to be excessive. Additionally, the results of Table D-4 indicate that the relative change in the neutron count rates when the system undergoes the transition from normal ^{235}U concentration to the postulated reflux conditions remains the same at $\approx 20\%$.

Table D-4. The 1E Bank Neutron Count Rate versus the 1E Bank SS Plate thickness

Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Interacting (n/sec)	% of Normal
The 1E Bank's Bottom, Front, and Back Plates Thickness of ¼"						
Normal Conditions	126.1	0.30%	125.6	0.31%	N/A	
100% Reflux Conditions	151.8	0.27%	151.6	0.27%	120.5%	
Bank Zero	124.9	0.25%	124.6	0.26%	99.1%	
The 1E Bank's Bottom, Front, and Back Plates Thickness of ½"						
Normal Conditions	106.0	0.4%	106.1	0.4%	N/A	
100% Reflux Conditions	127.5	0.4%	128.0	0.4%	120.5%	
Bank Zero	105.1	0.4%	105.3	0.4%	99.2%	
Net Change						
Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Change From Normal	
Normal Conditions	-15.94%		-15.53%		N/A	
100% Reflux Conditions	-15.99%		-15.59%		~0	
Bank Zero	-15.85%		-15.49%		~ -0.1%	

D.5 Sensitivity of the Transition Region Length on the Count Rate and Reflux Detectability

The neutron count rates versus the length of the transition regions are presented in Tables D-5 for the 1E Mixer-Settler Bank. Note that in the studies presented previously, the transition region is modeled with a length of ≈ 1 cm.

The results of Table D-5 indicate that the neutron count rates and relative change in the neutron count rates from normal conditions are virtually unaffected by the transition region length. That is, the 1E neutron monitoring system is unaffected by the length of the transition region. The neutron count rates for the two examined transition region lengths are statistically indistinguishable under bank zero, normal, and postulated reflux conditions.

Table D-5. The 1E Bank Neutron Count Rate versus Transition Region Length

Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Interacting (n/sec)	% of Normal
1E Bank with a ~1 cm Long Transition Region/Nominal Positions of Source & Detector						
Normal Conditions	126.1	0.30%	125.6	0.31%	82.6	N/A
100% Reflux Conditions	151.8	0.27%	151.6	0.27%	108.4	120.5%
Bank Zero	124.9	0.25%	124.6	0.26%	81.5	99.1%
1E Bank with a 30 cm Long Transition Region/Nominal Positions of Source & Detector						
Normal Conditions	126.0	0.4%	125.3	0.4%	82.4	N/A
100% Reflux Conditions	151.8	0.3%	151.3	0.3%	108.3	120.6%
Bank Zero	124.8	0.4%	124.0	0.4%	81.2	99.1%
Percent Change						
Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Interacting (n/sec)	
Normal Conditions	0.08%		0.24%		0.24%	
100% Reflux Conditions	0.00%		0.20%		0.09%	
Bank Zero	0.08%		0.48%		0.37%	

D.6 Affects of the Erroneous Sdef values on the Neutron Count Rates of the 1E Bank

As stated in Section 4.1, the neutron source model for the 1E Bank sensitivity studies (Section D.4 through D.8) utilized the wrong values in the "si2" and "si3" cards, part of the general source definition cards. In the MCNP simulations of the 1E Bank models, the Pu-Be neutron source is distributed over a height of 2.06 cm, rather than the 1.66688 cm (si2 card,) and distributed over a radius of 1.269 cm, rather than the 0.9524 cm (si3 card).

These errors cause neutrons to be started outside the Pu-Be material region. Note that this source model restricted neutrons to be emitted inside the stainless steel Pu-Be container in the radial direction. However, the erroneous extension value of 2.06 allowed neutrons to be started within about 0.1 cm above and below the stainless steel container of the Pu-Be source.

This error is expected to have an insignificant impact on the count rates, and even less of an impact on the relative change in the count rate. This is due to the following:

- ↳ Neutrons defined by the "sdef" cards represent (α, n) and spontaneous fission neutron produced in the Pu-Be region. The bulk of these neutrons are energetic neutrons with energies greater than 1 MeV. This is shown in Table A-1, where the probability of starting a neutron with energy above 1 MeV is $\approx 96\%$, above 2 MeV is $\approx 90\%$, and above 3 MeV is $\approx 77\%$.
- ↳ The MCNP output files indicate that the average mean free path (mfp) for these neutrons in the Pu-Be material regions is ≈ 6.6 cm, and ≈ 3 cm in the tantalum, stainless steel, and polyethylene regions. Note that the actual mfp would be higher than those values stated above due to the fact that these values are averaged over all neutrons interacting in these regions. That is, the mfp values are for neutrons that started in the Pu-Be (average neutron energy ~ 4.6 MeV) and for neutrons that are reflected back into these regions after losing part of their energies in the tantalum, stainless, and mainly the polyethylene regions.
- ↳ Since the mfp for the neutrons are significantly higher than the additional regions these neutrons are started in ($\approx \pm 0.16$ cm in the radial direction and $\approx \pm 0.20$ cm in the axial direction), then the impact of erroneous si2 and si3 values is expected to be insignificant.

Nevertheless, MCNP simulations are performed utilizing the distribution of the neutrons over the correct volume, results of which are listed in Table D-6. The results of Table D-6 indicate that employing the correct *si2* and *si3* values, i.e., starting neutrons only within the Pu-Be material, causes about a 1% increase in the neutron count rates and the relative increase (system reflux detectability) is virtually unchanged.

Table D-6. The 1E Bank Neutron Count Rate of the Corrected SDEF Parameters

Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Interacting (n/sec)	% of Normal
1E Bank with an erroneous source, distributed over a height of 2.06 cm and a radius of 1.27 cm						
Normal Conditions	126.1	0.30%	125.6	0.31%	82.6	N/A
100% Reflux Conditions	151.8	0.27%	151.6	0.27%	108.4	120.5%
Bank Zero	124.9	0.25%	124.6	0.26%	81.5	99.1%
1E Bank with the correct source, distributed over a height of 1.66688 cm and a radius of 0.9525 cm						
Normal Conditions	127.1	0.4%	127.2	0.4%	83.0	N/A
100% Reflux Conditions	153.5	0.3%	152.8	0.3%	109.0	120.4%
Bank Zero	125.9	0.4%	126.0	0.4%	81.8	99.0%
Percent Change						
Description	Cell #300 (n/sec)		Cell #320 (n/sec)		Interacting (n/sec)	
Normal Conditions	0.79%		1.26%		0.48%	
100% Reflux Conditions	1.11%		0.79%		0.55%	
Bank Zero	0.79%		1.11%		0.37%	

APPENDIX E. SENSITIVITY STUDIES OF THE 1D BANK NEUTRON MONITORING SYSTEM

In this appendix, the sensitivity of the 1D Mixer-Settler Bank's neutron monitoring system, i.e., neutron count rates and reflux detectability, due to the following are investigated:

- ↳ *Perturbations in the position of the detector package.*
- ↳ *Perturbations in the position of the source package.*
- ↳ *Perturbation in the positions of the source and detector package.*
- ↳ *Transition region length.*
- ↳ *Erroneous thickness³⁷ of the stainless steel plate between the 4th and 5th stages.*

The reference neutron monitoring system investigated in this study differs slightly from the monitoring system described in Section 2.4.2 and shown in Figures 8, 11, and 12 of this report. The differences between the two systems are the following:

Detector Package and its Configuration

- ↳ *The detector package's stainless steel sleeves, where the BF₃ probes are inserted, utilize conical ends. A side view schematic is presented in Figure D-1 (refer to Figure 8 for the detector package employed in the 1E Bank).*
- ↳ *The polyethylene region below the end of the BF₃ probes is $\approx 1/2$ " thicker than the detector package of Figure 8.*
- ↳ *The boron in the BF₃ is modeled as 90 a% ¹⁰B versus the 96 a% of the actual probes.*

Other Differences

- ↳ *As indicated above, the thickness of the plate separating the 4th and 5th Stages is erroneously modeled as 3/8" thick rather than the correct thickness of 1/4". However, the effects of this error are investigated in this section.*

E.1 Sensitivity of the Detector Position on the 1D Bank Count Rate and Reflux Detectability

Results of the Monte Carlo simulations for various 1D Mixer-Settler Bank configurations are presented in Table E-1.³⁸ The results of Table E-1 reflect the nominal configuration of the neutron source package and nominal and perturbed positions of the detector package. The configurations examined in this section represent twice the as-built tolerances of the detector location. That is, the 1D neutron monitoring system, source and detector, are built with a tolerance of $\pm 1/8$ ", while the configurations examined herein relocate the detector package by $\pm 1/4$ ". In the configurations examined in Table E-1, the neutron source packages are fixed at their nominal positions, as depicted in Figures 11 and 12.

³⁷ The thickness of the stainless-steel plate between Stages 5 and 6 is erroneously modeled as 3/8" rather than the 1/4" thickness, as stated in Table 1 of this document.

³⁸ The MCNP produced neutron count rates have been multiplied by 0.9216 as outlined previously in Section 4.3

Table E-1. 1D Bank Neutron Count Rate Versus Neutron Detector Package Positions^a

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec) ^b	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
Nominal Position								
Bank ZERO	109.5	0.5%	128.3	0.5%	95.7%	95.5%	56.9	67.7
Normal Conditions	114.4	0.5%	134.4	0.4%	N/A	NA	61.9	73.8
Low 1DX Flow	136.0	0.5%	159.7	0.5%	118.9%	118.8%	83.5	99.1
Low 1DX TBP	126.1	0.5%	149.2	0.5%	110.2%	111.0%	73.5	88.6
High 1DS' Flow	123.8	0.5%	146.5	0.5%	108.2%	109.1%	71.3	86.0
High 1DS Flow	131.2	0.6%	155.0	0.5%	114.7%	115.4%	78.6	94.4
Dead Count ^c	52.5	0.5%	60.6	0.5%	48.0%	47.2%	0.0	0.0
Detector Package Moved by ¼" Downwards and by ¼" toward Stage 4								
Bank ZERO	102.7	0.4%	120.9	0.4%	95.4%	95.7%	52.7	62.9
Normal Conditions	107.7	0.4%	126.3	0.4%	N/A	NA	57.7	68.3
Low 1DX Flow	128.2	0.4%	150.0	0.4%	119.0%	118.8%	78.2	92.1
Low 1DX TBP	119.2	0.4%	140.6	0.4%	110.6%	111.4%	69.2	82.7
High 1DS' Flow	116.7	0.4%	138.2	0.4%	108.3%	109.5%	66.7	80.2
High 1DS Flow	123.9	0.4%	146.0	0.4%	115.0%	115.7%	73.9	88.0
Dead Count ^c	50.0	0.5%	58.0	0.5%	48.7%	48.0%	0.0	0.0
Detector Package Moved Horizontally by ¼" Inwards (further under Stage 5, δy = ¼")								
Bank ZERO	103.7	0.5%	121.0	0.5%	95.7%	95.2%	55.9	66.2
Normal Conditions	108.3	0.6%	127.1	0.6%	N/A	NA	60.6	72.3
Low 1DX Flow	130.1	0.6%	152.7	0.5%	120.1%	120.1%	82.3	97.9
Low 1DX TBP	120.5	0.6%	142.5	0.5%	111.2%	112.1%	72.8	87.7
High 1DS' Flow	117.9	0.5%	139.3	0.5%	108.9%	109.6%	70.2	84.5
High 1DS Flow	125.2	0.5%	147.4	0.5%	115.6%	116.0%	77.4	92.6
Dead Count ^c	47.7	0.5%	54.8	0.5%	46.0%	45.3%	0.0	0.0
Detector Package Moved Horizontally by ¼" Outwards from under Stage 5, δy = -¼"								
Bank ZERO	114.1	0.6%	135.6	0.5%	95.8%	95.8%	57.5	69.4
Normal Conditions	119.1	0.5%	141.5	0.5%	N/A	NA	62.5	75.3
Low 1DX Flow	141.0	0.5%	167.1	0.5%	118.4%	118.1%	84.4	101.0
Low 1DX TBP	131.5	0.6%	157.4	0.5%	110.4%	111.2%	74.9	91.2
High 1DS' Flow	128.3	0.5%	154.5	0.5%	107.7%	109.2%	71.7	88.4
High 1DS Flow	136.3	0.5%	163.0	0.5%	114.4%	115.2%	79.7	96.8
Dead Count ^c	56.6	0.5%	66.2	0.5%	49.6%	48.8%	0.0	0.0

^a The neutron count rates have been multiplied by 0.9216 to correct for the reduced probe diameter, as indicated previously in Section 4.3.

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the normal measurements.

^c This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Additionally, the results also indicate that the lowest increase in the neutron count rate is for the "**High 1DS' Flow**" scenario, where only about an 8% and 9% increase in cells #300 and #320, respectively, is obtained. This is due to the fact that the lowest increase in the ²³⁵U levels in Stage 5 occurs with the postulated "**High 1DS' Flow**" scenario, as it compares with the other postulated reflux scenarios as shown in Table 2. Another factor, although to a lesser extent, is that the ²³⁵U levels in Stage 4 decrease below their normal operational levels in both the aqueous and solvent materials when the system undergoes the transition from normal to the postulated "**High 1DS' Flow**" scenario.

Regarding the sensitivity of the monitor system to the detector package position, results shown in Table E-1 indicate the following:

- ↳ Moving the detector outwards from under Stage 5 causes the total count rate and dead count rates to increase. However, the increase in the dead count rates is larger than the increase in all other counts, thereby making the system less efficient.
- ↳ Moving the detector downwards, to the side toward Stage 4, and outwards from under the stage increases the fraction of non-interacting neutrons.
- ↳ The different configurations listed in Table E-1 indicate that the system retains its ability to produce adequate neutron count rates and to predict all postulated reflux conditions.

E.2 1D Bank Count Rate Sensitivity due to Source Package Location

Presented in Table E-2 are the 1D Bank neutron count rates versus the neutron source packages location. The configurations examined in this section represent as much as four times the as-built tolerances in the location of the source package. Additionally, the configurations examined in this section reposition both sources by the same amount. In the configurations of Table E-2, the neutron detector package is fixed at its nominal position, as depicted in Figures 11 and 12.

Results of Table E-2 indicate that moving the sources away from the stages and downwards cause the count rates to increase at a cost of declining the system's efficiency. This is due to the fact that both these configurations result in increasing the fraction of non-interacting neutrons. The results of Table E-2 indicate that moving the source packages upwards increases the system's efficiency, however, at a cost of a decrease in the neutron count rates. Nevertheless, all examined configurations indicate that when relocating the neutron source packages by as much as four times their as-built tolerances, the neutron detection system of the 1D Bank retains its ability to produce adequate neutron count rates. Additionally, the detection system retains its ability to produce sufficient increase in the neutron count rate when the system undergoes the postulated transition from normal to abnormal reflux conditions. Note that the only examined reflux condition is the "High 1DS' Flow" scenario, since previous studies (Section E.3) indicate that this scenario produces the least increase in the neutron count rate.

E.3 Effects of Source & Detector Position on the Neutron Count Rate and Reflux Detectability

Presented in Table E-3 are the 1D Bank neutron count rates for the following neutron source and detector configuration:

- ↳ *Neutron Detector Package.* With reference to the detector's nominal position (Figures 11 and 12), the detector is moved by $\frac{1}{4}$ " toward Stage 4 (δx), moved away from under Stage 5 by $\frac{1}{4}$ " (δy), and lowered $\frac{1}{4}$ " (δz).
- ↳ *Neutron Source Packages.* With reference to the sources' nominal positions (Figures 11 and 12), both source packages are moved by $\frac{1}{4}$ " away from the stages (δy) and moved $\frac{1}{4}$ " downward closer to the detector package (δz).

Table E-2. 1D Bank Neutron Count Rate Versus Neutron Source Package Positions ^a

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec) ^b	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
Nominal Position (results of Table E-1 reproduced below)								
Bank ZERO	109.5	0.5%	128.3	0.5%	95.7%	95.5%	56.9	67.7
Normal Conditions	114.4	0.5%	134.4	0.4%	N/A	NA	61.9	73.8
High 1DS' Flow	123.8	0.5%	146.5	0.5%	108.2%	109.1%	71.3	86.0
Dead Count ^c	52.5	0.5%	60.6	0.5%	48.0%	47.2%	0.0	0.0
Both Sources Moved by ¼" Away from the Stages (increasing surface-to-surface separation distance by ¼")								
Bank ZERO	107.0	0.6%	125.6	0.5%	95.7%	95.8%	53.8	64.2
Normal Conditions	111.8	0.6%	131.1	0.5%	N/A	NA	58.6	69.7
High 1DS' Flow	120.5	0.5%	143.2	0.5%	107.8%	109.2%	67.4	81.8
Dead Count ^c	53.1	0.6%	61.4	0.5%	49.7%	48.9%	0.0	0.0
Both Sources Moved by ¼" Upwards								
Bank ZERO	103.7	0.6%	121.0	0.5%	95.1%	95.5%	55.5	66.1
Normal Conditions	109.0	0.6%	126.7	0.5%	N/A	NA	60.9	71.8
High 1DS' Flow	117.8	0.5%	139.4	0.5%	108.1%	110.0%	69.7	84.5
Dead Count ^c	48.1	0.6%	54.9	0.5%	46.4%	45.4%	0.0	0.0
Both Sources Moved by ½" Downwards								
Bank ZERO	120.4	0.5%	143.4	0.5%	95.9%	96.0%	58.5	70.7
Normal Conditions	125.5	0.5%	149.4	0.5%	N/A	NA	63.6	76.7
High 1DS' Flow	134.9	0.5%	162.2	0.5%	107.5%	108.6%	73.1	89.6
Dead Count ^c	61.9	0.5%	72.7	0.5%	51.4%	50.7%	0.0	0.0

^a The neutron count rates have been multiplied by 0.9216 to correct for the reduced probe diameter, as indicated previously in Section 4.3.

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the normal measurements.

^c This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Table E-3. The 1D Bank Neutron Count Rate for the Modified Neutron Monitoring System Configuration ^a

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec) ^b	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
Nominal Position (results of Table E-1 reproduced below)								
Bank ZERO	109.5	0.5%	128.3	0.5%	95.7%	95.5%	56.9	67.7
Normal Conditions	114.4	0.5%	134.4	0.4%	N/A	NA	61.9	73.8
High 1DS' Flow	123.8	0.5%	146.5	0.5%	108.2%	109.1%	71.3	86.0
Dead Count ^c	52.5	0.5%	60.6	0.5%	48.0%	47.2%	0.0	0.0
Modified Configuration								
Bank ZERO	112.1	0.6%	131.1	0.5%	96.2%	96.1%	52.3	60.5
Normal Conditions	116.5	0.6%	136.3	0.5%	N/A	NA	56.7	65.7
High 1DS' Flow	124.9	0.5%	147.5	0.5%	107.2%	108.2%	65.1	76.9
Dead Count ^c	59.8	0.6%	70.6	0.5%	53.4%	53.9%	0.0	0.0

^a The neutron count rates have been multiplied by 0.9216 to correct for the reduced probe diameter, as indicated previously in Section 4.3.

^b This value represents the relative inefficiency of the neutron monitoring system as it relates to the normal measurements.

^c This value represents the relative inefficiency of the neutron monitoring system as it relates to the bank zero measurements.

Table E-3 indicates that, despite the fact that the neutron source packages and neutron detector package have been repositioned by $\approx 0.35''$ and $\approx 0.43''$, respectively, from their nominal positions³⁹, the neutron monitoring system retains the ability to produce an adequate neutron count rate and to detect the postulated reflux condition. For the configuration examined in this section, Table E-3 indicates that the neutron count rate increases by an average of $\approx 2\%$ for the bank zero and normal conditions, and less than 1% for the "High IDS' Flow"⁴⁰ reflux scenario condition. Additionally, Table E-3 indicates that the neutron count rates increase by a minimum of 7% when the system undergoes the postulated transition from normal to the "High IDS' Flow" reflux scenario condition.

E.4 Sensitivity of the Transition Region Length on the Count Rate and Reflux Detectability

The neutron count rates versus the length of the transition region are presented in Tables E-4 for the 1D Bank. Note that in the studies presented previously, the transition region is modeled with a length of ≈ 1 cm.

The results of Table E-4 indicate that the neutron count rates and relative change in the neutron count rates from normal conditions are virtually unaffected by the transition region length. That is, the 1D neutron monitoring systems are unaffected by the length of the transition region. The neutron count rates for the two examined transition region lengths are statistically indistinguishable under bank zero, normal, and postulated reflux conditions.

Table E-4. 1D Bank Neutron Count Rate versus Transition Region Length

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec)	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
1D Bank with a ~1 cm Long Transition Region/Nominal Positions of Source & Detector								
Bank ZERO	109.5	0.5%	128.3	0.5%	95.7%	95.5%	56.9	67.7
Normal Conditions	114.4	0.5%	134.4	0.4%	N/A	NA	61.9	73.8
High IDS' Flow	123.8	0.5%	146.5	0.5%	108.2%	109.1%	71.3	86.0
1D Bank with a 40 cm Long Transition Region/Nominal Positions of Source & Detector								
Bank ZERO	109.2	0.6%	127.9	0.5%	95.7%	95.6%	56.8	68.0
Normal Conditions	114.1	0.6%	133.8	0.5%	N/A	NA	61.7	73.9
High IDS' Flow	123.3	0.6%	146.6	0.5%	108.1%	109.5%	71.0	86.6
Percent Change								
Description	Neutron Count Rate (n/sec)				Interacting Rate (n/sec)			
	Cell #300		Cell #320		Cell #300		Cell #320	
Bank ZERO	0.27%		0.31%		0.18%		0.44%	
Normal Conditions	0.26%		0.45%		0.32%		0.14%	
High IDS' Flow	0.41%		0.07%		0.42%		0.69%	

³⁹ Neutron detector repositioned by $\delta x = +1/4''$, $\delta y = -1/4''$, and $\delta z = -1/4''$, while both neutron source packages are repositioned by $\delta y = -1/4''$ and $\delta z = -1/4''$.

⁴⁰ Since previous studies indicated that the "High IDS' Flow" scenario produces the least amount of increase in the neutron count rate, then if the system is able to detect this scenario, all other reflux scenarios (described in Table 2 of this document) are deemed detectable as well.

E.5 Count Rate and Reflux Detectability Sensitivity Due to Nitric Acid in the Aqueous Material

In Sections E.1 through E.4, the aqueous regions of the 1D Mixer-Settler Bank are modeled as being free of HNO_3 . Although this is a valid assumption for the 1E Mixer-Settler Bank, since its HNO_3 content is 0.03 M, the aqueous regions of the 1D Bank may contain as much as 4M HNO_3 , depending on the particular stage. The HNO_3 contents of the aqueous regions⁴¹ of the 1D Bank are, therefore, investigated and the results of which are presented in Table E-5. Note that in Table E-5 the effects of the erroneous thickness⁴² of the stainless steel plate between Stages 4 and 5 embedded in the 1-D models of Sections E.3 through E.6 are also investigated.

Table E-5. 1D Bank Neutron Count Rate versus Acidity of the Aqueous Material

Description	Neutron Count Rate (n/sec)				Relative to Normal		Interacting Rate (n/sec)	
	Cell #300		Cell #320		Cell #300	Cell #320	Cell #300	Cell #320
1D Bank with a 0M of HNO ₃ in the Aqueous Material and Erroneous Plate Thickness between Stages 4 & 5								
Bank ZERO	109.5	0.5%	128.3	0.5%	95.7%	95.5%	56.9	67.7
Normal Conditions	114.4	0.5%	134.4	0.4%	N/A	NA	61.9	73.8
High 1DS' Flow	123.8	0.5%	146.5	0.5%	108.2%	109.1%	71.3	86.0
Dead Count	52.5	0.5%	60.6	0.5%	48.0%	47.2%	0.0	0.0
1D Bank with a 0M of HNO ₃ in the Aqueous Material with Corrected Plate Thickness between Stages 4 & 5								
Bank ZERO	109.3	0.6%	127.7	0.5%	95.7%	95.6%	57.1	67.9
Normal Conditions	114.2	0.6%	133.7	0.5%	N/A	NA	62.1	73.8
High 1DS' Flow	123.5	0.5%	146.3	0.5%	108.1%	109.4%	71.3	86.4
Dead Count	52.2	0.5%	59.9	0.5%	47.7%	46.9%	0.0	0.0
1D Bank with a 1M of HNO ₃ in the Aqueous Material with Corrected Plate Thickness between Stages 4 & 5								
Bank ZERO	109.6	0.6%	128.6	0.5%	95.6%	95.7%	57.4	68.7
Normal Conditions	114.7	0.6%	134.4	0.5%	N/A	NA	62.5	74.5
High 1DS' Flow	126.4	0.5%	149.2	0.5%	110.2%	111.1%	74.3	89.3
Dead Count	52.2	0.6%	59.9	0.5%	47.6%	46.6%	0.0	0.0
1D Bank with a 2M of HNO ₃ in the Aqueous Material with Corrected Plate Thickness between Stages 4 & 5								
Bank ZERO	110.2	0.6%	128.7	0.5%	95.4%	95.6%	58.0	68.8
Normal Conditions	115.5	0.6%	134.6	0.5%	N/A	NA	63.4	74.7
High 1DS' Flow	127.6	0.5%	149.8	0.5%	110.5%	111.3%	75.5	89.8
Dead Count	52.2	0.6%	59.9	0.5%	47.3%	46.6%	0.0	0.0
1D Bank with a 4M of HNO ₃ in the Aqueous Material with Corrected Plate Thickness between Stages 4 & 5								
Bank ZERO	110.9	0.6%	130.1	0.5%	95.4%	95.8%	58.8	70.1
Normal Conditions	116.2	0.6%	135.8	0.5%	N/A	NA	64.1	75.8
High 1DS' Flow	127.7	0.5%	150.3	0.5%	109.9%	110.7%	75.6	90.3
Dead Count	52.1	0.6%	60.0	0.5%	47.0%	46.1%	0.0	0.0

Results of the studies presented in Table E-5 indicate that the erroneous thickness of the plate separating the 4th and 5th Stages has an insignificant effect on both the neutron count rate and the reflux detectability. The results indicate that correcting for the plate thickness causes about a 0.2% decrease in the count rate,

⁴¹ This also includes regions containing a mixture of solvent and aqueous materials, such as the mixing regions.

⁴² The thickness of the stainless-steel plate between Stages 5 and 6 is erroneously modeled as 3/8" rather than the 1/4" thickness, as stated in Table 1 of this document.

which is significantly less than the statistical uncertainty of the Monte Carlo simulation (0.5% to 0.6%). The ability of the 1D NM system to detect the postulated reflux condition is statistically indistinguishable.

Table E-5 also indicates that HNO_3 in the aqueous material appear to increase the neutron count rate and enhance the ability of the NM system to detect the postulated reflux condition. However, these increases are within about a factor of three of the statistical uncertainty of the Monte Carlo results, and therefore should be assumed to be negligible. Additionally, these relatively small increases are considerably less than the variations in the neutron count rate and reflux detectability due to as-built tolerances.

Therefore, and in conclusion, the 1D NM system is deemed to be unaffected by the HNO_3 concentration in the aqueous material.

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