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ABSTRACT

This document presents the facility-recommended characterization of the neutron, prompt gamma ray, and delayed gamma ray radiation fields in the University of Texas at Austin Nuclear Engineering Teaching Laboratory (NETL) TRIGA reactor for the beam port 1/5 free-field environment at the 128-inch location adjacent to the core centerline. The designation for this environment is NETL-FF-BP1/5-128-cca. The neutron, prompt gamma ray, and delayed gamma ray energy spectra, uncertainties, and covariance matrices are presented as well as radial and axial neutron and gamma ray fluence profiles within the experiment area of the cavity. Recommended constants are given to facilitate the conversion of various dosimetry readings into radiation metrics desired by experimenters. Representative pulse operations are presented with conversion examples.

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ACRONYMS AND DEFINITIONS

ACRR	Annular Core Research Reactor
ASTM	American Society for Testing and Materials
Al	aluminum
B	boron
B_4C	boron carbide
BP1/5	through beam port 1-5
Bq	Becquerel (disintegrations/second)
C/E	calculated to experimental ratio
Cd	cadmium
dc	delayed critical
E_{th}	threshold energy
eV	electron volt
FP	Frenkel Pair
FWHM	full-width at half-maximum
Gy	Gray – unit of absorbed dose equal to 100 rad
k_{eff}	k-effective multiplying constant
keV	kilo-electron volt
krad	kilorad – unit of absorbed dose equal to 1000 rad
lbs	pounds
LSL-M3	Least-Squares Logarithmic Adjustment code
mb	millibarns
MCNP	Monte Carlo N-Particle Code
MeV	mega-electron volt
MJ	megajoule
ms	millisecond
MW	megawatts
Ni	nickel
n/cm^2	unit of fluence (neutrons per square centimeter)
NNSA	National Nuclear Security Administration
NETL	Nuclear Engineering Teaching Lab
Pb	lead
PCD	photo-conducting detector
PKA	primary knock-on atom
rad	unit of absorbed dose equal to 100 erg/gram in a specified material
SNL	Sandia National Laboratories

TC	thermocouple
TLD	thermoluminescent dosimeter
TRIGA	Training, Research, Isotopes, General Atomics Reactor
UZrH	uranium zirconium hydride
UT-Austin	University of Texas at Austin

1. INTRODUCTION

Characterization of the neutron and gamma ray environments in the University of Texas at Austin's (UT-Austin) Nuclear Engineering Teaching Laboratory (NETL) is important in order to maintain a high degree of fidelity in performing qualification and other testing at NETL. NETL is being explored as an auxiliary neutron test facility for the Sandia National Laboratories Radiation Effects Sciences (RES) Campaigns. Characterization includes both modeling and experimental efforts. Accurate neutronic models of NETL and the beam port environments can be used by experimenters for planning and designing experiments and in assessing experimental results. Experimental observations, including passive and active dosimetry, are important in order to determine the accuracy of the model, the energy dependent neutron fluence, the conversion constants for radiation metrics, the axial and radial neutron and gamma ray fluence profiles, and the time-dependent responses for different pulse sizes.

This document presents the facility-recommended characterization of the radiation fields in the NETL beam port 1-5 (BP1/5) though-port free-field environment at the radial centerline of the beam port at the axial centerline of the core that is core centerline adjacent, roughly 128-inches into either entrance of the beam port. The designation for this environment is NETL-FF-BP1/5-128-cca. The BP1/5 cavity of NETL has a 6-inch diameter at this test location. The free-field environment is the radiation environment within this beam port without the presence of any spectrum-modifying materials.

The neutron, prompt gamma ray, and delayed gamma ray energy spectra and uncertainties (and covariance matrices) are presented at the axial center of beam port 1/5 at the axial fuel centerline adjacent to the reactor core, the peak neutron fluence location. In addition, radial and axial neutron and gamma ray fluence profiles are given within the available experiment area inside of the beam port. Recommended constants are given that facilitate the conversion of various dosimetry readings into radiation metrics desired by experimenters. Temporal profiles for representative pulse operations are presented with conversion examples for the radiation metrics.

The neutronics model for NETL used in the BP1/5 free-field characterization was developed for the Monte Carlo N-Particle Transport Code (MCNPX). The NETL MCNP model was assembled by P. Michael Whaley (NETL) and later modified by William Charlton (NETL). Further alterations to NETL MCNP model were done by Danielle Redhouse and Curtis Peters (SNL) in 2020. Details of the NETL model and calculations are described later in this document. A pair of 640-group and 89-group neutron energy spectra and a 48-group gamma ray energy spectrum were calculated using MCNP 6.2 and the ENDF/B-VIII.0 cross sections for the NETL model with a scoring sphere at the radial centerline of the beam port at the axial centerline of the core. The calculated neutron spectrum can then be used with activation foil measurements and dosimetry cross sections, as the trial function in the unfolding codes SAND-IV (Griffin, 1994, McElroy, 1967) or LSL-M3.

For this work a total of 21 different foil types, resulting in 42 different reactions, were irradiated at the NETL-FF-BP1/5-128-cca. The LSL-M3 code and the IRDFF-II dosimetry cross-sections (IRDFF, Zsolnay 2012, Trkov 2020) were used in the unfolding analysis.

2. ENVIRONMENT DESCRIPTION

2.1. NETL Description

In the early 1950's, the US company General Atomics developed small research reactors that would be inherently safe, operationally flexible, used low enrichment fuel, and were relatively inexpensive. At the first Geneva Conference on Peaceful Uses of Atomic Energy, the Training, Research, Isotope Production General Atomics (TRIGA) reactors were presented to the public.

The Nuclear Engineering Teaching Laboratory (NETL) reactor is a TRIGA Mark-II pulse and steady-state, above-ground pool-type reactor. NETL is intended as a university research reactor typically used to perform irradiation experiments for students and customers and for radioisotope production, as well as a training reactor. Historically, NETL has been used for a wide variety of experiment campaigns, including radiation damage in materials testing, neutron radiography, neutron activation analysis, prompt gamma ray activation analysis, and radioisotope production of xenon (Xe). The NETL reactor is currently fully operational. The main irradiation facilities at NETL include five dry beam port irradiation locations, a rotary specimen rack (RSR), a pneumatic rabbit system, two in-core dry irradiation locations for use with the pneumatic rabbit system, two in-core 3-element cutout locations (~1.5" diameter), two in-core 7-element cutout locations (~2.75" diameter), and a wet central thimble element. The NETL fission rate is driven by thermal neutrons, and therefore most of the irradiation locations feature a strong thermal neutron flux. NETL does maintain four irradiation modifying capabilities that utilize absorbers such as cadmium or boron to remove thermal and epithermal neutrons. NETL has capabilities for pulsing operations and steady-state operations for reactor power levels between 0.1 kW and 1100 kW.

NETL is located at the J.J. Pickle Research Center at the University of Texas at Austin (UT-Austin) in Austin, Texas. UT-Austin previously operated a TRIGA reactor on the UT-Austin main campus from 1963 to 1988. The fuel from the previous TRIGA reactor was moved to the current reactor location, and construction on the current reactor began in 1986. Initial criticality of the NETL TRIGA reactor was achieved on March 12, 1992. The fuel elements for NETL are the standard uranium zirconium hydride (UZrH) TRIGA fuel.

Figure 1 shows the NETL reactor through the viewpoint of looking into the pool from above (during a low-power steady-state power operation). The NETL core is shown in the center of the figure. The five beam ports are shown with the BP 1/5 through-port shown extending from the top center to the bottom left. Each beam port is a dry cavity with a diameter of about 6 inches. The reactor facility also accommodates in-core irradiation with the pneumatic transfer system, called the pneumatic "rabbit". Two other in-core irradiation locations involve changes to the core's configuration. These include the 3-element irradiator (3L) and the 7-element irradiator (7L), the latter of which can have significant effects to the maximum power and flux capabilities. The 7L allows for a larger in-core dry irradiation cavity of about 3 inches. The NETL tank and high bay are shown in Figure 2, with the floor level equal to the reactor core location. Figure 3 shows BP 1/5 with the SNL test fixture with active cabling.

NETL maintains a thermal neutron fluence spectrum in the core and beam port cavities. Beam port filters and stops can be used with moderators to thermalize or harden the neutron fluence, respectively. For an unmoderated condition, the neutron fluence at the center of BP 1-5, at the adjacent core axial centerline, is ~8.2E+12 n/cm^2 per MJ of reactor energy. About 67% of the neutron fluence is below 1 keV and 22% above 100 keV. The 1-MeV Damage-Equivalent Silicon (DES) fluence is ~1.6E+12 n/cm^2 per MJ of reactor energy. The prompt gamma ray dose at the same position is ~2.5E+03 rad(Si) per MJ. The delayed gamma ray dose is ~9.6E+02 rad(Si) per MJ.

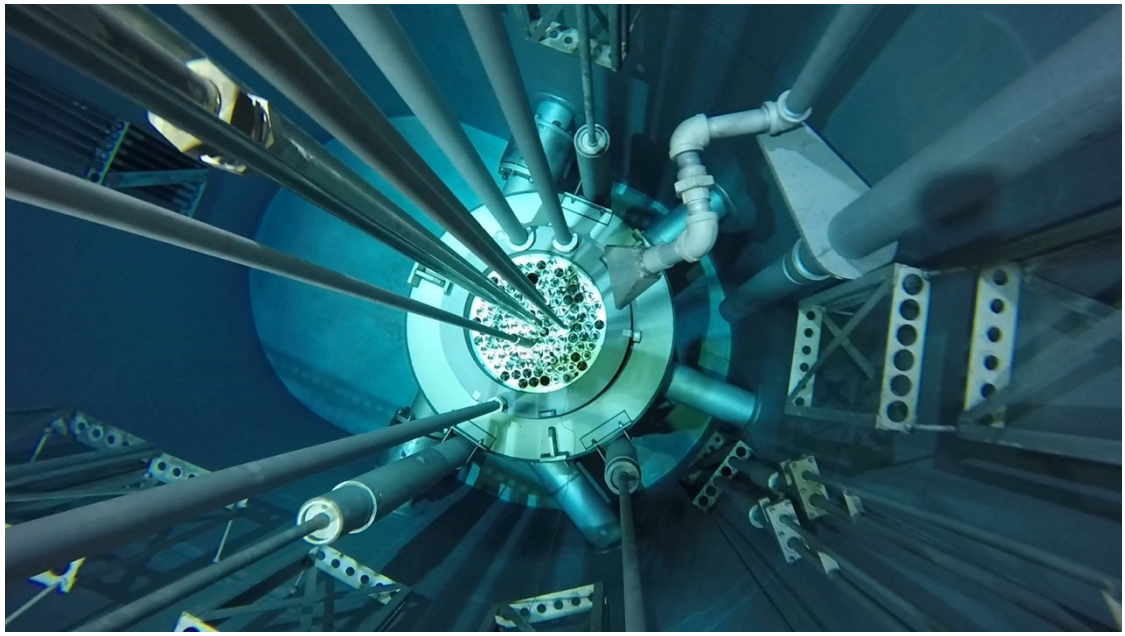

Figure 1. Top View NETL Reactor and Core Pool.

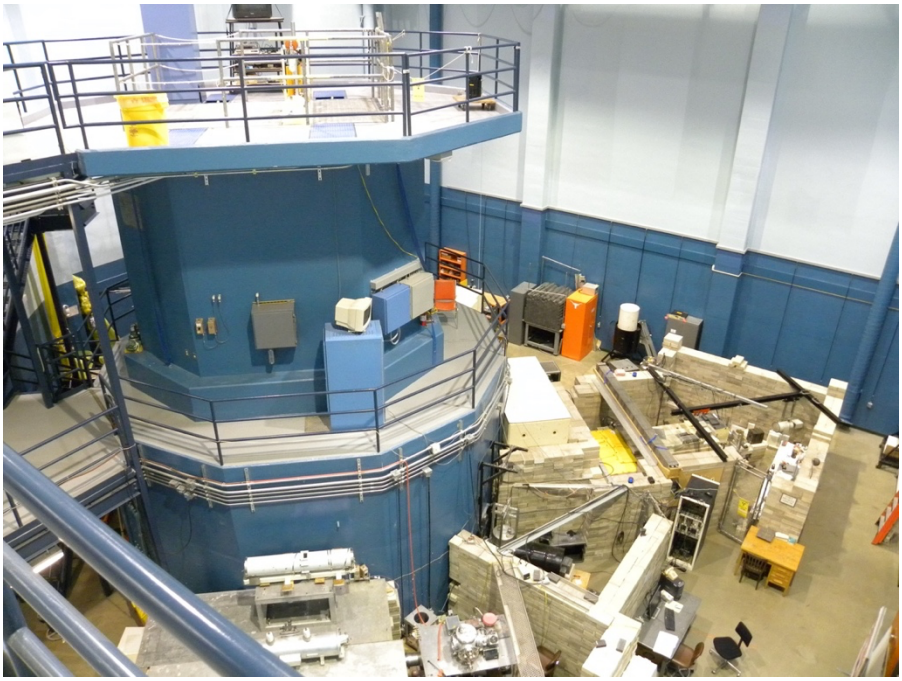

Figure 2. NETL Reactor Pedestal and High Bay.

Figure 3. NETL Beam Port 1/5 Tube

NETL can operate in a steady-state or pulse mode. In the steady-state mode, the operating power level is limited to ~1.1 MW. In the pulse mode, a maximum pulse size of ~23 MJ with a full-width half-maximum (FWHM) of 12 ms can be attained. In the square-wave pulse mode, the reactor is ramped to a desired power level (<1.1 MW), and power is maintained via automated control system for a prescribed time period and then rapidly decreased to shutdown. This configuration results in a square pulse shape and can be tailored to the desired requirements for higher total reactor energy depositions.

The coupling factor is defined as the amount of fission energy that can be produced in a fissile experiment per gram of fissile fuel and per MJ of reactor power. The coupling factor for the unmoderated BP1/5 is ~7.9 J/g-MJ. These coupling factors allow for fueled experiments to be designed for a wide variety of test conditions for steady-state and pulse operations.

NETL is fueled by a hexagonal array of UZrH fuel elements. There are 116 possible fuel locations in the reactor, with the core currently operating with 113 fuel elements. The fuel uses uranium enriched to 19.5 weight percent U-235. The UZrH contains a fine metallic dispersion of uranium in a ZrH matrix, with 8.5% of the mass of the fuel material as uranium. The H:Zr ratio is nominally 1.6. The NETL fuel elements are stainless steel clad, 1.47 inches (37.5 mm) in diameter and 28.4 inches in length. The fuel meat is 1.43 inches (36.4 mm) in diameter and 15.0 inches long. NETL is controlled by two fuel-followed shim safety rods, one fuel-followed regulating rod, and one void-followed transient rod. The control rods are positioned in four fuel locations in the normal core configuration.

NETLs thermal spectrum can be modified by the use of thermal absorbers to give a harder spectrum or by the use of moderator materials to give a softer spectrum. Spectrum-modifying cavity sleeves or buckets, such as lead-boron and lead-polyethylene, provide the facility with the ability to change the

inherent neutron spectrum found in the reactor as well as allowing adjustment of the neutron-to-gamma dose ratio.

The NETL core is situated in an open pool approximately 9 feet (3 m) in diameter and 32.3 feet (8.2 m) deep. The pool is filled with 11,000 gallons of deionized water. The core is cooled by natural convection of the pool water. The pool water is cooled by a heat exchanger that exchanges the reactor produced heat with the campus chilled-water system and cooling tower. For steady-state mode operations, NETL operates continuously at up to 1.1 MW. The pool is cooled using a heat rejection system rated to support steady-state operations up to 2 MW.

2.2. NETL-FF-BP1/5-128-cca Environment

2.2.1. Free-Field Description

The most prominent feature of NETL is the six available test locations that include both in-core and beam port locations. While there are several sleeves used to alter the spectrum of the NETL beam ports for experimenters, occasionally it is desired to perform an experiment with the thermal spectrum of the reactor without modification. In this case, all of the metrics presented in the previous section for the unmoderated beam port cavity remain valid such as the 1-MeV damage-equivalent silicon fluence and the delayed gamma ray dose.

The beam port locations are tubing that traverse the reactor pool, with the radius of the tubes being smallest near the reactor core. Each beam port space allows installation of experiment assemblies at the center of the port either normal or adjacent to the core, where neutron fluence levels are highest. BP1/5 starts as a stainless-steel cavity and transitions to aluminum to allow for minimal neutron activation and interaction. Schematics of beam ports 1 and 5 are shown in Figure 4 and Figure 5, respectively. Within the beam ports, experiments can be adjusted axially through the use of pedestals or sleds.

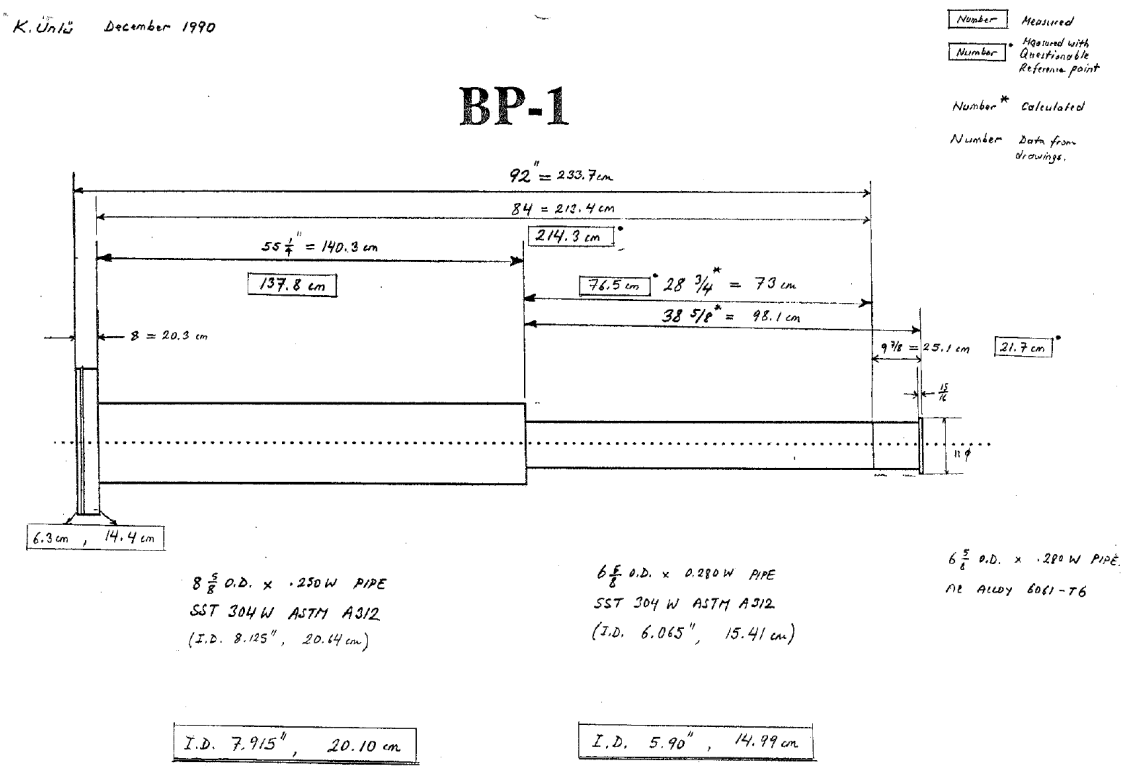

Figure 4. Engineering Schematic of Beam Port 1

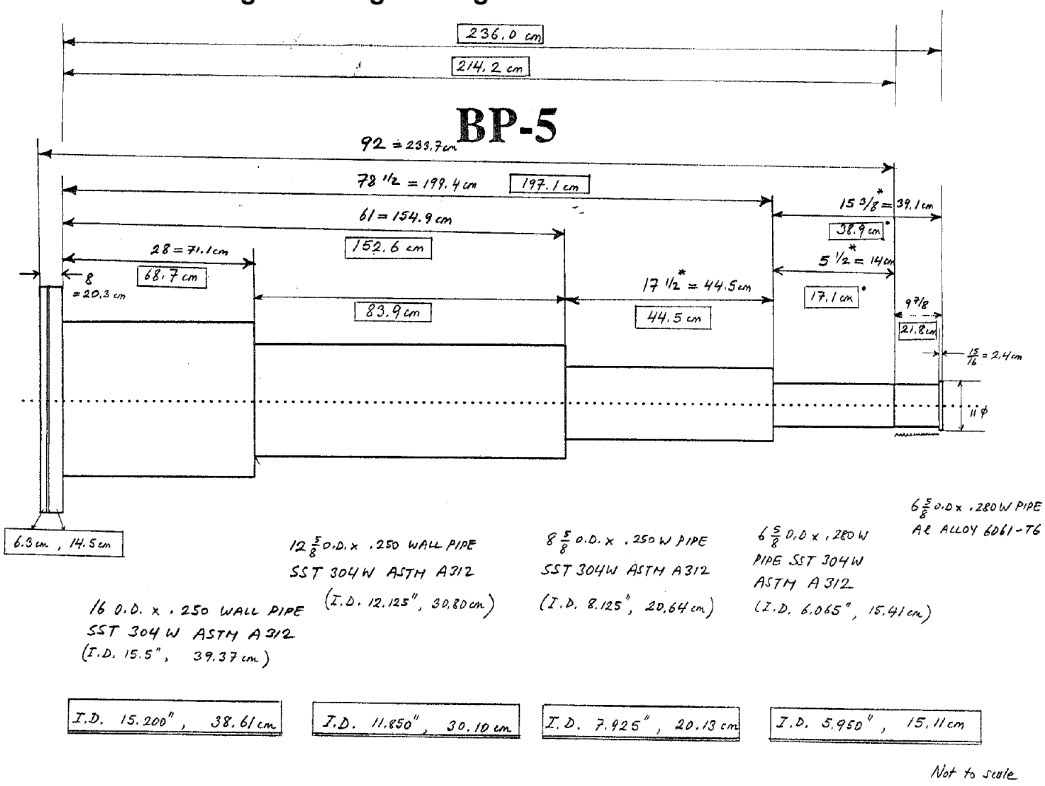

Figure 5. Engineering Schematic of Beam Port 5

The free-field environment does not provide any attenuation of gamma rays that accompany fission. Thus, if the desire is to attempt to isolate the effect of neutron irradiation in an experiment, a spectrum altering sleeve containing lead should be used.

2.2.2. MCNP Model

The MCNP model of the NETL reactor and its five beam ports is shown in Figure 6. The input model is included in Appendix A of this document. The MCNP model of NETL includes all of the fuel elements as well as the control and safety rods that make up the core. The control and safety rods can be adjusted in the vertical direction in the model to whatever position is desired. Typically, the model is run with the shim safety and transient rods banked to the same height for the approximately delayed critical (dc) position. The calculated dc position can be found for the model by iterating on the control rod position until k_{eff} is equal to one. The model is typically run using room-temperature (300 K) cross sections, $S(\alpha,\beta)$ values, and water density. All cross-section temperatures can be modeled if desired.

Neutron, prompt gamma ray, and delayed gamma ray energy spectra and fluence per fission were calculated using a 6-cm diameter tally sphere. For the NETL-FF-BP1/5-128-cca position, the sphere was positioned at the radial center of the cavity at the axial centerline of the beam port, which is core adjacent. Calculations were performed using the MCNP k-code mode for the neutron and prompt gamma ray environments and in the source mode for the delayed gamma ray environment.

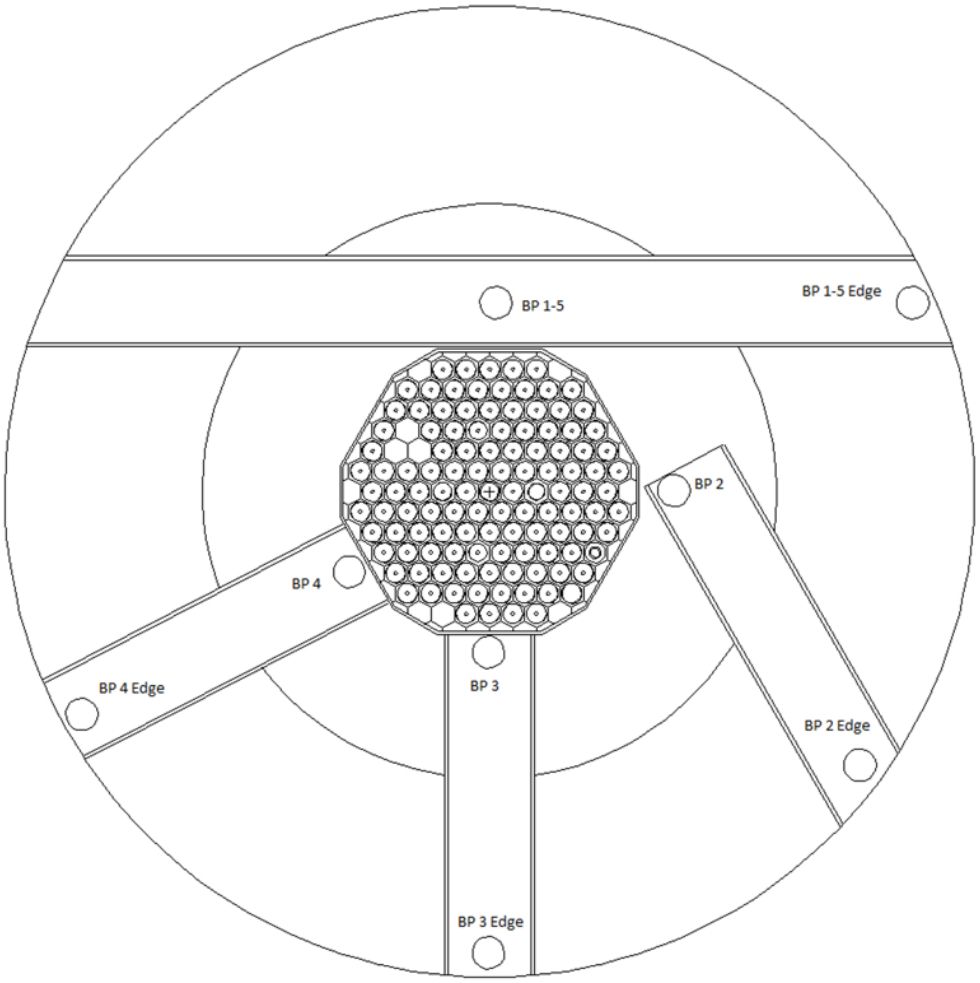

Figure 6. MCNP Model of the NETL Core and beam ports in the reactor pool with tally spheres.

3. SPECTRUM CHARACTERIZATION

3.1. Neutron

The neutron environment includes both prompt and delayed neutrons from NETL core. The neutron energy spectrum is first calculated using MCNP, and then a least-squares spectrum adjustment is performed using passive neutron activation dosimetry measurements to produce a "characterized" neutron spectrum. The process for determining a characterized neutron spectrum is to first generate an *a priori* 640-group and an 89-group neutron energy trial spectrum from the MCNP model presented in Section 2 for the 6-cm diameter tally sphere. To provide reasonable statistics in all of the energy groups, the model was run on a parallel machine for 20 billion source neutrons. The 89-group MCNP result represents the trial function that is then adjusted using a least-squares-based unfolding code. For this work a total of 22 different dosimetry foil types, resulting in 35 different transmutation reactions, were irradiated at the NETL-FF-BP1/5-128-cca location. The LSL-M3 code (Stallmann, 1985) and the IRDFF-II dosimetry cross sections (IRDFF, 2014; Capote, 2012; Zsolnay, 2012), were used in the unfolding analysis to determine the characterized neutron energy spectrum.

3.1.1. MCNP Model Results – 640-Group Neutron Energy Spectra

The neutron energy spectrum was calculated for a 640-group and an 89-group energy structure using the MCNP model presented in Section 2 for the 6-cm diameter tally sphere. MCNP 6.2 was used with the ENDF/B-VIII.0 cross sections. The MCNP model with the free-field environment on BP1/5 is included in Appendix A of this report. Room temperature cross sections were used for the calculations. The model was run in the k-code mode using both neutrons and photons. This arrangement allowed for both the neutron energy spectrum and the prompt gamma ray energy spectrum to be generated in one run. The gamma ray spectrum used a 48- group energy structure. To achieve reasonable statistics in all of the energy groups, the model was run on a parallel machine for 20 billion source neutrons. The results generated in the tally sphere were in units of neutron fluence per source neutron. These results were then converted to fluence per fission in a spreadsheet. The neutron fluence results were converted from fluence per fission to fluence per MJ of reactor power using 192.4 MeV per fission. This value represents the fission fragment, neutron, prompt gamma ray, capture gamma ray and delayed gamma ray energy deposition in the reactor core and surrounding water, per fission event. These energy deposition values were calculated using MCNP except for the delayed gamma ray energy, which was assumed to be the total delayed gamma energy of 6.33 MeV per fission as characterized in the ENDF/B-VIII.0 nuclear data file. The 89-group neutron energy spectrum result was used as the trial function for the LSL-M3 code.

Figure 7 and Figure 8 show the MCNP-generated 640-group and 89-group neutron energy fluence on a linear and logarithmic y-axis, respectively. The units on the y-axis are in lethargy fluence or energy fluence, equal to $Ed\phi/dE$ (MeV/MeV-cm^2-MJ). With the energy fluence represented linearly on the y-axis and the neutron energy on the x-axis represented logarithmically, the area under the curve represents the total neutron fluence. This representation allows for the best visual depiction of the fluence over the complete neutron energy range.

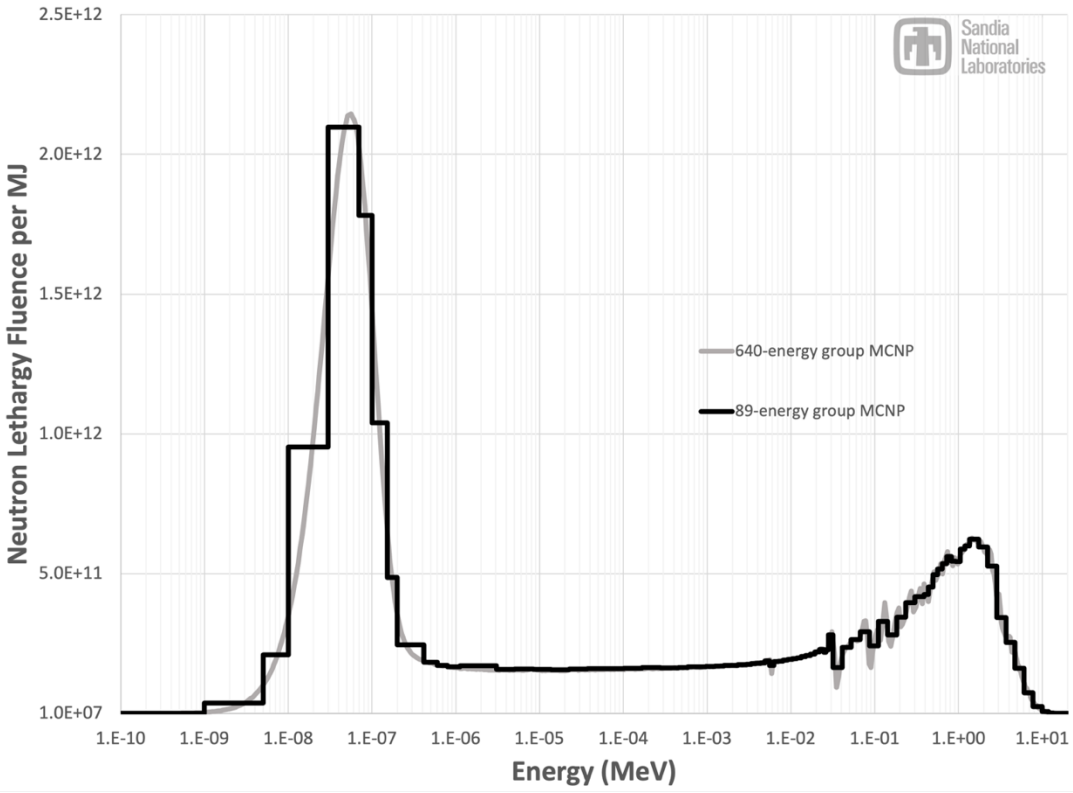

Figure 7. MCNP 640-Group and 89-Group Neutron Lethargy Fluence Energy Spectra (Linear-Log)

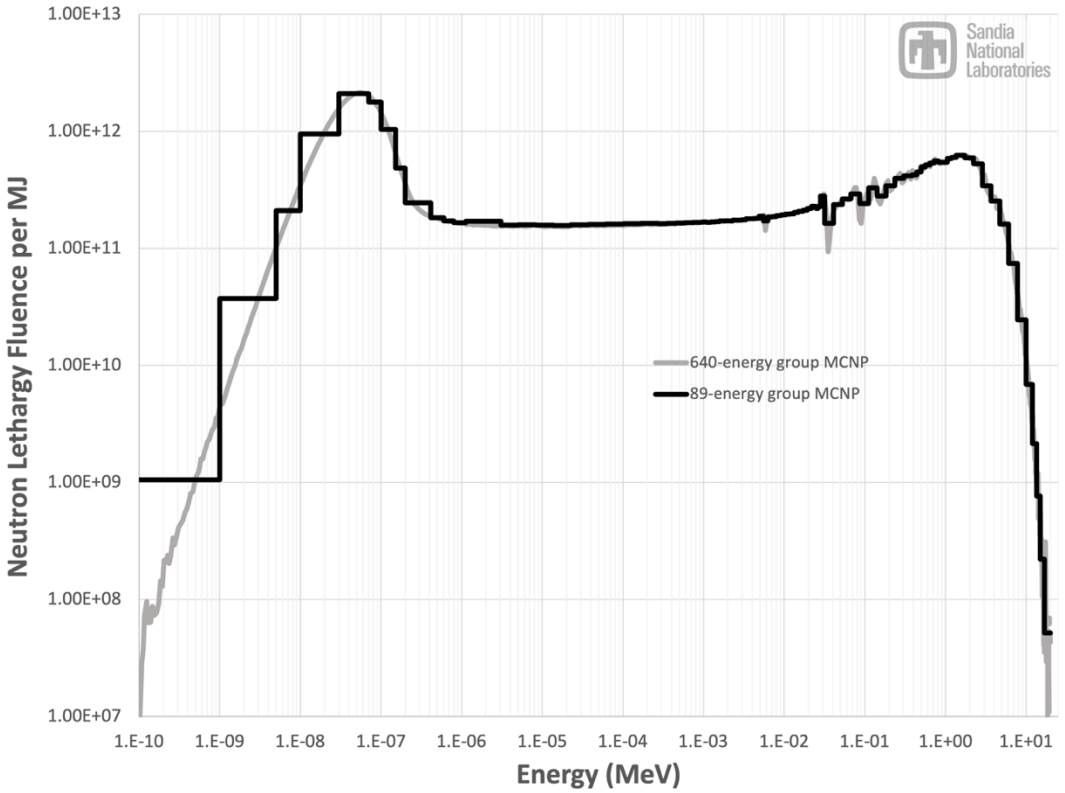

Figure 8. MCNP 640-Group and 89-Group Neutron Lethargy Fluence Energy Spectra (Log-Log)

The energy fluence is found to peak in the thermal region at 0.07 eV (5.5E-8 MeV). The fission peak occurs at ~1.5 MeV. The results for the 640-group and 89-group neutron energy fluence are in very close agreement, as expected. The 640-group neutron energy calculation shows more structure in the fluence spectrum, which is more notably observed in the energy range of 1E-2 MeV to 1 MeV. This structure is considered to be real and not an artifact of the code or cross-section set. It is caused by resonances in the cross sections, especially from the oxygen elastic scattering cross section. The structure in the energy range below 0.01 eV (1.0E-8 MeV) indicates uncertainty in the MCNP results in this energy range are greater than 10%. This structure indicates that the Monte Carlo statistics are poor and that the results have a low confidence. The calculated standard deviation from MCNP for each energy bin in the 640-group energy fluence in the energy range from 0.005 eV (5.0E-9 MeV) to 6 MeV is less than 1%. A similar but less resolved structure is also seen in the 89-group energy fluence. The 89-group energy structure is the energy grouping used in the NuGET code (DePriest, 2004).

3.1.2. Dosimetry Foils

The results of the MCNP calculation of the NETL with the free-field environment represent a good initial representation for the neutron spectrum characterization. However, a considerable uncertainty in the results can exist due to model representation uncertainty (geometry, density, and composition) and uncertainty in the transport cross sections. An improved spectrum can be obtained by combining this initial trial spectrum with measured integral values that correspond to the reaction rates from high-fidelity passive dosimetry reactions. The resulting least-squares adjusted neutron fluence spectrum includes an energy-dependent uncertainty. The spectrum can then be considered "characterized," in that it quantifies the "true" neutron-fluence energy spectrum with a stated accuracy, including energy dependent uncertainties and a covariance matrix. If the least-squares spectrum is found to have inconsistent inputs in comparing the MCNP *a priori* trial spectrum and the measured dosimetry results, as determined by a measure of the chi-squared per degree of freedom (χ^2/dof) in the spectrum adjustment, the dosimetry measurements would be reexamined and/or the MCNP model for NETL would be reexamined and modified or modeled with greater fidelity. In addition to the adjusted neutron spectrum, uncertainty and covariance results are found from the least-squares analysis using LSL-M3. The characterized neutron spectrum can be used, with the corresponding uncertainty values and the correlation matrix, to support the evaluation of various damage and dose metrics relevant to users of NETL free-field environment. The characterized spectrum can be used directly by the NuGET code or as an isotropic shell source in MCNP to calculate the radiation internal to a complex test object. For this work, the LSL-M3 code was used to generate an 89-group neutron energ spectrum that is used in the NuGET code. The SAND-IV code can also be used to determine an adjusted 640-group energy spectrum. This calculation may be performed in the future for comparison purposes but is beyond the scope of this work.

The selection of passive dosimetry foils and activation reactions has been studied and evaluated over many years. A summary of the work can be found in ASTM E720, Griffin (2011a), Griffin (2011b) and references therein. No complete and perfect set of activation reactions exists that allows the neutron fluence energy spectrum to be calculated by dosimetry alone. However, there are enough reactions to cover the relevant energy range with high-fidelity dosimetry cross sections to allow for adjusted neutron fluence results to be generated with a quantified accuracy. The passive dosimetry foils and the associated neutron activities, at the end of irradiation, used to perform the neutron fluence characterization for the free-field environment are shown in Table 1.

Table 1. Neutron Activation Dosimetry Used for NETL-FF-BP1/5-128-cca.

Activation Reaction	Half-Life	Specific Activity (Bq/atom-isotope)	Counting Uncertainty (%)
$^{58}Ni(n,p)^{58}Co$ - Reference	70.86 d	3.8026E-19	2.11
$^{24}Mg(n,p)^{24}Na$	14.957 h *	6.0257E-19	0.05
$^{27}Al(n,\alpha)^{24}Na$	14.957 h *	2.4885E-19	3.75
$^{24}Al(n,p)^{27}Mg$	9.462 m *	1.1924E-16	2.56
$^{32}S(n,p)^{32}P$ Cf-equ	14.284 d	1.865E+12 n/cm^2	1.05
$^{46}Ti(n,p)^{46}Sc$	84.79 d	2.9902E-20	3.75
$^{47}Ti(n,p)^{47}Sc$	3.345 d	1.2844E-18	2.08
$^{48}Ti(n,p)^{48}Sc$	43.67 h	3.3129E-20	1.31
$^{54}Fe(n,p)^{54}Mn$	312.3 d	5.2798E-20	3.71
$^{56}Fe(n,p)^{56}Mn$	2.578 h *	2.2592E-18	3.48
$^{58}Ni(n,2n)^{57}Ni$	35.65 h	2.3033E-21	15.76
$^{60}Ni(n,p)^{60}Co$	1925.5 d	1.4355E-21	7.03
$^{90}Zr(n,2n)^{89}Zr$	78.41 h	5.4908E-20	26.72
$^{115}In(n,n')^{115m}In$	4.486 h *	9.0043E-18	2.15
$^{115}In(n,2n)^{114m}In$	49.51 d	1.6917E-16	1.74
$^{23}Na(n,\gamma)^{24}Na$	14.9654 h *	4.8116E-16	3.42
$^{45}Sc(n,\gamma)^{46}Sc$	84.79 d	2.5889E-16	2.11
$^{55}Mn(n,\gamma)^{56}Mn$	2.5785 h *	9.1375E-14	2.26
$^{58}Fe(n,\gamma)^{59}Fe$	44.496 d	2.1729E-17	1.60
$^{59}Co(n,\gamma)^{60}Co$	1925.5 d	1.5123E-17	2.44
$^{63}Cu(n,\gamma)^{64}Cu$	12.701 h *	6.7252E-15	2.50
$^{93}Nb(n,\gamma)^{94m}Nb$	6.263 m *	2.4082E-09	1.27
$^{96}Zr(n,\gamma)^{97}Zr$	16.744 h*	3.4434E-16	2.03
$^{98}Mo(n,\gamma)^{99}Mo$	65.94 h	1.5474E-16	2.37
$^{109}Ag(n,\gamma)^{110m}Ag$	249.76 d	1.6455E-17	1.91
$^{115}In(n,\gamma)^{116m}In$	54.41 m *	2.2301E-12	1.81
$^{186}W(n,\gamma)^{187}W$	23.9 h *	3.9707E-14	1.80
$^{197}Au(n,\gamma)^{198}Au$	2.6943 d	3.6426E-14	2.14
$^{23}Na(n,\gamma)^{24}Na$ - Cd	14.9654 h *	2.1049E-17	3.43
$^{45}Sc(n,\gamma)^{46}Sc$ - Cd	84.79 d	5.9782E-18	2.28
$^{55}Mn(n,\gamma)^{56}Mn$ - Cd	2.5785 h *	3.6905E-15	1.81
$^{58}Fe(n,\gamma)^{59}Fe$ - Cd	44.496 d	1.0682E-18	2.36
$^{59}Co(n,\gamma)^{60}Co$ - Cd	1925.5 d	1.0340E-18	2.53
$^{63}Cu(n,\gamma)^{64}Cu$ - Cd	12.701 h *	2.5189E-16	2.07
$^{98}Mo(n,\gamma)^{99}Mo$ - Cd	65.94 h	9.0848E-17	2.55
$^{109}Ag(n,\gamma)^{110m}Ag$ - Cd	249.76 d	3.1107E-18	1.91
$^{197}Au(n,\gamma)^{198}Au$ - Cd	2.6943 d	1.3851E-14	1.46
$^{235}U(n,f)FP$ – Bare	^{140}Ba – 12.752 d	9.7601E-11 #fiss	1.64
$^{238}U(n,f)FP$ – Bare	^{140}Ba – 12.752 d	9.9184E-12 #fiss	1.22
$^{239}Pu(n,f)FP$ – Bare	^{140}Ba – 12.752 d	1.0853E-10 #fiss	1.64
$^{239}Np(n,f)FP$ - Bare	^{140}Ba – 12.752 d	5.9570E-11 #fiss	1.67

* half-life less than one day ** half-life less than one hour #fiss = units are fissions per atom isotope
Cd = foil is located within a standard Cd cup Bare =Free-Field, foil is not covered in moderating material
Reference – all foil activities are normalized to a $^{58}Ni(n,p)^{58}Co$ activity for each irradiation

The foils and activation reactions chosen for the analysis represent expert judgment and references to previous work, including characterization of the ACRR Free-Field (Parma, 2013) and historical characterization of the ACRR free-field condition and the LB36 bucket (Griffin, 2011b; Griffin, 1994b). A complete set of dosimetry foils and reaction data will vary for a given neutron environment being characterized. Typically, neutron activation resulting in the emission of protons (n,p), neutrons (n,2n), (n,n'), or alpha particles (n,α) represent high neutron-energy reactions of 1 MeV or greater. Neutron activation resulting in prompt gamma ray emission from radiative capture (n,γ) or fission reactions determine the shape of the thermal and epithermal region of the neutron spectrum. Covering foils with cadmium (Cd) can allow for resonances above the associated cutoff energies to become more prominent, allowing for additional information to be included in the analysis.

A total of 22 different foil types, resulting in 35 different reactions, were irradiated at the NETL-FF-BP1/5-128-cca. The foils were irradiated in three different maximum pulse (23 MJ) operations. The four fission foils (U-235, U-238, Pu-239, and Np-237) were irradiated together in a free-field configuration in one pulse operation. Four foils (In, Mo, Nb) were also irradiated but were not used in the analysis due to significant inconsistencies in the unfolding results. It is unsure at this time if there are problems in the measurement technique for these reactions, foil pre-exposure issues, or if there are issues with the dosimetry cross sections Figure 9 shows a picture of some of the dosimetry foils used, from left to right, top to bottom: Nb, Mn, Al, Co, Sc, NaCl, Cu, Ni-28, Au, Fe, Ti, Zr, Mg, W, Zn, Co, Ag, and In. For reference, the nickel (Ni) (28, 29) foils are typically 1.27 cm in diameter. The irradiations were all performed at the peak axial neutron fluence location within the beam port. From sulfur tablet irradiations, presented in Section 4 of this report, the peak axial fast neutron fluence is in a square position on the standard SNL irradiation fixture, 1.25 inches from the end of the sled centering pedestal. Multiple foils were irradiated on a specially designed aluminum stand, which held the foils at the 128-inch position in the beam port. In order to minimize any self-shielding effects, the foils were never stacked together. Instead, the foils were arranged randomly on the surface of an aluminum plate and held in place with tape. For each irradiation, at least one nickel foil was irradiated and used to normalize all of the irradiations. Several foils were run for each operation, and multiple foils of the same type were tested during the campaign. Several nickel foils were used to verify the normalization required for other foils.

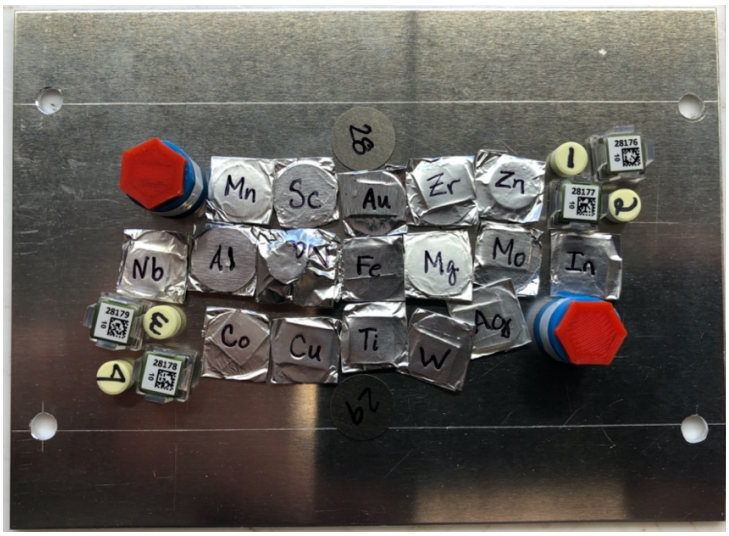

Figure 9. Typical Dosimetry Foils – Characterization Test Setup

The free-field environment was used to perform all the foil irradiations identified in Table 1. High variation in the flux was found radially and axially within the beam port 1/5 position. However, there exists a test region where the neutron fluence varies ±5%; this analysis is presented in Section 5. Careful testing considerations should be made when testing in beam port 1/5. Additional uncertainty in the analysis was included to account for possible variation due to geometry effects.

The free-field environment requires adequate coverage of the thermal, epithermal, and high-energy neutron reactions in order to perform a successful adjustment to the neutron fluence energy spectrum. Cd covers are used to discriminate energy regions in some reactions. Table 1 shows each activation reaction used in the analysis, as well as the half-life for the transmuted isotope, the measured activity decay corrected to the end of the irradiation, and the counting uncertainty. The reactions are grouped in order of reaction type. The first group represents the high-energy (n,p), (n,2n), (n,n'), and (n, α) reactions. The second group represents the low-energy radiative capture reactions for bare foils. The third group represents the radiative capture reactions with each individual foil placed in a cadmium cover. The fourth group represents the fission foils. Reactions identified with a dark-gray colored box represent reactions that were not used in the final spectrum adjustment due to inconsistencies in the results.

3.1.3. LSL Spectrum Unfold Results

The LSL-M3 code was run using the *a priori* 640-group trial neutron energy spectrum from MCNP converted to the NuGET 89-group structure and the dosimetry data presented in Table 1. Also required in the analysis was an initial uncertainty estimate in the neutron spectrum as a function of energy, an initial energy-dependent correlation matrix, the energy dependent self-shielding factors, and the dosimetry cross section library that also included uncertainties and covariance matrices. The input deck used for the LSL calculation is included in Appendix B of this report. In addition to the counting uncertainty, an additional 2% uncertainty was included for the foils to address uncertainty contributions due to positioning and possible geometrical effects in the central region of the beam port. The output is the 89-group NuGET energy format described earlier.

The resulting value for χ^2/dof is 1.013, which represents an acceptable value Figure 10 and Figure 11 show the same representation of the neutron energy spectra as previously shown in Figure 7 and Figure 8, with the additional 89-group adjusted neutron eneergy spectrum result from the LSL analysis (light blue curve). Figure 12 shows the percent adjustment made to the trial spectrum (purple line), and the percent standard deviation in the adjusted spectrum (black curve). The adjusted neutron fluence in Figure 12 shows a lower value in the thermal energy range (1E-8 to 3E-6 MeV) than calculated using the MCNP model. This difference could be due to a number of factors, including accuracy of the geometry and density of materials in the NETL MCNP model, cross section or scattering model discrepancies in MCNP.

Figure 13 to Figure 17 show the dosimetry foil relative reaction probabilities as a function of energy from the LSL analysis. Each relative reaction probability sums to 100%. It is desirable to have diverse coverage over the complete energy range. Peaks represent areas of higher probability that allow for energy discrimination in the analysis. Figure 13 shows all of the reactions used in the analysis. Figure 14 through Figure 17 represent the high-energy reactions, the radiative capture reactions, the Cd covered radiative capture reactions, and the fission reactions, respectively. The cadmium cutoff value is at 0.5 eV. Figure 13Figure 13 shows that there is good coverage with many peaks in the energy range between 0.001 eV and 1 keV, and 1 MeV to 10 MeV. There is less coverage in the range 1 keV to 1 MeV.

Table 2 shows the result of the calculated to experimental (C/E) dosimetry results for the trial spectrum and the adjusted spectrum. Also shown is the factor adjusted from the trial spectrum to the adjusted spectrum for the dosimetry reactions. For the high-energy reactions, the C/E-1 values are found to be both positive and negative for the trial spectrum and are reduced for the adjusted spectrum. For the radiative capture reactions, the C/E-1 values are all positive, with the exception of a single reaction, for the trial spectrum. This result implies that the thermal/epithermal calculated fluence is too high. After the adjustment, the results become much closer to zero for C/E-1.

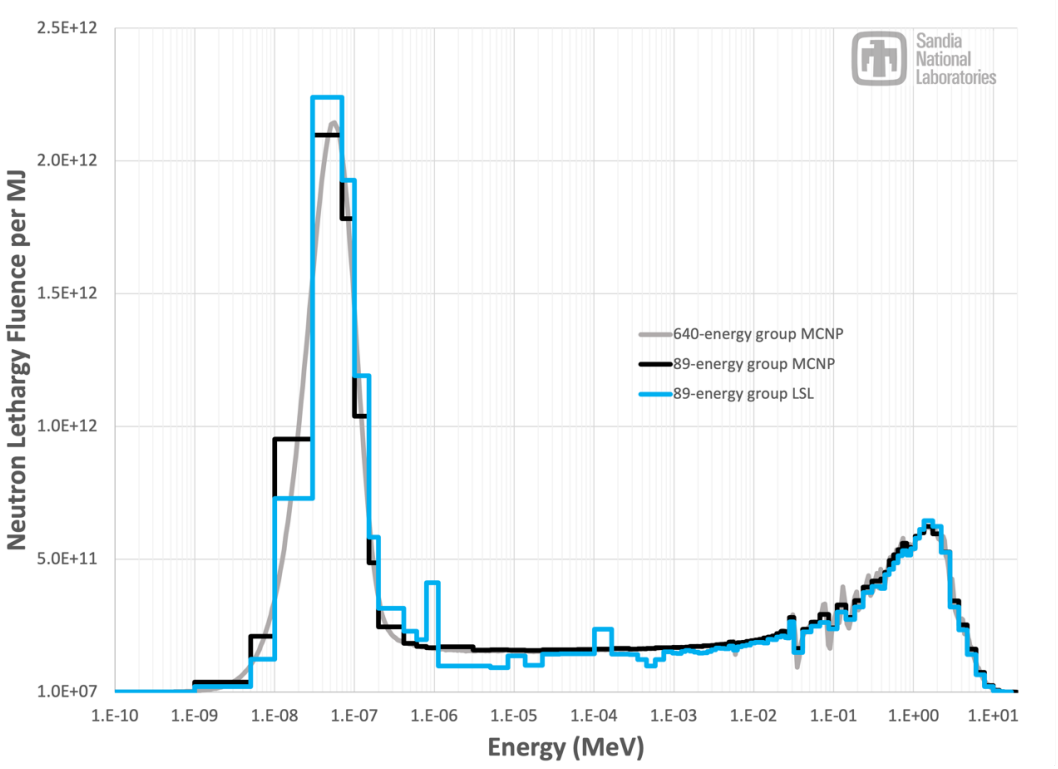

Figure 10. LSL Adjusted 89-Group Neutron Lethargy Fluence Energy Spectrum Compared to the MCNP Calculated Results (linear-log)

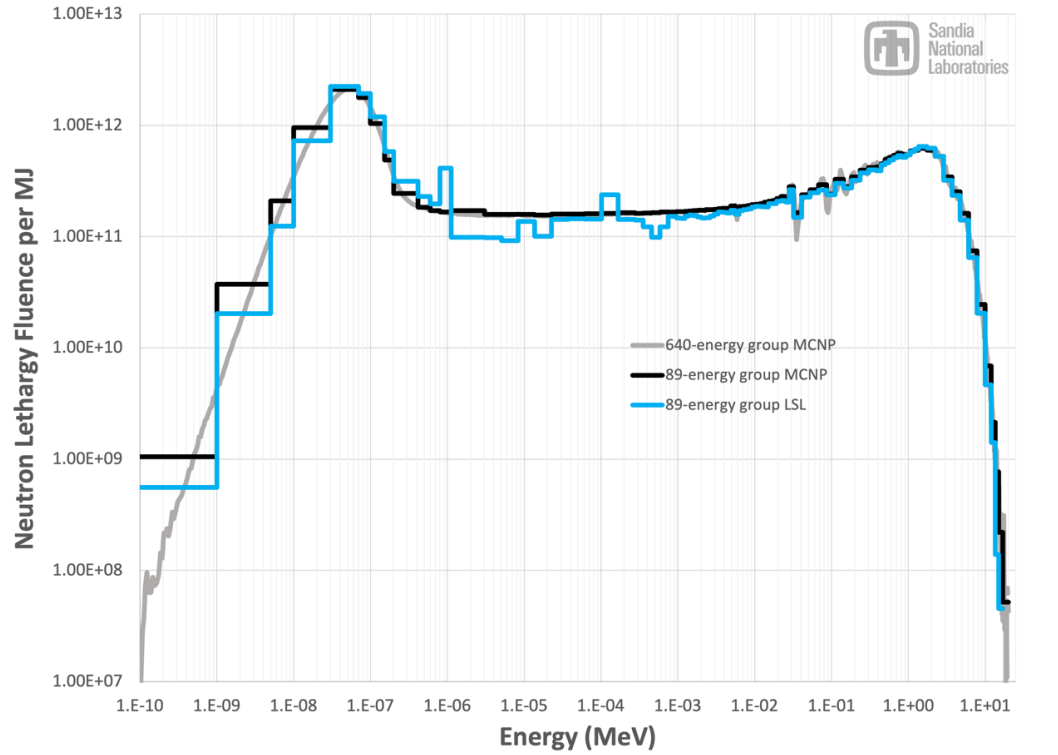

Figure 11. LSL Adjusted 89-Group Neutron Lethargy Fluence Energy Spectrum Compared to the MCNP Calculated Results (log-log)

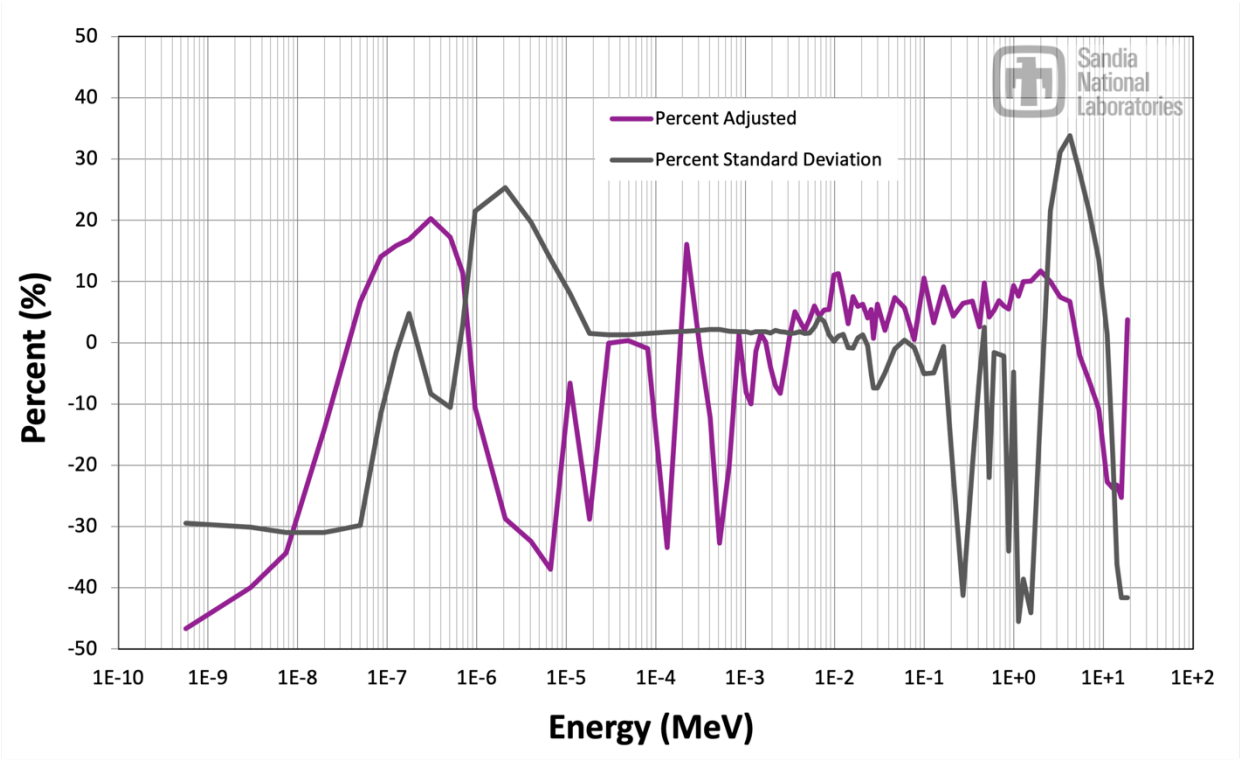

Figure 12. LSL Percent Adjustment to the Trial Spectrum and Standard Deviation Results for the 89-Group Adjusted Neutron Spectrum.

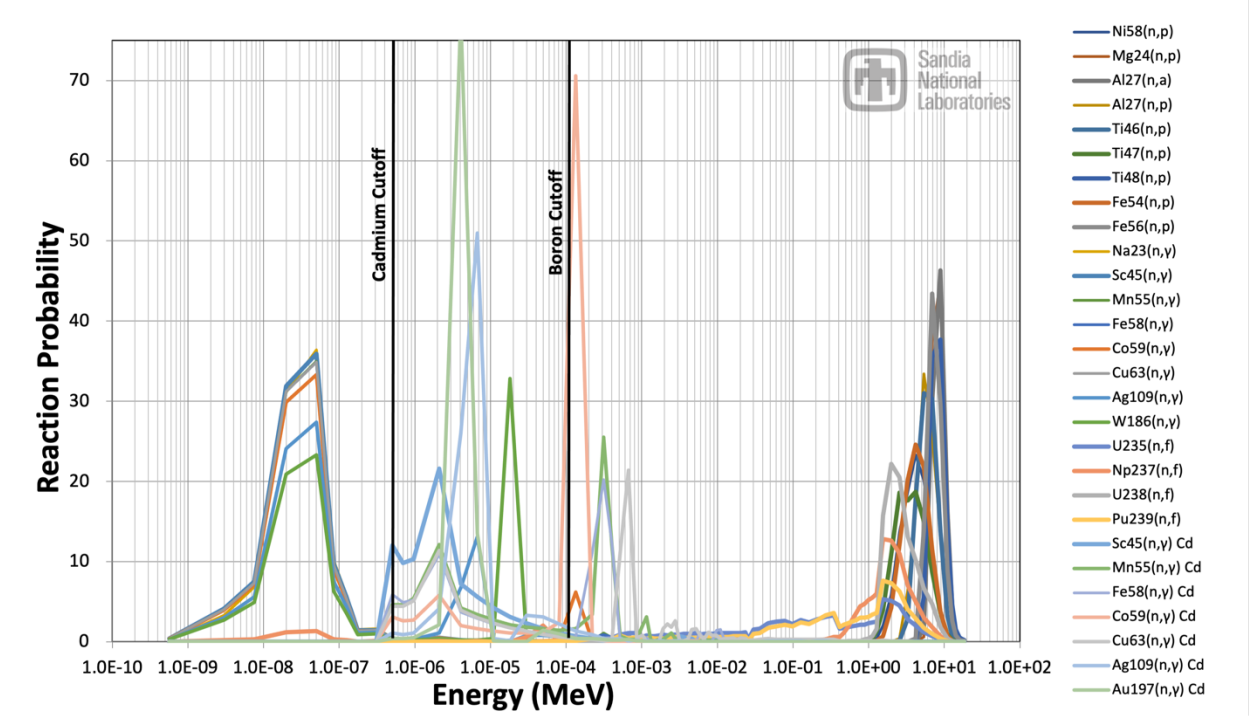

Figure 13. Relative Reaction Probabilities for the Complete Dosimetry Reaction Set.

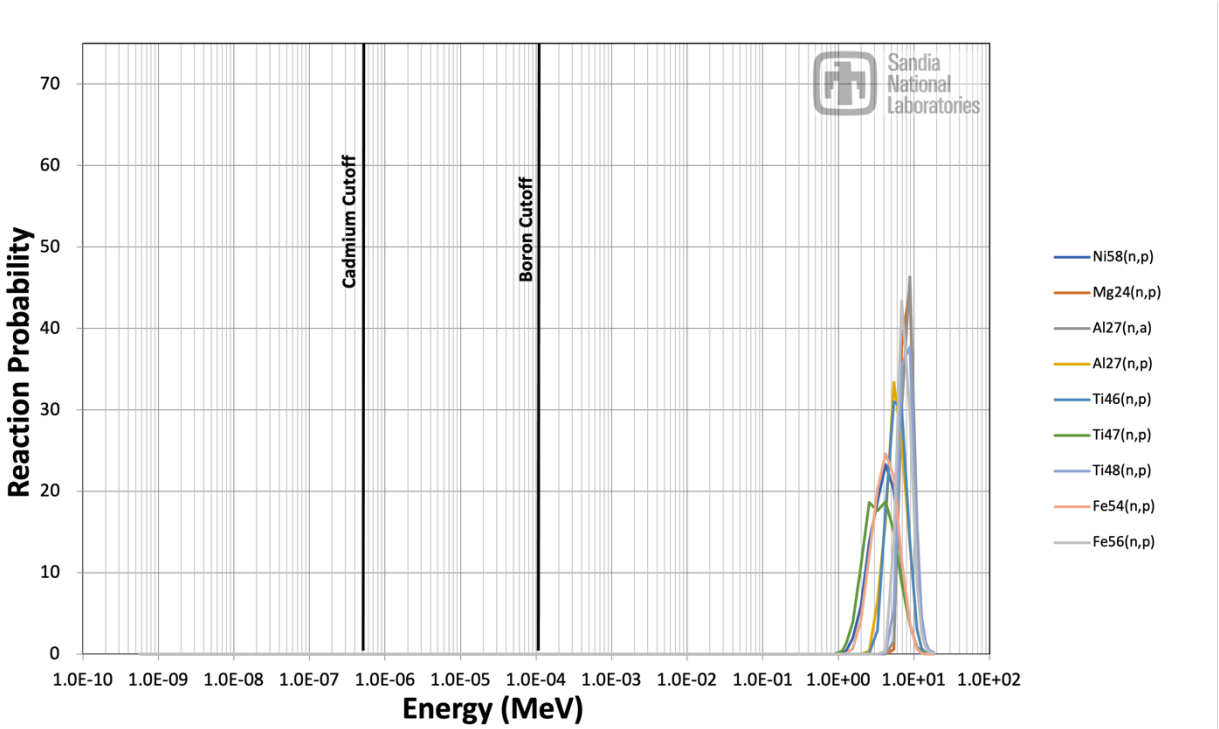

Figure 14. Relative Reaction Probabilities for the High Energy Dosimetry Reaction Set.

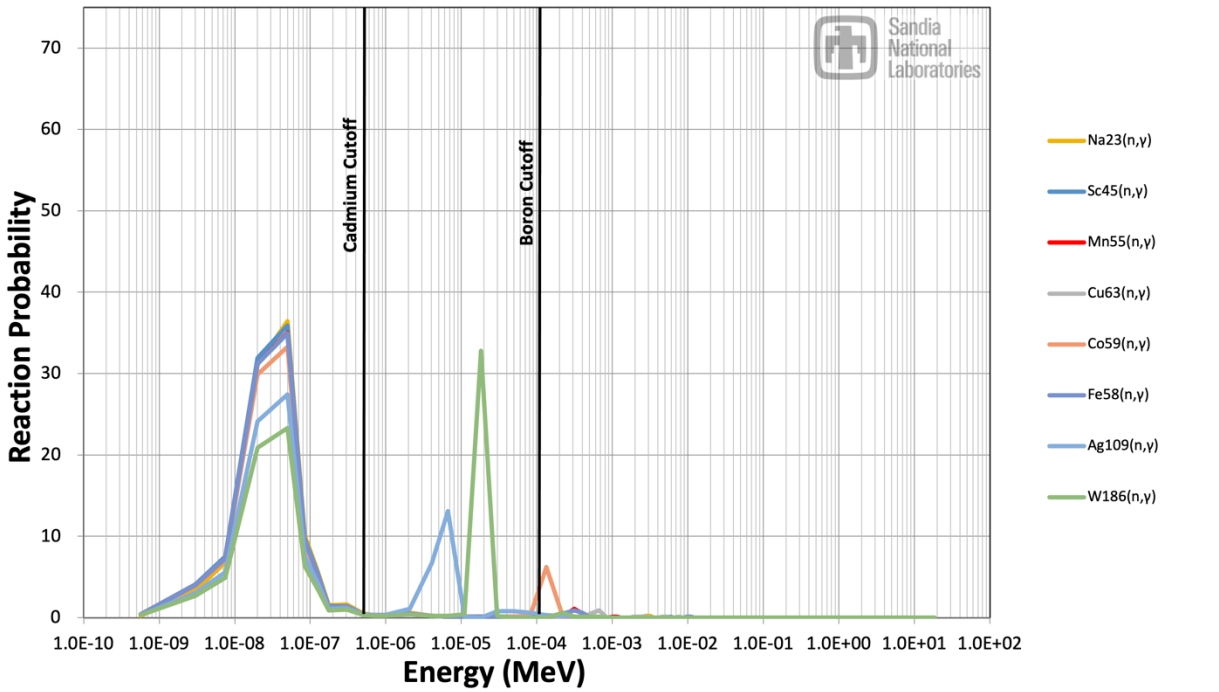

Figure 15. Relative Reaction Probabilities for the Radiative Capture Dosimetry Reaction Set.

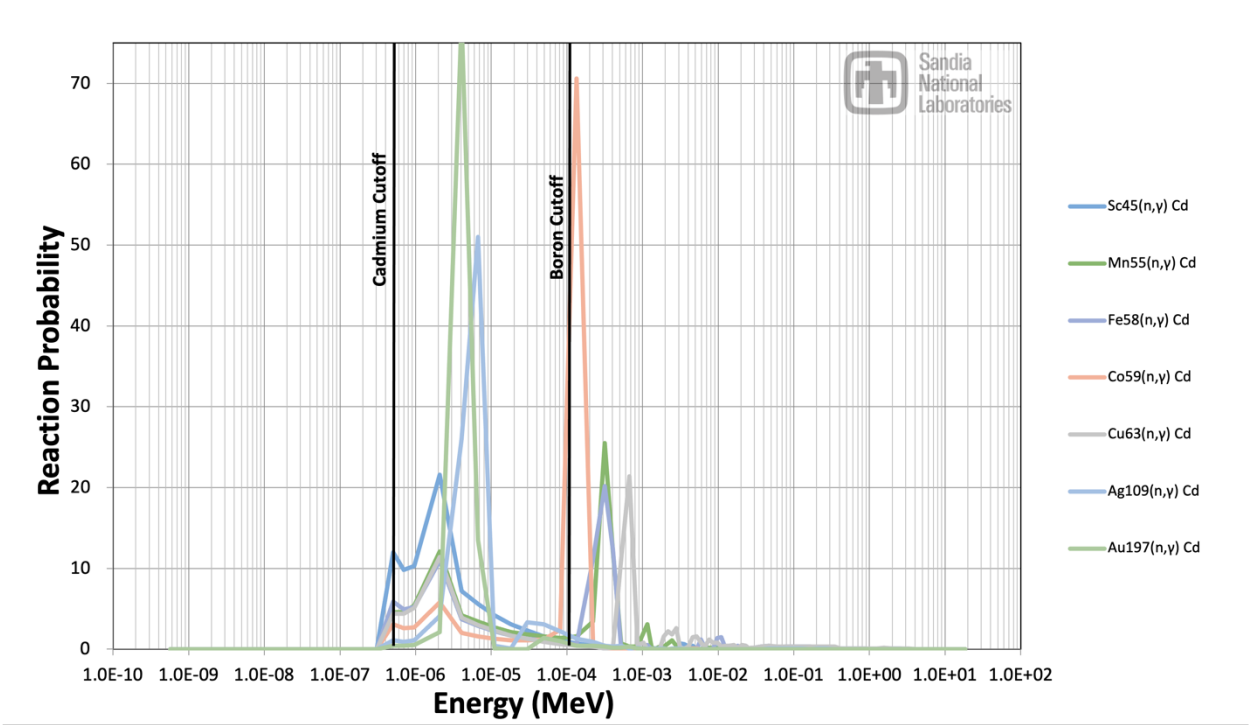

Figure 16. Relative Reaction Probabilities for the Radiative Capture Dosimetry Reaction Set with Cd Covers.

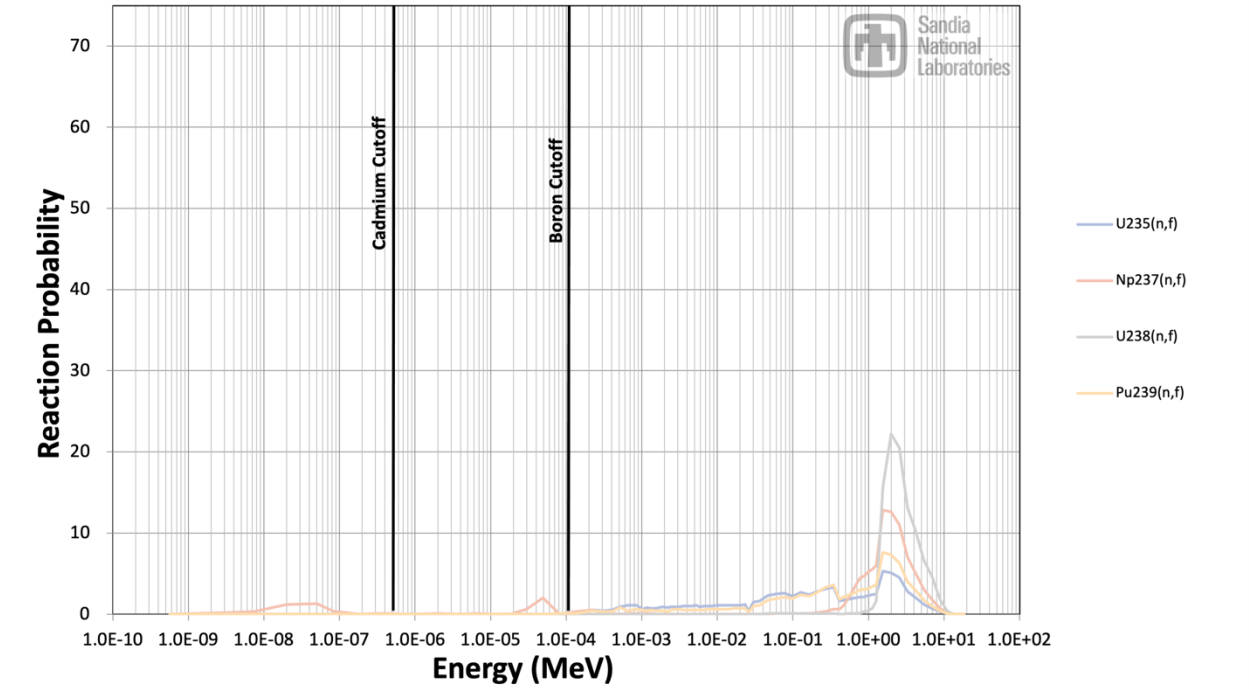

Figure 17. Relative Reaction Probabilities for the Fission Dosimetry Reaction Set.

Table 2. C/E Values for the Trial and Adjusted LSL Neutron Energy Spectrum.

Activation Reaction	C/E-1 Trial Spectrum (%)	C/E-1 Adjusted Spectrum (%)	Factor Adjusted (%)
$^{58}Ni(n,p)^{58}Co$ - Reference	0.00	0.80	-0.80
$^{24}Mg(n,p)^{24}Na$	17.56	-1.60	-24.11
$^{27}Al(n,\alpha)^{24}Na$	21.16	-1.80	-24.66
$^{24}Al(n,p)^{27}Mg$	17.01	1.50	-14.30
$^{46}Ti(n,p)^{46}Sc$	11.48	-0.40	-15.12
$^{47}Ti(n,p)^{47}Sc$	7.31	-0.30	-6.78
$^{48}Ti(n,p)^{48}Sc$	29.38	-3.80	-26.02
$^{54}Fe(n,p)^{54}Mn$	15.87	2.80	-8.05
$^{56}Fe(n,p)^{56}Mn$	17.99	-1.50	-20.69
$^{23}Na(n,\gamma)^{24}Na$	15.90	2.00	-17.70
$^{45}Sc(n,\gamma)^{46}Sc$	15.75	0.00	-16.32
$^{55}Mn(n,\gamma)^{56}Mn$	20.70	-3.90	-18.82
$^{58}Fe(n,\gamma)^{59}Fe$	22.33	0.40	-19.64
$^{59}Co(n,\gamma)^{60}Co$	21.50	0.10	-21.15
$^{63}Cu(n,\gamma)^{64}Cu$	14.43	1.20	-17.46
$^{109}Ag(n,\gamma)^{110m}Ag$	50.70	0.50	-49.98
$^{186}W(n,\gamma)^{187}W$	30.08	-0.60	-29.02
$^{45}Sc(n,\gamma)^{46}Sc$ - Cd	20.15	-1.30	-20.84
$^{55}Mn(n,\gamma)^{56}Mn$ - Cd	25.49	-2.70	-23.14
$^{58}Fe(n,\gamma)^{59}Fe$ - Cd	12.78	1.00	-16.29
$^{59}Co(n,\gamma)^{60}Co$ - Cd	44.27	-2.30	-43.95
$^{63}Cu(n,\gamma)^{64}Cu$ - Cd	30.10	4.80	-28.42
$^{109}Ag(n,\gamma)^{110m}Ag$ - Cd	50.70	0.50	-49.98
$^{197}Au(n,\gamma)^{198}Au$ - Cd	49.27	0.00	-49.55
$^{235}U(n,f)FP$ – Bare	6.85	0.10	-7.57
$^{237}Np(n,f)FP$ - Bare	5.58	-1.10	-5.30
$^{238}U(n,f)FP$ – Bare	4.16	-9.40	-3.98
$^{239}Pu(n,f)FP$ – Bare	4.78	0.10	-5.84

Table 3 shows the adjusted neutron fluence spectrum in a tabular format for the 89-group NuGET energy structure. Column 5 represents the number fraction, column 6 the energy fraction, column 7 the differential number fraction, column 8 the differential energy fraction, and column 9 the percent standard deviation for the adjusted spectrum. The number fraction, represented as a histogram, can be used in MCNP source calculations as an isotropic spherical surface source. The average neutron energy is calculated to be 0.302 MeV. The peak differential number fraction occurs in energy group 5 at 0.03 eV. The differential fluence at 1 MeV (Group 74) is almost three orders of magnitude lower than the peak. The differential energy fluence for the same comparison is about the same order of magnitude as for the 1 MeV value. The LSL adjusted results for the number fraction, percent standard deviation, and covariance as a function of the 89-group energy structure are included in an LSL format in Appendix C of this report.

Table 3. Neutron 89- Group Adjusted Neutron Energy Spectrum for NETL-FF-BP1/5-128-cca.

Group	Lower Energy (MeV)	Upper Energy (MeV)	Midpoint Energy (MeV)	Number Fraction	Energy Fraction	Differential Number dN/dE	Differential Energy dE/dE	Standard Deviation (%)
1	1.0000E-10	1.0000E-09	5.5000E-10	1.4696E-04	2.5320E-13	1.6329E+05	8.9809E-05	186.85
2	1.0000E-09	5.0000E-09	3.0000E-09	3.6112E-03	3.3937E-11	9.0279E+05	2.7084E-03	123.56
3	5.0000E-09	1.0000E-08	7.5000E-09	1.1142E-02	2.6177E-10	2.2283E+06	1.6713E-02	94.52
4	1.0000E-08	3.0000E-08	2.0000E-08	9.9131E-02	6.2107E-09	4.9565E+06	9.9131E-02	47.24
5	3.0000E-08	7.0000E-08	5.0000E-08	2.1673E-01	3.3946E-08	5.4182E+06	2.7091E-01	27.87
6	7.0000E-08	1.0000E-07	8.5000E-08	8.6881E-02	2.3134E-08	2.8960E+06	2.4616E-01	48.45
7	1.0000E-07	1.5230E-07	1.2615E-07	6.0421E-02	2.3877E-08	1.1553E+06	1.4574E-01	58.82
8	1.5230E-07	2.0000E-07	1.7615E-07	1.8648E-02	1.0290E-08	3.9094E+05	6.8864E-02	65.27
9	2.0000E-07	4.1400E-07	3.0700E-07	2.4885E-02	2.3932E-08	1.1629E+05	3.5700E-02	60.00
10	4.1400E-07	6.0000E-07	5.0700E-07	9.5274E-03	1.5132E-08	5.1222E+04	2.5970E-02	56.08
11	6.0000E-07	8.0000E-07	7.0000E-07	6.6237E-03	1.4525E-08	3.3119E+04	2.3183E-02	49.28
12	8.0000E-07	1.1250E-06	9.6250E-07	6.0802E-03	1.8333E-08	1.8708E+04	1.8007E-02	73.27
13	1.1250E-06	3.0590E-06	2.0920E-06	1.3628E-02	8.9311E-08	7.0466E+03	1.4742E-02	67.86
14	3.0590E-06	5.0430E-06	4.0510E-06	6.3447E-03	8.0515E-08	3.1979E+03	1.2955E-02	11.17
15	5.0430E-06	8.3150E-06	6.6790E-06	5.9461E-03	1.2441E-07	1.8173E+03	1.2137E-02	17.76
16	8.3150E-06	1.3710E-05	1.1013E-05	8.7526E-03	3.0195E-07	1.6224E+03	1.7866E-02	36.05
17	1.3710E-05	2.2600E-05	1.8155E-05	6.6119E-03	3.7603E-07	7.4375E+02	1.3503E-02	16.01
18	2.2600E-05	3.7270E-05	2.9935E-05	9.4335E-03	8.8462E-07	6.4305E+02	1.9250E-02	31.60
19	3.7270E-05	6.1440E-05	4.9355E-05	9.5056E-03	1.4696E-06	3.9328E+02	1.9410E-02	27.57
20	6.1440E-05	1.0130E-04	8.1370E-05	9.4491E-03	2.4086E-06	2.3706E+02	1.9289E-02	25.63
21	1.0130E-04	1.6700E-04	1.3415E-04	6.3984E-03	2.6888E-06	9.7388E+01	1.3065E-02	11.50
22	1.6700E-04	2.7540E-04	2.2120E-04	1.1290E-02	7.8230E-06	1.0415E+02	2.3038E-02	32.94
23	2.7540E-04	3.5360E-04	3.1450E-04	4.8079E-03	4.7367E-06	6.1482E+01	1.9336E-02	19.48
24	3.5360E-04	4.5400E-04	4.0380E-04	4.3131E-03	5.4558E-06	4.2959E+01	1.7347E-02	32.42
25	4.5400E-04	5.8300E-04	5.1850E-04	3.3333E-03	5.4141E-06	2.5839E+01	1.3398E-02	42.01
26	5.8300E-04	7.4850E-04	6.6575E-04	4.0082E-03	8.3592E-06	2.4219E+01	1.6124E-02	22.31
27	7.4850E-04	9.6110E-04	8.5480E-04	5.0813E-03	1.3606E-05	2.3901E+01	2.0430E-02	26.06
28	9.6110E-04	1.0890E-03	1.0251E-03	2.3310E-03	7.4851E-06	1.8225E+01	1.8682E-02	36.39
29	1.0890E-03	1.2340E-03	1.1615E-03	2.2812E-03	8.3002E-06	1.5733E+01	1.8273E-02	40.05
30	1.2340E-03	1.3980E-03	1.3160E-03	2.5106E-03	1.0350E-05	1.5308E+01	2.0146E-02	44.60
31	1.3980E-03	1.5850E-03	1.4915E-03	2.6156E-03	1.2221E-05	1.3987E+01	2.0862E-02	42.85
32	1.5850E-03	1.7960E-03	1.6905E-03	2.5943E-03	1.3738E-05	1.2295E+01	2.0785E-02	40.92
33	1.7960E-03	2.0350E-03	1.9155E-03	2.4951E-03	1.4972E-05	1.0440E+01	1.9997E-02	39.80
34	2.0350E-03	2.3060E-03	2.1705E-03	2.4155E-03	1.6424E-05	8.9134E+00	1.9346E-02	38.84
35	2.3060E-03	2.6130E-03	2.4595E-03	2.4186E-03	1.8634E-05	7.8780E+00	1.9376E-02	38.71
36	2.6130E-03	2.9600E-03	2.7865E-03	2.5380E-03	2.2154E-05	7.3140E+00	2.0380E-02	37.75
37	2.9600E-03	3.3550E-03	3.1575E-03	2.7011E-03	2.6717E-05	6.8383E+00	2.1592E-02	37.64
38	3.3550E-03	3.8010E-03	3.5780E-03	2.8339E-03	3.1764E-05	6.3541E+00	2.2735E-02	37.48
39	3.8010E-03	4.3070E-03	4.0540E-03	2.8107E-03	3.5694E-05	5.5547E+00	2.2519E-02	37.00
40	4.3070E-03	4.8810E-03	4.5940E-03	2.7844E-03	4.0071E-05	4.8509E+00	2.2285E-02	35.58
41	4.8810E-03	5.5310E-03	5.2060E-03	2.9558E-03	4.8204E-05	4.5474E+00	2.3674E-02	35.08
42	5.5310E-03	6.2670E-03	5.8990E-03	2.7471E-03	5.0763E-05	3.7324E+00	2.2018E-02	34.93
43	6.2670E-03	7.1020E-03	6.6845E-03	2.9342E-03	6.1442E-05	3.5141E+00	2.3490E-02	34.27
44	7.1020E-03	8.0470E-03	7.5745E-03	2.9827E-03	7.0773E-05	3.1563E+00	2.3908E-02	34.19
45	8.0470E-03	9.1190E-03	8.5830E-03	3.0424E-03	8.1800E-05	2.8380E+00	2.4359E-02	33.37
46	9.1190E-03	1.0330E-02	9.7245E-03	3.2418E-03	9.8754E-05	2.6770E+00	2.6032E-02	32.19
47	1.0330E-02	1.1710E-02	1.1020E-02	3.2993E-03	1.1390E-04	2.3908E+00	2.6347E-02	31.71
48	1.1710E-02	1.3270E-02	1.2490E-02	3.2231E-03	1.2611E-04	2.0661E+00	2.5806E-02	32.16
49	1.3270E-02	1.5030E-02	1.4150E-02	3.1617E-03	1.4015E-04	1.7964E+00	2.5419E-02	31.20
50	1.5030E-02	1.7040E-02	1.6035E-02	3.3860E-03	1.7008E-04	1.6846E+00	2.7012E-02	31.66
51	1.7040E-02	1.9300E-02	1.8170E-02	3.3785E-03	1.9230E-04	1.4949E+00	2.7162E-02	30.42
52	1.9300E-02	2.1880E-02	2.0590E-02	3.5492E-03	2.2892E-04	1.3757E+00	2.8325E-02	29.54
53	2.1880E-02	2.4790E-02	2.3335E-02	3.5945E-03	2.6275E-04	1.2352E+00	2.8824E-02	28.42
54	2.4790E-02	2.6060E-02	2.5425E-02	1.3979E-03	1.1134E-04	1.1007E+00	2.7986E-02	30.11
55	2.6060E-02	2.8090E-02	2.7075E-02	2.0832E-03	1.7669E-04	1.0262E+00	2.7785E-02	29.82
56	2.8090E-02	3.1830E-02	2.9960E-02	4.5160E-03	4.2384E-04	1.2075E+00	3.6176E-02	28.96
57	3.1830E-02	4.0870E-02	3.6350E-02	5.0405E-03	5.7396E-04	5.5758E-01	2.0268E-02	23.96
58	4.0870E-02	5.2480E-02	4.6675E-02	7.6648E-03	1.1207E-03	6.6019E-01	3.0815E-02	23.17
59	5.2480E-02	6.7380E-02	5.9930E-02	8.4033E-03	1.5776E-03	5.6398E-01	3.3799E-02	22.23
60	6.7380E-02	8.6520E-02	7.6950E-02	8.8617E-03	2.1361E-03	4.6300E-01	3.5627E-02	21.48
61	8.6520E-02	1.1110E-01	9.8810E-02	8.0403E-03	2.4887E-03	3.2711E-01	3.2321E-02	20.62

Group	Lower Energy (MeV)	Upper Energy (MeV)	Midpoint Energy (MeV)	Number Fraction	Energy Fraction	Differential Number dN/dE	Differential Energy dE/dE	Standard Deviation (%)
62	1.1110E-01	1.4260E-01	1.2685E-01	1.0199E-02	4.0527E-03	3.2377E-01	4.1071E-02	20.70
63	1.4260E-01	1.8320E-01	1.6290E-01	9.2533E-03	4.7219E-03	2.2791E-01	3.7127E-02	20.36
64	1.8320E-01	2.3520E-01	2.0920E-01	1.0805E-02	7.0807E-03	2.0778E-01	4.3468E-02	19.76
65	2.3520E-01	3.0200E-01	2.6860E-01	1.2684E-02	1.0672E-02	1.8987E-01	5.1000E-02	19.67
66	3.0200E-01	3.8770E-01	3.4485E-01	1.3423E-02	1.4500E-02	1.5663E-01	5.4012E-02	19.31
67	3.8770E-01	4.3940E-01	4.1355E-01	6.6088E-03	8.5616E-03	1.2783E-01	5.2864E-02	21.44
68	4.3940E-01	4.9790E-01	4.6865E-01	7.4942E-03	1.1002E-02	1.2811E-01	6.0037E-02	21.25
69	4.9790E-01	5.6420E-01	5.3105E-01	7.8148E-03	1.3000E-02	1.1787E-01	6.2595E-02	21.04
70	5.6420E-01	6.3930E-01	6.0175E-01	8.2221E-03	1.5499E-02	1.0948E-01	6.5881E-02	20.56
71	6.3930E-01	7.2440E-01	6.8185E-01	8.6642E-03	1.8506E-02	1.0181E-01	6.9420E-02	20.16
72	7.2440E-01	8.2080E-01	7.7260E-01	8.9836E-03	2.1742E-02	9.3190E-02	7.1999E-02	19.97
73	8.2080E-01	9.3010E-01	8.7545E-01	8.6842E-03	2.3816E-02	7.9453E-02	6.9557E-02	19.61
74	9.3010E-01	1.0540E+00	9.9205E-01	8.9769E-03	2.7897E-02	7.2453E-02	7.1877E-02	18.44
75	1.0540E+00	1.1940E+00	1.1240E+00	9.5377E-03	3.3582E-02	6.8126E-02	7.6574E-02	19.12
76	1.1940E+00	1.3530E+00	1.2735E+00	9.9674E-03	3.9763E-02	6.2688E-02	7.9833E-02	18.71
77	1.3530E+00	1.7380E+00	1.5455E+00	2.0711E-02	1.0027E-01	5.3795E-02	8.3139E-02	15.65
78	1.7380E+00	2.2310E+00	1.9845E+00	2.0025E-02	1.2449E-01	4.0619E-02	8.0609E-02	14.22
79	2.2310E+00	2.8650E+00	2.5480E+00	1.7459E-02	1.3935E-01	2.7537E-02	7.0164E-02	14.50
80	2.8650E+00	3.6790E+00	3.2720E+00	1.1108E-02	1.1385E-01	1.3646E-02	4.4649E-02	14.65
81	3.6790E+00	4.7240E+00	4.2015E+00	8.1536E-03	1.0731E-01	7.8025E-03	3.2782E-02	14.56
82	4.7240E+00	6.0650E+00	5.3945E+00	4.7558E-03	8.0367E-02	3.5465E-03	1.9131E-02	13.62
83	6.0650E+00	7.7880E+00	6.9265E+00	2.1051E-03	4.5677E-02	1.2218E-03	8.4627E-03	14.55
84	7.7880E+00	1.0000E+01	8.8940E+00	6.5963E-04	1.8378E-02	2.9821E-04	2.6523E-03	14.66
85	1.0000E+01	1.1910E+01	1.0955E+01	1.1203E-04	3.8447E-03	5.8656E-05	6.4258E-04	22.02
86	1.1910E+01	1.3500E+01	1.2705E+01	2.4805E-05	9.8721E-04	1.5600E-05	1.9820E-04	27.75
87	1.3500E+01	1.4920E+01	1.4210E+01	7.1142E-06	3.1668E-04	5.0100E-06	7.1192E-05	30.78
88	1.4920E+01	1.6900E+01	1.5910E+01	2.4873E-06	1.2396E-04	1.2562E-06	1.9986E-05	33.87
89	1.6900E+01	2.0000E+01	1.8450E+01	1.0919E-06	6.3110E-05	3.5224E-07	6.4988E-06	35.97

The results for a number of integral metrics and conversion factors are shown in Table 4. The total neutron fluence is normalized to 1.00, and the other values for fluence are in reference to this value. These values were calculated as part of the LSL analysis. Conversion values to translate to n/cm^2 are given for fissions in the reactor, MJ of reactor energy, and $^{58}Ni(n,p)^{58}Co$ activity at the characterized location in the cavity. In order to maintain consistency, the experimenter should always use a reference fast neutron reaction or reactions, e.g, $^{58}Ni(n,p)^{58}Co$ and $^{32}S(n,p)\ ^{32}P$, as a normalizing metric between operations. Typically, Ni, S, and TLD sensors are included in an experiment package in order to normalize the results of the experiment. Figure 18 showed the energy-dependent spectrum uncertainty. It must be noted that portions of the energy spectrum are highly correlated, so the uncertainty in the integral metric can be much less than the average uncertainty. Users should perform uncertainty propagation using the full energy-dependent covariance matrix given in Appendix C in order to determine the correlated uncertainty.

Table 4. Integral Neutron Spectrum Metrics and Associated Uncertainties.

Metric	Integral Response	Standard Deviation (%)
Total Neutron Fluence Average Neutron Energy = 0.302 MeV	1.00	--
Fluence > 3 MeV	0.024	3.0
Fluence > 1 MeV	0.101	3.4
Fluence > 100 keV	0.218	3.0
Fluence > 10 keV	0.282	2.8
Fluence < 1 eV	0.534	15.8
Fluence 1-MeV(Si) Eqv. E722-94 (Ref. 1-MeV value = 95 MeV-mb)	18.5 MeV-mb 0.195	2.9
Fluence 1-MeV(GaAs) Eqv. E722-94 (Ref. 1-MeV value = 70 MeV-mb)	15.8 MeV-mb 0.225	2.6
$^{58}Ni(n,p)^{58}Co$ Spectrum Avg. Cross-Section IRDFF-II	12.80 mb	3.8
$^{32}S(n,p)^{32}P$ Spectrum Avg. Cross-Section IRDFF-II (Ref. Cf spectrum = 74.10 mb +/- 2.6%)	8.05 mb	4.1
Total Fluence Conversion ([n/cm^2]/fission)	2.527E-04	0.3
Total Fluence Conversion ([n/cm^2]/MJ)	1.094E+13	2.1
Total Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([n/cm^2]/[Bq/atom$_{Ni-58}$])	6.896E+32	3.9
Total Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([n/cm^2]/[Bq/g$_{Ni-58}$])	6.670E+10	3.9
Power Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ (MJ/[Bq/atom$_{Ni-58}$])	8.395E+19	4.0
Power Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ (MJ/[Bq/g$_{Ni-58}$])	8.076E-03	4.0
Total Fluence Conversion From S Activation ([n/cm^2]/Fluence $^{32}S(n,p)$ Cf-eqv)	9.209	4.8

Table 5 shows representative integral metrics that may be useful to the experimenter. These values were calculated using the LSL adjusted 89-group neutron energy spectrum and the SNL NuGET code with various response functions. Included are responses for Si dose, Si damage, C dose, GaAs dose, GaAs damage, TLD dose, Alanine dose, and Teflon dose.

Table 5. Other Neutron Spectrum Metrics.

Metric	Integral Response
Total Si Dose (rad[Si]/[n/cm^2])	1.486E-11
Ionizing Si Dose (rad[Si]/[n/cm^2])	8.611E-12
Percent Neutron Si Dose Ionizing (%)	57.9
Total Carbon Dose (rad[C]/[n/cm^2])	6.78.3E-11
Ionizing C Dose (rad[C]/[n/cm^2])	5.842E-101
Percent Neutron C Dose Ionizing (%)	86.1
Total GaAs Dose (rad[GaAs]/[n/cm^2])	3.194E-12
Ionizing GaAs Dose (rad[GaAs]/[n/cm^2])	9.587E-13
Percent Neutron GaAs Dose Ionizing (%)	30.0
Total CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/[n/cm^2])	3.110E-11
Effective Ionizing CaF_2:Mn Dose (rad[CaF_2:Mn]/[n/cm^2])	3.305E-12
Percent Neutron CaF_2:Mn Dose total light (%)	10.6
Total Alanine Dose (rad[Alanine]/[n/cm^2])	5.339E-10
Effective Alanine EPR Dose – Waligorski (rad[CaF_2:Mn]/[n/cm^2])	4.592E-10
Percent Neutron Alanine EPR Dose (%)	50.6
Effective Alanine EPR Dose – Gerstenberg (rad[CaF_2:Mn]/[n/cm^2])	4.136E-10
Percent Neutron Alanine EPR Dose (%)	45.6
Total Teflon Dose (rad[Teflon]/[n/cm^2])	4.682E-11

3.2. Prompt Gamma Ray

The gamma ray environment includes both prompt and delayed gamma rays. Prompt gamma rays are generated from the direct fission process in the NETL fuel and from radiative capture and inelastic scattering of neutrons in the NETL fuel and structure and the beam port. Delayed gamma rays are generated by fission-product decay in the NETL fuel and decay from activated materials in the core and beam port. All gamma rays are considered to fall into one of these two categories, prompt or delayed. Gamma rays generated from the direct fission process as the reactor power decreases following a pulse are considered prompt gamma rays.

It is not currently practical to use experimental integral measurements to adjust the gamma ray energy spectrum as it is for neutrons, using the current state-of-the-art technology in gamma ray detection and energy-deposition measurements. For photon energies above the K-edges for photon cross sections (~80 keV), most material response functions fail to show any strong energy-dependent

structure that can be used to resolve the spectrum. There is simply no effective way to discriminate energy groups in a gamma ray fluence within a small volume in a reactor core. Integral dose measurements can be performed and are used as benchmarks for calculated integral responses. These integral measurements have value in validation but are not useful for spectrum adjustment. However, both passive dosimeters (e.g., TLDs) and active dosimeters (e.g., calorimeters) have some neutron and delayed gamma ray contribution effects that make deciphering the results much more complex.

3.2.1. MCNP Results – 48-Group Prompt Gamma Ray Energy Spectrum

The prompt gamma ray fluence can be calculated in a similar way as was performed for the neutron environment. With both neutrons and photons (gamma rays) turned "on" in the k-code mode of MCNP, the prompt gamma rays generated by fission, neutron radiative capture, and neutron inelastic scattering will be tracked properly, without any additional input from the user. The production and energy spectrum for the source fission gamma rays are modeled for the MCNP 6.2/ENDF-supplied 80c fissile and fissionable cross sections. The radiative capture cross sections for neutron absorption are also modeled, but one must be sure that the gamma ray production cross section is included in the cross-section data for each reaction of interest. For example, radiative capture gamma ray production for the naturally occurring cadmium isotopes is not included in the 80c or other cross sections available in the MCNP library. This information for each individual isotope can be found in Appendix G – MCNP Data Libraries of the MCNP manual. Typically, it is estimated that there are about seven gamma rays generated in the fission process at energies of about 1 MeV each. Another 1 to 12 MeV of radiative capture gamma rays can be emitted. This value is dependent on the type of reactor and absorbing materials in the fuel elements, structure, and control elements. For NETL, the total energy calculated for the prompt gamma rays (fission, radiative capture, and inelastic scattering) is ~13 MeV per fission.

Figure 18 and Figure 19 show the MCNP generated 48-group prompt gamma ray energy fluence on a linear and logarithmic y-axis, respectively. The units on the y-axis are in energy fluence, equal to $Ed\phi/dE$ (MeV/MeV-cm^2-MJ). With the energy fluence represented linearly on the y-axis and the photon energy on the x-axis represented logarithmically, the area under the curve represents the total prompt gamma ray fluence. The gamma ray energy fluence has a prominent peak at ~0.5 MeV and another peak at ~0.8 MeV.

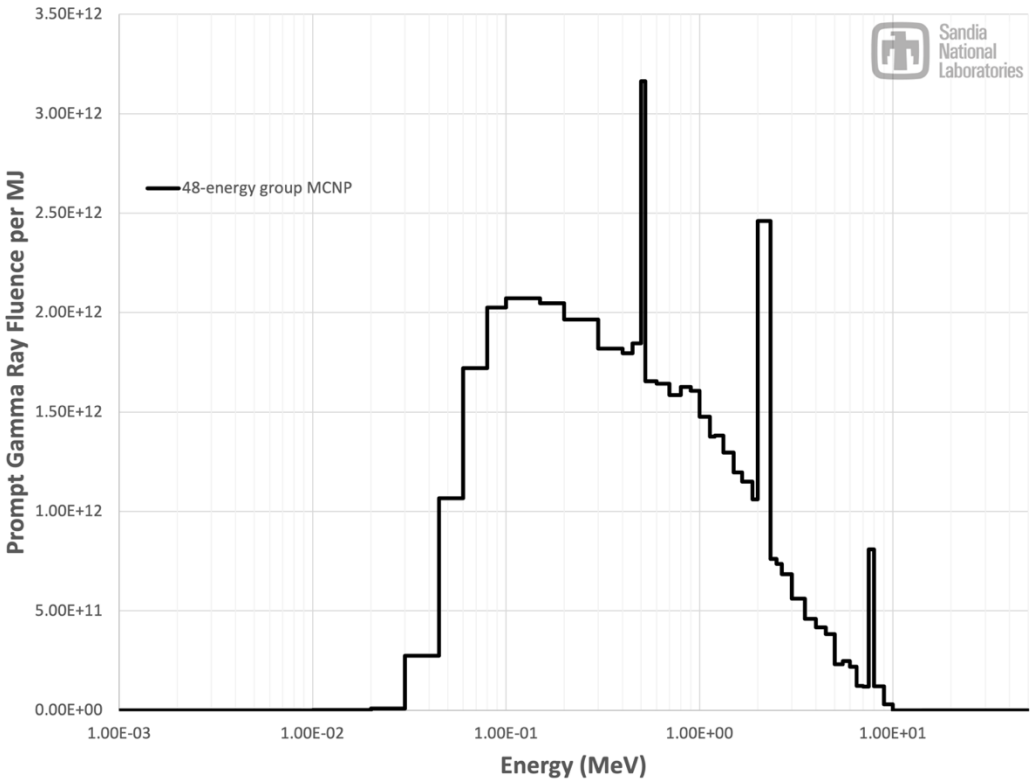

Figure 18. MCNP 48-Group Prompt Gamma Ray Energy Spectrum (linear–log).

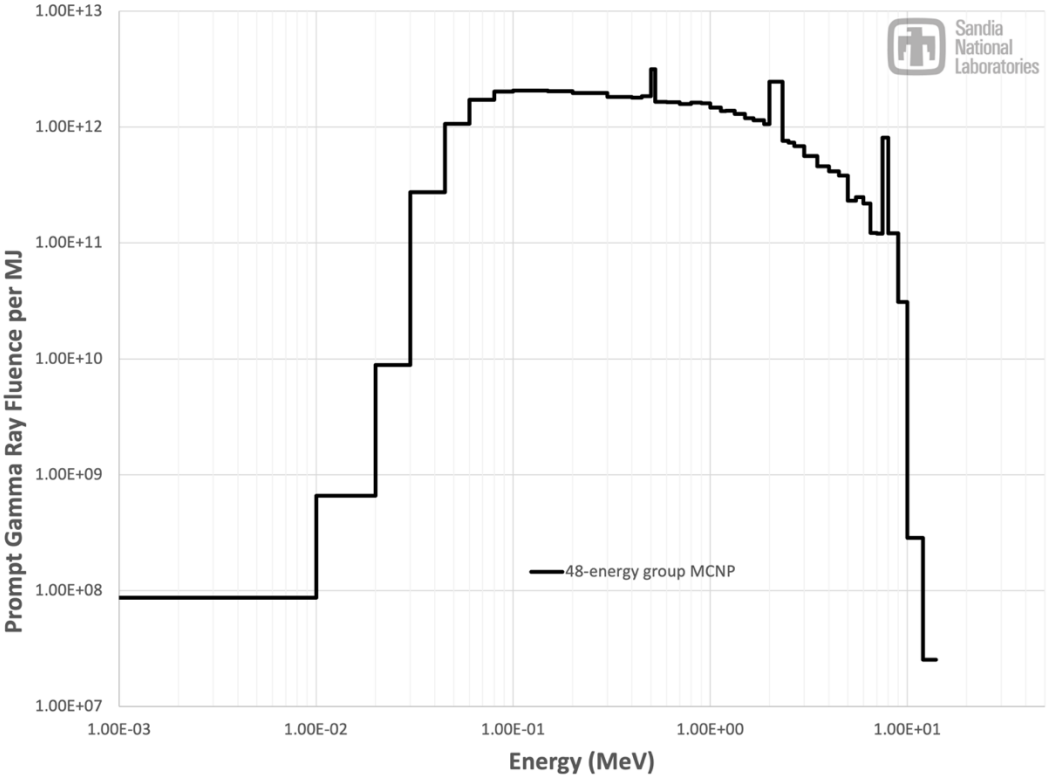

Figure 19. MCNP 48-Group Prompt Gamma Ray Energy Spectrum (log–log).

Table 6 shows the prompt gamma ray fluence spectrum in a tabular format for the 48-group NuGET energy structure. Column 5 represents the number fraction, column 6 the energy fraction, column 7 the differential number fraction, column 8 the differential energy fraction, and column 9 the percent standard deviation. The number fraction, represented as a histogram, can be used in MCNP source calculations as an isotropic spherical surface source. The average gamma ray energy is calculated to be 0.825 MeV. The peak differential energy fluence occurs in energy group 14 at 0.5125 MeV. This is the large peak seen in Figure 18 and represents the electron-positron annihilation photon energy (0.511 MeV).

The uncertainty and covariance matrix represents a combination of expert judgment and perturbation analyses using MCNP and LSL. The covariance matrix satisfies the spectrum normalization condition and is positive semi-definite, with non-negative eigenvalues.

The results for a number of integral metrics and conversion factors are shown in Table 7. Conversion values to translate to γ/cm^2 are given relative to fissions in the core, MJ of reactor energy, and $^{58}Ni(n,p)^{58}Co$ activity at the characterized location in the bucket. The same caveats presented in the neutron discussion using reactor power apply to the prompt gamma rays. Table 7 also shows additional integral metrics that may be useful to the experimenter. These values were calculated using the 48-group gamma ray energy spectrum and the NuGET code with various response functions. Included are responses for Si dose, C dose, GaAs dose, TLD dose, Alanine dose, and Teflon dose.

Table 6. Prompt Gamma Ray 48-Group Gamma Ray Energy Spectrum for NETL-FF-BP1/5-128-cca

Group	Lower Energy (MeV)	Upper Energy (MeV)	Midpoint Energy (MeV)	Number Fraction	Energy Fraction	Differential Number dN/dE	Differential Energy dE/dE	Standard Deviation (%)
1	1.0000E-03	1.0000E-02	5.5000E-03	1.8875E-05	1.2586E-07	2.0972E-03	1.1535E-05	81.56
2	1.0000E-02	2.0000E-02	1.5000E-02	5.8463E-05	1.0632E-06	5.8463E-03	8.7694E-05	64.96
3	2.0000E-02	3.0000E-02	2.5000E-02	4.7064E-04	1.4265E-05	4.7064E-02	1.1766E-03	52.24
4	3.0000E-02	4.5000E-02	3.7500E-02	1.4606E-02	6.6406E-04	9.7372E-01	3.6514E-02	42.15
5	4.5000E-02	6.0000E-02	5.2500E-02	4.0522E-02	2.5793E-03	2.7015E+00	1.4183E-01	34.79
6	6.0000E-02	8.0000E-02	7.0000E-02	6.5380E-02	5.5488E-03	3.2690E+00	2.2883E-01	33.52
7	8.0000E-02	1.0000E-01	9.0000E-02	5.9904E-02	6.5366E-03	2.9952E+00	2.6957E-01	32.41
8	1.0000E-01	1.5000E-01	1.2500E-01	1.1022E-01	1.6704E-02	2.2044E+00	2.7555E-01	30.96
9	1.5000E-01	2.0000E-01	1.7500E-01	7.7815E-02	1.6510E-02	1.5563E+00	2.7235E-01	29.48
10	2.0000E-01	3.0000E-01	2.5000E-01	1.0460E-01	3.1704E-02	1.0460E+00	2.6149E-01	27.90
11	3.0000E-01	4.0000E-01	3.5000E-01	6.9133E-02	2.9336E-02	6.9133E-01	2.4197E-01	26.42
12	4.0000E-01	4.5000E-01	4.2500E-01	2.8112E-02	1.4485E-02	5.6224E-01	2.3895E-01	25.56
13	4.5000E-01	5.0000E-01	4.7500E-01	2.5850E-02	1.4887E-02	5.1699E-01	2.4557E-01	25.07
14	5.0000E-01	5.2500E-01	5.1250E-01	2.0531E-02	1.2757E-02	8.2125E-01	4.2089E-01	24.74
15	5.2500E-01	6.0000E-01	5.6250E-01	2.9360E-02	2.0023E-02	3.9146E-01	2.2020E-01	24.33
16	6.0000E-01	7.0000E-01	6.5000E-01	3.3598E-02	2.6478E-02	3.3598E-01	2.1839E-01	23.69
17	7.0000E-01	8.0000E-01	7.5000E-01	2.8123E-02	2.5573E-02	2.8123E-01	2.1092E-01	23.06
18	8.0000E-01	9.0000E-01	8.5000E-01	2.5437E-02	2.6214E-02	2.5437E-01	2.1622E-01	22.51
19	9.0000E-01	1.0000E+00	9.5000E-01	2.2509E-02	2.5925E-02	2.2509E-01	2.1383E-01	22.02
20	1.0000E+00	1.1250E+00	1.0625E+00	2.3975E-02	3.0884E-02	1.9180E-01	2.0379E-01	21.52
21	1.1250E+00	1.2000E+00	1.1625E+00	1.1003E-02	1.5508E-02	1.4671E-01	1.7054E-01	21.13
22	1.2000E+00	1.3300E+00	1.2650E+00	1.8883E-02	2.8961E-02	1.4525E-01	1.8375E-01	20.75
23	1.3300E+00	1.5000E+00	1.4150E+00	2.0726E-02	3.5557E-02	1.2192E-01	1.7252E-01	20.26
24	1.5000E+00	1.6600E+00	1.5800E+00	1.6126E-02	3.0891E-02	1.0079E-01	1.5924E-01	20.00
25	1.6600E+00	1.8750E+00	1.7675E+00	1.9009E-02	4.0734E-02	8.8412E-02	1.5627E-01	20.00
26	1.8750E+00	2.0000E+00	1.9375E+00	8.7233E-03	2.0492E-02	6.9787E-02	1.3521E-01	20.00
27	2.0000E+00	2.3330E+00	2.1665E+00	4.9902E-02	1.3108E-01	1.4986E-01	3.2466E-01	20.00
28	2.3330E+00	2.5000E+00	2.4165E+00	7.1287E-03	2.0886E-02	4.2687E-02	1.0315E-01	20.00
29	2.5000E+00	2.6600E+00	2.5800E+00	6.4353E-03	2.0130E-02	4.0221E-02	1.0377E-01	20.00
30	2.6600E+00	3.0000E+00	2.8300E+00	1.0589E-02	3.6333E-02	3.1145E-02	8.8139E-02	20.00
31	3.0000E+00	3.5000E+00	3.2500E+00	1.1504E-02	4.5328E-02	2.3007E-02	7.4773E-02	20.00
32	3.5000E+00	4.0000E+00	3.7500E+00	8.1485E-03	3.7048E-02	1.6297E-02	6.1114E-02	20.00
33	4.0000E+00	4.5000E+00	4.2500E+00	6.5229E-03	3.3611E-02	1.3046E-02	5.5445E-02	20.00
34	4.5000E+00	5.0000E+00	4.7500E+00	5.3541E-03	3.0834E-02	1.0708E-02	5.0864E-02	20.00
35	5.0000E+00	5.5000E+00	5.2500E+00	2.9430E-03	1.8733E-02	5.8861E-03	3.0902E-02	20.00
36	5.5000E+00	6.0000E+00	5.7500E+00	2.8689E-03	2.0000E-02	5.7378E-03	3.2992E-02	20.00
37	6.0000E+00	6.5000E+00	6.2500E+00	2.3257E-03	1.7623E-02	4.6514E-03	2.9071E-02	22.00
38	6.5000E+00	7.0000E+00	6.7500E+00	1.2015E-03	9.8329E-03	2.4030E-03	1.6220E-02	25.77
39	7.0000E+00	7.5000E+00	7.2500E+00	1.1019E-03	9.6857E-03	2.2038E-03	1.5977E-02	29.27
40	7.5000E+00	8.0000E+00	7.7500E+00	6.9503E-03	6.5307E-02	1.3901E-02	1.0773E-01	32.53
41	8.0000E+00	9.0000E+00	8.5000E+00	1.8944E-03	1.9522E-02	1.8944E-03	1.6102E-02	37.05
42	9.0000E+00	1.0000E+01	9.5000E+00	4.3252E-04	4.9817E-03	4.3252E-04	4.1089E-03	42.50
43	1.0000E+01	1.2000E+01	1.1000E+01	6.8780E-06	9.1729E-05	3.4390E-06	3.7829E-05	48.33
44	1.2000E+01	1.4000E+01	1.3000E+01	5.1940E-07	8.1865E-06	2.5970E-07	3.3761E-06	54.25
45	1.4000E+01	1.7000E+01	1.5500E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	59.98
46	1.7000E+01	2.0000E+01	1.8500E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	66.02
47	2.0000E+01	3.0000E+01	2.5000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	76.31
48	3.0000E+01	5.0000E+01	4.0000E+01	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	92.37

Table 7. Prompt Gamma Ray Spectrum Metrics.

Metric	Integral Response
Average Gamma Ray Energy (MeV)	0.825
Fluence Conversion ([γ/cm^2]/[n/cm^2])	0.920
Fluence Conversion ([γ/cm^2]/fission)	2.320E-04
Fluence Conversion ([γ/cm^2]/MJ)	7.528+12
Fluence Conversion From Ni Activation ^{58}Ni(n,p)^{58}Co ([γ/cm^2]/[Bq/atom$_{Ni-58}$])	6.324E+32
Fluence Conversion From Ni Activation ^{58}Ni(n,p)^{58}Co ([γ/cm^2]/[Bq/g$_{Ni-58}$])	6.084E+10
Total (Ionizing) Si Dose (rad[Si]/[γ/cm^2])	3.357E-10
Total (Ionizing) Carbon Dose (rad[C]/[γ/cm^2])	3.007E-10
Total (Ionizing) GaAs Dose (rad[GaAs]/[γ/cm^2])	6.359E-10
Total (Ionizing) CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/[γ/cm^2])	3.558E-10
Total Alanine Dose (rad[Alanine]/[γ/cm^2])	3.254E-10
Total Teflon Dose (rad[Teflon]/[γ/cm^2])	2.947E-10

3.3. Delayed Gamma Ray

Delayed gamma rays are generated by fission-product decay in NETL fuel and by the decay of activated materials in the reactor core. MCNP does not intrinsically calculate the source for these gamma rays. MCNP6.2 can be used with the burnup feature of the code to generate fission products and activation products in defined regions of the core. But in order to generate the decay gamma ray source, a separate calculation would need to be performed that would generate the time-dependent or time-integrated gamma ray energy spectrum from the unique isotopic inventory and gamma ray lines. For the analysis presented in this report, a much simpler approach was taken. The assumption was made that only early-time fission product generated decay gamma rays would be modeled. This model ignores the gamma ray contribution from neutron activation in the core. A generic fission product decay gamma ray energy spectrum was used in the MCNP analysis and transported the gamma rays from the fission distribution in the NETL fuel to the detector sphere in the beam port.

3.3.1. MCNP Results – 48-Group Delayed Gamma Ray Energy Spectrum

The decay gamma ray fluence was calculated with MCNP using the source mode and with photons only. The same model of the NETL and bucket configuration was used with a represented fission product gamma ray source energy spectrum. The same 48-group energy structure was used as for prompt gamma rays. The fission-product delayed gamma ray energy spectrum used was for fast U-235 fission in the time interval from 0.2 to 0.5 seconds as given in Engle (1962) and Fisher (1964).

The gamma ray source distribution within the NETL fuel was radially by row in the core. The distribution function was generated from a separate MCNP k-code calculation by tallying the number of fissions in each row of fuel. A constant axial source distribution was assumed. The results gave the transported delayed gamma ray fluence spectrum per source photon.

The total delayed gamma ray energy released from the fission products used was 6.33 MeV per fission for U-235 fission from ENDF/B-VIII.0. This value is about half of the value emitted as prompt gamma rays, and therefore cannot be ignored as a trivial quantity. The number of delayed gamma rays emitted per fission was then calculated to be 6.57 delayed photons/fission, using the source delayed gamma ray energy spectrum for fast U-235 fission.

Figure 20 shows the delayed gamma ray energy source distribution in units of gamma rays per MeV as a function of energy. This spectrum was used in a histogram format for the source calculation in MCNP described above. The resulting transported gamma ray fluence to the tally sphere is in units of fluence per source delayed gamma ray. Although fission products continue to decay over many years, the majority of the energy (~85%) is released from the shorter-lived products over 1E4 seconds (2.8 hours). The fractional energy release up to 0.1 s is ~1%, ~6.5% up to 1 s, ~23.2% up to 10 s, and ~55% up to 300 s (5 minutes).

Figure 21and Figure 22 show the MCNP generated 48-group delayed gamma ray energy fluence on a linear and logarithmic y-axis, respectively. The units on the y-axis are in energy fluence, equal to $Ed\phi/dE$ (MeV/MeV-cm^2-MJ). With the energy fluence represented linearly on the y-axis and the photon energy on the x-axis represented logarithmically, the area under the curve represents the total gamma ray fluence. The scale of the plots is the same as presented for the prompt gamma rays. The delayed gamma ray energy fluence has a prominent peak at ~0.5 MeV.

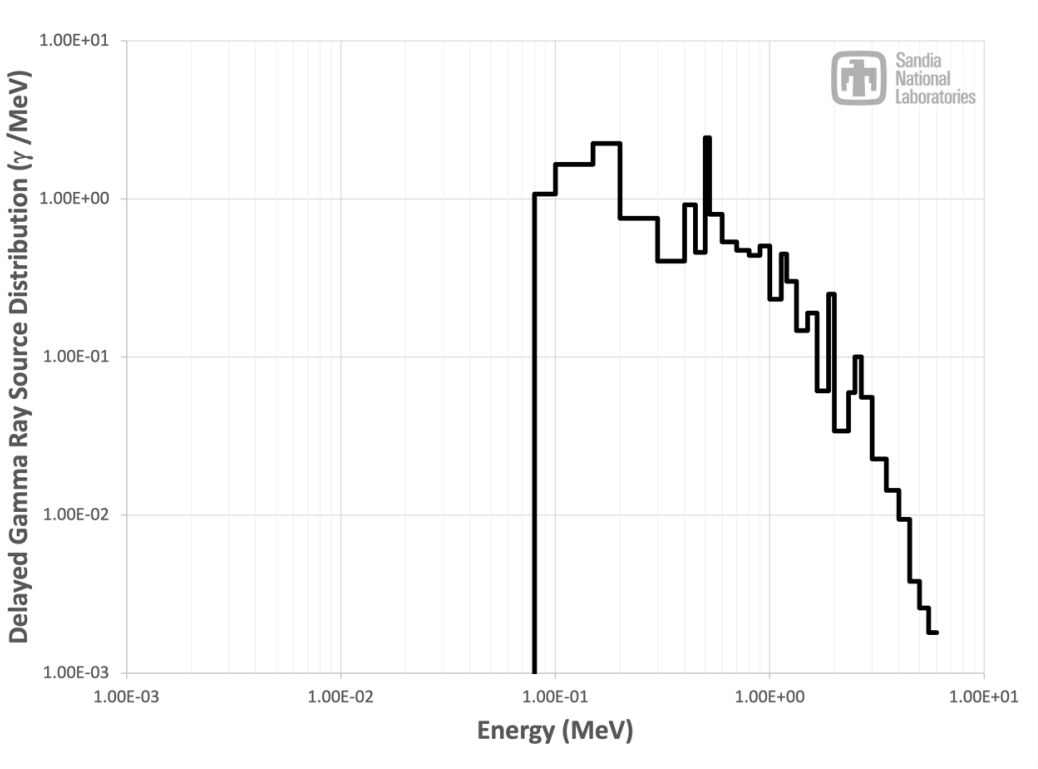

Figure 20. Delayed Gamma Ray Source Distribution Used for MCNP Analysis.

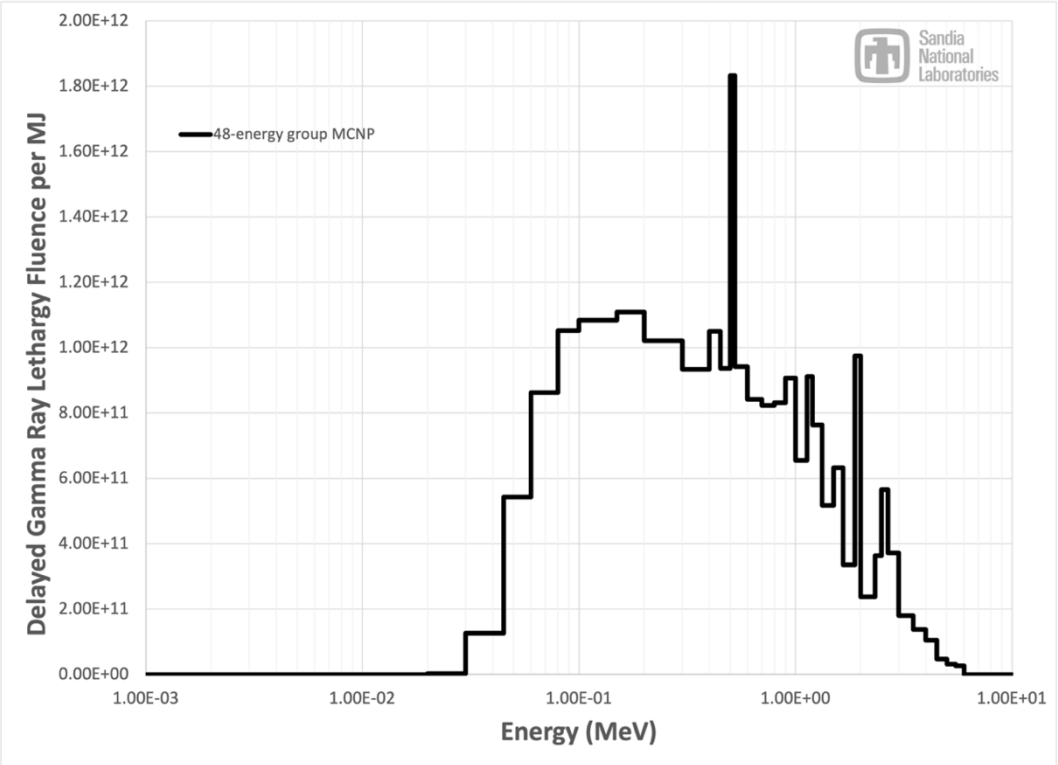

Figure 21. MCNP 48-Group Delayed Gamma Ray Energy Spectrum (lin–log).

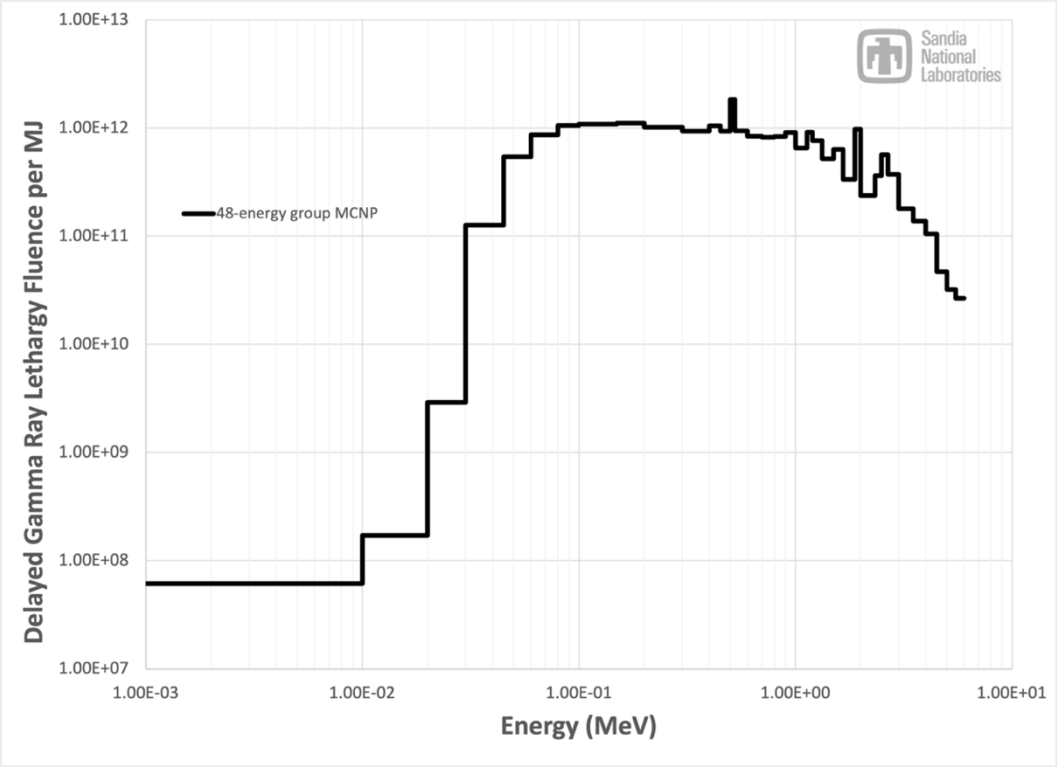

Figure 22. MCNP 48-Group Delayed Gamma Ray Energy Spectrum (log–log).

Table 8 shows the delayed gamma ray fluence spectrum in a tabular format for the 48-group NuGET enerrgy structure. Column 5 represents the number fraction, column 6 the energy fraction, column 7 the differential number fraction, column 8 the differential energy fraction, and column 9 the percent standard deviation. The number fraction, represented as a histogram, can be used in MCNP source calculations as an isotropic spherical surface source. The average delayed gamma ray energy is calculated to be 0.593 MeV. The peak differential energy fluence again occurs in energy group 14 at 0.5125 MeV. This is the large peak seen in Figure 21 and represents the electron-positron annihilation photon energy (0.511 MeV).

Table 8. Delayed Gamma Ray 48-Group Delayed Gamma Ray Energy Spectrum for NETL-FF-BP1/5-128-cca

Group	Lower Energy (MeV)	Upper Energy (MeV)	Midpoint Energy (MeV)	Number Fraction	Energy Fraction	Differential Number dN/dE	Differential Energy dE/dE	Standard Deviation (%)
1	1.0000E-03	1.0000E-02	5.5000E-03	2.76693E-05	2.56095E-07	3.07437E-03	1.69090E-05	102.67
2	1.0000E-02	2.0000E-02	1.5000E-02	3.13853E-05	7.92241E-07	3.13853E-03	4.70780E-05	102.05
3	2.0000E-02	3.0000E-02	2.5000E-02	3.19228E-04	1.34302E-05	3.19228E-02	7.98071E-04	101.62
4	3.0000E-02	4.5000E-02	3.7500E-02	1.39486E-02	8.80244E-04	9.29910E-01	3.48716E-02	74.73
5	4.5000E-02	6.0000E-02	5.2500E-02	4.27118E-02	3.77353E-03	2.84745E+00	1.49491E-01	53.47
6	6.0000E-02	8.0000E-02	7.0000E-02	6.77462E-02	7.98037E-03	3.38731E+00	2.37112E-01	53.40
7	8.0000E-02	1.0000E-01	9.0000E-02	6.43378E-02	9.74426E-03	3.21689E+00	2.89520E-01	54.05
8	1.0000E-01	1.5000E-01	1.2500E-01	1.19239E-01	2.50824E-02	2.38478E+00	2.98098E-01	46.60
9	1.5000E-01	2.0000E-01	1.7500E-01	8.71448E-02	2.56637E-02	1.74290E+00	3.05007E-01	42.43
10	2.0000E-01	3.0000E-01	2.5000E-01	1.12370E-01	4.72750E-02	1.12370E+00	2.80926E-01	42.27
11	3.0000E-01	4.0000E-01	3.5000E-01	7.33552E-02	4.32055E-02	7.33552E-01	2.56743E-01	42.28
12	4.0000E-01	4.5000E-01	4.2500E-01	3.39868E-02	2.43075E-02	6.79737E-01	2.88888E-01	44.30
13	4.5000E-01	5.0000E-01	4.7500E-01	2.71235E-02	2.16810E-02	5.42470E-01	2.57673E-01	41.91
14	5.0000E-01	5.2500E-01	5.1250E-01	2.45906E-02	2.12082E-02	9.83624E-01	5.04108E-01	38.56
15	5.2500E-01	6.0000E-01	5.6250E-01	3.45606E-02	3.27147E-02	4.60808E-01	2.59204E-01	38.98
16	6.0000E-01	7.0000E-01	6.5000E-01	3.56245E-02	3.89675E-02	3.56245E-01	2.31559E-01	14.56
17	7.0000E-01	8.0000E-01	7.5000E-01	3.02147E-02	3.81347E-02	3.02147E-01	2.26610E-01	10.72
18	8.0000E-01	9.0000E-01	8.5000E-01	2.68967E-02	3.84732E-02	2.68967E-01	2.28622E-01	9.12
19	9.0000E-01	1.0000E+00	9.5000E-01	2.62698E-02	4.19972E-02	2.62698E-01	2.49563E-01	7.98
20	1.0000E+00	1.1250E+00	1.0625E+00	2.20030E-02	3.93416E-02	1.76024E-01	1.87026E-01	7.19
21	1.1250E+00	1.2000E+00	1.1625E+00	1.50784E-02	2.94978E-02	2.01046E-01	2.33716E-01	5.46
22	1.2000E+00	1.3300E+00	1.2650E+00	2.15957E-02	4.59725E-02	1.66121E-01	2.10143E-01	4.60
23	1.3300E+00	1.5000E+00	1.4150E+00	1.71042E-02	4.07285E-02	1.00613E-01	1.42367E-01	4.74
24	1.5000E+00	1.6600E+00	1.5800E+00	1.76234E-02	4.68585E-02	1.10147E-01	1.74032E-01	5.10
25	1.6600E+00	1.8750E+00	1.7675E+00	1.14654E-02	3.41026E-02	5.33273E-02	9.42560E-02	5.14
26	1.8750E+00	2.0000E+00	1.9375E+00	1.65952E-02	5.41083E-02	1.32761E-01	2.57225E-01	5.34
27	2.0000E+00	2.3330E+00	2.1665E+00	9.97737E-03	3.63760E-02	2.99621E-02	6.49128E-02	6.03
28	2.3330E+00	2.5000E+00	2.4165E+00	7.03799E-03	2.86204E-02	4.21437E-02	1.01840E-01	6.92
29	2.5000E+00	2.6600E+00	2.5800E+00	1.02252E-02	4.43947E-02	6.39074E-02	1.64881E-01	7.50
30	2.6600E+00	3.0000E+00	2.8300E+00	1.19141E-02	5.67399E-02	3.50415E-02	9.91676E-02	8.44
31	3.0000E+00	3.5000E+00	3.2500E+00	7.61052E-03	4.16234E-02	1.52210E-02	4.94684E-02	9.98
32	3.5000E+00	4.0000E+00	3.7500E+00	5.04431E-03	3.18326E-02	1.00886E-02	3.78323E-02	11.59
33	4.0000E+00	4.5000E+00	4.2500E+00	3.38472E-03	2.42076E-02	6.76944E-03	2.87701E-02	12.97
34	4.5000E+00	5.0000E+00	4.7500E+00	1.35854E-03	1.08594E-02	2.71709E-03	1.29062E-02	14.18
35	5.0000E+00	5.5000E+00	5.2500E+00	8.43403E-04	7.45134E-03	1.68681E-03	8.85573E-03	15.22
36	5.5000E+00	6.0000E+00	5.7500E+00	6.38842E-04	6.18160E-03	1.27768E-03	7.34668E-03	16.11
37	6.0000E+00	6.5000E+00	6.2500E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
38	6.5000E+00	7.0000E+00	6.7500E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
39	7.0000E+00	7.5000E+00	7.2500E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
40	7.5000E+00	8.0000E+00	7.7500E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
41	8.0000E+00	9.0000E+00	8.5000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
42	9.0000E+00	1.0000E+01	9.5000E+00	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
43	1.0000E+01	1.2000E+01	1.1000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
44	1.2000E+01	1.4000E+01	1.3000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
45	1.4000E+01	1.7000E+01	1.5500E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
46	1.7000E+01	2.0000E+01	1.8500E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
47	2.0000E+01	3.0000E+01	2.5000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00
48	3.0000E+01	5.0000E+01	4.0000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	100.00

The results for the number fraction, percent standard deviation, and covariance as a function of the 48-group energy structure are included in an LSL format in Appendix E of this report. The covariance matrix represents a combination of expert judgment and perturbation analyses using MCNP. The covariance matrix satisfies the spectrum normalization condition and is positive definite, with non-negative eigenvalues.

The results for a number of integral metrics and conversion factors are shown in Table 9. Conversion values to translate to γ/cm^2 are given for fissions in the core, MJ of reactor energy, and $^{58}Ni(n,p)^{58}Co$ activity at the characterized location in the beam port. The same caveats presented in the neutron discussion using reactor power apply to the delayed gamma rays. Table 9 also shows additional integral metrics that may be useful to the experimenter. These values were calculated using the 48-group delayed gamma ray energy spectrum and the NuGET code with various response functions. Included are responses for Silicon (Si) dose, Carbon (C) dose, Gallium-Arsenide (GaAs) dose, thermoluminescence dosimeter (TLD) dose, Alanine dose, and Teflon dose.

Table 9. Delayed Gamma Ray Spectrum Metrics.

Metric	Integral Response
Average Delayed Gamma Ray (dγ) Energy (MeV)	0.593
Fluence Conversion ([dγ/cm^2]/[source dγ])	1.670E-05
Source Delayed Gamma Rays (source dγ/fission)	6.567
Fluence Conversion ([dγ/cm^2]/[γ/cm^2])	0.473
Fluence Conversion ([dγ/cm^2]/fission)	1.097E-04
Fluence Conversion ([dγ/cm^2]/MJ)	3.564E+12
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([dγ/cm^2]/[Bq/atom$_{Ni-58}$])	2.992E+32
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([dγ/cm^2]/[Bq/g$_{Ni-58}$])	2.878E+10
Total (Ionizing) Si Dose (rad[Si]/[dγ/cm^2])	2.705E-10
Total (Ionizing) Carbon Dose (rad[C]/[dγ/cm^2])	2.419E-10
Total (Ionizing) GaAs Dose (rad[GaAs]/[dγ/cm^2])	5.850E-10
Total (Ionizing) CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/[dγ/cm^2])	2.932E-10
Total Alanine Dose (rad[Alanine]/[dγ/cm^2])	2.619E-10
Total Teflon Dose (rad[Teflon]/[dγ/cm^2])	2.363E-10

4. RADIAL AND AXIAL FLUENCE PROFILES

Passive dosimetry was used to determine the axial and radial neutron and gamma ray fluence profiles for the free-field environment on the SNL test fixture. From these profiles, the peak axial fluence location can be determined as well as any radial variation. For these runs, the reactor was operated in both pulse and steady-state modes. The axial profiles were performed in beam port 1-5 (BP1/5) though port free-field environment at the radial centerline of the beam port at the axial centerline of the core that is core centerline adjacent, roughly 128-inches into either entrance of the beam port. Figure 23 shows a model of the dosimetry fixture.

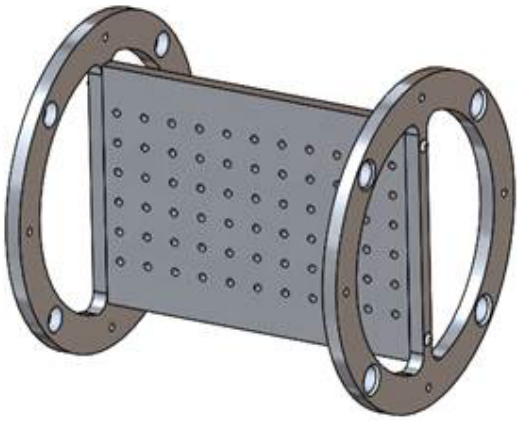

Figure 23. Mapping Fixture used in Beam Port 1/5

5. NEUTRON-SULFUR MAP

Figure 24 shows the results for the sulfur axial (vertical) neutron fast fluence profile on the test fixture that is commonly used in BP1/5. The sulfur activation reaction is $^{32}S(n,p)^{32}P$, which is a fast neutron reaction. The ^{32}P decays by β- emission with a 14.3-day half-life. The results show that over a majority of the test fixture, the fluence magnitude varies by only ±5%, with slightly higher fluence rates favoring the top of the test fixture. For reference, the axial fuel centerline is ~6.985 cm (2.75 inches) from the top of the 6-inch BP1/5 fixture. The NETL fuel is 52.25 cm in length (20.57 inches).

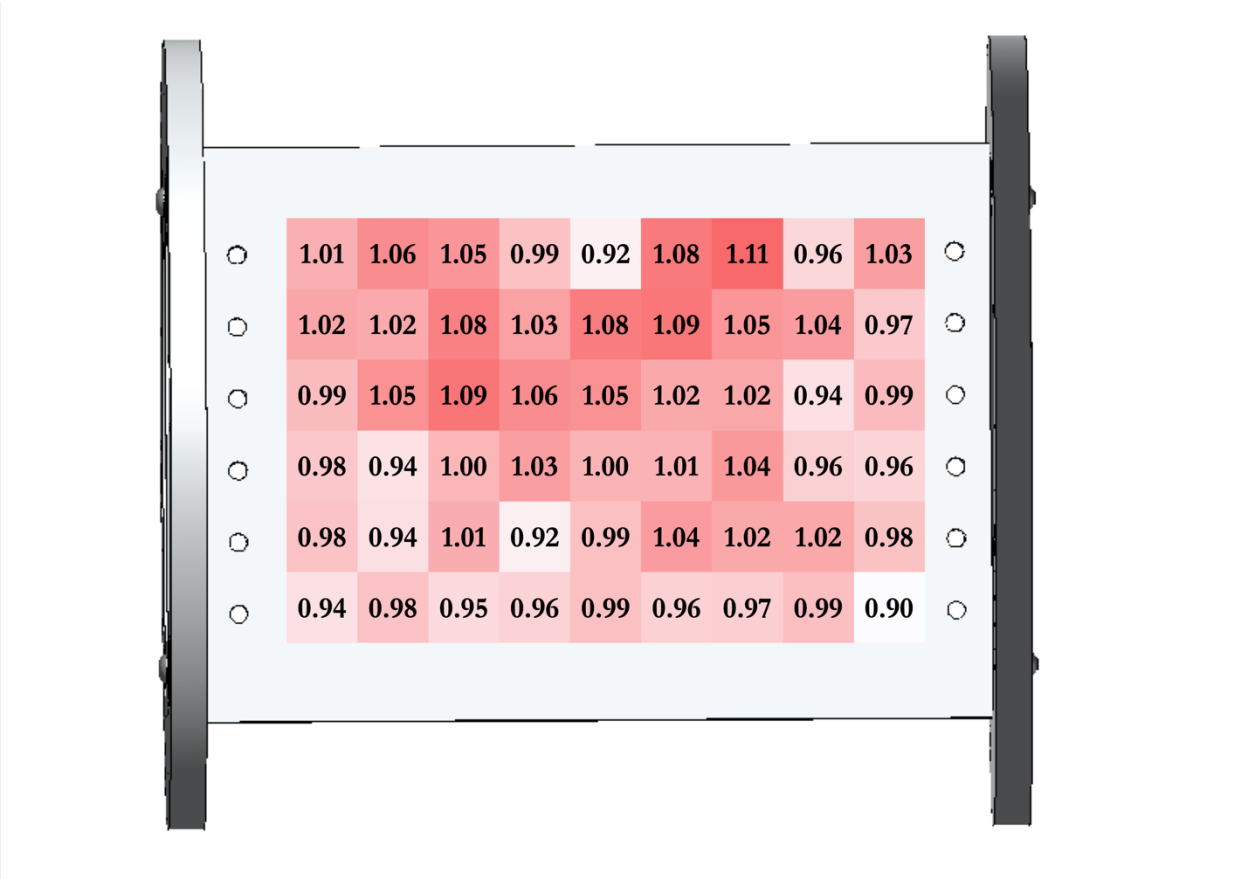

Figure 24. Sulfur Map for the NETL-FF-BP1/5-128-cca test fixture.

6. CONCLUSIONS

This report presents the characterized neutron, prompt gamma ray, and delayed gamma ray radiation environments for the free-field environment in the BP1/5 of the NETL TRIGA reactor. The characterized location is 128-inches into beam port 1/5 loaded from the entrance of beam port 1. The designation for this location is NETL-FF-BP1/5-128-cca. A 640-group and 89-group neutron eenergy spectrum, a 48-group prompt gamma ray energy spectrum, and a 48-group delayed gamma ray energy spectrum were calculated using MCNP using a high-fidelity model of NETL. The neutron spectrum was adjusted to align more closely with neutron activation dosimetry. The adjustment was performed using the least-squares code LSL-M3, an SNL unreleased modified version of LSL-M2. Neutron, prompt gamma ray, and delayed gamma ray conversion factors are presented to facilitate the conversion of various dosimetry readings into radiation metrics desired by the experimenter.

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APPENDIX A. MCNP NETL MODEL WITH BP1/5 128-INCH LOCATION

```
c Core Configuration on 2/22/2018 at 337.894 MWD
c Note: Densities in cell cards, negative means g/cm3, + means a/barn-cm
c ***************************** BEGIN CELLS *********************************
c VOID
1101  0 (1:5:-2)
c Reflector Canister
1102  2 -1.0 (202:204) 403 -5 -1 $ water over reflector
1103  2 -1.0 (202:204) -418 2 -5 $ water under reflector
c Hexagonal Shroud
1104  6 -2.7 (-201 202:-203 204) -201 -203 -403 418 $ hex wall
1105  8 -0.001225 (201:203) -320 -403 409 $ Hex to RSR level, air
          1341 1342 1343 1344 1345 1346 1347 1348 1349 1350
          1351 1352 1353 1354 1355 1356 1357 1358 1359 1360
          1361 1362 1363 1364 1365 1366 1367 1368 1369 1370
          1371 1372 1373 1374 1375 1376 1377 1378 1379 1380
1106  5 -1.6 -6 ((320 -403 409):(418 (201:203) -409)) 502 # $
      (-507 203.6)#(-504 -505)#(-509 203.4)
c POOL # $ pool water, not beam ports
1107  2 -1.0 -403 418 6 -5 502#(-507 203.6)#(-504 -505)#(-509 203.4)
c BP1/5 (Through Beam)
1108  6 -2.7  203 -502 501 -5
1109  8 -0.001225 203 -501 -5
c BP2 (Tangential)
1110  6 -2.7  -504 503 -505 -5
1111  8 -0.001225 -503 -505 -5
c BP3 (Radial Penetrating)
1112  6 -2.7 203 -507 506 -4 -5
1113  8 -0.001225 203 -506 -4 -5
c BP4 (Radial)
1114  6 -2.7  203 -509 508 -3 -5
1115  8 -0.001225 203 -508 -3 -5
c ---------------------------------------------------------------------------
c SOLID AL: fill=1 ** WATER VOID: fill=2 ** GRAPHITE ROD: fill=3
c FUEL: fill=4 ** CENTRAL THIMBLE: fill=5 ** TRANSIENT ROD: fill=6 **
c REGULATING ROD: fill=7 ** SHIM 1 fill=8 ** SHIM 2: fill=9 **
c PNT: fill=10 ** SOURCE: fill=11
c ---------------------------------------------------------------------------
1201   0 -1 406 -202 -204 fill=20 $ lattice space
c   FACET: -(L) +(R) -(Lu) +(Rl) -(Ru) +(Ll) +(l) -(u)
1202   0 -101 102 -103 104 -105 106 -1 406 u=20 lat=2 $ lattice 19.05<z<70
      fill=-7:7 -7:7 0:0
   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 1
    1 1 1 1 1 1 1 1 2 4 4 4 4 1 1 $ROW 2
```

```
    1 1 1 1 1 1 4 4 4 4 4 4 4 11 1 $ROW 3
     1 1 1 1 1 4 4 4 4 4 4 4 4 4 1 $ROW 4
     1 1 1 1 4 4 4 4 9 4 4 4 4 10 1 $ROW 5
      1 1 1 4 4 4 4 4 4 4 4 4 4 4 1 $ROW 6
      1 1 4 4 4 4 4 4 4 4 4 4 4 4 1 $ROW 7
       1 1 4 4 4 7 4 5 4 6 4 4 4 1 1 $ROW 8
       1 4 4 4 4 4 4 4 4 4 4 4 4 1 1 $ROW 9
        1 4 2 2 4 4 4 4 4 4 4 4 1 1 1 $ROW 10
        1 4 2 4 4 8 4 4 4 4 4 1 1 1 1 $ROW 11
         1 4 4 4 4 4 4 4 4 4 1 1 1 1 1 $ROW 12
         1 4 4 4 4 4 4 4 4 1 1 1 1 1 1 $ROW 13
          1 1 4 4 4 4 4 1 1 1 1 1 1 1 1 $ROW 14
          1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 15
1203   0 -406 413 -202 -204 fill=21 $ lattice space
1204   0 -101 102 -103 104 -105 106 -406 413 u=21 lat=2 $ lattice -19.05<z<19.05
      fill=-7:7 -7:7 0:0
         1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 1
     1 1 1 1 1 1 1  2  727 728 729 730 1 1 $ROW 2
    1 1 1 1 1 1 724 621 622 623 624 625 626 11 1 $ROW 3
     1 1 1 1 1 723 620 517 518 519 520 521 627 733 1 $ROW 4
     1 1 1 1 722 619 516 413  9 415 416 522 628 10 1 $ROW 5
      1 1 1 721 618 515 412 309 310 311 417 523 629 735 1 $ROW 6
      1 1 720 617 514 411 308 205 206 312 418 524 630 736 1 $ROW 7
       1 1 616 513 410  7 204 5 201  6 401 501 601 1 1 $ROW 8
       1 718 615 512 409 306 203 202 302 402 502 602 702 1 1 $ROW 9
        1 717 2 2 408 305 304 303 403 503 603 703 1 1 1 $ROW 10
        1 716 2 510 407  8 405 404 504 604 704 1 1 1 1 $ROW 11
         1 715 612 509 508 507 506 505 605 705 1 1 1 1 1 $ROW 12
         1 714 611 610 609 608 607 606 706 1 1 1 1 1 1 $ROW 13
          1 1  712 711 710 709 708 1 1 1 1 1 1 1 1 $ROW 14
          1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 15
1205   0 -413 2 -202 -204 fill=22 $ lattice space
1206   0 -101 102 -103 104 -105 106 -413 2 u=22 lat=2 $ lattice -70<z<-19.05
      fill=-7:7 -7:7 0:0
   1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 1
    1 1 1 1 1 1 1 2 4 4 4 4 1 1 $ROW 2
    1 1 1 1 1 1 4 4 4 4 4 4 4 11 1 $ROW 3
     1 1 1 1 1 4 4 4 4 4 4 4 4 1 $ROW 4
     1 1 1 1 4 4 4 4 9 4 4 4 4 10 1 $ROW 5
      1 1 1 4 4 4 4 4 4 4 4 4 4 1 $ROW 6
      1 1 4 4 4 4 4 4 4 4 4 4 4 1 $ROW 7
       1 1 4 4 4 7 4 5 4 6 4 4 4 1 1 $ROW 8
       1 4 4 4 4 4 4 4 4 4 4 4 4 1 1 $ROW 9
        1 4 2 2 4 4 4 4 4 4 4 4 1 1 1 $ROW 10
        1 4 2 4 4 8 4 4 4 4 4 1 1 1 1 $ROW 11
```

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         1 4 4 4 4 4 4 4 4 4 1 1 1 1 1 $ROW 12
         1 4 4 4 4 4 4 4 4 4 1 1 1 1 1 1 $ROW 13
          1 1 4 4 4 4 4 4 1 1 1 1 1 1 1 1 $ROW 14
          1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 $ROW 15
c ------------------------------------------------------------------------
c UNIVERSE 1: Solid Grid Plate and Water
10001 2 -1.0   402 u=1 $ H2O > UPPER GRID PLATE
10002 6 -2.7 -402 403 u=1 $ UPPER GRID PLATE AL
10003 2 -1.0 -403 422 u=1 $ H2O BETWEEN GRID PLATES
10004 6 -2.7 -422 423 u=1 $ LOWER GRID PLATE AL
10005 2 -1.0   -423 u=1 $ H2O < LOWER GRID PLATE
c UNIVERSE 2: Water Holes
20001 2 -1.0      402 u=2 $ H2O > UPPER GRID PLATE
20002 2 -1.0 -319 -402 403 u=2 $ H2O UPPER GRID
20003 6 -2.7 319 -402 403 u=2 $ UPPER GRID PLATE AL
20004 22 -1.0   -403 422 u=2 $ H2O BETWEEN GRID PLATE
20005 6 -2.7 309 -422 423 u=2 $ LOWER GRID PLATE AL
20006 2 -1.0 -309 -422 423 u=2 $ LOWER GRID PLATE H2O
20007 2 -1.0     -423 u=2 $ H2O < LOWER GRID PLATE
c UNIVERSE 3: Graphite Element
30001 2 -1.0       (317:401:424) 402 u=3 $ H2O > UPPER GRID PLATE
30002 2 -1.0  (317:401:424) -319 -402 403 u=3 $ H2O UPPER GRID
30003 6 -2.7          319 -402 403 u=3 $ UPPER GRID PLATE AL
30004 22 -1.0     (317:401:424) -403 422 u=3 $ H2O INSIDE GRID PLATE
30005 55 -1.6         -316 -404 420 u=3 $ GRAPHITE
30006 6 -2.7          309 -422 423 u=3 $ LOWER GRID PLATE AL
30007 2 -1.0    (317:424) -309 -422 423 u=3 $ LOWER GRID PLATE H2O
30008 2 -1.0       (317:401:424) -423 u=3 $ H2O < LOWER GRID PLATE
30009 6 -2.7 -317 -401 -424#(-316 -404 420) u=3 $ CLADDING
c UNIVERSE 4: Fuel Element
40001 2 -1.0      (317:401:424) 402 u=4 $ H2O > UPPER GRID PLATE
40002 22 -1.0 (317:401:424) -319 -402 403 u=4 $ H2O AROUND UPPER GRID PLATE
40003 6 -2.7        319 -402 403 u=4 $ UPPER GRID PLATE AL
40004 22 -1.0     (317:401) -403 406 u=4 $ H2O ABOVE FUEL
40005 8 -0.001225     -316 -404 405 u=4 $ AIR BELOW PLUG
40006 8 -0.001225   315 -316 -405 406 u=4 $ AIR ABOVE FUEL
40007 55 -1.6        -315 -405 406 u=4 $ UPPER GRAPHITE
40008 4  0.0858    316 -317 -404 406 u=4 $ UPPER CLADDING
40009 4  0.0858      -317 -401 404 u=4 $ UPPER FLUTES
40010 8 -0.001225   315 -316 -413 420 u=4 $ AIR BELOW FUEL
40011 4  0.0858    316 -317 -413 420 u=4 $ LOWER CLADDING
40012 22 -1.0     (317:424) -413 422 u=4 $ H2O BELOW FUEL
40013 6 -2.7        309 -422 423 u=4 $ LOWER GRID PLATE AL
40014 2 -1.0   (317:424) -309 -422 423 u=4 $ LOWER GRID PLATE H2O
40015 2 -1.0     (317:401:424) -423 u=4 $ H2O < LOWER GRID PLATE
```

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40016 4  0.0858      -317 -424 -420 u=4 $ LOWER FLUTES
40017 10 -10.3        -315 -413 414 u=4 $ MOLY DISK
40018 55 -1.6        -315 -414 420 u=4 $ LOWER GRAPHITE
c Portion of Fuel Element in Axial Fuel Meat Region (Universe 21 above)
40019 22 -1.0      317 -406 413 u=4 $ H2O
40020 4 0.0858  316 -317 -406 413 u=4 $ CLADDING
40021 3 0.0408    -301 -406 413 u=4 $ ZIRC FILL ROD
40022 1 -5.85   -316 301 -406 407 u=4 $ FUEL SLUG 1
40023 1 -5.85   -316 301 -407 411 u=4 $ FUEL SLUG 2
40024 1 -5.85   -316 301 -411 413 u=4 $ FUEL SLUG 3
c UNIVERSE 5: Central Thimble
50001 2 -1.0   318 402 u=5 $ H2O > UPPER GRID PLATE
50002 6 -2.7 318 -402 403 u=5 $ UPPER GRID PLATE AL
50003 22 -1.0 318 -403 422 u=5 $ H2O BETWEEN GRID PLATE
50004 6 -2.7 318 -422 423 u=5 $ LOWER GRID PLATE AL
50005 22 -1.0    -313 2 u=5 $ H2O in thimble
50006 6 -2.7  313 -318 2 u=5 $ Thimble (aluminum)
50007 2 -1.0  318 -423 2 u=5 $ H2O < LOWER GRID PLATE
c UNIVERSE 6, Transient Rod
60001 2 -1.0      (309:601:-607) 402 u=6 $ H2O > UPPER GRID
60002 22 -1.0 (309:601:-607) -319 -402 403 u=6 $ H2O IN UPPER GRID
60003 6 -2.7         319 -402 403 u=6 $ UPPER GRID PLATE AL
60004 22 -1.0   (309:601:-607) -403 422 u=6 $ H2O BETWEEN GRIDS
60005 22 -1.0 (309:601:-607) -319 -422 423 u=6 $ H2O IN LOWER GRID
60006 6 -2.7         319 -422 423 u=6 $ LOWER GRID PLATE AL
60007 2 -1.0     (309:601:-607) -423 u=6 $ H2O < LOWER GRID
60008 6 -2.7   308 -309 -601 607 u=6 $ CLADDING
60009 6 -2.7     -308 -601 602 u=6 $ element clad
60010 6 -2.7     -308 -602 603 u=6 $ spacer plug
60011 9 -2.48     -307 -603 604 u=6 $ absorber
60012 8 -0.001225 307 -308 -603 604 u=6 $ air around absorber
60013 6 -2.7     -308 -604 605 u=6 $ spacer plug
60014 8 -0.001225   -308 -605 606 u=6 $ air follower
60015 6 -2.7     -308 -606 607 u=6 $ end plug
c UNIVERSE 7: Fuel Follower Control Rod, Regulating Rod
70001 2 -1.0      (314:701:-714) 402 u=7 $ H2O > UPPER GRID
70002 22 -1.0 (314:701:-714) -319 -402 403 u=7 $ H2O IN UPPER GRID
70003 6 -2.7         319 -402 403 u=7 $ UPPER GRID PLATE AL
70004 22 -1.0    (314:701:-714) -403 422 u=7 $ H2O BETWEEN GRIDS
70005 22 -1.0 (314:701:-714) -319 -422 423 u=7 $ H2O IN LOWER GRID
70006 6 -2.7         319 -422 423 u=7 $ LOWER GRID PLATE AL
70007 2 -1.0      (314:701:-714) -423 u=7 $ H2O < LOWER GRID
70008 4 0.0858    -312 -701 702 u=7 $ end plug
70009 8 -0.001225   -312 -702 703 u=7 $ top space
70010 4 0.0858    -312 -703 704 u=7 $ spacer plug
```

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70011 8 -0.001225   -312 -704 705 u=7 $ void gap
70012 9 -2.48     -311 -705 706 u=7 $ absorber
70023 8 -0.001225 311 -312 -705 706 u=7 $ air around absorber
70013 4 0.0858    -312 -706 707 u=7 $ spacer plug
70014 8 -0.001225   -312 -707 708 u=7 $ void gap
c **  fuel  **
70015 9948 -6.0124 -312 301 -708 709 vol=106.41 u=7 $ Fuel Slug 1
70016 9948 -6.0124 -312 301 -709 710 vol=106.41 u=7 $ Fuel Slug 2
70017 9948 -6.0124 -312 301 -710 711 vol=106.41 u=7 $ Fuel Slug 3
c ** end fuel **
70018 3 0.0408   -301 -708 711 u=7 $ Zr rod
70019 4 0.0858   -312 -711 712 u=7 $ spacer plug
70020 8 -0.001225  -312 -712 713 u=7 $ bottom void
70021 4 0.0858   -312 -713 714 u=7 $ end plug
70022 4 0.0858 312 -314 -701 714 u=7 $ element clad
c UNIVERSE 8: Fuel Follower Control Rod, Shim 1 Rod
80001 2 -1.0      (314:801:-814) 402 u=8 $ H2O > UPPER GRID
80002 22 -1.0 (314:801:-814) -319 -402 403 u=8 $ H2O IN UPPER GRID
80003 6 -2.7         319 -402 403 u=8 $ UPPER GRID PLATE AL
80004 22 -1.0    (314:801:-814) -403 422 u=8 $ H2O BETWEEN GRIDS
80005 22 -1.0 (314:801:-814) -319 -422 423 u=8 $ H2O IN LOWER GRID
80006 6 -2.7         319 -422 423 u=8 $ LOWER GRID PLATE AL
80007 2 -1.0      (314:801:-814) -423 u=8 $ H2O < LOWER GRID
80008 4 0.0858    -312 -801 802 u=8 $ end plug
80009 8 -0.001225   -312 -802 803 u=8 $ top space
80010 4 0.0858    -312 -803 804 u=8 $ spacer plug
80011 8 -0.001225   -312 -804 805 u=8 $ void gap
80012 9  -2.48    -311 -805 806 u=8 $ absorber
80023 8 -0.001225 311 -312 -805 806 u=8 $ air around absorber
80013 4 0.0858    -312 -806 807 u=8 $ spacer plug
80014 8 -0.001225   -312 -807 808 u=8 $ void gap
c **  fuel  **
80015 9946 -6.0124 -312 301 -808 809 vol=106.41 u=8 $ Fuel Slug 1
80016 9946 -6.0124 -312 301 -809 810 vol=106.41 u=8 $ Fuel Slug 2
80017 9946 -6.0124 -312 301 -810 811 vol=106.41 u=8 $ Fuel Slug 3
c ** end fuel **
80018 3 0.0408   -301 -808 811 u=8 $ Zr rod
80019 4 0.0858   -312 -811 812 u=8 $ spacer plug
80020 8 -0.001225  -312 -812 813 u=8 $ bottom void
80021 4 0.0858   -312 -813 814 u=8 $ end plug
80022 4 0.0858 312 -314 -801 814 u=8 $ element cladding
c UNIVERSE 9: Fuel Follower Control Rod, Shim 2 Rod
90001 2 -1.0      (314:901:-914) 402 u=9 $ H2O > UPPER GRID
90002 22 -1.0 (314:901:-914) -319 -402 403 u=9 $ H2O IN UPPER GRID
90003 6 -2.7         319 -402 403 u=9 $ UPPER GRID PLATE AL
```

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90004 22 -1.0    (314:901:-914) -403 422 u=9 $ H2O BETWEEN GRIDS
90005 22 -1.0 (314:901:-914) -319 -422 423 u=9 $ H2O IN LOWER GRID
90006 6 -2.7         319 -422 423 u=9 $ LOWER GRID PLATE AL
90007 2 -1.0      (314:901:-914) -423 u=9 $ H2O < LOWER GRID
90008 4 0.0858    -312 -901 902 u=9 $ end plug
90009 8 -0.001225   -312 -902 903 u=9 $ top space
90010 4 0.0858    -312 -903 904 u=9 $ spacer plug
90011 8 -0.001225   -312 -904 905 u=9 $ void gap
90012 9  -2.48    -311 -905 906 u=9 $ absorber
90023 8 -0.001225 311 -312 -905 906 u=9 $ air around absorber
90013 4 0.0858    -312 -906 907 u=9 $ spacer plug
90014 8 -0.001225   -312 -907 908 u=9 $ void gap
c ** fuel  **
90015 9947 -6.0124 -312 301 -908 909 vol=106.41 u=9 $ Fuel Slug 1
90016 9947 -6.0124 -312 301 -909 910 vol=106.41 u=9 $ Fuel Slug 2
90017 9947 -6.0124 -312 301 -910 911 vol=106.41 u=9 $ Fuel Slug 3
c ** end fuel **
90018 3 0.0408   -301 -908 911 u=9 $ Zr rod
90019 4 0.0858   -312 -911 912 u=9 $ spacer plug
90020 8 -0.001225  -312 -912 913 u=9 $ bottom void
90021 4 0.0858   -312 -913 914 u=9 $ end plug
90022 4 0.0858 312 -314 -901 914 u=9 $ element clad
c UNIVERSE 10: Pneumatic Tube
100001 2 -1.0         402 u=10 $ H2O > UPPER GRID PLATE
100002 6 -2.7     319 -402 403 u=10 $ UPPER GRID PLATE AL
100003 22 -1.0     319 -403 422 u=10 $ H2O BETWEEN GRID PLATE
100004 6 -2.7     319 -422 423 u=10 $ LOWER GRID PLATE AL
100005 2 -1.0         -423 u=10 $ H2O < LOWER GRID PLATE
c Use 100006-100014 if modeling unlined rabbit
100006 6 -2.7 302 -303 -402 412 u=10 $ Pneumatic Tube top (aluminum)
100007 2 -1.0 303 -319 -402 412 u=10 $ Pneumatic Tube top (water)
100008 6 -2.7   -303 -412 417 u=10 $ Pneumatic Tube middle (aluminum)
100009 2 -1.0 303 -319 -412 417 u=10 $ Pneumatic Tube middle (water)
100010 6 -2.7   -310 -417 419 u=10 $ Pneumatic Tube connecting tube (aluminum)
100011 2 -1.0 310 -319 -417 419 u=10 $ Pneumatic Tube connecting tube (water)
100012 6 -2.7   -303 -419 423 u=10 $ Pneumatic Tube bottom (aluminum)
100013 2 -1.0 303 -319 -419 423 u=10 $ Pneumatic Tube bottom (water)
100014 8 -0.001225 -302 -402 412 u=10 $ Air in Tube
c Use 100006-100023 if modeling cadmium rabbit
c 100006 6 -2.7   302 -303 -402 412 u=10 $ Pneumatic Tube top (aluminum)
c 100007 8 -0.001225   -302 -402 412 u=10 $ Air in Tube
c 100008 20 -8.65  303 -304 -402 412 u=10 $ Cadmium double wrap
c 100009 8 -0.001225 304 -306 -402 412 u=10 $ Air between cadmium and outer tube
c 100010 6 -2.7   306 -310 -402 412 u=10 $ Pneumatic Tube (aluminum)
c 100011 22 -1.0   310 -319 -402 412 u=10 $ Pneumatic Tube top (water)
```

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c 100012 6 -2.7     -310 -412 415 u=10 $ Pneumatic Tube middle (aluminum)
c 100013 22 -1.0   310 -319 -412 415 u=10 $ Pneumatic Tube middle (water)
c 100014 20 -8.65     -302 -415 416 u=10 $ Pneumatic Tube Cd discs (cadmium)
c 100015 6 -2.7   302 -303 -415 416 u=10 $ Pneumatic Tube Cd discs (aluminum)
c 100016 22 -1.0   303 -319 -415 416 u=10 $ Pneumatic Tube Cd discs (water)
c 100017 6 -2.7     -316 -416 417 u=10 $ Pneumatic Tube middle (aluminum)
c 100018 22 -1.0   316 -319 -416 417 u=10 $ Pneumatic Tube middle (water)
c 100019 6 -2.7     -310 -417 419 u=10 $ Pneumatic Tube connecting tube (aluminum)
c 100020 22 -1.0   310 -319 -417 419 u=10 $ Pneumatic Tube connecting tube (water)
c 100021 6 -2.7     -316 -419 423 u=10 $ Pneumatic Tube bottom (aluminum)
c 100022 22 -1.0   316 -319 -419 423 u=10 $ Pneumatic Tube bottom (water)
c 100023 8 -0.001225   -302 -402 412 u=10 $ Air in Tube
c UNIVERSE 11: Source
110001 2 -1.0        402 u=11 $ H2O > UPPER GRID PLATE
110002 6 -2.7    319 -402 403 u=11 $ UPPER GRID PLATE AL
110003 22 -1.0    319 -403 422 u=11 $ H2O BETWEEN GRID PLATE
110004 22 -1.0 316 -319 -402 422 u=11 $ Water around source
110005 6 -2.7    309 -422 423 u=11 $ LOWER GRID PLATE AL
110006 2 -1.0   -309 -422 423 u=11 $ LOWER GRID PLATE AL
110007 2 -1.0        -423 u=11 $ H2O < LOWER GRID PLATE
110008 6 -2.7   -316 -402 408 u=11 $ Source Holder top (aluminum)
110009 6 -2.7 305 -316 -408 410 u=11 $ Source Holder middle (aluminum)
110010 8 -0.001225 -305 -408 410 u=11 $ Air in Tube (source)
110011 6 -2.7   -316 -410 421 u=11 $ Source Holder (bottom)
110012 22 -1.0   -316 -421 422 u=11 $ Water under source
c ************************* END UNIVERSES **************************
c ************************ BEGIN SURFACES ******************************
c UNIVERSE BOUNDS
1   pz 80
2   pz -80
3   px  0
4   py  0
5   cz 90  $ Reactor Pool
6   cz 53.34 $ Reflector outer radius (42" OD)
c HEXAGONAL LATTICE CELL GEOMETRY, pitch (1.714 in.)
101    px 2.17678
102    px -2.17678
103  1 py 2.17678
104  1 py -2.17678
105  2 px 2.17678
106  2 px -2.17678
c HEXAGONAL SHROUD
201   rhp 0 0 -100 0 0 200 27.78125 0 0
202   rhp 0 0 -100 0 0 200 27.305 0 0
203  1 rhp 0 0 -100 0 0 200 26.43188 0 0
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204  1 rhp 0 0 -100 0 0 200 25.95563 0 0
c Cylindrical Surfaces
301 cz 0.3175 $ Fuel inner radius/Zr fill rod (0.25 in. ID)
302 cz 0.86995 $ Rabbit ID (0.685 in. ID)
303 cz 1.11125 $ Rabbit OD (7/8 in. OD)
304 cz 1.21285 $ Cadmium in Rabbit OD (0.02 in thick double wrapped)
305 cz 1.245  $ Source cavity OD (0.981 in., per Maintenance Manual)
306 cz 1.4224 $ Cadmium Rabbit ID (1.12 in)
307 cz 1.50749 $ Transient Rod - OD of absorber (1.187 in. ID)
308 cz 1.51638 $ Transient Rod - clad inner surface (0.028 in. wall)
309 cz 1.5875 $ Transient Rod - clad outer surface (1.25 in. OD)
310 cz 1.5875 $ Cadmium Rabbit OD (1.25 in)
311 cz 1.651  $ FFCR - OD of absorber (1.300 in. ID)
312 cz 1.6637 $ FFCR - clad inner surface (0.02 in. wall, 1.31 in. ID)
313 cz 1.69  $ Central Thimble ID (1.33 in. ID)
314 cz 1.7145 $ FFCR - clad outer surface (1.35 in. OD)
315 cz 1.8161 $ Fuel graphite reflector radius (1.43 in. OD)
316 cz 1.82245 $ Fuel Meat outer radius (1.435 in. OD)
317 cz 1.87325 $ Fuel Cladding outer radius (1.475 in. OD)
318 cz 1.905  $ Central Thimble OD (1.5 in. OD)
319 cz 1.91135 $ Grid Plate penetrations (1.505 in. top)
320 cz 36.35375 $ RSR cavity outer ring (28 5/8" OD)
c Core Axial Surfaces
401  k/z 0 0 34.2792 0.25 -1 $ upper cone
402  pz 32.385 $ Upper grid plate, top (0.62 in. thick, 12.75 in. from midplane)
403  pz 30.8102 $ Upper grid plate, bottom (and top of reflector can)
404  pz 26.924 $ Bottom of top end fitting (0.5 in. air gap = 1.27 cm)
405  pz 25.654 $ Top of upper graphite slug (2.6 in. = 6.604 cm)
406  pz 19.05  $ Upper graphite slug bottom/upper fuel slug top
407  pz  6.35  $ Fuel upper slug bottom/middle slug top
408  pz  3.81  $ Top of source cavity
409  pz  3.334 $ Bottom of rotating rack (27.4 cm deep)
410  pz -3.81  $ Bottom of source cavity (3 in. cavity)
411  pz -6.35  $ Fuel middle slug bottom/lower slug top
412  pz -18.7182 $ Top of Rabbit shock absorber
413  pz -19.05  $ Fuel Bottom
414  pz -19.13  $ Moly disk/top of lower graphite slug (1/32 in. = 0.08 cm)
415  pz -21.2582 $ Top of Cd Rabbit discs
416  pz -21.309 $ Bottom of Cd Rabbit discs (0.0508 cm thick)
417  pz -23.849 $ Rabbit terminus connecting tube (1.25" OD portion)
418  pz -27.94  $ Bottom of reflector can (8.25 in. from bp center at -6.985 cm)
419  pz -28.0215 $ Rabbit terminus lower end (1.45" OD, 5.2275" long)
420  pz -28.528 $ Bottom of lower graphite/plug top (3.7 in. = 9.398 cm)
421  pz -31.979 $ Bottom of source holder (0.5 in. above lower grid plate)
422  pz -33.1724 $ Lower grid plate, top (1.25 in. thick, 13.06 in. from midplane)
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423  pz -36.3474 $ Lower grid plate, bottom
424  k/z 0 0 -36.1489 0.25 1 $ lower cone
c Beam Port Surfaces
501  c/x 35.2425 -6.985 7.70255 $ Tangential thru beam port bp1/5
502  c/x 35.2425 -6.985 8.41375 $ Tangential thru beam port bp1/5
503  10 cy 7.70255 $ Tangential beam port, bp2
504  10 cy 8.41375 $ Tangential beam port, bp2
505  3 py -12.621 $ Tangential beam port, bp2
506  c/y 0 -6.985 7.70255 $ Radial penetrating beam port, bp3
507  c/y 0 -6.985 8.41375 $ Radial penetrating beam port, bp3
508  11 cy 7.70255 $ Radial beam port, bp4
509  11 cy 8.41375 $ Radial beam port, bp4
c Lazy Susan (1.0" OD tubes, 0.058" wall thickness, 13.156" to tube center)
1301 c/z  0      33.41624   1.12268 $ lazy susan rack position 01
1302 c/z  5.227451628 33.00483063 1.12268 $ lazy susan rack position 02
1303 c/z 10.32618605  31.7807328  1.12268 $ lazy susan rack position 03
1304 c/z 15.1706555  29.77408785 1.12268 $ lazy susan rack position 04
1305 c/z 19.64157306  27.03430605 1.12268 $ lazy susan rack position 05
1306 c/z 23.62884991  23.62884991 1.12268 $ lazy susan rack position 06
1307 c/z 27.03430605  19.64157306 1.12268 $ lazy susan rack position 07
1308 c/z 29.77408785  15.1706555  1.12268 $ lazy susan rack position 08
1309 c/z 31.7807328  10.32618605 1.12268 $ lazy susan rack position 09
1310 c/z 33.00483063  5.227451628 1.12268 $ lazy susan rack position 10
1311 c/z 33.41624    0      1.12268 $ lazy susan rack position 11
1312 c/z 33.00483063  -5.227451628 1.12268 $ lazy susan rack position 12
1313 c/z 31.7807328  -10.32618605 1.12268 $ lazy susan rack position 13
1314 c/z 29.77408785 -15.1706555  1.12268 $ lazy susan rack position 14
1315 c/z 27.03430605 -19.64157306 1.12268 $ lazy susan rack position 15
1316 c/z 23.62884991 -23.62884991 1.12268 $ lazy susan rack position 16
1317 c/z 19.64157306 -27.03430605 1.12268 $ lazy susan rack position 17
1318 c/z 15.1706555  -29.77408785 1.12268 $ lazy susan rack position 18
1319 c/z 10.32618605 -31.7807328  1.12268 $ lazy susan rack position 19
1320 c/z  5.227451628 -33.00483063 1.12268 $ lazy susan rack position 20
1321 c/z  0      -33.41624   1.12268 $ lazy susan rack position 21
1322 c/z -5.227451628 -33.00483063 1.12268 $ lazy susan rack position 22
1323 c/z -10.32618605 -31.7807328  1.12268 $ lazy susan rack position 23
1324 c/z -15.1706555  -29.77408785 1.12268 $ lazy susan rack position 24
1325 c/z -19.64157306 -27.03430605 1.12268 $ lazy susan rack position 25
1326 c/z -23.62884991 -23.62884991 1.12268 $ lazy susan rack position 26
1327 c/z -27.03430605 -19.64157306 1.12268 $ lazy susan rack position 27
1328 c/z -29.77408785 -15.1706555  1.12268 $ lazy susan rack position 28
1329 c/z -31.7807328  -10.32618605 1.12268 $ lazy susan rack position 29
1330 c/z -33.00483063  -5.227451628 1.12268 $ lazy susan rack position 30
1331 c/z -33.41624    0      1.12268 $ lazy susan rack position 31
1332 c/z -33.00483063  5.227451628 1.12268 $ lazy susan rack position 32
```

```
1333 c/z -31.7807328  10.32618605 1.12268 $ lazy susan rack position 33
1334 c/z -29.77408785  15.1706555  1.12268 $ lazy susan rack position 34
1335 c/z -27.03430605  19.64157306 1.12268 $ lazy susan rack position 35
1336 c/z -23.62884991  23.62884991 1.12268 $ lazy susan rack position 36
1337 c/z -19.64157306  27.03430605 1.12268 $ lazy susan rack position 37
1338 c/z -15.1706555  29.77408785 1.12268 $ lazy susan rack position 38
1339 c/z -10.32618605  31.7807328  1.12268 $ lazy susan rack position 39
1340 c/z -5.227451628 33.00483063 1.12268 $ lazy susan rack position 40
c Lazy Susan Sample Tube Cladding (1" diameter holes and 0.058" wall thickness)
1341 c/z  0      33.41624   1.27 $ lazy susan rack position 01
1342 c/z  5.227451628 33.00483063 1.27 $ lazy susan rack position 02
1343 c/z 10.32618605  31.7807328  1.27 $ lazy susan rack position 03
1344 c/z 15.1706555  29.77408785 1.27 $ lazy susan rack position 04
1345 c/z 19.64157306  27.03430605 1.27 $ lazy susan rack position 05
1346 c/z 23.62884991  23.62884991 1.27 $ lazy susan rack position 06
1347 c/z 27.03430605  19.64157306 1.27 $ lazy susan rack position 07
1348 c/z 29.77408785  15.1706555  1.27 $ lazy susan rack position 08
1349 c/z 31.7807328  10.32618605 1.27 $ lazy susan rack position 09
1350 c/z 33.00483063  5.227451628 1.27 $ lazy susan rack position 10
1351 c/z 33.41624    0      1.27 $ lazy susan rack position 11
1352 c/z 33.00483063  -5.227451628 1.27 $ lazy susan rack position 12
1353 c/z 31.7807328  -10.32618605 1.27 $ lazy susan rack position 13
1354 c/z 29.77408785 -15.1706555  1.27 $ lazy susan rack position 14
1355 c/z 27.03430605 -19.64157306 1.27 $ lazy susan rack position 15
1356 c/z 23.62884991 -23.62884991 1.27 $ lazy susan rack position 16
1357 c/z 19.64157306 -27.03430605 1.27 $ lazy susan rack position 17
1358 c/z 15.1706555  -29.77408785 1.27 $ lazy susan rack position 18
1359 c/z 10.32618605 -31.7807328  1.27 $ lazy susan rack position 19
1360 c/z  5.227451628 -33.00483063 1.27 $ lazy susan rack position 20
1361 c/z  0      -33.41624   1.27 $ lazy susan rack position 21
1362 c/z -5.227451628 -33.00483063 1.27 $ lazy susan rack position 22
1363 c/z -10.32618605 -31.7807328  1.27 $ lazy susan rack position 23
1364 c/z -15.1706555  -29.77408785 1.27 $ lazy susan rack position 24
1365 c/z -19.64157306 -27.03430605 1.27 $ lazy susan rack position 25
1366 c/z -23.62884991 -23.62884991 1.27 $ lazy susan rack position 26
1367 c/z -27.03430605 -19.64157306 1.27 $ lazy susan rack position 27
1368 c/z -29.77408785 -15.1706555  1.27 $ lazy susan rack position 28
1369 c/z -31.7807328  -10.32618605 1.27 $ lazy susan rack position 29
1370 c/z -33.00483063  -5.227451628 1.27 $ lazy susan rack position 30
1371 c/z -33.41624    0      1.27 $ lazy susan rack position 31
1372 c/z -33.00483063  5.227451628 1.27 $ lazy susan rack position 32
1373 c/z -31.7807328  10.32618605 1.27 $ lazy susan rack position 33
1374 c/z -29.77408785  15.1706555  1.27 $ lazy susan rack position 34
1375 c/z -27.03430605  19.64157306 1.27 $ lazy susan rack position 35
1376 c/z -23.62884991  23.62884991 1.27 $ lazy susan rack position 36
```

```
1377 c/z -19.64157306  27.03430605 1.27 $ lazy susan rack position 37
1378 c/z -15.1706555  29.77408785 1.27 $ lazy susan rack position 38
1379 c/z -10.32618605  31.7807328  1.27 $ lazy susan rack position 39
1380 c/z -5.227451628 33.00483063 1.27 $ lazy susan rack position 40
c Lazy Susan Axial Planes from top to bottom
1381 pz 13.334 $ 10 cm above the bottom of the lazy susan
1382 pz 12.334 $ 9 cm above the bottom of the lazy susan
1383 pz 11.334 $ 8 cm above the bottom of the lazy susan
1384 pz 10.334 $ 7 cm above the bottom of the lazy susan
1385 pz 9.334 $ 6 cm above the bottom of the lazy susan
1386 pz 8.334 $ 5 cm above the bottom of the lazy susan
1387 pz 7.334 $ 4 cm above the bottom of the lazy susan
1388 pz 6.334 $ 3 cm above the bottom of the lazy susan
1389 pz 5.334 $ 2 cm above the bottom of the lazy susan
1390 pz 4.334 $ 1 cm above the bottom of the lazy susan
c Control element surfaces
c Transient Rod (688 units, 72.4% withdrawn)
601 pz 50.452 $ Control element - element plug, end (0.5 in. plug)
602 pz 49.182 $ Control element - magneform plug, upper (1 in. magneform)
603 pz 46.642 $ Control element - top of absorber (15 in. absorber)
604 pz 8.542 $ Control element - bottom of absorber
605 pz 6.002 $ Control element - magneform plug, lower (1 in. double magneform)
606 pz -44.163 $ Control element - air follower section (19.75 in. void)
607 pz -45.433 $ Control element - element plug, end (0.5 in. plug)
c
c Regulating Rod (684 units, 72.0% withdrawn)
701 pz 60.77 $ Control element - element plug, end (1.5 in. plug)
702 pz 56.96 $ Control element - void gap (3.5 in. gap)
703 pz 48.07 $ Control element - magneform plug, upper (0.5 in. magneform)
704 pz 46.8 $ Control element - void gap (1/8 in. gap)
705 pz 46.482 $ Control element - top of absorber (15 in. absorber)
706 pz 8.382 $ Control element - bottom of absorber
707 pz 7.112 $ Control element - magneform plug, lower (0.5 in. magneform)
708 pz 6.477 $ Control element - void gap/top of fuel (0.25 in. gap)
709 pz -6.223 $ Bottom of top fuel slug
710 pz -18.923 $ Bottom of middle fuel slug
711 pz -31.623 $ Bottom of bottom fuel slug
712 pz -34.163 $ Control element - magneform (1 in. double magneform)
713 pz -47.816 $ Control element - void gap (5 3/8 in. gap)
714 pz -49.086 $ Control element - element plug, end (0.5 in. plug)
c
c Shim 1 Rod (684 units, 72.0% withdrawn)
801 pz 60.77 $ Control element - element plug, end (1.5 in. plug)
802 pz 56.96 $ Control element - void gap (3.5 in. gap)
803 pz 48.07 $ Control element - magneform plug, upper (0.5 in. magneform)
```

```
804 pz 46.8 $ Control element - void gap (1/8 in. gap)
805 pz 46.482 $ Control element - top of absorber (15 in. absorber)
806 pz 8.382 $ Control element - bottom of absorber
807 pz 7.112 $ Control element - magneform plug, lower (0.5 in. magneform)
808 pz 6.477 $ Control element - void gap/top of fuel (0.25 in. gap)
809 pz -6.223 $ Bottom of top fuel slug
810 pz -18.923 $ Bottom of middle fuel slug
811 pz -31.623 $ Bottom of bottom fuel slug
812 pz -34.163 $ Control element - magneform (1 in. double magneform)
813 pz -47.816 $ Control element - void gap (5 3/8 in. gap)
814 pz -49.086 $ Control element - element plug, end (0.5 in. plug)
c
c Shim 2 Rod (683 units, 71.9% withdrawn)
901 pz 60.729 $ Control element - element plug, end (1.5 in. plug)
902 pz 56.919 $ Control element - void gap (3.5 in. gap)
903 pz 48.029 $ Control element - magneform plug, upper (0.5 in. magneform)
904 pz 46.759 $ Control element - void gap (1/8 in. gap)
905 pz 46.442 $ Control element - top of absorber (15 in. absorber)
906 pz 8.342 $ Control element - bottom of absorber
907 pz 7.072 $ Control element - magneform plug, lower (0.5 in. magneform)
908 pz 6.437 $ Control element - void gap/top of fuel (0.25 in. gap)
909 pz -6.263 $ Bottom of top fuel slug
910 pz -18.963 $ Bottom of middle fuel slug
911 pz -31.663 $ Bottom of bottom fuel slug
912 pz -34.203 $ Control element - magneform (1 in. double magneform)
913 pz -47.856 $ Control element - void gap (5 3/8 in. gap)
914 pz -49.126 $ Control element - element plug, end (0.5 in. plug)
c ------------------------ END SURFACES ------------------------------

c ************************ BEGIN MATERIAL CARDS *********************
c For coordinate transforms Q1 Q2 Q3 B1 B2 B3 B4 B5 B6 B7 B8 B9 M
c *tr means Bi are angles in degrees rather than cosines of angles
c Q1-Q3 = displacement vector of the transformation
c B1-B9 = rotation matrix of the transformation
c B1=X,X' B2=Y,X' B3=Z,X' B4=X,Y' B5=Y,Y' B6=Z,Y' B7=X,Z' B8=Y,Z' B9=Z,Z'
c M = 1 means displacement vector is in origin of aux coordinate system
*tr1 0 0 0 30 120 90 60 30 90 j j j
*tr2 0 0 0 120 30 90 30 60 90 j j j
*tr3 0 0 0 20 100 90 125 20 90 j j j
*tr10 35.255 6.222 -6.985 150 120 90 60 150 90 j j j
*tr11 -22.871 -13.216 -6.985 75 120 90 60 75 90 j j j
c Note: positive number means atom fraction, negative number means mass fraction
m1  1001.80c  -0.014355 $ UZrH fuel, 5.8 g/cc
   24000 -0.013573 25055.80c -0.0014287 26000 -0.049647
   28000 -0.0067863 92235.80c -0.0152 92238.80c -0.061568
```

```
   40090.80c -0.43706 40091.80c -0.0942 40092.80c -0.14253
   40094.80c -0.14136 40096.80c -0.02228
mt1  h-zr.20t zr-h.30t
c Water that is not heated (rho = 1.0 g/cc)
m2  1001.80c 0.6667 8016.80c 0.3333 $ h2o (always .80c)
mt2  lwtr.20t $ h2o salphabeta card (always .20t)
c Water that is heated
m22  1001.80c 0.6667 8016.80c 0.3333 $ (possibly heated)
mt22 lwtr.21t $ h2o salphabeta card (possibly heated)
c Zirconium $ Zirc Filler, rho = 6.5 g/cc
m3  40090.81c .5145 40091.81c .1122 40092.81c .1715 $ zirconium (possibly heated)
   40094.81c .1738 40096.81c .0280
c Stainless Steel rho = 7.9 g/cc
m4  6000.81c 0.00031519 24050.81c 7.8200E-4 24052.81c 1.4501E-2 $ SS 304 Clad (possibly heated)
   24053.81c 1.6130E-3 24054.81c 3.9400E-4 26054.81c 3.5540E-3
   26056.81c 5.5110E-2 26057.81c 1.2570E-3 26058.81c 1.6600E-4
   28058.81c 5.5580E-3 28060.81c 2.0700E-3 28061.81c 8.8500E-5
   28062.81c 2.7800E-4 28064.81c 6.8500E-5
c Graphite rho = 1.6 g/cc
m5  6000.80c 1 $ Graphite, 1.6 g/cc (always .80c)
mt5  grph.20t
c Graphite rho = 1.6 g/cc
m55  6000.81c 1 $ Graphite, 1.6 g/cc (possibly heated)
mt55  grph.23t
c Aluminum rho = 2.699 g/cc
m6   5010.80c 2.3945E-7 12024.80c 5.3511E-4 12025.80c 6.5030E-5 $ 6061-T6 aluminum (always .80c)
   12026.80c 6.8851E-5 13027.80c 5.9015E-2 14028.80c 3.2153E-4
   14029.80c 1.5771E-5 14030.80c 1.0062E-5 24050.80c 2.6872E-6
   24052.80c 4.9830E-5 24053.80c 5.5435E-6 24054.80c 1.3544E-6
   29063.80c 5.0017E-5 29065.80c 2.1628E-5
m66   5010.81c 2.3945E-7 12024.81c 5.3511E-4 12025.81c 6.5030E-5 $ 6061-T6 aluminum (possibly heated)
   12026.81c 6.8851E-5 13027.81c 5.9015E-2 14028.81c 3.2153E-4
   14029.81c 1.5771E-5 14030.81c 1.0062E-5 24050.81c 2.6872E-6
   24052.81c 4.9830E-5 24053.81c 5.5435E-6 24054.81c 1.3544E-6
   29063.81c 5.0017E-5 29065.81c 2.1628E-5
c Air rho = 0.001205
m8  7014.80c 0.79 8016.80c 0.21 $ air (always .80c)
c Boron Carbide rho = 2.48 (possibly heated)
m9  5010.81c 0.1592 5011.81c 0.6408 6000.81c 0.2
c Molybdenum rho = 10.3 (possibly heated)
m10  42092.81c .1477 42094.81c .0923 42095.81c .159
   42096.81c .1668 42097.81c .0956 42098.81c .2419 42100.81c .0967 $ 9.33 g/cc
c Cadmium rho = 8.65 (possibly heated)
m20  48106.81c 0.0125 48108.81c 0.0089 48110.81c 0.1249 48111.81c 0.1280
   48112.81c 0.2413 48113.81c 0.1222 48114.81c 0.2873 48116.81c 0.0749
```

```
c ------------------- END DATA -----------------
m2902
     92234.81c -3.732E-08
     92235.81c -1.415E-02
     92236.81c -2.815E-04
     92237.81c -4.606E-08
     92238.81c -6.359E-02
     92239.81c -8.307E-09
     93237.81c -1.161E-06
     93239.81c -1.200E-06
     94238.81c -1.591E-08
     94239.81c -1.338E-04
     94240.81c -6.833E-06
     94241.81c -4.314E-07
     94242.81c -8.269E-09
     95241.81c -4.302E-09
     1001.81c -1.599E-02
     1002.81c -1.616E-06
     2004.81c -3.932E-10
     32074.81c -3.872E-10
     32076.81c -1.255E-08
     33075.81c -3.532E-09
     34077.81c -3.245E-08
     34078.81c -8.722E-08
     34079.81c -1.877E-07
     34080.81c -5.485E-07
     34082.81c -1.414E-06
     35081.81c -8.769E-07
     36082.81c -3.513E-10
     36083.81c -2.768E-06
     36084.81c -4.414E-06
     36085.81c -1.183E-06
     36086.81c -9.585E-06
     37085.81c -4.242E-06
     37087.81c -1.191E-05
     38088.81c -1.656E-05
     38089.81c -3.138E-06
     38090.81c -2.712E-05
     39089.81c -1.921E-05
     39090.81c -7.072E-09
     39091.81c -4.651E-06
     40090.81c -4.654E-01
     40091.81c -1.015E-01
     40092.81c -1.551E-01
     40093.81c -3.880E-05
```

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40094.81c -1.572E-01
40095.81c -6.357E-06
40096.81c -2.535E-02
41095.81c -3.693E-06
42092.81c -1.000E-07
42095.81c -2.506E-05
42096.81c -4.291E-08
42097.81c -3.945E-05
42098.81c -3.011E-05
42099.81c -2.616E-08
42100.81c -3.366E-05
43099.81c -3.829E-05
44100.81c -1.713E-07
44101.81c -3.380E-05
44102.81c -2.352E-05
44103.81c -1.823E-06
44104.81c -1.074E-05
44106.81c -1.673E-06
45103.81c -1.533E-05
45105.81c -3.299E-10
46104.81c -2.741E-07
46105.81c -6.667E-06
46106.81c -9.608E-07
46107.81c -1.041E-06
46108.81c -4.444E-07
46110.81c -1.894E-07
47109.81c -2.665E-07
47111.81c -1.400E-09
48110.81c -2.984E-09
48111.81c -1.179E-07
48112.81c -8.473E-08
48113.81c -1.318E-08
48114.81c -1.614E-07
48116.81c -8.505E-08
49115.81c -6.788E-08
50115.81c -2.650E-09
50116.81c -2.953E-09
50117.81c -8.147E-08
50118.81c -7.346E-08
50119.81c -8.330E-08
50120.81c -8.251E-08
50122.81c -1.033E-07
50123.81c -2.921E-09
50124.81c -1.813E-07
50125.81c -1.160E-09
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50126.81c -3.882E-07
51121.81c -8.138E-08
51123.81c -1.011E-07
51125.81c -1.965E-07
52125.81c -2.788E-08
52126.81c -1.431E-08
52128.81c -2.412E-06
52130.81c -1.262E-05
52132.81c -4.343E-08
53127.81c -8.766E-07
53129.81c -4.086E-06
53131.81c -2.553E-07
54128.81c -6.641E-10
54130.81c -1.251E-08
54131.81c -2.488E-05
54132.81c -3.067E-05
54133.81c -2.977E-07
54134.81c -5.637E-05
54136.81c -6.570E-05
55133.81c -5.915E-05
55134.81c -3.175E-07
55135.81c -2.760E-05
55136.81c -2.910E-09
55137.81c -4.462E-05
56134.81c -6.027E-08
56136.81c -7.271E-08
56137.81c -7.057E-07
56138.81c -4.983E-05
56140.81c -1.194E-06
57139.81c -5.742E-05
57140.81c -1.802E-07
58140.81c -4.490E-05
58141.81c -3.799E-06
58142.81c -4.429E-05
58143.81c -1.488E-09
58144.81c -2.445E-05
59141.81c -4.900E-05
59143.81c -1.418E-06
60142.81c -5.272E-08
60143.81c -5.539E-05
60144.81c -1.932E-05
60145.81c -3.639E-05
60146.81c -2.357E-05
60147.81c -3.616E-07
60148.81c -1.328E-05
```

```
     60150.81c -5.276E-06
     61147.81c -1.939E-05
     61148.81c -3.147E-09
     61149.81c -3.202E-09
     62147.81c -4.958E-06
     62148.81c -5.455E-07
     62149.81c -7.043E-07
     62150.81c -1.050E-05
     62151.81c -1.910E-06
     62152.81c -5.103E-06
     62154.81c -6.330E-07
     63151.81c -8.722E-09
     63152.81c -1.355E-09
     63153.81c -1.708E-06
     63154.81c -5.745E-08
     63155.81c -1.939E-07
     63156.81c -1.073E-08
     64152.81c -6.800E-10
     64154.81c -1.346E-09
     64155.81c -6.398E-09
     64156.81c -2.729E-07
     64157.81c -2.725E-09
     64158.81c -9.155E-08
     64160.81c -1.159E-09
     65159.81c -8.985E-09
     60150.81c -1.700E-06
mt2902 h-zr.23t zr-h.33t
…… (OMITTED FOR LENGTH)
ksrc 4.73664 -0.38308 0 $ B1 source
   4.73664 -0.38308 10
   4.73664 -0.38308 -10
   5.15225 -0.79869 0
   5.15225 -0.79869 10
   5.15225 -0.79869 -10
   5.47543 -1.12187 0
   5.47543 -1.12187 10
   5.47543 -1.12187 -10
   2.55986 -4.15244 0 $ B2 source
   2.55986 -4.15244 10
   2.55986 -4.15244 -10
   2.97547 -4.56805 0
   2.97547 -4.56805 10
   2.97547 -4.56805 -10
   3.29865 -4.89123 0
   3.29865 -4.89123 10
```

```
   3.29865 -4.89123 -10
   -2.55986 -4.15244 0 $ B3 source
   -2.55986 -4.15244 10
   -2.55986 -4.15244 -10
   -2.97547 -4.56805 0
   -2.97547 -4.56805 10
   -2.97547 -4.56805 -10
   -3.29865 -4.89123 0
   -3.29865 -4.89123 10
   -3.29865 -4.89123 -10
   -4.73664 -0.38308 0 $ B4 source
   -4.73664 -0.38308 10
   -4.73664 -0.38308 -10
   -5.15225 -0.79869 0
   -5.15225 -0.79869 10
   -5.15225 -0.79869 -10
   -5.47543 -1.12187 0
   -5.47543 -1.12187 10
   -5.47543 -1.12187 -10
   -2.55986 4.15244 0 $ B5 source
   -2.55986 4.15244 10
   -2.55986 4.15244 -10
   -2.97547 4.56805 0
   -2.97547 4.56805 10
   -2.97547 4.56805 -10
   -3.29865 4.89123 0
   -3.29865 4.89123 10
   -3.29865 4.89123 -10
   2.55986 4.15244 0 $ B6 source
   2.55986 4.15244 10
   2.55986 4.15244 -10
   2.97547 4.56805 0
   2.97547 4.56805 10
   2.97547 4.56805 -10
   3.29865 4.89123 0
   3.29865 4.89123 10
   3.29865 4.89123 -10
……(OMITTED FOR LENGTH)
c f4:n (
c   () T
c fm4 -1.2352e04 9488 (-6 -8)  $ energy per cc in W/cc
mode n
kcode 100000 1.0 25 100
imp:n  0 1 1357r
```

APPENDIX B. INPUT DECK FOR NEUTRON SPECTRUM ADJUSTMENT USING LSL-M3 CODE

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

------------------------------------------------------------
-----------------------------------------------
@actv
 1.0e+0   (activities given in bq/nucleus)
NETL_BP15_FF
@end
@description
 ag109g:sld   netl  cdnm  -3.1110E-18   0.019
 ag109g:sld   netl  bare  -1.6450E-17   0.019
 al27a:sld    netl  bare  -2.4890E-19   0.038
 al27p:sld    netl  bahl  -1.1920E-16   0.026
 au197g:sld   netl  cdna  -1.3850E-14   0.015
 au197g:sld   netl  bare  -3.5240E-14   0.015
 co59g:sld    netl  bare  -1.5120E-17   0.024
 co59g:sld    netl  cdnm  -1.0140E-18   0.021
 cu63g:sld    netl  baep  -6.7250E-15   0.025
 cu63g:sld    netl  cdep  -2.5190E-16   0.021
 fe54p:sld    netl  bahl  -5.2800E-20   0.037
 fe56p:sld    netl  bare  -2.2590E-18   0.035
 fe58g:sld    netl  bahl  -2.1730E-17   0.016
 fe58g:sld    netl  cdhl  -1.0680E-18   0.024
 mg24p:sld    netl  bare  -5.4230E-19   0.058
 mn55g:sld    netl  bahl  -9.1370E-14   0.023
 mn55g:sld    netl  cdhl  -3.6910E-15   0.018
 na23g:sld    netl  baep  -5.8116E-16   0.034
 ni58p:sld    netl  bare  -3.8030E-19   0.031  *
 np237f:sld   netl  void  -5.9570E-11   0.022
 rmldu:sld    netl  void  -9.9180E-12   0.016
 rmleu:sld    netl  void  -9.9600E-11   0.022
 rmlpu:sld    netl  void  -1.1180E-10   0.022
 sc45g:sld    netl  bare  -2.5890E-16   0.021
 sc45g:sld    netl  cdnm  -5.9780E-18   0.023
 ti46p:sld    netl  bahl  -2.9900E-20   0.038
 ti47p:sld    netl  baep  -1.2840E-18   0.021
 ti48p:sld    netl  baep  -3.3130E-20   0.013
 w186g:sld    netl  bare  -3.9710E-14   0.018
@end
@posit
0.02
@end
@actcov
@end
@outgrd
= nug89
@end
@trlgrd
= SANDII
@end
@calf
group fluences
 89  1
1.00
@end
@hsty
1,3600
dosimetry position
  10  26  17  00   1.000000E+0  1
```

```
  10  26  17  01   0.000000000  1
  -1  26  17  01   0.000000000  1
@end
@cora
correction file not needed
end
@end
@refflx
REF640 NVSA
@end
@trlflx
= NETL_BP15_FF drr
@end
@covf
new
@end
```

APPENDIX C. LSL FORMAT NEUTRON OUTPUT

```
*cor    (library)    (mat.#)    (temp)k
*number of energies plus 1
   90
*energy grid ( ev )
  1.00000E-04  1.00000E-03  5.00000E-03  1.00000E-02  3.00000E-02  7.00000E-02  1.00000E-01  1.52300E-01
  2.00000E-01  4.14000E-01  6.00000E-01  8.00000E-01  1.12500E+00  3.05900E+00  5.04300E+00  8.31500E+00
  1.37100E+01  2.26000E+01  3.72700E+01  6.14400E+01  1.01300E+02  1.67000E+02  2.75400E+02  3.53600E+02
  4.54000E+02  5.83000E+02  7.48500E+02  9.61100E+02  1.08900E+03  1.23400E+03  1.39800E+03  1.58500E+03
  1.79600E+03  2.03500E+03  2.30600E+03  2.61300E+03  2.96000E+03  3.35500E+03  3.80100E+03  4.30700E+03
  4.88100E+03  5.53100E+03  6.26700E+03  7.10200E+03  8.04700E+03  9.11900E+03  1.03300E+04  1.17100E+04
  1.32700E+04  1.50300E+04  1.70400E+04  1.93000E+04  2.18800E+04  2.47900E+04  2.60600E+04  2.80900E+04
  3.18300E+04  4.08700E+04  5.24800E+04  6.73800E+04  8.65200E+04  1.11100E+05  1.42600E+05  1.83200E+05
  2.35200E+05  3.02000E+05  3.87700E+05  4.39400E+05  4.97900E+05  5.64200E+05  6.39300E+05  7.24400E+05
  8.20800E+05  9.30100E+05  1.05400E+06  1.19400E+06  1.35300E+06  1.73800E+06  2.23100E+06  2.86500E+06
  3.67900E+06  4.72400E+06  6.06500E+06  7.78800E+06  1.00000E+07  1.19100E+07  1.35000E+07  1.49200E+07
  1.69000E+07  2.00000E+07
*number fraction
  1.46960E-04 3.61115E-03 1.11417E-02 9.91305E-02 2.16726E-01 8.68806E-02 6.04209E-02 1.86479E-02
  2.48851E-02 9.52736E-03 6.62370E-03 6.08023E-03 1.36282E-02 6.34473E-03 5.94608E-03 8.75263E-03
  6.61193E-03 9.43349E-03 9.50559E-03 9.44913E-03 6.39837E-03 1.12897E-02 4.80788E-03 4.31306E-03
  3.33328E-03 4.00820E-03 5.08132E-03 2.33103E-03 2.28122E-03 2.51056E-03 2.61557E-03 2.59428E-03
  2.49510E-03 2.41552E-03 2.41855E-03 2.53796E-03 2.70111E-03 2.83393E-03 2.81066E-03 2.78441E-03
  2.95579E-03 2.74707E-03 2.93424E-03 2.98272E-03 3.04237E-03 3.24180E-03 3.29934E-03 3.22314E-03
  3.16168E-03 3.38598E-03 3.37846E-03 3.54918E-03 3.59447E-03 1.39794E-03 2.08321E-03 4.51598E-03
  5.04052E-03 7.66484E-03 8.40328E-03 8.86173E-03 8.04027E-03 1.01989E-02 9.25328E-03 1.08046E-02
  1.26836E-02 1.34228E-02 6.60881E-03 7.49420E-03 7.81484E-03 8.22208E-03 8.66418E-03 8.98356E-03
  8.68417E-03 8.97693E-03 9.53765E-03 9.96735E-03 2.07109E-02 2.00252E-02 1.74585E-02 1.11077E-02
  8.15361E-03 4.75580E-03 2.10513E-03 6.59634E-04 1.12033E-04 2.48045E-05 7.11415E-06 2.48727E-06
  1.09194E-06
*% standard deviation
  1.86845E+02  1.23557E+02  9.45190E+01  4.72384E+01  2.78717E+01  4.84457E+01  5.88239E+01  6.52730E+01
  6.00004E+01  5.60827E+01  4.92803E+01  7.32679E+01  6.78645E+01  1.11650E+01  1.77640E+01  3.60521E+01
  1.60110E+01  3.15998E+01  2.75717E+01  2.56301E+01  1.14960E+01  3.29402E+01  1.94832E+01  3.24160E+01
  4.20053E+01  2.23099E+01  2.60641E+01  3.63886E+01  4.00455E+01  4.45980E+01  4.28475E+01  4.09246E+01
  3.98031E+01  3.88418E+01  3.87095E+01  3.77484E+01  3.76366E+01  3.74813E+01  3.69967E+01  3.55821E+01
  3.50798E+01  3.49294E+01  3.42703E+01  3.41890E+01  3.33659E+01  3.21859E+01  3.17110E+01  3.21640E+01
  3.12030E+01  3.16610E+01  3.04161E+01  2.95437E+01  2.84192E+01  3.01145E+01  2.98196E+01  2.89592E+01
  2.39564E+01  2.31739E+01  2.22304E+01  2.14773E+01  2.06194E+01  2.06999E+01  2.03624E+01  1.97571E+01
  1.96686E+01  1.93099E+01  2.14445E+01  2.12543E+01  2.10384E+01  2.05585E+01  2.01560E+01  1.99723E+01
  1.96078E+01  1.84372E+01  1.91245E+01  1.87062E+01  1.56478E+01  1.42201E+01  1.44951E+01  1.46504E+01
  1.45588E+01  1.36154E+01  1.45504E+01  1.46616E+01  2.20220E+01  2.77532E+01  3.07768E+01  3.38710E+01
  3.59662E+01
*correlation coefficient -- upper triangular
  1.00000E+02  6.83129E+01  4.40379E+01  9.45745E+00 -3.01436E+01 -1.98108E+01 -1.31618E+01 -8.75922E+00
 -2.59556E+00  2.64619E+00  6.42215E+00  1.06365E+01  1.24123E+01  3.64727E+01  2.34273E+01  1.19359E+01
  2.29656E+01  1.32962E+01  1.50356E+01  1.62780E+01  3.55758E+01  1.21161E+01  1.76928E+01  9.46953E+00
  6.26383E+00  1.61450E+01  1.59577E+01  1.14293E+01  1.03864E+01  9.41611E+00  9.79720E+00  1.02532E+01
```

1.04379E+01 1.06985E+01 1.09580E+01 1.16457E+01 1.18041E+01 1.16469E+01 1.14753E+01 1.17177E+01
1.18774E+01 1.19299E+01 1.22535E+01 1.21843E+01 1.25838E+01 1.31471E+01 1.33412E+01 1.30539E+01
1.34467E+01 1.32501E+01 1.37956E+01 1.41951E+01 1.47506E+01 1.39305E+01 1.40657E+01 1.45719E+01
1.75758E+01 1.81573E+01 1.89193E+01 1.95735E+01 2.03772E+01 2.02944E+01 2.06256E+01 2.12493E+01
2.13425E+01 2.17352E+01 1.95941E+01 1.96809E+01 1.98852E+01 2.02693E+01 2.06791E+01 2.08740E+01
2.12693E+01 2.25586E+01 2.16695E+01 2.21720E+01 2.66385E+01 2.94067E+01 2.88415E+01 2.85264E+01
2.87091E+01 3.07049E+01 2.87380E+01 2.85166E+01 1.89722E+01 1.50426E+01 1.35603E+01 1.23169E+01
1.15983E+01
1.00000E+02 7.59332E+01 1.94111E+01 -4.77533E+01 -3.34647E+01 -2.24049E+01 -1.48881E+01 -5.65274E+00
3.05465E+00 9.32097E+00 1.69628E+01 1.97982E+01 5.73300E+01 3.67699E+01 1.87064E+01 3.67307E+01
2.08700E+01 2.36242E+01 2.55210E+01 5.60574E+01 1.89040E+01 2.77290E+01 1.47902E+01 9.96422E+00
2.54236E+01 2.50700E+01 1.78644E+01 1.62253E+01 1.47359E+01 1.54270E+01 1.60512E+01 1.63069E+01
1.67163E+01 1.71918E+01 1.81348E+01 1.84165E+01 1.81923E+01 1.80034E+01 1.84071E+01 1.86585E+01
1.88319E+01 1.91929E+01 1.91408E+01 1.97119E+01 2.06304E+01 2.10254E+01 2.05405E+01 2.11578E+01
2.08492E+01 2.17056E+01 2.23333E+01 2.32059E+01 2.19176E+01 2.21300E+01 2.27809E+01 2.75892E+01
2.85031E+01 2.97003E+01 3.07282E+01 3.19911E+01 3.18613E+01 3.23816E+01 3.33618E+01 3.35084E+01
3.41254E+01 3.06770E+01 3.09496E+01 3.11866E+01 3.18413E+01 3.24848E+01 3.27908E+01 3.33298E+01
3.53260E+01 3.40577E+01 3.48461E+01 4.18149E+01 4.61894E+01 4.53692E+01 4.48758E+01 4.50944E+01
4.82291E+01 4.51392E+01 4.47916E+01 2.98009E+01 2.36290E+01 2.13008E+01 1.93479E+01 1.82192E+01
1.00000E+02 4.00514E+01 -5.94929E+01 -4.57436E+01 -3.17616E+01 -2.29249E+01 -9.94895E+00 1.10089E+00
8.80579E+00 2.00652E+01 2.50316E+01 6.86198E+01 4.38515E+01 2.24166E+01 4.48019E+01 2.49633E+01
2.82298E+01 3.04786E+01 6.73866E+01 2.26503E+01 3.34334E+01 1.80164E+01 1.21794E+01 3.05454E+01
2.99664E+01 2.12854E+01 1.94151E+01 1.75920E+01 1.83974E+01 1.91644E+01 1.95106E+01 1.99113E+01
2.04025E+01 2.14334E+01 2.19116E+01 2.17029E+01 2.15536E+01 2.20069E+01 2.23061E+01 2.24931E+01
2.29248E+01 2.29703E+01 2.35455E+01 2.46051E+01 2.50571E+01 2.46037E+01 2.52535E+01 2.48839E+01
2.59960E+01 2.66589E+01 2.77020E+01 2.61622E+01 2.64160E+01 2.72805E+01 3.29251E+01 3.40173E+01
3.55314E+01 3.67599E+01 3.81886E+01 3.81132E+01 3.87349E+01 3.99062E+01 4.00812E+01 4.08187E+01
3.67161E+01 3.69606E+01 3.72637E+01 3.80666E+01 3.88368E+01 3.91238E+01 3.98675E+01 4.22931E+01
4.07008E+01 4.17230E+01 5.00365E+01 5.52373E+01 5.42399E+01 5.36480E+01 5.39255E+01 5.76751E+01
5.39811E+01 5.35648E+01 3.56357E+01 2.82534E+01 2.54688E+01 2.31330E+01 2.17833E+01
1.00000E+02 -4.52310E+01 -7.58660E+01 -6.12140E+01 -4.74008E+01 -3.05981E+01 -1.35972E+01 -2.12891E+00
2.26486E+01 3.32208E+01 7.20177E+01 4.54975E+01 2.37748E+01 4.89162E+01 2.60999E+01 2.96430E+01
3.19182E+01 7.23959E+01 2.39288E+01 3.60090E+01 1.98660E+01 1.38398E+01 3.27675E+01 3.13165E+01
2.23476E+01 2.03023E+01 1.83621E+01 1.91107E+01 1.99251E+01 2.03797E+01 2.07336E+01 2.11817E+01
2.21106E+01 2.26248E+01 2.26547E+01 2.25612E+01 2.31325E+01 2.33506E+01 2.35367E+01 2.40697E+01
2.40288E+01 2.47211E+01 2.58302E+01 2.62923E+01 2.57322E+01 2.64926E+01 2.60197E+01 2.71860E+01
2.79617E+01 2.90494E+01 2.73678E+01 2.77093E+01 2.85229E+01 3.44428E+01 3.56532E+01 3.71530E+01
3.84367E+01 4.00142E+01 3.98425E+01 4.04905E+01 4.17143E+01 4.18948E+01 4.26677E+01 3.83848E+01
3.86518E+01 3.90603E+01 3.99266E+01 4.06693E+01 4.10623E+01 4.17825E+01 4.43840E+01 4.27419E+01
4.37564E+01 5.24966E+01 5.80241E+01 5.69532E+01 5.63139E+01 5.66206E+01 6.05703E+01 5.67023E+01
5.62583E+01 3.74027E+01 2.97099E+01 2.67822E+01 2.43253E+01 2.29091E+01
1.00000E+02 1.17153E+01 -2.03087E+01 -2.48222E+01 -2.63949E+01 -2.42143E+01 -2.24072E+01 -5.25466E+00
1.97191E-01 -3.83975E+01 -2.54123E+01 -1.24223E+01 -2.46018E+01 -1.44382E+01 -1.63624E+01 -1.76382E+01
-3.52167E+01 -1.33680E+01 -1.96361E+01 -1.04858E+01 -7.35875E+00 -1.76223E+01 -1.69651E+01 -1.20053E+01
-1.09971E+01 -1.00163E+01 -1.05393E+01 -1.09092E+01 -1.11439E+01 -1.14074E+01 -1.15684E+01 -1.20669E+01
-1.21118E+01 -1.19169E+01 -1.18451E+01 -1.23175E+01 -1.24326E+01 -1.25924E+01 -1.28311E+01 -1.28919E+01
-1.31726E+01 -1.36837E+01 -1.38843E+01 -1.37543E+01 -1.41011E+01 -1.39212E+01 -1.45541E+01 -1.48996E+01
-1.55031E+01 -1.47137E+01 -1.48685E+01 -1.53094E+01 -1.84452E+01 -1.90952E+01 -1.98958E+01 -2.05990E+01

-2.14602E+01 -2.14076E+01 -2.17704E+01 -2.24412E+01 -2.26550E+01 -2.30674E+01 -2.06922E+01 -2.07700E+01
-2.09596E+01 -2.13946E+01 -2.16840E+01 -2.17485E+01 -2.21098E+01 -2.32930E+01 -2.22811E+01 -2.28097E+01
-2.72843E+01 -3.02418E+01 -2.97175E+01 -2.94653E+01 -2.96295E+01 -3.16371E+01 -2.95635E+01 -2.93630E+01
-1.96378E+01 -1.56617E+01 -1.41531E+01 -1.28911E+01 -1.21473E+01
 1.00000E+02 6.53332E+01 4.16109E+01 2.18057E+01 7.12774E+00 -2.47378E+00 -1.98316E+01 -2.76667E+01
-7.05840E+01 -4.49208E+01 -2.39261E+01 -4.80762E+01 -2.64890E+01 -2.98962E+01 -3.22016E+01 -7.00836E+01
-2.44052E+01 -3.62970E+01 -1.98030E+01 -1.39775E+01 -3.28556E+01 -3.11903E+01 -2.22308E+01 -2.01864E+01
-1.82494E+01 -1.91073E+01 -1.98839E+01 -2.02419E+01 -2.06264E+01 -2.09082E+01 -2.18603E+01 -2.22476E+01
-2.22835E+01 -2.21391E+01 -2.27372E+01 -2.30939E+01 -2.31879E+01 -2.37441E+01 -2.37054E+01 -2.43807E+01
-2.54433E+01 -2.58174E+01 -2.53843E+01 -2.61822E+01 -2.57096E+01 -2.68385E+01 -2.76424E+01 -2.87344E+01
-2.71135E+01 -2.73853E+01 -2.81932E+01 -3.41147E+01 -3.52718E+01 -3.67498E+01 -3.80304E+01 -3.96018E+01
-3.94670E+01 -4.01204E+01 -4.13418E+01 -4.15318E+01 -4.22937E+01 -3.80199E+01 -3.83578E+01 -3.86317E+01
-3.93966E+01 -4.00622E+01 -4.03118E+01 -4.10387E+01 -4.32884E+01 -4.15756E+01 -4.24766E+01 -5.10877E+01
-5.64792E+01 -5.55159E+01 -5.49636E+01 -5.52973E+01 -5.91025E+01 -5.52813E+01 -5.48758E+01 -3.65857E+01
-2.90762E+01 -2.62369E+01 -2.38579E+01 -2.24721E+01
 1.00000E+02 8.11576E+01 5.11379E+01 2.71427E+01 1.30753E+01 -2.42509E+01 -3.85186E+01 -6.34668E+01
-3.95757E+01 -2.26161E+01 -4.42870E+01 -2.44365E+01 -2.75136E+01 -2.95112E+01 -6.49857E+01 -2.18993E+01
-3.04782E+01 -1.56910E+01 -1.04484E+01 -2.85243E+01 -2.83774E+01 -2.02196E+01 -1.83598E+01 -1.66017E+01
-1.73886E+01 -1.80890E+01 -1.82905E+01 -1.85256E+01 -1.89214E+01 -1.97224E+01 -2.04363E+01 -2.04579E+01
-2.03933E+01 -2.08047E+01 -2.10181E+01 -2.12125E+01 -2.17247E+01 -2.16820E+01 -2.23042E+01 -2.32871E+01
-2.37348E+01 -2.32245E+01 -2.39482E+01 -2.35111E+01 -2.45464E+01 -2.52762E+01 -2.62687E+01 -2.47959E+01
-2.50426E+01 -2.57773E+01 -3.11702E+01 -3.22210E+01 -3.36661E+01 -3.48293E+01 -3.62564E+01 -3.61326E+01
-3.67257E+01 -3.78347E+01 -3.80068E+01 -3.86990E+01 -3.48112E+01 -3.50182E+01 -3.52627E+01 -3.59551E+01
-3.65565E+01 -3.68773E+01 -3.74429E+01 -3.94796E+01 -3.78228E+01 -3.87425E+01 -4.64196E+01 -5.14338E+01
-5.05582E+01 -5.00521E+01 -5.03570E+01 -5.38246E+01 -5.02665E+01 -4.99762E+01 -3.33147E+01 -2.64725E+01
-2.38860E+01 -2.18266E+01 -2.05654E+01
 1.00000E+02 7.18404E+01 4.10566E+01 2.37577E+01 -2.67167E+01 -4.47692E+01 -5.11100E+01 -3.10320E+01
-1.95253E+01 -3.66756E+01 -2.05221E+01 -2.28894E+01 -2.45238E+01 -5.40807E+01 -1.74438E+01 -2.16225E+01
-9.59967E+00 -5.35575E+00 -2.13514E+01 -2.32998E+01 -1.65854E+01 -1.50581E+01 -1.37398E+01 -1.42951E+01
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-1.79280E+01 -1.68933E+01
 1.00000E+02 7.61441E+01 5.05036E+01 -3.21466E+01 -6.15975E+01 -3.24054E+01 -1.76268E+01 -1.54630E+01
-2.55167E+01 -1.52288E+01 -1.63934E+01 -1.73894E+01 -3.84997E+01 -1.09155E+01 -7.51596E+00 2.87186E-01
 3.12599E+00 -1.02994E+01 -1.59935E+01 -1.12827E+01 -1.02396E+01 -9.41086E+00 -9.78929E+00 -1.01380E+01
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3.56223E+01 8.22103E+00 -3.84188E-01 -7.72442E+00 -1.11272E+01 5.54939E+00 1.67148E+01 1.16972E+01
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1.00000E+02 2.10684E+01 -3.11667E+01 -1.03972E+01 2.34273E+01 1.12298E+01 1.08283E+01 9.90084E+00
7.13782E+00 6.91547E+00 7.77065E+00 9.68891E+00 1.11664E+01 1.17451E+01 1.13803E+01 9.73171E+00
8.65922E+00 8.55597E+00 9.21198E+00 8.35355E+00 6.18223E+00 7.25921E+00 8.17300E+00 7.39145E+00
4.66241E+00 4.16104E+00 6.80847E+00 8.40955E+00 8.53550E+00 8.47740E+00 8.98972E+00 9.52595E+00
8.91853E+00 8.81853E+00 8.90959E+00 1.08422E+01 1.11195E+01 1.18892E+01 1.22312E+01 1.27589E+01
1.26809E+01 1.28932E+01 1.33848E+01 1.34392E+01 1.37021E+01 1.22833E+01 1.23130E+01 1.22967E+01
1.24826E+01 1.26994E+01 1.27721E+01 1.30763E+01 1.37113E+01 1.31178E+01 1.37725E+01 1.71709E+01
1.97785E+01 1.96310E+01 1.93057E+01 1.93748E+01 2.06823E+01 1.93878E+01 1.92208E+01 1.27215E+01
1.00274E+01 9.01688E+00 8.16694E+00 7.68516E+00
1.00000E+02 -1.64102E+01 -3.64335E+00 4.24679E+01 1.75462E+01 -8.13144E-01 -6.25490E+00 2.19662E+00
6.91840E+00 9.06381E+00 1.13991E+01 1.15949E+01 1.12567E+01 1.40781E+01 1.45083E+01 1.41498E+01
1.44870E+01 1.57372E+01 1.53129E+01 1.34724E+01 1.32822E+01 1.37881E+01 1.38059E+01 1.33727E+01
1.32377E+01 1.37236E+01 1.45960E+01 1.44473E+01 1.45629E+01 1.51081E+01 1.57516E+01 1.47695E+01
1.48116E+01 1.50692E+01 1.82444E+01 1.87302E+01 1.95311E+01 2.02014E+01 2.10277E+01 2.09027E+01
2.12345E+01 2.18734E+01 2.19580E+01 2.23705E+01 2.01439E+01 2.03240E+01 2.05663E+01 2.11240E+01
2.15939E+01 2.18386E+01 2.23914E+01 2.40046E+01 2.32285E+01 2.38653E+01 2.86110E+01 3.15253E+01
3.08566E+01 3.04397E+01 3.06616E+01 3.28507E+01 3.07981E+01 3.05308E+01 2.01994E+01 1.59148E+01
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3.28695E+00 1.34472E+00 -1.79348E-01 -1.38637E-01 1.94704E+00 5.61669E+00 6.86172E+00 6.08999E+00
4.76344E+00 3.79293E+00 3.73938E+00 4.62626E+00 4.52420E+00 4.64630E+00 4.35527E+00 4.84630E+00
5.78333E+00 6.44899E+00 6.40462E+00 6.67778E+00 6.80069E+00 7.21409E+00 6.83852E+00 6.91124E+00
7.15701E+00 8.54720E+00 8.96434E+00 9.43117E+00 9.73578E+00 1.00492E+01 1.00593E+01 1.01690E+01
1.05453E+01 1.07624E+01 1.10884E+01 1.00434E+01 1.02338E+01 1.05465E+01 1.10411E+01 1.14820E+01
1.17920E+01 1.20659E+01 1.39707E+01 1.42013E+01 1.46343E+01 1.71253E+01 1.81188E+01 1.73341E+01
1.68859E+01 1.71523E+01 1.85275E+01 1.75787E+01 1.72894E+01 1.11298E+01 8.51607E+00 7.51079E+00
6.55624E+00 6.12084E+00
1.00000E+02 -2.62142E+01 8.65468E-01 4.57589E-01 1.07161E+00 2.33978E+00 2.30321E+00 5.71333E-01

-4.22436E+00 -7.06226E+00 -6.77955E+00 -4.84185E+00 1.31271E+00 3.82430E+00 2.30081E+00 -6.21680E-01
-1.81607E+00 -4.60665E-01 8.72599E-01 2.97073E-01 7.38473E-01 1.09496E+00 2.11987E+00 2.74544E+00
 3.07569E+00 3.07072E+00 3.42678E+00 3.39082E+00 3.71199E+00 3.66118E+00 3.71196E+00 4.07127E+00
 4.74033E+00 5.06326E+00 5.48607E+00 5.58989E+00 5.59111E+00 5.70796E+00 5.76158E+00 5.94810E+00
 6.23913E+00 6.49961E+00 5.90963E+00 6.15904E+00 6.34854E+00 6.75691E+00 7.12503E+00 7.39931E+00
 7.59768E+00 9.67484E+00 1.03028E+01 1.07129E+01 1.24424E+01 1.28947E+01 1.20108E+01 1.15571E+01
 1.17891E+01 1.28615E+01 1.24123E+01 1.20962E+01 7.46249E+00 5.38857E+00 4.65255E+00 3.82870E+00
 3.61755E+00
 1.00000E+02 2.09618E+01 1.13844E+01 1.15806E+01 9.83724E+00 9.20793E+00 7.49151E+00 2.35450E+00
-2.23564E-01 2.02688E-01 1.96736E+00 8.12056E+00 1.06860E+01 9.11332E+00 6.30889E+00 5.61134E+00
 7.78989E+00 9.33804E+00 8.53565E+00 9.40115E+00 1.08281E+01 1.20661E+01 1.19829E+01 1.23128E+01
 1.20988E+01 1.30205E+01 1.33643E+01 1.38757E+01 1.33055E+01 1.35954E+01 1.42432E+01 1.76160E+01
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 2.19194E+01 2.08220E+01 2.12459E+01 2.55319E+01 2.85297E+01 2.81168E+01 2.78737E+01 2.80074E+01
 2.98645E+01 2.78659E+01 2.77546E+01 1.86934E+01 1.49892E+01 1.36240E+01 1.25784E+01 1.18872E+01
 1.00000E+02 1.15586E+01 9.29426E+00 7.94442E+00 8.28804E+00 8.51856E+00 8.45840E+00 8.61600E+00
 8.62458E+00 9.14741E+00 9.68049E+00 9.87876E+00 9.66861E+00 9.86409E+00 1.00484E+01 1.04600E+01
 1.07609E+01 1.06663E+01 1.11556E+01 1.18397E+01 1.20195E+01 1.17821E+01 1.21013E+01 1.19005E+01
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 8.69155E+00 8.95485E+00 8.43925E+00 8.70207E+00 8.97054E+00 1.13944E+01 1.16645E+01 1.20767E+01
 1.25814E+01 1.33499E+01 1.31075E+01 1.33991E+01 1.37134E+01 1.35181E+01 1.36934E+01 1.23827E+01
 1.24954E+01 1.27288E+01 1.29860E+01 1.32756E+01 1.35077E+01 1.38807E+01 1.38225E+01 1.27471E+01
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1.98939E+01 1.98964E+01 2.12375E+01 1.99047E+01 1.97353E+01 1.31546E+01 1.03979E+01 9.36293E+00
8.49259E+00 7.99812E+00
1.00000E+02 4.78274E+01 1.81174E+01 8.94408E+00 6.79906E+00 6.36883E+00 6.41759E+00 6.32486E+00
6.66414E+00 6.59948E+00 7.01857E+00 7.27720E+00 7.56900E+00 7.19330E+00 7.37130E+00 7.57064E+00
1.00691E+01 1.01986E+01 1.06580E+01 1.12027E+01 1.20209E+01 1.17722E+01 1.20843E+01 1.24394E+01
1.21680E+01 1.24527E+01 1.14274E+01 1.16346E+01 1.19645E+01 1.24181E+01 1.28974E+01 1.32234E+01
1.37823E+01 1.42811E+01 1.35836E+01 1.41656E+01 1.76818E+01 2.04268E+01 2.03336E+01 2.00730E+01
2.00770E+01 2.14310E+01 2.00863E+01 1.99152E+01 1.32733E+01 1.04912E+01 9.53729E+00 8.65990E+00
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6.82939E+00 7.24963E+00 7.50899E+00 7.89157E+00 7.42455E+00 7.60277E+00 7.80292E+00 1.03062E+01
1.04367E+01 1.08972E+01 1.14425E+01 1.23454E+01 1.20968E+01 1.24087E+01 1.27637E+01 1.24924E+01
1.27769E+01 1.16671E+01 1.18745E+01 1.22046E+01 1.26586E+01 1.31382E+01 1.34643E+01 1.39413E+01
1.44435E+01 1.36632E+01 1.42472E+01 1.77067E+01 2.04675E+01 2.04383E+01 2.02450E+01 2.02493E+01
2.15426E+01 2.01909E+01 2.00189E+01 1.33420E+01 1.06347E+01 9.67655E+00 8.79557E+00 8.29500E+00
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7.43783E+00 7.79214E+00 8.09195E+00 7.61419E+00 7.79392E+00 8.08954E+00 1.06301E+01 1.07679E+01
1.12379E+01 1.17910E+01 1.27029E+01 1.24532E+01 1.27689E+01 1.30488E+01 1.28618E+01 1.30690E+01
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2.05858E+01 2.04105E+01 1.36860E+01 1.09280E+01 9.86008E+00 9.05312E+00 8.54325E+00
1.00000E+02 4.97166E+01 1.90370E+01 1.05438E+01 7.72839E+00 7.43547E+00 7.09557E+00 7.43291E+00
7.78701E+00 8.08660E+00 7.69942E+00 7.78887E+00 8.08432E+00 1.06239E+01 1.07614E+01 1.12311E+01
1.17840E+01 1.26956E+01 1.23621E+01 1.27614E+01 1.30411E+01 1.27715E+01 1.30611E+01 1.19227E+01
1.21323E+01 1.24651E+01 1.29259E+01 1.34111E+01 1.37399E+01 1.42225E+01 1.46659E+01 1.37941E+01

1.43875E+01 1.79940E+01 2.08631E+01 2.08248E+01 2.06262E+01 2.06335E+01 2.19545E+01 2.05769E+01
2.04017E+01 1.35952E+01 1.08340E+01 9.85556E+00 8.95764E+00 8.44748E+00
1.00000E+02 4.97996E+01 1.97562E+01 1.03453E+01 8.42721E+00 7.54160E+00 7.70968E+00 8.07087E+00
8.38140E+00 7.97812E+00 8.07004E+00 8.37362E+00 1.09721E+01 1.11212E+01 1.16063E+01 1.21716E+01
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1.28588E+01 1.33295E+01 1.38229E+01 1.41558E+01 1.46466E+01 1.50414E+01 1.42352E+01 1.48396E+01
1.84618E+01 2.14562E+01 2.14047E+01 2.11984E+01 2.12102E+01 2.25724E+01 2.11560E+01 2.09758E+01
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1.00000E+02 5.47098E+01 1.96913E+01 1.15603E+01 8.60300E+00 8.24979E+00 8.44351E+00 8.86127E+00
8.34211E+00 8.52768E+00 8.75532E+00 1.14523E+01 1.17068E+01 1.22168E+01 1.28024E+01 1.37529E+01
1.34156E+01 1.38304E+01 1.41431E+01 1.38803E+01 1.41904E+01 1.29384E+01 1.31563E+01 1.34995E+01
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2.23538E+01 2.23463E+01 2.21279E+01 2.21467E+01 2.35759E+01 2.20289E+01 2.19082E+01 1.46773E+01
1.17094E+01 1.06526E+01 9.77997E+00 9.14183E+00
1.00000E+02 4.91906E+01 2.09612E+01 1.10945E+01 9.12599E+00 8.78633E+00 9.03178E+00 8.50349E+00
8.69033E+00 8.92280E+00 1.16538E+01 1.19148E+01 1.24337E+01 1.30266E+01 1.39855E+01 1.36473E+01
1.40656E+01 1.43855E+01 1.41242E+01 1.43575E+01 1.31618E+01 1.33815E+01 1.37270E+01 1.42196E+01
1.47310E+01 1.50725E+01 1.56627E+01 1.60456E+01 1.51274E+01 1.57567E+01 1.95804E+01 2.26975E+01
2.26822E+01 2.25271E+01 2.24806E+01 2.39337E+01 2.23644E+01 2.22408E+01 1.48972E+01 1.18827E+01
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1.51166E+01
1.00000E+02 7.62628E+01 4.13835E+01 3.10047E+01 3.16296E+01 3.57069E+01 3.87517E+01 4.02706E+01
4.17344E+01 3.85761E+01 3.84242E+01 2.55955E+01 2.01504E+01 1.81342E+01 1.63590E+01 1.53953E+01
1.00000E+02 6.75354E+01 4.03225E+01 2.73914E+01 2.98842E+01 3.57907E+01 3.95599E+01 4.10418E+01
3.72318E+01 3.71534E+01 2.46813E+01 1.93306E+01 1.72188E+01 1.54144E+01 1.44803E+01
1.00000E+02 6.33805E+01 2.54565E+01 2.42085E+01 3.43307E+01 4.14855E+01 4.32001E+01 3.79952E+01
3.79638E+01 2.55597E+01 1.99277E+01 1.79252E+01 1.60014E+01 1.50434E+01
1.00000E+02 4.47537E+01 2.17231E+01 3.58733E+01 4.93445E+01 5.36518E+01 4.54308E+01 4.51953E+01
3.07608E+01 2.41768E+01 2.16370E+01 1.94753E+01 1.83281E+01
1.00000E+02 4.66730E+01 3.11796E+01 4.39288E+01 5.92030E+01 5.27310E+01 4.95437E+01 3.21484E+01
2.52169E+01 2.26805E+01 2.05731E+01 1.93681E+01
1.00000E+02 4.92653E+01 2.93834E+01 5.08196E+01 5.46191E+01 4.93814E+01 2.92288E+01 2.27975E+01
2.04923E+01 1.85510E+01 1.75010E+01
1.00000E+02 4.63186E+01 3.44805E+01 4.92067E+01 5.16052E+01 3.25035E+01 2.53562E+01 2.26576E+01
2.03644E+01 1.92071E+01
1.00000E+02 3.94282E+01 3.35666E+01 5.47308E+01 4.37684E+01 3.45469E+01 3.10217E+01 2.77156E+01
2.59061E+01

1.00000E+02 3.97722E+01 4.66009E+01 4.62947E+01 3.84070E+01 3.49950E+01 3.23428E+01 3.03192E+01

1.00000E+02 3.06233E+01 1.00139E+00 3.20066E+00 4.23244E+00 6.24996E+00 6.29202E+00

1.00000E+02 4.32406E+00 -1.43739E+01 -1.90094E+01 -2.65341E+01 -2.47982E+01

1.00000E+02 9.44726E+01 8.94675E+01 9.03613E+01 8.42734E+01

1.00000E+02 9.49998E+01 9.15678E+01 8.50306E+01

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