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Radiation Characterization Summary: ACRR Cadmium-Polyethylene (CdPoly) Bucket Located in the Central Cavity on the 32-Inch Pedestal at the Core Centerline (ACRR-CdPoly-CC-32-cl)

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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 Annular Core Research Reactor (ACRR) for the cadmium-polyethylene (CdPoly) bucket in the central cavity on the 32-inch pedestal at the core centerline. The designation for this environment is ACRR-CdPoly-CC-32-cl. 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 bucket. 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.

Acknowledgements

The authors wish to thank the Annular Core Research Reactor staff and the Radiation Metrology Laboratory staff for their support of this work. Also thanks to Drew Tonigan for helping field the activation experiments in ACRR, David Samuel for helping to finalize the drawings and get the parts fabricated, and Elliot Pelfrey for preparing the active dosimetry plots.

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Nomenclature / Acronyms

ASTM	American Society for Testing and Materials
ACRR	Annular Core Research Reactor
Al	aluminum
B	boron
B_4C	boron carbide
Bq	Becquerel (disintegrations/second)
C/E	calculated to experiment ratio
Cd	cadmium
CdPoly	cadmium-polyethylene
dc	delayed critical
E_{th}	threshold energy
eV	electron volt
FP	Frenkel Pair
FREC-II	Fueled Ring External Cavity – version 2
FWHM	full-width at half-maximum
Gy	Gray – unit of absorbed dose equal to 100 rad
keff	k-effective multiplying constant
keV	kilo-electron volt
krad	kilorad – unit of absorbed dose equal to 1000 rad
lbs	pounds
LB36	36-inch-long lead-boron bucket
LB44	44-inch-long lead-boron bucket
LSL-M2	Least-Squares Logarithmic Adjustment code
mb	millibarns
MCNP	Monte Carlo N-Particle
MeV	mega-electron volt
MJ	megajoule
ms	milliseconds
MW	megawatts
n/cm^2	units of fluence (neutrons per cm^2)
NuGET	Neutron-Gamma Environment Transport code
Pb	lead
PCD	photo-conducting detector
PKA	primary knock-on atom
PLG	polyethylene-lead-graphite
rad	unit of absorbed dose equal to 100 erg/g in a specified material
SNL	Sandia National Laboratories
TA-V	Technical Area V
TC	thermocouple
TLD	thermoluminescent dosimeter
TRIGA	Training, Research, Isotopes, General Atomics
UO_2-BeO	uranium dioxide – beryllium oxide
UZrH	uranium zirconium hydride

1. Introduction

Characterization of the neutron and gamma-ray environments in the Annular Core Research Reactor (ACRR) central cavity and the Fueled Ring External Cavity (FREC-II) is important in order to maintain a high degree of fidelity in performing qualification and other testing at the ACRR. Characterization includes both modeling and experimental efforts. Building accurate neutronic models of the ACRR and "bucket" environments that can be used by experimenters is important in planning and designing experiments as well as in assessing experimental results. Experimental observations, including passive and active dosimetry, are important in order to determine the accuracy of the models, 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.

There are several existing neutron and gamma-ray spectrum modifying "buckets" that can be used in the ACRR central cavity. Since the ACRR neutron spectrum in the central cavity has a large epithermal component, buckets with a moderating material, like polyethylene, can be used to thermalize the neutron spectrum. Thermal neutron absorbing materials, like boron carbide and cadmium, can be used to remove the thermal neutron component of the spectrum. Buckets with lead can be used to attenuate some of the prompt and delayed gamma rays in the cavity. Typically, some combination of materials is used to create the desired neutron and gamma-ray environment desired by the experimenter.

This document presents the facility-recommended characterization of the radiation fields in the ACRR for the cadmium-polyethylene (CdPoly) bucket in the central cavity on the 32-inch pedestal at the core centerline. The designation for this environment is ACRR-CdPoly-CC-32-cl. The CdPoly bucket was designed and fabricated to enhance the gamma-ray to neutron ratio in the central cavity, while maintaining the maximum irradiation space possible. The bucket is designed to fit within the 9-inch-diameter ACRR central cavity and maintain a 7.5-inch diameter inner irradiation space. The bucket has and aluminum shell structure with a high-density polyethylene annulus (0.55 in. thickness) and an inner cadmium liner (0.030 in.). The polyethylene thermalizes some of the neutron fluence entering the cavity. The cadmium liner absorbs thermal neutrons and emits a prompt gamma-ray in a radiative capture (n,γ) reaction. This produces a higher gamma-ray fluence environment and allows for a lower 1-MeVdamage equivalent in silicon (DES) neutron fluence in the irradiation volume. The ultimate effect for the geometry and materials used in the CdPoly bucket is a factor of 2 increase in the silicon dose to 1-MeV DES neutron fluence as compared to the free-field (no bucket) environment. The CdPoly bucket configuration has an overall height of 30 inches. One CdPoly bucket was constructed and is available for use by experimenters.

The neutron, prompt gamma-ray, and delayed gamma-ray energy spectra, uncertainties, and covariance matrices are presented at the radial centerline of the bucket at the axial fuel centerline at 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 bucket. 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 the ACRR used in the bucket characterization was developed for the Monte Carlo N-Particle Transport Code (MCNP, 2003). The original ACRR MCNP model was assembled by Wesley Fan and later modified by Phil Cooper and Ed Parma. Russell DePriest modified the model in 2006 to include a macrobody geometry description of the reactor core instead of the standard surface description (DePriest, 2006). The macrobody description for the CdPoly bucket on the 32-inch pedestal was modeled by Krista Kaiser and is included in Appendix A. Other models, including the ACRR with the FREC-II coupled, are also available. Details of the ACRR model and calculations are described later in this document. A 640-group and 89-group neutron energy spectrum and a 48-group gamma-ray energy spectrum were calculated using MCNP5 Version 1.6 and the ENDF/B-VII cross sections for the ACRR model with a scoring sphere at the radial centerline of the CdPoly bucket and 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, 1994a, McElroy, 1967), LSL-M2 (Stallmann, 1985), or other code.

For this work a total of 23 different foil types, resulting in 33 different reactions, were irradiated at the ACRR-CdPoly-CC-32-cl location. The LSL-M2 code and the IRDFF, version 1.02 dosimetry cross sections (IRDFF, 2014; Capote, 2012; Zsolnay, 2012), were used in the unfolding analysis.

2. Environment Description

ACRR Description

The ACRR is a pulse and steady-state, pool-type research reactor that maintains a large, dry irradiation cavity at the center of its core. The ACRR is typically used to perform irradiation testing where a high neutron fluence is required for a short period of time. Historically, the ACRR has been used for a wide variety of experiment campaigns including weapons effects testing, nuclear fuels testing, nuclear pumped laser experiments, space nuclear thermal propulsion testing, and medical isotopes production. The ACRR is currently fully operational. The ACRR's main attributes include a large, dry central irradiation cavity, epithermal neutron fluence, and large pulsing capabilities.

The ACRR is located in Technical Area V (TA-V) at the Sandia National Laboratories in Albuquerque, New Mexico. The reactor, in its current configuration, was assembled in 1978 to accommodate large experiments at the center of its core and have large pulsing capabilities. The fuel elements for the ACRR are similar in size and shape to TRIGA fuel. However, the fuel is unique in that the form of the fuel is uranium dioxide/beryllium oxide (UO_2-BeO) that was specially designed to have a large heat capacity and, thus, larger pulsing capabilities.

Figure 1 shows the ACRR looking into the pool during a 2 MW steady-state power operation. The ACRR core is shown on the left in the figure. The 9-inch-diameter dry cavity extends from above the pool through the center of the core. The reactor facility also accommodates the fueled ring external cavity-II (FREC-II), shown on the right in the figure, which maintains a larger dry cavity (20-inch diameter) and uses uranium/zirconium-hydride (U-ZrH) TRIGA fuel as a subcritical multiplier. FREC-II provides the user with a larger experimental volume and the fuel arrangement limits the neutron fluence gradient across the test volume.

The ACRR tank and high bay are shown in Figure 2 at floor level. The shield plug, shown on the left in the figure, is a borated polyethylene and lead cylinder that is in inserted into the central cavity after a bucket and/or experiment package is loaded. The shield plug is about five feet in length and sits on a lip inside the central cavity that is located about 10 feet below the pool surface. The dry central cavity, shown in Figure 3, extends from above the pool and goes directly through and below the core region. Another view of the ACRR and FREC-II is shown in Figure 4, with the reactor shut down and the FREC-II (on the left) tilted back in its "decoupled" configuration. Shown on the right in Figure 4 is the radiography tube.

The ACRR maintains an epithermal neutron fluence spectrum in the core and central cavity. This allows for the neutron energy fluence spectrum to be tailored to the desired specifications of an experiment. Moderators can be used within the cavity to thermalize the neutron spectrum. Boron and lead can be used to increase the fast neutron fluence ratio and decrease the gamma-ray fluence, respectively. For an unmoderated condition, the neutron fluence at the center of the central cavity, at the core axial centerline, is ~2.0E13 n/cm^2 per MJ of reactor energy. About 45% of the neutron fluence is above 100 keV and 56% above 10 keV. The 1-MeV damage-equivalent silicon fluence is ~7.9E12 n/cm^2 per MJ of reactor energy. The prompt gamma-ray dose at the same position is ~7.7E3 rad(Si) per MJ. The delayed gamma-ray dose is ~3.3E3 rad(Si) per MJ.

- 236 UO_2-BeO fueled elements
  - 1.5 in (3.8 cm) dia. x 20 in (51 cm)
  - 100 g U-235 per element – 35% enr.
- Operating Power level
  - 4 MW_{th} Steady State Mode
  - 250 MJ Pulse Mode (6 ms FWHM)
  - 300 MJ Transient Mode (Programmable)
- Dry cavity 9 in (23 cm) diameter
  - Extends full length of pool through core
  - Neutron Flux 4E13 n/cm^2-s at 2 MW
  - 65% > 1 eV, 56% > 10 keV, 45% > 100 keV
- Epithermal Spectrum
  - Flux in cavity can be tailored for desired energy spectrum (Poly, B4C)
- Open-pool type reactor
  - Fuel elements cooled by natural convection
  - Pool cooled by HX and cooling tower
- FREC-II uses previous ACPR fuel
  - TRIGA type (UZrH) – 20 in (51 cm) dia. dry cavity
- Fuel burnup is minimal
  - Reactor used for short duration power runs, pulses, and transients

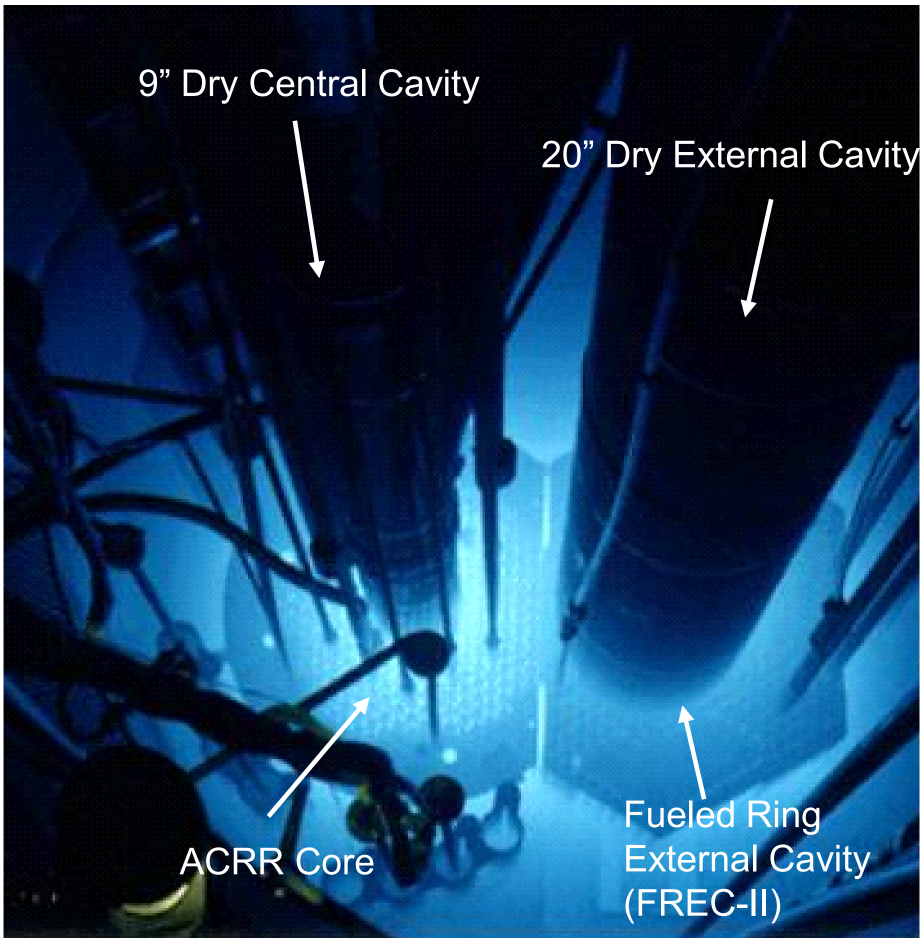

Figure 1. The ACRR and FREC-II Operating at 2-MW Steady-State Power.

Figure 2. The ACRR Tank and High Bay.

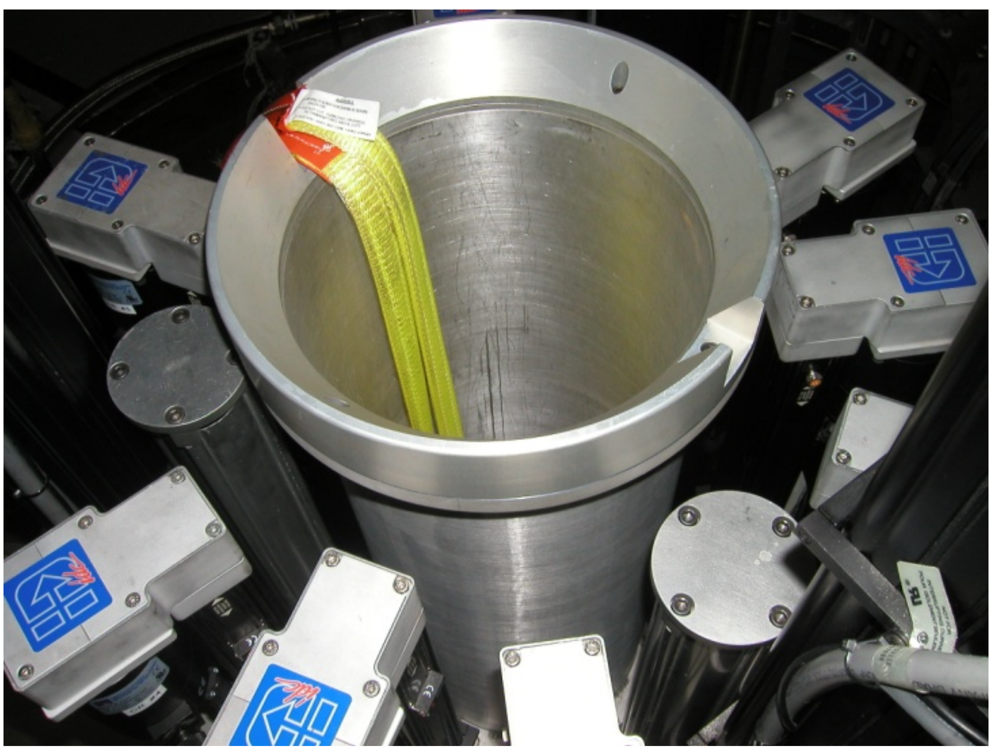

Figure 3. The ACRR Dry Central Cavity and Control Rod Drives.

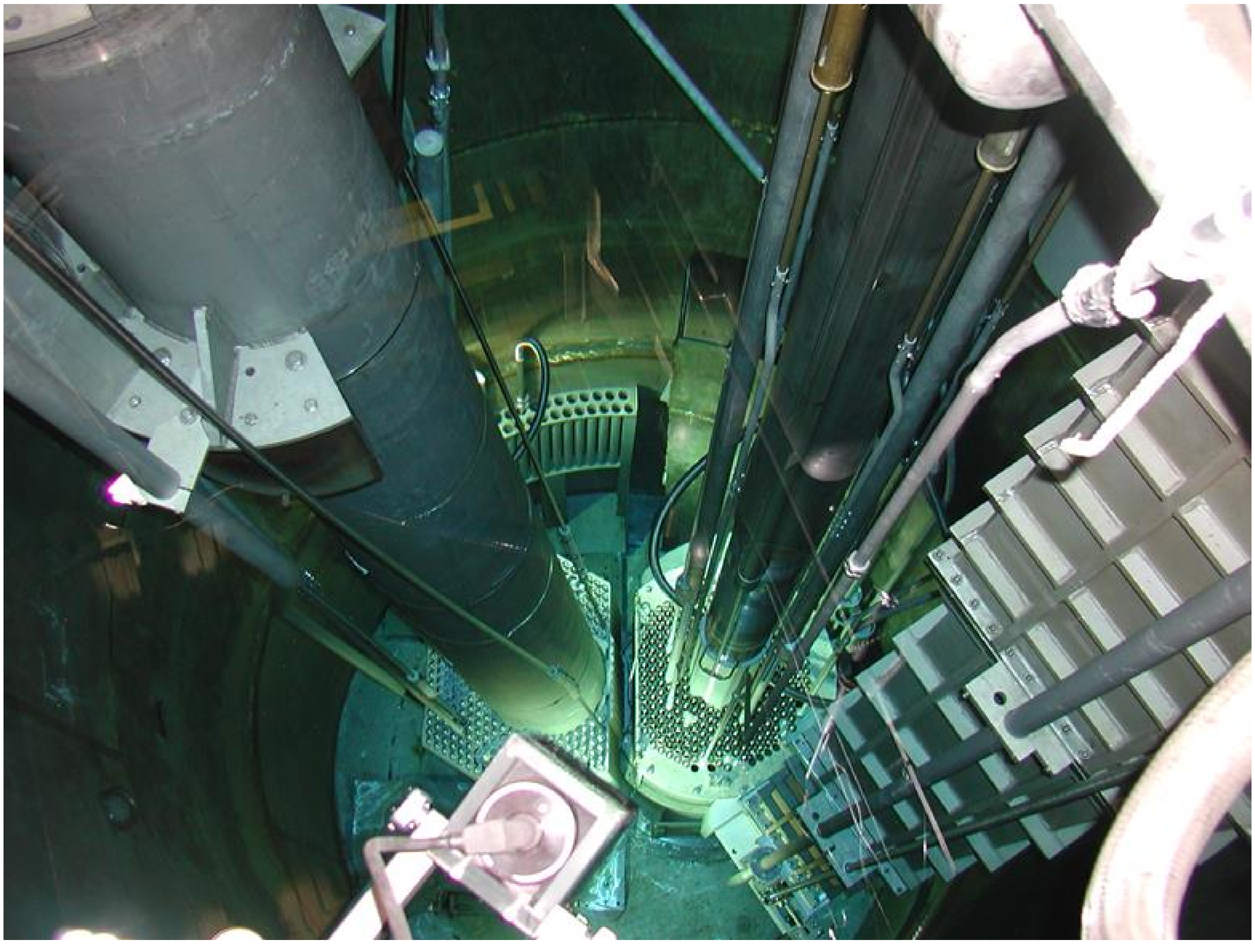

Figure 4. ACRR with FREC-II Decoupled.

The ACRR can operate in a steady-state, transient, or pulse mode. In the steady-state mode, the operating power level is limited to ~4 MW. In the pulse mode, a maximum pulse size of ~250 MJ with a full-width half-maximum (FWHM) of 6 ms can be attained. In the transient mode, the reactor power shape can be tailored to the desired requirements for a total reactor energy deposition of ~300 MJ. The transient mode can be used to increase the reactor power quickly; for example a ramp increase in power level linear with time from low power to high power.

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 an unmoderated cavity is ~18 J/g-MJ, and ~90 J/g-MJ for the moderated condition. These coupling factors allow for fueled experiments to be designed for a wide variety of test conditions for steady-state, transient, and pulse operations.

The ACRR is fueled by a 236-element array of UO_2-BeO fuel elements. The fuel is uranium enriched to 35 weight percent U-235, with 21.5 weight percent UO_2 and 78.5 weight percent BeO. The ACRR fuel elements are stainless steel clad, 1.5 inches in diameter and 21 inches in fuel length. Within the elements are niobium cups that hold the UO_2-BeO fuel pieces.

The ACRR is controlled by two fuel-followed safety rods, three poison (void-followed) transient rods, and six fuel-followed control rods. The control rods (safety and control) make up part of the 236 elements for the normal core configuration.

The ACRR central cavity and FREC-II cavity allow for a high degree of experiment flexibility, along with in-situ and real-time experiment instrumentation and diagnostics. The large size of the cavities allows for the possibility of flow loops and other complex experimental hardware to be fielded within the high-fluence region of the core. Because the ACRR is under-moderated, the neutron spectrum has a large epithermal component within the central cavity. This epithermal 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 inserts 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 normal mode of operation for the ACRR is to have the FREC-II tilted back and decoupled from the ACRR using a nickel plate on the FREC-II side of the core.

The ACRR core is located in an open pool 10 feet (3.0 m) in diameter and 28 feet (8.5 m) deep. The pool is filled with 64,000 liters of deionized water. The core is cooled by natural convection of the pool water. The pool water is cooled by a heat exchanger and cooling tower. For steady-state mode operations, the ACRR operates continuously at up to 4 MW. The pool is cooled using a heat rejection system rated to support steady-state operations up to 5 MW.

2.2 ACRR-CdPoly-CC-32-cl Environment

<u>CdPoly Bucket Description</u>

One CdPoly bucket was designed, fabricated, and tested in CY2016. The purpose of the CdPoly bucket is to fit within the 9-inch-diameter ACRR central cavity and increase the gamma-ray to neutron fluence by a factor of two compared to the free-field environment. The CdPoly bucket design contains an outer annular volume filled with high density polyethylene, and an inner sheet of cadmium. The polyethylene annulus produces a larger thermal neutron fluence environment, but the cadmium sheet, along the inner wall of the bucket, absorbs the thermal neutrons and produces prompt gamma rays from radiative capture. The environment was desired by one of the facility experimenters. The CdPoly bucket configuration maintains and inner irradiation diameter of about seven and one half inches and an overall height of about 30 inches.

A drawing of the CdPoly bucket is shown in Figure 5. A more detailed description of the bucket showing the major design features is shown in Figure 6. The bucket weighs approximately 34 lbs. and can support an additional experiment payload of up to 50 lbs. The bucket can be operated at up to 150 MJ in a pulse or steady-stope operation. The measured reactivity worth of the CdPoly bucket, compared to the free-field condition, is about -$4.00.

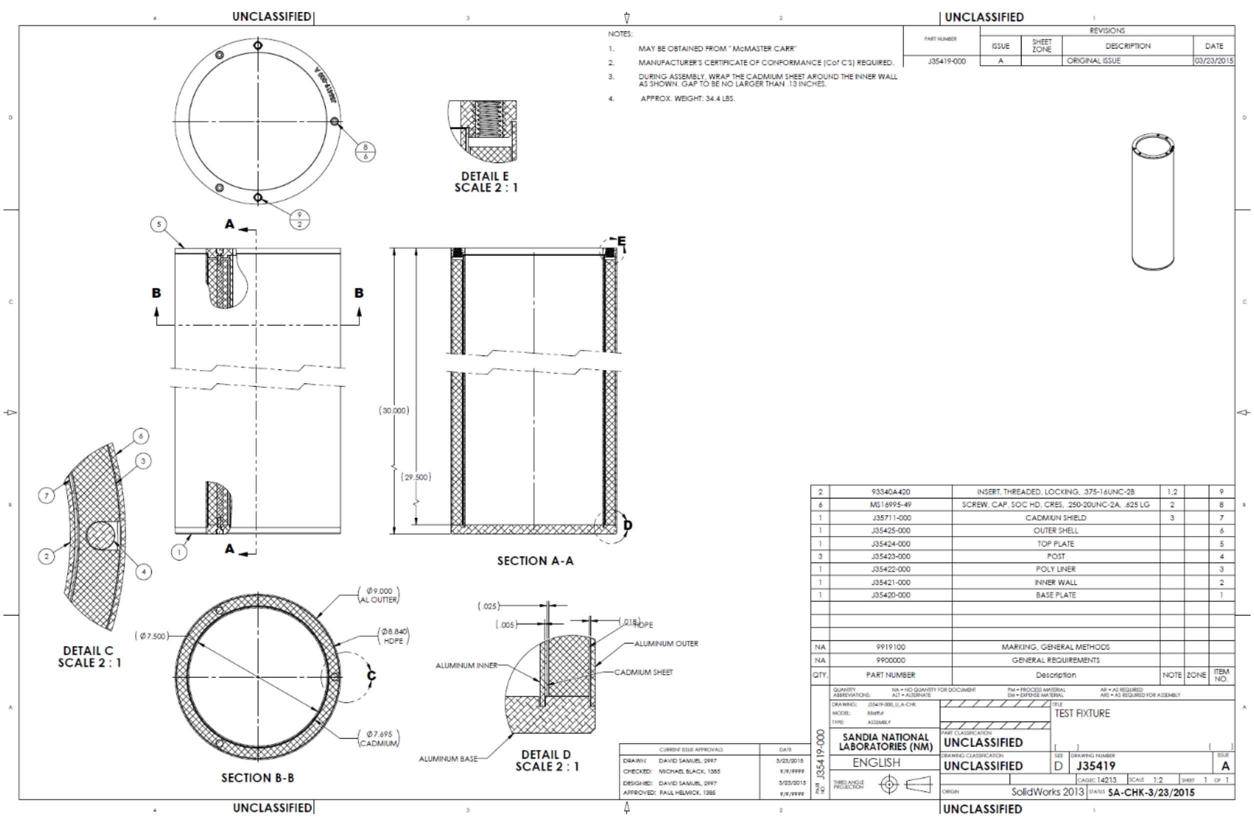

Figure 5. Drawing of the CdPoly Bucket.

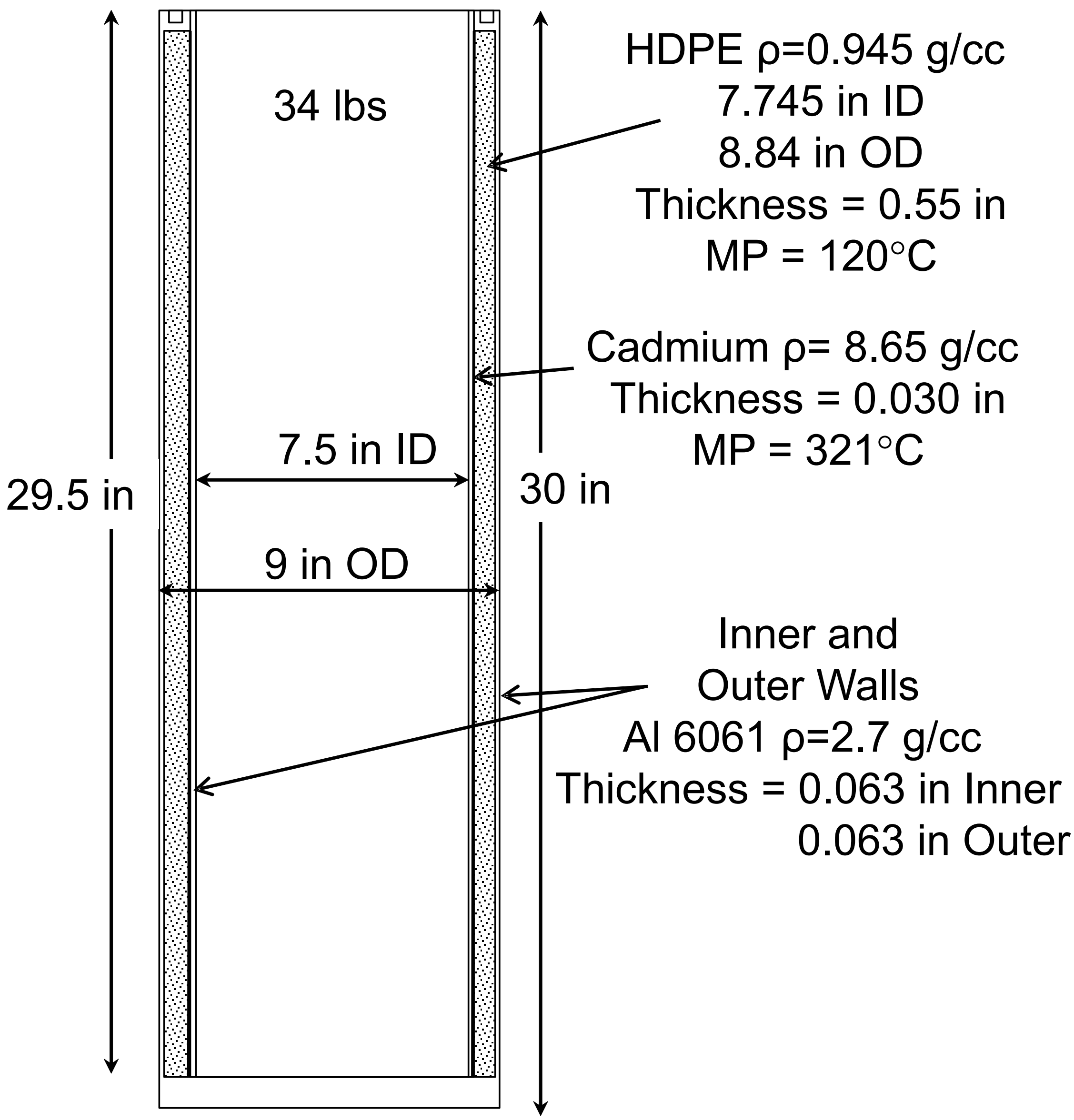

Figure 6. Details of the CdPoly Bucket.

The CdPoly bucket maintains an inner diameter of ~7.5 in. (~19.1 cm). The outer high density polyethylene annular thickness is 0.55 in. The inner cadmium sheet thickness is 0.03 in. The overall height of the bucket is ~30 in. and the internal height is 29.5 in. The structure for the bucket is aluminum (Al-6061). Two key inserts on the upper aluminum head are used to allow the bucket to be moved via steel cables and a crane.

Figure 7 shows three pictures of the CdPoly bucket. The top picture is a view of bucket with the steel cable rigging in place. The bottom left picture shows the name stamp on the bucket lip. The bottom right picture is looking into the bucket from above. The steel cables (~30 feet in length) that are used to hoist the bucket using the high bay penthouse crane are shown coiled up. Figure 8 shows a picture of the CdPoly bucket being loaded into the central cavity via the steel cables and the penthouse crane.

Figure 7. CdPoly Bucket – View From Above.

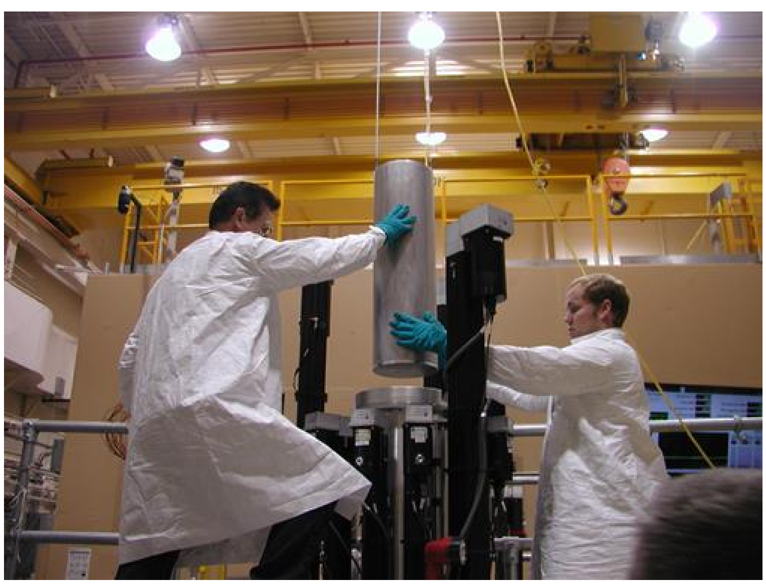

Figure 8. Installing the CdPoly Bucket into the ACRR Central Cavity.

MCNP Model

The MCNP model of the CdPoly bucket in the ACRR central cavity on the 32-inch pedestal is shown in Figure 9. The input model is included in Appendix A of this document. The model does not include the FREC-II. The reason for this is that, although the FREC-II is located within the core tank, the normal operating mode is to have it tilted back and decoupled from the core using a nickel plate. In this position the FREC-II has only a small effect on the neutronic behavior of the ACRR. The MCNP model of the ACRR includes all of the fuel elements and the control, safety, and transient rods that make up the core. The control, safety, and transient rods can be adjusted in the vertical direction in the model to whatever position is desired. Typically, the model is run with the safety and transient rods in the full-out position and the control rods in the full-out, full-in, or delayed critical (dc) position. The calculated dc position can be found for the model by iterating on the control rod position until keff is equal to one. The model is typically run using room-temperature (300 K) cross sections, S(α,β) values, and water density. Other 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 ACRR-CdPoly-CC-32-cl position, the sphere was positioned at the radial center of the bucket and at the axial centerline of the core. 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. The CdPoly worth, compared to the free field model, was calculated to be -\$4.45.

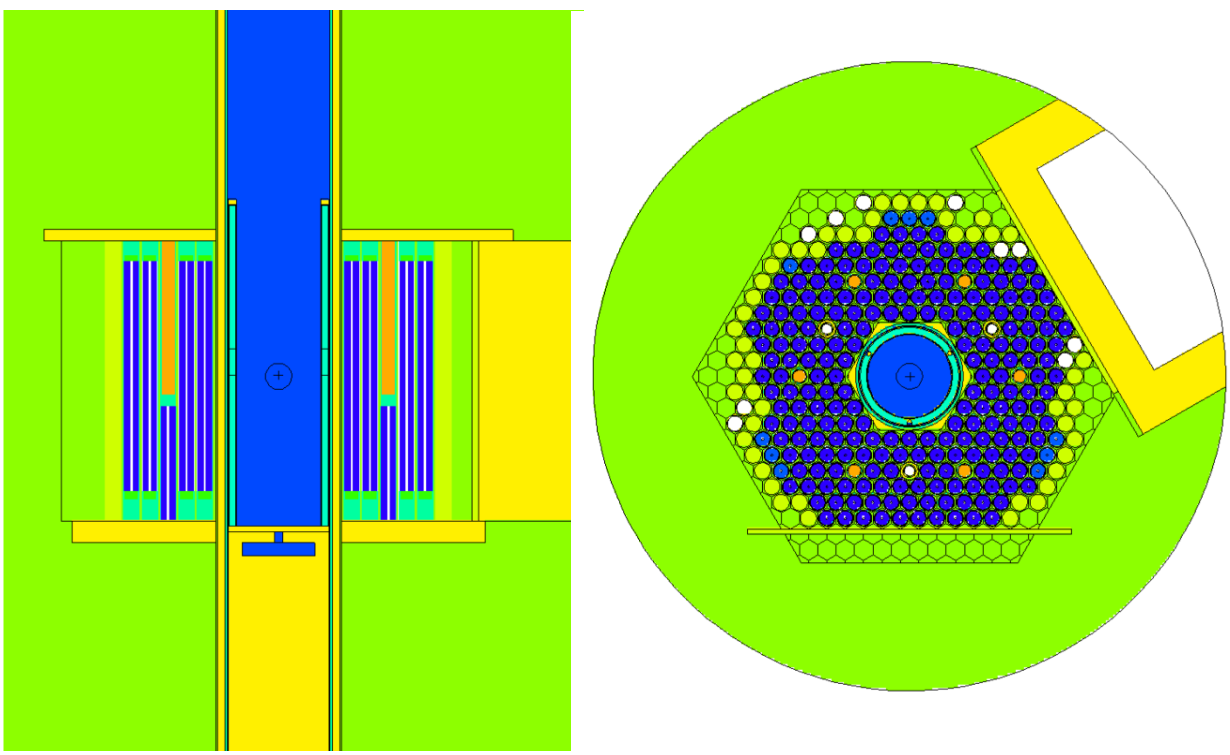

Figure 9. MCNP Model of the ACRR and the CdPoly Bucket on the 32-inch Pedestal.

3. Spectrum Characterization

Neutron

The neutron environment includes both prompt and delayed neutrons from the ACRR 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-energy group and an 89-energy group neutron trial spectrum from the MCNP model presented in Section 2 for the 6-cm diameter tally sphere. In order to have reasonable statistics in all of the energy groups, the model was run on a parallel machine for 20 billion source neutrons. The 640-group MCNP result represents the trial function that is then adjusted using a least-squares-based unfolding code. For this work a total of 23 different dosimetry foil types, resulting in 33 different transmutation reactions, were irradiated at the ACRR-CdPoly-CC-32-cl location. The LSL-M2 code (Stallmann, 1985) and the IRDFF, version 1.02 dosimetry cross sections (IRDFF, 2014; Capote, 2012; Zsolnay, 2012), were used in the unfolding analysis to determine the characterized neutron energy spectrum.

MCNP Model Results – 640-Group and 89-Group Neutron Energy Spectra

The neutron energy spectrum was calculated for a 640-energy group and an 89-energy group structure using the MCNP model presented in Section 2 for the 6-cm diameter tally sphere. MCNP5 version 1.60 was used with the ENDF/B-VII cross sections. The MCNP model with the CdPoly bucket 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 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-energy group structure. In order to have 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 with the exception of 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-VII nuclear data file. The 640-energy group neutron spectrum result was used as the trial function for the LSL-M2 code.

Figures 10 and 11 show the MCNP generated 640-energy group and 89-energy group neutron fluence on a linear and logarithmic y-axis, respectively. The units on the y-axis are in lethargy fluence or energy fluence, equal to $E d\phi/dE$ (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.

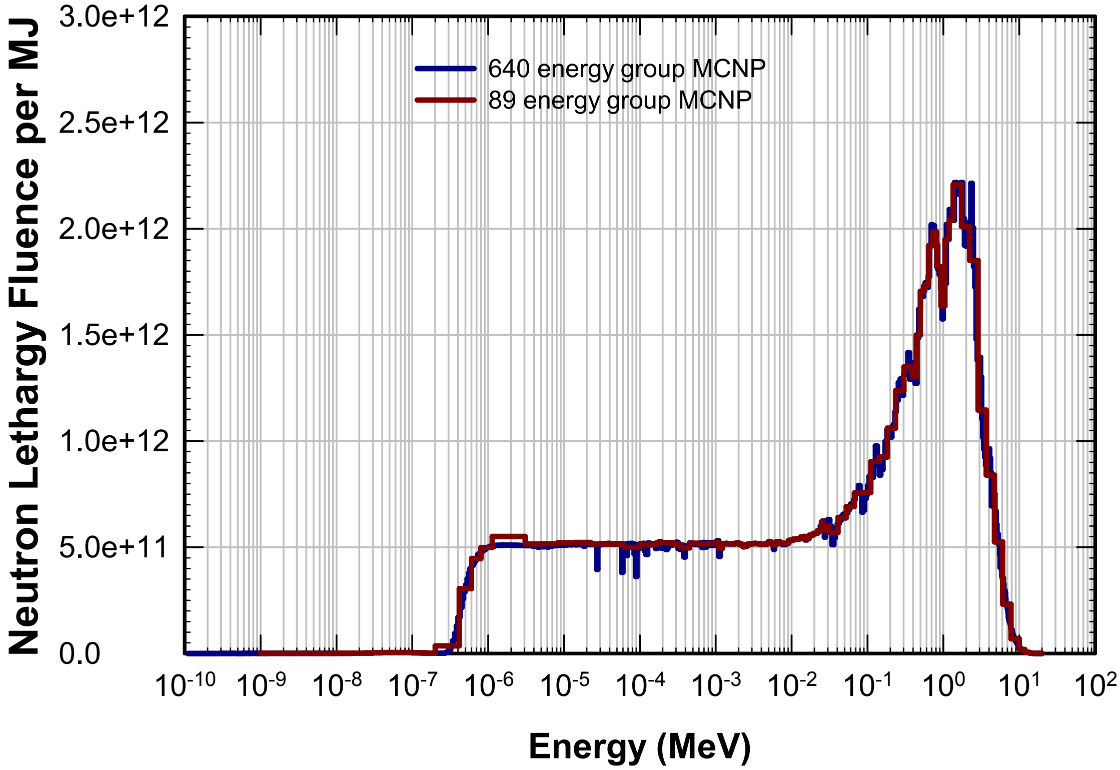

Figure 10. MCNP 640-Group and 89-Group Neutron Lethargy Fluence Energy Spectra (linear–log).

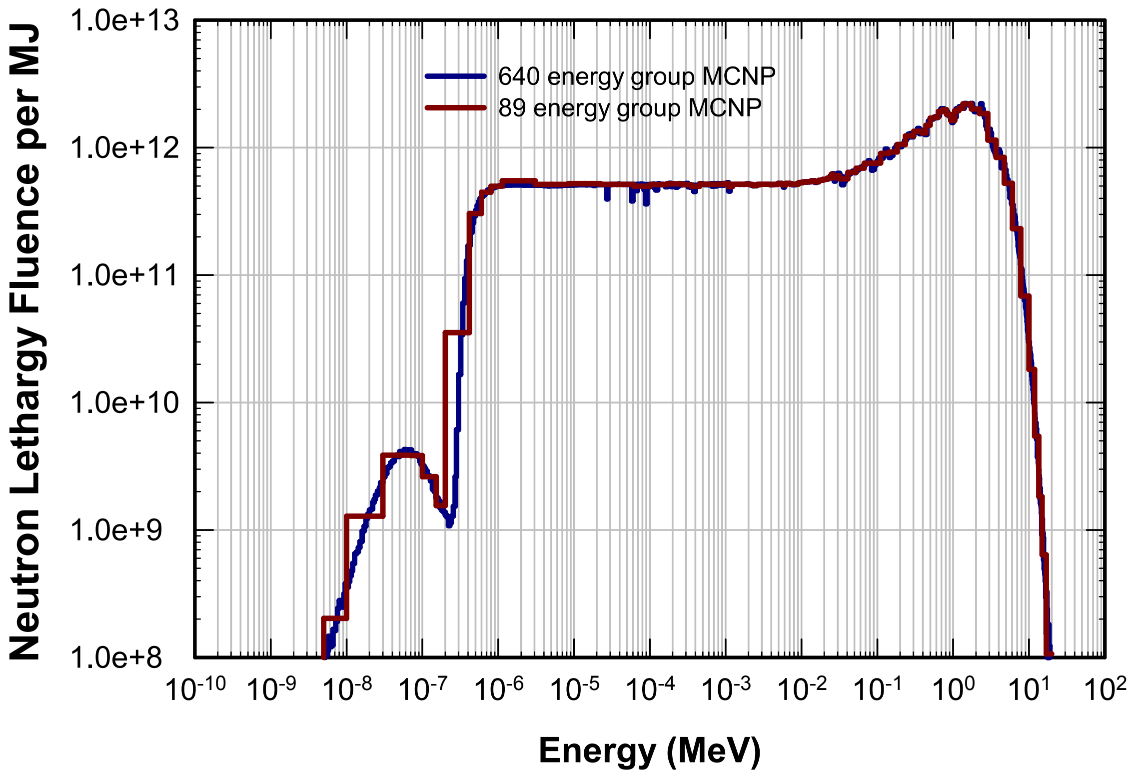

Figure 11. MCNP 640-Group and 89-Group Neutron Lethargy Fluence Energy Spectra (log–log).

The energy fluence is found to peak near 1 MeV. Neutrons below the cadmium cutoff energy of 0.5 eV are virtually non-existent due to the cadmium sheet present as the inner liner of the bucket. The results for the 640-energy group and 89-energy group neutron fluence are in very close agreement, as expected. The 640-energy group calculation shows more structure in the fluence spectrum, which is more notably observed in the energy range of 1E-5 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 calculated standard deviation for each energy bin in the 640-energy group fluence in the energy range from 0.005 eV (5.0E-9 MeV) to 6 MeV is less than 0.5%. A similar but less resolved structure is also seen in the 89-energy group fluence. The 89-energy group structure is the energy grouping used in the NuGET code (DePriest, 2004).

Dosimetry Foils

The results of the MCNP calculation of the ACRR with the CdPoly bucket 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 reactions 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 the ACRR and bucket 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 the LSL-M2 code. 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 the CdPoly bucket configuration. 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-M2 code was used to generate an 89-energy group neutron spectrum that is used in the NuGET code. The SAND-IV code can also be used to determine an adjusted 640-energy group spectrum. This 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 activation reactions used to perform the neutron fluence characterization for CdPoly are shown in Table 1.

Table 1. Neutron Activation Dosimetry Used for ACRR-CdPoly-CC-32-cl.

Activation Reaction	Half-Life	Activity (Bq/atom-isotope)	Counting Uncertainty (%)
$^{58}Ni(n,p)^{58}Co$ - Reference	70.83 d	6.1122E-18	3.0
$^{24}Mg(n,p)^{24}Na$	14.957 h *	8.6405E-18	1.9
$^{27}Al(n,p)^{27}Mg$	9.458 m **	2.3141E-15	2.2
$^{27}Al(n,\alpha)^{24}Na$	14.957 h *	4.0228E-18	1.8
$^{32}S(n,p)^{32}P$ Cf-equ	14.284 d	4.3499E+14 n/cm^2	3.6
$^{46}Ti(n,p)^{46}Sc$	83.788 d	4.9967E-19	1.5
$^{47}Ti(n,p)^{47}Sc$	3.349 d	2.3439E-17	3.1
$^{48}Ti(n,p)^{48}Sc$	43.67 h	6.0515E-19	1.0
$^{55}Mn(n,2n)^{54}Mn$	312.3 d	2.8166E-21	4.5
$^{54}Fe(n,p)^{54}Mn$	312.3 d	1.0366E-18	1.7
$^{56}Fe(n,p)^{56}Mn$	2.579 h *	3.8669E-17	1.6
$^{59}Co(n,p)^{59}Fe$	44.495 d	1.2296E-19	3.1
$^{59}Co(n,2n)^{58}Co$	70.83 d	1.1389E-20	18.3
$^{58}Ni(n,2n)^{57}Ni$	35.9 h	--	--
$^{60}Ni(n,p)^{60}Co$	1925.27 d	--	--
$^{63}Cu(n,\alpha)^{60}Co$	1925.27 d	1.1497E-21	4.4
$^{64}Zn(n,p)^{64}Cu$	12.701 h *	2.9304E-16	2.8
$^{90}Zr(n,2n)^{89}Zr$	78.41 h	1.2630E-19	2.2
$^{93}Nb(n,2n)^{92m}Nb$	10.15 d	1.7793E-19	1.9
$^{115}In(n,n')^{115m}In$	4.486 h *	5.1109E-15	5.6
$^{23}Na(n,\gamma)^{24}Na$	14.957 h *	3.0951E-16	1.8
$^{45}Sc(n,\gamma)^{46}Sc$	83.788 d	9.8273E-17	1.3
$^{55}Mn(n,\gamma)^{56}Mn$	2.579 h *	7.9671E-14	1.6
$^{58}Fe(n,\gamma)^{59}Fe$	44.495 d	2.0046E-17	1.9
$^{59}Co(n,\gamma)^{60}Co$	1925.27 d	1.3482E-17	1.4
$^{63}Cu(n,\gamma)^{64}Cu$	12.701 h *	5.3525E-15	2.8
$^{93}Nb(n,\gamma)^{94m}Nb$	6.263 m **	6.0332E-22	17.5
$^{98}Mo(n,\gamma)^{99}Mo$	2.748 d	1.4967E-15	1.0
$^{109}Ag(n,\gamma)^{110m}Ag$	249.78 d	4.8737E-17	0.6
$^{186}W(n,\gamma)^{187}W$	23.72 h *	1.0211E-13	1.0
$^{197}Au(n,\gamma)^{198}Au$	2.694 d	3.7488E-13	1.7
$^{235}U(n,f)FP$ - BB	^{140}Ba - 12.752 d	1.5452E-09 #fis	2.2
$^{238}U(n,f)FP$ - BB	^{140}Ba - 12.752 d	1.4603E-10 #fis	2.2
$^{237}Np(n,f)FP$ - BB	^{140}Ba - 12.752 d	7.9845E-10 #fis	3.6
$^{239}Pu(n,f)FP$ - BB	^{140}Ba - 12.752 d	1.5703E-09 #fis	3.5

* half life less than one day
** half life less than one hour
#fiss = units are fissions per atom isotope
BB = foil is located within a thick Cd cup and within a B_4C ball
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 LB44 bucket on the 32-inch pedestal (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) and/or boron (B) can allow for resonances above the associated cutoff energies to become more prominent, allowing for additional information to be included in the analysis. However, for the CdPoly bucket, activation of foils with Cd covers was not warranted, since the bucket maintains the Cd liner.

A total of 23 different foil types, resulting in 33 different reactions, were irradiated at the ACRR-CdPoly-CC-32-cl location. The foils were irradiated in three different pulse (150 MJ) operations. The four fission foils (U-235, U-238, Np-237, and Pu-239) were irradiated individually in a cadmium and boron ball configuration in four separate steady-state operations. Figure 12 shows a picture of some of the dosimetry foils used, from left to right: Co, Sc, Ni, and Fe. For reference, the Ni foil is 1.27 cm in diameter. The irradiations were all performed at the peak axial fast neutron fluence location within the bucket. From sulfur tablet irradiations, presented in Section 4 of this report, the peak axial fast neutron fluence is located 32 cm (12.6 in.) from the bottom of the inside of the CdPoly bucket, with the bucket on the 32-inch pedestal. The axial flux is relatively constant over +/- 10 cm (4 in.) from the peak value. For reference, the axial fuel centerline is 12.1 inches from the bottom of the inside of the PLG bucket. Multiple foils were irradiated on specially designed aluminum stand that placed a thin aluminum tray, which held the foils, at the 11 inch position in the bucket. The dosimetry stand, tray and holder are shown in Figure 13. Figure 14 shows the 10-slot dosimetry foil tray and foil packets. The tray was designed with the slots large enough to accommodate foils and Cd covered foils. In order to minimize any self-shielding effects, the foils were never stacked. Instead, the foils were arranged randomly on the tray and held in place with an aluminum cover. Figure 15 shows the boron ball and stand used for the irradiations. For each irradiation, at least one Ni foil was irradiated and used to normalize all of the irradiations.

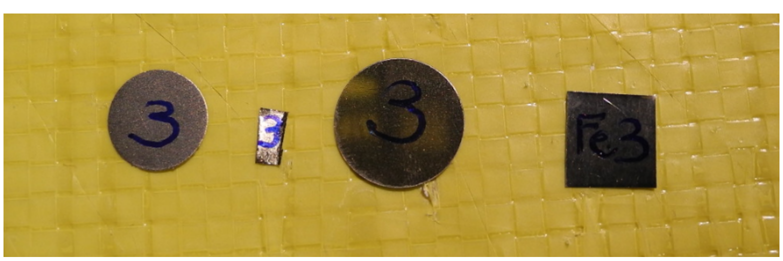

Figure 12. Typical Dosimetry Foils - Left to Right: Co, Sc, Ni, and Fe.

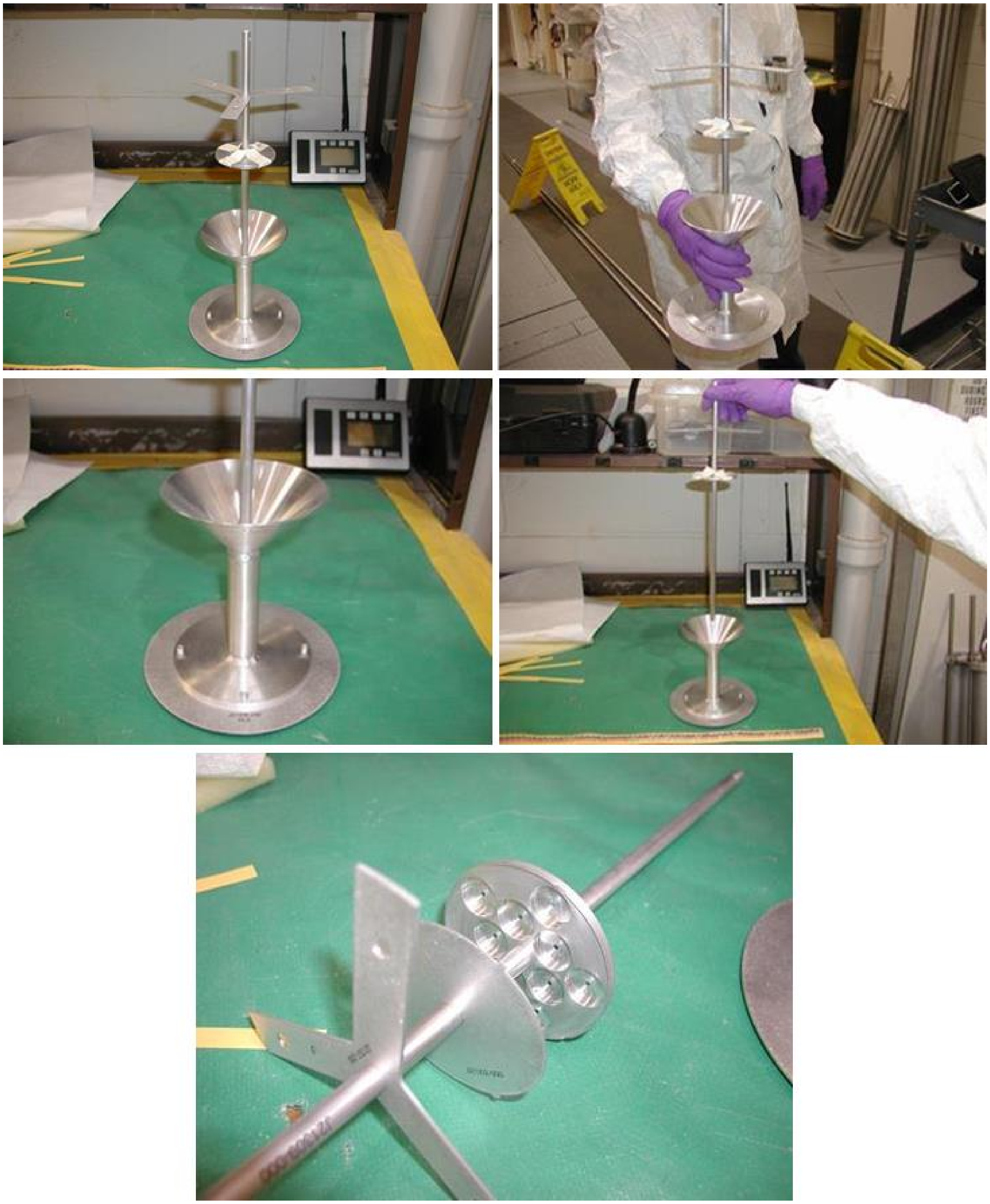

Figure 13. Drop-In Dosimetry Stand Used to Irradiate Foils in the Central Cavity.

Figure 14. Aluminum Dosimetry Tray and Foil Packets Awaiting Irradiation.

The CdPoly bucket was used to perform all of the foils irradiations identified in Table 1. No variation was found radially or azimuthally in the neutron fluence at the central region of the bucket, as presented in Section 4. The radial and azimuthal fluence variations are considered negligible for the CdPoly bucket at the 11-inch position.

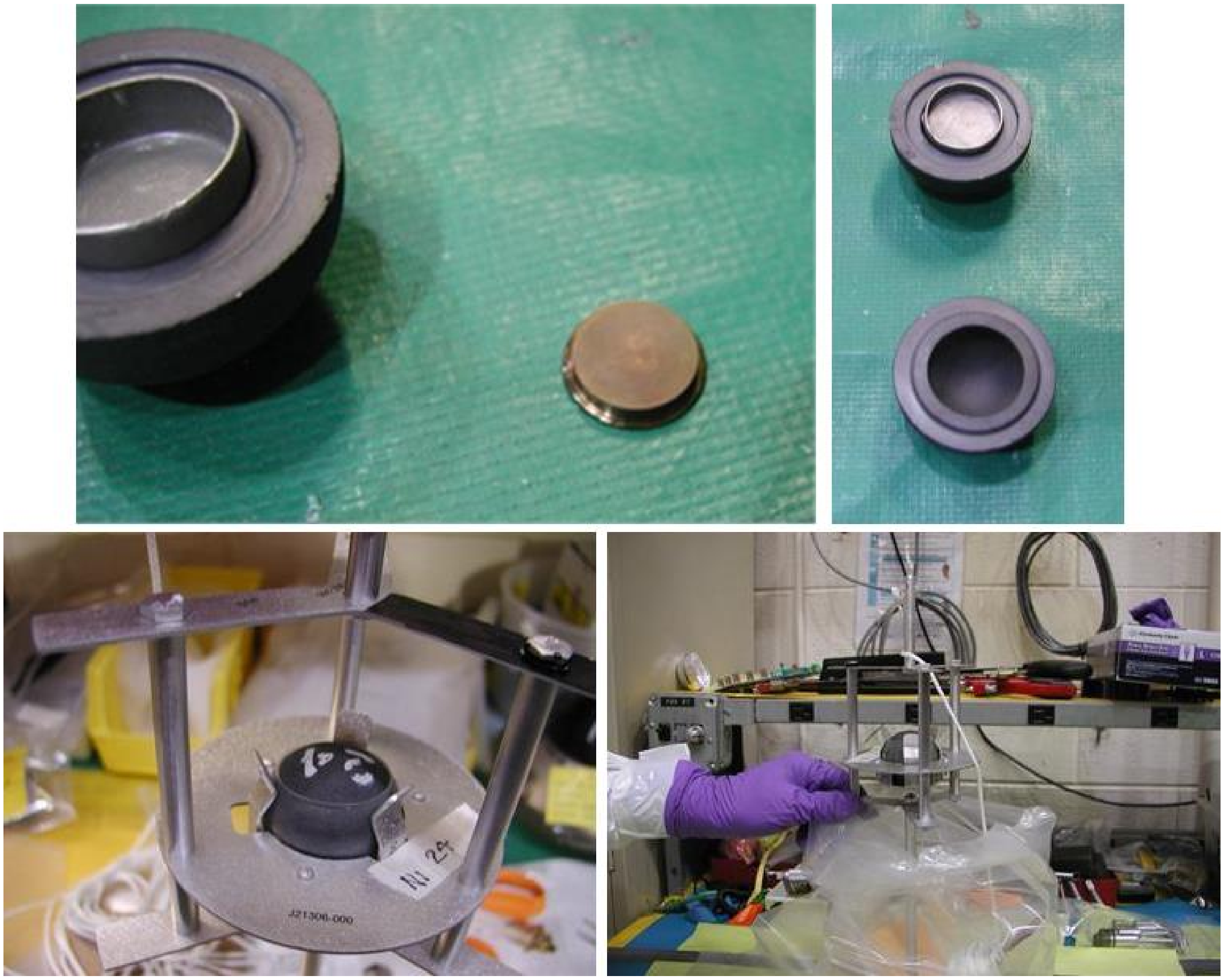

Figure 15. Boron Ball Configuration and Stand.

The CdPoly environment requires good coverage of the thermal, epithermal, and high-energy neutron reactions in order to perform an adequate adjustment to the neutron fluence energy spectrum. Cd and B_4C covers can be 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 fission foils placed in a cadmium cup within a boron ball configuration.

LSL Spectrum Unfold Results

LSL-M2 was run using the *a priori* 640-energy group trial spectrum from MCNP 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 core. The output was in the 89-energy group NuGET format described earlier.

The resulting value for χ^2/dof is 1.05, which represents an acceptable value. Figures 16 and 17 show the same representation of the neutron energy spectra as previously shown in Figures 10 and 11, with the additional 89-energy group adjusted spectrum result from the LSL analysis (green curve). Figure 18 shows the percent adjustment made to the trial spectrum (red curve), and the percent standard deviation in the adjusted spectrum (black curve). The adjusted neutron fluence in Figure 16 shows a lower value in the 1-3 MeV range, and some differences in the epithermal region than calculated using the MCNP model.

Figures 19 to 23 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 19 shows all of the reactions used in the analysis. Figures 20 through 22 represent the high-energy reactions, the radiative capture reactions, and the fission reactions, respectively. The reactions that are green in the legend represent those in the thermal region less than 1 eV. The cadmium cutoff value is at 0.5 eV. Although a B-10 cutoff energy does not exist, an effective value is shown at 100 eV that represents a nominal value. The reactions that are red in the legend represent the fission reactions. Figure 19 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 also both positive and negative. After the adjustment, the results become much closer to zero for C/E-1 for most of the reactions.

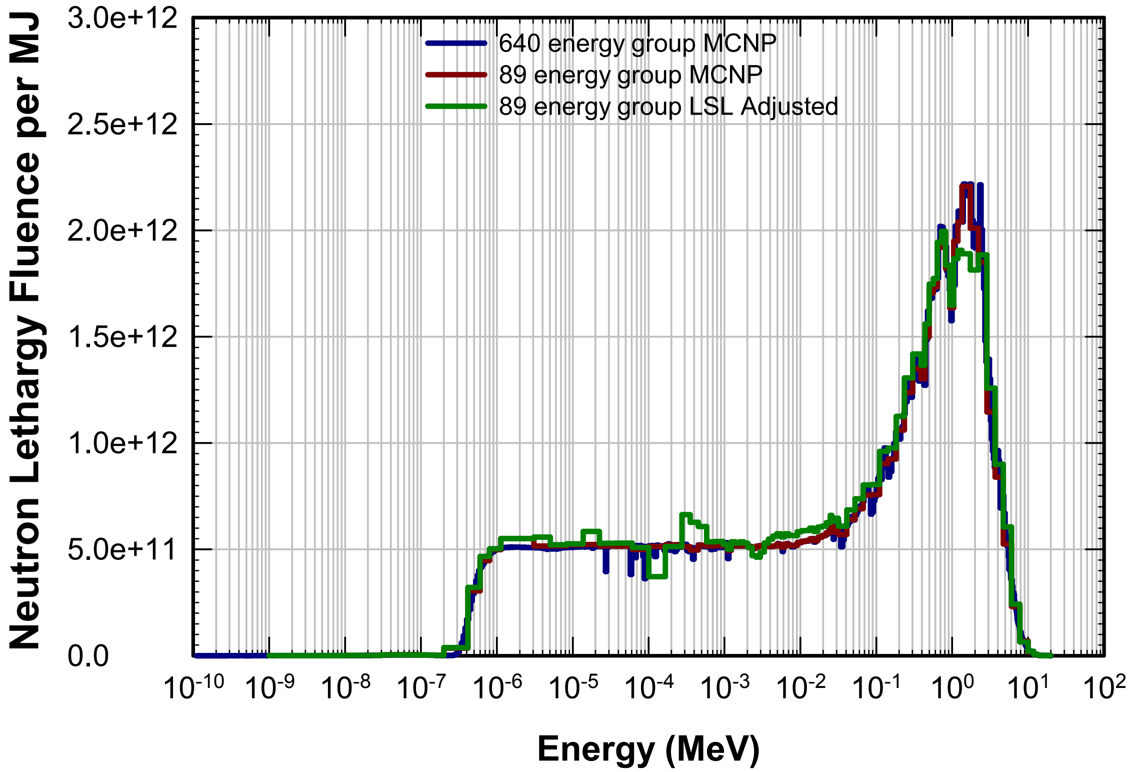

Figure 16. LSL Adjusted 89-Group Neutron Lethargy Fluence Energy Spectrum Compared to the MCNP Calculated Results (linear–log).

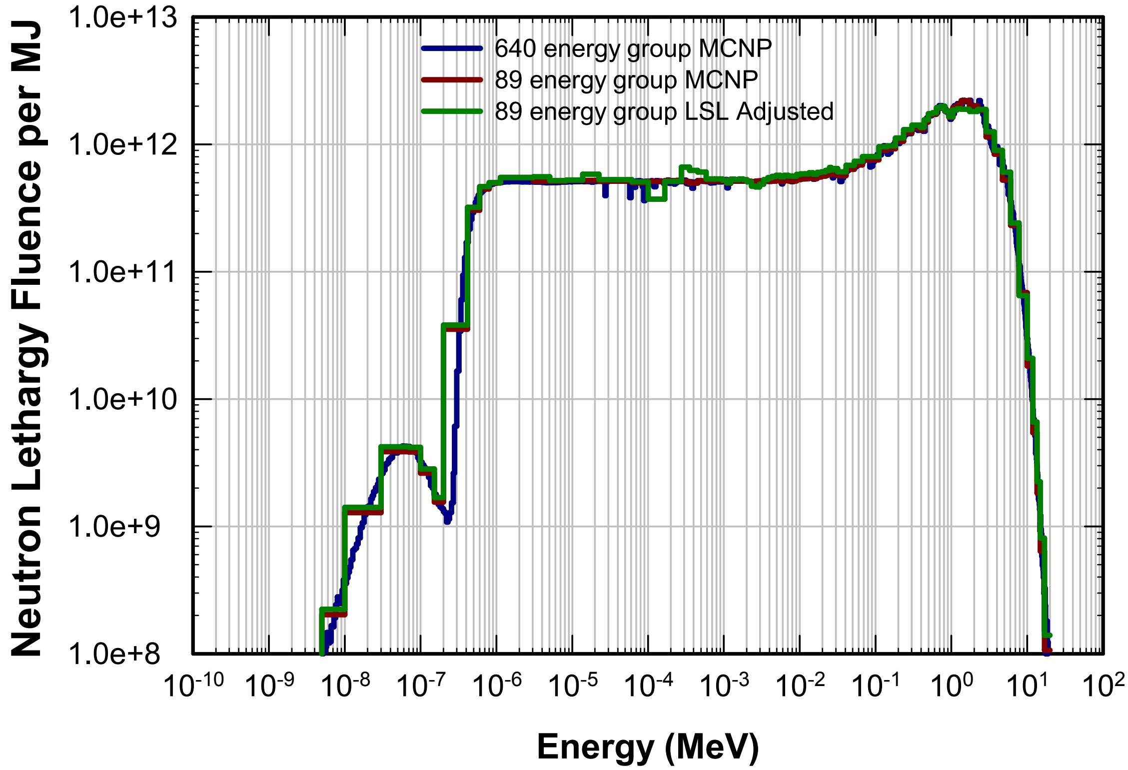

Figure 17. LSL Adjusted 89-Group Neutron Lethargy Fluence Energy Spectrum Compared to the MCNP Calculated Results (log–log).

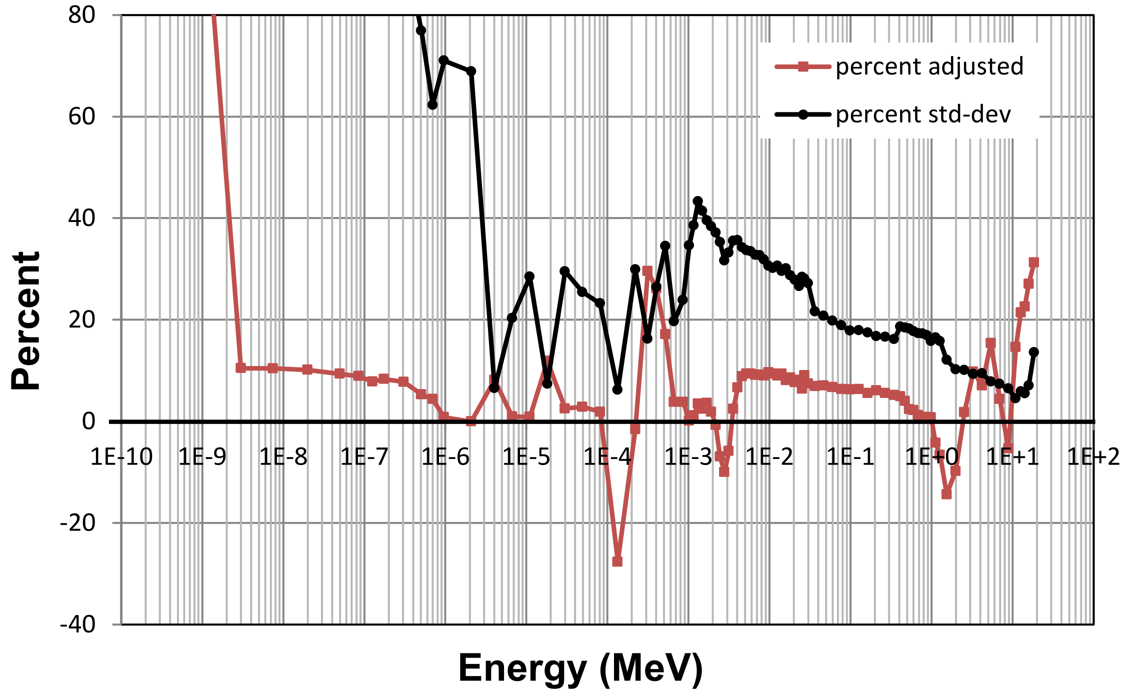

Figure 18. LSL Percent Adjustment to the Trial Spectrum and Standard Deviation Results for the 89-Group Adjusted Neutron Spectrum.

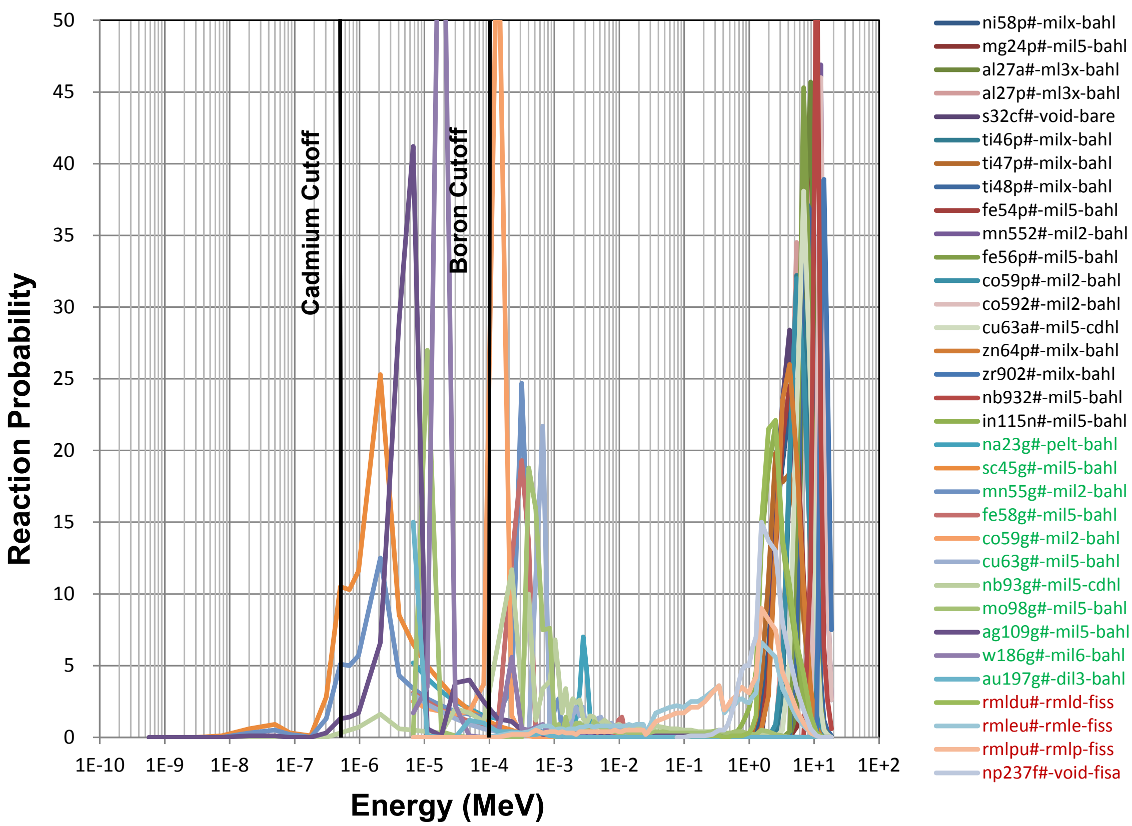

Figure 19. Relative Reaction Probabilities for the Complete Dosimetry Reaction Set.

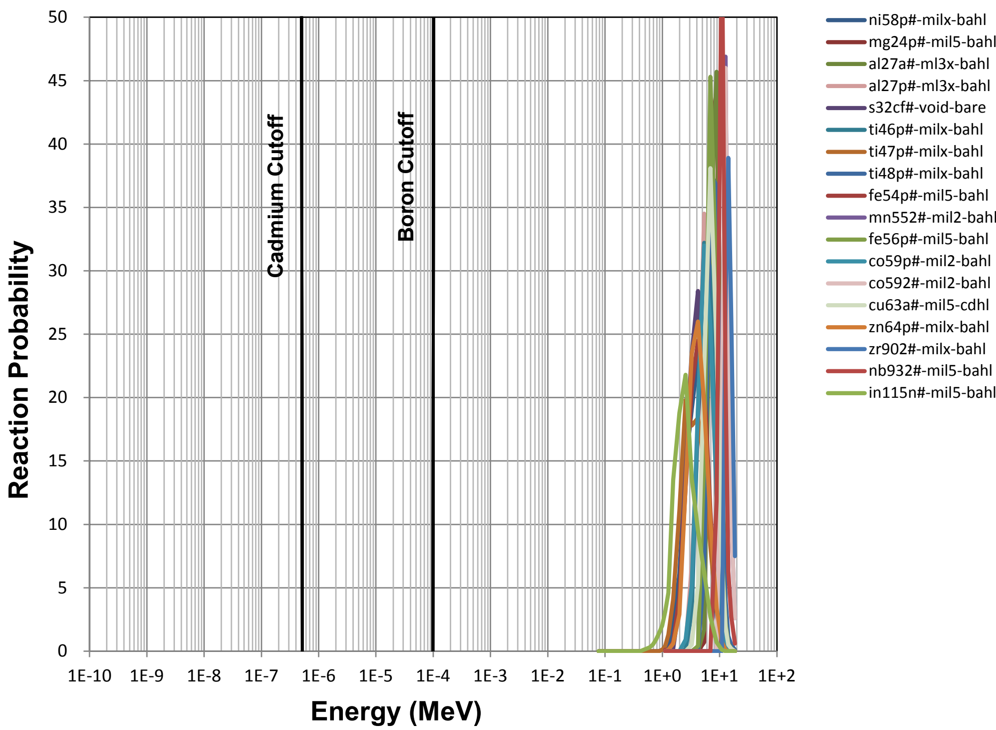

Figure 20. Relative Reaction Probabilities for the High Energy Dosimetry Reaction Set.

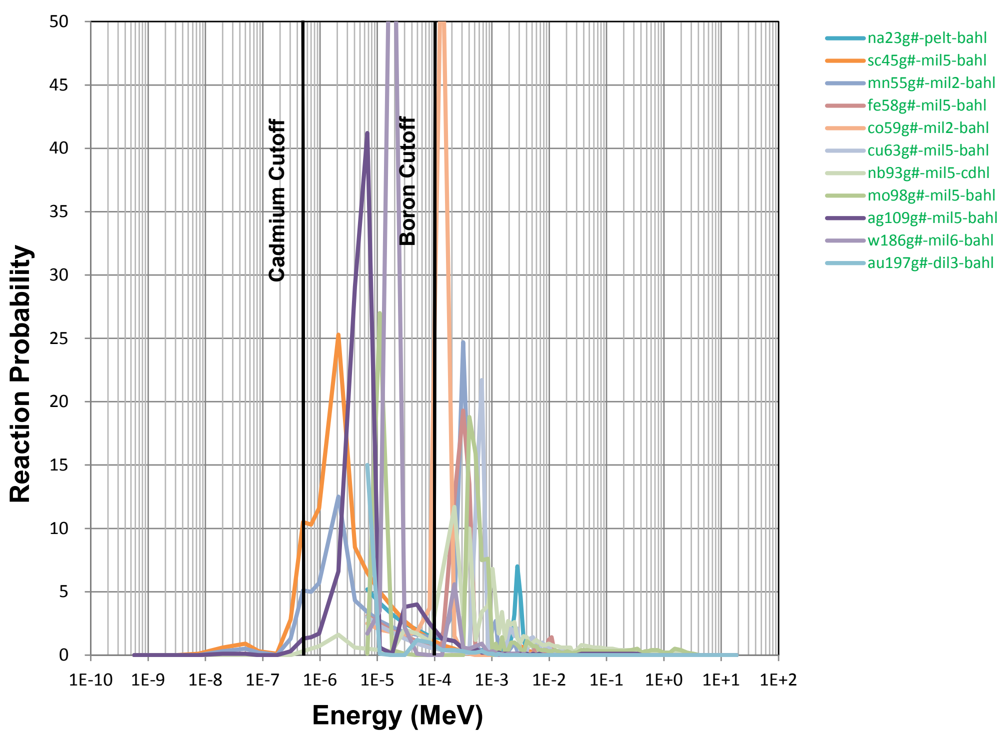

Figure 21. Relative Reaction Probabilities for the Radiative Capture Dosimetry Reaction Set.

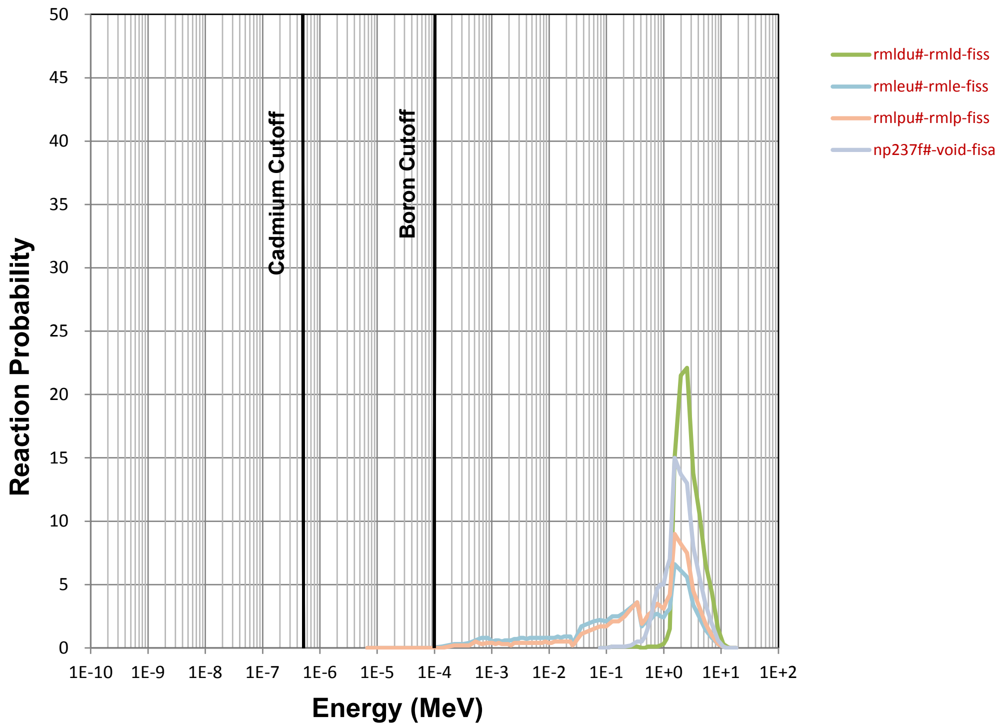

Figure 22. Relative Reaction Probabilities for the Fission Dosimetry Reaction Set.

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	-0.74	-0.74
$^{24}Mg(n,p)^{24}Na$	5.51	0.55	-4.93
$^{27}Al(n,p)^{27}Mg$	-3.97	-2.77	1.23
$^{27}Al(n,\alpha)^{24}Na$	5.87	1.49	-4.32
$^{32}S(n,p)^{32}P$ Cf-equ	6.61	4.41	-2.11
$^{46}Ti(n,p)^{46}Sc$	5.32	4.21	-1.07
$^{47}Ti(n,p)^{47}Sc$	-2.70	-4.86	-2.27
$^{48}Ti(n,p)^{48}Sc$	3.91	0.30	-3.60
$^{55}Mn(n,2n)^{54}Mn$	-14.18	-1.07	13.25
$^{54}Fe(n,p)^{54}Mn$	-1.42	-1.17	0.25
$^{56}Fe(n,p)^{56}Mn$	0.58	-1.14	-1.74
$^{59}Co(n,p)^{59}Fe$	0.06	0.77	0.70
$^{59}Co(n,2n)^{58}Co$	-7.79	5.21	12.36
$^{63}Cu(n,\alpha)^{60}Co$	-9.65	-9.44	0.23
$^{64}Zn(n,p)^{64}Cu$	-1.43	-1.07	0.36
$^{90}Zr(n,2n)^{89}Zr$	-14.90	0.35	15.20
$^{93}Nb(n,2n)^{92m}Nb$	-7.62	-0.48	7.17
$^{115}In(n,n')^{115m}In$	-5.99	-13.56	-8.76
$^{23}Na(n,\gamma)^{24}Na$	7.26	0.88	-6.32
$^{45}Sc(n,\gamma)^{46}Sc$	-0.18	-0.42	-0.24
$^{55}Mn(n,\gamma)^{56}Mn$	-3.73	-0.07	3.66
$^{58}Fe(n,\gamma)^{59}Fe$	-4.12	-0.31	3.82
$^{59}Co(n,\gamma)^{60}Co$	24.70	0.07	-24.61
$^{63}Cu(n,\gamma)^{64}Cu$	2.09	0.04	-2.05
$^{93}Nb(n,\gamma)^{94m}Nb$	25.00	16.58	-7.22
$^{98}Mo(n,\gamma)^{99}Mo$	-1.15	0.03	1.18
$^{109}Ag(n,\gamma)^{110m}Ag$	3.49	0.01	-3.48
$^{186}W(n,\gamma)^{187}W$	-2.51	-0.10	2.41
$^{197}Au(n,\gamma)^{198}Au$	0.26	-0.02	-0.28
$^{235}U(n,f)$FP - BB	0.04	-4.51	-4.76
$^{238}U(n,f)$FP - BB	12.80	5.02	-7.41
$^{237}Np(n,f)$FP - BB	11.91	3.04	-8.61
$^{239}Pu(n,f)$FP - BB	13.80	6.08	-7.28

Table 3 shows the adjusted neutron fluence spectrum in a tabular format for the 89-energy group NuGET 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 0.662 MeV. The peak differential number fraction occurs in energy group 11 at 0.7 eV. The differential fluence at 1 MeV (Group 74) is about five 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-Energy Group Adjusted Spectrum for ACRR-CdPoly-CC-32-cl.

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	2.48793E-07	2.06687E-16	2.76437E+02	1.52040E-07	250.39
2	1.0000E-09	5.0000E-09	3.0000E-09	3.04221E-06	1.37855E-14	7.60553E+02	2.28166E-06	213.61
3	5.0000E-09	1.0000E-08	7.5000E-09	1.17979E-05	1.33653E-13	2.35958E+03	1.76969E-05	196.51
4	1.0000E-08	3.0000E-08	2.0000E-08	1.11692E-04	3.37414E-12	5.58460E+03	1.11692E-04	168.98
5	3.0000E-08	7.0000E-08	5.0000E-08	2.66874E-04	2.01552E-11	6.67185E+03	3.33593E-04	148.08
6	7.0000E-08	1.0000E-07	8.5000E-08	1.16699E-04	1.49830E-11	3.88997E+03	3.30647E-04	135.67
7	1.0000E-07	1.5230E-07	1.2615E-07	9.26653E-05	1.76570E-11	1.77180E+03	2.23513E-04	124.13
8	1.5230E-07	2.0000E-07	1.7615E-07	3.60638E-05	9.59545E-12	7.56055E+02	1.33179E-04	115.74
9	2.0000E-07	4.1400E-07	3.0700E-07	2.10836E-03	9.77675E-10	9.85215E+03	3.02461E-03	93.52
10	4.1400E-07	6.0000E-07	5.0700E-07	9.32506E-03	7.14120E-09	5.01347E+04	2.54183E-02	76.91
11	6.0000E-07	8.0000E-07	7.0000E-07	1.05557E-02	1.11608E-08	5.27785E+04	3.69450E-02	62.29
12	8.0000E-07	1.1250E-06	9.6250E-07	1.34372E-02	1.95353E-08	4.13452E+04	3.97948E-02	70.98
13	1.1250E-06	3.0590E-06	2.0920E-06	4.02783E-02	1.27275E-07	2.08264E+04	4.35689E-02	68.90
14	3.0590E-06	5.0430E-06	4.0510E-06	2.16284E-02	1.32342E-07	1.09014E+04	4.41616E-02	6.51
15	5.0430E-06	8.3150E-06	6.6790E-06	2.02105E-02	2.03892E-07	6.17680E+03	4.12549E-02	20.32
16	8.3150E-06	1.3710E-05	1.1013E-05	2.04005E-02	3.39342E-07	3.78137E+03	4.16424E-02	28.45
17	1.3710E-05	2.2600E-05	1.8155E-05	2.26566E-02	6.21301E-07	2.54855E+03	4.62689E-02	7.35
18	2.2600E-05	3.7270E-05	2.9935E-05	2.05142E-02	9.27567E-07	1.39838E+03	4.18604E-02	29.54
19	3.7270E-05	6.1440E-05	4.9355E-05	2.05318E-02	1.53063E-06	8.49475E+02	4.19258E-02	25.46
20	6.1440E-05	1.0130E-04	8.1370E-05	1.97312E-02	2.42510E-06	4.95013E+02	4.02792E-02	23.23
21	1.0130E-04	1.6700E-04	1.3415E-04	1.44139E-02	2.92068E-06	2.19390E+02	2.94311E-02	6.18
22	1.6700E-04	2.7540E-04	2.2120E-04	1.98981E-02	6.64826E-06	1.83562E+02	4.06039E-02	29.88
23	2.7540E-04	3.5360E-04	3.1450E-04	1.30515E-02	6.20001E-06	1.66899E+02	5.24897E-02	16.27
24	3.5360E-04	4.5400E-04	4.0380E-04	1.23369E-02	7.52461E-06	1.22877E+02	4.96179E-02	26.41
25	4.5400E-04	5.8300E-04	5.1850E-04	1.19659E-02	9.37142E-06	9.27589E+01	4.80955E-02	34.52
26	5.8300E-04	7.4850E-04	6.6575E-04	1.05337E-02	1.05926E-05	6.36477E+01	4.23735E-02	19.69
27	7.4850E-04	9.6110E-04	8.5480E-04	1.05726E-02	1.36508E-05	4.97300E+01	4.25092E-02	23.85
28	9.6110E-04	1.0890E-03	1.0251E-03	5.17908E-03	8.01879E-06	4.04932E+01	4.15076E-02	34.63
29	1.0890E-03	1.2340E-03	1.1615E-03	4.95030E-03	8.68485E-06	3.41400E+01	3.96536E-02	38.60
30	1.2340E-03	1.3980E-03	1.3160E-03	5.27748E-03	1.04904E-05	3.21798E+01	4.23486E-02	43.31
31	1.3980E-03	1.5850E-03	1.4915E-03	5.25594E-03	1.18409E-05	2.81066E+01	4.19210E-02	41.41
32	1.5850E-03	1.7960E-03	1.6905E-03	5.29056E-03	1.35092E-05	2.50737E+01	4.23872E-02	39.53
33	1.7960E-03	2.0350E-03	1.9155E-03	5.22460E-03	1.51163E-05	2.18603E+01	4.18733E-02	38.37
34	2.0350E-03	2.3060E-03	2.1705E-03	5.03348E-03	1.65021E-05	1.85737E+01	4.03143E-02	37.13
35	2.3060E-03	2.6130E-03	2.4595E-03	4.64241E-03	1.72465E-05	1.51219E+01	3.71922E-02	35.25
36	2.6130E-03	2.9600E-03	2.7865E-03	4.56740E-03	1.92238E-05	1.31625E+01	3.66774E-02	31.63
37	2.9600E-03	3.3550E-03	3.1575E-03	4.82259E-03	2.30004E-05	1.22091E+01	3.85502E-02	33.23
38	3.3550E-03	3.8010E-03	3.5780E-03	5.22940E-03	2.82620E-05	1.17251E+01	4.19525E-02	35.51
39	3.8010E-03	4.3070E-03	4.0540E-03	5.41928E-03	3.31846E-05	1.07100E+01	4.34185E-02	35.64
40	4.3070E-03	4.8810E-03	4.5940E-03	5.55313E-03	3.85337E-05	9.67444E+00	4.44444E-02	34.22
41	4.8810E-03	5.5310E-03	5.2060E-03	5.66490E-03	4.45459E-05	8.71523E+00	4.53715E-02	33.68
42	5.5310E-03	6.2670E-03	5.8990E-03	5.51123E-03	4.91064E-05	7.48808E+00	4.41722E-02	33.49
43	6.2670E-03	7.1020E-03	6.6845E-03	5.66831E-03	5.72313E-05	6.78840E+00	4.53770E-02	32.77

44	7.1020E-03	8.0470E-03	7.5745E-03	5.57422E-03	6.37748E-05	5.89865E+00	4.46793E-02	32.70
45	8.0470E-03	9.1190E-03	8.5830E-03	5.57765E-03	7.23106E-05	5.20303E+00	4.46576E-02	31.84
46	9.1190E-03	1.0330E-02	9.7245E-03	5.74470E-03	8.43813E-05	4.74377E+00	4.61307E-02	30.63
47	1.0330E-02	1.1710E-02	1.1020E-02	5.82588E-03	9.69738E-05	4.22165E+00	4.65226E-02	30.14
48	1.1710E-02	1.3270E-02	1.2490E-02	5.81812E-03	1.09763E-04	3.72956E+00	4.65823E-02	30.59
49	1.3270E-02	1.5030E-02	1.4150E-02	5.90747E-03	1.26261E-04	3.35652E+00	4.74947E-02	29.57
50	1.5030E-02	1.7040E-02	1.6035E-02	5.79567E-03	1.40373E-04	2.88342E+00	4.62356E-02	30.07
51	1.7040E-02	1.9300E-02	1.8170E-02	5.95167E-03	1.63345E-04	2.63348E+00	4.78504E-02	28.75
52	1.9300E-02	2.1880E-02	2.0590E-02	6.03727E-03	1.87762E-04	2.34003E+00	4.81812E-02	27.83
53	2.1880E-02	2.4790E-02	2.3335E-02	6.17595E-03	2.17682E-04	2.12232E+00	4.95243E-02	26.62
54	2.4790E-02	2.6060E-02	2.5425E-02	2.60632E-03	1.00092E-04	2.05222E+00	5.21777E-02	28.41
55	2.6060E-02	2.8090E-02	2.7075E-02	3.75558E-03	1.53588E-04	1.85004E+00	5.00898E-02	28.10
56	2.8090E-02	3.1830E-02	2.9960E-02	6.38108E-03	2.88767E-04	1.70617E+00	5.11169E-02	27.21
57	3.1830E-02	4.0870E-02	3.6350E-02	1.19823E-02	6.57894E-04	1.32548E+00	4.81810E-02	21.59
58	4.0870E-02	5.2480E-02	4.6675E-02	1.34902E-02	9.51073E-04	1.16195E+00	5.42339E-02	20.79
59	5.2480E-02	6.7380E-02	5.9930E-02	1.45202E-02	1.31440E-03	9.74510E-01	5.84024E-02	19.77
60	6.7380E-02	8.6520E-02	7.6950E-02	1.58030E-02	1.83679E-03	8.25653E-01	6.35340E-02	18.89
61	8.6520E-02	1.1110E-01	9.8810E-02	1.58406E-02	2.36420E-03	6.44451E-01	6.36782E-02	17.84
62	1.1110E-01	1.4260E-01	1.2685E-01	1.88739E-02	3.61629E-03	5.99171E-01	7.60049E-02	17.93
63	1.4260E-01	1.8320E-01	1.6290E-01	1.92545E-02	4.73767E-03	4.74249E-01	7.72551E-02	17.47
64	1.8320E-01	2.3520E-01	2.0920E-01	2.21393E-02	6.99579E-03	4.25756E-01	8.90681E-02	16.75
65	2.3520E-01	3.0200E-01	2.6860E-01	2.57095E-02	1.04306E-02	3.84873E-01	1.03377E-01	16.63
66	3.0200E-01	3.8770E-01	3.4485E-01	2.79141E-02	1.45400E-02	3.25719E-01	1.12324E-01	16.16
67	3.8770E-01	4.3940E-01	4.1355E-01	1.35156E-02	8.44257E-03	2.61424E-01	1.08112E-01	18.66
68	4.3940E-01	4.9790E-01	4.6865E-01	1.54158E-02	1.09125E-02	2.63518E-01	1.23498E-01	18.44
69	4.9790E-01	5.6420E-01	5.3105E-01	1.72640E-02	1.38480E-02	2.60392E-01	1.38281E-01	18.21
70	5.6420E-01	6.3930E-01	6.0175E-01	1.75245E-02	1.59284E-02	2.33349E-01	1.40418E-01	17.74
71	6.3930E-01	7.2440E-01	6.8185E-01	1.92110E-02	1.97856E-02	2.25746E-01	1.53925E-01	17.36
72	7.2440E-01	8.2080E-01	7.7260E-01	1.97107E-02	2.30021E-02	2.04468E-01	1.57972E-01	17.26
73	8.2080E-01	9.3010E-01	8.7545E-01	1.81472E-02	2.39967E-02	1.66031E-01	1.45352E-01	16.94
74	9.3010E-01	1.0540E+00	9.9205E-01	1.63012E-02	2.44267E-02	1.31567E-01	1.30521E-01	15.79
75	1.0540E+00	1.1940E+00	1.1240E+00	1.84111E-02	3.12577E-02	1.31508E-01	1.47815E-01	16.51
76	1.1940E+00	1.3530E+00	1.2735E+00	1.88412E-02	3.62426E-02	1.18498E-01	1.50907E-01	15.77
77	1.3530E+00	1.7380E+00	1.5455E+00	3.72723E-02	8.70095E-02	9.68112E-02	1.49622E-01	12.08
78	1.7380E+00	2.2310E+00	1.9845E+00	3.56756E-02	1.06938E-01	7.23643E-02	1.43607E-01	10.23
79	2.2310E+00	2.8650E+00	2.5480E+00	3.71265E-02	1.42888E-01	5.85591E-02	1.49209E-01	10.11
80	2.8650E+00	3.6790E+00	3.2720E+00	2.47753E-02	1.22446E-01	3.04365E-02	9.95882E-02	9.29
81	3.6790E+00	4.7240E+00	4.2015E+00	1.77038E-02	1.12352E-01	1.69414E-02	7.11794E-02	9.47
82	4.7240E+00	6.0650E+00	5.3945E+00	1.19215E-02	9.71390E-02	8.89001E-03	4.79571E-02	7.82
83	6.0650E+00	7.7880E+00	6.9265E+00	4.76153E-03	4.98163E-02	2.76351E-03	1.91415E-02	7.35
84	7.7880E+00	1.0000E+01	8.8940E+00	1.28071E-03	1.72052E-02	5.78983E-04	5.14947E-03	6.46
85	1.0000E+01	1.1910E+01	1.0955E+01	2.88673E-04	4.77672E-03	1.51138E-04	1.65571E-03	4.50
86	1.1910E+01	1.3500E+01	1.2705E+01	6.53615E-05	1.25432E-03	4.11079E-05	5.22275E-04	5.91
87	1.3500E+01	1.4920E+01	1.4210E+01	1.77324E-05	3.80604E-04	1.24876E-05	1.77449E-04	5.48
88	1.4920E+01	1.6900E+01	1.5910E+01	7.97937E-06	1.91757E-04	4.02998E-06	6.41171E-05	7.07
89	1.6900E+01	2.0000E+01	1.8450E+01	1.85848E-06	5.17924E-05	5.99510E-07	1.10610E-05	13.61

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 bucket. 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 = 0.662 MeV	1.00	--
Fluence > 3 MeV	0.056	3.8
Fluence > 1 MeV	0.216	4.0
Fluence > 100 keV	0.467	2.8
Fluence > 10 keV	0.587	2.2
Fluence < 1 keV	0.316	3.8
Fluence < 1 eV	0.030	50.8
Fluence 1-MeV(Si) Eqv. E722-94 (Ref. 1-MeV value = 95 MeV-mb)	39.5 MeV-mb 0.439	2.6
Fluence 1-MeV(GaAs) Eqv. E722-94 (Ref. 1-MeV value = 70 MeV-mb	32.1 MeV-mb 0.459	2.3
$^{58}Ni(n,p)^{58}Co$ Spectrum Avg. Cross-Section IRDFF-1.02	28.90 mb	3.3
$^{32}S(n,p)^{32}P$ Spectrum Avg. Cross-Section IRDFF-1.02 (Ref. Cf spectrum = 74.10 mb +/- 2.6%)	18.33 mb	3.9
Total Fluence Conversion ([n/cm^2]/fission)	3.894E-04	0.4
Total Fluence Conversion ([n/cm^2]/MJ)	1.263E+13	2.0
Total Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([n/cm^2]/[Bq/atom$_{Ni\text{-}58}$])	3.055E+32	3.3
Total Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([n/cm^2]/[Bq/g$_{Ni\text{-}58}$])	2.939E+10	3.3
Power Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ (MJ/[Bq/atom$_{Ni\text{-}58}$])	2.419E+19	3.9
Power Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ (MJ/[Bq/g$_{Ni\text{-}58}$])	2.327E-03	3.9
Total Fluence Conversion From S Activation ([n/cm^2]/Fluence $^{32}S(n,p)$ Cf-eqv)	4.042	4.7

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

Table 5. Other Neutron Spectrum Metrics.

Metric	Integral Response
Total Si Dose (rad[Si]/[n/cm^2])	3.245E-11
Ionizing Si Dose (rad[Si]/[n/cm^2])	1.859E-11
Percent Neutron Si Dose Ionizing (%)	57.3
Total Carbon Dose (rad[C]/[n/cm^2])	1.487E-10
Total CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/[n/cm^2])	6.787E-11
Effective Ionizing CaF_2:Mn Dose (rad[CaF_2:Mn]/[n/cm^2])	7.245E-12
Percent Neutron CaF_2:Mn Dose total light (%)	10.7

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 ACRR fuel, and from radiative capture and inelastic scattering of neutrons in the ACRR fuel and structure, the central cavity, and the bucket. Delayed gamma rays are generated by fission-product decay in the ACRR fuel and decay from activated materials in the core. 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 the calculated integral response. 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.

MCNP Model 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 MCNP5-supplied 70c 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 70c 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 the ACRR, the total energy calculated for the prompt gamma rays (fission, radiative capture, and inelastic scattering) is ~13 MeV per fission.

Figures 23 and 24 show the MCNP-generated 48-energy group prompt gamma-ray 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 neutron energy on the x-axis represented logarithmically, the area under the curve represents the total prompt gamma-ray fluence. The fluence value for each energy group is represented at the average energy for the group. The gamma-ray energy fluence has a prominent peak at ~0.5 MeV.

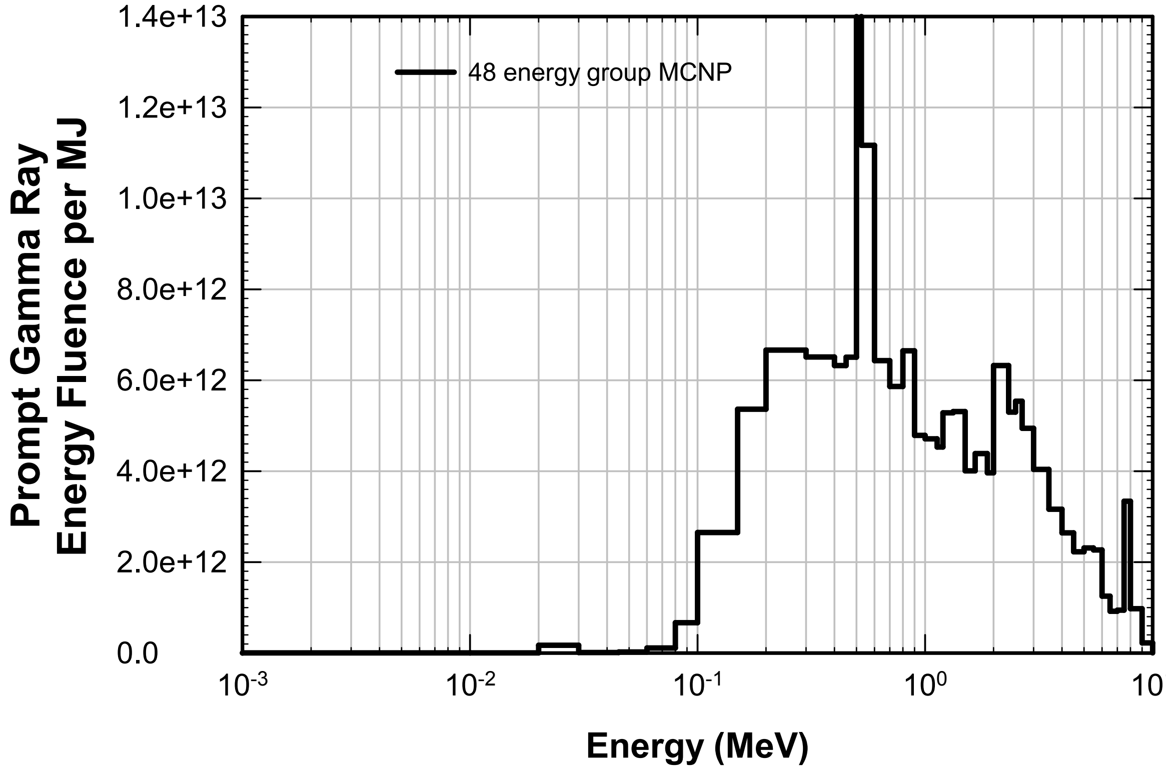

Figure 23. MCNP 48-Group Prompt Gamma-Ray Energy Spectrum (linear–log).

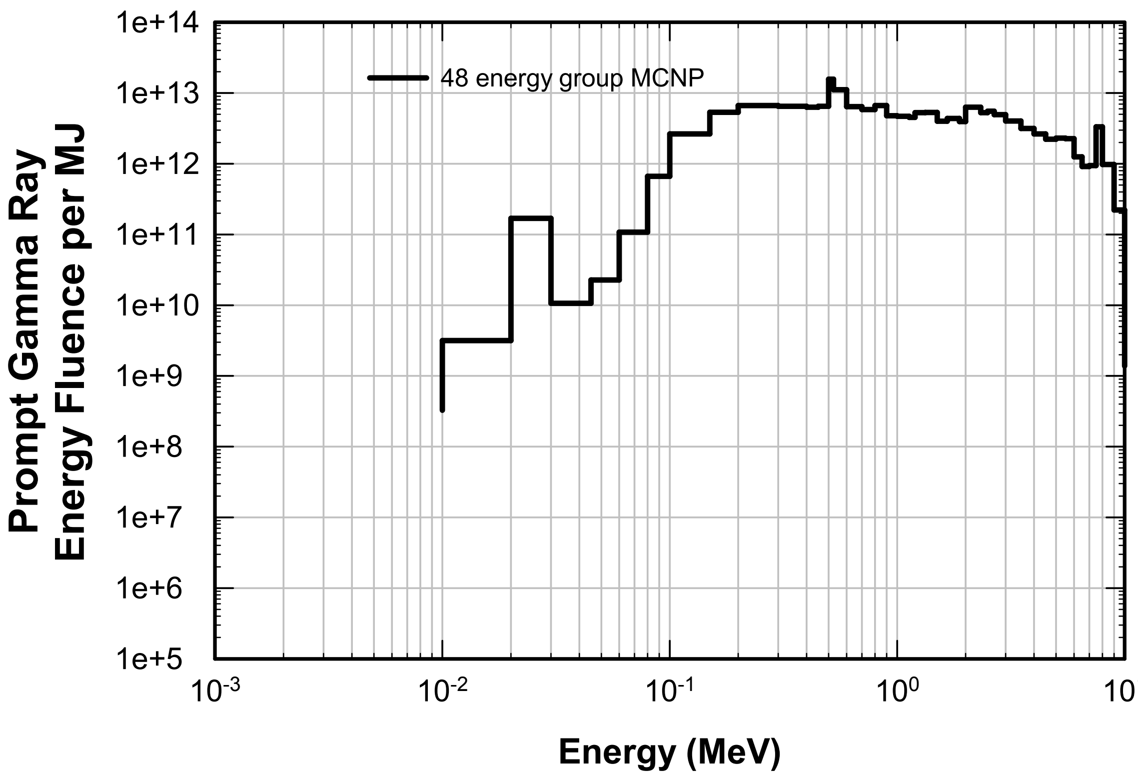

Figure 24. MCNP 48-Group Prompt Gamma-Ray Energy Spectrum (log–log).

Table 6 shows the prompt gamma-ray fluence spectrum in a tabular format for the 48-energy group NuGET 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 1.300 MeV. The peak differential number fraction occurs in energy group 14 at 0.5125 MeV. This is the large peak seen in Figure 23 and represents the electron-positron annihilation photon energy (0.511 MeV).

Table 6. Prompt Gamma-Ray 48-Energy Group Spectrum for ACRR-CdPoly-CC-32-cl.

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	2.40066E-05	1.01551E-07	2.66740E-03	1.46707E-05	81.49
2	1.0000E-02	2.0000E-02	1.5000E-02	9.49865E-05	1.09584E-06	9.49865E-03	1.42480E-04	64.92
3	2.0000E-02	3.0000E-02	2.5000E-02	3.05692E-03	5.87783E-05	3.05692E-01	7.64230E-03	52.23
4	3.0000E-02	4.5000E-02	3.7500E-02	1.91960E-04	5.53648E-06	1.27973E-02	4.79899E-04	42.15
5	4.5000E-02	6.0000E-02	5.2500E-02	2.93263E-04	1.18416E-05	1.95509E-02	1.02642E-03	34.78
6	6.0000E-02	8.0000E-02	7.0000E-02	1.39069E-03	7.48725E-05	6.95346E-02	4.86743E-03	33.52
7	8.0000E-02	1.0000E-01	9.0000E-02	6.65157E-03	4.60426E-04	3.32578E-01	2.99321E-02	32.41
8	1.0000E-01	1.5000E-01	1.2500E-01	4.77233E-02	4.58810E-03	9.54466E-01	1.19308E-01	30.96
9	1.5000E-01	2.0000E-01	1.7500E-01	6.89801E-02	9.28441E-03	1.37960E+00	2.41430E-01	29.48
10	2.0000E-01	3.0000E-01	2.5000E-01	1.20017E-01	2.30768E-02	1.20017E+00	3.00042E-01	27.90
11	3.0000E-01	4.0000E-01	3.5000E-01	8.37848E-02	2.25541E-02	8.37848E-01	2.93247E-01	26.42
12	4.0000E-01	4.5000E-01	4.2500E-01	3.35075E-02	1.09528E-02	6.70149E-01	2.84813E-01	25.56
13	4.5000E-01	5.0000E-01	4.7500E-01	3.08393E-02	1.12666E-02	6.16786E-01	2.92973E-01	25.07
14	5.0000E-01	5.2500E-01	5.1250E-01	3.45336E-02	1.36122E-02	1.38134E+00	7.07938E-01	24.74
15	5.2500E-01	6.0000E-01	5.6250E-01	6.70395E-02	2.90032E-02	8.93860E-01	5.02796E-01	24.33
16	6.0000E-01	7.0000E-01	6.5000E-01	4.45638E-02	2.22787E-02	4.45638E-01	2.89665E-01	23.69
17	7.0000E-01	8.0000E-01	7.5000E-01	3.51790E-02	2.02926E-02	3.51790E-01	2.63842E-01	23.06
18	8.0000E-01	9.0000E-01	8.5000E-01	3.52090E-02	2.30179E-02	3.52090E-01	2.99276E-01	22.50
19	9.0000E-01	1.0000E+00	9.5000E-01	2.26697E-02	1.65639E-02	2.26697E-01	2.15362E-01	22.01
20	1.0000E+00	1.1250E+00	1.0625E+00	2.58789E-02	2.11479E-02	2.07031E-01	2.19970E-01	21.52
21	1.1250E+00	1.2000E+00	1.1625E+00	1.22511E-02	1.09537E-02	1.63348E-01	1.89892E-01	21.12
22	1.2000E+00	1.3300E+00	1.2650E+00	2.44290E-02	2.37678E-02	1.87916E-01	2.37713E-01	20.75
23	1.3300E+00	1.5000E+00	1.4150E+00	2.87131E-02	3.12485E-02	1.68900E-01	2.38994E-01	20.26
24	1.5000E+00	1.6600E+00	1.5800E+00	1.82575E-02	2.21866E-02	1.14109E-01	1.80292E-01	20.00
25	1.6600E+00	1.8750E+00	1.7675E+00	2.45290E-02	3.33451E-02	1.14088E-01	2.01651E-01	20.00
26	1.8750E+00	2.0000E+00	1.9375E+00	1.10287E-02	1.64346E-02	8.82295E-02	1.70945E-01	20.00
27	2.0000E+00	2.3330E+00	2.1665E+00	4.34009E-02	7.23187E-02	1.30333E-01	2.82367E-01	20.00
28	2.3330E+00	2.5000E+00	2.4165E+00	1.67883E-02	3.12022E-02	1.00529E-01	2.42927E-01	20.00
29	2.5000E+00	2.6600E+00	2.5800E+00	1.64000E-02	3.25429E-02	1.02500E-01	2.64449E-01	20.00
30	2.6600E+00	3.0000E+00	2.8300E+00	2.58844E-02	5.63402E-02	7.61307E-02	2.15450E-01	20.00
31	3.0000E+00	3.5000E+00	3.2500E+00	2.79697E-02	6.99140E-02	5.59394E-02	1.81803E-01	20.00
32	3.5000E+00	4.0000E+00	3.7500E+00	1.89846E-02	5.47551E-02	3.79691E-02	1.42384E-01	20.00
33	4.0000E+00	4.5000E+00	4.2500E+00	1.39941E-02	4.57431E-02	2.79881E-02	1.18950E-01	20.00
34	4.5000E+00	5.0000E+00	4.7500E+00	1.05386E-02	3.85007E-02	2.10772E-02	1.00117E-01	20.00
35	5.0000E+00	5.5000E+00	5.2500E+00	9.90813E-03	4.00077E-02	1.98163E-02	1.04035E-01	20.00
36	5.5000E+00	6.0000E+00	5.7500E+00	8.87043E-03	3.92288E-02	1.77409E-02	1.02010E-01	20.00
37	6.0000E+00	6.5000E+00	6.2500E+00	4.50766E-03	2.16683E-02	9.01532E-03	5.63457E-02	22.00
38	6.5000E+00	7.0000E+00	6.7500E+00	3.05941E-03	1.58831E-02	6.11883E-03	4.13021E-02	25.76
39	7.0000E+00	7.5000E+00	7.2500E+00	2.92797E-03	1.63266E-02	5.85593E-03	4.24555E-02	29.26
40	7.5000E+00	8.0000E+00	7.7500E+00	9.69314E-03	5.77775E-02	1.93863E-02	1.50244E-01	32.53
41	8.0000E+00	9.0000E+00	8.5000E+00	5.16803E-03	3.37860E-02	5.16803E-03	4.39283E-02	37.05
42	9.0000E+00	1.0000E+01	9.5000E+00	1.05659E-03	7.72013E-03	1.05659E-03	1.00376E-02	42.49
43	1.0000E+01	1.2000E+01	1.1000E+01	1.13255E-05	9.58172E-05	5.66276E-06	6.22903E-05	48.26
44	1.2000E+01	1.4000E+01	1.3000E+01	9.90981E-08	9.90835E-07	4.95490E-08	6.44137E-07	53.97
45	1.4000E+01	1.7000E+01	1.5500E+01	3.55270E-09	4.23529E-08	1.18423E-09	1.83556E-08	59.98
46	1.7000E+01	2.0000E+01	1.8500E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	66.02
47	2.0000E+01	3.0000E+01	2.5000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	76.31
48	3.0000E+01	5.0000E+01	4.0000E+01	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00	92.37

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 D of this report. The uncertainty and covariance matrix represents a combination of expert judgment and perturbation analyses using MCNP. 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-energy group gamma-ray spectrum and the NuGET code with various response functions. Included are responses for Si dose, C dose, and TLD dose.

Table 7. Prompt Gamma-Ray Spectrum Metrics.

Metric	Integral Response
Average gamma-ray energy (MeV)	1.300
Fluence Conversion ($[\gamma/cm^2]/[n/cm^2]$)	1.800
Fluence Conversion ($[\gamma/cm^2]$/fission)	7.009E-04
Fluence Conversion ($[\gamma/cm^2]$/MJ)	2.273E+13
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ($[\gamma/cm^2]/[Bq/atom_{Ni\text{-}58}]$)	5.499E+32
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ($[\gamma/cm^2]/[Bq/g_{Ni\text{-}58}]$)	5.290E+10
Total (Ionizing) Si Dose (rad[Si]/$[\gamma/cm^2]$)	4.861E-10
Total (Ionizing) Carbon Dose (rad[C]/$[\gamma/cm^2]$)	4.564E-10
Total (Ionizing) CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/$[\gamma/cm^2]$)	4.837E-10

3.3 Delayed Gamma Ray

Delayed gamma rays are generated by fission-product decay in the ACRR fuel and by the decay of activated materials in the reactor core. MCNP does not intrinsically calculate the source for these gamma rays. MCNPX or MCNP6 could 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 ACRR fuel to the detector sphere in the central cavity.

MCNP Model 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 ACRR and bucket configuration was used with a represented fission product gamma-ray source energy spectrum. The same 48-energy group structure was used as was used 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 ACRR 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-VII.1. 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 25 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. Figure 26 shows the time-integrated energy fraction from the emission of the delayed gamma rays on a per fission basis. 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).

Figures 27 and 28 show the MCNP-generated 48-energy group delayed gamma-ray 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 neutron 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.

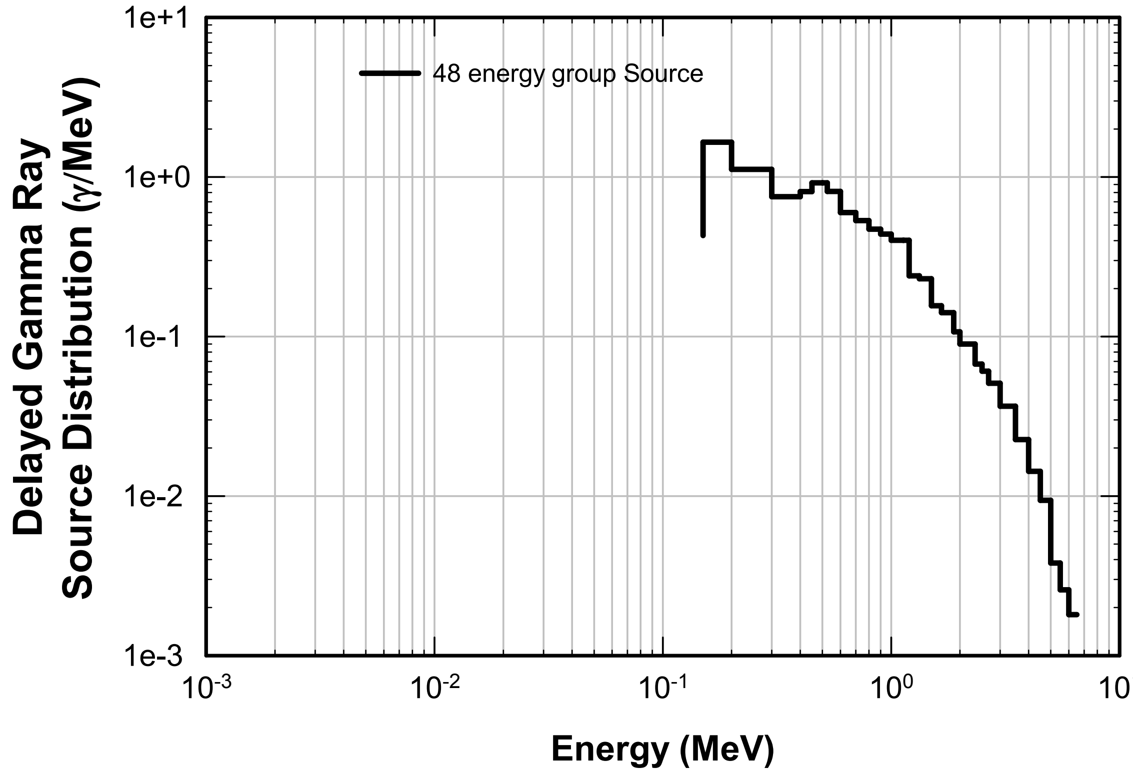

Figure 25. Delayed Gamma-Ray Source Distribution Used for MCNP Analysis.

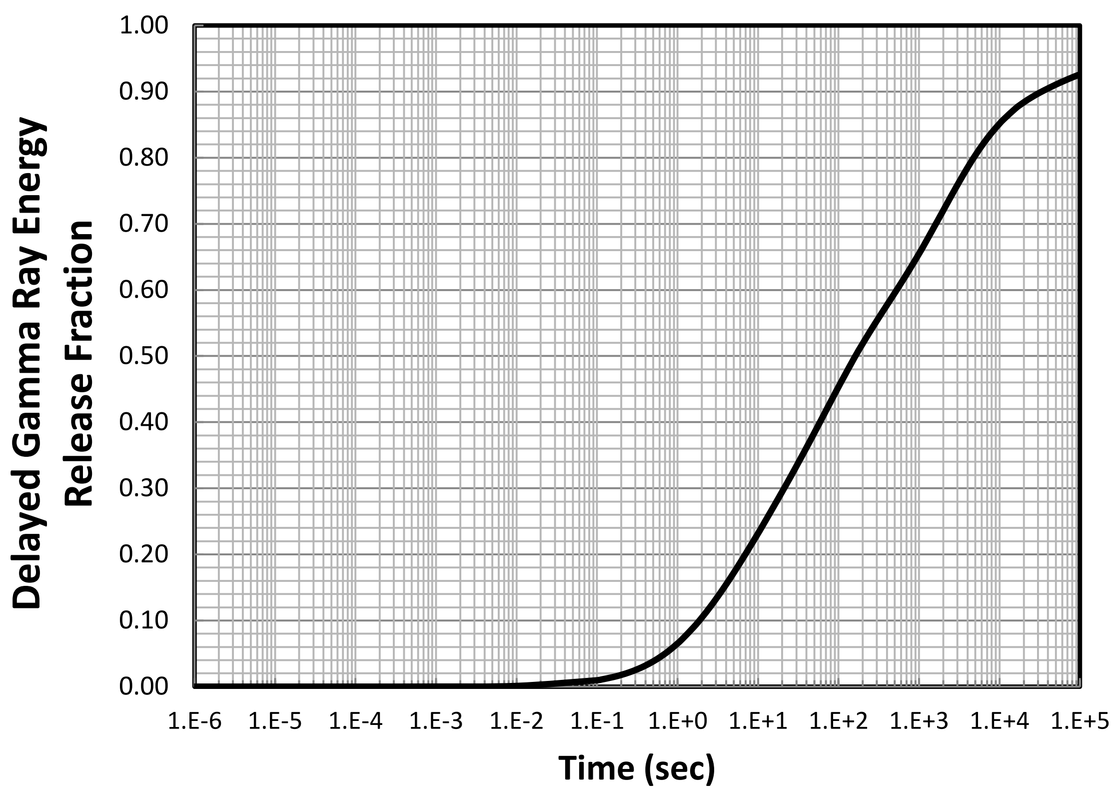

Figure 26. Time Dependent Delayed Gamma-Ray Energy Release Fraction from Fission.

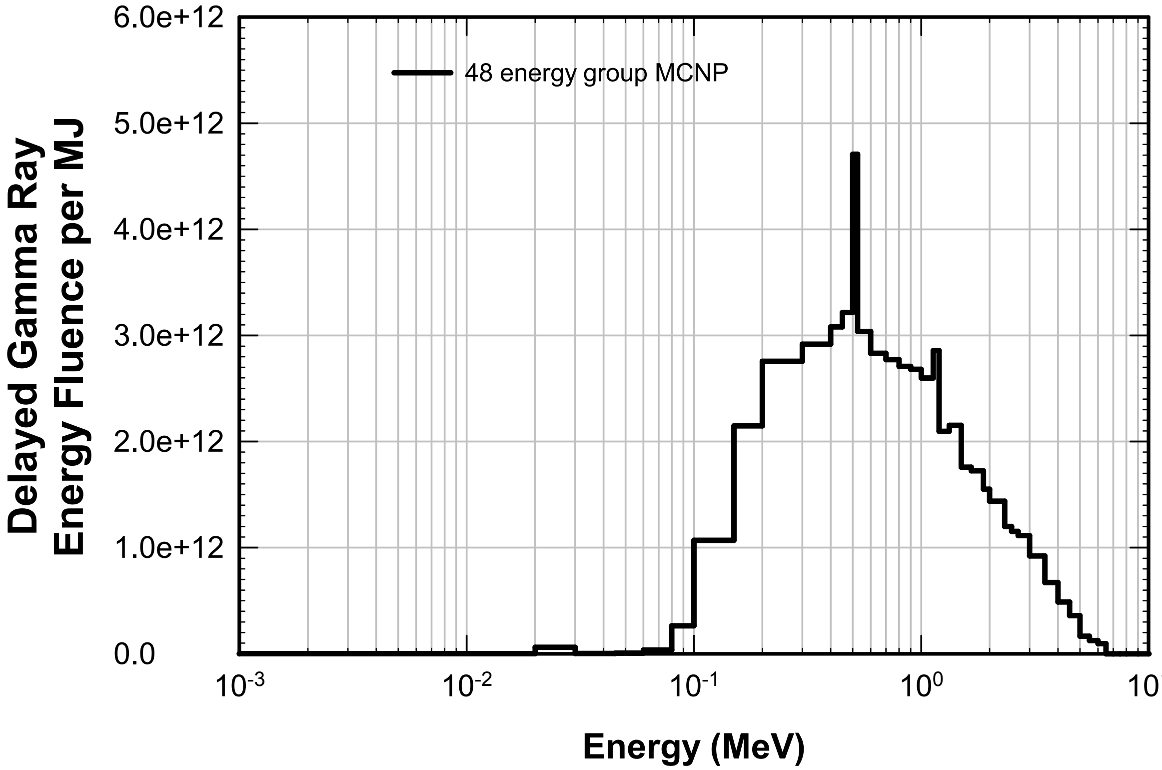

Figure 27. MCNP 48-Group Delayed Gamma-Ray Energy Spectrum (lin–log).

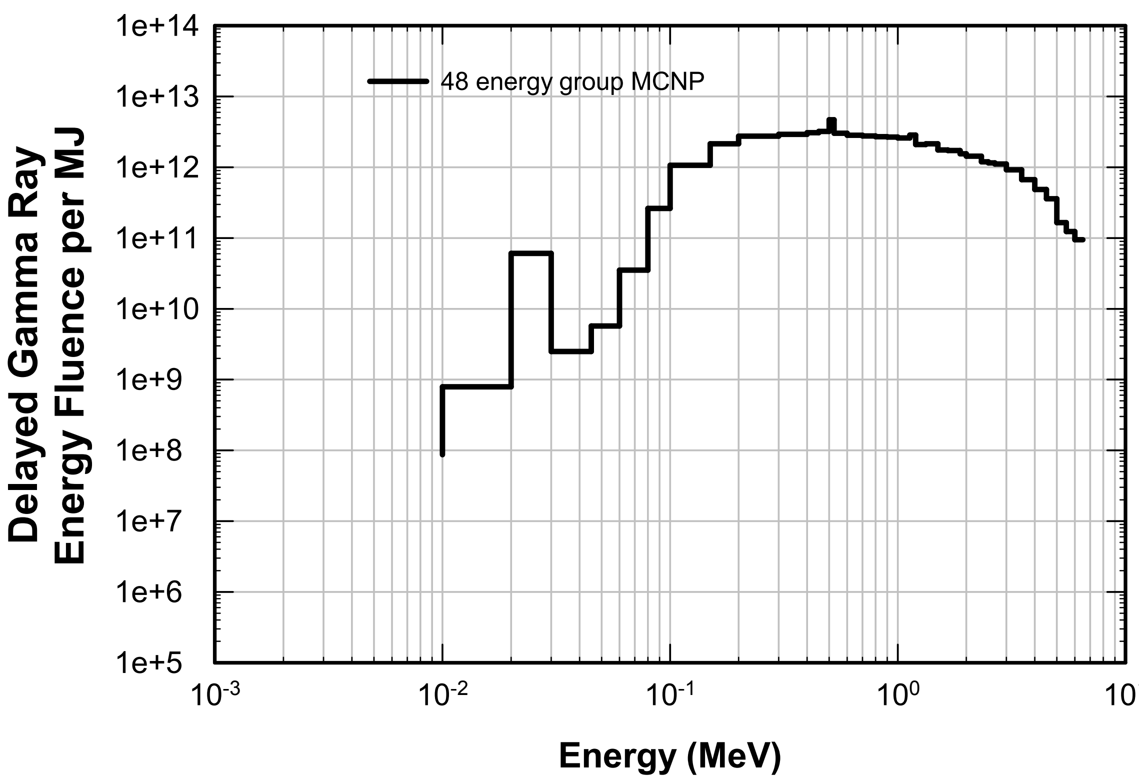

Figure 28. MCNP 48-Group Delayed Gamma-Ray Energy Spectrum (log–log).

Table 8 shows the delayed gamma-ray fluence spectrum in a tabular format for the 48-energy group NuGET 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 0.881 MeV. The peak differential number fraction again occurs in energy group 14 at 0.5125 MeV. This is the large peak seen in Figure 28 and represents the electron-positron annihilation photon energy (0.511 MeV).

Table 8. Delayed Gamma-Ray 48-Energy Group Spectrum for ACRR-CdPoly-CC-32-cl.

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	1.73938E-05	1.08584E-07	1.93265E-03	1.06296E-05	102.26
2	1.0000E-02	2.0000E-02	1.5000E-02	6.46482E-05	1.10067E-06	6.46482E-03	9.69724E-05	101.64
3	2.0000E-02	3.0000E-02	2.5000E-02	2.99848E-03	8.50846E-05	2.99848E-01	7.49621E-03	101.50
4	3.0000E-02	4.5000E-02	3.7500E-02	1.22784E-04	5.22614E-06	8.18557E-03	3.06959E-04	74.71
5	4.5000E-02	6.0000E-02	5.2500E-02	2.01256E-04	1.19927E-05	1.34170E-02	7.04395E-04	53.46
6	6.0000E-02	8.0000E-02	7.0000E-02	1.24333E-03	9.87856E-05	6.21665E-02	4.35166E-03	53.39
7	8.0000E-02	1.0000E-01	9.0000E-02	7.17715E-03	7.33168E-04	3.58857E-01	3.22972E-02	54.04
8	1.0000E-01	1.5000E-01	1.2500E-01	5.25341E-02	7.45350E-03	1.05068E+00	1.31335E-01	46.59
9	1.5000E-01	2.0000E-01	1.7500E-01	7.53933E-02	1.49755E-02	1.50787E+00	2.63877E-01	42.42
10	2.0000E-01	3.0000E-01	2.5000E-01	1.35536E-01	3.84594E-02	1.35536E+00	3.38839E-01	42.26
11	3.0000E-01	4.0000E-01	3.5000E-01	1.02486E-01	4.07138E-02	1.02486E+00	3.58701E-01	42.27
12	4.0000E-01	4.5000E-01	4.2500E-01	4.45531E-02	2.14920E-02	8.91062E-01	3.78701E-01	44.29
13	4.5000E-01	5.0000E-01	4.7500E-01	4.16120E-02	2.24348E-02	8.32240E-01	3.95314E-01	41.90
14	5.0000E-01	5.2500E-01	5.1250E-01	2.82233E-02	1.64176E-02	1.12893E+00	5.78577E-01	38.54
15	5.2500E-01	6.0000E-01	5.6250E-01	4.97993E-02	3.17947E-02	6.63991E-01	3.73495E-01	38.97
16	6.0000E-01	7.0000E-01	6.5000E-01	5.35667E-02	3.95201E-02	5.35667E-01	3.48184E-01	14.55
17	7.0000E-01	8.0000E-01	7.5000E-01	4.54459E-02	3.86870E-02	4.54459E-01	3.40844E-01	10.71
18	8.0000E-01	9.0000E-01	8.5000E-01	3.91419E-02	3.77633E-02	3.91419E-01	3.32707E-01	9.11
19	9.0000E-01	1.0000E+00	9.5000E-01	3.46841E-02	3.73993E-02	3.46841E-01	3.29499E-01	7.97
20	1.0000E+00	1.1250E+00	1.0625E+00	3.89825E-02	4.70119E-02	3.11860E-01	3.31351E-01	7.17
21	1.1250E+00	1.2000E+00	1.1625E+00	2.11051E-02	2.78477E-02	2.81401E-01	3.27128E-01	5.45
22	1.2000E+00	1.3300E+00	1.2650E+00	2.64743E-02	3.80123E-02	2.03648E-01	2.57615E-01	4.59
23	1.3300E+00	1.5000E+00	1.4150E+00	3.17838E-02	5.10472E-02	1.86964E-01	2.64554E-01	4.72
24	1.5000E+00	1.6600E+00	1.5800E+00	2.18783E-02	3.92356E-02	1.36740E-01	2.16049E-01	5.08
25	1.6600E+00	1.8750E+00	1.7675E+00	2.63274E-02	5.28173E-02	1.22453E-01	2.16436E-01	5.12
26	1.8750E+00	2.0000E+00	1.9375E+00	1.17894E-02	2.59264E-02	9.43150E-02	1.82735E-01	5.32
27	2.0000E+00	2.3330E+00	2.1665E+00	2.69395E-02	6.62458E-02	8.08995E-02	1.75269E-01	6.01
28	2.3330E+00	2.5000E+00	2.4165E+00	1.03693E-02	2.84411E-02	6.20917E-02	1.50044E-01	6.89
29	2.5000E+00	2.6600E+00	2.5800E+00	9.31184E-03	2.72687E-02	5.81990E-02	1.50153E-01	7.48
30	2.6600E+00	3.0000E+00	2.8300E+00	1.59185E-02	5.11327E-02	4.68192E-02	1.32498E-01	8.42
31	3.0000E+00	3.5000E+00	3.2500E+00	1.74383E-02	6.43275E-02	3.48766E-02	1.13349E-01	9.95
32	3.5000E+00	4.0000E+00	3.7500E+00	1.09920E-02	4.67863E-02	2.19841E-02	8.24402E-02	11.56
33	4.0000E+00	4.5000E+00	4.2500E+00	7.04223E-03	3.39710E-02	1.40845E-02	5.98590E-02	12.94
34	4.5000E+00	5.0000E+00	4.7500E+00	4.64911E-03	2.50653E-02	9.29823E-03	4.41666E-02	14.12
35	5.0000E+00	5.5000E+00	5.2500E+00	1.94326E-03	1.15798E-02	3.88652E-03	2.04042E-02	15.14
36	5.5000E+00	6.0000E+00	5.7500E+00	1.32238E-03	8.63044E-03	2.64476E-03	1.52074E-02	16.02
37	6.0000E+00	6.5000E+00	6.2500E+00	9.31320E-04	6.60676E-03	1.86264E-03	1.16415E-02	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 bucket. 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-energy group gamma-ray spectrum and the NuGET code with various response functions. Included are responses for Si dose, C dose, and TLD dose.

Table 9. Delayed Gamma-Ray Spectrum Metrics.

Metric	Integral Response
Average delayed gamma-ray (dγ) energy (MeV)	0.881
Fluence Conversion ([dγ/cm^2]/[source dγ])	3.819E-05
Source Delayed Gamma Rays (source dγ/fission)	6.567
Fluence Conversion ([dγ/cm^2]/[γ/cm^2])	0.366
Fluence Conversion ([dγ/cm^2]/fission)	2.508E-04
Fluence Conversion ([dγ/cm^2]/MJ)	8.329E+12
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([dγ/cm^2]/[Bq/atom$_{Ni\text{-}58}$])	2.013E+32
Fluence Conversion From Ni Activation $^{58}Ni(n,p)^{58}Co$ ([dγ/cm^2]/[Bq/g$_{Ni\text{-}58}$])	1.936E+10
Total (Ionizing) Si Dose (rad[Si]/[dγ/cm^2])	3.617E-10
Total (Ionizing) Carbon Dose (rad[C]/[dγ/cm^2])	3.498E-10
Total (Ionizing) CaF_2:Mn (TLD) Dose (rad[CaF_2:Mn]/[dγ/cm^2])	3.608E-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 CdPoly bucket on the 32-inch pedestal. 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 a mode. Sulfur tablets and TLDs were used for the axial profiles and for the radial profiles. The axial profiles were performed at the radial centerline of the bucket. The radial profiles were performed at an axial position 11 inches from the inside bottom of the bucket. Figures 29 shows the axial dosimetry fixture with sulfur tablets and TLDs at 1 cm increments along the axial height within the CdPoly bucket. Figure 30 shows the radial dosimetry fixture used for sulfur tablets and TLDs.

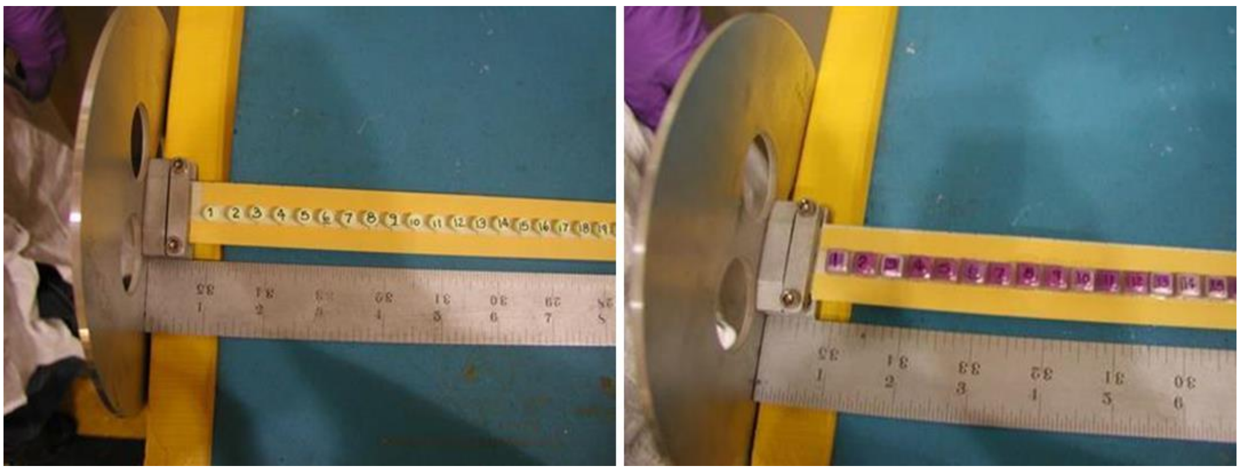

Figure 29. Axial Profile Mapping Fixture for Sulfur Tablets (left) and TLDs (right).

Figure 30. Radial Profile Mapping Fixture for Sulfur Tablets.

Neutron-Sulfur Map

Figure 31 shows the results for the sulfur axial (vertical) neutron fast fluence profile along the center axis for the CdPoly bucket. 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 y-axis is in units of californium (^{252}Cf) equivalent fluence, which is related to how a transfer calibration from NIST is used to calibrate the sulfur beta counter. The results show that the peak occurs at about 32 cm (~12.5 in.) from the bottom of the inside of the bucket. The peak is relatively flat between the regions of 25 cm to 35 cm, covering a range of about 10 cm (~4 in.). For reference, the axial fuel centerline is ~31 cm (12.1 inches) from the bottom of the inside of the PLG bucket. The ACRR fuel is 52.25 cm in length (20.57 inches). The range in which the fuel extends in Figure 31 is from ~5 cm to ~57 cm.

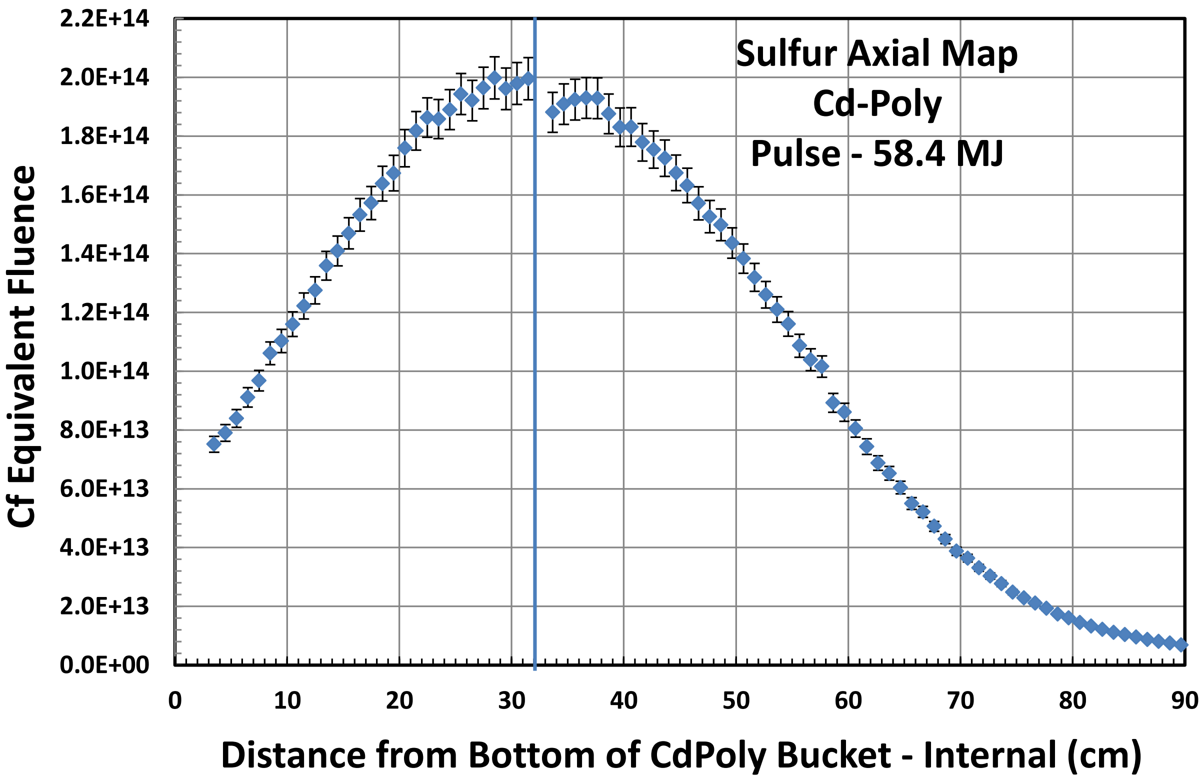

Figure 31. Sulfur Axial Neutron Fluence Profile for CdPoly.

Figures 32 through 35 show the results for the sulfur radial neutron fluence profile for the CdPoly bucket at an axial position of 11 inches from the bottom of the bucket. Measurements were made parallel and perpendicular to the front face of the FREC-II, and at 45° angles. The sulfur tablets were arranged on a plate that covered the complete area within the 7.5-inch-diameter bucket. All of the plots have the same y-axis scaling. The solid line represents the average value for all of the tablets measured on the plate. The counting uncertainties are within each data point symbol. The error bar represents the total uncertainty for the conversion to the californium equivalent fluence. The results show that for the sulfur activation reactions, there is no significant variation in the fast neutron fluence across the internal diameter of the bucket at the peak axial location.

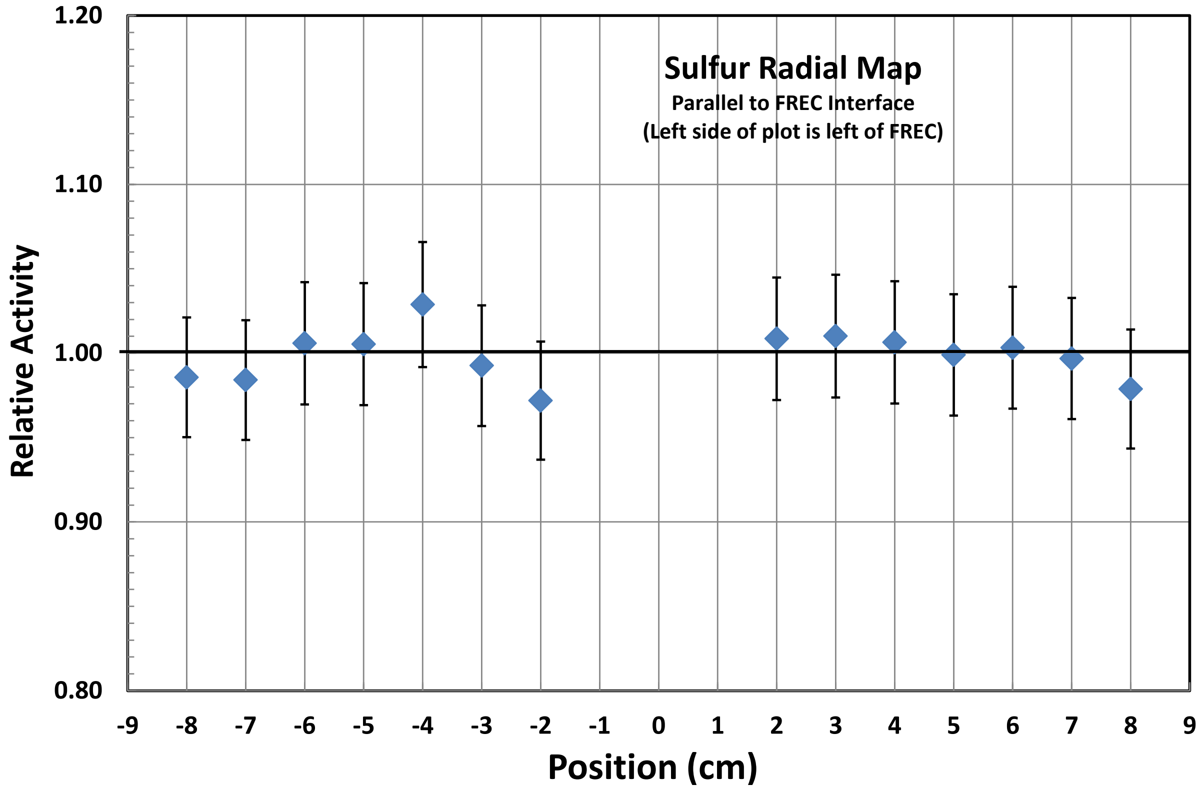

Figure 32. Sulfur Radial Neutron Fluence Profile for CdPoly Parallel to FREC Face.

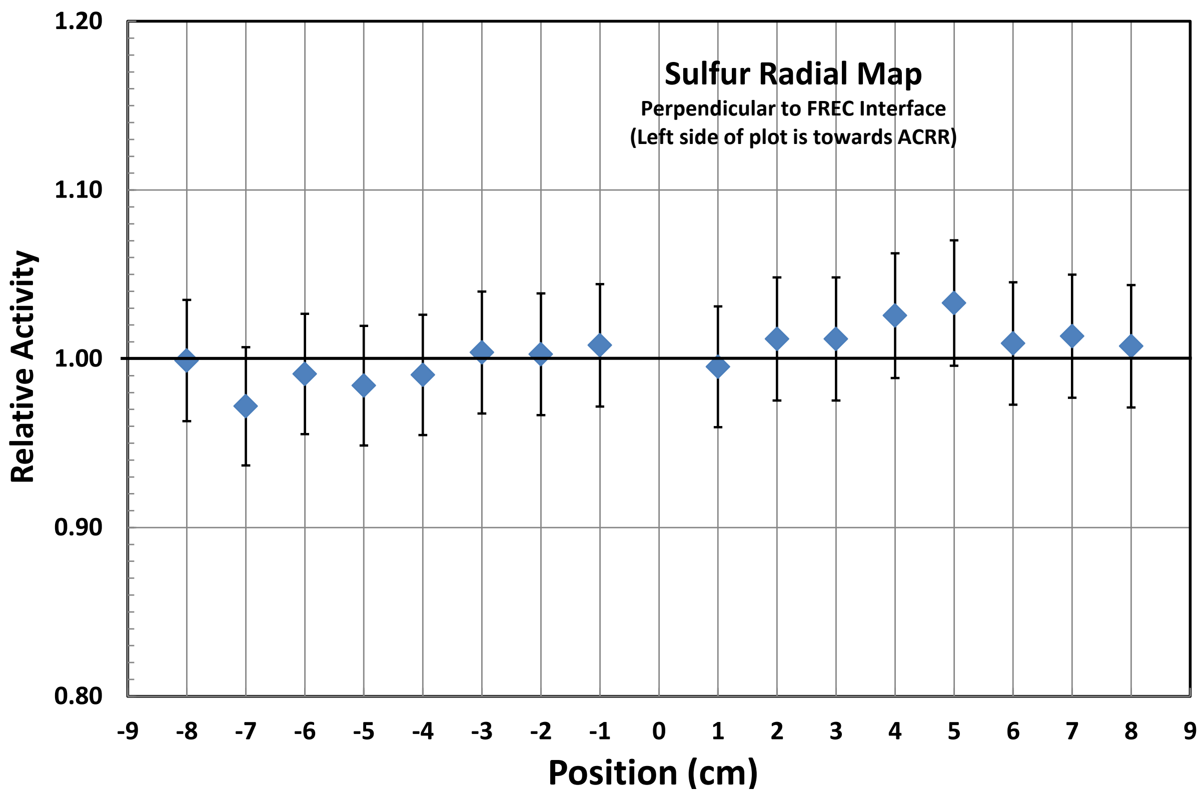

Figure 33. Sulfur Radial Neutron Fluence Profile for CdPoly Perpendicular to FREC.

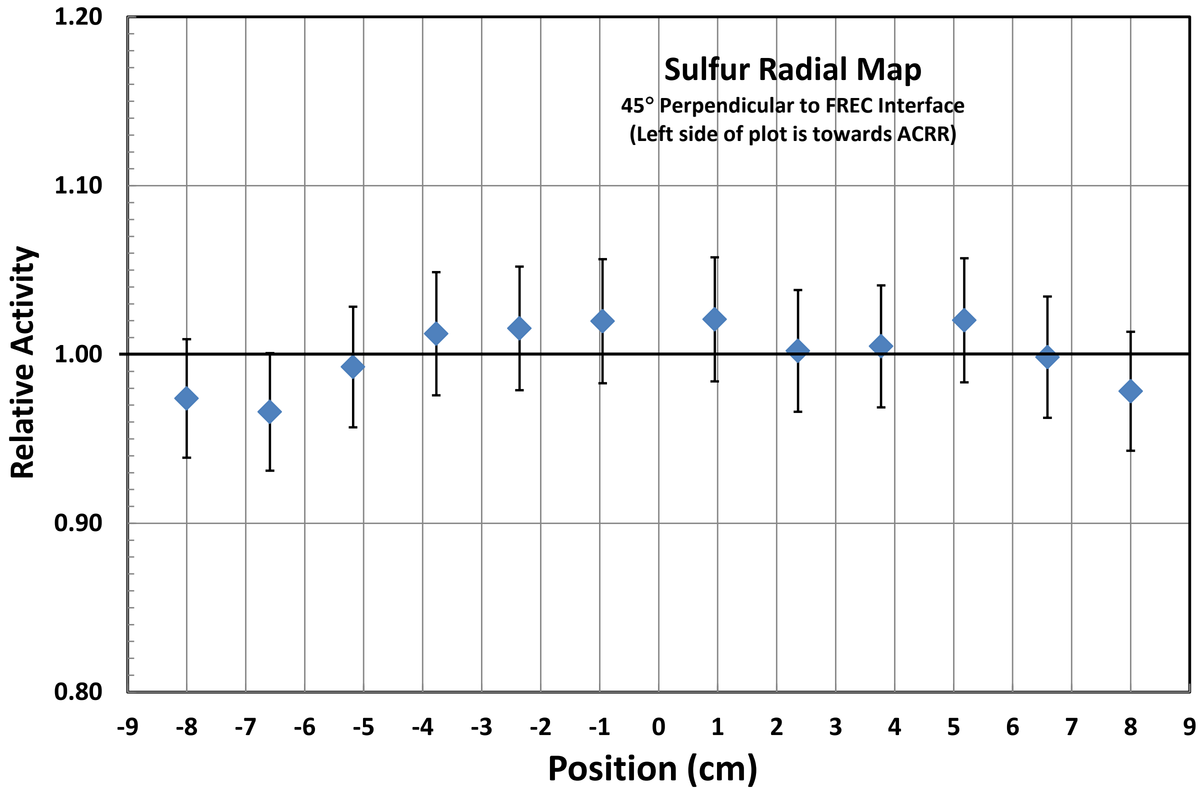

Figure 34. Sulfur Radial Neutron Fluence Profile for CdPoly +45° to FREC Face.

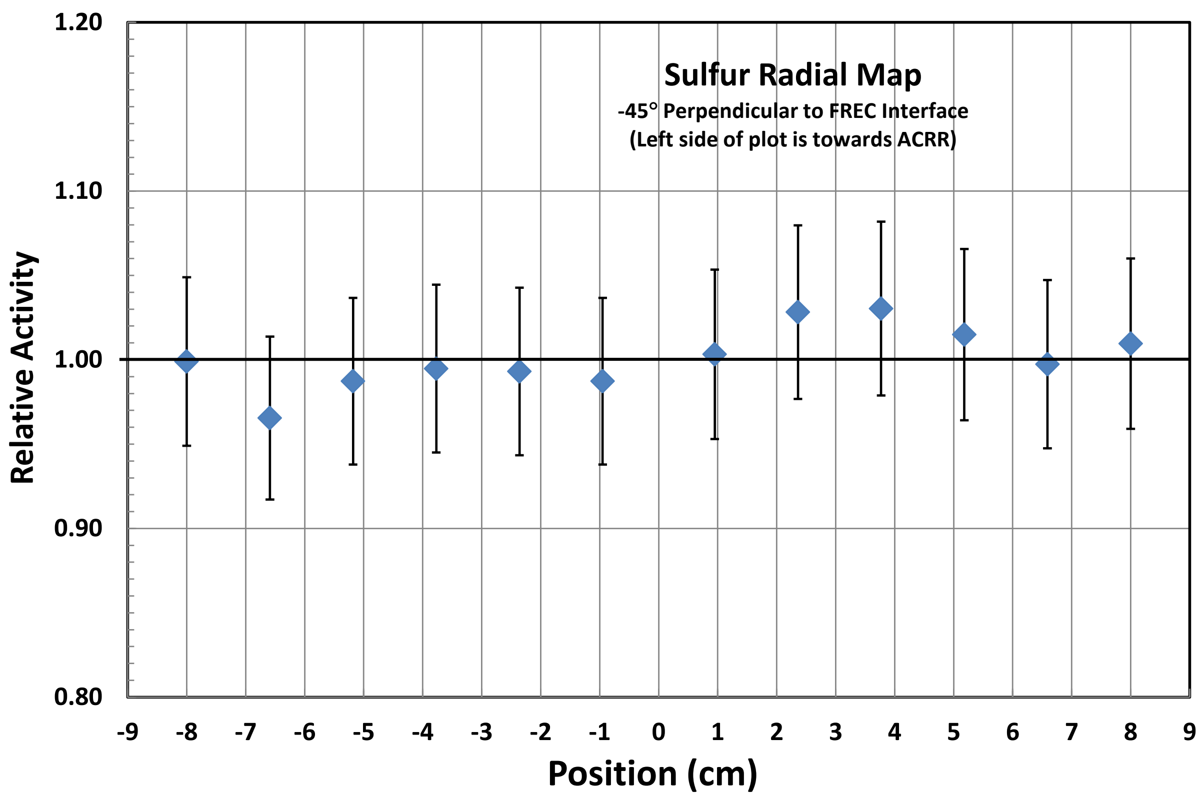

Figure 35. Sulfur Radial Neutron Fluence Profile for CdPoly -45° to FREC Face.

4.2 Gamma-Ray TLD Map

Figure 36 shows the results for the TLD axial gamma fluence profile for CdPoly. The y-axis is in units of absorbed dose in Gray (Gy) for the TLD material CaF_2:Mn. One Gy is equal to 100 rads. Note that the CaF_2:Mn TLDs have a small sensitivity to neutrons. The CaF_2:Mn TLD responds to absorbed dose induced by neutron deposited energy with about a factor of 10 less light emission than seen for a similar photon-induced deposited dose. Again, this scale is completely arbitrary for the purposes of this analysis. The results show that, as for the sulfur results, the peak occurs at about 32 cm (~12.5 inches) from the bottom of the inside of the bucket. The peak is relatively flat between the regions of 20 cm to 40 cm, covering a range of about 20 cm (~8 in.).

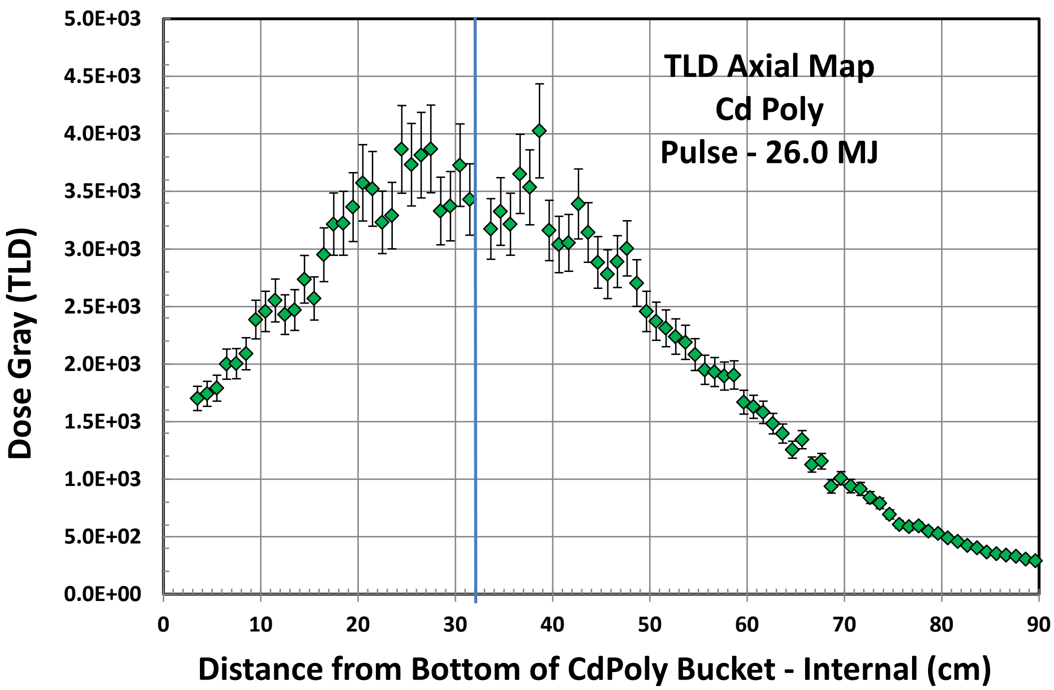

Figure 36. TLD Axial Gamma-Ray Fluence Profile for CdPoly.

Figures 37 through 40 show the results for the TLD radial gamma fluence profile for the CdPoly bucket at an axial position of 11 inches for the TLDs arranged perpendicular and parallel to the front face of the FREC-II, and at 45° angles. The TLDs were arranged on a plate that covered the complete area within the 7.5-inch-diameter bucket. Both plots have the same y-axis scaling. The solid line in each figure represents the average value for all of the TLDs measured on the plate. The results show that for the TLD response, there is no statistically significant variation in the fluence across the internal diameter of the bucket at the peak axial location.

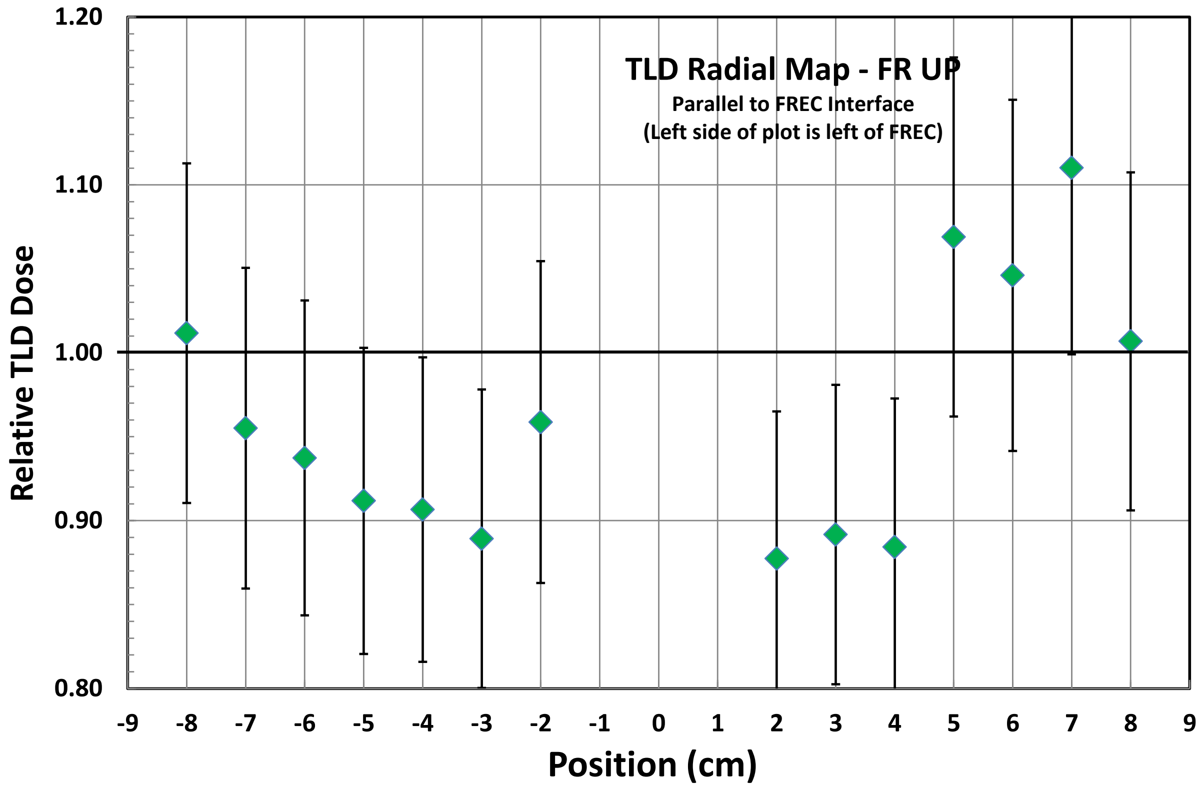

Figure 37. TLD Radial Gamma Fluence Profile for CdPoly Parallel to FREC Face.

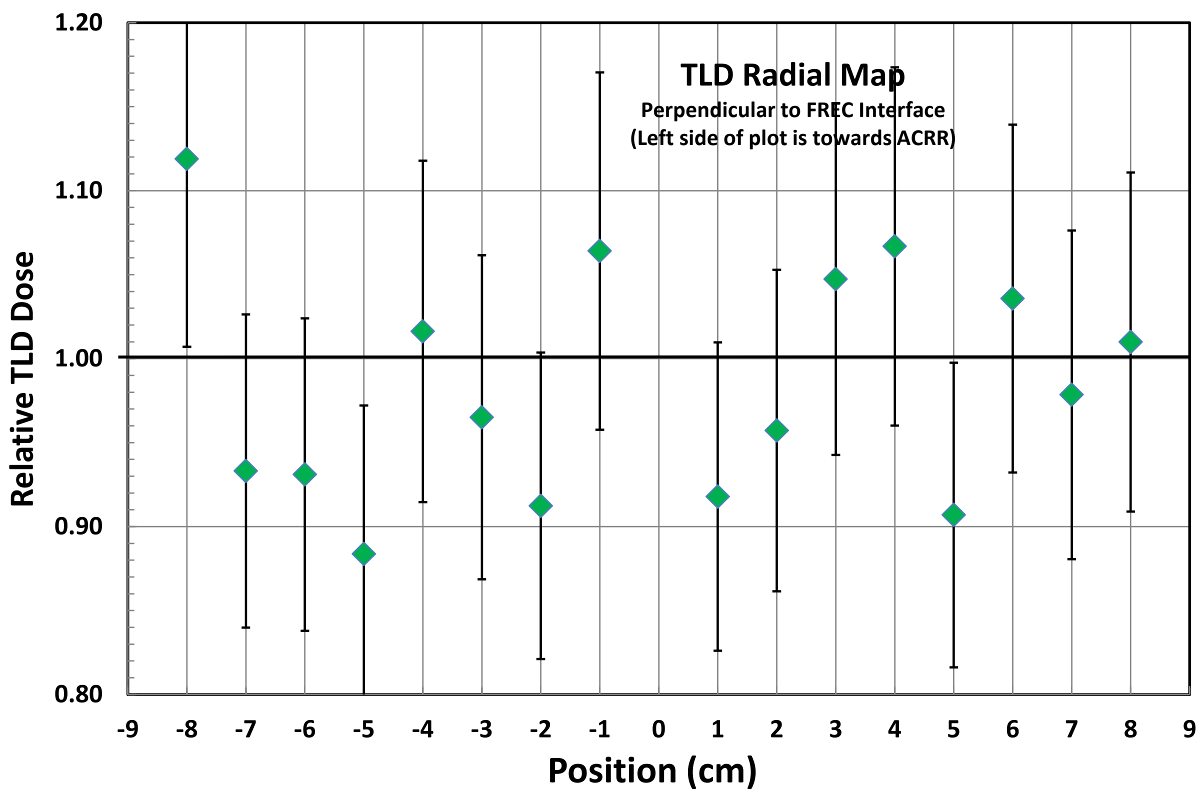

Figure 38. TLD Radial Gamma Fluence Profile for CdPoly Perpendicular to FREC.

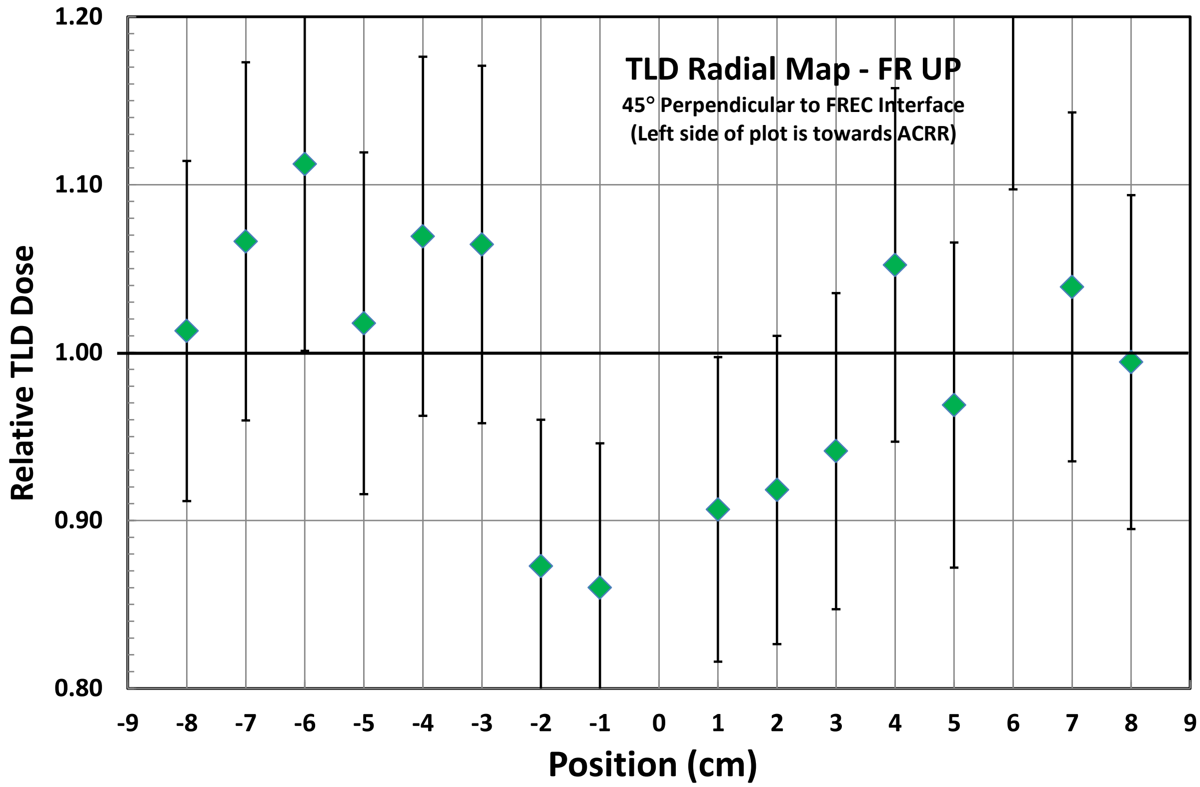

Figure 39. TLD Radial Gamma Fluence Profile for CdPoly +45° to FREC Face.

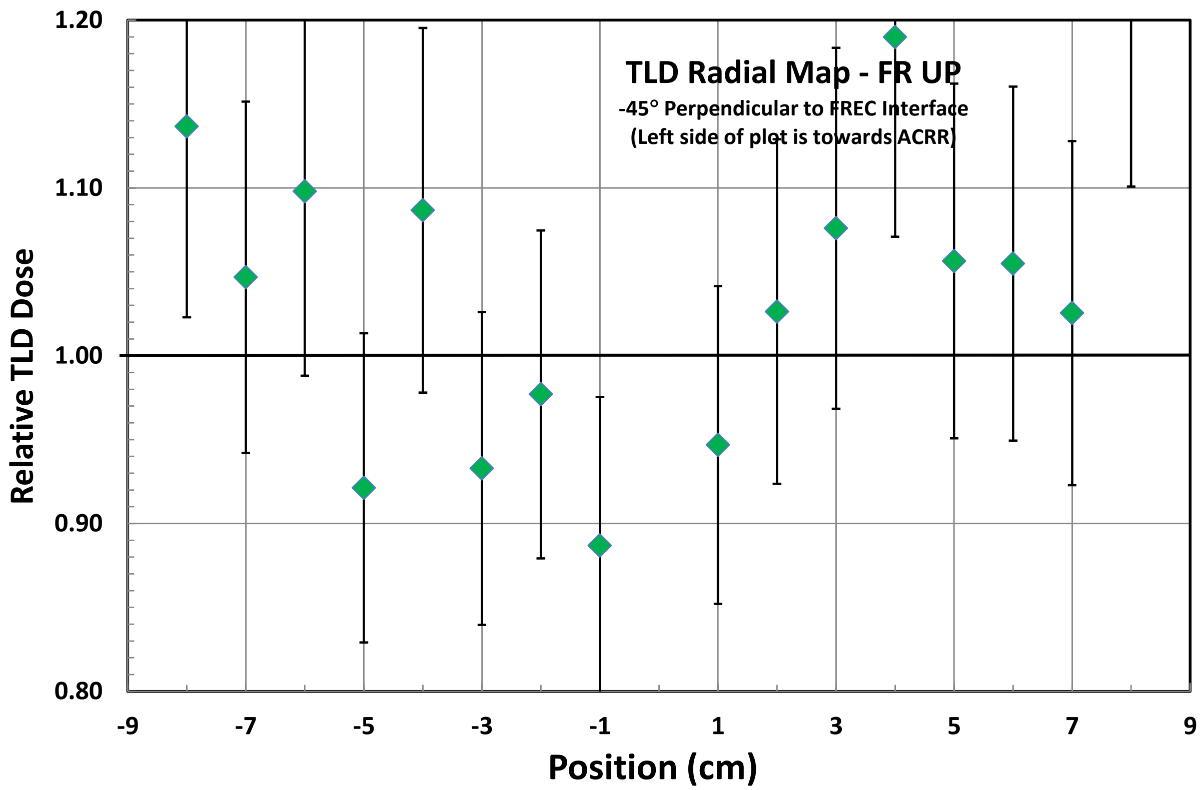

Figure 40. TLD Radial Gamma Fluence Profile for CdPoly -45° to FREC Face.

5. Sample Operations

Three sample ACRR operations are presented for ACRR-CdPoly-CC-32-cl to show how dosimetry data can be used to determine the derived metrics, such as neutron fluence, 1-MeV Si equivalent fluence, prompt and delayed gamma-ray fluence, and dose. The radiation environment conversion factors and metrics used are those presented in Tables 4 and 5 for neutrons, Table 7 for prompt gamma rays, and Table 9 for delayed gamma rays. Typically Ni foils and/or sulfur tablets are used to establish the normalization factors for comparative experiments. Of course, once an experiment is placed in the bucket, the irradiation conditions can, and will change depending on many factors, such as experiment neutron moderation, absorption, etc. Due diligence must be paid to ensure that the results of the experiment are valid within uncertainty bounds. Both experimental and analytical work must be performed along with expert judgment to ensure the integrity of the results.

The sample operations represent a small, medium, and large pulse operation for the CdPoly bucket. For each operation active dosimetry was fielded that included a diamond photoconductive detector (PCD) and Si, Bi, Sn, and Zr calorimeters at the axial centerline of the ACRR. Passive dosimetry included a Ni foil, sulfur tablets, and TLDs. The PCD fielded was a 1 mm x 2 mm x 1 mm diamond biased to 750 VDC.

Small Pulse Operation

A small pulse operation (~25 MJ) was performed on 6/9/2015 for ACRR-CdPoly-CC-32-cl using both active and passive dosimetry. The reactor was operated in the pulse mode with a reactivity addition of $1.32. The reactor shot number was #11491. Figure 41 shows the shot information for the run. Figure 42 shows the power history and cumulative reactor energy from the ACRR pulse diagnostic system. The reported reactor energy was 21.2 MJ taken at the peak of the pulse plus three full-width half maximum (FWHM) time values. The reported total reactor energy was 27.5 MJ from the pulse diagnostics information. Figure 43 shows the results for the PCD transient response from the digital scope. Figures 44 through 47 show the results for the Si, Bi, Sn, and Zr calorimeters transient response, respectively, from the digital scope. The data can be converted to temperature and then dose units using the heat capacity for the calorimeter materials.

Shot Information			**Predicted Values**			
Run Number	11491		**Expected MW**		500	
Operator	Krista Kaiser		**Expected TTP**		0.4933	
Date \ Time	6/9/2015 10:51		**Expected MJ**		28.29	
Experimenter Name	Ed Parma		**Expected Fuel Temp**		98.1	
Experiment Plan #	1181, 1182		**Dialed In MW**		-153.4	
Package Worth $	-4.086					
Shot Worth $	1.32					
Rod Hold Up (sec)	0.4					
FREC Mode	Decoupled					
FREC RODS	DOWN					
Comments	Rafe Campbell - ROIT					
	Average	**CH-1**	**CH-2**	**CH-3**	**CH-4**	**CH-5**
Detector		DE5-1	DE4-9		DE5-8	DE2-98
Detector Calibration		44.1	45.3		52.29	53.6
Channel Type		PXI Amp	SR570 Amp		PXI Amp	Terminated
Average Used		Peak	Both		Both	Peak
Period Used		No	Yes		No	No
PEAK DATA:						
Peak (MW)	**261.1**	272.6	253.1		262.9	298.2
TTP (sec)	0.44204	0.4318	0.43424		0.43364	0.44204
FWHM (sec)	0.06032	0.06016	0.06124		0.06036	0.051
LEHM (sec)	0.035	0.0248	0.0276		0.02684	0.031
TEHM (sec)	0.02532	0.03536	0.03364		0.03352	0.02
Ratio (LE/TE)	1.382	0.701	0.82		0.801	1.55
Shot Worth	1.2	2.053	1.305		1.885	7.228
YIELD DATA:						
Total Yield (MJ)	**27.516**	31.8	26.683		28.584	45.569
TTP+3fwhm (MJ)	21.22	22.167	20.859		21.191	19.142
Yield @ Peak (MJ)	9.95	7.796	7.841		7.884	9.474
Min Period (sec)	0.015747	0.003071	0.010531		0.003656	0.0005

Figure 41. Shot Information for Pulse Operation #11491 – 27.5 MJ.

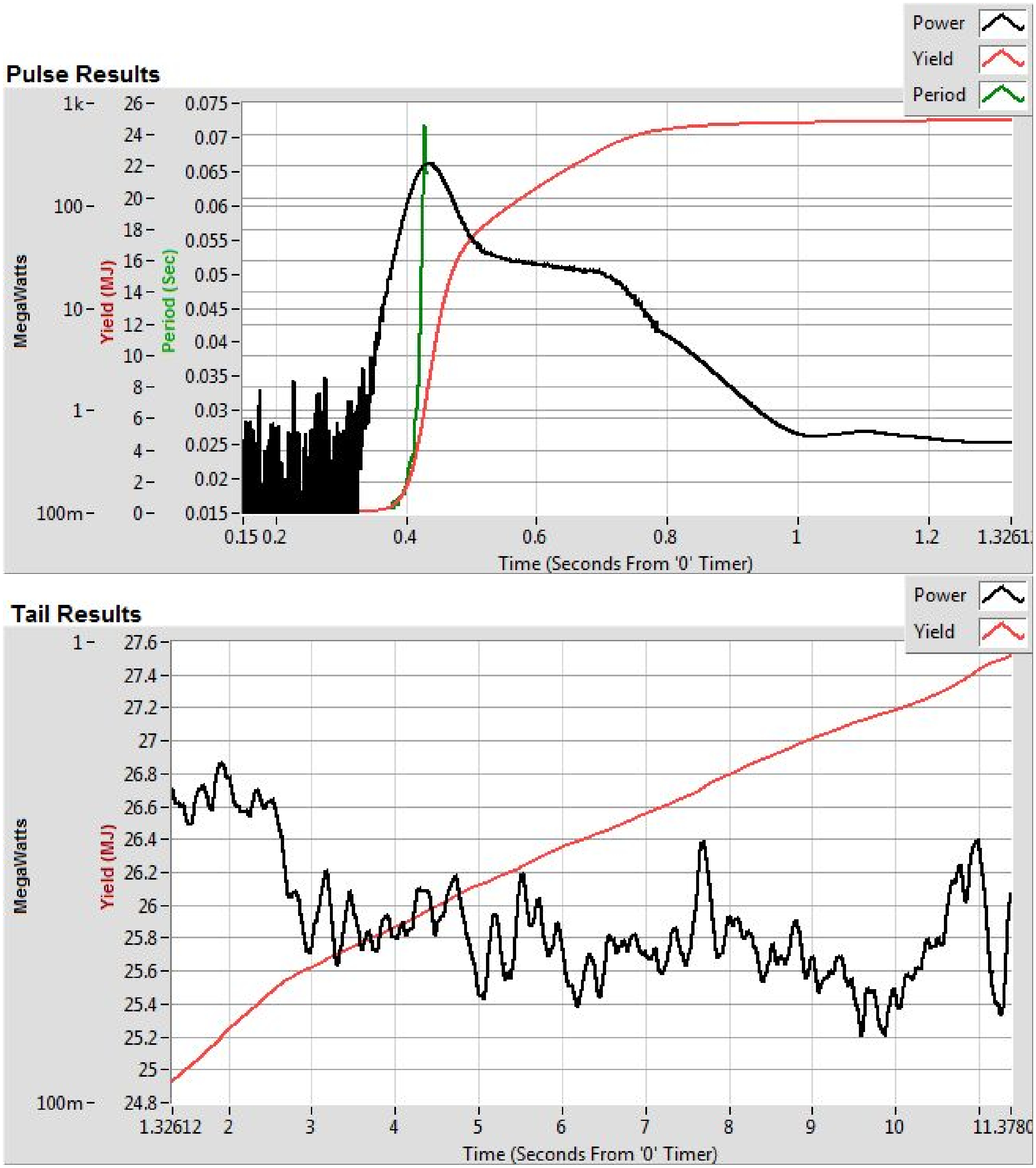

Figure 42. Power and Energy Trace for Pulse Operation #11491 – 27.5 MJ.

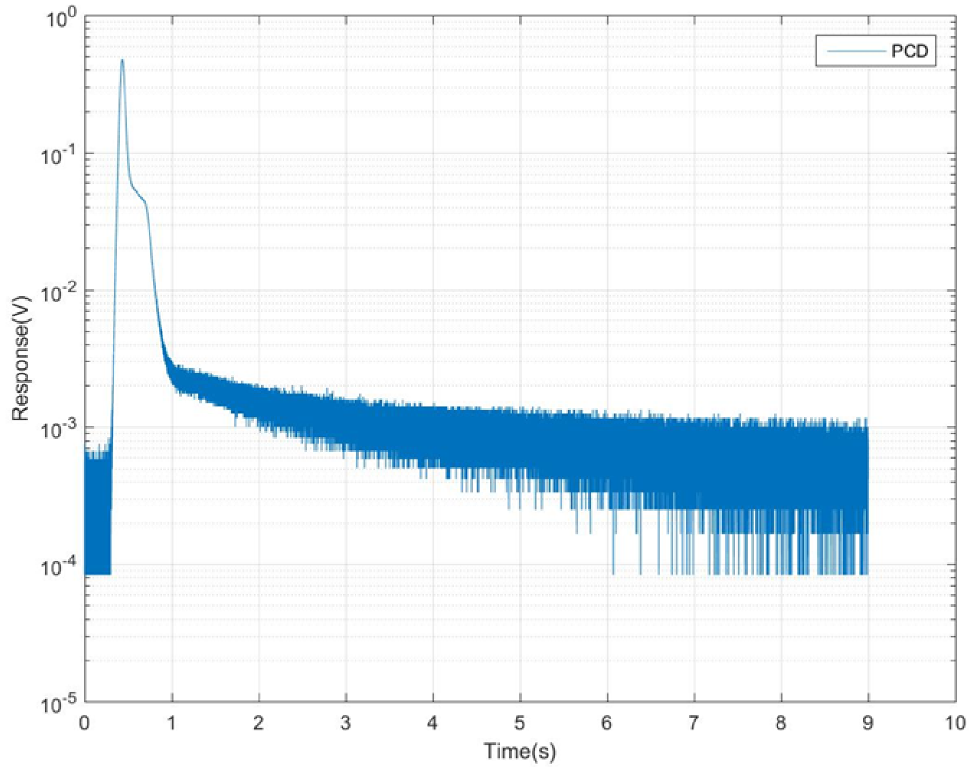

Figure 43. PCD Transient Response for Pulse Operation #11491 – 27.5 MJ.

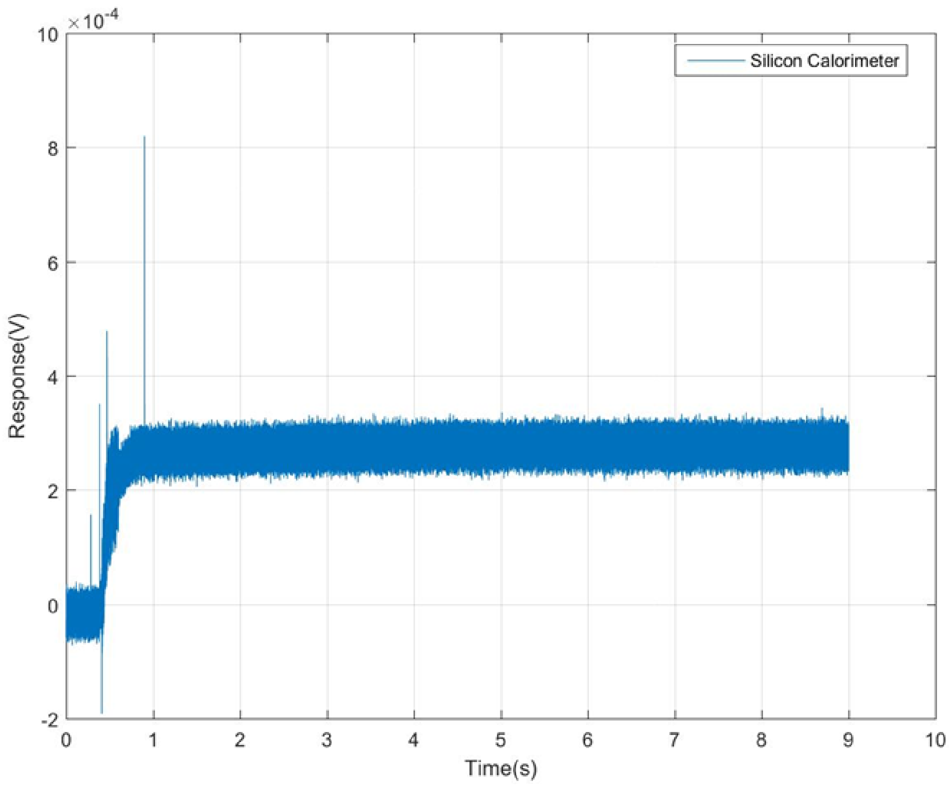

Figure 44. Si Calorimeter Transient Response for Pulse Operation #11491 – 27.7 MJ.

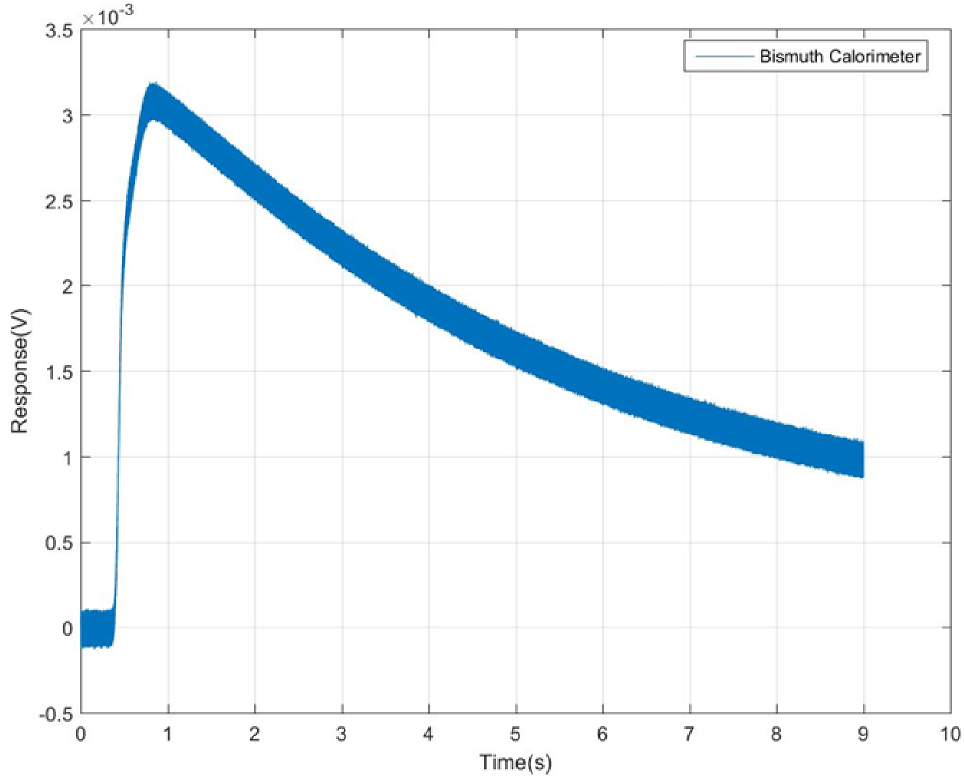

Figure 45. Bi Calorimeter Transient Response for Pulse Operation #11491 – 27.7 MJ.

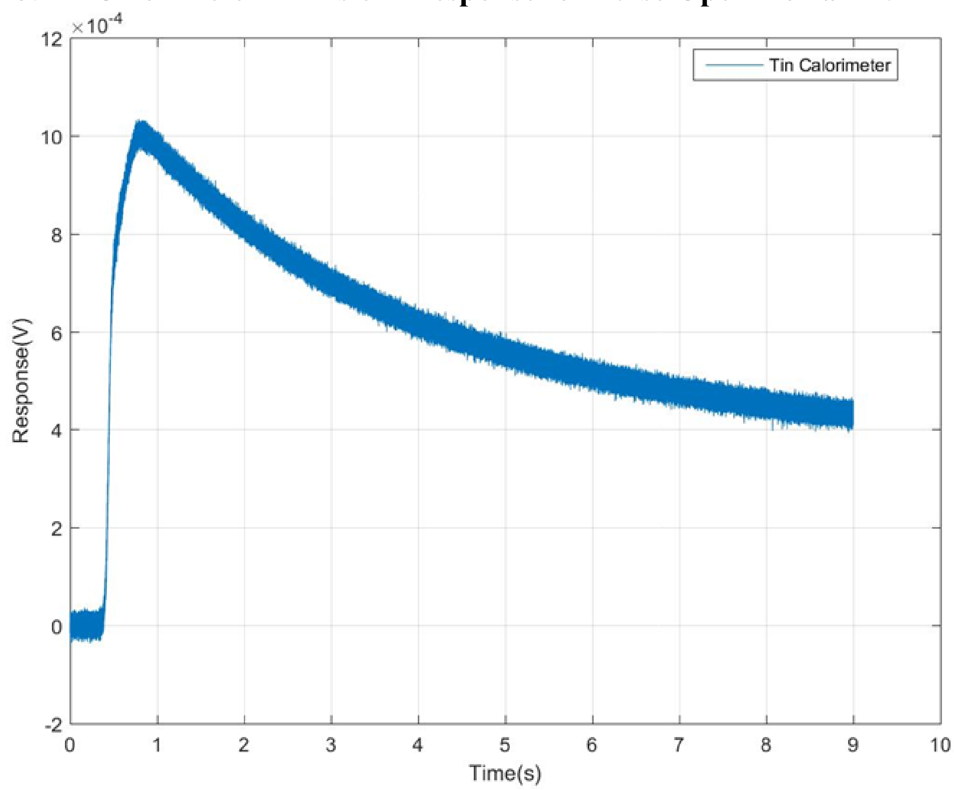

Figure 46. Sn Calorimeter Transient Response for Pulse Operation #11491 – 27.7 MJ.

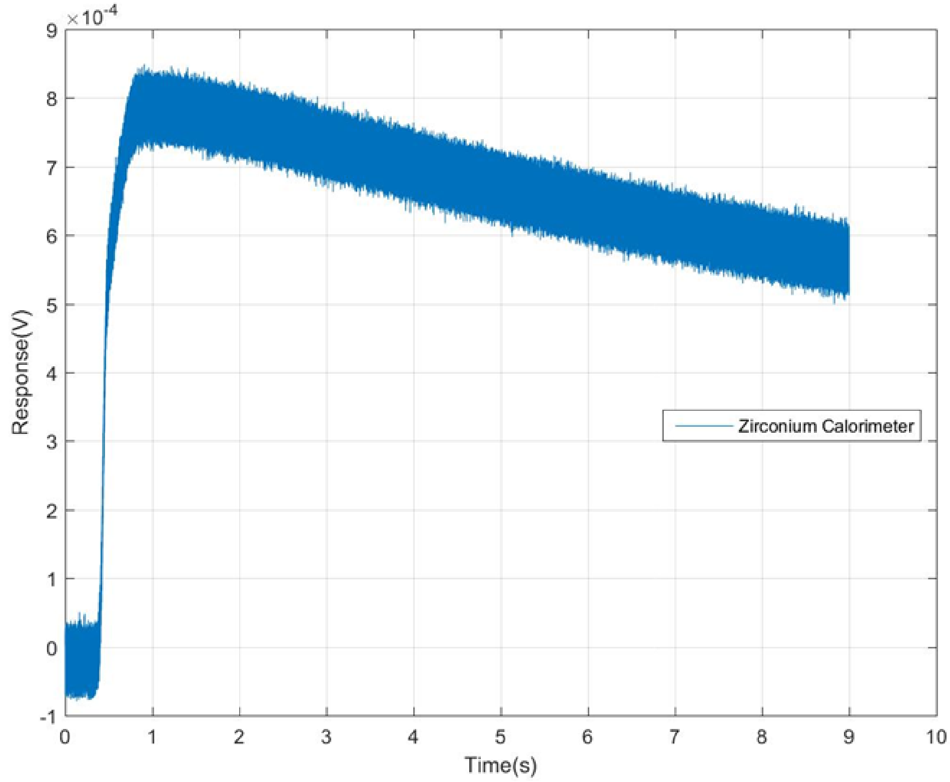

Figure 47. Zr Calorimeter Transient Response for Pulse Operation #11491 – 27.7 MJ.

Shot Number ACRR 11491 – Summary

Shot Date: 6/9/2015
Description: Small pulse operation, $1.32, FWHM = 60.3 ms
Experiment: ACRR-CdPoly-CC-32-cl, passive dosimetry Ni, S, TLDs, active PCD, Si, Bi, Sn, Zr
Reported ACRR Energy: 21.2 MJ at Peak+3FWHM, 27.5 MJ total

Dosimetry Results

Measured $^{58}Ni(n,p)^{58}Co$ Activity:		1.322E+04 Bq/g_{Ni-58} ± 3.0%
Measured $^{32}S(n,p)^{32}P$ Activity (Avg of 4):		8.959E+13 Cf equ ± 3.6%
Measured TLD Response (Average of 4):		4.120E+03 Gy(CaF_2:Mn)
		412.0 krad(CaF_2:Mn)
Uncertainty:	Type A (statistical) one TLD	± 8.5%
	Type B (other) one TLD	± 7.0%

Derived Conversion Metrics

Total Neutron Fluence (Ni):	3.885E+14 n/cm^2
Total Neutron Fluence (S):	3.621E+14 n/cm^2
1-MeV Si Equivalent Neutron Fluence:	1.706E+14 n/cm^2
>1 MeV Neutron Fluence:	8.392E+13 n/cm^2
Total prompt γ Fluence:	6.993E+14 γ/cm^2
Total delayed γ Fluence:	2.559E+14 γ/cm^2
Calculated ACRR Energy (Ni):	30.8 MJ
Calculated ACRR Energy (S):	28.7 MJ
Total Si Dose (neutron):	1.261E+04 rad(Si)
Ionizing Si Dose (neutron):	7.220E+03 rad(Si)
Total/Ionizing Si Dose (prompt γ):	3.399E+05 rad(Si)
Total/Ionizing Si Dose (delayed γ):	9.257E+04 rad(Si)
Total C Dose (neutron):	5.777E+04 rad(C)
Total/Ionizing C Dose (prompt γ):	3.192E+05 rad(C)
Total/Ionizing C Dose (delayed γ):	8.953E+04 rad(C)
Total CaF_2:Mn (TLD) Dose (neutron):	2.637E+04 rad(CaF_2:Mn)
Effective Ionizing CaF_2:Mn Dose (neutron):	2.815E+03 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (prompt γ):	3.382E+05 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (delayed γ):	9.234E+04 rad(CaF_2:Mn)
Sum (Ionizing) CaF_2:Mn (TLD) Dose (n-eff+pγ+dγ):	430.5 krad(CaF_2:Mn)
Calculated to Measured TLD Dose Response:	1.045

Comments: The derived Ni and S reactor energies are within 7% of each other, well within the measurement uncertainty and spectrum adjusted uncertainty. The derived reactor energy (avg Ni and S) is within 8% of the pulse diagnostic measured value with the pulse diagnostic measured value being smaller than the derived value. The calculated-to-measured TLD response is within 5%, which is well within one standard deviation from the measured result.

5.2 Medium Pulse Operation

A medium pulse operation (~50 MJ) was performed on 6/9/2015 for ACRR-CdPoly-CC-32-cl using both active and passive dosimetry. The reactor was operated in the pulse mode with a reactivity addition of $1.57. The reactor shot number was #11492. Figure 48 shows the shot information for the run. Figure 49 shows the power history and cumulative reactor energy from the ACRR pulse diagnostic system. The reported reactor energy was 40.1 MJ taken at the peak of the pulse plus three full-width half maximum (FWHM) time values. The reported total reactor energy was 48.9 MJ from the pulse diagnostics information. Figure 50 shows the results for the PCD transient response from the digital scope. Figures 51 through 54 show the results for the Si, Bi, Sn, and Zr calorimeters transient response, respectively, from the digital scope. The data can be converted to temperature and then dose units using the heat capacity for the calorimeter materials.

Shot Information			**Predicted Values**			
Run Number	11492		**Expected MW**		1500	
Operator	Krista Kaiser		**Expected TTP**		0.3914	
Date \ Time	6/9/2015 11:46		**Expected MJ**		62.06	
Experimenter Name	Ed Parma		**Expected Fuel Temp**		191.1	
Experiment Plan #	1181, 1182		**Dialed In MW**		1079.51	
Package Worth $	-4.075					
Shot Worth $	1.566					
Rod Hold Up (sec)	0.4					
FREC Mode	Decoupled					
FREC RODS	DOWN					
Comments						
	Average	**CH-1**	**CH-2**	**CH-3**	**CH-4**	**CH-5**
Detector		DE5-1	DE4-9		DE5-8	DE2-98
Detector Calibration		44.1	45.3		52.29	53.6
Channel Type		PXI Amp	SR570 Amp		PXI Amp	Terminated
Average Used		Both	Both		Both	Peak
Period Used		No	Yes		Yes	No
PEAK DATA:						
Peak (MW)	**1240.4**	1301.8	1221.8		1243.6	1198
TTP (sec)	0.36148	0.36136	0.36156		0.3616	0.36212
FWHM (sec)	0.02676	0.027	0.02708		0.02712	0.02608
LEHM (sec)	0.01264	0.01292	0.01284		0.01312	0.0128
TEHM (sec)	0.01412	0.01408	0.01424		0.014	0.01328
Ratio (LE/TE)	0.895	0.918	0.902		0.937	0.964
Shot Worth	1.452	1.997	1.725		1.951	7.207
YIELD DATA:						
Total Yield (MJ)	**48.899**	51.763	47.979		48.949	51.29
TTP+3fwhm (MJ)	40.062	42	39.416		40.134	38.639
Yield @ Peak (MJ)	18.192	18.93	17.712		18.383	18.596
Min Period (sec)	0.007143	0.003244	0.004467		0.003402	0.000502

Figure 48. Shot Information for Pulse Operation #11492 – 48.9 MJ.

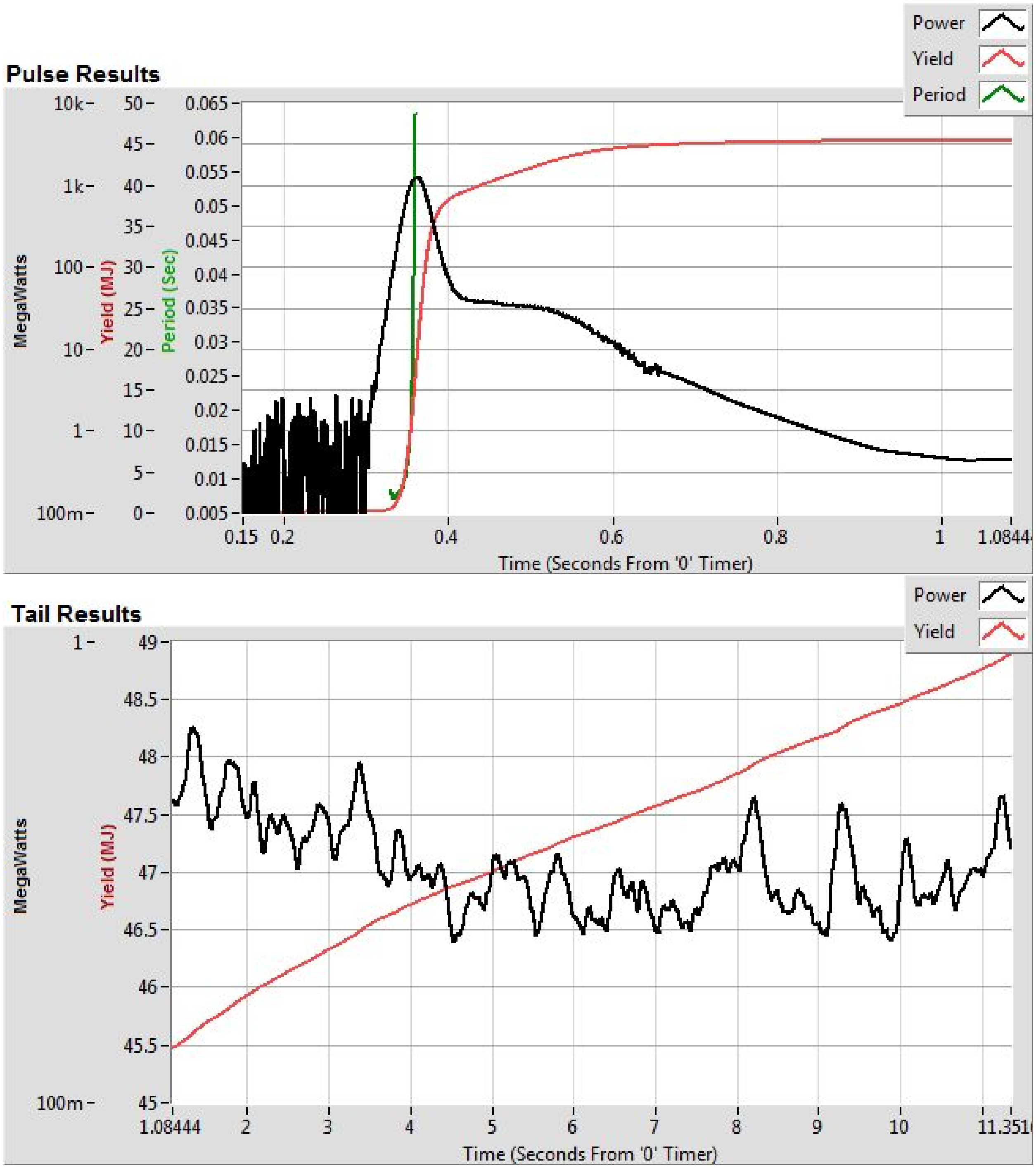

Figure 49. Power and Energy Trace for Pulse Operation #11492 – 48.9 MJ.

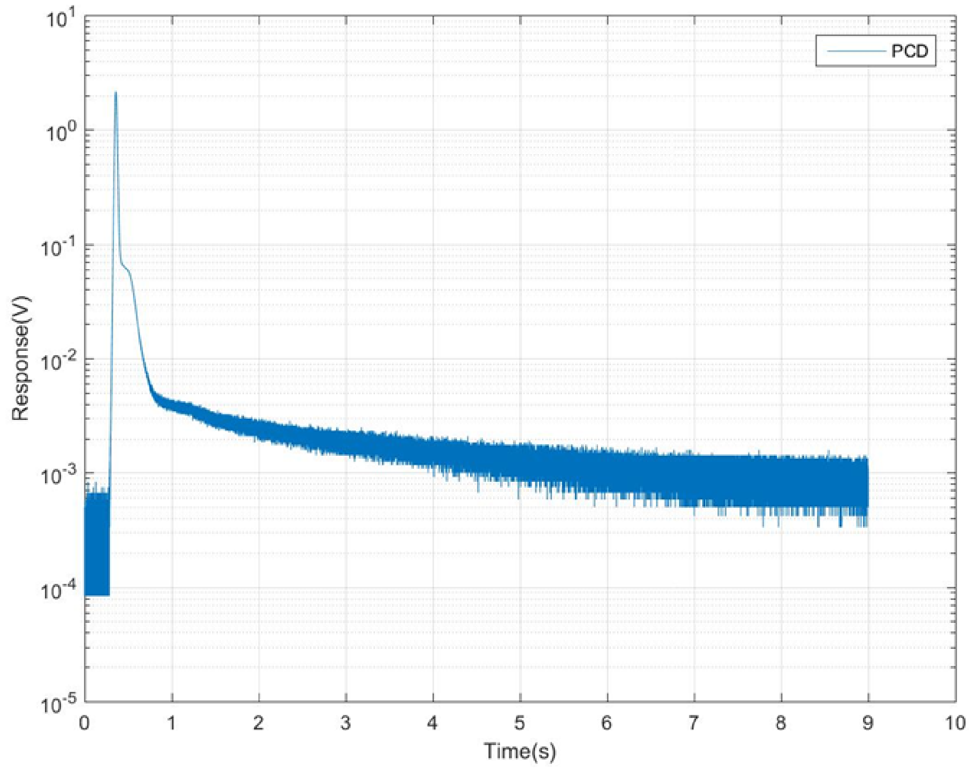

Figure 50. PCD Transient Response for Pulse Operation #11492 – 48.9 MJ.

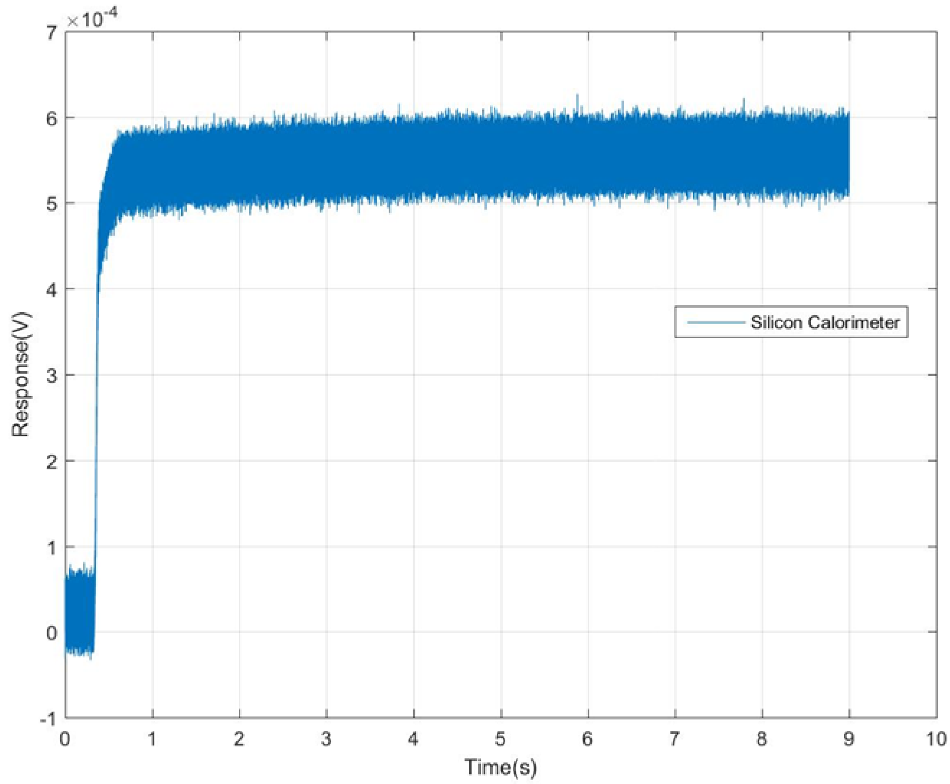

Figure 51. Si Calorimeter Transient Response for Pulse Operation #11492 – 48.9 MJ.

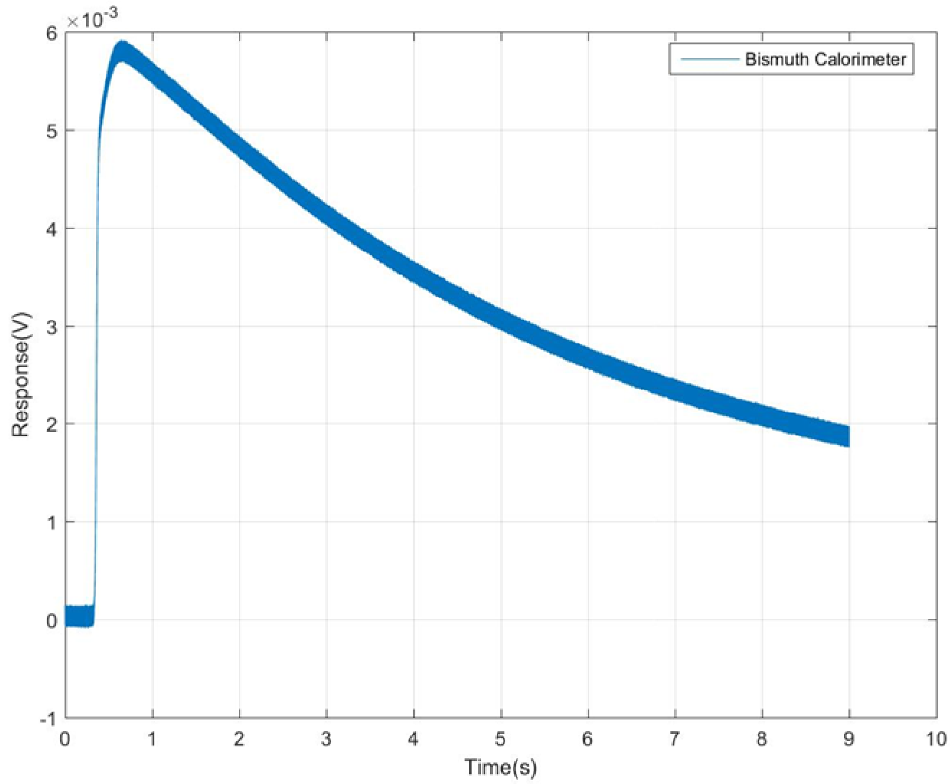

Figure 52. Bi Calorimeter Transient Response for Pulse Operation #11492 – 48.9 MJ.

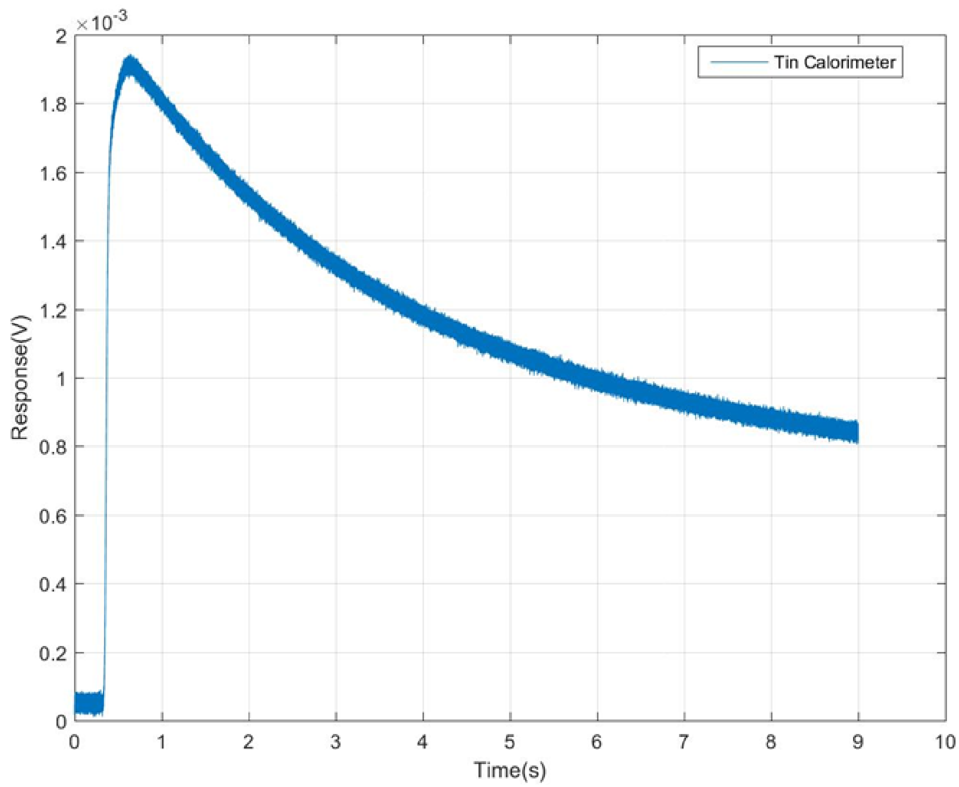

Figure 53. Sn Calorimeter Transient Response for Pulse Operation #11492 – 48.9 MJ.

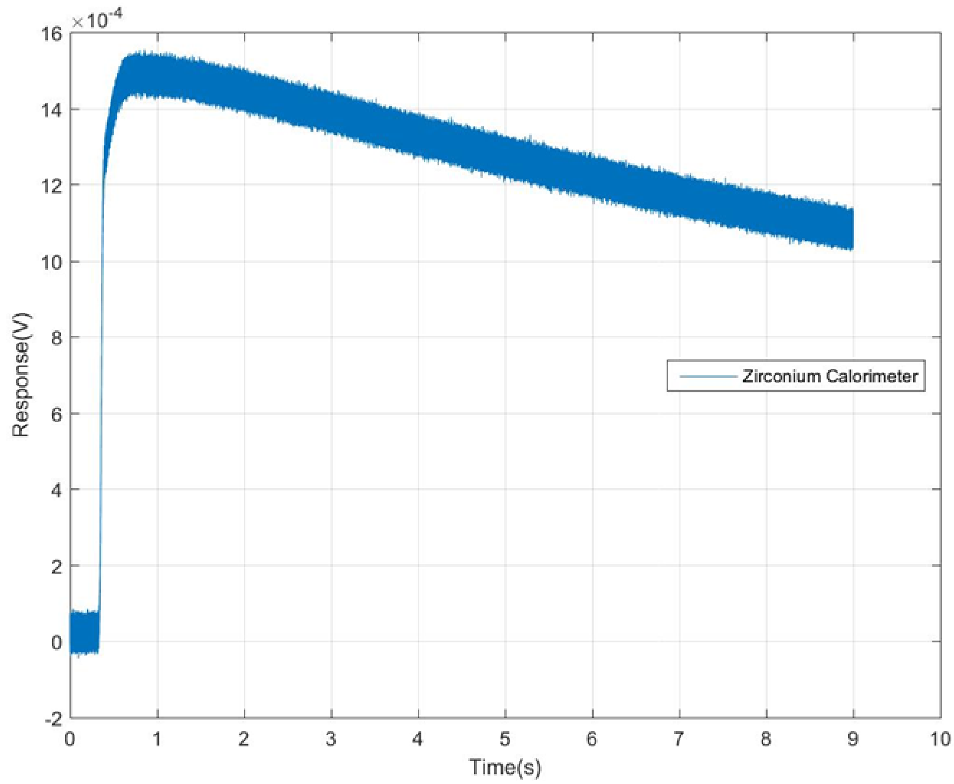

Figure 54. Zr Calorimeter Transient Response for Pulse Operation #11492 – 48.9 MJ.

Shot Number ACRR 11492 – Summary

Shot Date: 6/9/2015
Description: Medium pulse operation, \$1.57, FWHM = 26.8 ms
Experiment: ACRR-CdPoly-CC-32-cl, passive dosimetry Ni, S, TLDs, active PCD, Si, Bi, Sn, Zr
Reported ACRR Energy: 40.1 MJ at Peak+3FWHM, 48.9 MJ total

Dosimetry Results

Measured ^{58}Ni(n,p)^{58}Co Activity:		2.248E+04 Bq/$g_{Ni\text{-}58}$ ± 3.0%
Measured ^{32}S(n,p)^{32}P Activity (Avg of 4):		1.596E+14 Cf equ ± 3.6%
Measured TLD Response (Average of 4):		5.640E+03 Gy(CaF_2:Mn)
		564.0 krad(CaF_2:Mn)
Uncertainty:	Type A (statistical) one TLD	± 12.3%
	Type B (other) one TLD	± 7.2%

Derived Conversion Metrics

Total Neutron Fluence (Ni):	6.608E+14 n/cm^2
Total Neutron Fluence (S):	6.451E+14 n/cm^2
1-MeV Si Equivalent Neutron Fluence:	2.901E+14 n/cm^2
>1 MeV Neutron Fluence:	1.427E+14 n/cm^2
Total prompt γ Fluence:	1.189E+15 γ/cm^2
Total delayed γ Fluence:	4.353E+14 γ/cm^2
Calculated ACRR Energy (Ni):	52.3 MJ
Calculated ACRR Energy (S):	51.1 MJ
Total Si Dose (neutron):	2.144E+04 rad(Si)
Ionizing Si Dose (neutron):	1.228E+04 rad(Si)
Total/Ionizing Si Dose (prompt γ):	5.782E+05 rad(Si)
Total/Ionizing Si Dose (delayed γ):	1.575E+05 rad(Si)
Total C Dose (neutron):	9.826E+04 rad(C)
Total/Ionizing C Dose (prompt γ):	5.424E+05 rad(C)
Total/Ionizing C Dose (delayed γ):	1.523E+05 rad(C)
Total CaF_2:Mn (TLD) Dose (neutron):	4.485E+04 rad(CaF_2:Mn)
Effective Ionizing CaF_2:Mn Dose (neutron):	4.787E+03 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (prompt γ):	5.753E+05 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (delayed γ):	1.571E+05 rad(CaF_2:Mn)
Sum (Ionizing) CaF_2:Mn (TLD) Dose (n-eff+pγ+dγ):	737.2 krad(CaF_2:Mn)
Calculated to Measured TLD Dose Response:	1.307

Comments: The derived Ni and S reactor energies are within 2% of each other, well within the measurement uncertainty and spectrum adjusted uncertainty. The derived reactor energy (avg Ni and S) is within 7% of the pulse diagnostic measured value with the pulse diagnostic measured value being smaller than the derived value. The calculated-to-measured TLD response is 30%. This large difference is due to the TLD measurements approaching their useful dose measurement limit of 500 to 700 krads(CaF2:Mn).

5.3 Large Pulse Operation

A large pulse operation (~100 MJ) was performed on 6/9/2015 for ACRR-CdPoly-CC-32-cl using both active and passive dosimetry. The reactor was operated in the pulse mode with a reactivity addition of \$2.00. The reactor shot number was #11493. Figure 55 shows the shot information for the run. Figure 56 shows the power history and cumulative reactor energy from the ACRR pulse diagnostic system. The reported reactor energy was 84.4 MJ taken at the peak of the pulse plus three full-width half maximum (FWHM) time values. The reported total reactor energy was 104.7 MJ from the pulse diagnostics information. Figure 57 shows the results for the PCD transient response from the digital scope. Figures 58 through 61 show the results for the Si, Bi, Sn, and Zr calorimeters transient response, respectively, from the digital scope. The data can be converted to temperature and then dose units using the heat capacity for the calorimeter materials.

Shot Information			Predicted Values			
Run Number	11493		Expected MW		7500	
Operator	Krista Kaiser		Expected TTP		0.3395	
Date \ Time	6/9/2015 13:51		Expected MJ		121.71	
Experimenter Name	Ed Parma		Expected Fuel Temp		358.8	
Experiment Plan #	1181, 1182		Dialed In MW		5184.69	
Package Worth $	-4.058					
Shot Worth $	2.001					
Rod Hold Up (sec)	0.4					
FREC Mode	Decoupled					
FREC RODS	DOWN					
Comments	ROIT - Rafe Campbell					
	Average	CH-1	CH-2	CH-3	CH-4	CH-5
Detector		DE5-1	DE4-9		DE5-8	DE2-98
Detector Calibration		44.1	45.3		52.29	53.6
Channel Type		PXI Amp	SR570 Amp		PXI Amp	Terminated
Average Used		Peak	Both		Both	Peak
Period Used		Yes	Yes		Yes	No
PEAK DATA:						
Peak (MW)	**4914.8**	5142.1	4852.4		4924.2	4761.2
TTP (sec)	0.322	0.32192	0.3222		0.32208	0.32172
FWHM (sec)	0.01492	0.01492	0.01496		0.01492	0.01488
LEHM (sec)	0.0072	0.0072	0.0072		0.00736	0.00704
TEHM (sec)	0.00772	0.00772	0.00776		0.00756	0.00784
Ratio (LE/TE)	0.933	0.933	0.928		0.974	0.898
Shot Worth	1.843	2.524	2.343		2.276	7.207
YIELD DATA:						
Total Yield (MJ)	**104.729**	114.212	105.467		104.062	128.242
TTP+3fwhm (MJ)	84.369	88.135	83.357		84.415	81.575
Yield @ Peak (MJ)	39.756	41.358	39.264		40.334	37.687
Min Period (sec)	0.00384	0.002116	0.002404		0.002532	0.000502

Figure 55. Shot Information for Pulse Operation #11493 – 104.7 MJ.

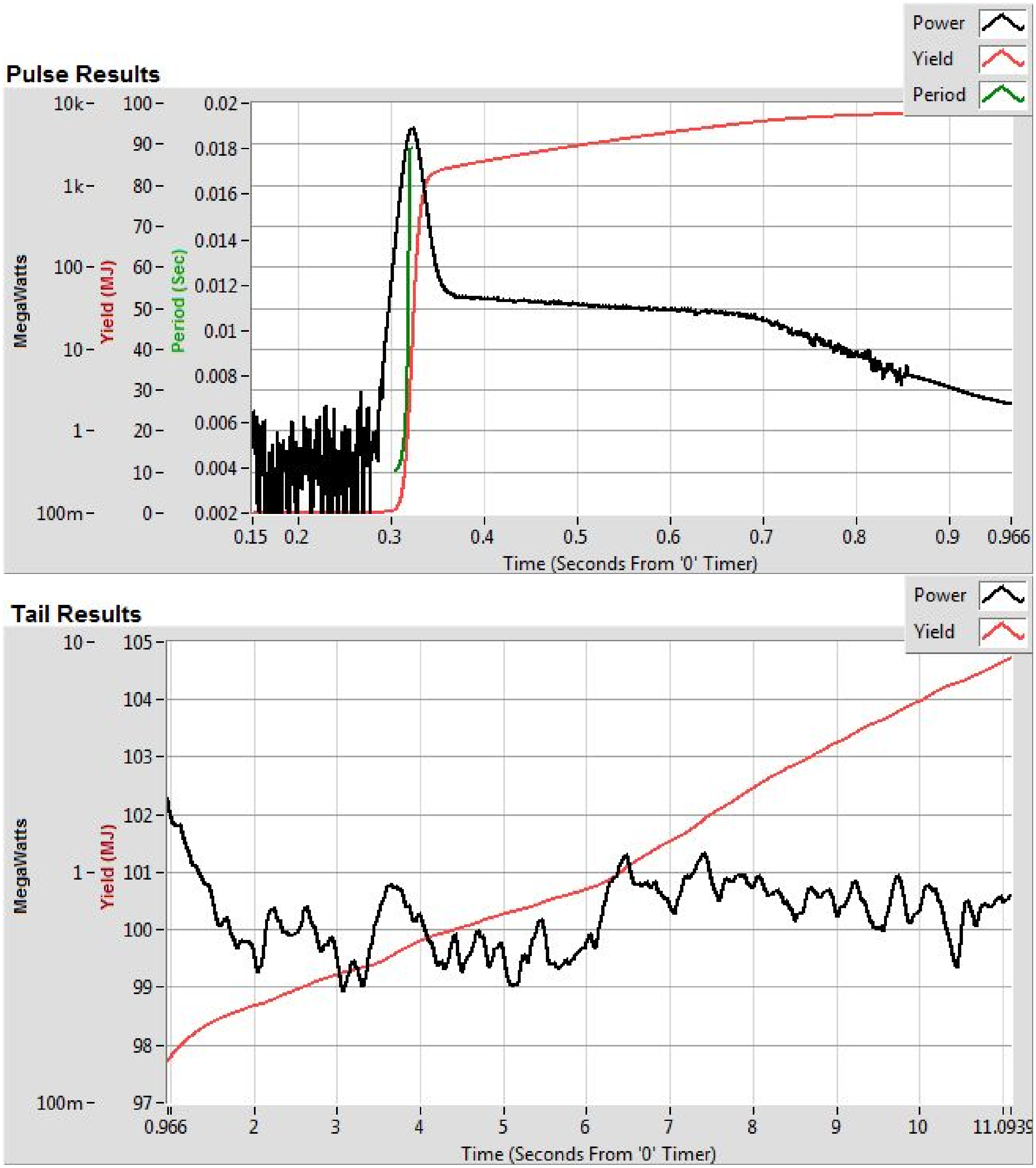

Figure 56. Power and Energy Trace for Pulse Operation #11493 – 104.7 MJ.

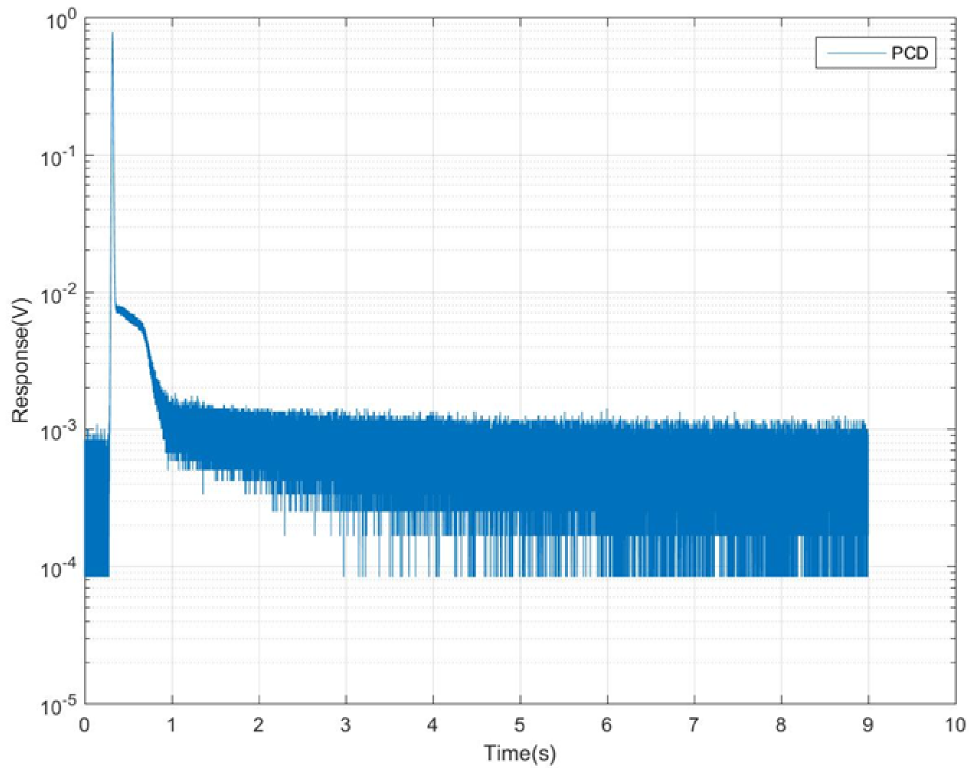

Figure 57. PCD Transient Response for Pulse Operation #11493 – 104.7 MJ.

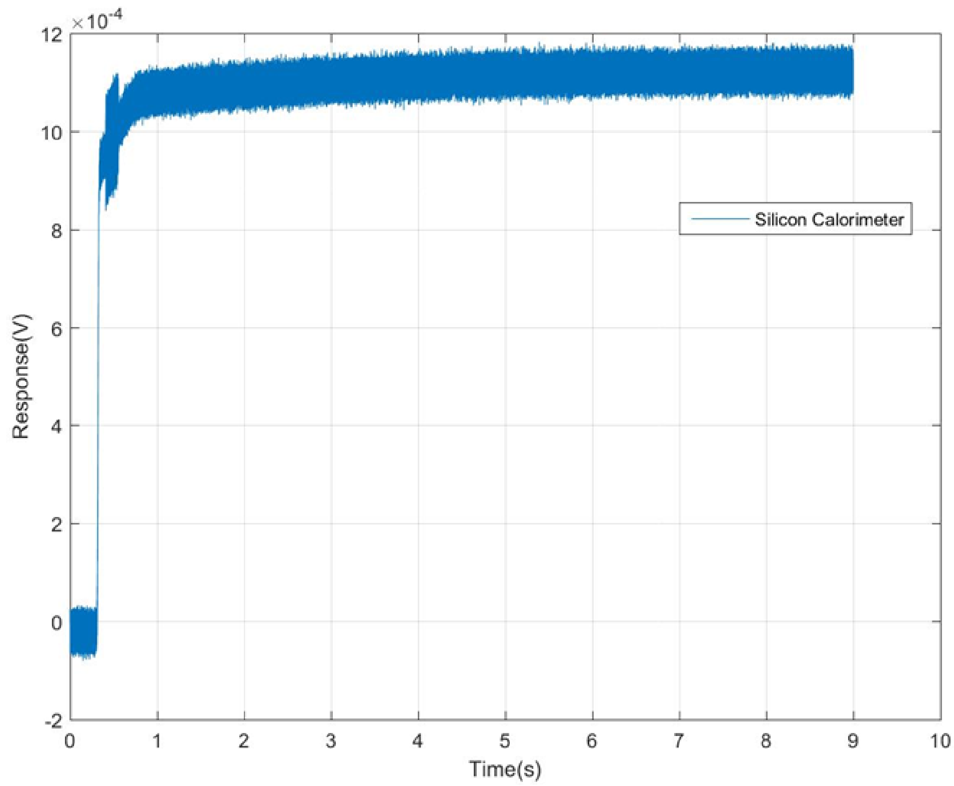

Figure 58. Si Calorimeter Transient Response for Pulse Operation #11493 – 104.7 MJ.

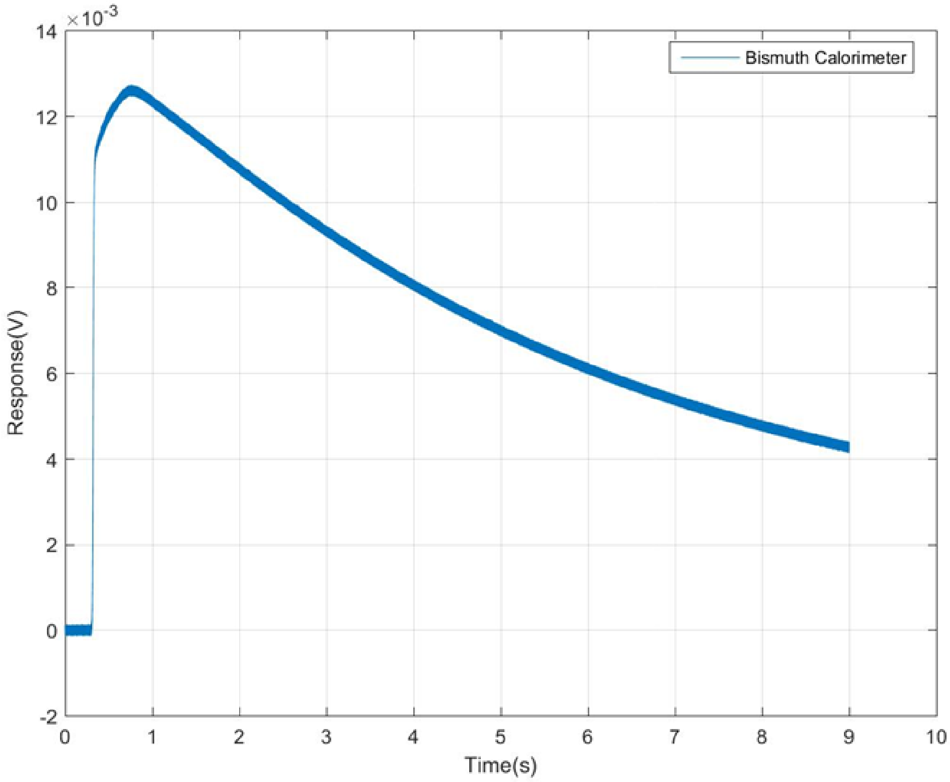

Figure 59. Bi Calorimeter Transient Response for Pulse Operation #11493 – 104.7 MJ.

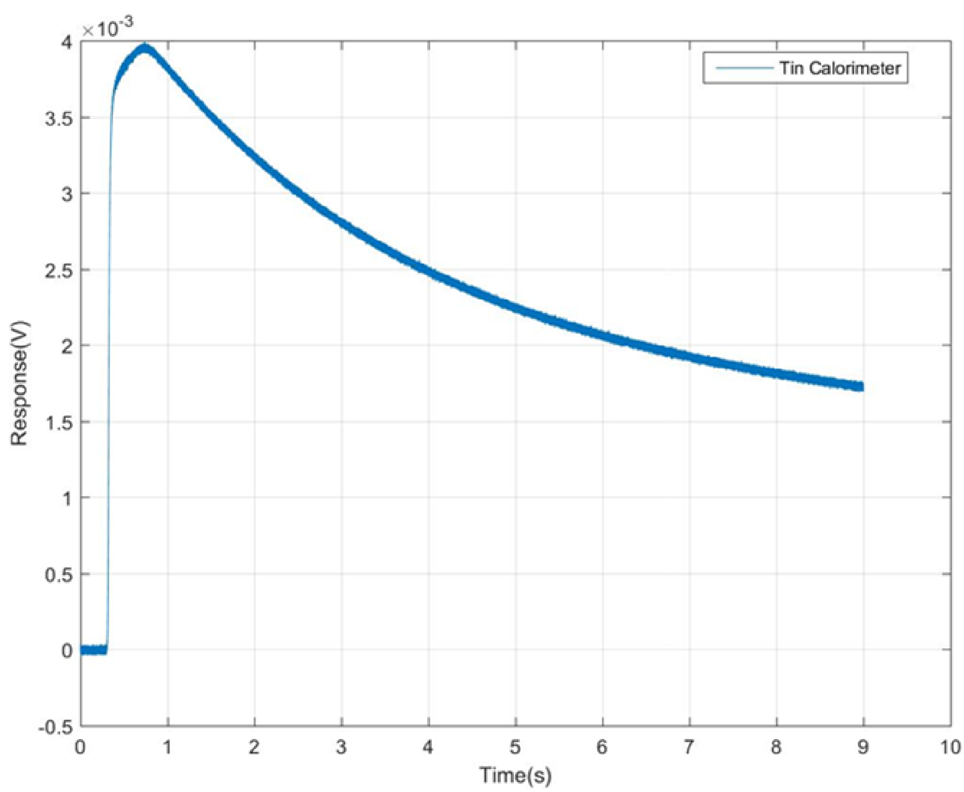

Figure 60. Sn Calorimeter Transient Response for Pulse Operation #11493 – 104.7 MJ.

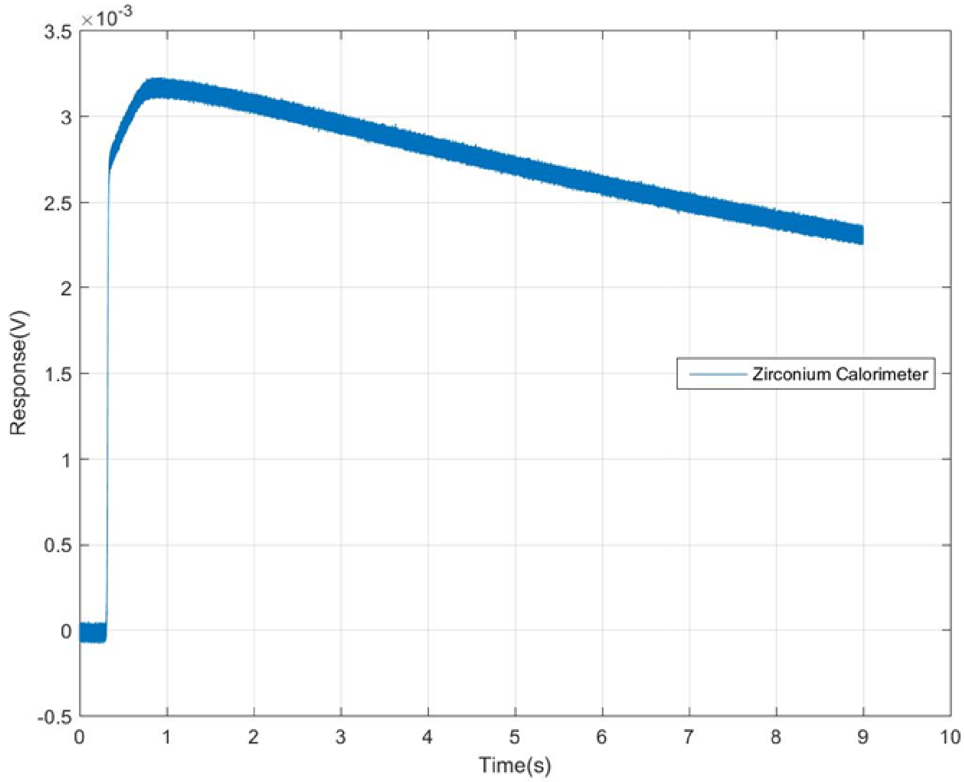

Figure 61. Zr Calorimeter Transient Response for Pulse Operation #11493 – 104.7 MJ.

Shot Number ACRR 11493 – Summary

Shot Date: 6/9/2015
Description: Large pulse operation, \$2.00, FWHM = 14.9 ms
Experiment: ACRR-CdPoly-CC-32-cl, passive dosimetry Ni, S, TLDs, active PCD, Si, Bi, Sn, Zr
Reported ACRR Energy: 84.4 MJ at Peak+3FWHM, 104.7 MJ total

Dosimetry Results

Measured ^{58}Ni(n,p)^{58}Co Activity:		4.940E+04 Bq/$g_{Ni\text{-}58}$ ± 3.0%
Measured ^{32}S(n,p)^{32}P Activity (Avg of 4):		3.383E+14 Cf equ ± 3.6%
Measured TLD Response (Average of 4):		Not Measured – Out of Range
Uncertainty:	Type A (statistical) one TLD	N/A
	Type B (other) one TLD	N/A

Derived Conversion Metrics

Total Neutron Fluence (Ni):	1.452E+15 n/cm^2
Total Neutron Fluence (S):	1.367E+15 n/cm^2

1-MeV Si Equivalent Neutron Fluence:	6.374E+14 n/cm^2
>1 MeV Neutron Fluence:	3.136E+14 n/cm^2
Total prompt γ Fluence:	2.614E+15 γ/cm^2
Total delayed γ Fluence:	9.565E+14 γ/cm^2
Calculated ACRR Energy (Ni):	115.0 MJ
Calculated ACRR Energy (S):	108.2 MJ
Total Si Dose (neutron):	4.712E+04 rad(Si)
Ionizing Si Dose (neutron):	2.699E+04 rad(Si)
Total/Ionizing Si Dose (prompt γ):	1.270E+06 rad(Si)
Total/Ionizing Si Dose (delayed γ):	3.460E+05 rad(Si)
Total C Dose (neutron):	2.159E+05 rad(C)
Total/Ionizing C Dose (prompt γ):	1.193E+06 rad(C)
Total/Ionizing C Dose (delayed γ):	3.346E+05 rad(C)
Total CaF_2:Mn (TLD) Dose (neutron):	9.854E+04 rad(CaF_2:Mn)
Effective Ionizing CaF_2:Mn Dose (neutron):	1.054E+04 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (prompt γ):	1.264E+06 rad(CaF_2:Mn)
Total (Ionizing) CaF_2:Mn (TLD) Dose (delayed γ):	3.451E+05 rad(CaF_2:Mn)
Sum (Ionizing) CaF_2:Mn (TLD) Dose (n-eff+pγ+dγ):	1619.6 krad(CaF_2:Mn)
Calculated to Measured TLD Dose Response:	N/A

Comments: The derived Ni and S reactor energies are within 6% of each other, well within the measurement uncertainty and spectrum adjusted uncertainty. The derived reactor energy (avg Ni and S) is within 10% of the pulse diagnostic measured value with the pulse diagnostic measured value being smaller than the derived value. There were no TLD measurements taken since they would have been outside of their measurement range.

6. Conclusions

This report presents the characterized neutron, prompt gamma-ray, and delayed gamma-ray radiation environments for the cadmium-polyethylene bucket in the central cavity of the ACRR. The characterized location is 11 inches from the bottom of the inside of the bucket with the bucket on the 32-inch pedestal. The designation for this location is ACRR-CdPoly-CC-32-cl. A 640-energy group and 89-energy group neutron spectrum, a 48-energy group prompt gamma-ray spectrum, and a 48-energy group delayed gamma-ray spectrum were calculated using MCNP and a high-fidelity model of the ACRR and CdPoly bucket. The neutron spectrum was adjusted to align more closely with neutron activation dosimetry. The adjustment was performed using the least-squares code 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. The CdPoly bucket is currently available for experimenters to use. The bucket allows for a factor of two increase in the Si dose to 1-MeV DES fluence, compared to the free field environment.

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A Appendix – MCNP ACRR Model With CdPoly Bucket on 32-inch Pedestal

```
STANDARD ACRR Model (Extended Cavity, 32" Pedestal, CdPoly Bucket)
c
c  Origianl Model Developed by W. Fan
c  Modified by P. Cooper and E. Parma with new cavity
c  Macrobody Model Developed by R. DePriest
c  New Cadmium-Polyethylene Bucket Model Developed by K. Kaiser
c
c
c     standard 236-element core configuration with new cavity
c     no FREC
c     room temp 70c cross sections with S(a,b)
c     CdPoly-cl-32 - Cadmium Poly bucket on 32inch pedestal
c     tally is a 6cm diameter sphere at fuel centerline
c         89 and 640 neutron energy groups
c         48 gamma energy groups
c
c       control rods   : variable
c       safety rods    : variable
c       transient rods : variable
c
c
c        1         2         3         4         5         6         7         8
c 34567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
c ******************************************************************************
c *                               CELL CARDS                                   *
c ******************************************************************************
c
c
c  Universe definitions for the standard 236-element core.
c
c     U=1:fuel rods              U=2:water rods
c     U=3:control rods           U=4:safety rods
c     U=5:transient rods         U=6:nickel rods
c     U=7:90% fuel rods          U=9:al rods (empty)
c
c   ********  U=8 is the reactor core fill.  *******
c
c
c  Regular Fuel Elements
c
   10     0         -10  u=1 $Void
   11     1 -3.3447 10 -11  u=1 $UO2-BeO fuel
   14     0         11 -14  u=1 $Void
   15     2    -8.4 14 -15  u=1 $Niobium
   16     0         15 -16  u=1 $Void Gap
   17     4    -2.8 -17  u=1 $Lower BeO Plug
   18     4    -2.8 -18  u=1 $Upper BeO Plug
   19     3   -8.03 17 -19  u=1 $Lower SS Plug
   20     3   -8.03 18 -20  u=1 $Upper SS Plug
   21     3   -8.03 19 20 16 -21  u=1 $SS304
   22     5      -1 21 -22  u=1 $Water
c
c
c  Water Rods
c
   23     5      -1 -22  u=2 $Water
c
c
c  Control Rods:  Poison section
c
   25     8   -2.48 -25  u=3 $B4C poison
   26     0         25 -26  u=3 $Void Cap
   27     3   -8.03 26 -27  u=3 $Poison sleeve
   28     3   -8.03 -28  u=3 $Magnaform plug
   29     5      -1 27 28 -29  u=3 $Water
c
c  Control Rods:  Fuel follower
c
   30     0         -30  u=3 $Void
   31     1 -3.3447 30 -31  u=3 $UO2-BeO fuel
   32     0         31 -32  u=3 $Void
   33     2    -8.4 32 -33  u=3 $Niobium
   34     0         33 -34  u=3 $Void gap
```

```
   35     4    -2.8 -35  u=3 $BeO plug
   36     0         -36  u=3 $Void
   37     3   -8.03 34 35 36 -37  u=3 $SS304
   38     5      -1 37 -38  u=3 $Water
c
c
c  Safety Rods:  Poison section
c
   39     8   -2.48 -39  u=4 $B4C poison
   40     0         39 -40  u=4 $Void cap
   41     3   -8.03 40 -41  u=4 $Poison sleeve
   42     3   -8.03 -42  u=4 $Magnaform plug
   43     5      -1 41 42 -43  u=4 $Water
c
c  Safety Rods:  Fuel follower
c
   44     0         -44  u=4 $Void
   45     1 -3.3447 44 -45  u=4 $UO2-BeO fuel
   46     0         45 -46  u=4 $Void
   47     2    -8.4 46 -47  u=4 $Niobium
   48     0         47 -48  u=4 $Void gap
   49     4    -2.8 -49  u=4 $BeO plug
   50     0         -50  u=4 $Void
   51     3   -8.03 48 49 50 -51  u=4 $SS304
   52     5      -1 51 -52  u=4 $Water
c
c
c  Transient Rods:  Void section
c
   53     0         -53  u=5 $Void
   54     7    -2.7 53 -54 58 60 61  u=5 $Al tubing
   55     5      -1 54 -55  u=5 $Water
   56     7    -2.7 55 -56  u=5 $Al guidex
   57     5      -1 56 -57  u=5 $Water
   58     7    -2.7 -58  u=5
c
c  Transient Rods:  Poison section
c
   59     8   -2.48 -59  u=5 $Poison
   60     7    -2.7 59 -60  u=5 $Inner sleeve
   61     0         -61  u=5 $Void
   62     7    -2.7 -62 54  u=5 $End plug
c
c
c  Nickel Rods
c
   65     6    -8.9 -21  u=6 $Nickel
   66     5      -1 21 -22  u=6 $Water
c
c
c  90% Fuel Element
c
   70     0         -10  u=7 $Void
   71    11 -3.0102 10 -11  u=7 $UO2-BeO fuel
   74     0         11 -14  u=7 $Void
   75     2    -8.4 14 -15  u=7 $Niobium
   76     0         15 -16  u=7 $Void Gap
   77     4    -2.8 -17  u=7 $Lower BeO Plug
   78     4    -2.8 -18  u=7 $Upper BeO Plug
   79     3   -8.03 17 -19  u=7 $Lower SS Plug
   80     3   -8.03 18 -20  u=7 $Upper SS Plug
   81     3   -8.03 19 20 16 -21  u=7 $SS304
   82     5      -1 21 -22  u=7 $Water
c
c
c  Empty Aluminum Rod
c
  600     0         -90  u=25 $Void
  601     7    -2.7 90 -21  u=25 $Al Rod
  602     5      -1 21 -22  u=25 $Water
c
c
c  Empty Aluminum Rod
c
   90     0         -90  u=9 $Void
   91     7    -2.7 90 -21  u=9 $Al Rod
   92     5      -1 21 -22  u=9 $Water
c
c
c  Core  (UNIVERSE = 8)
c
```

```
   1     0         -300 311 210 211 213 220  fill=8
c
   2     5      -1 -320  u=8 lat=2 $ interfa
           fill=-12:12 -12:12 0:0
     2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 1
      2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 2
       2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  $ROW 3
        2 2 2 2 2 2 2 2 2 2 2 6 1 1 1 1 1 1 1 1 1 1 6 2 2  $ROW 4
         2 2 2 2 2 2 2 2 2 6 6 1 1 1 1 1 1 1 1 1 1 1 6 6 2  $ROW 5
          2 2 2 2 2 2 2 2 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 6 2  $ROW 6
           2 2 2 2 2 2 2 6 7 1 1 1 3 1 1 5 1 1 3 1 1 1 7 6 2  $ROW 7
            2 2 2 2 2 2 6 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7 6 2  $ROW 8
             2 2 2 2 2 6 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 7 6 2  $ROW 9
              2 2 2 2 9 6 1 1 1 4 1 1 2 2 2 2 1 1 1 1 1 1 6 2 2  $ROW 10
               2 2 2 2 9 6 1 1 1 1 1 2 2 2 2 2 1 1 1 1 1 6 6 2 2  $ROW 11
                2 2 2 6 6 1 1 1 1 1 2 2 2 2 2 2 1 1 1 1 1 6 2 2 2  $ROW 12
                 2 2 2 6 1 1 3 1 1 2 2 2 2 2 2 2 1 1 3 1 1 6 2 2 2  $ROW 13
                  2 2 6 6 1 1 1 1 1 2 2 2 2 2 2 1 1 1 1 1 9 6 2 2 2  $ROW 14
                   2 2 6 1 1 1 1 1 1 2 2 2 2 2 1 1 1 1 1 1 9 2 2 2 2  $ROW 15
                    2 6 1 1 1 1 5 1 1 2 2 2 2 1 1 5 1 1 1 1 2 2 2 2 2  $ROW 16
                     2 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 $ROW 17
          2
                      2 6 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 $ROW 18
          2
                       2 6 1 1 1 1 3 1 1 4 1 1 3 1 1 1 1 2 2 2 2 2 2 $ROW 19
          2 2
                        2 6 7 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 $ROW 20
          2 2
                         2 6 6 6 1 1 1 1 1 1 1 1 1 9 9 2 2 2 2 2 2 2 $ROW 21
          2 2 2
                          2 2 9 6 6 6 1 1 1 1 6 6 6 6 2 2 2 2 2 2 2 2 $ROW 22
          2 2 2
                           2 2 2 9 2 6 7 7 7 6 2 6 2 2 2 2 2 2 2 2 2 $ROW 23
          2 2 2 2
                            2 2 2 2 25 6 6 6 6 9 2 2 2 2 2 2 2 2 2 2 $ROW 24
          2 2 2 2 2
                             2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 $ROW 25
          2 2 2 2 2
c
c
c  This fuel loading reflects the board as of May 2003.
c
c        1         2         3         4         5         6         7         8
c 3456789012345678901234567890123456789012345678901234567890123456789012345678901234567890
c
c
c
c ********  END OF UNIVERSE DEFINITIONS AND CORE FILL  ********
c
c
c  NEW CENTRAL CAVITY
c
c   To add 32-in pedestal, remove C from line 2.
c   To add 8-in pedestal, remove C from line 2 and 3.
c   You must also remove the C's from the cells in the pedestal
c    descriptions (Cells 110-116).
c
c    Use Line 4 of Cell 100 to exclude surface of buckets and experiments.
c     Exclude surface 706 for Pb-B4C; Exclude surface 711 for Al dosimetry bucke
c     Exclude surface 725 for LP-1
c     Exclude surfaces 730, 731, and 734 for Boom Box
c
  100   702 -0.0010245 -100 #1001 #110 #111 #112 #2000 #2001 #2002 #2003 $Void
          #2004 #2005 #2010 #2011 #2012 #2013 #2014 #2015 #2016 #2017 #2018
c                  113 114 116
c   for LB44                     899              IMP:N,P=1 $Void
  101     3   -8.03 100 -101  $Stainless liner
  102     7    -2.7 -311 101 -102  $Aluminum
  103     5      -1 -311 102  $Water
c
c
c  Central Cavity Additions (32" and 8" Pedestals)
c
c  32-in pedestal
c
  110     7    -2.7 -110 111 112  $32-in pedestal
  111   702 -0.0010245 -111  $32-in pedestal inset
  112   702 -0.0010245 -112  $Inset Notch
c
c
c  8-in pedestal
```

```
c
c 113  7  -2.7000   -113                  IMP:N,P=1 $Bottom plate
c 114  7  -2.7000   -114                  IMP:N,P=1 $Top plate
c 115  702 -1.0245e-3   -115                  IMP:N,P=1 $Center Void
c 116  7  -2.7000   -116  115             IMP:N,P=1 $Support Tube
c
c
c   End of Central Cavity Additions
c
c
c  Top and Bottom Grid Plates
c
  200     7    -2.7 -200 311 201  $Top plate
  201     5      -1 -200 220 -201  $Water
  202     7    -2.7 -202 311  $Bottom plate
c
c
c  Nickel Plate and Window to the Radiography Lab
c
  210     6    -8.9 -210  $Nickel Plate
  211     5      -1 -211 210 -900  $Water
  212     0         -212 -900  $Void
  213     7    -2.7 -213 212 -900  $Aluminum
c
c
c  FREC-II Side Ni Plate
c
  220     6    -8.9 -220
c
c
c  Surrounding Water
c
  230     5      -1 -900 220 213 212 211 202 200 300 311
c
c
c
c   EXPERIMENTAL or SPECTRUM MODIFYING BUCKETS  (700's)
c
c  Pb-B4C Bucket  (700-706)
c  Weight of Bucket per L. Martin (8/21/2003) - 446 lbs
c  Weight of Model Bucket                     - 450.81
c  Density of B4C layer changed to 2.12 g/cc to make weight 446.19 lbs
c
c
c 700  702  -1.0245e-3  -700              IMP:N,P=1 $Inside Bucket
c 701   7   -2.7100  -701  700            IMP:N,P=1 $1/16" Al liner
c 702  700  -11.350  -702 701 7091 7092   IMP:N,P=1 $1" Pb on bottom
c 703  701  -2.5300  -703  7091 7092      IMP:N,P=1 $Boral on bottom
c 707   0            -707  702            IMP:N,P=1 $Slop between Cannister and
c 708   8   -2.1200  -708                 IMP:N,P=1 $B4C layer on the bottom
c
c 704   7   -2.7100  -704  703  707  708
c                          7091 7092      IMP:N,P=1 $Al layer
c 705   8   -2.1200  -705  704            IMP:N,P=1 $B4C layer
c 706   7   -2.7100 -706 705 7091 7092    IMP:N,P=1 $Al exterior
c 7091  3   -8.0300 -7091                 IMP:N,P=1 $Dowel 1
c 7092  3   -8.0300 -7092                 IMP:N,P=1 $Dowel 2
c
c
c
c
c  Standard Aluminum Experiment Bucket (710-711)
c   Add -900 to 710 and 711 if using 24" Bucket
c
c 710  702 -1.0245e-3  -710                IMP:N,P=1 $Inside Bucket
c 711  7   -2.7000     -711  710           IMP:N,P=1 $Aluminum Bucket
c
c
c
c
c  Pb-Poly Bucket (720-725) -- Designated as LP-1
c
c  720   702 -0.0010245 -720 1001  $Bottom of Inside
c  721     7    -2.7 -721 720 726  $1/16" Al Liner
c  722   700  -11.35 -722 721 724 726  $0.4" Pb Layer
c  723   704  -0.945 -723 722 726  $0.8" HDPE
c  724   704  -0.945 -724  $HDPE fill-in
c  725     7    -2.7 -725 721 723 726  $Al Container
c  726   702 -0.0010245 -726  $Top of Inside
c
c
```

```
c
c
c
c  Boombox for NG testing (730-738)
c
c 730  765 -7.28    -730  736  737  738    IMP:N,P=1 $Lower Boom Box
c 731  765 -7.28    -731  733              IMP:N,P=1 $Upper part of clamping rin
c 732  765 -7.28    -732  733              IMP:N,P=1 $Lower part of clamping rin
c 733  702 -1.0245e-3  -733               IMP:N,P=1 $"Void" in clamping ring
c 734  702 -1.0245e-3  -734 732           IMP:N,P=1 $"Void" at ring lip
c 735  765 -7.28    -735                   IMP:N,P=1 $Plug
c 736  702 -1.0245e-3  -736 735           IMP:N,P=1 $"Void" around the plug
c 737  702 -1.0245e-3  -737               IMP:N,P=1 $Lower "void"
c 738  702 -1.0245e-3  -738               IMP:N,P=1 $Lip "void"
c
c
c  PLG-1 Bucket (740-747)
c  RT Bucket --> Designated as PLG-1
c
c 740  7  -2.7000    -740 741  742  743  744 #745 #746 #747   IMP:N,P=1 $ Al Pla
c 741 704 -0.9450    -741                                     IMP:N,P=1 $ Bottom
c 742 700 -11.350    -742                                     IMP:N,P=1 $ Bottom
c 743 780 -1.8200    -743                                     IMP:N,P=1 $ Bottom
c 744 702 -1.0245e-3 -744 1001                                IMP:N,P=1 $ Cavity
c
c 745 704 -0.9450    -745  746                                IMP:N,P=1 $ Poly W
c 746 700 -11.350    -746  747                                IMP:N,P=1 $ Lead W
c 747 780 -1.8200    -747  748                                IMP:N,P=1 $ Graphi
c
c
c
c
c
c New 44" Pb-B4C Bucket
c Base Plate w/ B4C Volume
c From Ktech drawing labeled "PbB BASEII"
c  800  8   -1.274704138 (-802):(817 -815):(818 -816)       IMP:N,P=1 $ B4C Cavi
c  801  766 -7.83 -803:-809                                 IMP:N,P=1 $ All-thre
c    From McMaster-Carr catalog, Item # 98914A033, Threaded Rods and Studs, Gene
c  802  767 -7.82 (805 -806):(811 -812)                     IMP:N,P=1 $ Washers
c    From McMaster-Carr catalog, Item #94744A285, Zinc-Plated Steel Washer for S
c  803  767 -7.82 (803 -807):(809 -813)                     IMP:N,P=1 $ All-thre
c    From McMaster-Carr catalog, Item # 93939A823, Hex Nut, Grade 8 Steel
c  804  702 -1.0245e-3 (803 -804):(809 -810):(803 -805):(809 -811):
c                    (806 807 803 -808):(812 813 809 -814) IMP:N,P=1 $ Void insi
c  805  7 -2.704  (-817 819):(-818 820)                      IMP:N,P=1 $ Al6061
c    From McMaster-Carr catalog, Item # 44705K334, Low-Pressure Aluminum Threade
c  806  702 -1.0245e-3 (-819):(-820)                        IMP:N,P=1 $ Void in
c  807  7 -2.704       (-800:-801) 802 804 808 810 814 815 816
c                                                         IMP:N,P=1 $ Al6061 Bas
c Containment Base
c From Ktech drawing labeled "CONTAINMENT BASE II"
c  830  702 -1.0245e-3  801 -830                            IMP:N,P=1 $ Void
c  831  7 -2.704       (830 833 834 -831):(831 -832)        IMP:N,P=1 $ Al6061 C
c  832  766 -7.83      -833:-834                            IMP:N,P=1 $ All-thre
c Lead Material
c Unchamfered lead rings
c  840  702 -1.0245e-3 -853                                 IMP:N,P=1 $ Void ins
c  841  766 -7.83      -847:-848                            IMP:N,P=1 $ All-thre
c  842  702 -1.0245e-3 (847 -843):(848 -844)                IMP:N,P=1 $ Void bet
c  843  702 -1.0245e-3 -849:-851                            IMP:N,P=1 $ Void ins
c  844  7 -2.704  (849 -850):(851 -852)                     IMP:N,P=1 $ Al6061 t
c  845  702 -1.0245e-3 (850 -845):(852 -846)                IMP:N,P=1 $ Void bet
c  846  700 -11.35     (862 863 860 843 844 845 846 -842):(-840 843 844 845 846)
c                    (853 -854 843 844 845 846)           IMP:N,P=1 $ Unchamfere
c Inner Aluminum 6061 Sleeves (Items #14 and 15 in DWG titled "LEAD BORON BUCKET
c  860  7 -2.704       -860                                 IMP:N,P=1 $ Al6061 b
c  861  702 -1.0245e-3 (-861 1001):-863                     IMP:N,P=1 $ Aluminum
c  862  7 -2.704        861 -862                            IMP:N,P=1 $ Al6061 s
c Al6061 Double Wall Weldment (Item #9 in DWG titled "LEAD BORON BUCKET ASSEMBLY
c  870  702 -1.0245e-3 (840 842 831 854 -868):
c                    (840 842 831 854 -870):
c                    (840 842 831 854 -872)               IMP:N,P=1 $ Void Betwe
c  871  7 -2.704       (868 -869):(870 -871):(872 -873):
c                    (874 -875):(876 -877):(878 -879)     IMP:N,P=1 $ Al6061 Inn
c  872  8 -1.449249072 (869 -874):(871 -885):(886 -876):
c                               (873 -883):(-878 884)     IMP:N,P=1 $ B4C Powder
c PbB Top: Top Plate (Item #1 in DWG titled "LEAD BORON BUCKET ASSEMBLY II")
c  880  702 -1.0245e-3 -880:-881:(-887 848):(-888 847):
c                    -891:-892:-893:-894                  IMP:N,P=1 $ Voids
c  881  7 -2.704       (880 881 -882 887 888 889 890 891 892 893 894):
```

```
c                    (883 -884):(885 -886)                IMP:N,P=1 $ Top Plate
c Modified Hex Head Plugs, 1/4 NPT, AL6061-T6 (Item #16 in DWG titled "LEAD BORO
c From McMaster-Carr catalog, Item # 3867T65, High-Pressure Aluminum Pipe Fittin
c  882  7 -2.704       (-821 852):(-822 852):(-823 850):(-824 850)
c                                                         IMP:N,P=1 $ Modified H
c Outside World
c  889  702 -1.0245e-3 -899 800 831 832 875 877 879 821 822 823 824
c                     882 847 848 850 852                IMP:N,P=1 $ Enclosing
c
c     EXPERIMENT PACKAGES (1000's)
c   1001  702 -1.0245e-3 -1001 1002                         IMP:N,P=1 $ 6 cm di
c   1002  6   -8.902     -1002                              IMP:N,P=1 $ Ni Foil
 1001   702 -0.0010245 -1001  $ 6 cm dia s
c
c
c
 2000     7    -2.7 -2000 2001 #1001 #2005 #2010 #2012 #2014  $ Al
 2001   704 -0.9217 -2006 2002 #2010 #2011 #2012 #2013 #2014 #2015 #2016
                 vol=6804.4
 2002   320   -8.28 -2007 2003 #2005 #2017 vol=343.63 $ Cad liner
 2003     7    -2.7 -2003 2004 #2001 #2005 #2018 vol=654.8  $ al inner liner
 2004     7    -2.7 -2005  $ al base
 2005     7    -2.7 -2008 2009 #2010 #2011 #2012 #2013 #2014 #2015  $ top al rin
 2010   702 -0.0010245 -2010 #2011
 2011     7    -2.7 -2011
 2012   702 -0.0010245 -2012 #2013
 2013     7    -2.7 -2013
 2014   702 -0.0010245 -2014 #2015
 2015     7    -2.7 -2015
 2016   704 -0.9217 -2016 2017 #2011 #2010 #2012 #2013 #2014 #2015 vol=95.93
 2017   320   -8.28 -2019 2018 vol=4.66
 2018     7    -2.7 -2021 2020 vol=4.31
c
c     EXTERNAL WORLD
c
c
c
  900     0         900  $Outside world

c        1         2         3         4         5         6         7         8
c 345678901234567890123456789012345678901234567890123456789012345678901234567890
c ******************************************************************************
c *                              SURFACE CARDS                                 *
c ******************************************************************************
c
c    Fuel Elements
c
   10       rcc 0 0 23.32 0 0 52.25 0.2413  $Void
   11       rcc 0 0 23.32 0 0 52.25 1.684  $Fuel
   14       rcc 0 0 23.32 0 0 52.25 1.72025  $Void
   15       rcc 0 0 23.32 0 0 52.25 1.77125  $Niobium
   16       rcc 0 0 23.32 0 0 52.25 1.82225  $Void gap
   17       rcc 0 0 21.415 0 0 1.905 1.487  $Lower plug
   18       rcc 0 0 75.57 0 0 1.905 1.487  $Upper plug
   19       rcc 0 0 16.32 0 0 7 1.82225  $Lower plug
   20       rcc 0 0 75.57 0 0 5 1.82225  $Upper plug
   21       rcc 0 0 16.32 0 0 98.89 1.87325  $
   22       rcc 0 0 16.32 0 0 98.89 5  $Water
c
c   Control Rods
c
   25     3 rcc 0 0 78.11 0 0 52.25 1.4605  $B4C poison
   26     3 rcc 0 0 78.11 0 0 98.89 1.50495  $Void cap
   27     3 rcc 0 0 78.11 0 0 98.89 1.74625  $poison sleeve
   28     3 rcc 0 0 75.57 0 0 2.54 1.74625  $Magnaform plug
   29     3 rcc 0 0 75.57 0 0 101.43 5  $Water
   30     3 rcc 0 0 23.32 0 0 52.25 0.2413  $Void
   31     3 rcc 0 0 23.32 0 0 52.25 1.684  $Fuel
   32     3 rcc 0 0 23.32 0 0 52.25 1.72025  $Void
   33     3 rcc 0 0 23.32 0 0 52.25 1.77125  $Niobium
   34     3 rcc 0 0 23.32 0 0 52.25 1.82225  $Void gap
   35     3 rcc 0 0 20.78 0 0 2.54 1.82225  $BeO plug
   36     3 rcc 0 0 -79.22 0 0 100 1.82225  $Void
   37     3 rcc 0 0 -79.22 0 0 154.79 1.87325  $SS304
   38     3 rcc 0 0 -79.22 0 0 154.79 5  $Water
c
c    Safety Rods
c
   39     4 rcc 0 0 78.11 0 0 52.25 0.5715  $B4C poison
   40     4 rcc 0 0 78.11 0 0 98.89 0.83185  $Void cap
   41     4 rcc 0 0 78.11 0 0 98.89 1.74625  $Poison sleeve
```

```
   42     4 rcc 0 0 75.57 0 0 2.54 1.74625  $Magnaform plug
   43     4 rcc 0 0 75.57 0 0 101.43 5  $Water
   44     4 rcc 0 0 23.32 0 0 52.25 0.2413  $Void
   45     4 rcc 0 0 23.32 0 0 52.25 1.684  $Fuel
   46     4 rcc 0 0 23.32 0 0 52.25 1.72025  $Void
   47     4 rcc 0 0 23.32 0 0 52.25 1.77125  $Niobium
   48     4 rcc 0 0 23.32 0 0 52.25 1.82225  $Void gap
   49     4 rcc 0 0 20.78 0 0 2.54 1.82225  $BeO plug
   50     4 rcc 0 0 -79.22 0 0 100 1.82225  $Void
   51     4 rcc 0 0 -79.22 0 0 154.79 1.87325  $SS304
   52     4 rcc 0 0 -79.22 0 0 154.79 5  $Water
c
c    Transient Rods
c
   53     5 rcc 0 0 -76.2762 0 0 73.1012 1.2  $Void
   54       rcc 0 0 -79.22 0 0 200 1.27  $Al tubing
   55       rcc 0 0 -79.22 0 0 200 1.4986  $Water
   56       rcc 0 0 -79.22 0 0 200 2.02438  $Al guidex
   57       rcc 0 0 -79.22 0 0 200 5  $Water
   58     5 rcc 0 0 -3.175 0 0 3.174 1.2
   59     5 rcc 0 0 -0.001 0 0 76.201 0.88  $Poison
   60     5 rcc 0 0 -0.001 0 0 76.201 1.2  $Inner sleeve
   61     5 rcc 0 0 76.2 0 0 123.8 1.2  $Void
   62     5 rcc 0 0 -100 0 0 23.7238 1.2  $End plug
c
c    Aluminum Rods
c
   90       rcc 0 0 15.41 0 0 66.14 1.77125  $Void in Al rod
c
c    Central Cavity Surfaces
c
  100       rcc 0 0 -67.395 0 0 202.395 11.645  $Void
  101       rcc 0 0 -67.395 0 0 202.395 12.28
  102       rcc 0 0 -67.395 0 0 202.395 13.97
c
c   Cavity Additions
c
  110       rcc 0 0 -67.395 0 0 81.28 11.43  $32-in pedestal
  111       rcc 0 0 8.4748 0 0 2.8702 8.255  $32-in inset
  112       rpp -0.9525 0.9525 -8.255 8.255 11.345 13.885  $Inset Notch
  113       rcc 0 0 13.885 0 0 1.27 10.3188  $Bottom plate (8-in)
  114       rcc 0 0 32.935 0 0 1.27 10.3188  $Top plate (8-in)
  115       rcc 0 0 15.155 0 0 17.78 5.715  $Center void (8-in)
  116       rcc 0 0 15.155 0 0 17.78 6.35  $Support tube (8-in)
c
c    Top and Bottom Grid Plates
c
  200       rcc 0 0 80.55 0 0 2.54 53.35  $Top plate
  201        py -34.925  $Cutoff of top plate
  202       rcc 0 0 11.33 0 0 5.08 47  $Bottom plate
c
c
c    Window to Radiography Lab
c
  210     1 rpp 38.1 39.37 -26.67 26.67 16.41 80.55  $Ni plate
  211     1 rpp 38.1 39.37 -38.1 38.1 16.41 80.55  $Water
  212     1 rpp 48.895 100 -26.67 26.67 16.41 80.55  $Void
  213     1 rpp 39.37 100 -38.1 38.1 16.41 80.55  $Aluminum
c
c   Nickel Plate near FREC-II
c
  220       rpp -36.83 36.83 -36.195 -34.925 16.41 83.09  $Nickel Plate
c
c    Hexes for the lattice, inner and outer core, and core boundary
c
  320       rhp 0 0 -132 0 0 400 2.0855 0 0  $Lattice element
  300     1 rhp 0 0 16.41 0 0 64.14 42.7 0 0  $outer core bound
  310     1 rhp 0 0 -67.395 0 0 202.395 11.65 0 0  $Inner line
  311     1 rhp 0 0 -67.395 0 0 202.395 12.285 0 0  $Outer line
c
c
c   Buckets  (700's)
c
c  Pb-B4C Bucket
c
  700     7 rcc 0 0 6.35 0 0 85.09 6.2738  $Void
  701     7 rcc 0 0 6.26872 0 0 85.17128 6.35508  $0.032" Al liner
  702     7 rcc 0 0 3.65125 0 0 87.78875 9.7663  $Pb layers
  703     7 rcc 0 0 3.01625 0 0 0.635 9.17575  $Boral
  704     7 rcc 0 0 1.905 0 0 89.535 10.16  $Al layer
  705     7 rcc 0 0 1.905 0 0 89.535 11.1125  $B4C
```

```
  706     7 rcc 0 0 0 0 0 91.44 11.43  $Al layer
  707     7 rcc 0 0 3.65125 0 0 87.78875 9.8425
  708     7 rcc 0 0 1.905 0 0 0.635 7.62  $B4C bottom
 7091     7 rcc 0 -8.89 0 0 0 91.44 0.3175  $Dowel 1
 7092     7 rcc 0 8.89 0 0 0 91.44 0.3175  $Dowel 2
c
c  14" Aluminum Bucket
c
  710     7 rcc 0 0 0.15875 0 0 35.40125 11.27125  $Void
  711     7 rcc 0 0 0 0 0 35.56 11.43  $Al bucket
c
c USE these for a 24" Aluminum Bucket
c
c 710 7 RCC  0.0 0.0 0.15875  0.0 0.0 60.80125 11.27125   $Void
c 711 7 RCC  0.0 0.0 0.00000  0.0 0.0 60.96000 11.43000   $Al bucket
c
c  LP-1 Surfaces
c
  720     7 rcc 0 0 5.74675 0 0 62.18825 7.46125  $Inside
  721     7 rcc 0 0 5.588 0 0 73.152 7.62  $Al liner
  722     7 rcc 0 0 3.556 0 0 64.379 8.636  $Pb
  723     7 rcc 0 0 2.54 0 0 65.395 10.668  $HDPE
  724     7 rcc 0 0 3.556 0 0 1.016 7.62  $HDPE fill-in
  725     7 rcc 0 0 0 0 0 78.74 11.43  $Al Container
  726     7 rcc 0 0 67.935 0 0 10.805 7.46125
c
c  Boom Box Surfaces
c
  730     7 rcc 0 0 0 0 0 65.786 9.8425
  731     7 rcc 0 0 65.913 0 0 3.048 9.8425
  732     7 rcc 0 0 65.786 0 0 0.127 8.128
  733     7 rcc 0 0 65.786 0 0 3.175 5.08
  734     7 rcc 0 0 65.786 0 0 0.127 9.8425
  735     7 rcc 0 0 59.436 0 0 6.35 6.6675
  736     7 rcc 0 0 59.436 0 0 6.35 6.7945
  737     7 rcc 0 0 2.54 0 0 54.864 7.9375
  738     7 rcc 0 0 57.404 0 0 2.032 5.08
c
c  PLG-1 Surfaces
c
  740     7 rcc 0 0 0 0 0 72.8726 11.43
  741     7 rcc 0 0 2.54 0 0 0.635 8.89
  742     7 rcc 0 0 3.175 0 0 0.3175 8.89
  743     7 rcc 0 0 3.4925 0 0 0.635 8.89
  744     7 rcc 0 0 4.7625 0 0 68.1101 8.89
  745     7 rcc 0 0 2.54 0 0 60.0964 10.795
  746     7 rcc 0 0 2.54 0 0 60.0964 10.16
  747     7 rcc 0 0 2.54 0 0 60.0964 9.8425
  748        cz 9.2075
c
c
c New 44" Pb-B4C Bucket
c Base Plate w/ B4C Volume
c From Ktech drawing labeled "PbB BASEII"
c
  800     7 rcc 0 0 0 0 0 1.905 11.43  $ Base Plate Bottom
  801     7 rcc 0 0 1.905 0 0 1.905 7.9375  $ Base Plate Top
  802     7 rcc 0 0 2.2225 0 0 1.27 7.62  $ B4C Cavity
c Bolts/Bolt Holes
c Big Bolts/Bolt Holes
c From McMaster-Carr catalog, Item # 98914A033, Threaded Rods and Studs
  803     7 rcc 8.89 0 0 0 0 1.905 0.53594  $ All-Thread #1
  804     7 rcc 8.89 0 1.524 0 0 0.381 0.65151  $ All-Thread Hole
  805     7 rcc 8.89 0 1.2954 0 0 0.2286 0.674688  $ All-Thread Wash
  806     7 rcc 8.89 0 1.2954 0 0 0.2286 1.27  $ All-Thread Wash
  807     7 rcc 8.89 0 0.50165 0 0 0.79375 0.9525  $ All-Thread Nut
  808     7 rcc 8.89 0 0 0 0 1.524 1.5875  $ All-Thread Nut
  809     7 rcc -8.89 0 0 0 0 1.905 0.53594  $ All-Thread #2
  810     7 rcc -8.89 0 1.524 0 0 0.381 0.65151  $ All-Thread Hole
  811     7 rcc -8.89 0 1.2954 0 0 0.2286 0.674688  $ All-Thread Wash
  812     7 rcc -8.89 0 1.2954 0 0 0.2286 1.27  $ All-Thread Wash
  813     7 rcc -8.89 0 0.50165 0 0 0.79375 0.9525  $ All-Thread Nut
  814     7 rcc -8.89 0 0 0 0 1.524 1.5875  $ All-Thread Nut
c Small Bolts/Bolt Holes
c From McMaster-Carr catalog, Item # 44705K334, Low-Pressure Aluminum Threaded S
  815     7 rcc 0 5.3975 0 0 0 2.2225 0.71374  $ Small Hole #1
  816     7 rcc 0 -5.3975 0 0 0 2.2225 0.71374  $ Small Hole #2
  817     7 rcc 0 5.3975 0 0 0 1.2192 0.71374  $ Plug #1
  818     7 rcc 0 -5.3975 0 0 0 1.2192 0.71374  $ Plug #2
  819     7 rpp -0.357188 0.357188 5.040313 5.754688 0 0.862648  $ Plug #1 9/32"
  820     7 rpp -0.357188 0.357188 -5.754688 -5.040313 0 $ Plug #2 9/32"
```

```
                0.862648
c
c Containment Base
c From Ktech drawing labeled "CONTAINMENT BASE II"
c
  830     7 rcc 0 0 1.905 0 0 1.905 7.9883  $ Inner void
  831     7 rcc 0 0 1.905 0 0 1.905 9.779  $ Inner Disc Region
  832     7 rcc 0 0 1.905 0 0 0.635 11.43  $ Outer Disc Region
  833     7 rcc 8.89 0 1.905 0 0 1.905 0.53594  $ All-thread #1, G
  834     7 rcc -8.89 0 1.905 0 0 1.905 0.53594  $ All-thread #2, G
c
c Lead Bottom, Floor, and Rings (Items #4, 5, and 6 in DWG titled "LEAD BORON BU
c Drawn March 22, 2010 by S. Padias
c Unchamfered lead components
c
  840     7 rcc 0 0 3.81 0 0 2.54 9.7663  $ Lead bottom disc
c 841  7 RCC  0.000  0.000  6.350  0.000  0.000  100.33 6.477   $ Inner lead voi
  842     7 rcc 0 0 6.35 0 0 100.33 9.7663  $ Lead ring
  843     7 rcc 8.89 0 3.81 0 0 106.68 0.65532  $ Right-side big l
  844     7 rcc -8.89 0 3.81 0 0 106.68 0.65532  $ Left-side big le
  845     7 rcc 0 8.89 3.81 0 0 106.68 0.32639  $ Top-side small l
  846     7 rcc 0 -8.89 3.81 0 0 106.68 0.32639  $ Bottom-side smal
c From McMaster-Carr catalog, Item # 98914A033, Threaded Rods and Studs
  847     7 rcc 8.89 0 3.81 0 0 113.665 0.53594  $ Right-side All-
  848     7 rcc -8.89 0 3.81 0 0 113.665 0.53594  $ Left-side All-T
c General Purpose Aluminum Tubing
c From McMaster-Carr catalog, Item # 89965K42, General Purpose Aluminum Tubing
  849     7 rcc 0 8.89 3.81 0 0 111.76 0.2286  $ Top-side inner
  850     7 rcc 0 8.89 3.81 0 0 111.76 0.3175  $ Top-side outer
  851     7 rcc 0 -8.89 3.81 0 0 111.76 0.2286  $ Bottom-side inn
  852     7 rcc 0 -8.89 3.81 0 0 111.76 0.3175  $ Bottom-side out
c Chamfered lead components
  853     7 trc 0 0 106.68 0 0 3.81 6.477 7.62  $ Chamfered l
  854     7 rcc 0 0 106.68 0 0 3.81 9.7663  $ Chamfered lead r
c
c Inner Aluminum 6061 Sleeves (Items #14 and 15 in DWG titled "LEAD BORON BUCKET
c
  860     7 rcc 0 0 6.35 0 0 0.08255 6.477  $ Al6061 Base Plat
  861     7 rcc 0 0 6.43255 0 0 100.1776 6.39445  $ Al6061 Sheet v
  862     7 rcc 0 0 6.43255 0 0 100.1776 6.477  $ Al6061 Sheet
  863     7 rcc 0 0 106.6102 0 0 0.0698 6.477  $ Void
c
c PbB base II Double Wall Weldment (Item #9 in DWG titled "LEAD BORON BUCKET ASS
c
  868     7 rcc 0 0 2.54 0 0 107.315 9.8425  $ Inner Surface of
  869     7 rcc 0 0 2.54 0 0 107.315 10.16  $ Inner Skin II L1
  870     7 rcc 0 0 109.855 0 0 0.254 9.8425  $ Inner Surface of
  871     7 rcc 0 0 109.855 0 0 0.254 10.16  $ Inner Skin II L2
  872     7 rcc 0 0 110.109 0 0 0.381 9.8425  $ Inner Surface of
  873     7 rcc 0 0 110.109 0 0 0.381 10.16  $ Inner Skin II L3
  874     7 rcc 0 0 2.54 0 0 107.315 11.1125  $ B4C Powder Regi
  875     7 rcc 0 0 2.54 0 0 107.315 11.43  $ Outer Skin II L1
  876     7 rcc 0 0 109.855 0 0 0.254 11.1125  $ B4C Powder Regi
  877     7 rcc 0 0 109.855 0 0 0.254 11.43  $ Outer Skin II L2
  878     7 rcc 0 0 110.109 0 0 0.381 11.1125  $ B4C Powder Regi
  879     7 rcc 0 0 110.109 0 0 0.381 11.43  $ Outer Skin II L3
c
c PbB Top: Top Plate (Item #1 in DWG titled "LEAD BORON BUCKET ASSEMBLY II")
c
  880     7 rcc 0 0 110.49 0 0 0.4318 7.62  $ Lower void
  881     7 trc 0 0 110.9218 0 0 0.8382 7.62 8.103935  $ Upper void
  882     7 rcc 0 0 110.49 0 0 1.27 11.43  $ Al6061 Disc
  883     7 rcc 0 0 110.49 0 0 -0.381 10.1727  $ Lower B4C Cap vo
  884     7 rcc 0 0 110.49 0 0 -0.381 11.0998  $ B4C Cap
  885     7 trc 0 0 109.855 0 0 0.254 10.4267 10.1727  $ Inner ch
  886     7 trc 0 0 109.855 0 0 0.254 10.8458 11.0998  $ Outer ch
c Top Plate holes
  887     7 rcc -8.89 0 110.49 0 0 1.27 0.65151  $ Left Large hole
  888     7 rcc 8.89 0 110.49 0 0 1.27 0.65151  $ Right Large hole
  889     7 rcc 0 -8.89 110.49 0 0 1.27 0.65151  $ Bottom Large hol
  890     7 rcc 0 8.89 110.49 0 0 1.27 0.65151  $ Top Large hole
  891     7 rcc -2.54 8.89 110.49 0 0 1.27 0.3175  $ Small Hole #1
  892     7 rcc 2.54 8.89 110.49 0 0 1.27 0.3175  $ Small Hole #2
  893     7 rcc -2.54 -8.89 110.49 0 0 1.27 0.3175  $ Small Hole #1
  894     7 rcc 2.54 -8.89 110.49 0 0 1.27 0.3175  $ Small Hole #2
c Modified Hex Head Plugs, 1/4 NPT, AL6061-T6 (Item #16 in DWG titled "LEAD BORO
c From McMaster-Carr catalog, Item # 3867T65, High-Pressure Aluminum Pipe Fittin
  821     7 rcc 0 -8.89 111.76 0 0 -1.27 0.65151  $ Bottom Hex Threa
  822     7 rcc 0 -8.89 111.76 0 0 0.635 0.79375  $ Bottom Hex Head
  823     7 rcc 0 8.89 111.76 0 0 -1.27 0.65151  $ Top Hex Thread
  824     7 rcc 0 8.89 111.76 0 0 0.635 0.79375  $ Top Hex Head
```

```
c
c Enclosing surface for the 44" Pb-B4C bucket
c
  899     7 rcc 0 0 0 0 0 117.475 11.43  $ Enclosing surfac
c
c
c  EXPERIMENT SURFACES
c
 1001     6  so 3  $ 6 cm dia scoring sphere
 1002     6 rcc 0 -0.013301675 0 0 0.026603351 0 0.635  $ Nickel Foil
c
c cad/poly bucket
 2000     8 rcc 0 0 0 0 0 74.295 11.43  $ outer AL diameter
 2001     8 rcc 0 0 0 0 0 74.295 11.2268  $inner AL diameter
 2006     8 rcc 0 0 0 0 0 73.3425 11.2268  $ HPDE thickness card
 2002     8 rcc 0 0 0 0 0 73.3425 9.77265  $ HDPE
 2003     8 rcc 0 0 0 0 0 73.9775 9.69645  $ Cad liner
 2007     8 rcc 0 0 0 0 0 73.9755 9.77265  $ cad thickness card
 2004     8 rcc 0 0 0 0 0 74.265 9.62533  $ AL inner liner
 2005     7 rcc 0 0 0 0 0 1.27 11.43  $ bottom AL plate
 2008     8 rcc 0 0 73.66 0 0 1.27 11.43  $ Top al ring
 2009     8 rcc 0 0 73.66 0 0 1.27 9.62533 $ top al ring
 2010     9 rpp 0 0.7633 0 0.9779 0 74.93
 2011    10 rcc 0 0 0 0 0 74.93 0.4889
 2012    11 rpp 0 0.9779 0 0.7633 0 74.93
 2013    12 rcc 0 0 0 0 0 74.93 0.4889
 2014    13 rpp 0 0.9779 0 0.7633 0 74.93
 2015    14 rcc 0 0 0 0 0 74.93 0.4889
 2016    18 rcc 0 0 0 0 0 1 11.2268
 2017    18 rcc 0 0 0 0 0 1 9.77265
 2018    18 rcc 0 0 0 0 0 1 9.69645
 2019    18 rcc 0 0 0 0 0 1 9.77265
 2020    18 rcc 0 0 0 0 0 1 9.62533
 2021    18 rcc 0 0 0 0 0 1 9.69645
c    External Cutoff
c
  900       rcc 0 0 -67.395 0 0 202.395 72

c
c
mode  n p
kcode 5000000 1.0 3 4000
ksrc  20.000000 0.000000 50.000000
      0.000000 20.000000 60.000000
      30.000000 0.000000 40.000000
      0.000000 30.000000 60.000000
c
c ********************
c *  MATERIAL CARDS  *
c ********************
c  Materials cards use the latest available cross sections
c
c  UO2-BeO fuel (3.3447 g/cc)  (XSEC Temp - 293.6 K)
c
c
m1    4009.70c     -0.2827602
      8016.70c      -0.527769 92235.70c    -0.0662957 92238.70c    -0.1222844
      92234.70c    -0.0004547 92236.70c    -0.0004358
c
c
c  UO2-BeO fuel (3.0102 g/cc)  -- This is the 90% fuel
c                                 (XSEC Temp - 293.6 K)
c   Included as a separate material to avoid warning message
c
c
m11   4009.70c     -0.2827602
      8016.70c      -0.527769 92235.70c    -0.0662957 92238.70c    -0.1222844
      92234.70c    -0.0004547 92236.70c    -0.0004358
c
c     NIOBIUM (8.4 g/cc)
c
m2    41093.70c             1
c
c
c  SS-304L from Ktech Materials Database Rev. 118
c   Material Number:  3410
c     Values are weight %
c      Si: 0.0100  Cr: 0.1900  Mn: 0.0200  Fe: 0.6800  Ni: 0.1000
c
c FM multiplier (neutrons):  1.76109641E-10  3410  -4   1
c FM multiplier (photons):   1.76109641E-10  3410  -5  -6
```

```
c
c  Density:  7.896 g/cc
c
m3    14028.70c     -0.009187
      14029.70c     -0.000483 14030.70c     -0.000329 24050.70c      -0.00793
      24052.70c     -0.159029 24053.70c      -0.01838 24054.70c     -0.004661
      25055.70c         -0.02 26054.70c      -0.03839 26056.70c      -0.62493
      26057.70c     -0.014691 26058.70c     -0.001989 28058.70c     -0.067198
      28060.70c     -0.026776 28061.70c     -0.001183 28062.70c     -0.003834
      28064.70c     -0.001009
c
c
c     BeO (2.8 g/cc)
c
m4    4009.70c            0.5
      8016.70c      0.4998096 8017.70c      0.0001904
c
c     Water (1 g/cc)
c
m5    1001.70c      0.6665667
      1002.70c         0.0001 8016.70c      0.3332063 8017.70c       0.000127
c
c
c  Ni reflector
c           Values are weight %
c           Ni-58: 67.19780  Ni-60: 26.77586  Ni-61:  1.18346
c           Ni-62:  3.83429  Ni-64:  1.00859
c    Converted Data from Nuclear Wallet Card to w/o with "Weight_Frac" program
c  Density:  8.9020 g/cc
c
c
m6    28058.70c     -0.671978
      28060.70c    -0.2677586 28061.70c    -0.0118346 28062.70c    -0.0383429
      28064.70c    -0.0100859
c
c
c  Al-6061 from Ktech Materials Database Rev. 118
c    Material Number:  3110
c     Values are weight %
c      Mg: 0.0110  Al: 0.9670  Si: 0.0080  Ti: 0.0007
c      Cr: 0.0020  Mn: 0.0013  Fe: 0.0056  Ni: 0.0004
c      Cu: 0.0030  Zn: 0.0010
c
c FM multiplier (neutrons):  3.55249469E-10  3110  -4   1
c FM multiplier (photons):   3.55249469E-10  3110  -5  -6
c
c  Density:  2.704 g/cc
c
m7    12000.66c        -0.011
      13027.70c        -0.967 14028.70c      -0.00735 14029.70c     -0.000387
      14030.70c     -0.000263 22000.66c       -0.0007 24050.70c     -8.4e-005
      24052.70c     -0.001674 24053.70c     -0.000193 24054.70c     -4.9e-005
      25055.70c       -0.0013 26054.70c     -0.000316 26056.70c     -0.005147
      26057.70c     -0.000121 26058.70c     -1.6e-005 28058.70c     -0.000269
      28060.70c     -0.000107 28061.70c       -5e-006 28062.70c     -1.5e-005
      28064.70c       -4e-006 29063.70c     -0.002055 29065.70c     -0.000945
      30000.42c        -0.001
c
c
c    B4C poison (2.48 g/cc)
c    Composition data taken from Jeff Wemple (KTech) Memo dated June 18, 2010
c    and titled "Re: Drawing of new Lead-boron bucket"
c    Manufacturer of powder is READE ADVANCED MATERIALS
c    Density of packed powder in the 44" Pb-B4C bucket is 1.2505 (half of 2.51 g
c
m8    6000.70c            0.2
      5010.70c         0.1592 5011.70c         0.6408
c
c
c  Natural Lead
c  True Weight %:  Pb-204:  1.37808  Pb-206: 23.95550
c                  Pb-207: 22.07430  Pb-208: 52.59212
c  Weight % based on Available MCNP XSEC:
c                  Pb-206: 24.29024  Pb-207: 22.38275
c                  Pb-208: 53.32701
c
c    Converted Data from Nuclear Wallet Card to w/o with "Weight_Frac" program
c  Density is 11.35 g/cc from Nuclear Wallet Cards.
c
c
m700  82206.70c    -0.2429024
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      82207.70c    -0.2238275 82208.70c    -0.5332701
c
c
c Boral Plate Composition
c
c  Composition found in Nuclear Science and Engineering
c   Vol. 65, No. 1, pgs. 41-48, January 1978.
c   Values are weight %
c         B: 27.40   C:  7.61  Al: 63.68
c        Cu:  0.09  Zn:  0.16  Fe:  0.45
c        Cr:  0.10  Mn:  0.10  Mg:  0.05
c        Ti:  0.10  Li:  0.26
c
c   Density:  2.53 g/cc
c
c
m701  5010.70c      -0.050242
      5011.70c      -0.223758 6000.70c        -0.0761 13027.70c       -0.6368
      29063.70c     -0.000616 29065.70c     -0.000284 30000.42c       -0.0016
      26056.70c       -0.0045 24050.70c     -4.2e-005 24052.70c     -0.000837
      24053.70c     -9.7e-005 24054.70c     -2.4e-005 25055.70c        -0.001
      12000.66c       -0.0005 22000.66c        -0.001 3006.70c      -0.000171
      3007.70c      -0.002429
c
c
c
c  Air
c   Standard Density:  1.205e-3 g/cc @ 20 deg C, 1 atm
c   Albuquerque:       1.0245e-3 g/cc in ABQ
c  See Attix p.531-532
c
m702  7014.70c      -0.752308
      7015.70c       -0.00296 8016.70c      -0.231687 8017.70c      -9.4e-005
      6000.70c      -0.000124 18000.42c     -0.012827
c
c
c   HELIUM  For Leak Test
c    @ 2 atm density = 3.57e-4 g/cc
c
m703  2003.70c      1.37e-006
      2004.70c      0.9999986
c
c
c HDPE-> (C2H4)n    --          --
c                   |   H    H   |
c                   |   |    |   |
c                  -|-  C -- C  -|-
c                   |   |    |   |
c                   |   H    H   |
c                   --          --
c
m704  1001.70c       0.666667
      6000.70c       0.333333
c
c
c   A517 Carbon Steel  (den = 7.28 g/cc)
c     Modified to match the mill test cert.
c     from Tubos de Acero de Mexico, S.A.
c
c   Summary of MatMCNP Calculations:
c
c  Isotope  Number Fraction    Weight Fraction       Atoms/b-cm
c   C-12       0.0118115          0.0025688          0.0009385
c   C-13       0.0001326          0.0000312          0.0000105
c  Si-28       0.0048924          0.0024807          0.0003887
c  Si-29       0.0002484          0.0001305          0.0000197
c  Si-30       0.0001638          0.0000890          0.0000130
c  Cr-50       0.0000184          0.0000167          0.0000015
c  Cr-52       0.0003557          0.0003348          0.0000283
c  Cr-53       0.0000403          0.0000387          0.0000032
c  Cr-54       0.0000100          0.0000098          0.0000008
c  Mn-55       0.0078340          0.0078003          0.0006225
c  Fe-54       0.0568920          0.0556172          0.0045205
c  Fe-56       0.8930822          0.9053674          0.0709617
c  Fe-57       0.0206252          0.0212829          0.0016388
c  Fe-58       0.0027448          0.0028820          0.0002181
c  Cu-63       0.0007628          0.0008700          0.0000606
c  Cu-65       0.0003400          0.0004001          0.0000270
c  Mo-92       0.0000068          0.0000114          0.0000005
c  Mo-94       0.0000043          0.0000072          0.0000003
c  Mo-95       0.0000073          0.0000126          0.0000006
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c  Mo-96       0.0000077          0.0000133          0.0000006
c  Mo-97       0.0000044          0.0000077          0.0000003
c  Mo-98       0.0000111          0.0000197          0.0000009
c  Mo-100      0.0000044          0.0000080          0.0000004
c
c  The total compound atom density (atom/b-cm):  0.07945702
c
m765  6000.70c       0.011944
      14028.70c     0.0048924 14029.70c     0.0002484 14030.70c     0.0001638
      24050.70c     1.84e-005 24052.70c     0.0003557 24053.70c     4.03e-005
      24054.70c        1e-005 25055.70c      0.007834 26054.70c      0.056892
      26056.70c     0.8930822 26057.70c     0.0206252 26058.70c     0.0027448
      29063.70c     0.0007628 29065.70c       0.00034 42000.66c      4.6e-005
c
c      Cadmium (8.65 g/cc)
m320  48000.70c             1
c
c
c  General Purpose Steel, Grade B7
c   7 Comment Cards
c
c  1
c  2 The weight fraction for elements of General Purpose Steel, Grade B7 is
c  3 The weight fractions are used for each element.
c  4 The density of natural cadmium is 7.83 g/cc,
c  5 The MCNP material number is found after the material.
c  6 The line below "7" gives the density.
c  7
c
c   Summary of MatMCNP Calculations:
c
c  Isotope  Number Fraction    Weight Fraction       Atoms/b-cm
c   C-12       0.0194064          0.0042483          0.0016694
c   C-13       0.0002178          0.0000517          0.0000187
c  Mn-55       0.0087306          0.0087500          0.0007510
c   P-31       0.0006194          0.0003500          0.0000533
c   S-32       0.0006498          0.0003790          0.0000559
c   S-33       0.0000051          0.0000031          0.0000004
c   S-34       0.0000288          0.0000178          0.0000025
c   S-36       0.0000001          0.0000001          0.0000000
c  Si-28       0.0045003          0.0022968          0.0003871
c  Si-29       0.0002285          0.0001208          0.0000197
c  Si-30       0.0001506          0.0000824          0.0000130
c  Cr-50       0.0004466          0.0004069          0.0000384
c  Cr-52       0.0086125          0.0081607          0.0007409
c  Cr-53       0.0009766          0.0009432          0.0000840
c  Cr-54       0.0002431          0.0002392          0.0000209
c  Mo-92       0.0001696          0.0002843          0.0000146
c  Mo-94       0.0001057          0.0001811          0.0000091
c  Mo-95       0.0001819          0.0003150          0.0000157
c  Mo-96       0.0001906          0.0003335          0.0000164
c  Mo-97       0.0001091          0.0001929          0.0000094
c  Mo-98       0.0002758          0.0004925          0.0000237
c  Mo-100      0.0001101          0.0002006          0.0000095
c  Fe-54       0.0557637          0.0548720          0.0047968
c  Fe-56       0.8753707          0.8932369          0.0753001
c  Fe-57       0.0202161          0.0209977          0.0017390
c  Fe-58       0.0026904          0.0028434          0.0002314
c
c  The total compound atom density (atom/b-cm):  0.08602087
c
c  This material contains an isotope that is often
c  modified by an S(alpha,beta). Check MCNP
c  Manual Appendix G to see if an
c  S(alpha,beta) is required.
c
c  MCNP Material 766
c
m766  6000.70c      0.0196242
      25055.70c     0.0087306 15031.70c     0.0006194 16000.66c     0.0006838
      14028.70c     0.0045003 14029.70c     0.0002285 14030.70c     0.0001506
      24050.70c     0.0004466 24052.70c     0.0086125 24053.70c     0.0009766
      24054.70c     0.0002431 42000.66c     0.0011428 26054.70c     0.0557637
      26056.70c     0.8753707 26057.70c     0.0202161 26058.70c     0.0026904
c
c  Caution: The natural zaid is used for Carbon.
c
c  Caution: The natural zaid is used for Sulfur.
c
c  Caution: The natural zaid is used for Molybdenum.
c
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c  If the natural zaid is used for any element, the atom fractions of each isoto
c  of that element are added together and listed with the natural zaid just once
c
c  To convert a particle flux to rad[Material]
c  use FM  1.76023016E-10 766  -4 1 for neutrons
c   or FM  1.76023016E-10 766  -5 -6 for photons.
c
c
c  Carbon Steel
c   8 Comment Cards
c
c  1
c  2 The weight fraction for elements of carbon steel is used.
c  3 The weight fractions are used for each element.
c  4 Data obtained from MCNP Primer by C.D. Harmon and R.D. Busch (1994)
c  5 The density of natural cadmium is 7.82 g/cc,
c  6 The MCNP material number is found after the material.
c  7 The line below "8" gives the density.
c  8
c
c   Summary of MatMCNP Calculations:
c
c  Isotope  Number Fraction    Weight Fraction       Atoms/b-cm
c   C-12       0.0225772          0.0049399          0.0019386
c   C-13       0.0002534          0.0000601          0.0000218
c  Fe-54       0.0571155          0.0561733          0.0049043
c  Fe-56       0.8965919          0.9144202          0.0769875
c  Fe-57       0.0207062          0.0214957          0.0017780
c  Fe-58       0.0027556          0.0029108          0.0002366
c
c  The total compound atom density (atom/b-cm):  0.08586678
c
c  This material contains an isotope that is often
c  modified by an S(alpha,beta). Check MCNP
c  Manual Appendix G to see if an
c  S(alpha,beta) is required.
c
c  MCNP Material 767
c
m767  6000.70c      0.0228306
      26054.70c     0.0571155 26056.70c     0.8965919 26057.70c     0.0207062
      26058.70c     0.0027556
c **************************
c *     TRANSFORMATIONS     *
c **************************
c
c  TR1 rotates the hexes for the outer core bound and the cavity liner
c
*tr1 0 0 0 30 60 90 120 30 90  j  j  j
c
c  TR3-->Movement of control rods -0.001 (full up) to -55.001 (full down)
c
c
c   Measured Up DC with 32-in pedestal is -39.731               (03/03/2004)
c   Measured Down DC is -30.851                                 (03/03/2004)
c    -->Up DC position of 1527 Rod Units
c    -->Down DC position of 2415 Rod Units
c   Measured Up DC with 8-in + 32-in pedestal is -40.421        (03/01/2004)
c   Measured Down DC with 8-in + 32-in pedestal is -31.291      (03/01/2004)
c    -->Up DC position of 1428 Rod Units
c    -->Down DC position of 2371 Rod Units
c   Measured Up DC with Pb-B4C on 32-in pedestal is -22.951     (03/09/2004)
c   Measured Down DC with Pb-B4C on 32-in pedestal is -10.741   (03/09/2004)
c    -->Up DC position of 3205 Rod Units
c    -->Down DC position of 4426 Rod Units
c   Measured DC with LP-1 on 32-in pedestal is -31.941          (03/11/2004)
c   Measured Down DC with LP-1 on 32-in pedestal is -23.721     (03/11/2004)
c    -->Up DC position of 2306 Rod Units
c    -->Down DC position of 3128 Rod Units
c
*tr3 0 0 -29.16
c
c  TR4-->Movement of safety rods 0.001 (full up) to -54.999 (full down)
c
c    Measured worth of safety rods:  -$2.12                     (03/30/2004)
c
*tr4 0 0 0.001
c
c  TR5-->Movement of transient rods 0 (full down) to 90 (full up)
c
c    Measured worth of transient rods:  -$4.14                  (03/30/2004)
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c
*tr5 0 0 90
c
c  TR6-->Moves experiment package from origin (0 0 0) to fuel centerline
c
*tr6 0 0 49.445
c
c  TR7-->Puts buckets on 8" (34.205) or 32" (13.885) pedestals
c   Use 32" pedestal for LP-1
c   Use 8" for Standard Al buckets
c
*tr7 0 0 13.885
*tr8 0 0 15.155
*tr9 9.31 4.8 15.155 30 60 90 120 30 90  j  j  j
*tr10 9.12 5.255 15.155
*tr11 -9.365 4.7 15.155 60 30 90 150 60 90  j  j  j
*tr12 -9.18 5.16 15.155
*tr13 -0.4889 -11.225 15.155
*tr14 0 -10.47 15.155
*tr18 0 0 48.945
imp:n   1 102r       0             $ 10, 900
imp:p   1 102r       0             $ 10, 900
kopts  blocksize=10  kinetics=yes  precursor=yes
mt1     beo.60t      $ S(alpha, beta) for UO2-BeO (Temp - 294 K)
mt11    beo.60t      $ S(alpha, beta) for BeO (Temp - 294 K)
mt4     beo.60t      $ S(alpha, beta) for BeO (Temp - 294 K)
mt5    lwtr.60t     $ S(alpha, beta) for water (Temp - 294 K)
mt704  poly.60t
c
c  Caution: The natural zaid is used for Carbon.
c
c  If the natural zaid is used for any element, the atom fractions of each isoto
c  of that element are added together and listed with the natural zaid just once
c
c  To convert a particle flux to rad[Material]
c  use FM  1.75917531E-10 767  -4 1 for neutrons
c   or FM  1.75917531E-10 767  -5 -6 for photons.
c
c ********************
c * TALLIES  *
c ********************
c
f14:p   1001
fc14    gamma fluence  g/cm**2/source neutron - 48 group
e14     1.38880e-10
        1.00e-03 1.00E-02 2.00E-02 3.00E-02 4.50E-02
        6.00e-02 8.00E-02 1.00E-01 1.50E-01 2.00E-01
        3.00e-01 4.00E-01 4.50E-01 5.00E-01 5.25E-01
        6.00e-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00
        1.13e+00 1.20E+00 1.33E+00 1.50E+00 1.66E+00
        1.88e+00 2.00E+00 2.33E+00 2.50E+00 2.67E+00
        3.00e+00 3.50E+00 4.00E+00 4.50E+00 5.00E+00
        5.50e+00 6.00E+00 6.50E+00 7.00E+00 7.50E+00
        8.00e+00 9.00E+00 1.00E+01 1.20E+01 1.40E+01
        1.70e+01 2.00E+01 3.00E+01 5.00E+01
c
f24:n   1001
fc24    neutron fluence  n/cm**2/source neutron - 640 group
e24    1.050e-10   1.100e-10   1.150e-10   1.200e-10   1.275e-10
       1.350e-10   1.425e-10   1.500e-10   1.600e-10   1.700e-10   1.800e-10
       1.900e-10   2.000e-10   2.100e-10   2.200e-10   2.300e-10   2.400e-10
       2.550e-10   2.700e-10   2.800e-10   3.000e-10   3.200e-10   3.400e-10
       3.600e-10   3.800e-10   4.000e-10   4.250e-10   4.500e-10   4.750e-10
       5.000e-10   5.250e-10   5.500e-10   5.750e-10   6.000e-10   6.300e-10
       6.600e-10   6.900e-10   7.200e-10   7.600e-10   8.000e-10   8.400e-10
       8.800e-10   9.200e-10   9.600e-10   1.000e-09   1.050e-09   1.100e-09
       1.150e-09   1.200e-09   1.275e-09   1.350e-09   1.425e-09   1.500e-09
       1.600e-09   1.700e-09   1.800e-09   1.900e-09   2.000e-09   2.100e-09
       2.200e-09   2.300e-09   2.400e-09   2.550e-09   2.700e-09   2.800e-09
       3.000e-09   3.200e-09   3.400e-09   3.600e-09   3.800e-09   4.000e-09
       4.250e-09   4.500e-09   4.750e-09   5.000e-09   5.250e-09   5.500e-09
       5.750e-09   6.000e-09   6.300e-09   6.600e-09   6.900e-09   7.200e-09
       7.600e-09   8.000e-09   8.400e-09   8.800e-09   9.200e-09   9.600e-09
       1.000e-08   1.050e-08   1.100e-08   1.150e-08   1.200e-08   1.275e-08
       1.350e-08   1.425e-08   1.500e-08   1.600e-08   1.700e-08   1.800e-08
       1.900e-08   2.000e-08   2.100e-08   2.200e-08   2.300e-08   2.400e-08
       2.550e-08   2.700e-08   2.800e-08   3.000e-08   3.200e-08   3.400e-08
       3.600e-08   3.800e-08   4.000e-08   4.250e-08   4.500e-08   4.750e-08
       5.000e-08   5.250e-08   5.500e-08   5.750e-08   6.000e-08   6.300e-08
       6.600e-08   6.900e-08   7.200e-08   7.600e-08   8.000e-08   8.400e-08
       8.800e-08   9.200e-08   9.600e-08   1.000e-07   1.050e-07   1.100e-07
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1.150e-07	1.200e-07	1.275e-07	1.350e-07	1.425e-07	1.500e-07
1.600e-07	1.700e-07	1.800e-07	1.900e-07	2.000e-07	2.100e-07
2.200e-07	2.300e-07	2.400e-07	2.550e-07	2.700e-07	2.800e-07
3.000e-07	3.200e-07	3.400e-07	3.600e-07	3.800e-07	4.000e-07
4.250e-07	4.500e-07	4.750e-07	5.000e-07	5.250e-07	5.500e-07
5.750e-07	6.000e-07	6.300e-07	6.600e-07	6.900e-07	7.200e-07
7.600e-07	8.000e-07	8.400e-07	8.800e-07	9.200e-07	9.600e-07
1.000e-06	1.050e-06	1.100e-06	1.150e-06	1.200e-06	1.275e-06
1.350e-06	1.425e-06	1.500e-06	1.600e-06	1.700e-06	1.800e-06
1.900e-06	2.000e-06	2.100e-06	2.200e-06	2.300e-06	2.400e-06
2.550e-06	2.700e-06	2.800e-06	3.000e-06	3.200e-06	3.400e-06
3.600e-06	3.800e-06	4.000e-06	4.250e-06	4.500e-06	4.750e-06
5.000e-06	5.250e-06	5.500e-06	5.750e-06	6.000e-06	6.300e-06
6.600e-06	6.900e-06	7.200e-06	7.600e-06	8.000e-06	8.400e-06
8.800e-06	9.200e-06	9.600e-06	1.000e-05	1.050e-05	1.100e-05
1.150e-05	1.200e-05	1.275e-05	1.350e-05	1.425e-05	1.500e-05
1.600e-05	1.700e-05	1.800e-05	1.900e-05	2.000e-05	2.100e-05
2.200e-05	2.300e-05	2.400e-05	2.550e-05	2.700e-05	2.800e-05
3.000e-05	3.200e-05	3.400e-05	3.600e-05	3.800e-05	4.000e-05
4.250e-05	4.500e-05	4.750e-05	5.000e-05	5.250e-05	5.500e-05
5.750e-05	6.000e-05	6.300e-05	6.600e-05	6.900e-05	7.200e-05
7.600e-05	8.000e-05	8.400e-05	8.800e-05	9.200e-05	9.600e-05
1.000e-04	1.050e-04	1.100e-04	1.150e-04	1.200e-04	1.275e-04
1.350e-04	1.425e-04	1.500e-04	1.600e-04	1.700e-04	1.800e-04
1.900e-04	2.000e-04	2.100e-04	2.200e-04	2.300e-04	2.400e-04
2.550e-04	2.700e-04	2.800e-04	3.000e-04	3.200e-04	3.400e-04
3.600e-04	3.800e-04	4.000e-04	4.250e-04	4.500e-04	4.750e-04
5.000e-04	5.250e-04	5.500e-04	5.750e-04	6.000e-04	6.300e-04
6.600e-04	6.900e-04	7.200e-04	7.600e-04	8.000e-04	8.400e-04
8.800e-04	9.200e-04	9.600e-04	1.000e-03	1.050e-03	1.100e-03
1.150e-03	1.200e-03	1.275e-03	1.350e-03	1.425e-03	1.500e-03
1.600e-03	1.700e-03	1.800e-03	1.900e-03	2.000e-03	2.100e-03
2.200e-03	2.300e-03	2.400e-03	2.550e-03	2.700e-03	2.800e-03
3.000e-03	3.200e-03	3.400e-03	3.600e-03	3.800e-03	4.000e-03
4.250e-03	4.500e-03	4.750e-03	5.000e-03	5.250e-03	5.500e-03
5.750e-03	6.000e-03	6.300e-03	6.600e-03	6.900e-03	7.200e-03
7.600e-03	8.000e-03	8.400e-03	8.800e-03	9.200e-03	9.600e-03
1.000e-02	1.050e-02	1.100e-02	1.150e-02	1.200e-02	1.275e-02
1.350e-02	1.425e-02	1.500e-02	1.600e-02	1.700e-02	1.800e-02
1.900e-02	2.000e-02	2.100e-02	2.200e-02	2.300e-02	2.400e-02
2.550e-02	2.700e-02	2.800e-02	3.000e-02	3.200e-02	3.400e-02
3.600e-02	3.800e-02	4.000e-02	4.250e-02	4.500e-02	4.750e-02
5.000e-02	5.250e-02	5.500e-02	5.750e-02	6.000e-02	6.300e-02
6.600e-02	6.900e-02	7.200e-02	7.600e-02	8.000e-02	8.400e-02
8.800e-02	9.200e-02	9.600e-02	1.000e-01	1.050e-01	1.100e-01
1.150e-01	1.200e-01	1.275e-01	1.350e-01	1.425e-01	1.500e-01
1.600e-01	1.700e-01	1.800e-01	1.900e-01	2.000e-01	2.100e-01
2.200e-01	2.300e-01	2.400e-01	2.550e-01	2.700e-01	2.800e-01
3.000e-01	3.200e-01	3.400e-01	3.600e-01	3.800e-01	4.000e-01
4.250e-01	4.500e-01	4.750e-01	5.000e-01	5.250e-01	5.500e-01
5.750e-01	6.000e-01	6.300e-01	6.600e-01	6.900e-01	7.200e-01
7.600e-01	8.000e-01	8.400e-01	8.800e-01	9.200e-01	9.600e-01
1.000e+00	1.100e+00	1.200e+00	1.300e+00	1.400e+00	1.500e+00
1.600e+00	1.700e+00	1.800e+00	1.900e+00	2.000e+00	2.100e+00
2.200e+00	2.300e+00	2.400e+00	2.500e+00	2.600e+00	2.700e+00
2.800e+00	2.900e+00	3.000e+00	3.100e+00	3.200e+00	3.300e+00
3.400e+00	3.500e+00	3.600e+00	3.700e+00	3.800e+00	3.900e+00
4.000e+00	4.100e+00	4.200e+00	4.300e+00	4.400e+00	4.500e+00
4.600e+00	4.700e+00	4.800e+00	4.900e+00	5.000e+00	5.100e+00
5.200e+00	5.300e+00	5.400e+00	5.500e+00	5.600e+00	5.700e+00
5.800e+00	5.900e+00	6.000e+00	6.100e+00	6.200e+00	6.300e+00
6.400e+00	6.500e+00	6.600e+00	6.700e+00	6.800e+00	6.900e+00
7.000e+00	7.100e+00	7.200e+00	7.300e+00	7.400e+00	7.500e+00
7.600e+00	7.700e+00	7.800e+00	7.900e+00	8.000e+00	8.100e+00
8.200e+00	8.300e+00	8.400e+00	8.500e+00	8.600e+00	8.700e+00
8.800e+00	8.900e+00	9.000e+00	9.100e+00	9.200e+00	9.300e+00
9.400e+00	9.500e+00	9.600e+00	9.700e+00	9.800e+00	9.900e+00
1.000e+01	1.010e+01	1.020e+01	1.030e+01	1.040e+01	1.050e+01
1.060e+01	1.070e+01	1.080e+01	1.090e+01	1.100e+01	1.110e+01
1.120e+01	1.130e+01	1.140e+01	1.150e+01	1.160e+01	1.170e+01
1.180e+01	1.190e+01	1.200e+01	1.210e+01	1.220e+01	1.230e+01
1.240e+01	1.250e+01	1.260e+01	1.270e+01	1.280e+01	1.290e+01
1.300e+01	1.310e+01	1.320e+01	1.330e+01	1.340e+01	1.350e+01
1.360e+01	1.370e+01	1.380e+01	1.390e+01	1.400e+01	1.410e+01
1.420e+01	1.430e+01	1.440e+01	1.450e+01	1.460e+01	1.470e+01
1.480e+01	1.490e+01	1.500e+01	1.510e+01	1.520e+01	1.530e+01
1.540e+01	1.550e+01	1.560e+01	1.570e+01	1.580e+01	1.590e+01
1.600e+01	1.610e+01	1.620e+01	1.630e+01	1.640e+01	1.650e+01
1.660e+01	1.670e+01	1.680e+01	1.690e+01	1.700e+01	1.710e+01
1.720e+01	1.730e+01	1.740e+01	1.750e+01	1.760e+01	1.770e+01
1.780e+01	1.790e+01	1.800e+01	1.810e+01	1.820e+01	1.830e+01

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       1.840e+01   1.850e+01   1.860e+01   1.870e+01   1.880e+01   1.890e+01
       1.900e+01   1.910e+01   1.920e+01   1.930e+01   1.940e+01   1.950e+01
       1.960e+01   1.970e+01   1.980e+01   1.990e+01   2.000e+01
c
f34:n   1001
fc34    neutron fluence  n/cm**2/source neutron - 89 group
e34     1.39E-10 1.00E-09 5.00E-09 1.00E-08 3.00E-08 7.00E-08 1.00E-07
        1.52e-07 2.00E-07 4.14E-07 6.00E-07 8.00E-07 1.13E-06 3.06E-06
        5.04e-06 8.32E-06 1.37E-05 2.26E-05 3.73E-05 6.14E-05 1.01E-04
        1.67e-04 2.75E-04 3.54E-04 4.54E-04 5.83E-04 7.49E-04 9.61E-04
        1.09e-03 1.23E-03 1.40E-03 1.58E-03 1.80E-03 2.03E-03 2.31E-03
        2.61e-03 2.96E-03 3.35E-03 3.80E-03 4.31E-03 4.88E-03 5.53E-03
        6.27e-03 7.10E-03 8.05E-03 9.12E-03 1.03E-02 1.17E-02 1.33E-02
        1.50e-02 1.70E-02 1.93E-02 2.19E-02 2.48E-02 2.61E-02 2.81E-02
        3.18e-02 4.09E-02 5.25E-02 6.74E-02 8.65E-02 1.11E-01 1.43E-01
        1.83e-01 2.35E-01 3.02E-01 3.88E-01 4.39E-01 4.98E-01 5.64E-01
        6.39e-01 7.24E-01 8.21E-01 9.30E-01 1.05E+00 1.19E+00 1.35E+00
        1.74e+00 2.23E+00 2.87E+00 3.68E+00 4.72E+00 6.07E+00 7.79E+00
        1.00e+01 1.19E+01 1.35E+01 1.49E+01 1.69E+01 2.00E+01
c
f44:n  1001
fc44   total neutron fluence  n/cm**2/source neutron
c
c Tallies in Rad[Bi]/MJ are getting the MJ component from the source term
f104:n  2016
fc104   Neutron Dose (Rad[poly] / MJ)
fm104  2.07022e-9 704  -4  1
c
f114:p  2016
fc114   Photon Dose (Rad[poly] / MJ)
fm114  2.07022e-9 704  -5 -6
c
f106:n  2016
fc106   Neutron Dose (Rad[poly] / MJ)
fm106   1.602e-8
c
f116:p  2016
fc116   Photon Dose (Rad[poly]/ MJ)
fm116   1.602e-8
c
c  Cd 112.4
c Tallies in Rad[Bi]/MJ are getting the MJ component from the source term
f204:n  2017
fc204   Neutron Dose (Rad[Cd] / MJ)
fm204  8.58348E-11 320  -4  1
c
f214:p  2017
fc214   Photon Dose (Rad[Cd] / MJ)
fm214  8.58348E-11 320  -5 -6
c
f206:n  2017
fc206   Neutron Dose (Rad[Cd] / MJ)
fm206   1.602e-8
c
f216:p  2017
fc216   Photon Dose (Rad[Cd]/ MJ)
fm216   1.602e-8
c
c Tallies in Rad[Bi]/MJ are getting the MJ component from the source term
f304:n  2018
fc304   Neutron Dose (Rad[Al] / MJ)
fm304  3.573e-10 7  -4  1
c
f314:p  2018
fc314   Photon Dose (Rad[AL] / MJ)
fm314  3.573e-10 7  -5 -6
c
f306:n  2018
fc306   Neutron Dose (Rad[al] / MJ)
fm306   1.602e-8
c
f316:p  2018
fc316   Photon Dose (Rad[al]/ MJ)
fm316   1.602e-8
F5534:n 1001
FC5534  Total Rad[Si]/source neutron  neutrons NuGET resp(4)
FM5534 1.0
E5534  1.00000e-09  5.00000e-09  1.00000e-08  3.00000e-08
       7.00000e-08  1.00000e-07  1.52300e-07  2.00000e-07
       4.13994e-07  6.00000e-07  8.00000e-07  1.12535e-06
       3.05902e-06  5.04348e-06  8.31529e-06  1.37096e-05
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       2.26033e-05  3.72665e-05  6.14421e-05  1.01301e-04
       1.67017e-04  2.75364e-04  3.53575e-04  4.53999e-04
       5.82947e-04  7.48518e-04  9.61117e-04  1.08909e-03
       1.23410e-03  1.39842e-03  1.58461e-03  1.79560e-03
       2.03468e-03  2.30560e-03  2.61259e-03  2.96045e-03
       3.35463e-03  3.80129e-03  4.30743e-03  4.88095e-03
       5.53084e-03  6.26727e-03  7.10174e-03  8.04733e-03
       9.11882e-03  1.03330e-02  1.17088e-02  1.32678e-02
       1.50344e-02  1.70362e-02  1.93045e-02  2.18749e-02
       2.47875e-02  2.60584e-02  2.80879e-02  3.18278e-02
       4.08677e-02  5.24752e-02  6.73795e-02  8.65170e-02
       1.11090e-01  1.42642e-01  1.83156e-01  2.35177e-01
       3.01974e-01  3.87742e-01  4.39369e-01  4.97871e-01
       5.64161e-01  6.39279e-01  7.24398e-01  8.20850e-01
       9.30145e-01  1.05399e+00  1.19433e+00  1.35335e+00
       1.73774e+00  2.23130e+00  2.86505e+00  3.67879e+00
       4.72367e+00  6.06531e+00  7.78801e+00  1.00000e+01
       1.19125e+01  1.34986e+01  1.49182e+01  1.69046e+01
       2.00000e+01
EM5534 2.9453E-13 1.2491E-13 7.4993E-14 4.6756E-14
       2.9204E-14  2.2020E-14  1.8134E-14  1.5288E-14
       1.1697E-14  9.0478E-15  7.6884E-15  6.5898E-15
       4.6553E-15  3.3904E-15  2.8020E-15  2.4485E-15
       2.3485E-15  2.5558E-15  3.1887E-15  4.4567E-15
       6.7264E-15  1.0592E-14  1.4812E-14  1.8835E-14
       2.4061E-14  3.0787E-14  3.9575E-14  4.7130E-14
       5.3411E-14  6.0242E-14  6.8206E-14  7.7048E-14
       8.7510E-14  1.2939E-13  1.1218E-13  1.2645E-13
       1.4290E-13  1.6120E-13  1.8300E-13  2.0983E-13
       2.3549E-13  2.6298E-13  2.9687E-13  3.3455E-13
       3.7695E-13  4.2457E-13  4.7687E-13  5.3632E-13
       6.0001E-13  6.8969E-13  7.5184E-13  8.3414E-13
       9.2816E-13  9.9107E-13  1.0376E-12  1.1220E-12
       1.2948E-12  1.1215E-12  6.5234E-12  2.7648E-12
       2.3185E-12  1.1829E-12  1.6308E-11  4.6795E-11
       3.0036E-11  2.7778E-11  2.9759E-11  3.1713E-11
       4.6317E-11  3.8152E-11  3.4773E-11  5.7662E-11
       6.0882E-11  6.1192E-11  4.4042E-11  6.2344E-11
       8.7416E-11  8.5690E-11  9.4520E-11  1.0191E-10
       1.3729E-10  2.0283E-10  4.8502E-10  8.3147E-10
       1.0388E-09  1.1783E-09  1.2616E-09  1.3551E-09
       1.4243E-09
c    Ionizing Dose Rad[Si]/source neutron  - neutrons  NuGET resp(10)
c
F5544:n 1001
FC5544  Ionizing Rad[Si]/source neutron  neutrons NuGET resp(10)
FM5544 1.0
E5544  1.00000e-09  5.00000e-09  1.00000e-08  3.00000e-08
       7.00000e-08  1.00000e-07  1.52300e-07  2.00000e-07
       4.13994e-07  6.00000e-07  8.00000e-07  1.12535e-06
       3.05902e-06  5.04348e-06  8.31529e-06  1.37096e-05
       2.26033e-05  3.72665e-05  6.14421e-05  1.01301e-04
       1.67017e-04  2.75364e-04  3.53575e-04  4.53999e-04
       5.82947e-04  7.48518e-04  9.61117e-04  1.08909e-03
       1.23410e-03  1.39842e-03  1.58461e-03  1.79560e-03
       2.03468e-03  2.30560e-03  2.61259e-03  2.96045e-03
       3.35463e-03  3.80129e-03  4.30743e-03  4.88095e-03
       5.53084e-03  6.26727e-03  7.10174e-03  8.04733e-03
       9.11882e-03  1.03330e-02  1.17088e-02  1.32678e-02
       1.50344e-02  1.70362e-02  1.93045e-02  2.18749e-02
       2.47875e-02  2.60584e-02  2.80879e-02  3.18278e-02
       4.08677e-02  5.24752e-02  6.73795e-02  8.65170e-02
       1.11090e-01  1.42642e-01  1.83156e-01  2.35177e-01
       3.01974e-01  3.87742e-01  4.39369e-01  4.97871e-01
       5.64161e-01  6.39279e-01  7.24398e-01  8.20850e-01
       9.30145e-01  1.05399e+00  1.19433e+00  1.35335e+00
       1.73774e+00  2.23130e+00  2.86505e+00  3.67879e+00
       4.72367e+00  6.06531e+00  7.78801e+00  1.00000e+01
       1.19125e+01  1.34986e+01  1.49182e+01  1.69046e+01
       2.00000e+01
EM5544 5.6388E-14 2.3915E-14 1.4358E-14 8.9523E-15
       5.5931E-15  4.2191E-15  3.4764E-15  2.9335E-15
       2.2510E-15  1.7513E-15  1.4983E-15  1.2977E-15
       9.6917E-16  8.0034E-16  7.8537E-16  8.7934E-16
       1.1255E-15  1.6036E-15  2.4469E-15  3.8787E-15
       5.4547E-15  5.9892E-15  8.0312E-15  7.9398E-15
       7.5542E-15  7.7746E-15  8.3614E-15  9.4487E-15
       1.0211E-14  1.1244E-14  1.2547E-14  1.4005E-14
       1.5783E-14  2.5784E-14  2.0237E-14  2.2954E-14
       2.6152E-14  2.9865E-14  3.4388E-14  4.0363E-14
       4.5863E-14  5.1699E-14  5.9290E-14  6.7910E-14
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       7.7886E-14  8.9214E-14  1.0196E-13  1.1672E-13
       1.3295E-13  1.5642E-13  1.7265E-13  1.9507E-13
       2.2123E-13  2.3906E-13  2.5255E-13  2.7769E-13
       3.3030E-13  2.9574E-13  1.8013E-12  7.9689E-13
       6.9076E-13  3.6256E-13  5.4889E-12  1.6127E-11
       1.0869E-11  1.0571E-11  1.1766E-11  1.2944E-11
       1.9592E-11  1.5811E-11  1.5216E-11  2.6417E-11
       2.7448E-11  2.7878E-11  2.0719E-11  3.1281E-11
       4.7004E-11  4.6906E-11  5.3930E-11  6.2175E-11
       8.9919E-11  1.4844E-10  4.2934E-10  7.7224E-10
       9.7986E-10  1.1165E-09  1.1998E-09  1.2913E-09
       1.3576E-09
c    Total (Ionizing) Dose Rad[Si]/source neutron  - gammas  NuGET resp(4,10)
c
F5574:p 1001
FC5574  Total (Ionizing) Rad[Si]/source neutron  gammas NuGET resp(4,10)
FM5574 1.0
E5574   1.00E-02 2.00E-02 3.00E-02 4.50E-02
        6.00E-02 8.00E-02 1.00E-01 1.50E-01 2.00E-01
        3.00E-01 4.00E-01 4.50E-01 5.00E-01 5.25E-01
        6.00E-01 7.00E-01 8.00E-01 9.00E-01 1.00E+00
        1.13E+00 1.20E+00 1.33E+00 1.50E+00 1.66E+00
        1.88E+00 2.00E+00 2.33E+00 2.50E+00 2.67E+00
        3.00E+00 3.50E+00 4.00E+00 4.50E+00 5.00E+00
        5.50E+00 6.00E+00 6.50E+00 7.00E+00 7.50E+00
        8.00E+00 9.00E+00 1.00E+01 1.20E+01 1.40E+01
        1.70E+01 2.00E+01 3.00E+01 5.00E+01
c
EM5574  2.2333E-08 2.6194E-09 8.5265E-10 3.6673E-10
        1.8119E-10  1.0802E-10  7.7607E-11  6.9732E-11
        8.2229E-11  1.1624E-10  1.6597E-10  2.0312E-10
        2.2729E-10  2.4509E-10  2.6821E-10  3.0734E-10
        3.5001E-10  3.9058E-10  4.2919E-10  4.6993E-10
        5.0517E-10  5.3936E-10  5.8756E-10  6.3817E-10
        6.9334E-10  7.4186E-10  8.0505E-10  8.7253E-10
        9.1592E-10  9.8154E-10  1.0910E-09  1.2213E-09
        1.3528E-09  1.4863E-09  1.6221E-09  1.7602E-09
        1.9005E-09  2.0430E-09  2.1873E-09  2.3334E-09
        2.5553E-09  2.8552E-09  3.3125E-09  3.9360E-09
        4.7448E-09  5.7667E-09  8.2196E-09  1.4500E-08
F4114:n 1001
FC4114   Neutron 89 1-MeV Equivalent Flux (n/cm^2)/source neutron
FM4114 1.0
E4114   1.00000e-09  5.00000e-09  1.00000e-08  3.00000e-08
       7.00000e-08  1.00000e-07  1.52300e-07  2.00000e-07
       4.13994e-07  6.00000e-07  8.00000e-07  1.12535e-06
       3.05902e-06  5.04348e-06  8.31529e-06  1.37096e-05
       2.26033e-05  3.72665e-05  6.14421e-05  1.01301e-04
       1.67017e-04  2.75364e-04  3.53575e-04  4.53999e-04
       5.82947e-04  7.48518e-04  9.61117e-04  1.08909e-03
       1.23410e-03  1.39842e-03  1.58461e-03  1.79560e-03
       2.03468e-03  2.30560e-03  2.61259e-03  2.96045e-03
       3.35463e-03  3.80129e-03  4.30743e-03  4.88095e-03
       5.53084e-03  6.26727e-03  7.10174e-03  8.04733e-03
       9.11882e-03  1.03330e-02  1.17088e-02  1.32678e-02
       1.50344e-02  1.70362e-02  1.93045e-02  2.18749e-02
       2.47875e-02  2.60584e-02  2.80879e-02  3.18278e-02
       4.08677e-02  5.24752e-02  6.73795e-02  8.65170e-02
       1.11090e-01  1.42642e-01  1.83156e-01  2.35177e-01
       3.01974e-01  3.87742e-01  4.39369e-01  4.97871e-01
       5.64161e-01  6.39279e-01  7.24398e-01  8.20850e-01
       9.30145e-01  1.05399e+00  1.19433e+00  1.35335e+00
       1.73774e+00  2.23130e+00  2.86505e+00  3.67879e+00
       4.72367e+00  6.06531e+00  7.78801e+00  1.00000e+01
       1.19125e+01  1.34986e+01  1.49182e+01  1.69046e+01
       2.00000e+01
EM4114 7.5961E-03  3.2240E-03  1.9363E-03  1.2056E-03
      7.5163E-04  5.6871E-04  4.6973E-04  3.9575E-04
      3.0190E-04  2.3304E-04  1.9795E-04  1.6939E-04
      1.1758E-04  8.2408E-05  6.4229E-05  5.0179E-05
      3.9147E-05  3.0427E-05  2.3676E-05  1.8442E-05
      1.4339E-05  9.7494E-05  2.6841E-04  4.0686E-04
      5.9064E-04  7.8570E-04  1.0342E-03  1.2319E-03
      1.4075E-03  1.5995E-03  1.8221E-03  2.0549E-03
      2.3256E-03  2.6184E-03  2.9743E-03  3.3457E-03
      3.7643E-03  4.2256E-03  4.7750E-03  5.5745E-03
      6.3047E-03  6.9425E-03  7.7809E-03  8.6990E-03
      9.7062E-03  1.0839E-02  1.2055E-02  1.3507E-02
      1.5133E-02  1.6986E-02  1.8947E-02  2.0858E-02
      2.2890E-02  2.4277E-02  2.5432E-02  2.7606E-02
      3.2838E-02  2.7784E-02  1.4632E-01  6.8038E-02
```

```
      5.6388E-02  3.1980E-02  3.2467E-01  9.3595E-01
      5.7694E-01  5.2662E-01  5.4894E-01  5.6944E-01
      8.3665E-01  6.8657E-01  6.0740E-01  9.4533E-01
      1.0008E+00  1.0100E+00  7.0485E-01  9.2531E-01
      1.2016E+00  1.1576E+00  1.2218E+00  1.1833E+00
      1.4055E+00  1.5923E+00  1.6248E+00  1.7277E+00
      1.7041E+00  1.7661E+00  1.7634E+00  1.8349E+00
      1.9197E+00
c    PRINT  10 60 100 110
c rand  GEN=2 SEED=19073486328125 STRIDE=152917
prdmp  50 50 0 1 0
```

B Appendix – Input Deck for Neutron Spectrum Adjustment Using the LSL-M2 Code

```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 ACRR CC CdPoly Bucket
----------------------------------------------------------------
-------------------------------------------------
@actv
 1.0e+0   (activities given in bq/nucleus)
CC-CdP
@end
@description
 ag109g:sld   mil5  bahl  -4.8737E-17   0.006
 al27a:sld    ml3x  bahl  -4.0228E-18   0.018
 al27p:sld    ml3x  bahl  -2.3141E-15   0.022
 au197g:sld   dil3  bahl  -3.7488E-13   0.017
 co59g:sld    mil2  bahl  -1.3482E-17   0.014
 co59p:sld    mil2  bahl  -1.2296E-19   0.031
 co592:sld    mil2  bahl  -1.1389E-20   0.183
 cu63a:sld    mil5  cdhl  -1.1497E-21   0.044
 cu63g:sld    mil5  bahl  -5.3525E-15   0.028
 fe54p:sld    mil5  bahl  -1.0366E-18   0.017
 fe56p:sld    mil5  bahl  -3.8669E-17   0.016
 fe58g:sld    mil5  bahl  -2.0046E-17   0.019
 in115n:sld   mil5  bahl  -5.1109E-15   0.056
 mg24p:sld    mil5  bahl  -8.6405E-18   0.019
 mn55g:sld    mil2  bahl  -7.9671E-14   0.016
 mn552:sld    mil2  bahl  -2.8166E-21   0.045
 mo98g:sld    mil5  bahl  -1.4967E-15   0.010
 na23g:sld    pelt  bahl  -3.0951E-16   0.018
 nb93g:sld    mil5  cdhl  -6.0332E-22   0.175
 nb932:sld    mil5  bahl  -1.7793E-19   0.019
 ni58p:sld    milx  bahl  -6.1122E-18   0.030  *
 np237f:sld   void  fisa  -7.9845E-10   0.036
 rmldu:sld    rmld  fiss  -1.4603E-10   0.022
 rmleu:sld    rmle  fiss  -1.5452E-09   0.022
 rmlpu:sld    rmlp  fiss  -1.5703E-09   0.035
 s32cf:sld    void  bare   4.3499E+14   0.036
 sc45g:sld    mil5  bahl  -9.8273E-17   0.013
 ti46p:sld    milx  bahl  -4.9967E-19   0.015
 ti47p:sld    milx  bahl  -2.3439E-17   0.031
 ti48p:sld    milx  bahl  -6.0515E-19   0.010
 w186g:sld    mil6  bahl  -1.0211E-13   0.021
 zn64p:sld    milx  bahl  -2.9304E-16   0.028
 zr902:sld    milx  bahl  -1.2630E-19   0.022
@end
@posit
0.02
@end
@actcov
@end
@outgrd
= nug89
@end
@trlgrd
= ref640
@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 watt1m
@end
@trlflx
= CC-CdP ejp
@end
@covf
new
@end
```

C Appendix – 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
  2.48793E-07 3.04221E-06 1.17979E-05 1.11692E-04 2.66874E-04 1.16699E-04 9.26653E-05 3.60638E-05
  2.10836E-03 9.32506E-03 1.05557E-02 1.34372E-02 4.02783E-02 2.16284E-02 2.02105E-02 2.04005E-02
  2.26566E-02 2.05142E-02 2.05318E-02 1.97312E-02 1.44139E-02 1.98981E-02 1.30515E-02 1.23369E-02
  1.19659E-02 1.05337E-02 1.05726E-02 5.17908E-03 4.95030E-03 5.27748E-03 5.25594E-03 5.29056E-03
  5.22460E-03 5.03348E-03 4.64241E-03 4.56740E-03 4.82259E-03 5.22940E-03 5.41928E-03 5.55313E-03
  5.66490E-03 5.51123E-03 5.66831E-03 5.57422E-03 5.57765E-03 5.74470E-03 5.82588E-03 5.81812E-03
  5.90747E-03 5.79567E-03 5.95167E-03 6.03727E-03 6.17595E-03 2.60632E-03 3.75558E-03 6.38108E-03
  1.19823E-02 1.34902E-02 1.45202E-02 1.58030E-02 1.58406E-02 1.88739E-02 1.92545E-02 2.21393E-02
  2.57095E-02 2.79141E-02 1.35156E-02 1.54158E-02 1.72640E-02 1.75245E-02 1.92110E-02 1.97107E-02
  1.81472E-02 1.63012E-02 1.84111E-02 1.88412E-02 3.72723E-02 3.56756E-02 3.71265E-02 2.47753E-02
  1.77038E-02 1.19215E-02 4.76153E-03 1.28071E-03 2.88673E-04 6.53615E-05 1.77324E-05 7.97937E-06
  1.85848E-06
*% standard deviation
  2.50393E+02  2.13613E+02  1.96509E+02  1.68975E+02  1.48079E+02  1.35673E+02  1.24133E+02  1.15741E+02
  9.35245E+01  7.69149E+01  6.22877E+01  7.09811E+01  6.88963E+01  6.50583E+00  2.03159E+01  2.84482E+01
  7.34851E+00  2.95430E+01  2.54570E+01  2.32278E+01  6.18006E+00  2.98824E+01  1.62676E+01  2.64092E+01
  3.45229E+01  1.96916E+01  2.38505E+01  3.46318E+01  3.86012E+01  4.33076E+01  4.14136E+01  3.95348E+01
  3.83738E+01  3.71255E+01  3.52467E+01  3.16320E+01  3.32259E+01  3.55119E+01  3.56370E+01  3.42242E+01
  3.36807E+01  3.34859E+01  3.27693E+01  3.27039E+01  3.18425E+01  3.06277E+01  3.01358E+01  3.05858E+01
  2.95714E+01  3.00710E+01  2.87492E+01  2.78299E+01  2.66211E+01  2.84127E+01  2.81047E+01  2.72066E+01
  2.15919E+01  2.07925E+01  1.97742E+01  1.88883E+01  1.78382E+01  1.79339E+01  1.74742E+01  1.67537E+01
  1.66269E+01  1.61635E+01  1.86589E+01  1.84382E+01  1.82147E+01  1.77424E+01  1.73638E+01  1.72605E+01
  1.69416E+01  1.57926E+01  1.65131E+01  1.57738E+01  1.20796E+01  1.02306E+01  1.01069E+01  9.29331E+00
  9.46830E+00  7.82431E+00  7.35033E+00  6.46006E+00  4.49866E+00  5.91122E+00  5.48399E+00  7.07039E+00
  1.36115E+01
*correlation coefficient -- upper triangular
  1.00000E+02  8.37612E+01  7.37067E+01  6.26670E+01  5.33302E+01  4.59893E+01  4.13353E+01  3.71815E+01
  3.11777E+01  2.35276E+01  1.75987E+01 -1.27310E+01 -2.37684E+01  6.47413E+00  9.40633E+00  1.36194E+00
  7.13601E+00  6.01249E-01  1.03866E+00  1.32385E+00  5.54667E+00  4.17683E-01  2.28426E-02  1.10059E+00
  5.73908E-01  3.79711E-01  1.70635E+00  1.27773E+00  1.24744E+00  1.11213E+00  1.15261E+00  1.00390E+00
  9.63838E-01  8.33154E-01  6.49989E-01  4.27824E-01  5.23083E-01  7.84435E-01  1.05344E+00  1.09612E+00
  1.10998E+00  1.21624E+00  1.23688E+00  1.24110E+00  1.17487E+00  1.22961E+00  1.34927E+00  1.32612E+00
  1.37206E+00  1.34911E+00  1.41248E+00  1.45895E+00  1.52377E+00  1.42776E+00  1.44565E+00  1.49626E+00
  1.88892E+00  1.95994E+00  2.06199E+00  2.15688E+00  2.28143E+00  2.26467E+00  2.31924E+00  2.41606E+00
  2.42922E+00  2.50352E+00  2.17655E+00  2.20794E+00  2.24551E+00  2.31833E+00  2.38392E+00  2.41403E+00
  2.46992E+00  2.82282E+00  2.85039E+00  3.00605E+00  3.88146E+00  4.41683E+00  4.33299E+00  4.69685E+00
  4.62906E+00  5.60365E+00  6.09461E+00  6.74509E+00  9.86694E+00  7.42381E+00  8.01701E+00  6.17198E+00
  3.20559E+00
  1.00000E+02  9.24400E+01  7.86236E+01  6.69101E+01  5.75918E+01  5.18522E+01  4.67127E+01  3.89398E+01
  2.95322E+01  2.20556E+01 -1.59424E+01 -2.97423E+01  8.16022E+00  1.17439E+01  1.73722E+00  8.99419E+00
  6.40910E-01  1.24150E+00  1.57328E+00  7.00104E+00  5.79192E-01  4.34851E-02  1.36445E+00  7.27987E-01
  5.60469E-01  2.16808E+00  1.59603E+00  1.53131E+00  1.36141E+00  1.51329E+00  1.27806E+00  1.15143E+00
  1.03650E+00  7.79923E-01  4.03111E-01  5.73052E-01  9.01712E-01  1.26448E+00  1.31909E+00  1.43735E+00
  1.44509E+00  1.47182E+00  1.47703E+00  1.52029E+00  1.58945E+00  1.61420E+00  1.68539E+00  1.74374E+00
  1.71459E+00  1.79499E+00  1.85406E+00  1.93658E+00  1.81455E+00  1.83706E+00  1.90109E+00  2.29889E+00
  2.38917E+00  2.51862E+00  2.63920E+00  2.79749E+00  2.77660E+00  2.84628E+00  2.96944E+00  3.08837E+00
  3.18236E+00  2.76595E+00  2.80531E+00  2.85202E+00  2.94324E+00  3.02504E+00  3.06171E+00  3.13160E+00
  3.54524E+00  3.54954E+00  3.74357E+00  4.84792E+00  5.55217E+00  5.47533E+00  5.93652E+00  5.84910E+00
  7.08037E+00  7.67278E+00  8.52644E+00  1.24421E+01  9.37959E+00  1.02160E+01  7.80114E+00  4.05178E+00
  1.00000E+02  8.80784E+01  7.48818E+01  6.45772E+01  5.81476E+01  5.22198E+01  4.38603E+01  3.31823E+01
  2.47383E+01 -1.79306E+01 -3.33247E+01  9.07857E+00  1.31456E+01  1.94968E+00  1.00770E+01  7.34210E-01
  1.36969E+00  1.82989E+00  7.81444E+00  5.83749E-01  5.37348E-02  1.62653E+00  8.29621E-01  5.90991E-01
  2.42985E+00  1.77650E+00  1.69219E+00  1.50260E+00  1.66075E+00  1.43338E+00  1.31459E+00  1.10884E+00
  7.68095E-01  4.16654E-01  5.72374E-01  9.81939E-01  1.34097E+00  1.50236E+00  1.52285E+00  1.63168E+00
  1.66189E+00  1.66765E+00  1.71612E+00  1.69327E+00  1.82130E+00  1.88906E+00  1.95444E+00  1.92178E+00
  2.01184E+00  2.07805E+00  2.17059E+00  2.03382E+00  2.05897E+00  2.13061E+00  2.58852E+00  2.68977E+00
  2.83480E+00  2.97002E+00  3.14754E+00  3.12431E+00  3.20264E+00  3.34081E+00  3.46198E+00  3.56716E+00
  3.10010E+00  3.14399E+00  3.19593E+00  3.29764E+00  3.38870E+00  3.42916E+00  3.50702E+00  3.95546E+00
```

3.94672E+00	4.26073E+00	5.49364E+00	6.19735E+00	6.12430E+00	6.64074E+00	6.54224E+00	7.91934E+00
8.56958E+00	9.44419E+00	1.39052E+01	1.04908E+01	1.14152E+01	8.72661E+00	4.53246E+00	
1.00000E+02	9.02874E+01	7.80139E+01	7.01077E+01	6.31988E+01	5.29765E+01	4.02522E+01	3.04597E+01
-2.12248E+01	-3.99938E+01	1.07581E+01	1.56713E+01	2.31690E+00	1.20210E+01	8.65305E-01	1.66350E+00
2.06878E+00	9.26683E+00	7.39676E-01	7.45939E-02	1.89387E+00	1.08526E+00	6.70092E-01	2.88485E+00
2.09023E+00	2.07153E+00	1.84711E+00	1.91606E+00	1.70257E+00	1.49845E+00	1.21000E+00	7.98468E-01
2.94342E-01	5.22941E-01	1.09689E+00	1.64824E+00	1.72123E+00	1.84568E+00	1.95606E+00	1.99212E+00
1.89885E+00	1.95637E+00	2.04807E+00	2.08116E+00	2.24294E+00	2.32056E+00	2.28177E+00	2.28847E+00
2.36705E+00	2.47690E+00	2.41480E+00	2.44459E+00	2.42934E+00	3.09209E+00	3.21234E+00	3.38453E+00
3.54514E+00	3.65490E+00	3.62742E+00	3.72044E+00	3.98595E+00	4.00922E+00	4.23558E+00	3.68074E+00
3.73270E+00	3.79404E+00	3.91437E+00	4.02200E+00	4.06954E+00	4.16164E+00	4.67288E+00	4.74128E+00
4.99605E+00	6.45797E+00	7.32914E+00	7.26161E+00	7.87441E+00	7.75705E+00	9.38983E+00	1.02350E+01
1.12166E+01	1.65520E+01	1.24385E+01	1.35177E+01	1.02532E+01	5.37450E+00		
1.00000E+02	9.18933E+01	8.27099E+01	7.48205E+01	6.30284E+01	4.82546E+01	3.72046E+01	-2.35491E+01
-4.64776E+01	1.20810E+01	1.79810E+01	2.50160E+00	1.35570E+01	8.16571E-01	1.76434E+00	2.20788E+00
1.04316E+01	7.17943E-01	1.51408E-01	2.17183E+00	1.27408E+00	8.31244E-01	3.24234E+00	2.33679E+00
2.29053E+00	2.03774E+00	2.11516E+00	1.91290E+00	1.62195E+00	1.24906E+00	6.64559E-01	1.06618E-03
3.05468E-01	1.14692E+00	1.79052E+00	1.87241E+00	2.09948E+00	2.21099E+00	2.25138E+00	2.15911E+00
2.22377E+00	2.32694E+00	2.36408E+00	2.42075E+00	2.50796E+00	2.46439E+00	2.58451E+00	2.67283E+00
2.79626E+00	2.71392E+00	2.64737E+00	2.74293E+00	3.38749E+00	3.52254E+00	3.71599E+00	3.89634E+00
4.13311E+00	4.10213E+00	4.20660E+00	4.39088E+00	4.51828E+00	4.65855E+00	4.13675E+00	4.19528E+00
4.26448E+00	4.40007E+00	4.52144E+00	4.57528E+00	4.67908E+00	5.24325E+00	5.39504E+00	5.68203E+00
7.32639E+00	8.23413E+00	8.16927E+00	8.85830E+00	8.72674E+00	1.05637E+01	1.14920E+01	1.25358E+01
1.86016E+01	1.39936E+01	1.51970E+01	1.15462E+01	6.04601E+00			
1.00000E+02	9.29925E+01	8.42186E+01	7.14398E+01	5.53916E+01	4.31686E+01	-2.47531E+01	-5.10898E+01
1.27785E+01	1.93770E+01	2.53240E+00	1.43640E+01	8.27544E-01	1.69711E+00	2.26197E+00	1.09226E+01
7.48419E-01	3.94163E-02	2.36382E+00	1.42086E+00	8.57124E-01	3.41159E+00	2.45364E+00	2.39373E+00
2.12636E+00	2.20764E+00	2.01107E+00	1.62833E+00	1.26474E+00	4.97497E-01	-3.42442E-01	4.69872E-02
1.06842E+00	1.80624E+00	1.99180E+00	2.12000E+00	2.33176E+00	2.27399E+00	2.28219E+00	2.35026E+00
2.35921E+00	2.49801E+00	2.55212E+00	2.64390E+00	2.59805E+00	2.72452E+00	2.81743E+00	2.94720E+00
2.75527E+00	2.79071E+00	2.89145E+00	3.57524E+00	3.71724E+00	3.92091E+00	4.11059E+00	4.25867E+00
4.22573E+00	4.43625E+00	4.62997E+00	4.75829E+00	4.90616E+00	4.35238E+00	4.41432E+00	4.48783E+00
4.63137E+00	4.76010E+00	4.81783E+00	4.92781E+00	5.62043E+00	5.66827E+00	5.97313E+00	7.70962E+00
8.68160E+00	8.61603E+00	9.34177E+00	9.20421E+00	1.11418E+01	1.21129E+01	1.32297E+01	1.96131E+01
1.47599E+01	1.60251E+01	1.21815E+01	6.37593E+00				
1.00000E+02	9.40897E+01	8.02301E+01	6.28150E+01	4.98136E+01	-2.59432E+01	-5.59885E+01	1.34649E+01
2.08935E+01	2.57870E+00	1.52424E+01	7.50777E-01	1.74773E+00	2.33449E+00	1.14141E+01	6.94257E-01
5.91678E-02	2.57791E+00	1.58454E+00	8.10332E-01	3.60047E+00	2.58402E+00	2.50888E+00	2.22526E+00
2.31084E+00	2.12063E+00	1.64721E+00	1.19460E+00	2.47112E-01	-7.66205E-01	-1.94680E-01	1.00432E+00
1.83554E+00	2.12505E+00	2.25436E+00	2.36683E+00	2.41079E+00	2.41956E+00	2.39166E+00	2.50678E+00
2.54766E+00	2.69873E+00	2.79562E+00	2.74722E+00	2.88077E+00	2.97881E+00	3.11566E+00	2.91312E+00
2.95067E+00	3.05718E+00	3.78476E+00	3.93454E+00	4.04910E+00	4.24905E+00	4.51149E+00	4.47641E+00
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5.02642E+00	5.08846E+00	5.10534E+00	5.93058E+00	5.97299E+00	6.39535E+00	8.23294E+00	9.27618E+00
9.11429E+00	9.88099E+00	9.73673E+00	1.17865E+01	1.28054E+01	1.40035E+01	2.08220E+01	1.56144E+01
1.69487E+01	1.28901E+01	6.74385E+00					
1.00000E+02	8.81095E+01	6.93277E+01	5.56453E+01	-2.67529E+01	-6.01826E+01	1.40818E+01	2.20644E+01
2.59293E+00	1.58856E+01	6.45673E-01	1.76429E+00	2.36856E+00	1.19070E+01	7.08902E-01	-8.34847E-02
2.74903E+00	1.71538E+00	8.10941E-01	3.74883E+00	2.58688E+00	2.59923E+00	2.30260E+00	2.39155E+00
2.20641E+00	1.74045E+00	1.09774E+00	6.63536E-02	-1.12462E+00	-4.67436E-01	9.12234E-01	1.83756E+00
2.13029E+00	2.35996E+00	2.47281E+00	2.51821E+00	2.52746E+00	2.50263E+00	2.62276E+00	2.66517E+00
2.81386E+00	2.91476E+00	2.86437E+00	3.00349E+00	3.10555E+00	3.24794E+00	3.03707E+00	3.07631E+00
3.18739E+00	3.84925E+00	4.00501E+00	4.22888E+00	4.43697E+00	4.60940E+00	4.67331E+00	4.79291E+00
5.00519E+00	5.13516E+00	5.39942E+00	4.68134E+00	4.85076E+00	4.93297E+00	5.09252E+00	5.23609E+00
5.30169E+00	5.32420E+00	6.17588E+00	6.31263E+00	6.65284E+00	8.57215E+00	9.67203E+00	9.50922E+00
1.03082E+01	1.01588E+01	1.22976E+01	1.33546E+01	1.45230E+01	2.17165E+01	1.62919E+01	1.76810E+01
1.33573E+01	7.03538E+00						
1.00000E+02	8.73215E+01	7.14263E+01	-2.87463E+01	-7.18932E+01	1.59482E+01	2.56951E+01	2.64777E+00
1.80924E+01	5.38549E-01	1.82240E+00	2.58408E+00	1.32506E+01	5.68289E-01	-2.65180E-01	3.20148E+00
2.03785E+00	8.48832E-01	4.11308E+00	2.90761E+00	2.98041E+00	2.54269E+00	2.74132E+00	2.37386E+00
1.83419E+00	1.02336E+00	-3.52114E-01	-1.97005E+00	-1.06068E+00	7.54082E-01	1.95797E+00	2.35970E+00
2.59119E+00	2.80437E+00	2.85395E+00	2.76541E+00	2.84964E+00	2.88626E+00	3.03272E+00	3.17367E+00
3.28714E+00	3.23048E+00	3.38712E+00	3.40222E+00	3.66137E+00	3.42449E+00	3.46913E+00	3.49513E+00
4.36481E+00	4.53954E+00	4.79147E+00	5.02496E+00	5.23103E+00	5.18851E+00	5.32155E+00	5.65992E+00
5.79187E+00	6.07700E+00	5.27238E+00	5.45128E+00	5.54623E+00	5.72881E+00	5.89398E+00	5.97165E+00
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1.14975E+01	1.39186E+01	1.51904E+01	1.64656E+01	2.45552E+01	1.84409E+01	2.00923E+01	1.51367E+01
7.95919E+00							
1.00000E+02	8.81967E+01	-2.27340E+01	-8.12345E+01	1.69166E+01	2.80669E+01	2.48741E+00	1.93234E+01
2.18623E-01	1.63501E+00	2.53249E+00	1.35735E+01	3.25430E-01	-7.02680E-01	3.53818E+00	2.29520E+00
6.88727E-01	4.32353E+00	3.05369E+00	3.00581E+00	2.64118E+00	2.74426E+00	2.48621E+00	1.67288E+00
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2.95521E+00	3.00462E+00	2.91773E+00	2.90731E+00	3.05189E+00	3.19933E+00	3.33525E+00	3.45452E+00
3.39500E+00	3.55996E+00	3.58099E+00	3.84707E+00	3.59854E+00	3.64638E+00	3.68023E+00	4.50074E+00
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6.37908E+00	5.53866E+00	5.72348E+00	5.82784E+00	6.02545E+00	6.20580E+00	6.29449E+00	6.34779E+00
7.45060E+00	7.68359E+00	8.11344E+00	1.04392E+01	1.16165E+01	1.14344E+01	1.22894E+01	1.22181E+01
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1.00000E+02	3.65561E+00	-8.69885E+01	1.69143E+01	2.86075E+01	1.67567E+00	1.93423E+01	-6.63633E-01
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 1.00000E+02  7.76129E+01  2.60398E+01  4.16919E+00 -1.70217E+00 -2.18730E+00 -2.18545E+00 -2.11366E+00
-2.34778E+00 -2.54849E+00 -2.87219E+00 -3.44990E+00 -3.68144E+00 -3.08634E+00 -3.26651E+00 -3.19659E+00
-3.12996E+00 -3.03462E+00 -2.69956E+00 -2.12896E+00 -2.78731E+00 -3.10252E+00 -2.82322E+00 -2.39482E+00
-9.70446E-01 -4.58576E-01 -5.72202E-01 -7.76391E-01 -9.44317E-01 -1.25177E+00 -7.74193E-01 -2.03603E+00
-1.31819E+00 -1.55739E+00 -7.38718E-01 -4.36978E-01
 1.00000E+02  4.82312E+01  9.25984E+00 -1.18504E+00 -2.07653E+00 -2.07431E+00 -2.00204E+00 -2.23658E+00
-2.43738E+00 -2.65817E+00 -3.23609E+00 -3.56961E+00 -2.97558E+00 -3.05308E+00 -3.08421E+00 -3.01617E+00
-2.91927E+00 -2.58282E+00 -2.01108E+00 -2.76242E+00 -3.07397E+00 -2.79022E+00 -2.34992E+00 -1.01772E+00
-4.12350E-01 -5.23423E-01 -7.26660E-01 -8.83939E-01 -1.27757E+00 -6.10156E-01 -1.92718E+00 -1.14618E+00
-1.46911E+00 -6.74761E-01 -3.04473E-01
 1.00000E+02  3.19150E+01  7.27628E-01 -1.89464E+00 -1.99569E+00 -2.02748E+00 -2.26328E+00 -2.36386E+00
-2.68919E+00 -3.26895E+00 -3.60208E+00 -3.00142E+00 -3.07767E+00 -3.10604E+00 -3.03472E+00 -2.93382E+00
-2.59276E+00 -2.01804E+00 -2.74842E+00 -3.14614E+00 -2.85085E+00 -2.39131E+00 -9.61392E-01 -3.67109E-01
-4.78774E-01 -6.77309E-01 -8.23648E-01 -1.20270E+00 -5.49323E-01 -1.81086E+00 -1.06443E+00 -1.37669E+00
-5.20894E-01 -2.74329E-01
 1.00000E+02  2.71906E+01 -6.69851E-02 -2.13397E+00 -2.09426E+00 -2.54419E+00 -2.66922E+00 -2.92082E+00
-3.72486E+00 -4.06382E+00 -3.36931E+00 -3.54120E+00 -3.55049E+00 -3.56190E+00 -3.33192E+00 -2.95462E+00
-2.25814E+00 -3.24502E+00 -3.81958E+00 -3.44554E+00 -2.92555E+00 -1.16910E+00 -3.76195E-01 -5.34226E-01
-7.83808E-01 -9.47895E-01 -1.53133E+00 -4.15942E-01 -2.18225E+00 -1.21314E+00 -1.68159E+00 -5.34050E-01
-2.82145E-01
 1.00000E+02  2.22380E+01 -4.00670E-01 -2.00739E+00 -2.56173E+00 -2.79486E+00 -3.05327E+00 -3.75817E+00
-4.20244E+00 -3.48584E+00 -3.65693E+00 -3.66304E+00 -3.67170E+00 -3.43726E+00 -3.05334E+00 -2.35344E+00
-3.41677E+00 -3.96721E+00 -3.67949E+00 -3.15704E+00 -1.22422E+00 -3.50600E-01 -5.21932E-01 -8.60094E-01
-1.03937E+00 -1.61324E+00 -4.48821E-01 -2.40718E+00 -1.33130E+00 -1.80285E+00 -5.51399E-01 -3.41237E-01
 1.00000E+02  2.44136E+01  3.20217E-02 -2.47743E+00 -2.81962E+00 -3.08522E+00 -3.89822E+00 -4.24067E+00
-3.60355E+00 -3.77293E+00 -3.77408E+00 -3.77765E+00 -3.63833E+00 -3.14270E+00 -2.33542E+00 -3.56375E+00
-4.18291E+00 -3.87437E+00 -3.23608E+00 -1.31770E+00 -3.70399E-01 -5.53037E-01 -7.81549E-01 -1.06155E+00
-1.70922E+00 -4.04829E-01 -2.50492E+00 -1.35660E+00 -1.82145E+00 -4.96930E-01 -2.63312E-01
 1.00000E+02  2.48870E+01 -6.77131E-01 -2.77654E+00 -3.25725E+00 -3.97228E+00 -4.42087E+00 -3.75503E+00
-3.92334E+00 -3.92018E+00 -3.92001E+00 -3.77482E+00 -3.27017E+00 -2.45807E+00 -3.75527E+00 -4.44324E+00
-4.11675E+00 -3.47472E+00 -1.38434E+00 -4.59953E-01 -6.59574E-01 -8.75487E-01 -1.17425E+00 -1.80881E+00
-4.68630E-01 -2.76175E+00 -1.50188E+00 -2.05971E+00 -6.37546E-01 -3.36585E-01
 1.00000E+02  2.28444E+01 -6.16339E-01 -2.96775E+00 -3.79288E+00 -4.24513E+00 -3.64685E+00 -3.81387E+00
-3.90837E+00 -3.80077E+00 -3.75101E+00 -3.23490E+00 -2.41667E+00 -3.77559E+00 -4.62508E+00 -4.27617E+00
-3.73063E+00 -1.57295E+00 -5.80778E-01 -7.04382E-01 -1.00233E+00 -1.22995E+00 -2.13319E+00 -4.91133E-01
-3.08095E+00 -1.69829E+00 -2.35095E+00 -6.33818E-01 -3.34987E-01
 1.00000E+02  2.18679E+01 -1.25693E+00 -4.25736E+00 -4.81550E+00 -4.10467E+00 -4.27255E+00 -4.36809E+00
-4.26227E+00 -4.11146E+00 -3.69849E+00 -2.77891E+00 -4.14516E+00 -4.89351E+00 -4.54888E+00 -3.92484E+00
-1.68219E+00 -5.88847E-01 -8.19314E-01 -1.11682E+00 -1.46525E+00 -2.18971E+00 -8.47083E-01 -3.24304E+00
-1.88247E+00 -2.46100E+00 -8.81152E-01 -5.13543E-01
 1.00000E+02  2.50241E+01 -2.76833E+00 -5.09537E+00 -4.35758E+00 -4.62873E+00 -4.61924E+00 -4.61538E+00
-4.46185E+00 -4.04318E+00 -3.12085E+00 -4.47118E+00 -5.19742E+00 -4.84417E+00 -4.23620E+00 -1.82484E+00
-7.45604E-01 -9.95438E-01 -1.28358E+00 -1.66653E+00 -2.39221E+00 -1.10400E+00 -3.58053E+00 -2.14651E+00
-2.74113E+00 -1.11287E+00 -6.34141E-01
 1.00000E+02  1.99093E+01 -3.74756E+00 -4.74432E+00 -5.11823E+00 -5.20761E+00 -5.09689E+00 -5.04027E+00
-4.50874E+00 -3.58092E+00 -4.99940E+00 -5.69073E+00 -5.31883E+00 -4.61291E+00 -2.03262E+00 -7.79345E-01
-1.05036E+00 -1.52262E+00 -1.83557E+00 -2.55171E+00 -1.23546E+00 -3.85261E+00 -2.36623E+00 -2.97006E+00
-1.31574E+00 -7.39846E-01
 1.00000E+02  2.35376E+01 -2.77144E+00 -5.11361E+00 -5.92705E+00 -6.12655E+00 -5.96589E+00 -5.43105E+00
-4.50206E+00 -5.91307E+00 -6.48945E+00 -6.01322E+00 -5.12394E+00 -2.16972E+00 -8.21578E-01 -1.20590E+00
-1.67393E+00 -2.01848E+00 -2.64848E+00 -1.65272E+00 -4.08438E+00 -2.60763E+00 -3.13888E+00 -1.61721E+00
-8.46184E-01
 1.00000E+02  3.01315E+01  4.27256E+00 -3.89137E+00 -6.15502E+00 -6.60741E+00 -6.37328E+00 -5.33564E+00
-6.91148E+00 -7.56234E+00 -6.86235E+00 -5.83339E+00 -2.18594E+00 -5.56678E-01 -1.04125E+00 -1.60177E+00
-1.93034E+00 -2.44427E+00 -1.65978E+00 -3.83135E+00 -2.48810E+00 -3.00386E+00 -1.62875E+00 -9.02724E-01
 1.00000E+02  4.80250E+01  8.59677E+00 -2.20160E+00 -5.23826E+00 -5.95638E+00 -5.34540E+00 -7.01793E+00
-7.77238E+00 -7.02654E+00 -5.87843E+00 -1.85237E+00 -5.01704E-02 -6.62885E-01 -1.26587E+00 -1.50551E+00
-1.77079E+00 -1.23697E+00 -2.83428E+00 -1.81162E+00 -2.21227E+00 -1.19007E+00 -5.73570E-01
 1.00000E+02  4.19311E+01  6.77264E+00 -3.34608E+00 -6.21284E+00 -6.21199E+00 -8.66704E+00 -9.50429E+00
-8.63881E+00 -7.04305E+00 -2.02223E+00  3.62763E-01 -3.40808E-01 -1.13975E+00 -1.35256E+00 -1.50746E+00
-1.15462E+00 -2.56168E+00 -1.60816E+00 -1.99039E+00 -1.02582E+00 -5.88422E-01
 1.00000E+02  4.29766E+01  6.29707E+00 -4.65489E+00 -6.99872E+00 -1.09338E+01 -1.21516E+01 -1.10570E+01
-8.97522E+00 -2.16119E+00  1.00104E+00  1.19665E-01 -8.76639E-01 -1.03386E+00 -1.06720E+00 -8.72367E-01
-1.91741E+00 -1.18530E+00 -1.44193E+00 -7.75188E-01 -4.08237E-01
 1.00000E+02  4.47656E+01  4.56173E+00 -5.73515E+00 -1.33718E+01 -1.52598E+01 -1.43237E+01 -1.14319E+01
-2.43260E+00  1.79095E+00  7.33796E-01 -5.54962E-01 -7.40073E-01 -6.38117E-01 -5.11969E-01 -1.14145E+00
-6.66770E-01 -8.77156E-01 -4.51284E-01 -1.90187E-01
 1.00000E+02  4.07957E+01  3.50832E+00 -1.38417E+01 -1.80148E+01 -1.76364E+01 -1.43169E+01 -2.83853E+00
 2.54038E+00  1.41278E+00 -1.69168E-01 -3.68509E-01 -3.44273E-02 -5.54616E-02 -3.15351E-01 -1.37937E-01
-2.03027E-01  5.59730E-02 -2.66250E-02
 1.00000E+02  4.21093E+01 -7.03634E+00 -1.74381E+01 -1.95259E+01 -1.64879E+01 -3.60670E+00  3.02351E+00
 2.12644E+00  4.43517E-01  4.16254E-02  5.07733E-01  5.51659E-01  6.50830E-01  5.31846E-01  5.20789E-01
 6.11511E-01  2.62020E-01
 1.00000E+02  2.48425E+01 -6.09455E+00 -1.74427E+01 -1.70090E+01 -4.78517E+00  2.59744E+00  2.50303E+00
 1.01682E+00  3.83000E-01  6.93799E-01  1.23757E+00  1.09107E+00  9.85061E-01  1.01369E+00  1.07582E+00
 5.52839E-01
 1.00000E+02  6.81797E+01  1.87600E+01 -5.84558E+00 -1.22455E+01 -3.50999E+00  4.19335E+00  5.98679E+00
 2.69874E+00  3.30187E+00  3.53283E+00  6.05878E+00  4.17876E+00  4.82790E+00  2.94305E+00  1.52241E+00
```

```
1.00000E+02  5.51221E+01  9.63580E+00 -1.63203E+01 -9.29680E+00  4.51824E+00  9.33092E+00  4.20761E+00
4.69153E+00  4.89522E+00  9.21309E+00  5.95342E+00  7.17724E+00  3.77387E+00  2.05197E+00
1.00000E+02  4.39221E+01 -2.02251E+01 -1.86675E+01  3.92798E+00  1.36568E+01  5.74236E+00  5.41461E+00
6.56751E+00  1.17352E+01  7.52728E+00  9.15127E+00  4.77032E+00  2.56871E+00
1.00000E+02  2.09595E+00 -3.56507E+01 -1.48967E+00  1.96739E+01  1.02327E+01  6.52321E+00  9.96728E+00
1.62768E+01  1.06193E+01  1.28091E+01  6.90873E+00  3.77143E+00
1.00000E+02 -7.56117E-01 -2.39326E+01  2.97359E+00  1.70908E+01  9.93577E+00  7.98360E+00  1.62794E+01
1.13994E+01  1.26508E+01  8.58914E+00  4.49929E+00
1.00000E+02 -4.95194E+00 -3.52753E+01  1.49632E+01  1.67235E+01  2.01385E+00  1.19185E+01  1.07901E+01
9.91860E+00  9.38026E+00  4.57463E+00
1.00000E+02 -1.62482E+01 -1.94273E+01  1.85740E+01  5.30954E+00  1.18576E+01  1.09924E+01  1.00846E+01
9.28830E+00  4.71794E+00
1.00000E+02 -3.26313E+01 -7.07789E+00  2.59042E+01  1.80278E+01  7.83027E+00  1.47744E+01  3.66071E+00
2.60711E+00
1.00000E+02 -2.16545E+01  2.01053E+01  2.70816E+01  1.00243E+01  1.82333E+01  2.58960E+00  2.41194E+00
1.00000E+02 -5.70725E+01 -2.22476E+00  3.01484E+01  1.64824E+00  3.80864E+01  1.54973E+01
1.00000E+02  3.14897E+01 -8.63903E+00  3.81482E+01 -2.31634E+01 -6.12828E+00
1.00000E+02  2.02110E+01 -2.09481E+00  4.36408E+01  2.27646E+01
1.00000E+02  2.48136E+01 -3.50660E+01 -2.64765E+01
1.00000E+02  1.65883E+01 -1.63467E+01
1.00000E+02  5.66087E+01
1.00000E+02
```

D Appendix – LSL Format Prompt Gamma Ray Output

```
*cor
*number of energies plus 1
   49
*energy grid (eV) - high to low energy order
 0.5000000E+08  0.3000000E+08  0.2000000E+08  0.1700000E+08  0.1400000E+08
 0.1200000E+08  0.1000000E+08   9000000.       8000000.       7500000.
  7000000.       6500000.       6000000.       5500000.       5000000.
  4500000.       4000000.       3500000.       3000000.       2660000.
  2500000.       2333000.       2000000.       1875000.       1660000.
  1500000.       1330000.       1200000.       1125000.       1000000.
  900000.0       800000.0       700000.0       600000.0       525000.0
  500000.0       450000.0       400000.0       300000.0       200000.0
  150000.0       100000.0       80000.00       60000.00       45000.00
  30000.00       20000.00       10000.00       1000.000
*spectrum number fractions -
   0.00000E+00 0.00000E+00 0.00000E+00 7.17624E-08 3.40990E-07
   2.15267E-05 1.67015E-03 8.40936E-03 1.72543E-02 4.61936E-03
   3.55724E-03 5.82932E-03 7.61868E-03 6.78364E-03 8.77546E-03
   1.20959E-02 1.53346E-02 2.27937E-02 2.09740E-02 1.35183E-02
   1.43027E-02 4.92663E-02 1.53827E-02 3.43175E-02 2.94298E-02
   3.93930E-02 3.49370E-02 2.00205E-02 4.39577E-02 3.61632E-02
   5.27783E-02 5.00014E-02 5.71092E-02 4.77903E-02 4.74301E-02
   3.82547E-02 3.81520E-02 7.32701E-02 5.75146E-02 2.16866E-02
   1.48673E-02 9.10248E-03 2.05195E-02 3.37632E-03 1.26602E-03
   3.28966E-04 1.00229E-04 2.55773E-05
*standard deviation (%)
  92.37442       76.31279       66.02299       59.97667       53.96589
  48.25708       42.48969       37.04626       32.52547       29.26157
  25.76435       21.99784       20.00000       20.00000       20.00000
  20.00000       20.00000       20.00000       20.00000       20.00000
  20.00000       20.00000       20.00000       20.00000       20.00000
  20.25727       20.75147       21.12413       21.52082       22.01440
  22.50493       23.05692       23.68803       24.32566       24.73621
  25.07133       25.56186       26.41813       27.90204       29.47505
  30.95897       32.40774       33.51609       34.78482       42.14988
  52.22706       64.92281       81.49094
 *correlation coefficients - upper triangular
  1.0000    0.41240    0.21365    0.12815    0.61365E-01 0.10903E-01 -0.37460E-01
-0.65499E-01 -0.87938E-01 -0.10420  -0.12245   -0.14472   -0.16105   -0.16553
-0.18295     -0.18211     -0.18113  -0.18020   -0.17953   -0.17901   -0.17833
-0.17678   -0.17498   -0.17324   -0.17074   -0.16642   -0.16034   -0.15540
-0.14960   -0.14798   -0.14904   -0.14965   -0.14982   -0.14952   -0.14890
-0.14787   -0.14566   -0.14116   -0.13406   -0.12837    -0.12439   -0.12141
-0.11913   -0.11609   -0.10302   -0.90090E-01 -0.76804E-01 -0.59182E-01
  1.0000    0.50774    0.35042    0.22681    0.13250    0.49092E-01 -0.20241E-02
-0.42572E-01 -0.71635E-01 -0.10373   -0.14180   -0.17135   -0.18377   -0.25068
-0.24966   -0.24848   -0.24735   -0.24655    -0.24591    -0.24509     -0.24321
-0.24104   -0.23893   -0.23591   -0.23031     -0.22226     -0.21578     -0.20825
-0.20567   -0.20638   -0.20650    -0.20603     -0.20502     -0.20387     -0.20231
-0.19919   -0.19300   -0.18323    -0.17522     -0.16945     -0.16500     -0.16165
-0.15733     -0.13857     -0.12024     -0.10197     -0.78812E-01
  1.0000    0.60229    0.41910    0.28014    0.16248    0.89811E-01  0.33044E-01
-0.69960E-02 -0.50405E-01 -0.10053   -0.14085   -0.16157   -0.28695     -0.28577
-0.28440   -0.28310   -0.28217   -0.28143     -0.28049     -0.27831     -0.27580
-0.27336   -0.26987   -0.26343   -0.25420     -0.24676     -0.23810     -0.23518
-0.23605   -0.23625   -0.23577   -0.23467     -0.23337     -0.23160     -0.22804
-0.22096   -0.20978   -0.20063   -0.19405     -0.18898     -0.18517     -0.18023
-0.15884     -0.13791     -0.11700     -0.90407E-01
  1.0000    0.58195    0.40718    0.26292    0.17413      0.10568      0.58053E-01
 0.72003E-02 -0.50294E-01 -0.97653E-01 -0.12492   -0.29891   -0.29761   -0.29611
-0.29467   -0.29365   -0.29284   -0.29180     -0.28941   -0.28664     -0.28395
-0.28011   -0.27324   -0.26347   -0.25557     -0.24634     -0.24348     -0.24477
-0.24535   -0.24521   -0.24438   -0.24318     -0.24142     -0.23776     -0.23039
-0.21877   -0.20934   -0.20265   -0.19756     -0.19371     -0.18865     -0.16680
-0.14532     -0.12357     -0.95357E-01
  1.0000    0.57454    0.39717    0.28898    0.20691      0.15077      0.91964E-01
 0.27229E-01 -0.27545E-01 -0.62923E-01 -0.29888   -0.29743   -0.29576   -0.29416
-0.29302   -0.29212   -0.29097   -0.28831   -0.28524   -0.28225     -0.27798
-0.27077   -0.26070   -0.25248   -0.24280     -0.24032     -0.24241     -0.24377
-0.24438   -0.24420   -0.24332     -0.24172     -0.23816     -0.23082     -0.21924
-0.21004   -0.20369   -0.19900     -0.19540     -0.19050     -0.16956     -0.14874
-0.12707     -0.97798E-01
  1.0000    0.56273    0.43152      0.33364      0.26784      0.20032      0.12810
 0.65305E-01  0.20326E-01 -0.29005   -0.28843   -0.28656     -0.28477     -0.28350
-0.28249   -0.28120   -0.27823    -0.27479     -0.27145     -0.26668     -0.25917
```

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-0.24895   -0.24051   -0.23046     -0.22860     -0.23182     -0.23428     -0.23599
-0.23675   -0.23638   -0.23507     -0.23176     -0.22467     -0.21350     -0.20491
-0.19924   -0.19527   -0.19215     -0.18763     -0.16865     -0.14941     -0.12849
-0.98523E-01
  1.0000    0.56912    0.45613      0.37990      0.30150      0.21757      0.14383
 0.89579E-01 0.63691E-01 0.83218E-02 -0.45090E-01 -0.96661E-01 -0.13848   -0.16216
-0.17651   -0.19655   -0.21318     -0.22395     -0.23380     -0.23797     -0.23718
-0.23452   -0.22944   -0.25638     -0.26011     -0.26298     -0.26500     -0.26595
-0.26557   -0.26412   -0.26042     -0.25246     -0.23992     -0.23029     -0.22397
-0.21957   -0.21609   -0.21104     -0.18985     -0.16832     -0.14483     -0.11102
  1.0000    0.57041    0.48659      0.40185      0.31329      0.23396      0.17157
 0.14176    0.78141E-01  0.16739E-01 -0.42634E-01 -0.90898E-01 -0.11832   -0.13497
-0.15835   -0.17786   -0.19061     -0.20242     -0.20848     -0.20953     -0.20790
-0.20354   -0.23935   -0.24482     -0.24938     -0.25310     -0.25552     -0.25590
-0.25489   -0.25157   -0.24397     -0.23201     -0.22327     -0.21798     -0.21467
-0.21191     -0.20743     -0.18917     -0.17000     -0.14755     -0.11255
  1.0000    0.58857    0.49840      0.40634      0.32237      0.25237      0.21950
 0.14814    0.79273E-01 0.12641E-01 -0.41609E-01 -0.72485E-01 -0.91259E-01 -0.11766
-0.13977   -0.15427   -0.16779     -0.17558     -0.17836     -0.17770     -0.17398
-0.21870   -0.22611   -0.23257     -0.23817     -0.24224     -0.24349     -0.24298
-0.24011   -0.23295   -0.22172     -0.21404     -0.20994     -0.20788     -0.20595
-0.20214     -0.18731     -0.17090     -0.14978     -0.11363
  1.0000    0.57684    0.48275      0.39562      0.31960      0.28487      0.20735
 0.13258    0.60216E-01  0.12537E-02 -0.32330E-01 -0.52749E-01 -0.81467E-01 -0.10555
-0.12136  -0.13612     -0.14524     -0.14941     -0.14948     -0.14623     -0.19843
-0.20764  -0.21587     -0.22323     -0.22884     -0.23090     -0.23087     -0.22843
-0.22172  -0.21122     -0.20456     -0.20160     -0.20073     -0.19959     -0.19642
-0.18487     -0.17114     -0.15135     -0.11424
  1.0000    0.57433      0.48424      0.40125      0.36517      0.28047      0.19884
0.11986 0.55458E-01 0.18763E-01 -0.35215E-02 -0.34829E-01 -0.61081E-01 -0.78301E-01
-0.94339E-01 -0.10493  -0.11069     -0.11160     -0.10880     -0.17015     -0.18180
-0.19244  -0.20221     -0.20993     -0.21310     -0.21372     -0.21188     -0.20580
-0.19631  -0.19108     -0.18969     -0.19046     -0.19041     -0.18813     -0.18112
-0.17109     -0.15316     -0.11483
  1.0000    0.59181      0.50076      0.46461      0.37146      0.28181      0.19509
 0.12436 0.84063E-01 0.59664E-01 0.25493E-01 -0.30998E-02 -0.21772E-01 -0.39030E-01
-0.51181E-01 -0.58720E-01 -0.60469E-01 -0.57996E-01 -0.13071  -0.14585     -0.15992
-0.17310  -0.18382     -0.18856     -0.19010     -0.18910     -0.18389     -0.17583
-0.17258  -0.17341     -0.17649     -0.17797     -0.17695     -0.17632     -0.17148
-0.15614     -0.11597
  1.0000    0.61372      0.57257      0.46891      0.36927      0.27299      0.19446
 0.14972  0.12259  0.84536E-01  0.52610E-01  0.31678E-01  0.12207E-01 -0.22652E-02
-0.12207E-01 -0.15339E-01 -0.13875E-01 -0.99526E-01 -0.11715  -0.13366     -0.14929
-0.16215  -0.16803     -0.17025     -0.16989     -0.16540     -0.15849     -0.15678
-0.15928  -0.16407     -0.16670     -0.16663     -0.17083     -0.16996     -0.15673
-0.11560
  1.0000    0.68527      0.56822      0.45580      0.34733      0.25899      0.20857
 0.17780   0.13427  0.97412E-01  0.72877E-01  0.49485E-01  0.31449E-01  0.18160E-01
 0.12753E-01  0.12010E-01 -0.88174E-01 -0.10605  -0.12282     -0.13874     -0.15187
-0.15792  -0.16028     -0.16011     -0.15594     -0.14953     -0.14830     -0.15121
-0.15636     -0.15924     -0.15944     -0.16490     -0.16518     -0.15288  -0.11253
  1.0000    0.74602    0.61753      0.49381      0.39326      0.33581      0.30052
 0.25023   0.20731  0.17835      0.15015     0.12706      0.10839      0.99274E-01
 0.94876E-01 -0.24797E-01 -0.44051E-1 -0.62312E-1 -0.79836E-1 -0.94518E-1 -0.10152
-0.10463  -0.10553     -0.10313     -0.99527E-01 -0.10096     -0.10614     -0.11331
-0.11761     -0.11933     -0.13180     -0.13846     -0.13139     -0.95413E-01
  1.0000    0.73852      0.59518      0.47900      0.41260      0.37159      0.31274
 0.26218   0.22766      0.19343      0.16507      0.14163      0.12928      0.12176
-0.21248E-1 -0.40579E-1 -0.58923E-1 -0.76538E-1 -0.91306E-01 -0.98362E-01 -0.10151
-0.10247  -0.10017     -0.96727E-01 -0.98314E-01 -0.10362     -0.11090     -0.11528
-0.11708     -0.12995     -0.13697     -0.13019     -0.94454E-01
  1.0000    0.72730      0.59043      0.51224      0.46373      0.39369      0.33318
 0.29145   0.24942      0.21427   0.18471   0.16823      0.15671     -0.17158E-01
-0.36578E-1 -0.55018E-1 -0.72736E-1 -0.87604E-1 -0.94721E-1 -0.97920E-1 -0.98952E-1
-0.96759E-01 -0.93500E-01 -0.95259E-01 -0.10071     -0.10812  -0.11259     -0.11450
-0.12781  -0.13524     -0.12880     -0.93349E-01
  1.0000    0.73992      0.64550      0.58670      0.50141      0.42742      0.37595
 0.32344   0.27922   0.24152      0.21956   0.20276     -0.13234E-01 -0.32739E-01
-0.51271E-1 -0.69090E-1 -0.84053E-1 -0.91229E-1 -0.94474E-1 -0.95573E-1 -0.93489E-1
-0.90404E-01 -0.92328E-01 -0.97919E-01 -0.10546  -0.11002     -0.11201     -0.12576
-0.13359     -0.12747     -0.92289E-01
  1.0000    0.79796      0.72705      0.62388      0.53417      0.47142      0.40684
 0.35225  0.30531   0.27714      0.25437     -0.10452E-01 -0.30018E-01 -0.48616E-01
-0.66505E-1 -0.81536E-1 -0.88754E-1 -0.92032E-1 -0.93177E-1 -0.91172E-1 -0.88209E-1
-0.90250E-01 -0.95941E-01 -0.10357     -0.10819     -0.11025  -0.12431     -0.13242
-0.12653     -0.91537E-01
  1.0000    0.83596      0.71874      0.61673      0.54520      0.47125      0.40866
 0.35461   0.32169   0.29435  -0.82424E-02 -0.27857E-01 -0.46506E-01 -0.64451E-01
-0.79536E-1 -0.86787E-1 -0.90092E-1 -0.91274E-1 -0.89330E-1 -0.86466E-1 -0.88600E-1
-0.94369E-01 -0.10207  -0.10674     -0.10885     -0.12315     -0.13149     -0.12578
-0.90940E-01
```

```
  1.0000      0.79429      0.68256   0.60410      0.52280      0.45392      0.39429
 0.35765  0.32674 -0.54082E-02 -0.25084E-01 -0.43800E-01 -0.61817E-01 -0.76971E-01
-0.84264E-1 -0.87603E-1 -0.88833E-1 -0.86968E-1 -0.84229E-1 -0.86483E-1 -0.92354E-1
-0.10014  -0.10488  -0.10706     -0.12167  -0.13029     -0.12482     -0.90175E-01
  1.0000      0.80686      0.71533   0.62019      0.53952      0.46945      0.42586
 0.38830 0.11069E-2 -0.18711E-1 -0.37579E-01 -0.55762E-01 -0.71075E-01 -0.78466E-01
-0.81882E-1 -0.83222E-1 -0.81539E-1 -0.79089E-1 -0.81617E-1 -0.87721E-1 -0.95714E-1
-0.10060   -0.10294  -0.11827  -0.12754  -0.12261  -0.88415E-01
  1.0000      0.84638   0.73470      0.64002      0.55761      0.50582      0.46046
 0.86356E-2 -0.11347E-1 -0.30391E-1 -0.48765E-1 -0.64262E-1 -0.71766E-1 -0.75272E-1
-0.76738E-1 -0.75266E-1 -0.73149E-1 -0.75994E-1 -0.82368E-1 -0.90600E-1 -0.95653E-1
-0.98172E-01 -0.11434     -0.12437     -0.12006     -0.86381E-01
  1.0000   0.84229   0.73432   0.64026      0.58078      0.52811      0.15958E-01
-0.41841E-2 -0.23400E-1 -0.41961E-1 -0.57635E-1 -0.65250E-01 -0.68842E-1 0.70432E-1
-0.69164E-1 -0.67372E-1 -0.70525E-1 -0.77161E-1 -0.85626E-1 -0.90843E-1 -0.93538E-1
-0.11051     -0.12128     -0.11757     -0.84403E-1
  1.0000   0.86597   0.75549      0.68520   0.62230      0.26421E-1  0.60514E-02
-0.13409E-1 -0.32236E-1 -0.48166E-1 -0.55937E-1 -0.59655E-1 -0.61421E-1 -0.60445E-1
-0.59116E-1 -0.62710E-1 -0.69721E-1 -0.78518E-1 -0.83971E-1 -0.86916E-1 -0.10505
-0.11687     -0.11403     -0.81576E-1
  1.0000   0.88307   0.80031      0.72558   0.35118E-1  0.14810E-1 -0.46155E-02
-0.23433E-1 -0.39381E-1 -0.47189E-1 -0.50966E-1 -0.52862E-1 -0.52151E-1 -0.51239E-1
-0.55168E-1 -0.62413E-1 -0.71386E-1 -0.76972E-1 -0.80096E-1 -0.98998E-1 -0.11158
-0.10952     -0.78100E-1
  1.0000    0.93311    0.84426  0.43163E-1  0.23145E-1  0.39745E-02 -0.14621E-1
-0.30405E-1 -0.38161E-1 -0.41954E-1 -0.43954E-1 -0.43508E-1 -0.43012E-1 -0.47221E-1
-0.54611E-1 -0.63653E-1 -0.69305E-1 -0.72568E-1 -0.92002E-1 -0.10518 -0.10390
-0.73841E-1
  1.0000   0.94712   0.51272E-1  0.31414E-1  0.12374E-1 -0.61189E-02 -0.21840E-01
-0.29593E-1 -0.33424E-1 -0.35539E-1 -0.35348E-1 -0.35254E-1 -0.39762E-1 -0.47339E-1
-0.56504E-1 -0.62255E-1 -0.65673E-1 -0.85745E-1 -0.99587E-1 -0.99055E-1 -0.70142E-1
  1.0000 0.62639E-1 0.42879E-1  0.23901E-1 0.54360E-02 -0.10296E-1 -0.18090E-1
-0.21997E-1 -0.24281E-1 -0.24437E-1 -0.24890E-1 -0.29834E-1 -0.37712E-1 -0.47099E-1
-0.53021E-1 -0.56671E-1 -0.77734E-1 -0.92562E-1 -0.93054E-1 -0.65523E-1
  1.0000   0.92951      0.80548      0.68123      0.57193      0.51005      0.46520
 0.40771   0.32334   0.20774      0.11488      0.49235E-1  0.18376E-02 -0.23636E-1
-0.42014E-1 -0.71828E-1 -0.91069E-1 -0.93030E-1 -0.66010E-1
  1.0000      0.88120    0.74598      0.62728      0.56007      0.51118      0.44825
 0.35557   0.22852   0.12649      0.54260E-1  0.19969E-02 -0.26316E-1 -0.47130E-1
-0.76874E-1 -0.95599E-1 -0.96873E-1 -0.69427E-1
  1.0000      0.83258      0.70162      0.62748   0.57339      0.50348      0.40025
 0.25876    0.14527    0.64786E-01     -0.63323E-02 -0.25673E-1 -0.49745E-1 -0.80219E-1
-0.99090E-1 -0.10013     -0.72501E-1
  1.0000    0.80313    0.71967      0.65862      0.57946      0.46233      0.30209
 0.17387      0.82787E-1  0.16320E-1 -0.20550E-1 -0.49022E-1 -0.81310E-01 -0.10126
-0.10271     -0.75266E-01
  1.0000    0.83096    0.76155      0.67134      0.53780      0.35574      0.21061
 0.10747  0.31850E-01 -0.10649E-01 -0.44313E-01 -0.79476E-01 -0.10150     -0.10417
-0.77385E-01
  1.0000    0.83863   0.74020      0.59456      0.39660      0.23933      0.12760
 0.45449E-01 -0.10877E-02 -0.38523E-01 -0.76194E-01 -0.10020 -0.10419  -0.78177E-01
  1.0000   0.80353   0.64696   0.43474      0.26668      0.14737      0.59467E-01
 0.93590E-02 -0.31439E-01 -0.71664E-01 -0.97775E-01 -0.10326     -0.78196E-01
  1.0000   0.73378   0.49835   0.31294    0.18153      0.84502E-01  0.28715E-01
-0.17462E-01 -0.62202E-01 -0.92156E-01 -0.10050     -0.77340E-01
  1.0000   0.62900   0.40830      0.25277      0.13773    0.70784E-01  0.13991E-01
-0.40240E-01 -0.78547E-01 -0.93437E-01 -0.74858E-01
  1.0000   0.61713   0.40826   0.25459      0.16412      0.85059E-01  0.10507E-01
-0.46352E-01 -0.76799E-01 -0.70339E-01
  1.0000   0.62851   0.41904   0.29578      0.18638      0.84466E-01  0.21043E-02
-0.51146E-01 -0.65299E-01
  1.0000   0.62807   0.46239   0.31508      0.17986      0.66741E-01 -0.14860E-01
-0.58175E-01
  1.0000  0.68125   0.48331   0.30510      0.15354      0.36686E-01 -0.46102E-01
  1.0000      0.65159      0.42981      0.24081      0.90591E-01 -0.30869E-01
  1.0000      0.61349      0.36921      0.17176     -0.42936E-02
  1.0000      0.57045      0.30184      0.44077E-01
  1.0000      0.51785      0.13033
  1.0000      0.29880
  1.0000
end
```

E Appendix – LSL Format Delayed Gamma Ray Output

```
*cor
*number of energies + 1
    -49
 *energy grid (eV) - high to low energy order
   0.5000000E+08   0.3000000E+08   0.2000000E+08   0.1700000E+08   0.1400000E+08
   0.1200000E+08   0.1000000E+08    9000000.        8000000.        7500000.
    7000000.        6500000.        6000000.        5500000.        5000000.
    4500000.        4000000.        3500000.        3000000.        2660000.
    2500000.        2333000.        2000000.        1875000.        1660000.
    1500000.        1330000.        1200000.        1125000.        1000000.
    900000.0        800000.0        700000.0        600000.0        525000.0
    500000.0        450000.0        400000.0        300000.0        200000.0
    150000.0        100000.0        80000.00        60000.00        45000.00
    30000.00        20000.00        10000.00       0.1000000E-05
*spectrum number fractions -
   0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
   0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00 0.00000E+00
   0.00000E+00 1.30170E-03 1.83797E-03 2.70165E-03 6.48044E-03
   9.83836E-03 1.53126E-02 2.44388E-02 2.23350E-02 1.30531E-02
   1.46107E-02 3.77509E-02 1.65329E-02 3.66744E-02 3.05998E-02
   4.37188E-02 3.64990E-02 2.80729E-02 5.21671E-02 4.59414E-02
   5.09584E-02 5.78900E-02 6.55257E-02 5.68895E-02 3.60669E-02
   4.34404E-02 4.27934E-02 7.75391E-02 5.95847E-02 2.16677E-02
   1.47488E-02 8.80604E-03 2.00329E-02 3.09186E-03 7.67033E-04
   2.34984E-04 7.46814E-05 1.88668E-05
*standard deviation (%)
    100.0000        100.0000        100.0000        100.0000        100.0000
    100.0000        100.0000        100.0000        100.0000        100.0000
    100.0000        100.0000        16.02117        15.14483        14.12357
    12.93757        11.56018        9.954620        8.415668        7.478934
    6.892618        6.008919        5.319580        5.116024        5.082303
    4.721325        4.587551        5.447469        7.171198        7.970987
    9.110368        10.70658        14.54979        38.97043        38.54490
    41.89580        44.28633        42.27082        42.25864        42.42124
    46.58898        54.03873        53.39265        53.45946        74.71307
    101.5013        101.6366        102.2580
 *correlation coefficients - upper triangular
    1.000000       0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00
    1.000000       0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00
    1.000000       0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00
    1.000000       0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
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0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
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0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
1.000000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00		
1.000000	0.9450000	0.9030000	0.8730000	0.8420000
0.8090000	0.7750000	0.7400000	0.7020000	0.6610000
0.6170000	0.5690000	0.5250000	0.4970000	0.4770000
0.4450000	0.4140000	0.3890000	0.3590000	0.3320000
0.3040000	0.2850000	0.2650000	0.2400000	0.2180000
0.1940000	0.1680000	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00			
1.000000	0.9540000	0.9230000	0.8900000	0.8560000
0.8210000	0.7840000	0.7440000	0.7020000	0.6560000
0.6060000	0.5610000	0.5310000	0.5110000	0.4780000
0.4450000	0.4190000	0.3890000	0.3600000	0.3310000
0.3110000	0.2900000	0.2640000	0.2400000	0.2150000
0.1880000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00				
1.000000	0.9670000	0.9330000	0.8970000	0.8600000
0.8220000	0.7800000	0.7370000	0.6900000	0.6380000
0.5910000	0.5600000	0.5390000	0.5050000	0.4720000
0.4450000	0.4140000	0.3840000	0.3550000	0.3330000
0.3110000	0.2850000	0.2600000	0.2340000	0.2050000
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
1.000000	0.9640000	0.9280000	0.8900000	0.8500000
0.8080000	0.7630000	0.7140000	0.6620000	0.6130000
0.5820000	0.5610000	0.5260000	0.4920000	0.4640000
0.4320000	0.4020000	0.3720000	0.3500000	0.3280000
0.3010000	0.2750000	0.2480000	0.2180000	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	
1.000000	0.9620000	0.9220000	0.8810000	0.8380000
0.7910000	0.7420000	0.6880000	0.6380000	0.6060000
0.5840000	0.5490000	0.5140000	0.4860000	0.4530000
0.4210000	0.3910000	0.3680000	0.3450000	0.3180000
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0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00		
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0.5740000	0.5380000	0.5090000	0.4750000	0.4430000
0.4120000	0.3890000	0.3650000	0.3370000	0.3090000
0.2800000	0.2490000	0.0000000E+00	0.0000000E+00	0.0000000E+00
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0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00			
1.000000	0.9550000	0.9080000	0.8590000	0.8060000
0.7480000	0.6960000	0.6620000	0.6390000	0.6010000
0.5640000	0.5350000	0.5000000	0.4670000	0.4350000
0.4110000	0.3870000	0.3580000	0.3300000	0.3000000
0.2670000	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00	0.0000000E+00
0.0000000E+00				
1.000000	0.9510000	0.8990000	0.8440000	0.7840000
0.7300000	0.6950000	0.6710000	0.6330000	0.5940000
0.5640000	0.5280000	0.4940000	0.4610000	0.4370000
0.4120000	0.3810000	0.3520000	0.3210000	0.2870000

```
0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 1.000000      0.9450000      0.8880000      0.8260000      0.7690000
0.7330000      0.7080000      0.6680000      0.6290000      0.5970000
0.5600000      0.5250000      0.4910000      0.4660000      0.4400000
0.4080000      0.3780000      0.3460000      0.3110000      0.0000000E+00
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 1.000000      0.9390000      0.8740000      0.8140000      0.7770000
0.7510000      0.7090000      0.6680000      0.6350000      0.5970000
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0.4080000      0.3750000      0.3380000      0.0000000E+00  0.0000000E+00
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0.0000000E+00  0.0000000E+00  0.0000000E+00
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0.0000000E+00  0.0000000E+00
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
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0.0000000E+00
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0.6000000      0.5630000      0.5280000      0.4890000      0.4470000
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
 1.000000      0.9670000      0.9160000      0.8660000      0.8260000
0.7800000      0.7370000      0.6940000      0.6640000      0.6320000
0.5940000      0.5570000      0.5180000      0.4740000      0.0000000E+00
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
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0.7620000      0.7190000      0.6870000      0.6550000      0.6160000
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0.0000000E+00  0.0000000E+00  0.0000000E+00
 1.000000      0.9450000      0.9030000      0.8530000      0.8060000
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0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00  0.0000000E+00
0.0000000E+00  0.0000000E+00  0.0000000E+00
 1.000000      0.9580000      0.9160000      0.8660000      0.8180000
0.7670000      0.7120000      0.0000000E+00  0.0000000E+00  0.0000000E+00
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0.0000000E+00  0.0000000E+00
```

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  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  0.0000000E+00
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  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
   1.000000       0.9450000       0.8880000       0.8260000       0.0000000E+00
  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
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  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  0.0000000E+00   0.0000000E+00   0.0000000E+00
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  0.0000000E+00   0.0000000E+00
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  0.0000000E+00
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  0.0000000E+00   0.0000000E+00
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  0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00   0.0000000E+00
  0.0000000E+00
   1.000000       0.9300000       0.8680000       0.0000000E+00   0.0000000E+00
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