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Neutron Environment Characterization of the Central Cavity in the Annular Core Research Reactor

Edward Parma (ejparma@sandia.gov), Gerald Naranjo, Lance Lippert and David Vehar
Applied Nuclear Technologies, Sandia National Laboratories, Albuquerque, New Mexico

ABSTRACT

Characterization of the neutron environment in the central cavity of the Sandia National Laboratories' Annular Core Research Reactor (ACRR) is important in order to provide experimenters with the most accurate spectral information and maintain a high degree of fidelity in performing reactor experiments. Neutron fluence characterizations of two bucket environments, LB44 and PLG, are presented. These two environments are used frequently and represent two extremes in the neutron spectrum. The neutron characterization for each bucket was performed by irradiating 20 different activation foil types, some of which were cadmium covered, resulting in 37 different reactions at the peak axial flux location in each bucket. The dosimetry results were used in the LSL-M2 code with a 640-energy group MCNP-generated trial spectrum, self-shielding correction factors, the SNLRML or IRDFF dosimetry cross-section library, trial spectrum uncertainty, and trial covariance matrix, to generate a least-squares adjusted neutron spectrum, spectrum uncertainty, and covariance matrix. Both environment characterizations are well documented and the environments are available for use by experimenters.

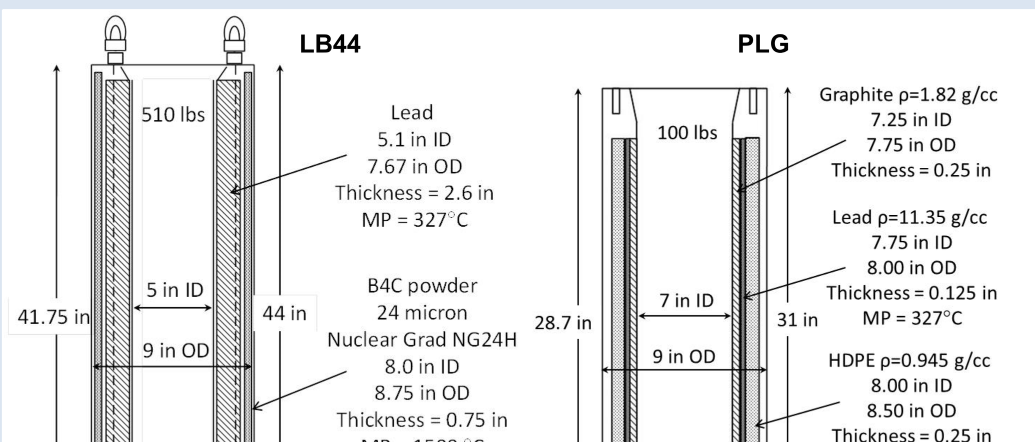
INTRODUCTION

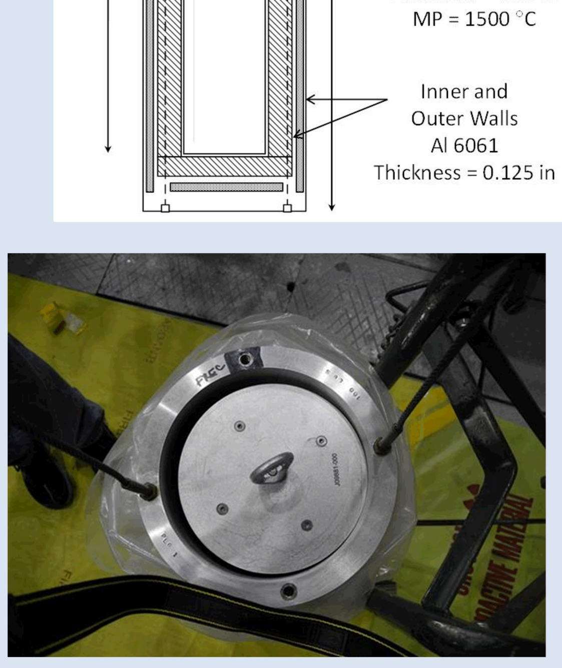
The ACRR is a pulse and steady-state pool-type research reactor that maintains a large, dry irradiation cavity at the center of its core. The ACRR is typically used to perform irradiation testing where a high neutron flux is required for a short period of time. The ACRR's main attributes include an epithermal neutron fluence and large pulsing capabilities. The ACRR is located in Technical Area V (TA-V) at Sandia National Laboratories in Albuquerque, New Mexico.

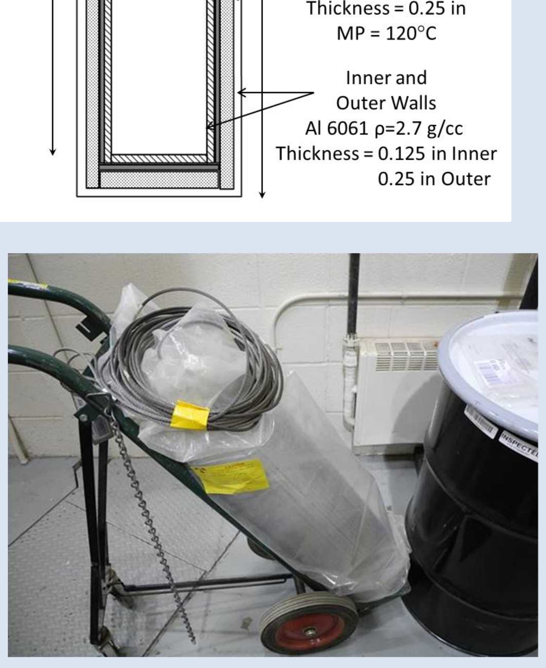
The fuel elements are unique in that the fuel is UO_2-BeO, specially designed to have a large heat capacity and, thus, large pulsing capabilities – up to 300 MJ. The 9-inch (22.9 cm) diameter dry cavity extends from above the pool through the center of the core. The reactor facility also accommodates the fueled ring external cavity (FREC), which maintains a larger dry cavity [20-inch (50.8 cm) diameter] and uses U-ZrH TRIGA fuel as a subcritical multiplier. FREC provides the user with a larger experimental volume.

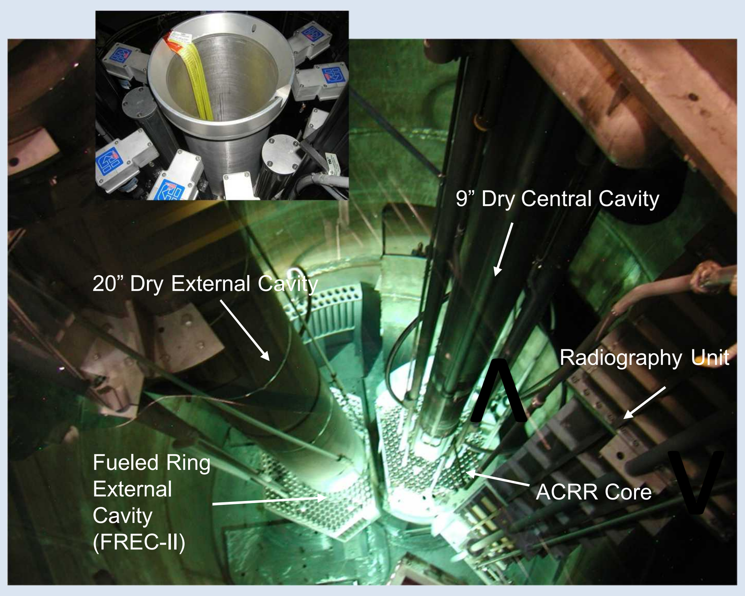
The epithermal neutron fluence spectrum in the central cavity allows the spectrum to be tailored to the desired specifications of an experiment. Moderators can be used within the cavity to thermalize the neutron spectrum. Boron and lead can be used to increase the fast neutron fluence ratio and to decrease the gamma-ray fluence, respectively.

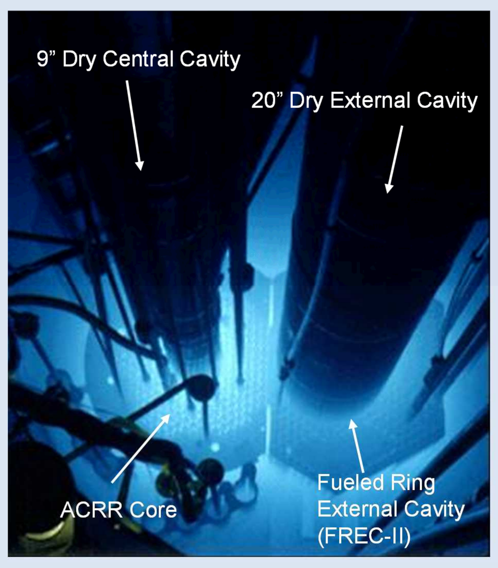
The LB44 bucket has annuli of B_4C and lead designed to remove the thermal component of the neutron spectrum and significantly attenuate the gamma-ray fluence. The PLG bucket has annuli of polyethylene, lead, and graphite designed to enhance the thermal component of the neutron spectrum and attenuate the gamma-ray fluence.





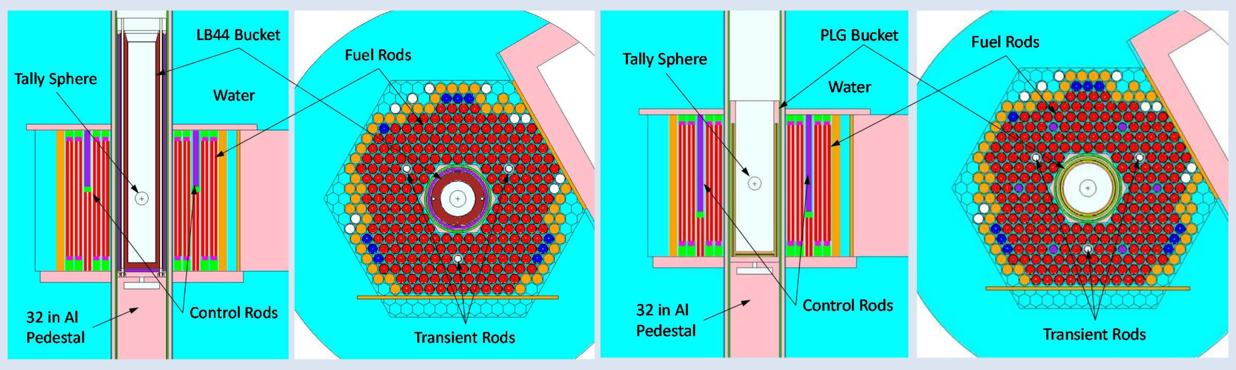






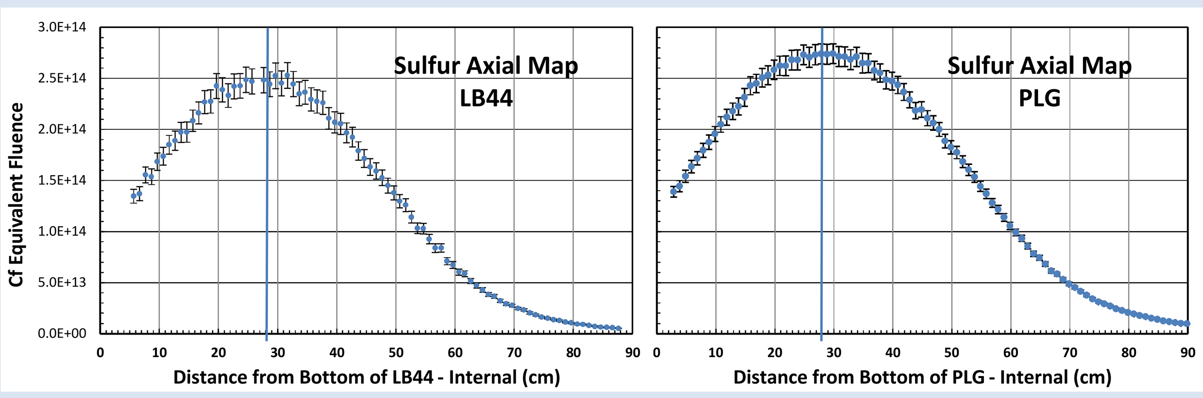
NEUTRONIC MODELING

The Monte Carlo N-Particle transport code, MCNP5 version 1.60 [1], was used to model the ACRR and the bucket environments. Shown below are the MCNP models of the ACRR [2] with the LB44 bucket and the PLG bucket, respectively, on the 32-inch (81.3 cm) pedestal in the central cavity. A 6-cm diameter tally sphere is modeled at the axial centerline of the cavity. The neutron energy spectrum was calculated for a 640-energy group and an 89-energy group structure using the ENDF/B-VII cross sections at 300K. The model was run on a parallel machine for 20 billion source neutrons. The 640-energy group neutron spectrum result was used as the trial function in the LSL-M2 spectrum adjustment code [3].



NEUTRONIC ACTIVATION DOSIMETRY

The initial characterization of each bucket included a neutron and gamma-ray axial and radial profile mapping to determine the peak and variation. Sulfur tablets and CaF2:Mn TLDs were used to perform the axial mapping in 1-cm increments from the bottom of each bucket up to 90 cm. The peak neutron flux was found to be at ~11 inches (27.9 cm) from the bottom of both buckets. The flux was relatively constant (within a few percent) over ~4 inches (10 cm). Radial mapping was performed using sulfur tablets, gold foils and CaF2:Mn TLDs. No significant radial variation was observed for either bucket.



Neutron activation foils were irradiated at the peak fluence location using an aluminum dosimetry stand that was designed to facilitate the irradiations and to minimize personnel dose. The stand is made up of two parts: the funnel, which stays in the bucket, and the drop-in thimble, which holds up to 10 foils at one time.

Dosimetry-quality foils were used to perform the neutron activation [4]. For each operation, a nickel foil was also irradiated to allow for all of the operations to be normalized to a given operating condition.

For LB44, 18 different activation foil types were used, some of which were cadmium (Cd) covered, resulting in 31 different reactions (Table 1). Four fission foils (^{235}U, ^{238}U, ^{239}Pu, and ^{237}Np) were irradiated individually in a standard Cd and boron ball configuration in four separate steady-state operations. For PLG, 20 different foil types were used, some of which were Cd covered, resulting in 37 different reactions (Table 2). Fission foils were also irradiated individually using boron balls. The foils were counted at the Sandia Radiation Metrology Laboratory (RML) located adjacent to the ACRR facility.

Table 1. LB44 C/E Values.

Activation Reaction	C/E-1 Trial Spectrum (%)	C/E-1 Adjusted Spectrum (%)	Factor Adjusted (%)
$^{58}Ni(n,p)^{58}Co$ - Reference	0.00	-0.82	-0.83
$^{59}Co(n,p)^{59}Fe$	2.86	1.54	-1.30
$^{27}Al(n,\alpha)^{24}Na$	8.35	5.71	-2.50
$^{27}Al(n,p)^{27}Mg$	-8.73	-1.64	7.21
$^{46}Ti(n,p)^{46}Sc$	-3.49	-0.81	2.70
$^{47}Ti(n,p)^{47}Sc$	3.35	0.81	-2.52
$^{48}Ti(n,p)^{48}Sc$	-3.53	-1.44	2.12
$^{54}Fe(n,p)^{54}Mn$	4.73	1.47	-3.21
$^{56}Fe(n,p)^{56}Mn$	0.62	0.68	0.06
$^{93}Nb(n,2n)^{92m}Nb$	-5.73	-0.8	4.97
$^{115}In(n,n')^{115m}In$	-6.88	-6.52	0.39
$^{55}Mn(n,2n)^{54}Mn$	4.41	5.43	0.97
$^{59}Co(n,2n)^{58}Co$	10.49	14.38	3.40
$^{60}Ni(n,p)^{60}Co$	-4.88	-0.88	4.04
$^{58}Fe(n,\gamma)^{59}Fe$	33.08	0.54	-32.37
$^{23}Na(n, \gamma)^{24}Na$	30.52	0.28	-30.16
$^{45}Sc(n, \gamma\ ^{46}Sc$	13.71	-0.28	-14.03
$^{55}Mn(n, \gamma)^{56}Mn$	17.16	-0.59	-17.86
$^{59}Co(n, \gamma)^{60}Co$	38.47	-0.11	-38.62
$^{63}Cu(n, \gamma)^{64}Cu$	2.38	-2.15	-4.63
$^{98}Mo(n, \gamma)^{99}Mo$	15.61	0.06	-15.54
$^{115}In(n, \gamma)^{116m}In$	18.21	0.8	-17.27
$^{197}Au(n, \gamma)^{198}Au$	-0.92	-0.46	0.46
$^{58}Fe(n, \gamma)^{59}Fe$ - BB	36.33	4.61	-30.32
$^{59}Co(n, \gamma)^{60}Co$ - BB	18.25	0.69	-17.44
$^{98}Mo(n, \gamma)^{99}Mo$ - BB	25.75	2.48	-22.71
$^{197}Au(n, \gamma)^{198}Au$ - BB	2.33	-6.11	-8.99
$^{235}U(n,f)FP$ - BB	6.86	0.76	-6.05
$^{238}U(n,f)FP$ - BB	1.3	0.56	-0.74
$^{237}Np(n,f)FP$ - BB	-3.86	-0.53	3.35
$^{239}Pu(n,f)FP$ - BB	2.78	-1.85	-4.72

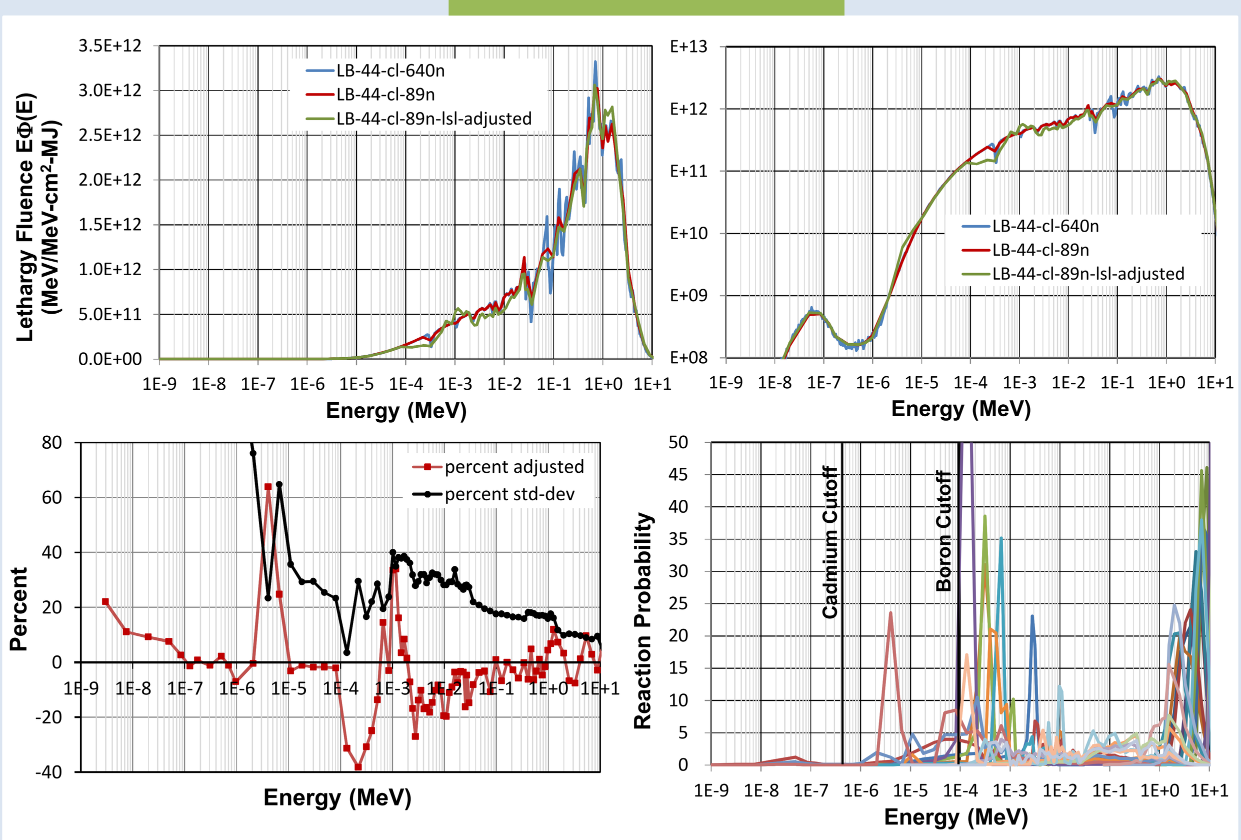
Table 2. PLG C/E Values.

Activation Reaction	C/E-1 Trial Spectrum (%)	C/E-1 Adjusted Spectrum (%)	Factor Adjusted (%)
$^{58}Ni(n,p)^{58}Co$ - Reference	0.00	-0.59	-0.59
$^{24}Mg(n,p)^{24}Na$	9.80	3.63	-5.95
$^{27}Al(n,\alpha)^{24}Na$	4.53	-1.78	-6.42
$^{32}S(n,p)^{32}P$ Cf-equ	7.83	4.36	-3.33
$^{46}Ti(n,p)^{46}Sc$	5.03	2.72	-2.25
$^{47}Ti(n,p)^{47}Sc$	-2.57	-2.48	0.09
$^{48}Ti(n,p)^{48}Sc$	4.71	0.01	-4.70
$^{55}Mn(n,2n)^{54}Mn$	-21.33	-16.85	5.39
$^{54}Fe(n,p)^{54}Mn$	1.37	0.56	-0.81
$^{56}Fe(n,p)^{56}Mn$	0.90	-1.36	-2.29
$^{59}Co(n,p)^{59}Fe$	1.26	-0.01	-1.27
$^{59}Co(n,2n)^{58}Co$	-4.01	0.39	4.38
$^{58}Ni(n,2n)^{57}Ni$	-2.05	5.48	7.14
$^{60}Ni(n,p)^{60}Co$	-1.07	-2.64	-1.61
$^{63}Cu(n,\alpha)^{60}Co$	-16.12	-17.5	-1.67
$^{64}Zn(n,p)^{64}Cu$	-1.52	-2.52	-1.03
$^{90}Zr(n,2n)^{89}Zr$	-9.17	-1.87	7.44
$^{93}Nb(n,2n)^{92m}Nb$	2.16	0.4	-1.75
$^{115}In(n,n')^{115m}In$	-7.89	-7.11	0.84
$^{23}Na(n, \gamma)^{24}Na$	24.56	1.34	-22.91
$^{45}Sc(n, \gamma)^{46}Sc$	21.72	0.08	-21.62
$^{58}Fe(n, \gamma)^{59}Fe$	20.61	0.07	-20.53
$^{59}Co(n, \gamma)^{60}Co$	20.58	-0.55	-21.25
$^{63}Cu(n, \gamma)^{64}Cu$	16.50	-2.45	-19.43
$^{98}Mo(n, \gamma)^{99}Mo$	0.97	0.4	-0.57
$^{197}Au(n, \gamma)^{198}Au$	7.78	-0.34	-8.15
$^{23}Na(n, \gamma)^{24}Na$ - Cd	11.43	0.53	-10.84
$^{45}Sc(n, \gamma)^{46}Sc$ - Cd	5.51	-0.64	-6.19
$^{55}Mn(n, \gamma)^{56}Mn$ - Cd	2.28	-0.68	-2.98
$^{58}Fe(n, \gamma)^{59}Fe$ - Cd	7.30	0.72	-6.53
$^{59}Co(n, \gamma)^{60}Co$ - Cd	16.79	0.13	-16.64
$^{63}Cu(n, \gamma)^{64}Cu$ - Cd	9.54	1.46	-7.96
$^{98}Mo(n, \gamma)^{99}Mo$ - Cd	-2.43	-0.45	1.99
$^{197}Au(n, \gamma)^{198}Au$ - Cd	2.58	0.25	-2.32
$^{235}U(n,f)FP$ - BB	-7.27	-4.88	2.51
$^{238}U(n,f)FP$ - BB	1.49	1.88	0.38
$^{239}Pu(n,f)FP$ - BB	5.97	4.72	-1.19

SPECTRUM ADJUSTMENT RESULTS

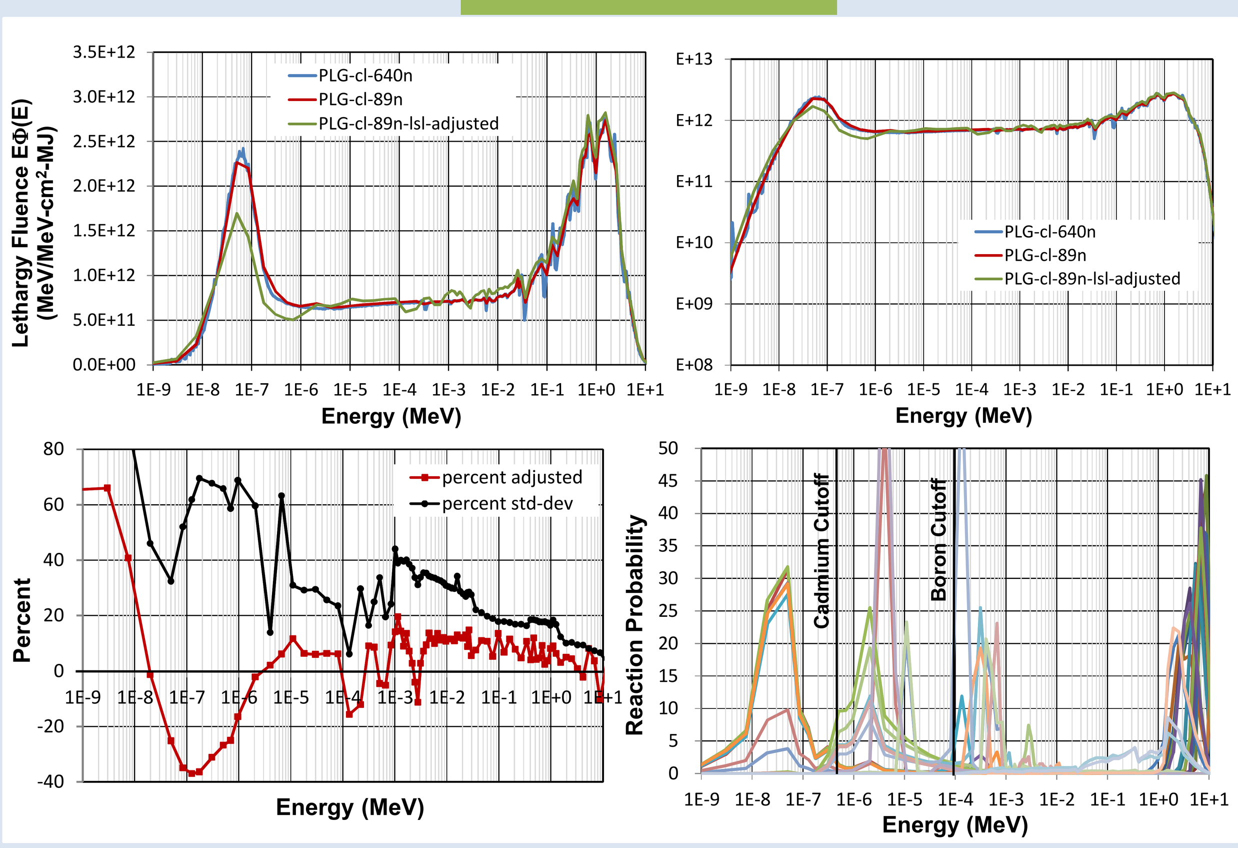
The activation results were used in the LSL-M2 code with the 640-energy group MCNP-generated trial spectrum, self-shielding correction factors, the SNLRML [5] or IRDFF [6,7] dosimetry cross-section library, trial spectrum uncertainty, and trial covariance matrix, to generate a least-squares adjusted neutron spectrum, spectrum uncertainty, and covariance matrix. The LSL-M2 adjustment process generated an 89-energy group spectrum.

LB44 RESULTS



The results of the LSL analysis for the LB44 bucket are shown above and the results of the PLG bucket are shown below. For LB44 and PLG, the resulting χ^2 per degree of freedom for the adjustment was 0.89 and 0.90, respectively, both acceptable values. For both cases, the adjusted spectrum was modified only by a few percent in the fast neutron region represented by the (n,p), (n,2n), (n,α), and (n,n') reactions. The adjustment was much more significant in the thermal and epithermal regions represented by the (n,γ) and Cd covered (n, γ) reactions.

PLG RESULTS



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