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Characterization of the NPOD3 Detectors in MCNP5 and MCNP6

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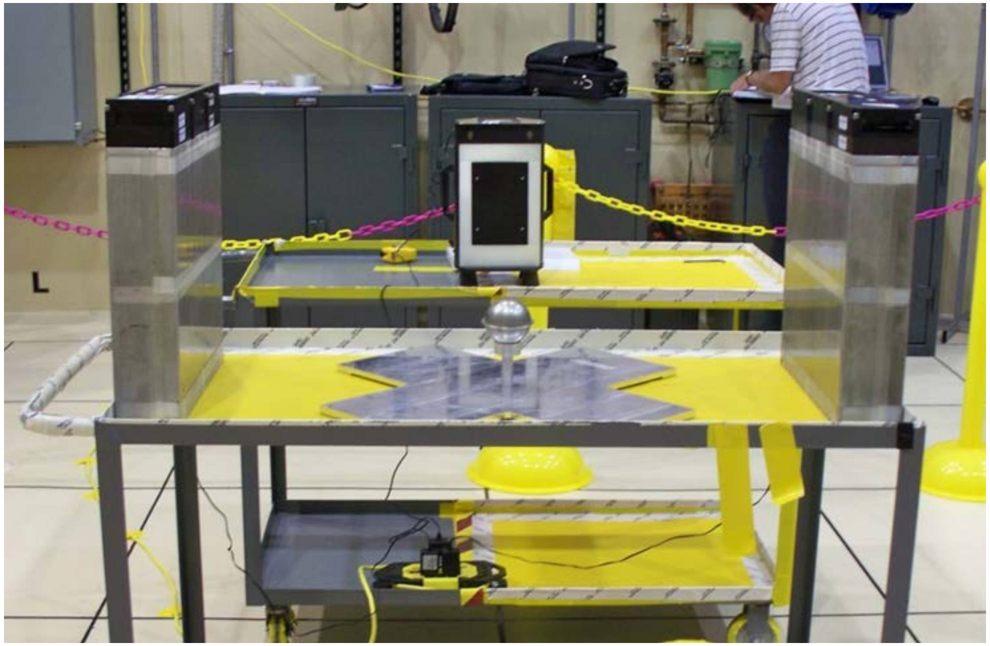
Abstract

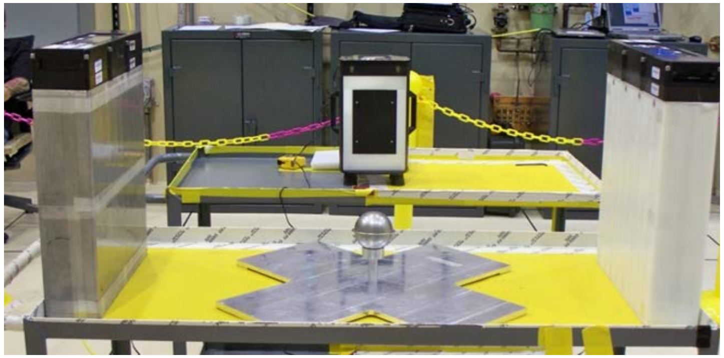
Researchers performed a series of measurements in May 2012 to characterize the NPOD3 detector systems. The detectors were placed in varying states of disassembly to determine the effect of individual components on the detector response. The Los Alamos BeRP Ball was used as the SNM source in both a bare configuration and reflected by varying thicknesses of polyethylene. A set of MCNP5 (with the list-mode patch) and MCNP6 simulations matching the experimental setups for the bare and half-inch reflected cases were run and the calculated list-mode data were compared to the measured data. The total multiplication results show that MCNP5 with the list-mode patch replicates the measurements quite well (to within 2%), while MCNP6 calculations exhibit a ~7% difference from measurements for the bare configuration. The benefits and limitations of each code for the use of obtaining list-mode data are explained.

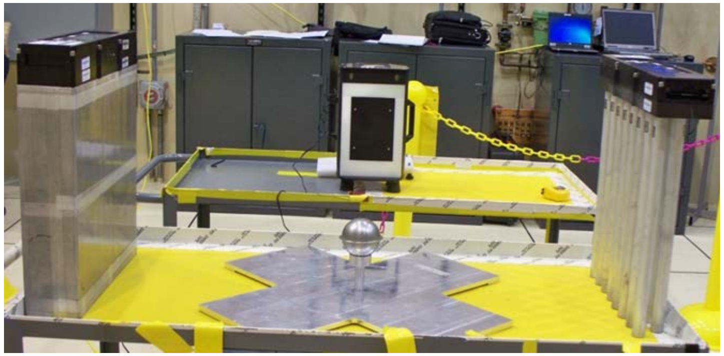
Introduction

- A series of subcritical measurements were taken in 2012 to characterize the NPOD detector systems
  - Source: BeRP ball in a bare configuration and reflected by varying thicknesses of polyethylene
  - Detectors:
    - One SNAP detector placed 100 in. from center of source
    - One NPOD in original configuration placed 50 in. from center of source
    - One NPOD in original config. and varying states of disassembly placed 50 in. from center of source 180 degrees from first NPOD

Experimental set-up







Configurations

Configuration	NPOD #1	NPOD #2	SNAP
1a	default	default	no poly
1b	default	default	poly
2a	blue cover	blue cover	no poly
2b	blue cover	blue cover	poly
3a	default	no cadmium	no poly
3b	default	no cadmium	poly
4a	default	no cadmium or poly	no poly
4b	default	no cadmium or poly	poly
5a	default	removed	no poly
5b	default	removed	poly
6	default	removed	removed
7a	default	removed	no poly, in line with NPOD
7b	default	removed	poly, in line with NPOD
8	default, 90 degrees	removed	removed
9a	default, 90 degrees	default, 90 degrees	no poly
9b	default, 90 degrees	default, 90 degrees	poly

Measurements

- List-mode data were acquired by the detectors
  - Time and location of absorption events within the detector volume
  - Can be used with a variety of analysis methods to infer system parameters
- SNAP detector delivers a gross neutron count rate
  - Used to calculate the effective neutron source strength
- NPOD detectors provide multiplicity data
  - Analyzed using Feynman-Y analysis to determine the (counting) moments and the multiplicity of the system under scrutiny

Feynman-Y (Hansen-Dowdy formalism)

- Multiplicity neutron counting
  - Purely random source exhibits a Poisson distribution of counts
  - A correlated (multiplying) source has a distribution which deviates from a pure Poisson
    - The magnitude of this deviation provides insight into the multiplicity of the system

$$Y_m = \frac{\overline{C^2}}{\bar{C}} - \bar{C} - 1$$

- Where $\bar{C}$ and $\overline{C^2}$ are the first and second moments of the distribution:

$$\bar{C} = \frac{\sum_n nC_n}{\sum_n C_n} \qquad \overline{C^2} = \frac{\sum_n n^2 C_n}{\sum_n C_n}$$

Total Multiplication

- Using the moments calculated from the list-mode data, along with some other parameters, the total multiplication, M_t, can be determined
- The prompt multiplication factor, k_p, is inferred from the total multiplication

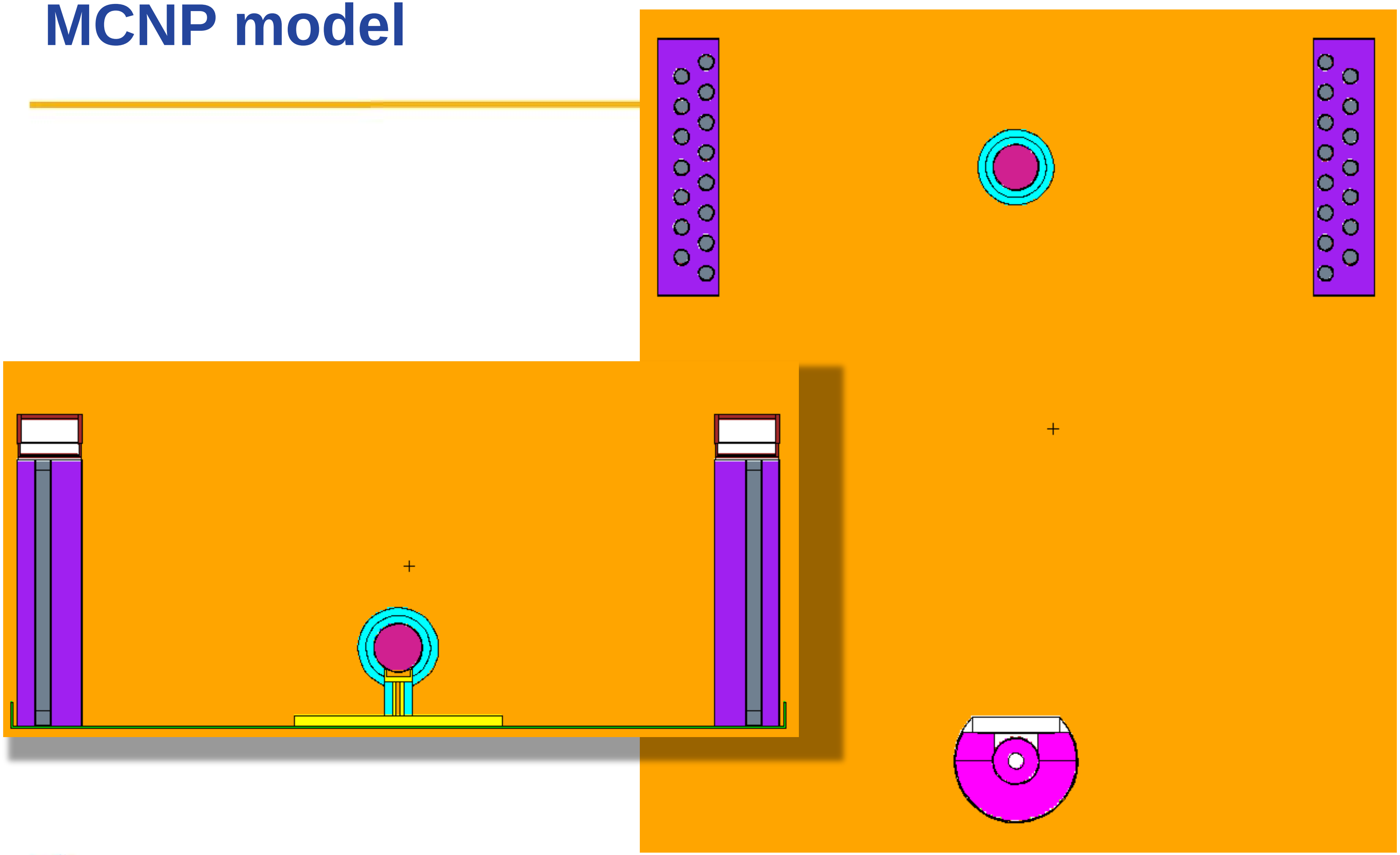
Param #	Description of Parameter	value
1	detector dead time (microsec)	2.5
2	time of measurement (seconds)	156
3	time bin width of detector (microsec)	256
4	neutron leakage from outermost surface (n/s)	1037264
5	id starter	Pu-240
6	0th order Divens (source) ~ Pu-240	1.769
7	id chain	Pu-239
8	1st order Divens (multiplier) ~ Pu-239	2.354
9	wt% of source ~ Pu-240	0.05954
10	#n/g-s emitted by SNM (Pu-240)	1020
11	neutron lifetime (seconds)	3.90E-05
12	non-correlated neutron source strength (n/s)	436.33
13	correlated neutron source strength (n/s)	282890
14	neutron leakage from SNM (n/s)	1037264

$$k_p = 1 - \frac{1}{M_t}$$

MC Calculations

- MCNP5.15 with the in-house multiplication patch and MCNP6.1 codes were used with ENDF/B-VII.0
- So far, only the bare and half-inch reflected cases have been simulated for Configs. 1, 3 and 4
  - Currently running simulations for the other reflected cases

MCNP model



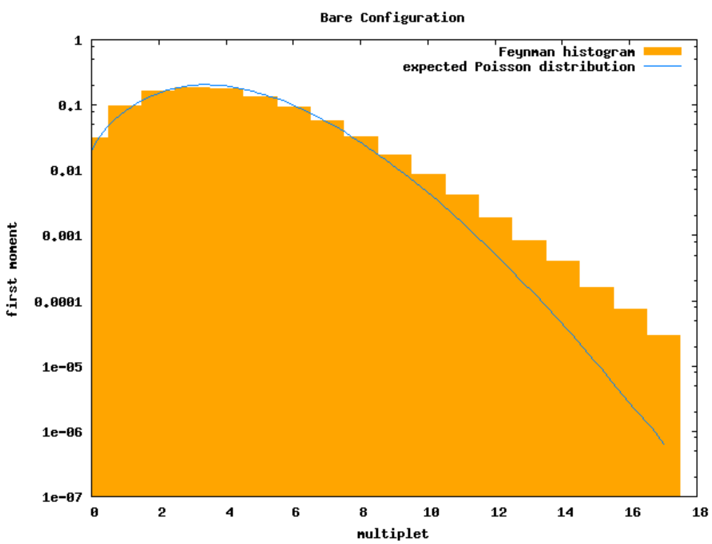
Results – 1st and 2nd moments

Config. (bare)	POLY on SNAP?	Measured		MCNP6				MCNP5 w/patch			
		1st mom.	2nd mom.	1st mom.	C/E	2nd mom.	C/E	1st mom.	C/E	2nd mom.	C/E
DEFAULT	YES	2.316	8.386	2.454	1.060	9.126	1.088	2.451	1.058	9.235	1.101
DEFAULT	YES	2.327	8.444	2.454	1.055	9.124	1.081	2.451	1.053	9.221	1.092
DEFAULT	NO	2.316	8.374	2.448	1.057	9.091	1.086	2.450	1.058	9.222	1.101
DEFAULT	NO	2.311	8.352	2.449	1.060	9.085	1.088	2.449	1.060	9.222	1.104
NO Cd	YES	2.313	8.347	2.454	1.061	9.119	1.092	2.450	1.059	9.227	1.105
NO Cd	NO	2.317	8.369	2.461	1.062	9.163	1.095	2.463	1.063	9.308	1.112
NO Cd OR POLY	YES	2.282	8.174	2.415	1.058	8.873	1.086	2.411	1.057	8.970	1.097
NO Cd OR POLY	NO	bad data	bad data	0.037	---	0.039	---	0.044	---	0.046	---

Config. (0.5 inch)	POLY on SNAP?	Measured		MCNP6				MCNP5 w/patch			
		1st mom.	2nd mom.	1st mom.	C/E	2nd mom.	C/E	1st mom.	C/E	2nd mom.	C/E
DEFAULT	YES	3.124	14.440	3.347	1.071	16.163	1.119	3.345	1.071	16.349	1.132
DEFAULT	YES	3.142	14.613	3.347	1.065	16.138	1.104	3.345	1.065	16.362	1.120
DEFAULT	NO	3.138	14.567	3.348	1.067	16.151	1.109	3.351	1.068	16.415	1.127
DEFAULT	NO	3.129	14.497	3.348	1.070	16.160	1.115	3.350	1.071	16.420	1.133
NO Cd	YES	3.126	14.464	3.345	1.070	16.134	1.115	3.345	1.070	16.360	1.131
NO Cd	NO	3.187	14.948	3.410	1.070	16.677	1.116	3.407	1.069	16.893	1.130
NO Cd OR POLY	YES	no data	no data	3.298	---	15.729	---	3.295	---	15.934	---
NO Cd OR POLY	NO	0.174	0.206	0.147	0.845	0.170	0.825	0.147	0.845	0.170	0.825
NO Cd OR POLY	NO	3.084	14.113	3.295	1.068	15.680	1.111	3.297	1.069	15.949	1.130

Results - Y_m

$$Y_m = \frac{\overline{C^2}}{\bar{C}} - \bar{C} - 1$$



Config. (bare)	POLY on SNAP?	Measured	MCNP6		MCNP5 w/patch	
		Ym	Ym	C/E	Ym	C/E
DEFAULT	YES	0.303	0.266	0.878	0.317	1.046
DEFAULT	YES	0.303	0.265	0.875	0.312	1.030
DEFAULT	NO	0.300	0.265	0.883	0.315	1.050
DEFAULT	NO	0.303	0.261	0.861	0.317	1.046
NO Cd	YES	0.296	0.263	0.889	0.316	1.068
NO Cd	NO	0.296	0.262	0.885	0.317	1.071
NO Cd OR POLY	YES	0.300	0.259	0.863	0.311	1.037
NO Cd OR POLY	NO	bad data	0.009	---	0.002	---

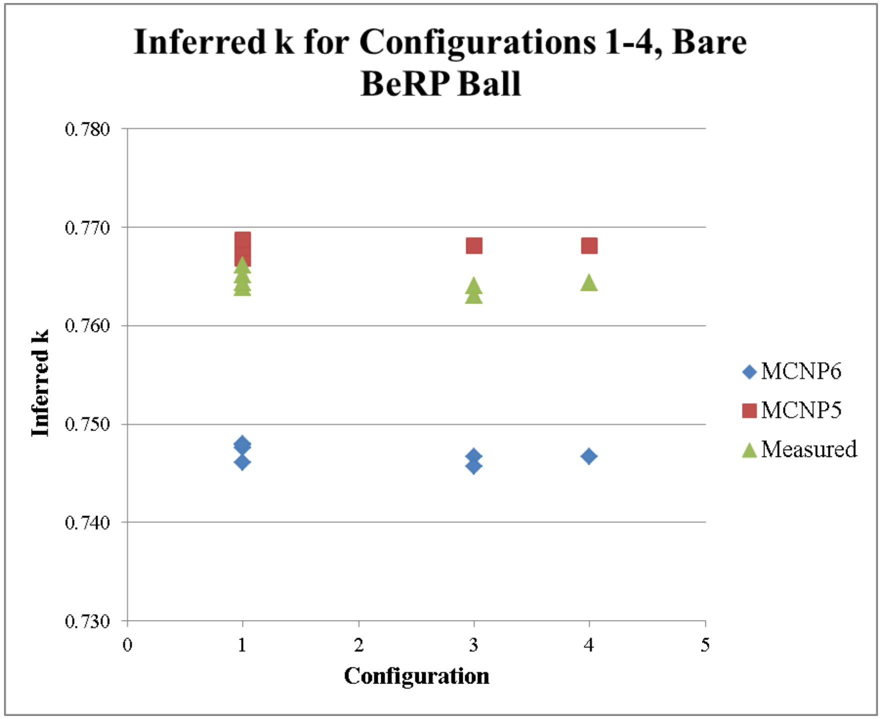
Config. (0.5 inch)	POLY on SNAP?	Measured	MCNP6		MCNP5 w/patch	
		Ym	Ym	C/E	Ym	C/E
DEFAULT	YES	0.499	0.483	0.968	0.543	1.088
DEFAULT	YES	0.508	0.475	0.935	0.546	1.075
DEFAULT	NO	0.504	0.477	0.946	0.547	1.085
DEFAULT	NO	0.504	0.478	0.948	0.553	1.097
NO Cd	YES	0.500	0.478	0.956	0.545	1.090
NO Cd	NO	0.503	0.480	0.954	0.551	1.095
NO Cd OR POLY	YES	no data	0.470	---	0.541	---
NO Cd OR POLY	NO	0.010	0.004	0.400	0.010	1.000
NO Cd OR POLY	NO	0.491	0.464	0.945	0.540	1.100

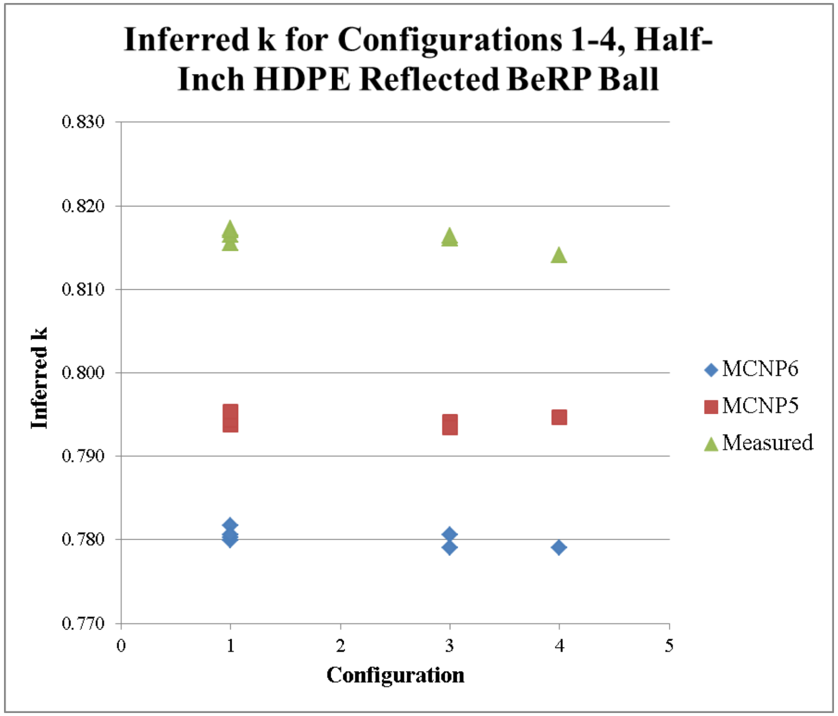
Results – total multiplication and inferred k

CONFIG. (bare)	POLY on SNAP?	MEASURED		MCNP6			MCNP5		
		Mt	k	Mt	k	C/E	Mt	k	C/E
DEFAULT	YES	4.276	0.766	3.968	0.748	0.928	4.322	0.769	1.011
DEFAULT	YES	4.258	0.765	3.962	0.748	0.930	4.288	0.767	1.007
DEFAULT	NO	4.234	0.764	3.967	0.748	0.937	4.307	0.768	1.017
DEFAULT	NO	4.243	0.764	3.938	0.746	0.928	4.323	0.769	1.019
NO Cd	YES	4.221	0.763	3.948	0.747	0.935	4.313	0.768	1.022
NO Cd	NO	4.239	0.764	3.933	0.746	0.928	4.313	0.768	1.017
NO Cd OR POLY	YES	4.243	0.764	3.947	0.747	0.930	4.313	0.768	1.016
NO Cd OR POLY	NO	bad data	--	5.888	0.830	--	2.375	0.579	--

CONFIG. (0.5 in)	POLY on SNAP?	MEASURED		MCNP6			MCNP5		
		Mt	k	Mt	k	C/E	Mt	k	C/E
DEFAULT	YES	5.422	0.816	4.581	0.782	0.845	4.850	0.794	0.895
DEFAULT	YES	5.472	0.817	4.545	0.780	0.831	4.862	0.794	0.889
DEFAULT	NO	5.449	0.816	4.551	0.780	0.835	4.863	0.794	0.892
DEFAULT	NO	5.467	0.817	4.558	0.781	0.834	4.886	0.795	0.894
NO Cd	YES	5.436	0.816	4.557	0.781	0.838	4.858	0.794	0.894
NO Cd	NO	5.446	0.816	4.525	0.779	0.831	4.841	0.793	0.889
NO Cd OR POLY	YES	no data	no data	4.552	0.780	---	4.875	0.795	---
NO Cd OR POLY	NO	1.302	0.232	2.057	0.514	1.580	3.147	0.682	2.417
NO Cd OR POLY	NO	5.380	0.814	4.525	0.779	0.841	4.870	0.795	0.905

Inferred k plot





Thoughts

- MCNP6's PTRAC option is not an ideal method for obtaining list-mode data
  - Cannot run in parallel
  - Huge output files
  - Bunch of irrelevant data to sift through
  - ASCII output format significantly truncates time stamp
  - Other output file format option is binary
  - If using EVENT=CAP, the recorded time is the time from the fission event to the time of capture, but list-mode needs to be from the time of the beginning of the measurement to the time of detection (capture).
    - This can be avoided by using a cell-flux tally instead of an F8 capture tally

References

1. M. SMITH-NELSON, et al, “Neutron Specialist Handbook and Informational Text,” LA-UR-07-6170, Los Alamos National Laboratory, Los Alamos, NM (2007).
2. K. CLARK, et al, “Comparison of MCNP-based Transport Codes for Subcritical Calculations,” American Nuclear Society Winter Meeting, San Diego, CA, November 11-15, 2012, ANS (2012).
3. W. WILSON, et al, “SOURCES4C: A Code for Calculating (alpha,n), Spontaneous Fission, and Delayed Neutron Sources and Spectra,” LA-UR-02-1839, Los Alamos National Laboratory, Los Alamos, NM (2002).
4. A. SOOD, et al, “Current Capabilities for Generating List-Mode Data for Simulated Subcritical Neutron Measurements Using MCNP,” NCSP Review Meeting, Oak Ridge, TN (2011).
5. C. SOLOMON, “Modifications to the MCNP5 Multiplication Patch,” LA-UR-11-04711, Los Alamos National Laboratory, Los Alamos, NM (2011).
6. D. PELOWITZ, “MCNP6 User’s Manual,” LA-CP-11-01708, Los Alamos National Laboratory, Los Alamos, NM (2011).
7. M. CHADWICK, et al, “ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data,” LA-UR-11-05121, Los Alamos National Laboratory, Los Alamos, NM (2011).
8. S. BOLDING and C. SOLOMON, “Simulations of Multiplicity Distributions with Perturbations to Nuclear Data,” American Nuclear Society Winter Meeting, Washington, D.C., November 10-14, 2013, ANS (2013).
9. E. MILLER, et al, “Simulations of Neutron Multiplicity Measurements with MCNP-PoliMi,” SAND2010-6830, Sandia National Laboratory, Albuquerque, NM (2010).

Acknowledgements

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