# Characterization of the NPOD3 Detectors in MCNP5 and MCNP6

Kimberly Klain (Clark) Jesson Hutchinson C.J. Solomon
Theresa Cutler Avneet Sood

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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 (HDPE). A set of MCNP5 (with the list-mode patch) and MCNP6 simulations matching the experimental setups for the bare and reflected cases were run and the calculated list-mode data were compared to the measured data. The singles and doubles count rates and the leakage multiplication results show that both MCNP5 with the list-mode patch and MCNP6 adequately replicate the measurements. The advantages and limitations of each code for the use of obtaining list-mode data are explained.

# Previous work

- Previous research compared the capabilities of various versions of MCNP developed both within and outside of LANL in simulating subcritical systems
- This work showed that MCNP5 with the LANL list-mode patch was best-suited for such calculations due to its accuracy and its ease of use

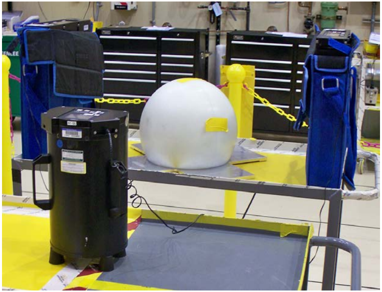
# Code comparison

- Verify the MCNP models of the detector systems
- Compare the strengths and weaknesses of the Monte Carlo N-Particle (MCNP) codes in predicting the behavior of subcritical systems

Prove that MCNP6, the production version of the MCNP code, is capable of simulating list-mode data as well as MCNP5 with the list-mode patch

# Why subcritical?

What are subcritical measurements?



Why are subcritical measurements important?

- Approach to critical
- Benchmarking
- Code validation
- Nuclear data validation
- Measurement of subcritical levels of materials
- Reactivity monitoring

# Measurements

# Experiment

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 cm from center of source
- One NPOD in original configuration placed 50 cm from center of source
- One NPOD in original configuration and in varying states of disassembly placed 50 cm from center of source and 180 degrees from first NPOD

# Configurations

| Config. | NPOD #1 | NPOD #2 |
|---|---|---|
| 1 | default | default |
| 2 | blue cover | blue cover |
| 3 | no cadmium | default |
| 4 | no cadmium or poly | default |
| 5 | removed | default |
| 6 | removed | default |
| 7 | removed | default |
| 8 | removed | default, 90 degrees |
| 9 | default, 90 degrees | default, 90 degrees |

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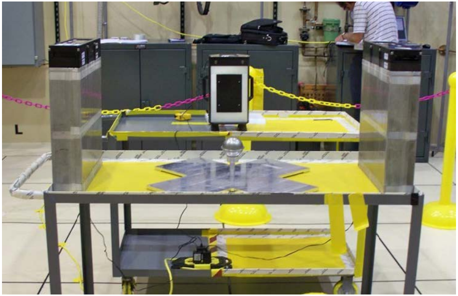
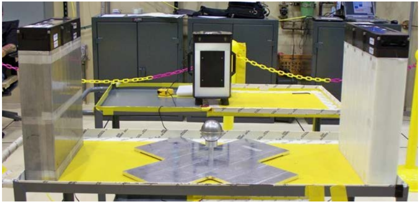
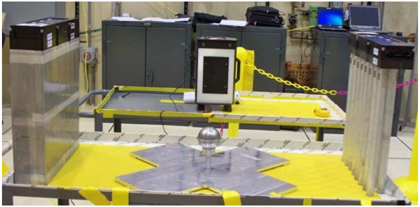
# Experimental set-up







# Measurements

- List-mode data were acquired by the detectors
  - SNAP detector delivers a gross neutron count rate
  - NPOD detectors provide multiplicity data:

| | |
|---|---|
| ... | |
| 3053 | 8680902604.70748 |
| 3053 | 14254079822.86892 |
| 3060 | 15151819451.43296 |
| 3055 | 4810218246.61435 |
| 3050 | 2713074280.99071 |
| 3048 | 7022566669.45221 |
| 3058 | 6223236526.46893 |
| 3056 | 7854715137.29732 |
| 3053 | 1573552607.36039 |
| ... | |

- Data analysis was performed using Feynman variance

# Feynman variance

- Method of calculating the moments of the count distribution
  - 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

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

where $\bar{C} = \frac{\sum_n nC_n}{\sum_n C_n}$ and $\bar{C^2} = \frac{\sum_n n^2 C_n}{\sum_n C_n}$

# Hage-Cifarelli formalism

- Uses *reduced factorial moments* to determine singles (R1), doubles (R2) and triples (R3) counting rates

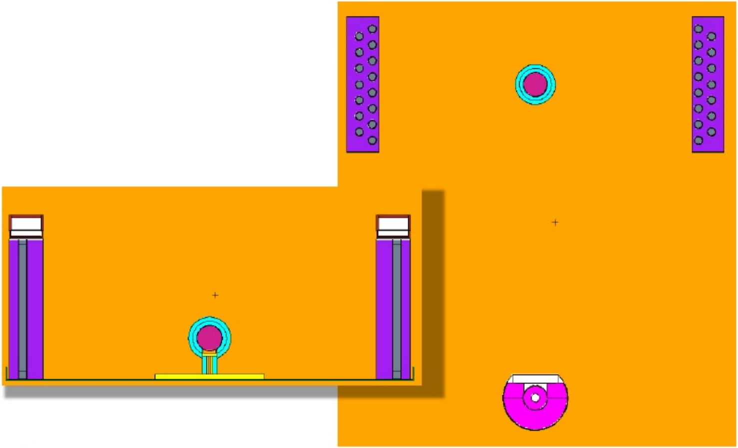
$$\bar{m}_{1!} = \frac{\sum nC_n}{1! \sum C_n} \qquad \bar{m}_{2!} = \frac{\sum n(n-1)C_n}{2! \sum C_n}$$

$$\bar{m}_{3!} = \frac{\sum n(n-1)(n-2)C_n}{3! \sum C_n}$$

- R1, R2, and R3 are then used, along with several other parameters, to determine the leakage multiplication value
- These calculations are performed using Momentum

# Calculations

# MCNP model



# MC calculations

- MCNP5.15 with the list-mode patch and MCNP6.1 codes were run with ENDF/B-VII.0
- Computation times:
  - MCNP5, 16 procs
    - Bare, 300s: 615 minutes / 16 procs = 40 min/proc
    - 3 inch HDPE, 300s: 3600 minutes / 16 procs = 225 min/proc
  - MCNP6, 16 procs
    - Bare, 300s: 820 minutes / 16 procs = 51 min/proc
    - 3 inch HDPE, 300s: 3890 minutes / 16 procs = 243 min/proc

# MCNP data post-processing

- MCNP5 w/patch outputs a list-mode file that resembles the detector output
- MCNP6 outputs a binary file that must be parsed and converted to ASCII prior to analysis
- Both outputs are converted to a special format to be read by Momentum

# mcnptools

- `mcnptools` is a C++ library (extended to Python) developed to aid the user in accessing data from MCNP output files:
  - mctal
  - meshtal
  - ptrac

Planned for eventual distribution with MCNP6 package from RSICC

# Results

# Results - R1 (Singles) and R2 (Doubles)

| NPOD1 config. | MEASURED R1 | MEASURED σ(R1) | MCNP5 R1 | MCNP5 σ(R1) | MCNP5 C/E | MCNP6 R1 | MCNP6 σ(R1) | MCNP6 C/E |
|---|---|---|---|---|---|---|---|---|
| **BARE BeRP** | | | | | | | | |
| 1 | 9018.48 | 5.65 | 9582.77 | 6.89 | 1.063 | 9530.62 | 6.70 | 1.057 |
| 1 | 9050.73 | 5.27 | 9582.77 | 6.89 | 1.059 | 9530.62 | 6.70 | 1.053 |
| 3 | 9045.88 | 4.68 | 9593.30 | 7.53 | 1.061 | 9687.68 | 6.85 | 1.071 |
| 4 | 268.90 | 0.64 | -- | -- | -- | 99.33 | 0.81 | 0.369 |
| **0.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 12250.92 | 7.04 | 13083.58 | 9.17 | 1.068 | 13112.09 | 9.02 | 1.070 |
| 1 | 12222.11 | 7.32 | 13083.58 | 9.17 | 1.070 | 13112.09 | 9.02 | 1.073 |
| 3 | 12449.68 | 7.97 | 13312.92 | 9.03 | 1.069 | 13350.20 | 8.65 | 1.072 |
| 4 | 682.94 | 1.18 | 573.23 | 1.42 | 0.839 | 575.65 | 1.53 | 0.843 |
| **1.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 15805.84 | 9.91 | 17118.25 | 11.33 | 1.083 | 17208.00 | 11.65 | 1.089 |
| 3 | 16951.94 | 10.95 | 18379.49 | 11.83 | 1.084 | 18427.64 | 12.01 | 1.087 |
| 4 | -- | -- | 2721.06 | 3.42 | -- | 2743.90 | 3.42 | -- |
| **1.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 18667.33 | 12.48 | 20470.70 | 14.86 | 1.097 | 20505.94 | 13.02 | 1.098 |
| 1 | 18277.74 | 12.97 | 20470.70 | 14.86 | 1.120 | 20505.94 | 13.02 | 1.122 |
| 3 | 21623.44 | 13.22 | 23735.00 | 14.49 | 1.098 | 23800.45 | 15.33 | 1.101 |
| 4 | 6771.83 | 3.77 | 7123.82 | 6.16 | 1.052 | 7146.92 | 6.29 | 1.055 |
| 4 | 6755.43 | 3.84 | 7123.82 | 6.16 | 1.055 | 7146.92 | 6.29 | 1.058 |
| **3.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 15605.71 | 11.58 | 16826.88 | 12.66 | 1.078 | 16870.70 | 12.51 | 1.081 |
| 3 | 22432.73 | 14.87 | 24339.76 | 16.49 | 1.085 | 24409.68 | 16.57 | 1.088 |
| 4 | 15296.51 | 9.88 | 16324.87 | 11.63 | 1.067 | 16394.22 | 12.50 | 1.072 |

| NPOD1 config. | MEASURED R2 | MEASURED σ(R2) | MCNP5 R2 | MCNP5 σ(R2) | MCNP5 C/E | MCNP6 R2 | MCNP6 σ(R2) | MCNP6 C/E |
|---|---|---|---|---|---|---|---|---|
| **BARE BeRP** | | | | | | | | |
| 1 | 1592.80 | 21.01 | 1823.41 | 24.64 | 1.145 | 1872.95 | 44.38 | 1.176 |
| 1 | 1603.80 | 17.51 | 1823.41 | 24.64 | 1.137 | 1872.95 | 44.38 | 1.168 |
| 3 | 1624.80 | 18.81 | 1908.58 | 22.30 | 1.175 | 1753.32 | 22.40 | 1.079 |
| 4 | 3.37 | 1.93 | -- | -- | -- | 0.04 | 0.36 | 0.012 |
| **0.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 3671.10 | 27.91 | 4204.77 | 35.70 | 1.145 | 4276.36 | 37.39 | 1.165 |
| 1 | 3684.80 | 31.07 | 4204.77 | 35.70 | 1.141 | 4276.36 | 37.39 | 1.161 |
| 3 | 3711.30 | 31.65 | 4383.80 | 39.24 | 1.181 | 4446.63 | 44.32 | 1.198 |
| 4 | 13.04 | 5.20 | 8.84 | 4.90 | 0.678 | 6.14 | 3.74 | 0.471 |
| **1.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 7961.10 | 49.31 | 9597.47 | 62.02 | 1.206 | 9627.04 | 64.51 | 1.209 |
| 3 | 9037.20 | 82.29 | 10975.57 | 92.45 | 1.214 | 10925.03 | 107.29 | 1.209 |
| 4 | -- | -- | 209.12 | 27.05 | -- | 232.46 | 28.93 | -- |
| **1.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 14393.00 | 93.69 | 17773.22 | 98.63 | 1.235 | 18067.36 | 111.46 | 1.255 |
| 1 | 13760.00 | 218.88 | 17773.22 | 98.63 | 1.292 | 18067.36 | 111.46 | 1.313 |
| 3 | 18863.00 | 206.05 | 23811.67 | 241.62 | 1.262 | 24044.95 | 287.15 | 1.275 |
| 4 | 1778.80 | 113.88 | 2124.66 | 136.81 | 1.194 | 2140.61 | 128.11 | 1.203 |
| 4 | 1763.90 | 121.74 | 2124.66 | 136.81 | 1.205 | 2140.61 | 128.11 | 1.214 |
| **3.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 14652.87 | 299.14 | 18342.37 | 333.16 | 1.252 | 18337.33 | 369.41 | 1.251 |
| 3 | 30382.37 | 249.81 | 38720.67 | 348.13 | 1.274 | 38511.92 | 352.58 | 1.268 |
| 4 | 13793.63 | 603.62 | 17480.07 | 641.77 | 1.267 | 17719.54 | 649.79 | 1.285 |

# Results - leakage multiplication

| NPOD1 | MEASURED | | MCNP5 | | | MCNP6 | | |
|---|---|---|---|---|---|---|---|---|
| config. | $M_L$ | $\sigma(M_L)$ | $M_L$ | $\sigma(M_L)$ | C/E | $M_L$ | $\sigma(M_L)$ | C/E |
| **BARE BeRP** | | | | | | | | |
| 1 | 3.426 | 0.194 | 3.545 | 0.202 | 1.035 | 3.598 | 0.222 | 1.050 |
| 1 | 3.431 | 0.190 | 3.545 | 0.202 | 1.033 | 3.598 | 0.222 | 1.049 |
| 3 | -- | -- | 3.618 | 0.203 | -- | 3.464 | 0.195 | -- |
| 4 | -- | -- | -- | -- | -- | 0.572 | 0.346 | -- |
| **0.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 3.991 | 0.123 | 4.123 | 0.129 | 1.033 | 4.152 | 0.130 | 1.040 |
| 1 | 4.003 | 0.124 | 4.123 | 0.129 | 1.030 | 4.152 | 0.130 | 1.037 |
| 3 | 3.982 | 0.124 | 4.170 | 0.131 | 1.047 | 4.193 | 0.134 | 1.053 |
| 4 | 1.241 | 0.208 | 1.150 | 0.248 | 0.926 | 1.016 | 0.220 | 0.818 |
| **1.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 5.254 | 0.139 | 5.528 | 0.148 | 1.052 | 5.522 | 0.148 | 1.051 |
| 3 | 5.397 | 0.151 | 5.696 | 0.158 | 1.055 | 5.676 | 0.161 | 1.052 |
| 4 | -- | -- | 2.230 | 0.174 | -- | 2.326 | 0.178 | -- |
| **1.5" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 6.912 | 0.232 | 7.318 | 0.243 | 1.059 | 7.370 | 0.247 | 1.066 |
| 1 | 6.833 | 0.260 | 7.318 | 0.243 | 1.071 | 7.370 | 0.247 | 1.079 |
| 3 | 7.334 | 0.262 | 7.846 | 0.278 | 1.070 | 7.872 | 0.286 | 1.073 |
| 4 | 4.151 | 0.247 | 4.405 | 0.264 | 1.061 | 4.413 | 0.255 | 1.063 |
| 4 | 4.139 | 0.256 | 4.405 | 0.264 | 1.064 | 4.413 | 0.255 | 1.066 |
| **3.0" HDPE REFLECTED BeRP** | | | | | | | | |
| 1 | 9.487 | 0.471 | 10.201 | 0.495 | 1.075 | 10.186 | 0.504 | 1.074 |
| 3 | 11.339 | 0.496 | 12.266 | 0.543 | 1.082 | 12.217 | 0.541 | 1.077 |
| 4 | 9.303 | 0.565 | 10.112 | 0.582 | 1.087 | 10.159 | 0.585 | 1.092 |

# Discussion

# Conclusion

- Except in very poor statistical situations, both codes performed well at simulating list-mode data
- The results may improve with the use of a new, more detailed NPOD model

# MCNP5 for list-mode data generation

- The list-mode patch was developed specifically for replicating passive subcritical measurements
- It works via a modification of the SOURCE and TALLYX subroutines and does not touch the main structure of the code
- Internal use only - not distributed in the RSICC package
- Nubar is hard-coded in the subroutine

# MCNP6 and the use of PTRAC for list-mode data generation

- MCNP6's PTRAC option is not the most ideal method for obtaining list-mode data
  - Cannot run in parallel; cannot do a continue-run
    - Forced parallel processing via `pstudy`
  - Large output files (GB)
    - Simulation run time is longer(than MCNP5 w/patch)
    - Bunch of irrelevant data to sift through
    - Keywords are important in reducing output file size
  - File must be written in binary

However, we have been able to prove that MCNP6 is indeed capable of providing accurate list-mode data

- This work, along with the development of the mcnptools package, has allowed for the use of MCNP6 for benchmark-quality subcritical calculations
- A benchmark study is currently underway, led by Benoit Richard, utilizing MCNP6's capabilities
- Benoit will be presenting details of a recently completed benchmark study at 2:15pm today during the Nuclear Criticality Safety III session in Grand Ballroom South A

# Acknowledgements

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# Thanks!