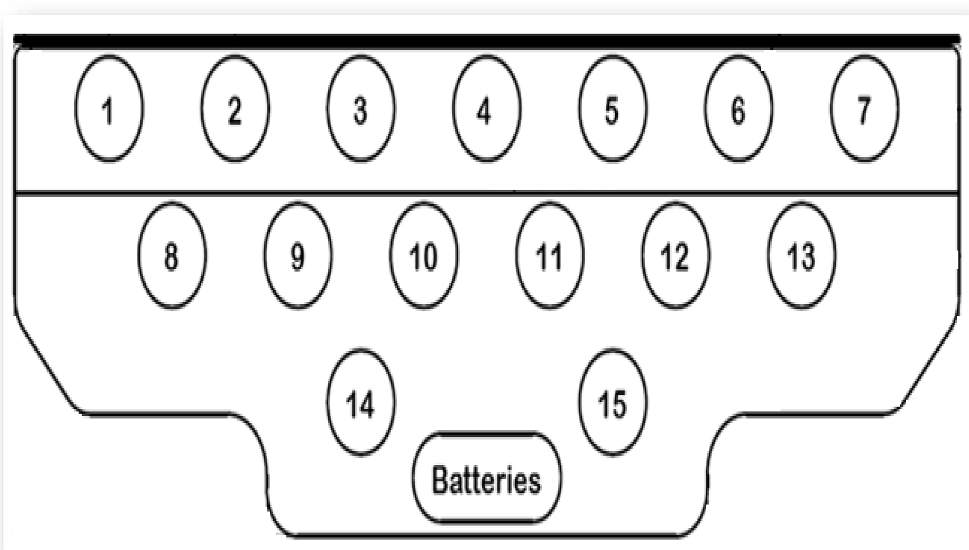
Characterization of MC-15 neutron multiplicity detector response using MCNP6

G.A. Sandler, University of Florida; S.D. Kiff, Sandia National Laboratories
PI: Dr. James Baciak, University of Florida
Consortium for Verification Technology (CVT)

Introduction

♦The MC-15 is a neutron multiplicity detector utilized to characterize objects containing special nuclear material (SNM). It consists of 15 ^{3}He tubes inside a body of high density polyethylene (HDPE) and is used to measure properties of an unknown object, such as its SNM mass and its neutron multiplication.



MC-15 Schematic

♦"Row ratios" are used to estimate the thickness and hydrogen content of neutron moderation around a source.

♦Accurate calculations of mass and multiplication require accurate knowledge of the MC-15 detector efficiency (ε).

♦Both the detachable panel and cadmium sheet are currently being explored for their possible benefits, using row ratios and detector efficiency as performance metrics.

♦Changes in the neutron energy distribution will not only change the number of reactions inside of the ^{3}He tubes, but also will change the calculated MC-15 row ratios due to the relative changes in neutron counts in each ^{3}He tube. Correlating the effect of varying neutron energy on the row ratios was performed with Monte Carlo simulations (using MCNP6) and experimental data.

MCNP6 Simulations

♦Mono-energetic sources ranged from 1E-08 to 14 MeV.

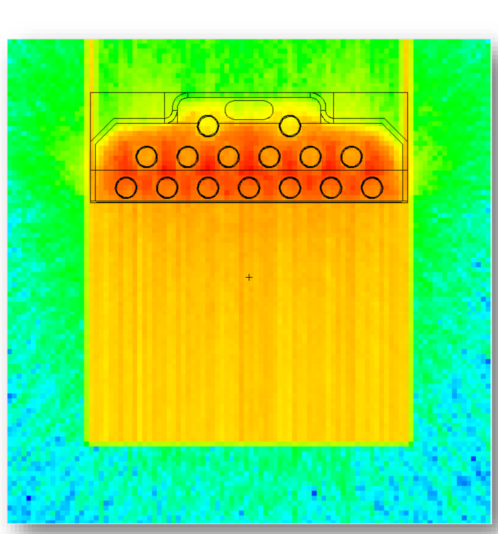
♦Neutron source placed 30 cm from MC-15.

♦Three directional source trials; Front source, side source, back source.

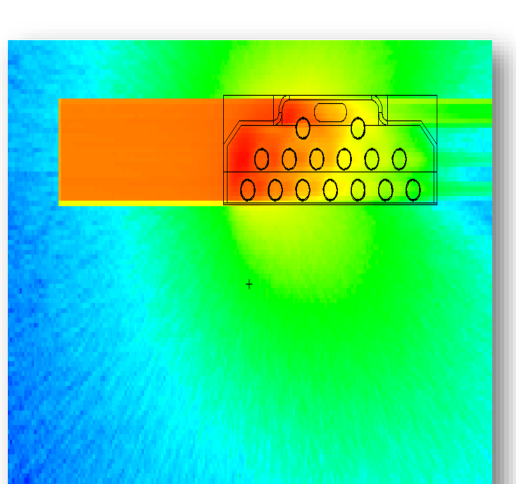
♦Simulations were performed to investigate the addition of a second MC-15 placed 5 cm back of the neutron source (detector crosstalk).

♦Extra side source simulations run with two MC-15s oriented face-to-face. Cf-252 source with varying HDPE moderation was then used in simulations and experimentation (50 cm between source and detector).

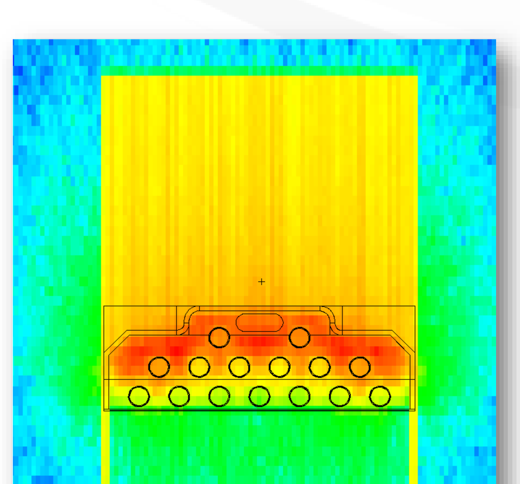
♦Experimental results with a D-T neutron generator were compared with simulations of a 14 MeV neutron source.



Front Source Trial

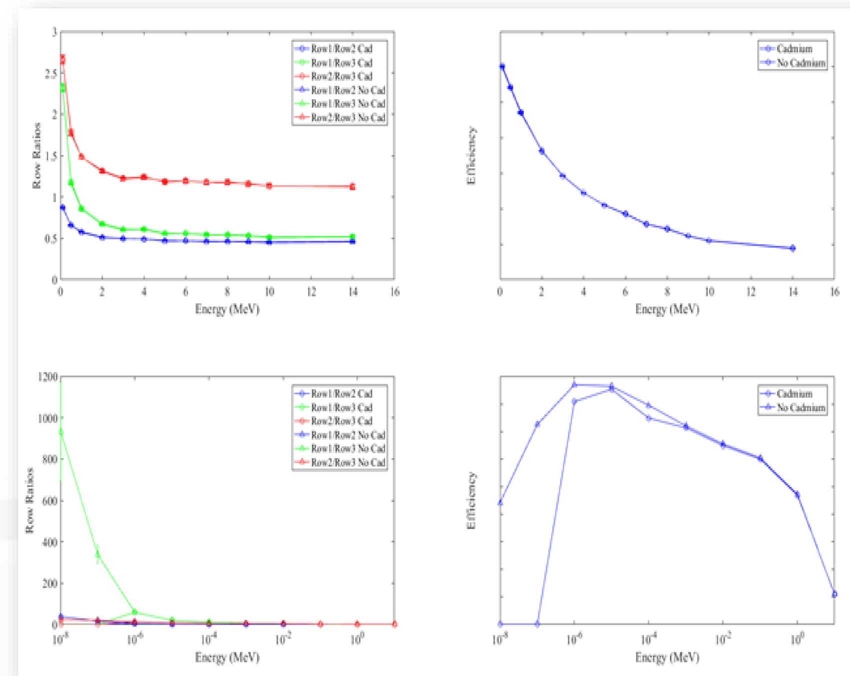


Side Source Trial

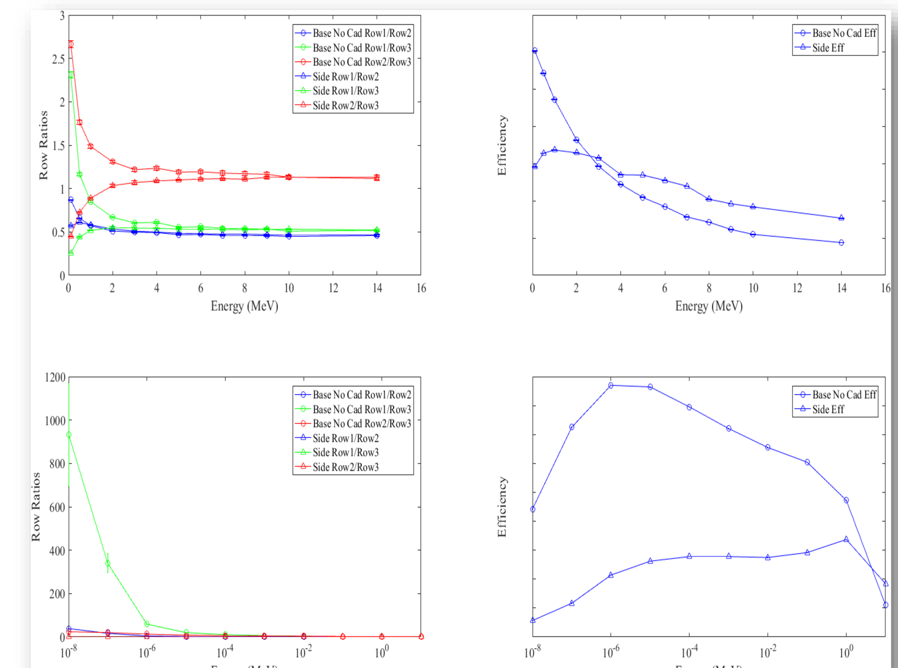


Back Source Trial

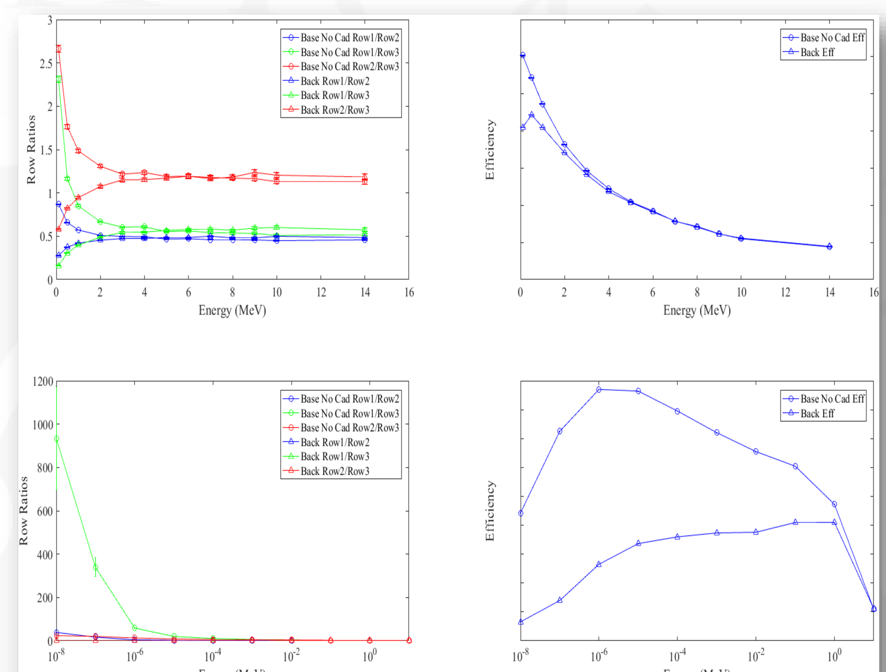
Simulation Results



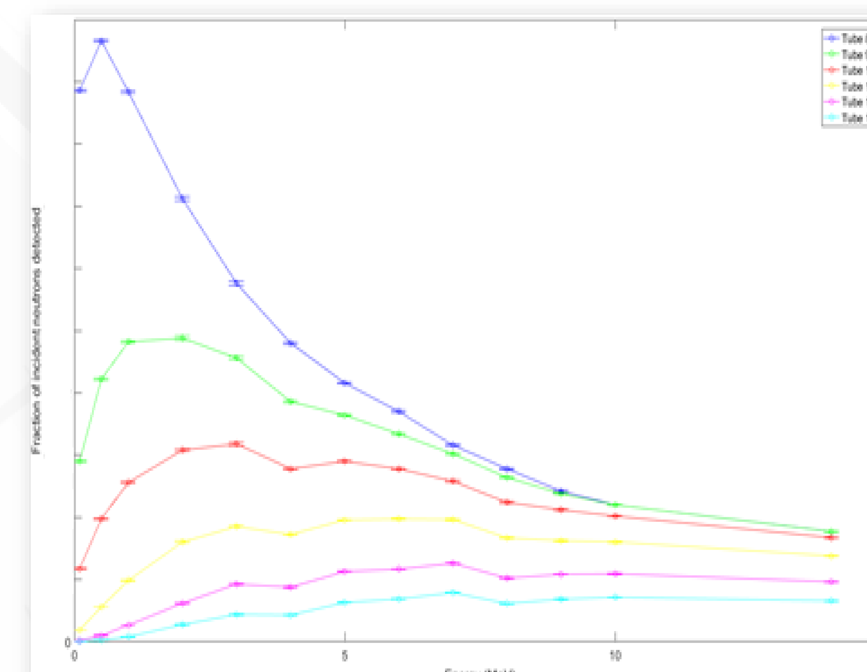
Baseline geometry, cadmium vs. no cadmium comparison



Comparison of base case vs side case



Comparison of base case vs back case



Alternate row analysis (side source simulation)

Row count dominance as a function of neutron energy (baseline geometry)

Neutron Energy Range (MeV)	Row Count Dominance
E < 0.01	Row1 > Row2 > Row3
0.01 < E < 0.7	Row2 > Row1 > Row3
E > 0.7	Row2 > Row3 > Row1

Row ratios as a function of high neutron energies (baseline geometry)

Neutron Energy (MeV)	Row1:Row2	Row1:Row3	Row2:Row3
5	0.476	0.562	1.181
14	0.466	0.524	1.123
100	0.464	0.522	1.125

Addition of MC-15 with side source and front source

Energy (MeV)	$\frac{\varepsilon\,(2\ MC-15s)}{\varepsilon\,(1\ MC-15)}$ Surface leaking	$\frac{\varepsilon\,(2\ MC-15s)}{\varepsilon\,(1\ MC-15)}$ Cross-talk	Energy (MeV)	$\frac{\varepsilon\,(2\ MC-15s)}{\varepsilon\,(1\ MC-15)}$ Surface leaking	$\frac{\varepsilon\,(2\ MC-15s)}{\varepsilon\,(1\ MC-15)}$ Cross-talk
1E-08	109.58%	108.77%	2	111.96%	104.20%
1E-07	107.29%	104.29%	3	113.12%	104.76%
0.000001	105.48%	102.84%	4	114.66%	106.15%
0.00001	105.18%	102.21%	5	115.28%	104.12%
0.0001	105.86%	103.45%	6	115.07%	103.84%
0.001	106.22%	104.06%	7	115.92%	104.11%
0.01	106.87%	104.88%	8	116.73%	105.72%
0.1	108.02%	105.05%	9	116.34%	105.36%
0.5	109.19%	104.43%	10	117.26%	105.08%
1	110.77%	104.81%	14	117.61%	103.63%

Experimental Results

Side source experiment results

HDPE Thickness (cm)	Exp/ MCNP	Tube 8	Tube 9	Tube 10	Tube 11	Tube 12	Tube 13
0	Exp	42.86%	24.45%	14.00%	8.26%	5.57%	4.86%
0	MCNP	42.90%	24.26%	14.06%	8.37%	5.64%	4.78%
2	Exp	45.65%	23.27%	12.89%	7.89%	5.28%	5.02%
2	MCNP	45.87%	22.91%	13.13%	7.91%	5.35%	4.84%
4	Exp	47.08%	22.46%	12.43%	7.54%	5.28%	5.21%
4	MCNP	47.49%	22.21%	12.50%	7.58%	5.32%	4.90%
8	Exp	48.60%	21.70%	11.72%	7.29%	5.24%	5.46%
8	MCNP	48.37%	21.38%	12.58%	7.39%	5.24%	5.04%

D-T neutron generator and 14 MeV MCNP results

Exp/MCNP	Detector	Cadmium	Row 1:2	Row 1:3	Row 2:3
Exp	Off Floor	Yes	0.672	0.818	1.217
Exp	On Floor	Yes	0.691	0.830	1.202
MCNP	Off Floor	Yes	0.504	0.554	1.099
Exp	Off Floor	No	0.789	0.961	1.218
Exp	On Floor	No	0.833	1.006	1.208
MCNP	Off Floor	No	0.505	0.562	1.113

Conclusion

♦For a source in front of the detector, the first row will dominate at energies lower than 10 keV. At higher energies, the second row will be the most prominent at neutron detection. Row ratios tend to remain constant at energies above 3-4 MeV.

♦For a source placed to the side, redefining the row ratio to include the end tube in the second row may provide more information on the neutron energy spectrum.

♦Placing a cadmium sheet on the front of the MC-15 can suppress the contribution of neutrons that were thermalized by the environment surrounding the SNM and detector.

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