LA-UR-14-25697
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Title: Verification of the MCNP6 FMESH Tally

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Intended for: 2014 LANL Student Symposium

Issued: 2014-09-10 (rev.1)

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LANL Student Symposium

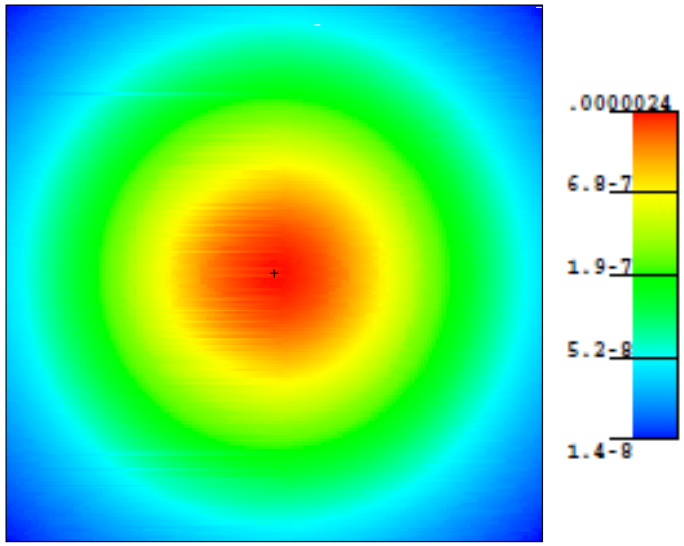
August 5-6, 2014

What is MCNP6?

- "Monte Carlo N-Particle"
- Monte Carlo physics code
  - Conducts statistical sampling of simulated particles (neutrons, photons, electrons, and combination of all three)
  - Tallies: Surface current & flux, volume flux, mesh tallies, heating, etc.
  - Applications vary from criticality calculations to radiation shielding design to radiography

What is an FMESH Tally?

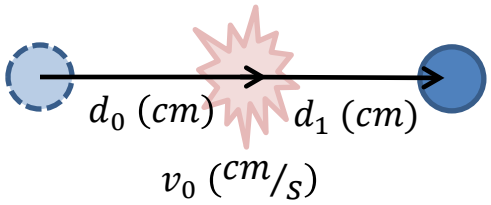
- FMESH tally places mesh over a geometry and tallies volumetric flux in each voxel
  - Useful for imaging applications (e.g. radiography, medical imaging)
  - Can be binned in time, energy, or both
  - Volumetric flux = Total particle track length divided by voxel volume
- Has fewer statistical checks than other MCNP6 tallies
  - Verification work important to ensure proper physics, statistics



Overview of Verification of FMESH Tally

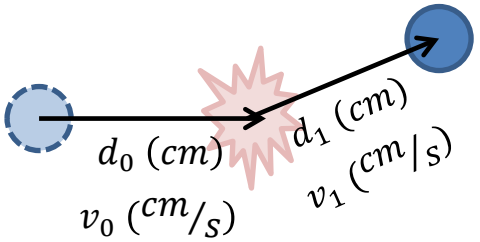
- FMESH tally binned in time to simulate neutron time of flight (TOF) for single scatters
- For verification, compare FMESH results to:
  - Analytic calculations of neutron time of flight (TOF)
    - Checks physics
  - F4 tally results
    - Calculates flux in same way as FMESH tally
    - Checks statistics

Direct Neutron TOF



$$TOF\ (s) = \frac{d_0 + d_1}{v_0}$$

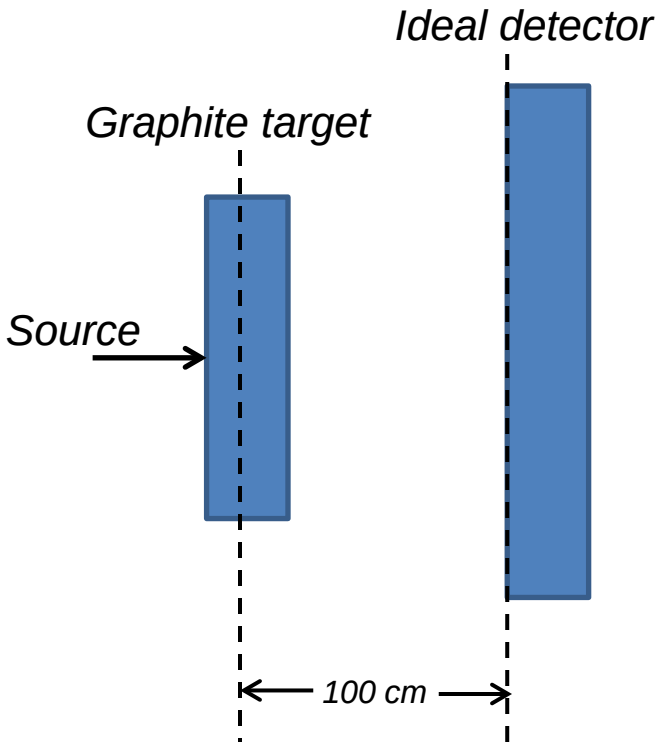
Scattered Neutron TOF



$$TOF\ (s) = \frac{d_0}{v_0} + \frac{d_1}{v_1}$$

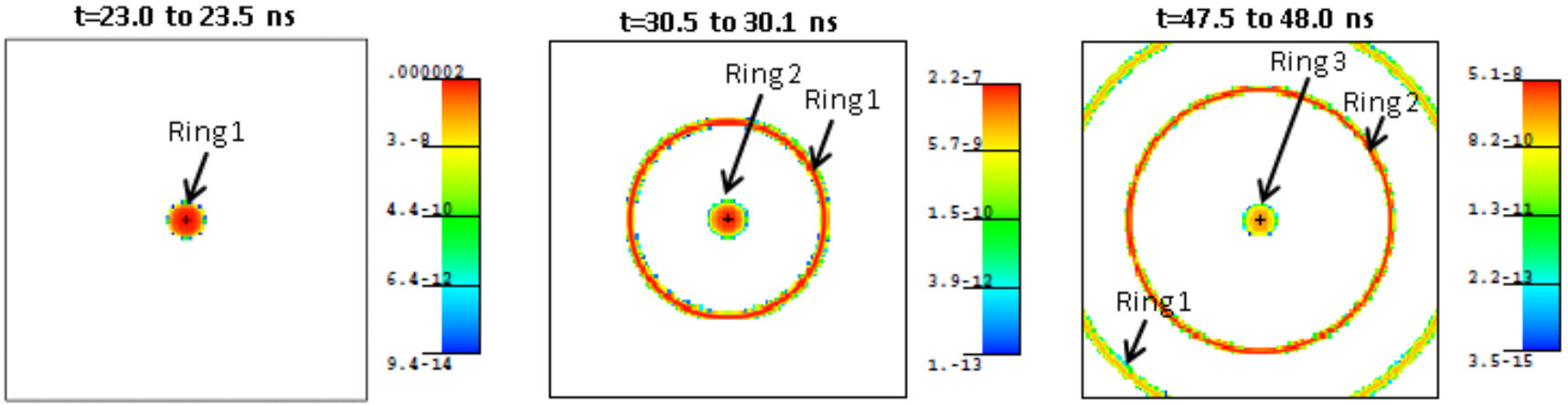
Overview of MCNP6 FMESH Tally

- Generic geometry modeled in MCNP6
  - Monoenergetic pencil beam neutron source (E=10.2 MeV, NPS=1x10^9)
  - Graphite target (100 x 100 x 5 cc)
  - Ideal detector (150 x 150 x 5 cc)
- FMESH tally on detector face
  - 5 x 2 x 2 cc voxel volume
  - Time bins of 0.5 ns
  - Provide time behavior of neutrons undergoing single scatter in graphite target



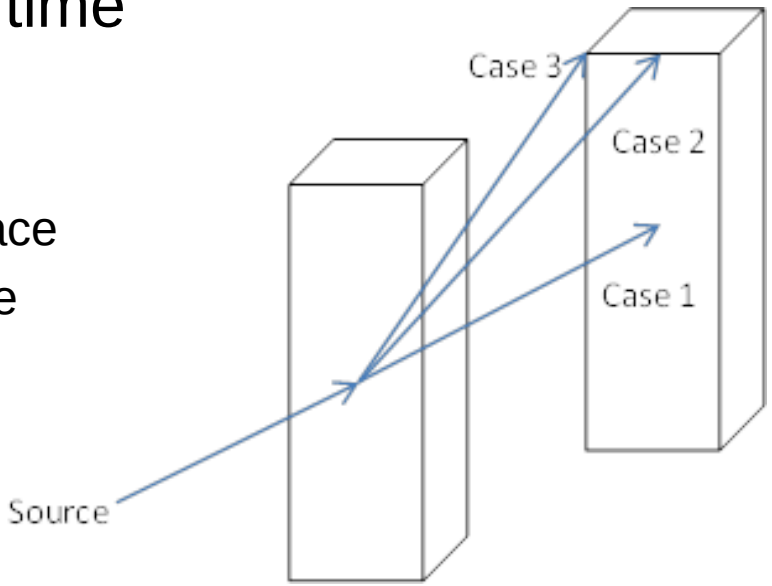
Simulated Physics for FMESH Verification

- Rings appear at 3 different times on detector face
  - Slower neutrons have a greater scattering angle, arrive later in time
    Ring shape is a result of geometry symmetry
  - Ring 1 = direct neutrons, Ring 2,3 = scattered neutrons
- Will serve as basis of verification



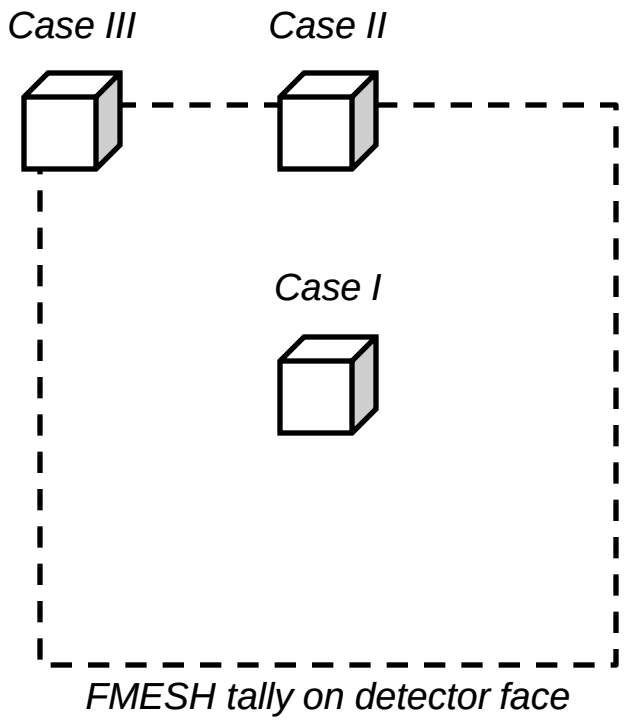
Overview of Analytic Calculations

- Three locations on detector face chosen to characterize growth in time of rings
  - Case 1: Center of detector face
  - Case 2: Center of top edge of detector face
  - Case 3: Upper left corner of detector face
- Two locations of single scatter
  - Front face of target
  - Back face of target
- Two types of non-relativistic scatter
  - Elastic
  - Inelastic



Overview of MCNP6 F4 Tally

- Like the FMESH tally, the F4 tally calculates volumetric fluence
  - Additional verification of FMESH tally
  - Fluence in cells (vs. FMESH voxels)
- Three F4 cell tallies similar to the FMESH tally:
  - Cell volume (5 x 2 x 2 cc)
  - Location (Case I, II, and III)
  - Time binning (0.5 ns bin width)
  - Particles immediately killed
  - 30 x 10^9 number of neutrons simulated



Comparison of FMESH Simulations and Analytic Results

RING 1	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error
Front of target scatter	Case I	23.2	23.0 to 23.5	–
	Case II	42.7	42.5 to 43.0	–
	Case III	54.4	55.5 to 56.0	+2.0%
Back of target scatter	Case I	23.2	23.0 to 23.5	–
	Case II	43.3	42.5 to 43.0	-0.7%
	Case III	55.1	55.5 to 56.0	+0.7%

Comparison of FMESH Simulations and Analytic Results (cont'd.)

RING 2	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error
Front of target scatter	Case I	31.1	30.5 to 31.0	-0.3%
	Case II	58.0	57.5 to 58.0	–
	Case III	73.4	75.5 to 76.0	+2.9%
Back of target scatter	Case I	30.7	30.5 to 31.0	–
	Case II	58.3	57.5 to 58.0	-0.5%
	Case III	73.9	75.5 to 76.0	+2.1%

Comparison of FMESH Simulations and Analytic Results (cont'd.)

RING 3	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error
Front of target scatter	Case I	49.1	47.5 to 48.0	-2.3%
	Case II	94.8	87.0 to 87.5	-7.7%
	Case III	117.9	113.5 to 114.0	-3.3%
Back of target scatter	Case I	47.8	47.5 to 48.0	–
	Case II	94.8	87.0 to 87.5	-7.7%
	Case III	118.1	113.5 to 114.0	-3.5%

Comparison of FMESH Simulations and F4 Simulations

	Location	F4 TOF (ns)	FMESH TOF (ns)	Percent Error
Ring 1	Case I	23.0 to 23.5	23.0 to 23.5	–
	Case II	42.5 to 43.0	42.5 to 43.0	–
	Case III	55.5 to 56.0	55.5 to 56.0	–
Ring 2	Case I	30.5 to 31.0	30.5 to 31.0	–
	Case II	57.5 to 58.0	57.5 to 58.0	–
	Case III	75.5 to 76.0	75.5 to 76.0	–
Ring 3	Case I	47.5 to 48.0	47.5 to 48.0	–
	Case II	86.5 to 87.0	87.0 to 87.5	+0.6%
	Case III	112.5 to 113.0	113.5 to 114.0	+0.9%

Comparison of FMESH Simulations and F4 Simulations

	Location	F4 Rel. Error (%)	FMESH Rel. Error (%)
Ring 1	Case I	0.07	0.07
	Case II	1.72	1.59
	Case III	24.32	12.14
Ring 2	Case I	0.44	0.19
	Case II	1.29	0.95
	Case III	10.84	4.99
Ring 3	Case I	4.67	0.92
	Case II	67.20	100.0
	Case III	78.76	100.0

Conclusions

- Very good agreement between FMESH tally results and F4 tally results
  - Maximum error of 0.9%
- FMESH tally results and analytic results do not match as well
  - Maximum error of 7.7%
  - Error increases as ring number increases (Ring 1 < Ring 2 < Ring 3)
- Overall, FMESH seems to be operating properly

Ongoing and Future Work

- Ongoing work to reduce error and improve agreement between results:
  - Improve MCNP statistics
    - Simulate more particles
    - Change geometry (thinner target, smaller detector)
    - Perhaps variance reduction?
  - Calculate relativistic TOF
- Future work can be expanded to include:
  - Additional particle types
  - Additional interactions, such as (n,f)
  - More complicated geometries

Questions?