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Title: A Verification of MCNP6 FMESH Tally Capabilities

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A Verification of MCNP6 FMESH Tally Capabilities

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2014 ANS Winter Meeting

November 9-13, 2014

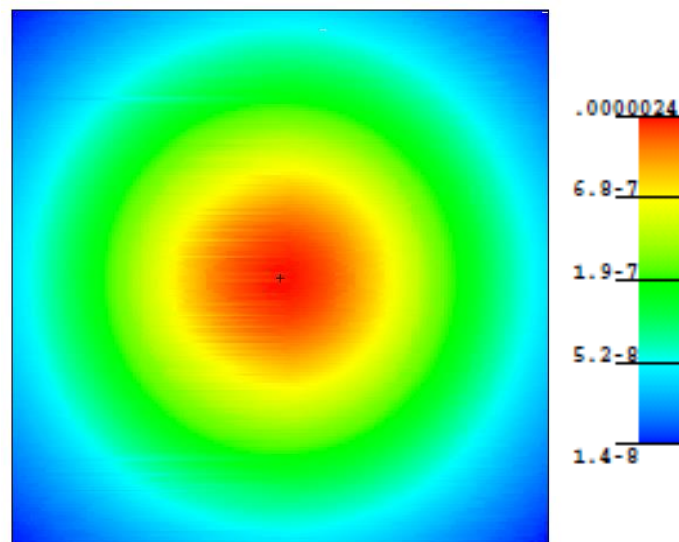
What is MCNP6?

- “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

mcnp

What is an FMESH Tally?

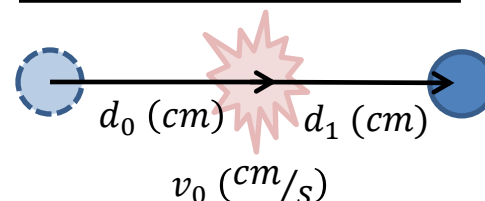
- FMESH tally places mesh over a geometry and tallies volumetric flux in each voxel
 - Useful for imaging applications (e.g. radiography, medical imaging)
 - Can be binned in time, energy, or both
 - Volumetric flux = Total particle track length divided by voxel volume
- Has fewer statistical checks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



Overview of Verification of FMESH Tally

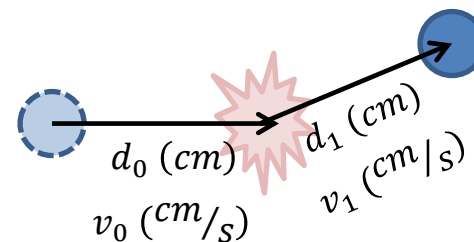
- FMESH tally binned in time to simulate neutron time of flight (TOF) for single scatters
- For verification, compare FMESH results to:
 - Analytic calculations of neutron time of flight (TOF)
 - Checks physics
 - F4 tally results
 - Like FMESH, the F4 tally also finds volumetric flux
 - Checks statistics

Direct Neutron TOF



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

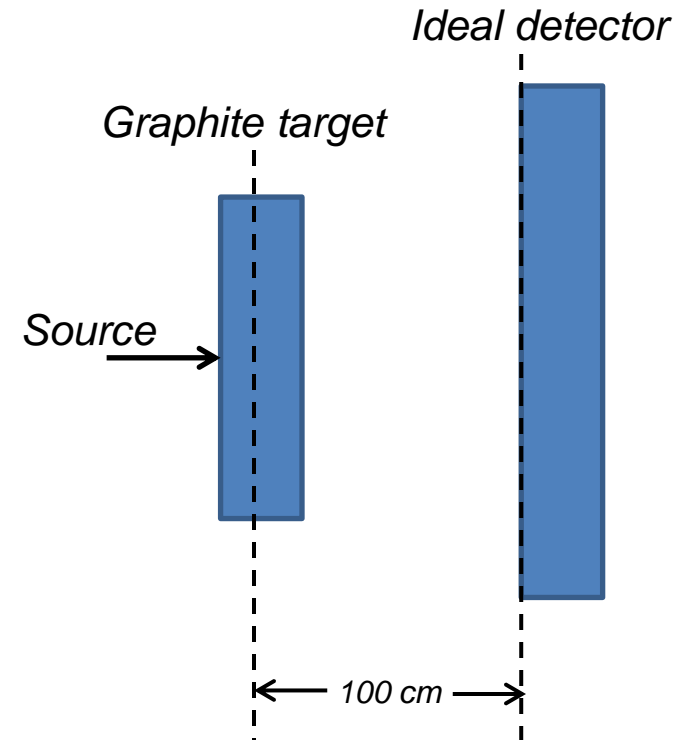
Scattered Neutron TOF



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

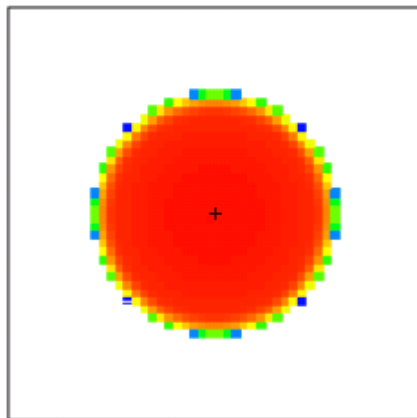
Overview of MCNP6 FMESH Tally

- Generic geometry modeled in MCNP6
 - Monoenergetic pencil beam neutron source ($E=10.2$ MeV, $NPS=100 \times 10^9$)
 - Graphite target ($5 \times 50 \times 50$ cc)
 - Ideal detector ($5 \times 100 \times 100$ cc)
- FMESH tally on detector face
 - $7 \times 2 \times 2$ cc voxel volume
 - Time bins of 1.0 ns
 - Provide time behavior of neutrons undergoing single scatter in graphite target

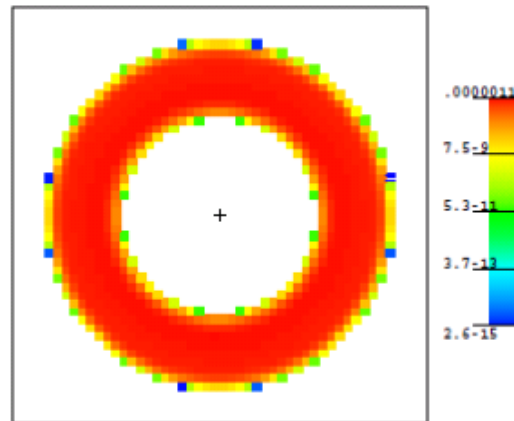


Simulated Physics for FMESH Verification

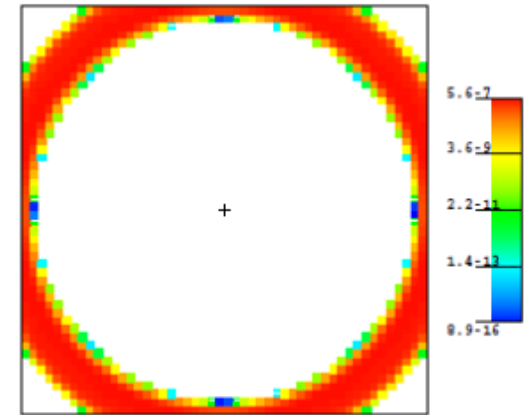
- Results: Rings appear at 3 different times on detector face
 - Slower neutrons have a greater scattering angle, arrive later in time
 - Ring shape is a result of geometry symmetry
 - Ring 1 = direct neutrons, Ring 2,3 = scattered neutrons
- Will serve as basis of verification



23.0 to 24.0 ns



24.0 to 25.0 ns



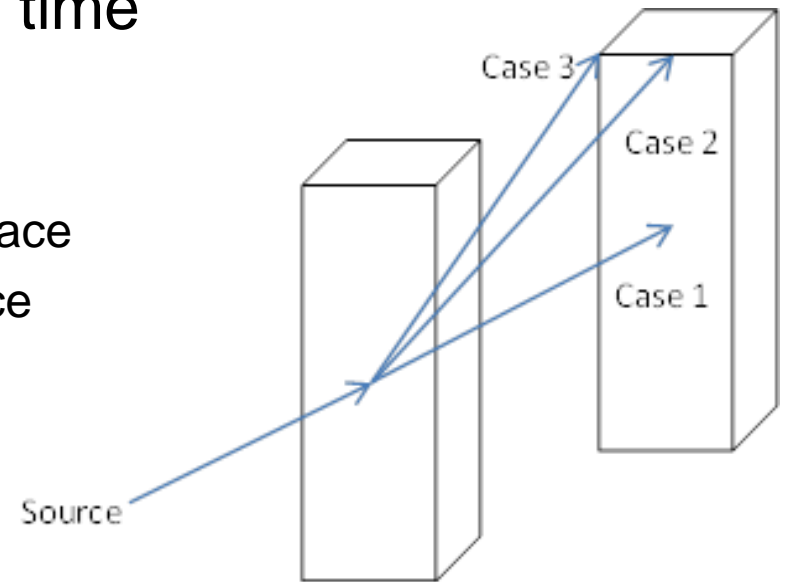
26.0 to 27.0 ns

RING 1 – ELASTIC SCATTER

UNCLASSIFIED

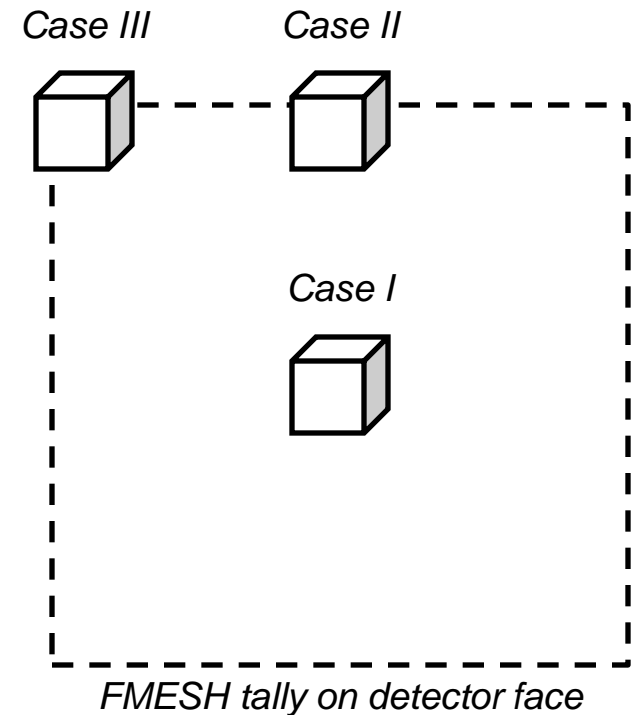
Overview of Analytic Calculations

- 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 (7 x 2 x 2 cc)
 - Location (Case I, II, and III)
 - Time binning (1.0 ns bin width)
 - Particles immediately killed
 - 100×10^9 number of neutrons simulated



Comparison of FMESH Simulations and Analytic Results

<u>RING 1</u>	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error (%)
Front of target scatter	Case I	23.0	23.0 to 24.0	—
	Case II	25.9	25.0 to 26.0	—
	Case III	28.5	28.0 to 29.0	—
Back of target scatter	Case I	23.0	23.0 to 24.0	—
	Case II	25.9	25.0 to 26.0	—
	Case III	28.6	28.0 to 29.0	—

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

<u>RING 2</u>	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error (%)
Front of target scatter	Case I	30.8	30.0 to 31.0	—
	Case II	34.7	34.0 to 35.0	—
	Case III	38.3	37.0 to 38.0	-0.8
Back of target scatter	Case I	30.6	30.0 to 31.0	—
	Case II	34.6	34.0 to 35.0	—
	Case III	38.3	37.0 to 38.0	-0.8

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

<u>RING 3</u>	Location	Analytic TOF (ns)	FMESH TOF (ns)	Percent Error (%)
Front of target scatter	Case I	48.6	47.0 to 48.0	-1.2
	Case II	55.3	53.0 to 54.0	-2.4
	Case III	61.3	58.0 to 59.0	-3.8
Back of target scatter	Case I	47.8	47.0 to 48.0	—
	Case II	54.7	53.0 to 54.0	-1.3
	Case III	60.9	58.0 to 59.0	-3.1

Comparison of FMESH Simulations and F4 Simulations

	Location	F4 TOF (ns)	FMESH TOF (ns)	Percent Error (%)
Ring 1	Case I	23.0 to 24.0	23.0 to 24.0	—
	Case II	25.0 to 26.0	25.0 to 26.0	—
	Case III	28.0 to 29.0	28.0 to 29.0	—
Ring 2	Case I	30.0 to 31.0	30.0 to 31.0	—
	Case II	34.0 to 35.0	34.0 to 35.0	—
	Case III	37.0 to 38.0	37.0 to 38.0	—
Ring 3	Case I	47.0 to 48.0	47.0 to 48.0	—
	Case II	53.0 to 54.0	53.0 to 54.0	—
	Case III	58.0 to 59.0	58.0 to 59.0	—

FMESH and F4 MCNP6-Generated Relative Error

FRONT OF TARGET	Location	F4 Rel. Error (%)	FMESH Rel. Error (%)
Ring 1	Case I	0.05	0.05
	Case II	0.08	0.08
	Case III	0.08	0.11
Ring 2	Case I	0.11	0.11
	Case II	0.13	0.15
	Case III	0.29	0.29
Ring 3	Case I	0.47	0.37
	Case II	15.43	15.75
	Case III	49.24	57.39

Conclusions

- Exact agreement between FMESH tally results and F4 tally results
- FMESH tally results and analytic results do not match as well
 - Maximum error of -3.8%
 - 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 for analytic comparison
- Future work can be expanded to include:
 - Additional particle types
 - Additional interactions, such as (n,f)
 - More complicated geometries

Questions?

Run times

- Input decks had NPS=5E9 and used script to continue run until a total of 100E9 particles were simulated
- 128 processors (8 nodes, 16 processors per node)
- F4 vs. FMESH run times
 - F4: 51,428.71 minutes (average of 2700 min per run)
 - FMESH: 36,995.06 minutes (average of 1950 min per run)

Other MCNP6 Imaging Tallies

- Detector Tallies (Tally Type 5) in the MCNP6 manual
 - F5 tally
 - Array of point or ring detectors
 - Especially prone to unreliable results due to limitations of the geometry
 - FIP tally
 - Pinhole image projection onto a planar grid
 - Mimics a pinhole camera and photographic film, with the pinhole set up as a point detector
 - FIR tally
 - Flux image on a rectangular radiograph planar grid
 - FIC tally
 - Flux image on a cylindrical radiograph grid

Other MCNP6 Imaging Tallies (cont'd.)

- TMESH vs. FMESH
 - TMESH was created for MCNPX, FMESH for MCNP5
 - Both allow the plotting of quantities besides flux (vs. the F5 tallies on the previous slide)
 - TMESH: Flux, dose, source mesh tally, energy deposition
 - FMESH: All of the above + time behavior, energy behavior, cell or surface flagging