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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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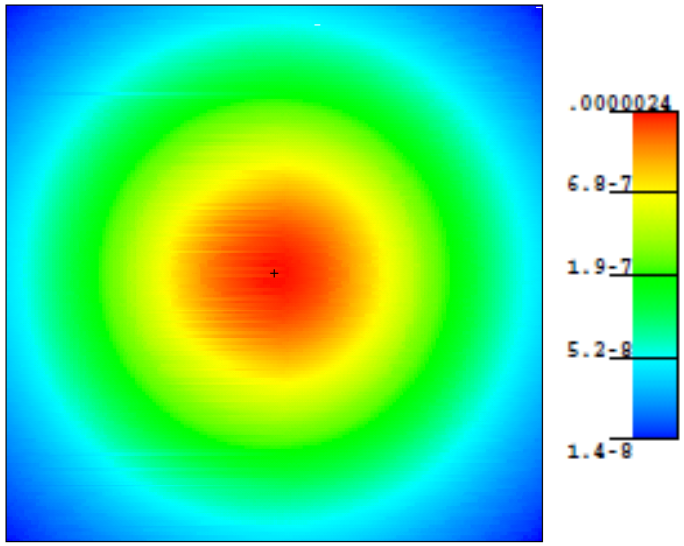
What is MCNP6?

- "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?

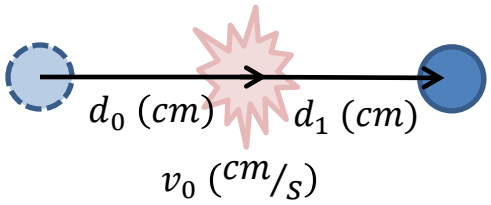
- FMESH tally places mesh over a geometry and tallies volumetric flux in each voxel
  - Useful for imaging applications (e.g. radiography, medical imaging)
  - Can be binned in time, energy, or both
  - Volumetric flux = Total particle track length divided by voxel volume
- Has fewer statistical checks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



Overview of Verification of FMESH Tally

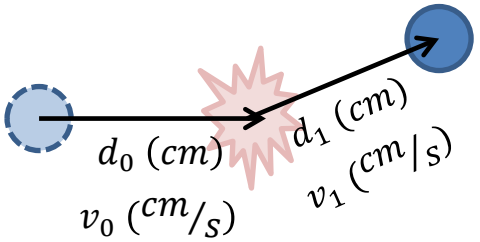
- FMESH tally binned in time to simulate neutron time of flight (TOF) for single scatters
- For verification, compare FMESH results to:
  - Analytic calculations of neutron time of flight (TOF)
    - Checks physics
  - F4 tally results
    - Like FMESH, the F4 tally also finds volumetric flux
    - Checks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

Direct Neutron TOF



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

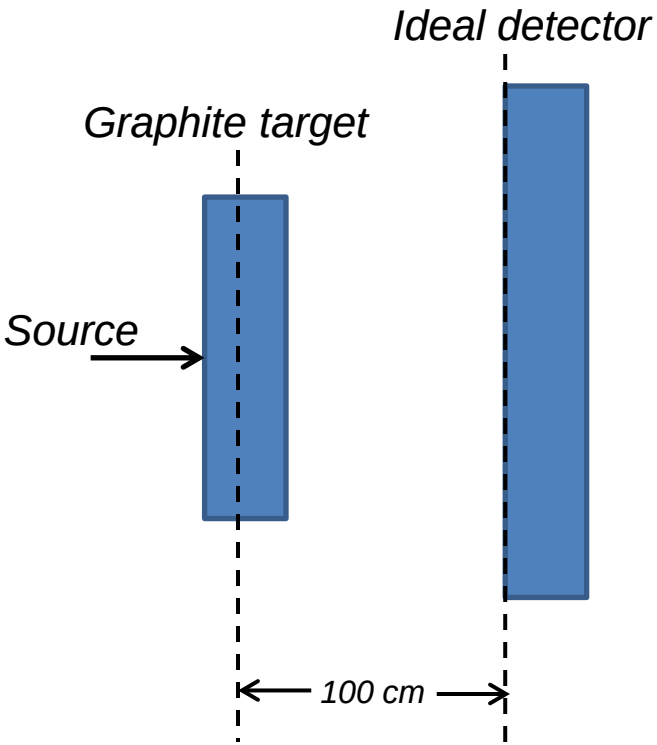
Scattered Neutron TOF



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

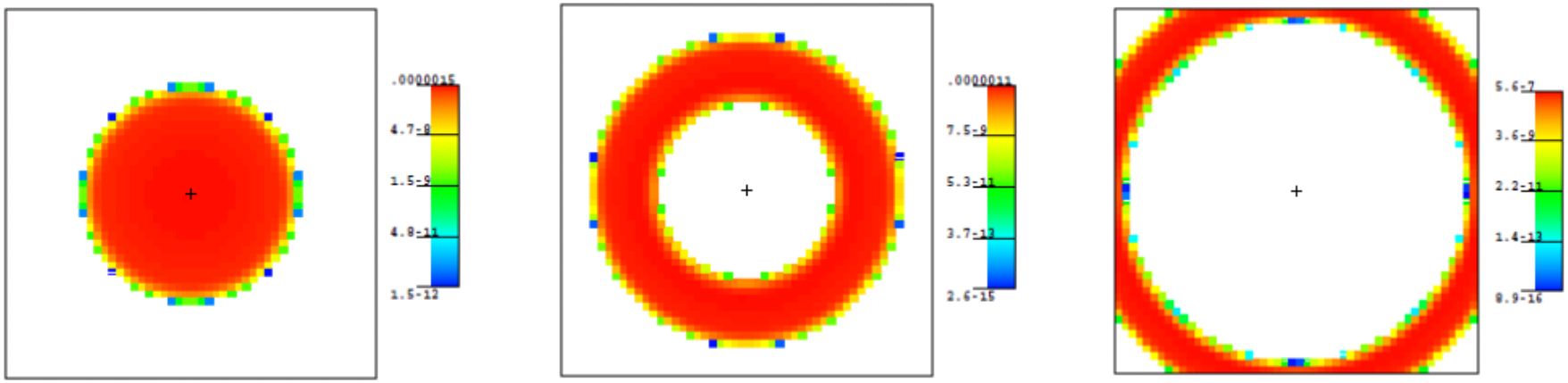
Overview of MCNP6 FMESH Tally

- Generic geometry modeled in MCNP6
  - Monoenergetic pencil beam neutron source (E=10.2 MeV, NPS=100x10^9)
  - Graphite target (5 x 50 x 50 cc)
  - Ideal detector (5 x 100 x 100 cc)
- FMESH tally on detector face
  - 7 x 2 x 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

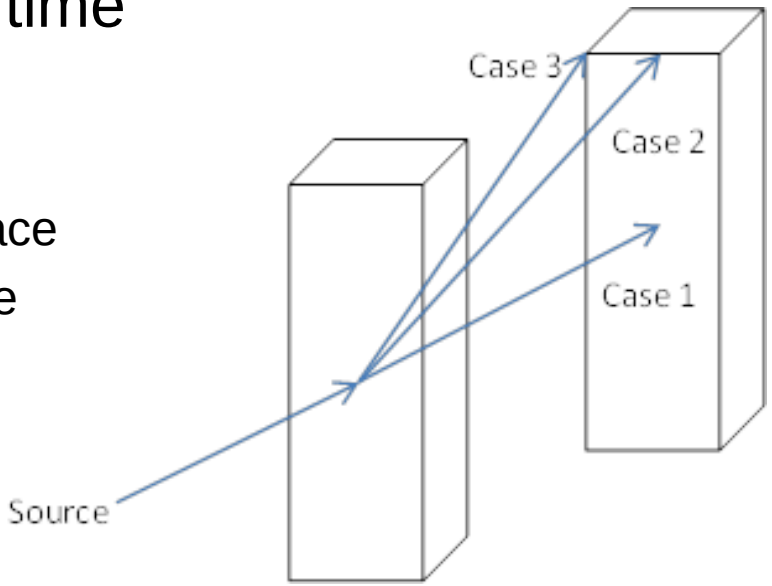


23.0 to 24.0 ns **24.0 to 25.0 ns** **26.0 to 27.0 ns**

RING 1 – ELASTIC SCATTER

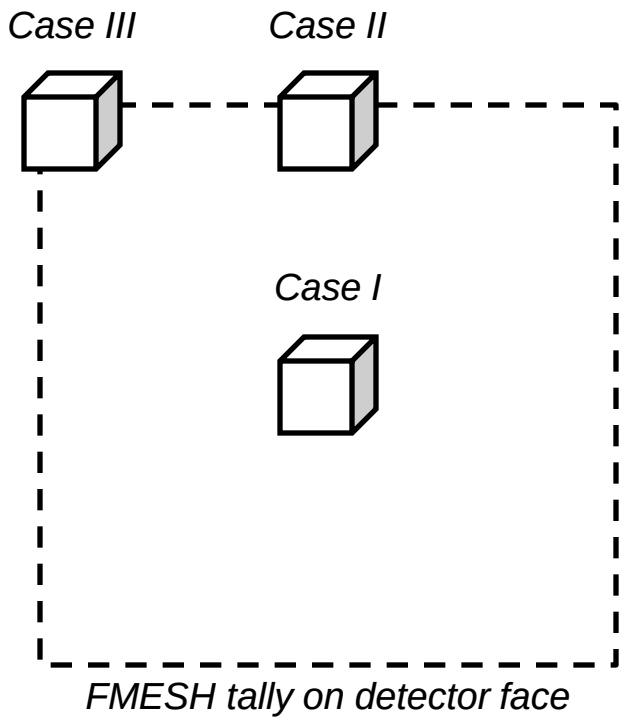
Overview of Analytic Calculations

- 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 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	23.0	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.)

RING 2	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.)

RING 3	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	–

Comparison of FMESH Simulations and F4 Simulations

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?