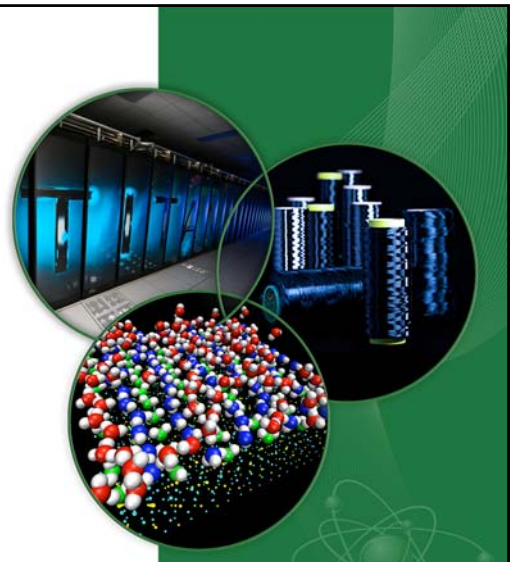
Comparison of ADVANTG Simulations to Simple Shielding Measurements



Douglas E. Peplow and Charles R. Daily
Reactor and Nuclear Systems Division
Oak Ridge National Laboratory

Thursday, September 18, 2014
18th Topical Meeting of the RPSD of the ANS
Knoxville, TN

ORNL is managed by UT-Battelle
for the US Department of Energy

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ADVANTG

- ADVANTG – **A**utomate**D** **VA**ria**N**ce reduc**T**ion **G**enerator
  - Uses results from deterministic calculation(s) to generate
    - Weight windows
    - Biased source(s)

    for MCNP
- Automated
  - Reads
    - MCNP input file
    - short text file with tally optimization parameters
  - Generates
    - wwinp file
    - modified MCNP input file with source biasing
- Variance Reduction – Consistent Adjoint Driven Importance Sampling
  - CADIS – accelerate a single tally
  - FW-CADIS – for multiple tallies or a mesh tally

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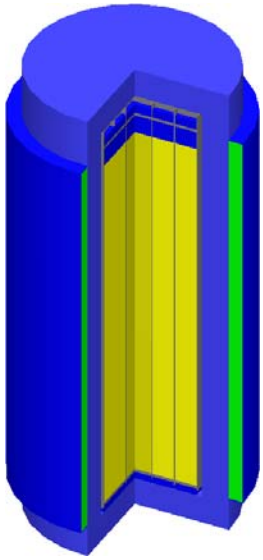
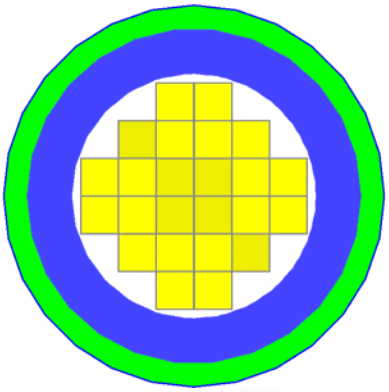
Example Problem: Simplified TN24P Cask



Spent fuel: neutrons and photons
Activated hardware: photons



Objective: Determine dose rates at various points outside of the cask

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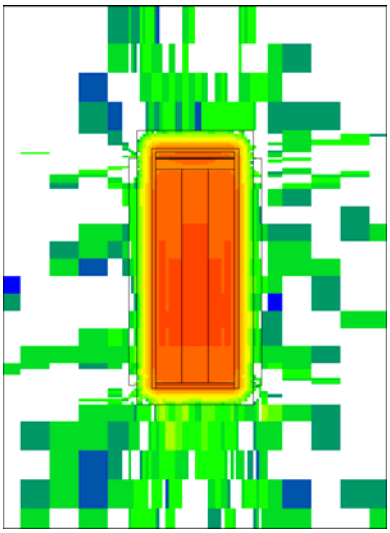
Analog



- Analog Monte Carlo
  - Sample a source particle
    - Position
    - Direction
    - Energy
  - Simulate its natural path
    - Distance before interaction
    - Sample possible interactions

Run Time: 100 hours

Can be slow to converge!

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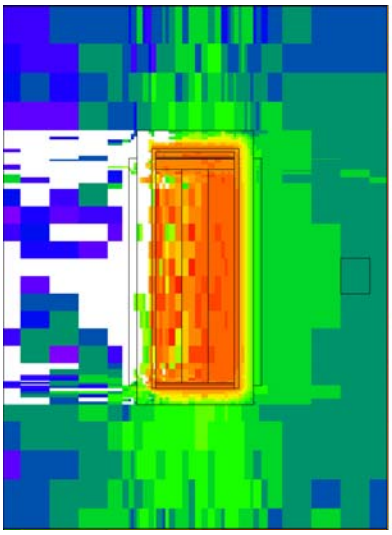
CADIS – Accelerate a single tally



Denovo 12 m; Monaco 45 m

Define the adjoint source = response

$$q^+(\vec{r},E) = \sigma_d(\vec{r},E)$$

Compute the adjoint flux $\phi^+(\vec{r},E)$

Estimate the detector response

$$R = \int_{V_s}\int_E q(\vec{r},E)\,\phi^+(\vec{r},E)\,dE\,dV$$

Construct weight windows

$$\bar{w}(\vec{r},E) = \frac{R}{\phi^+(\vec{r},E)}$$

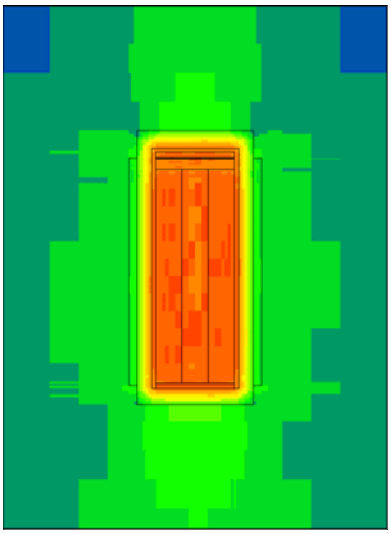
Construct biased source

$$\hat{q}(\vec{r},E) = \frac{1}{R}q(\vec{r},E)\phi^+(\vec{r},E)$$

Use in the Monte Carlo

5

FW-CADIS – for multiple tallies or a mesh tallies



Denovo 17 m, 13 m; Monaco 90 m

Adjoint source corresponds to the area to be optimized by the Monte Carlo
- more adjoint source in low-flux areas
- less adjoint source in high-flux areas

Estimate the forward flux $\phi(\vec{r},E)$

Estimate the dose rate $R(\vec{r},E)$

Adjoint source $q^+(\vec{r},E) = \sigma_d(\vec{r},E)/R(\vec{r},E)$

-- now same as CADIS --

Compute the adjoint flux $\phi^+(\vec{r},E)$

Construct weight windows $\bar{w}(\vec{r},E)$

Construct biased source $\hat{q}(\vec{r},E)$

Use in the Monte Carlo

6

CADIS and FW-CADIS

- Weight windows and biased source distribution work together
  - The final Monte Carlo calculation
    - spends more time on particles that will contribute to the desired tally/tallies
    - spends less time on particles that will not contribute
  - Note that when the desired tally/tallies are optimized, other areas of the problem will converge very slowly – very undersampled
  - The key is the adjoint source – corresponds to what should be optimized
- More Details:
  - "FW-CADIS Method for Global and Semi-Global Variance Reduction of Monte Carlo Radiation Transport Calculations," *Nuclear Science and Engineering* **177**, 37-57 (2014).
  - "ADVANTG—An Automated Variance Reduction Parameter Generator," ORNL/TM-2013/416, Nov. 2013.
  - "Comparison of Hybrid Methods for Global Variance Reduction in Shielding Calculations," ANS M&C Topical, Sun Valley, ID, May 5-9, 2013.
  - "Hybrid Monte Carlo/Deterministic Methods for Active Interrogation Modeling," *Nuclear Technology* **182**, 63-74 (2013).
  - "Consistent Adjoint Driven Importance Sampling using Space, Energy and Angle," ORNL/TM-2012/7, Aug. 2012.
  - "Monte Carlo Shielding Analysis Capabilities with MAVRIC," *Nuclear Technology* **174**, 289-313 (2011).
  - "Simultaneous Optimization of Tallies in Difficult Shielding Problems," *Nuclear Technology* **168**, 785-792 (2009).
  - "Automated Variance Reduction Applied to Nuclear Well-Logging Problems," *Nuclear Technology* **168**, 799-809 (2009).

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Project Overview

- Demonstrate that ADVANTG-enhanced MCNP
  - Gets the same result as standard MCNP
  - Has higher figure-of-merit (FOM)
- Use simple source/shield/detector problems
  - Real measurements would be nice
  - Simple models, neutrons and photons
- Four problems
  - Neutron leakage from an iron sphere
  - Neutron leakage from a heavy water sphere
  - Neutron and photon leakage from iron spheres
  - Neutron and photon leakage from lead spheres

Volume VIII:
Criticality Alarm / Shielding Measurements

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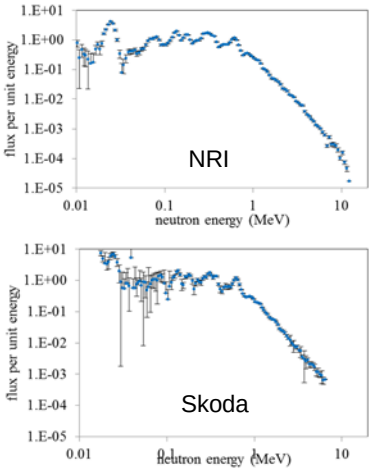
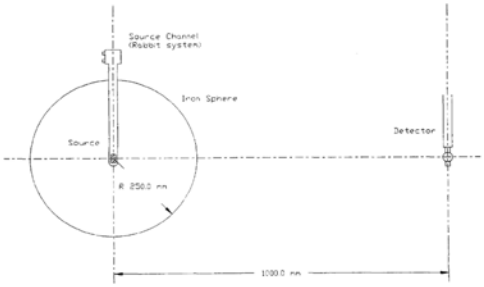
Neutron Leakage through an Iron Sphere

- E. Sajo, M. L. Williams, and M. Asgari, "Comparison of Measured and Calculated Neutron Transmission Through Steel for a ^{252}Cf Source," *Annals of Nuclear Energy* **20**(9), 585–604 (1993)





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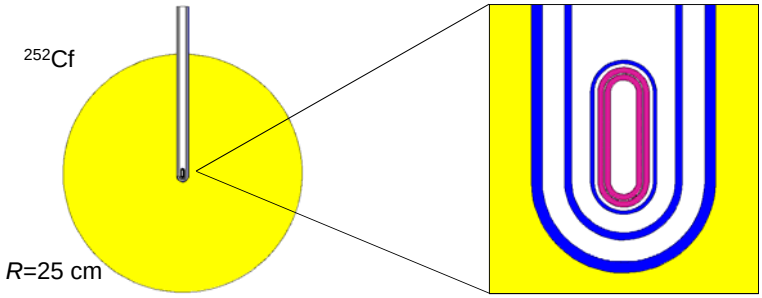
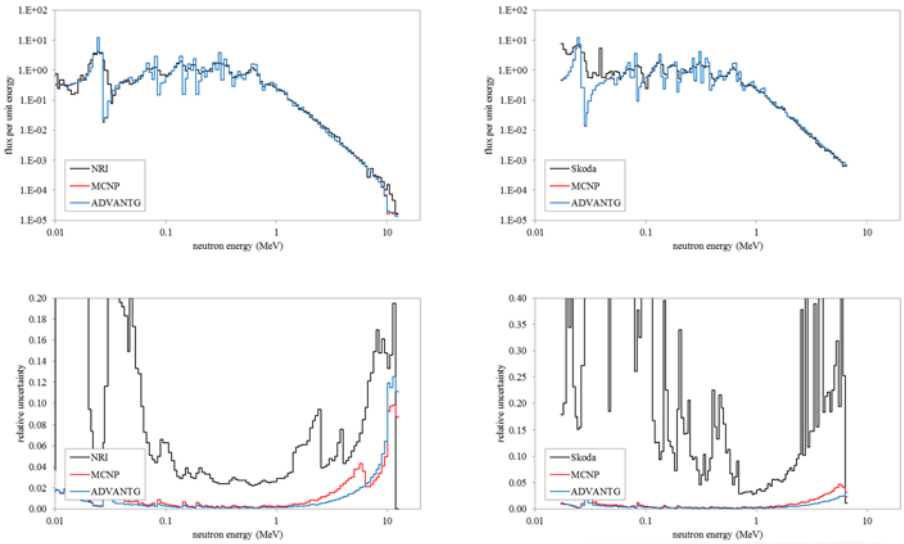
Neutron Leakage through an Iron Sphere



ADVANTG
- Denovo – 25×25×30 mesh (2 cm), 1 min
- MCNP – point detector at 1 m, 60 min

10

Neutron Leakage through an Iron Sphere



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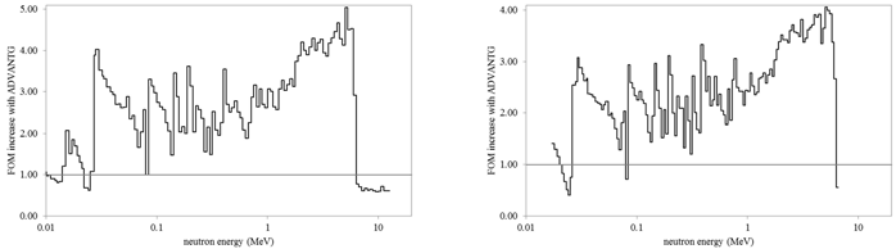
Neutron Leakage through an Iron Sphere

- Figure-of-Merit as a function of energy



NRI Skoda

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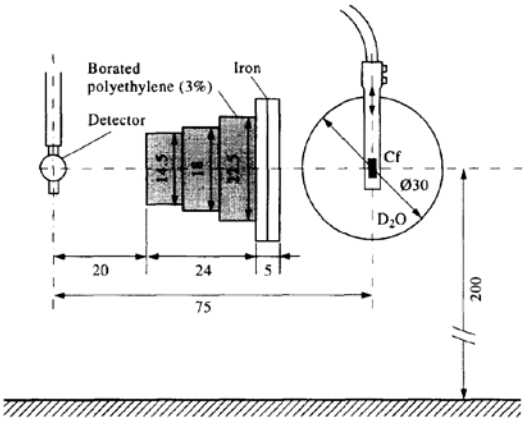
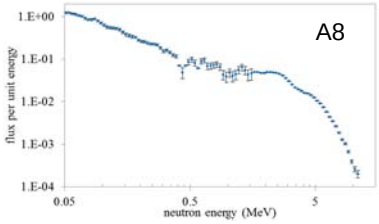
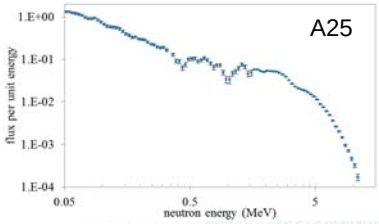
Neutron Leakage from a D_2O Sphere

- B. Jansky, Z. Turzik, E. Novak, J. Kyncl, F. Cvachovec, and P. Tiller, "Comparison of Measured and Calculated Neutron Transmission Through Heavy Water for ^{252}Cf Source Placed in the Center of 30 cm Diameter Sphere," *Annals of Nuclear Energy*, **24**(15), 1189–1212 (1997)







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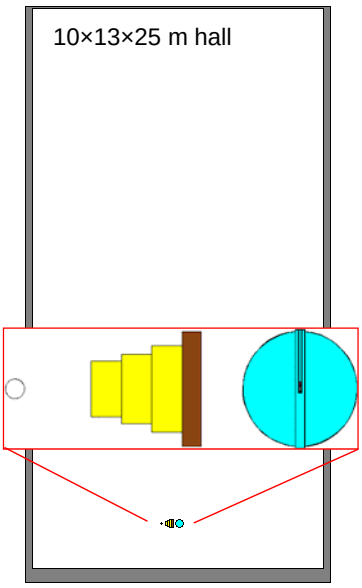
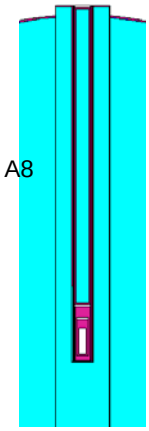
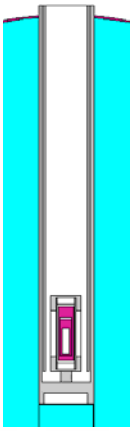
Neutron Leakage from a D_2O Sphere







ADVANTG
Denovo – 109×77×82 mesh, ~40 min
MCNP – point detector, 96 energy bins, 18 hours

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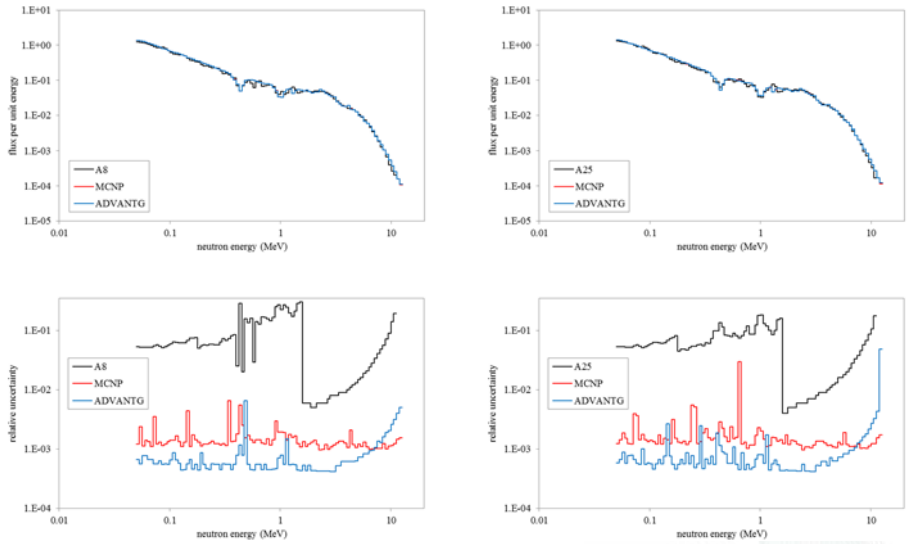
Neutron Leakage from a D_2O Sphere



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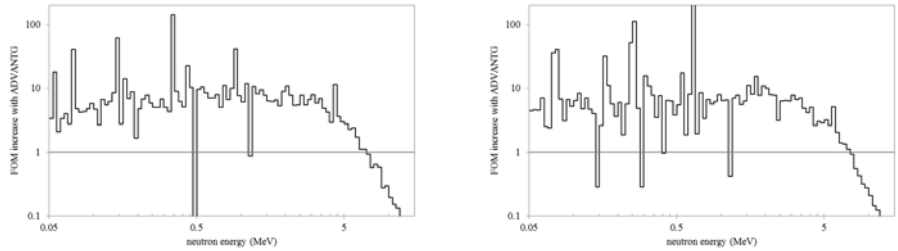
Neutron Leakage from a D_2O Sphere

- Figure-of-Merit as a function of energy



A8 A25

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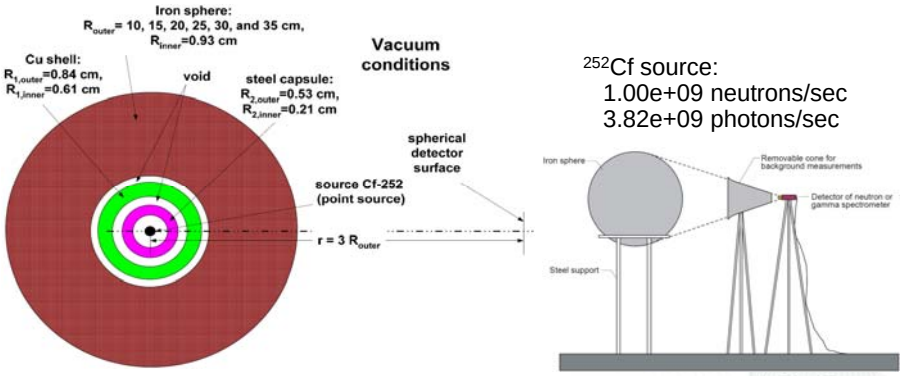
N and P Leakage from Fe Spheres

- G. Manturov, Y. Rozhikhin, and L. Trykov, "Neutron and Photon Leakage Spectra from Cf-252 Source at Centers of Six Iron Spheres of Different Diameters," ALARM-CF-FE-SHIELD-001, Volume VIII of the International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD-NEA), September 2012.



^{252}Cf source:
1.00e+09 neutrons/sec
3.82e+09 photons/sec

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N and P Leakage from Fe Spheres

- Seven shields
  - Radius (cm) of: Bare, 10, 15, 20, 25, 30, 35
- Three MCNP inputs
  - Neutron source, neutron tally
  - Neutron source, photon tally } Photon leakage
  - Photon source, photon tally
- For each combination
  - Standard MCNP (1 hr)
  - ADVANTG: Denovo (2-11 min), then MCNP (1 hour)
- Because no information was given on the size of the experiment hall
  - the shadow cones (borated polyethylene or lead) were not used

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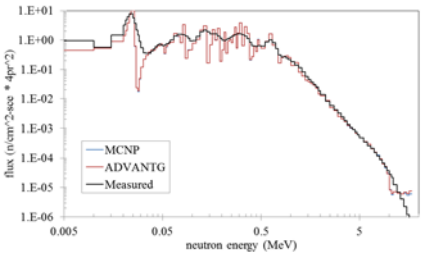
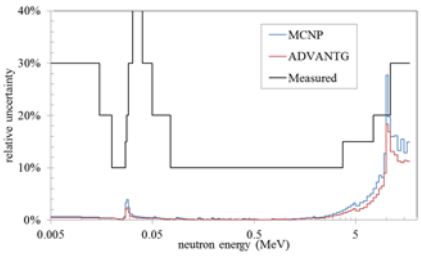
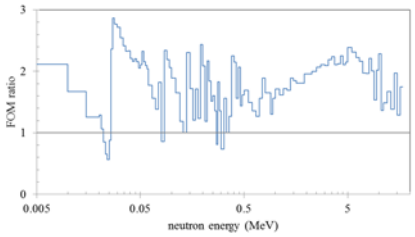
N and P Leakage from Fe Spheres





- Neutron flux, R=30 cm



- Neutron results:
  - ADVANTG matches MCNP
  - Both match measurements
  - FOM improvement 1-2
    - Thicker shields saw more gain

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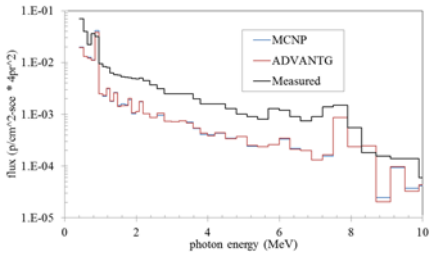
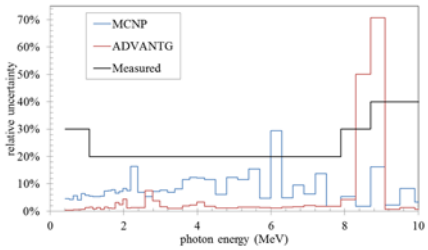
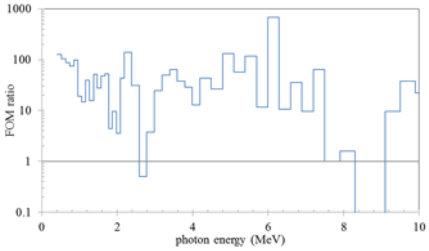
N and P Leakage from Fe Spheres





- Photon flux, R=30 cm



- Photon results:
  - ADVANTG matches MCNP
  - Neither matches measurements
  - FOM improvement 5-50
    - Thicker shields saw more gain

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N and P Leakage from Pb Spheres

- G. Manturov, Y. Rozhikhin, and L. Trykov, "Neutron and Photon Leakage Spectra from Cf-252 Source at Centers of Three Lead Spheres of Different Diameters," ALARM-CF-PB-SHIELD-001, Volume VIII of the International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, Organization for Economic Cooperation and Development, Nuclear Energy Agency (OECD-NEA), September 2012.

- Continuation of the Cf-Fe measurements
- Three shields
  - Radius (cm) of: 10, 20, 30

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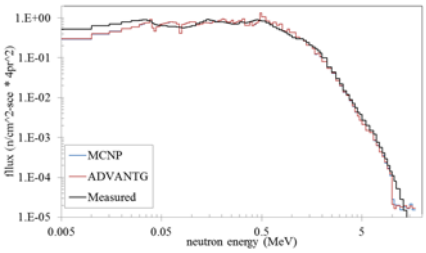
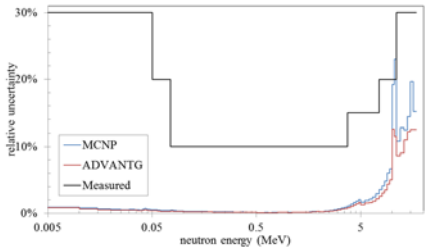
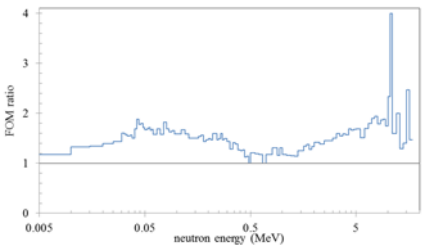
N and P Leakage from Pb Spheres





- Neutron flux, R=30 cm



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22

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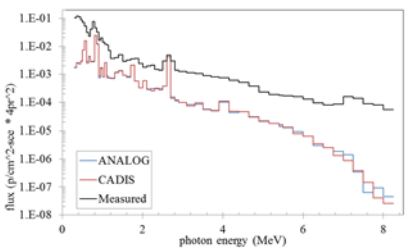
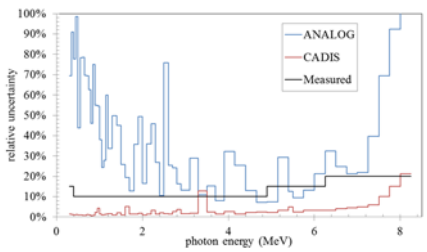
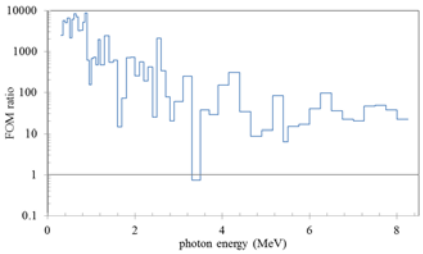
N and P Leakage from Pb Spheres





- Photon flux, R=30 cm



- Photon results:
  - ADVANTG matches MCNP
  - Neither matches measurements
  - FOM improvement 5-50
    - Thicker shields saw more gain

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Summary

- ADVANTG
  - Uses results from deterministic calculation(s) to generate weight windows and consistent biased sources for MCNP
  - Automated – user supplies small amount of extra input
  - Available through RSICC in Fall/Winter 2014
- ADVANTG for source/detector problems
  - Preserves the MCNP result
  - Increases the figure-of-merit
- For simple shielding applications
  - Calculations can be sped up
  - For photons, speed up can be dramatic

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Questions?

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