

CADIS Variance Reduction with MAVRIC

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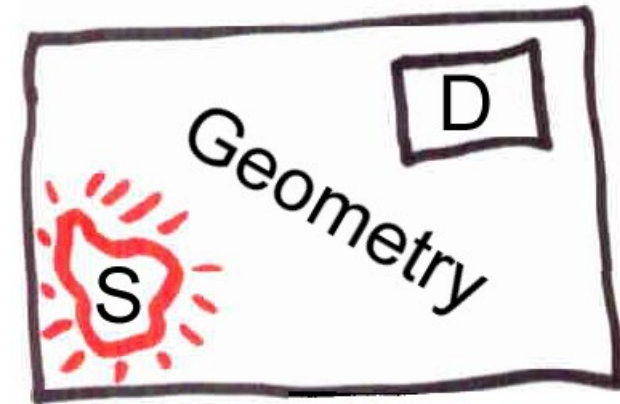
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MAVRIC

Monaco with Automated Variance Reduction using Importance Calculations

- Elements of a Shielding Calculation

- Physical Model
- Source
- Responses
- Computational Parameters

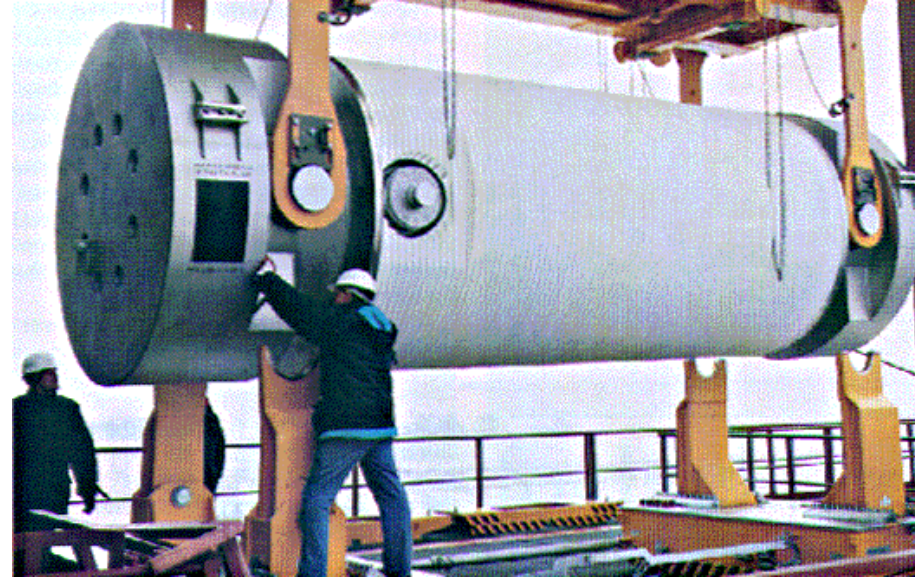


Physical Model

- Geometry description
 - Boolean operation of solid and surface equations
- Material compositions
 - Physical mixture: weight fractions, atomic fractions
 - Chemical formula
 - Density
 - Isotopic distribution of elements
- Interaction cross sections

Sources

- Particle type
- Spatial distribution
- Energy distribution
- Directional distribution



Responses

- Type of response
 - At a point
 - For a geometric region
 - Superimposed mesh
- Quantity to Calculate
 - Flux
 - Dose Rate
 - Reaction Rate
- Dimensionality
 - Total
 - Function of R , E , Ω , etc



SCALE Strategy for Shielding is Monte Carlo

- Computational Parameters for Monte Carlo Simulations
 - Minimum accuracy
 - Maximum runtime
 - Problem truncation
 - **Variance reduction**



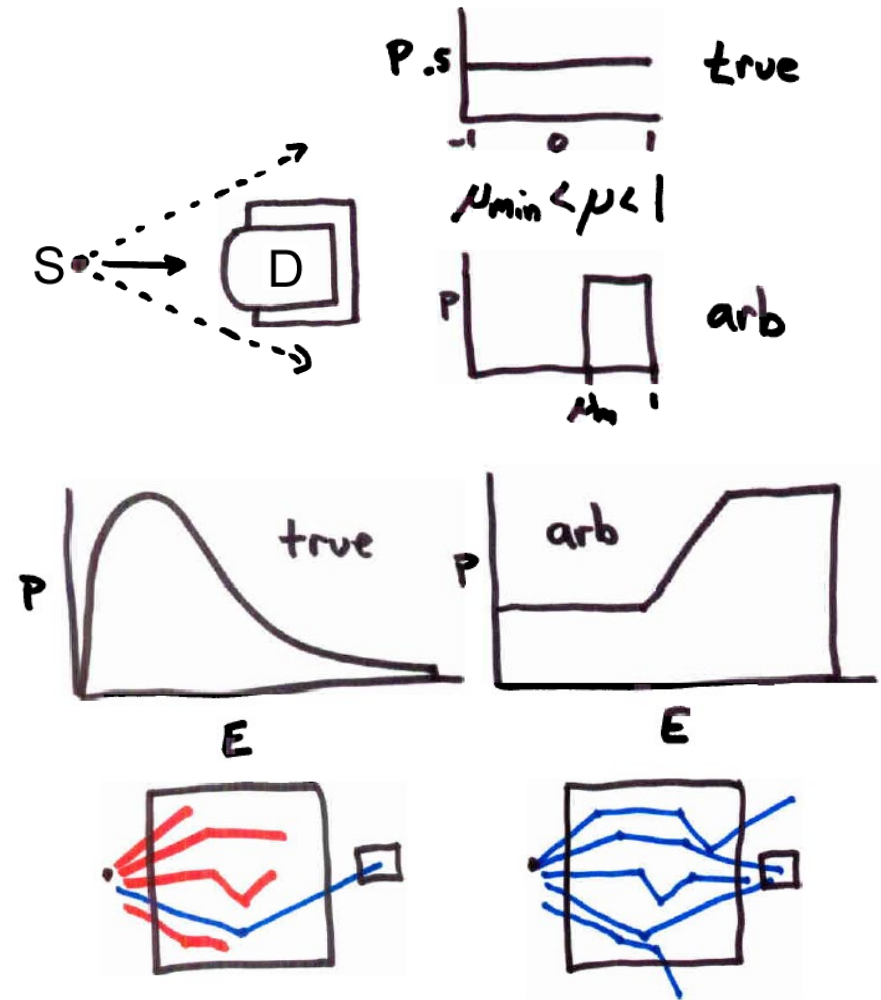
Monte Carlo Simulation Strengths and Drawbacks

- Strengths of MC
 - Straightforward physics
 - particle-based interactions,
 - physics expressed as probability distribution functions (pdf)
 - Geometry at any level of detail – no meshing approximations
- Drawbacks of MC
 - Time - depends on problem, how many results (tallies), level of geometry detail
- Difficult Problems
 - Streaming
 - Highly scattering
 - Deep penetration

Efficient Variance Reduction is key with Monte Carlo shielding problems!

Variance Reduction Methods

- Changing the sampling routines to optimize the simulation to get more particles to do *something*
 - Forcing, biasing, stretching, implicit capture, and weight windows
 - Requires knowledge about how the calculation will most likely proceed
 - May require iterative process to tune biasing
 - Multiple methods may work against each other
 - “Bad” biasing can slow the rate of convergence



Optimal Variance Reduction

- What is desired:
 - Tell MC code what tally/tallies to calculate
 - The MC code figures out the best way to do that
- Importance map (weight windows) comes close
 - If we know how “important” a given particle is as a function of space, energy, and angle then weight window target values can be assigned, using roulette and splitting to control particle weight
 - Importance is the solution to the adjoint equation, using the tally location as the spatial component of the adjoint source and the tally response function as the energy component of the adjoint source

CADIS (1/2)

Consistent Adjoint Driven Importance Sampling

Biased source and importance map work together

Ali Haghighat and John C. Wagner, "Monte Carlo Variance Reduction with Deterministic Importance Functions," Progress in Nuclear Energy, 42(1), 25-53, (2003).

- Solve the adjoint problem using the detector response function as the adjoint source.

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

- Weight window targets are inversely proportional to the adjoint flux (measure of importance of the particles to the response).

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

CADIS (2/2)

- We want source particles born with a weight matching the weight window targets

$$w_0(\vec{r}, E) = \frac{q(\vec{r}, E)}{\hat{q}(\vec{r}, E)} = \bar{w}(\vec{r}, E)$$

- So the biased source needs to be

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

- Since the biased source is a pdf, solve for c

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

Which is the
estimate of
response: R

CADIS Workflow

- Define the adjoint source

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

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

- Estimate the response R

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

- Construct weight windows and biased source

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

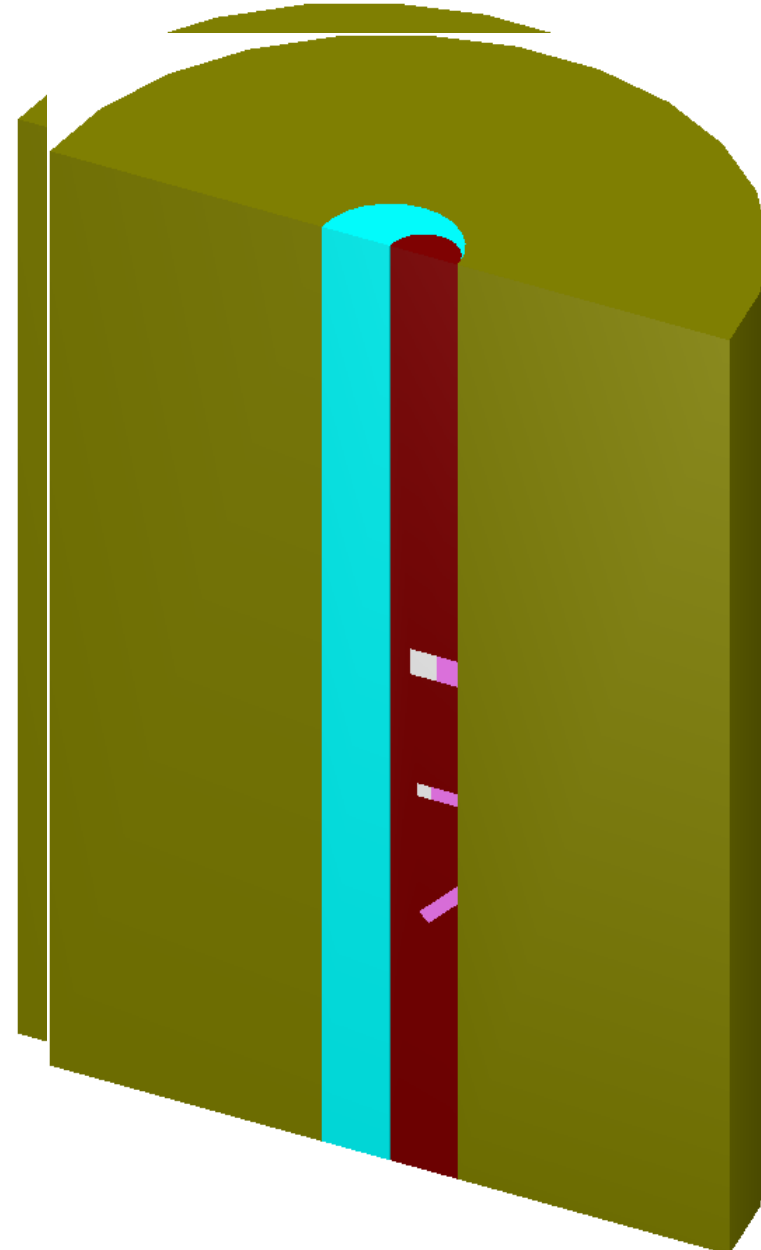
$$\hat{q}(\vec{r}, E) = \frac{1}{R} q(\vec{r}, E) \phi^+(\vec{r}, E)$$

CADIS Application

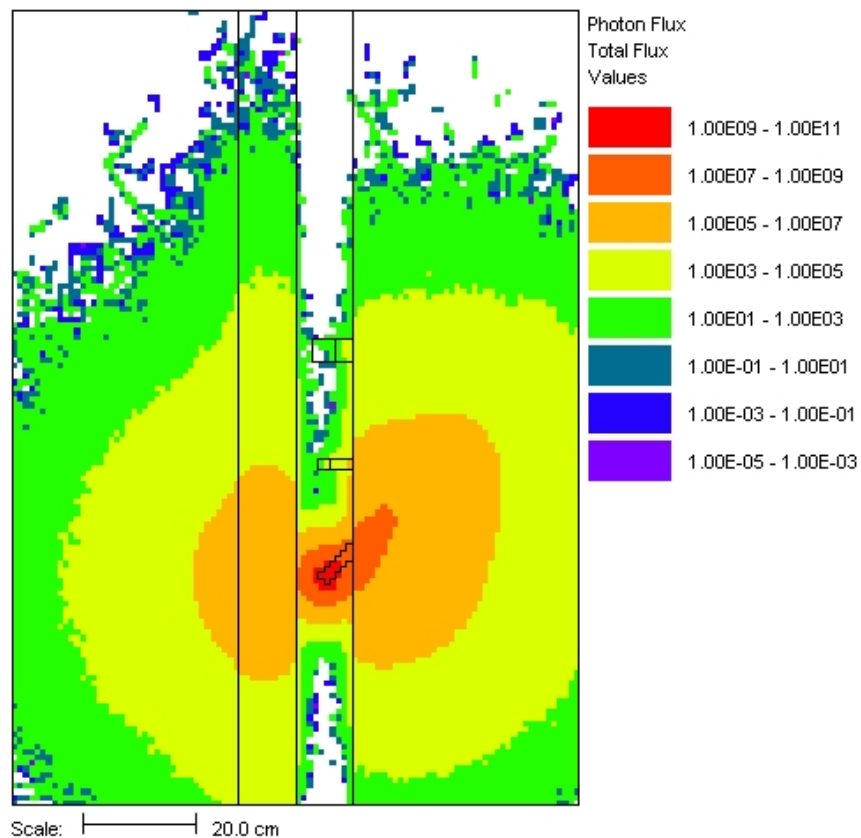
- Problem Description from

Robin P. Gardner and Kuruvilla Verghese, "Monte Carlo Nuclear Well Logging Benchmark Problems with Preliminary Intercomparison Results," *Nuclear Geophysics* 5(4), 429-438 (1991).

- Source: Cs-137, 2.7 Ci
- Detectors: NaI
 - Near: 2x2 at 20 cm
 - Far: 4x4 at 40 cm
- Borehole: 20 cm diam
- Tool: 10 cm diam

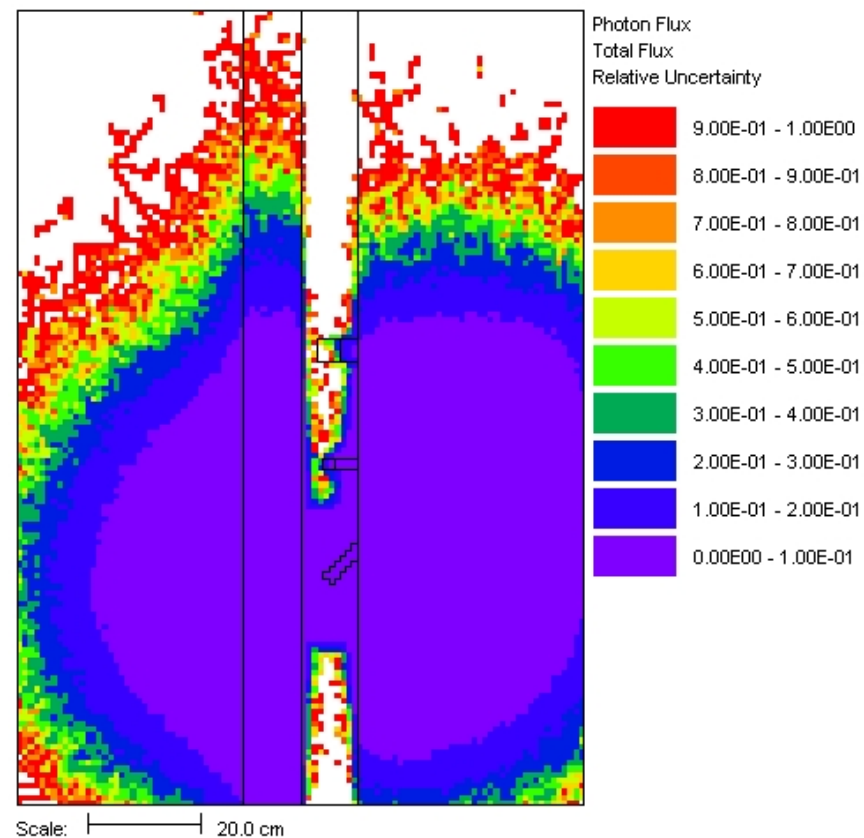


Analog



Total Photon Flux

Calculation	Minutes
Monte Carlo	2762

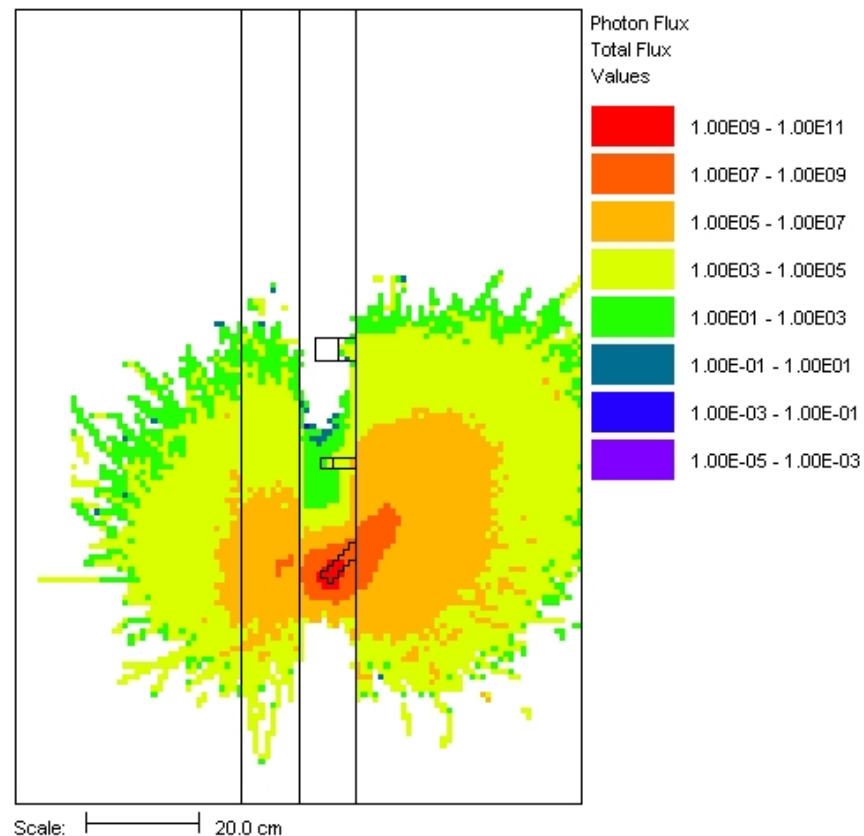


Relative Uncertainty

Results

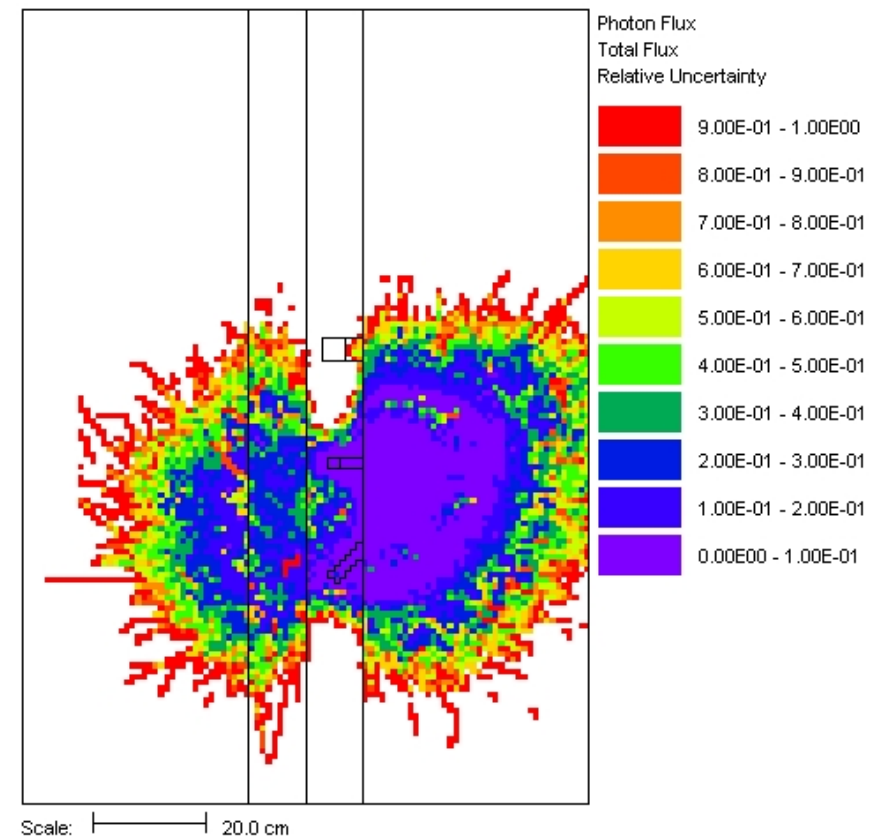
Near $1.49 \times 10^3 (\pm 8.2\%)$
 Far $6.13 \times 10^1 (\pm 19\%)$

CADIS – for Near Detector



Total Photon Flux

Calculation	Minutes
Adjoint DO	7
Monte Carlo	126

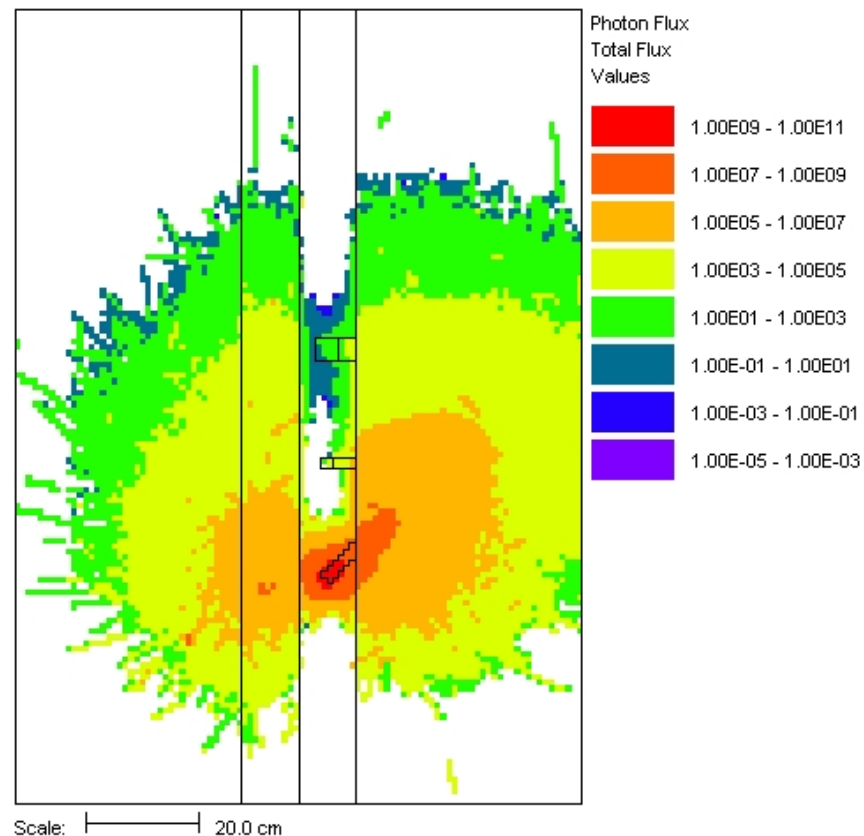


Relative Uncertainty

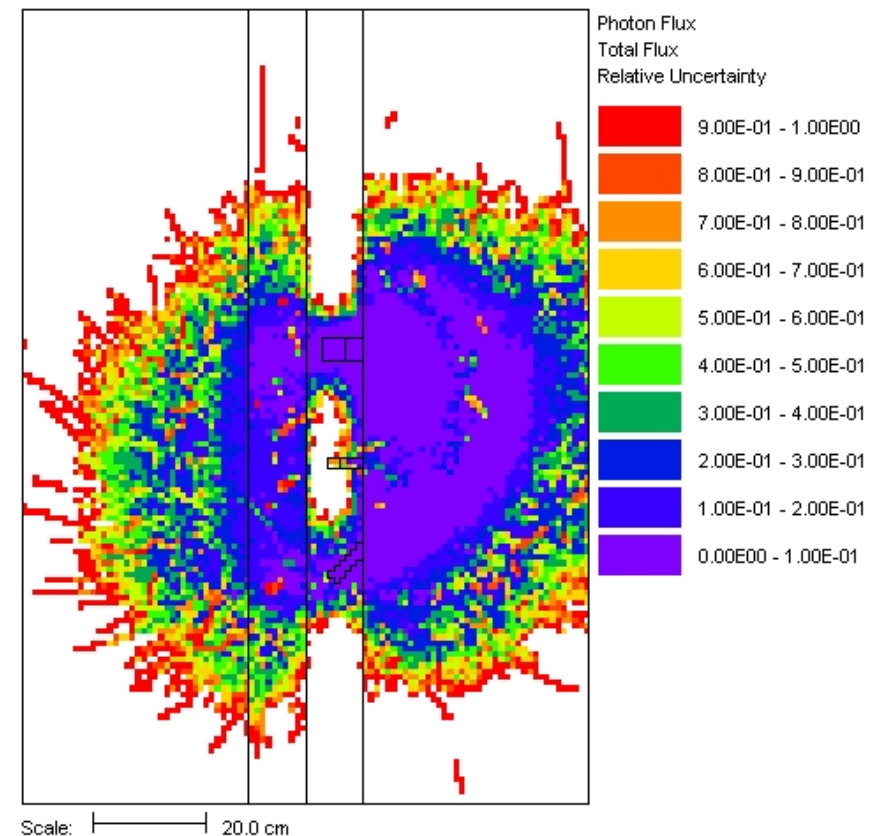
Results

Near $1.54 \times 10^3 (\pm 0.5\%)$
Far 0.00

CADIS – for Far Detector



Total Photon Flux



Relative Uncertainty

Calculation	Minutes
Adjoint DO	7
Monte Carlo	124

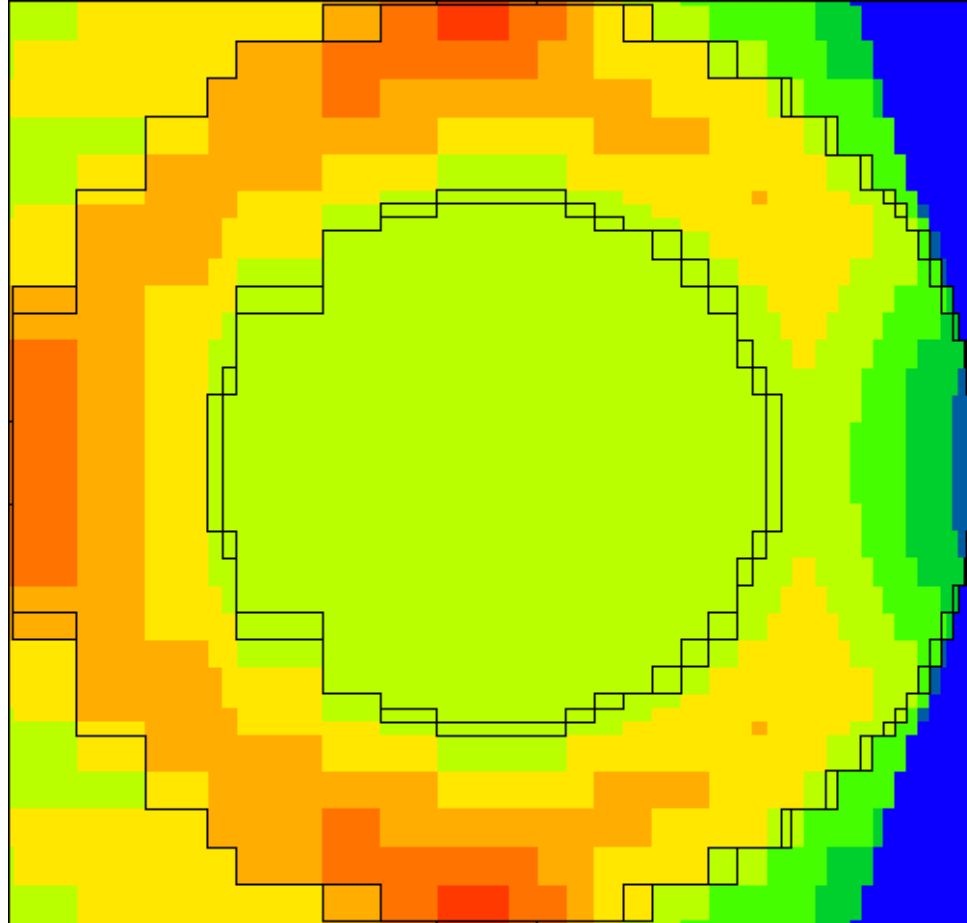
Results

Near 3.10×10^3 ($\pm 65\%$)
Far 5.59×10^1 ($\pm 0.3\%$)

CADIS Summary

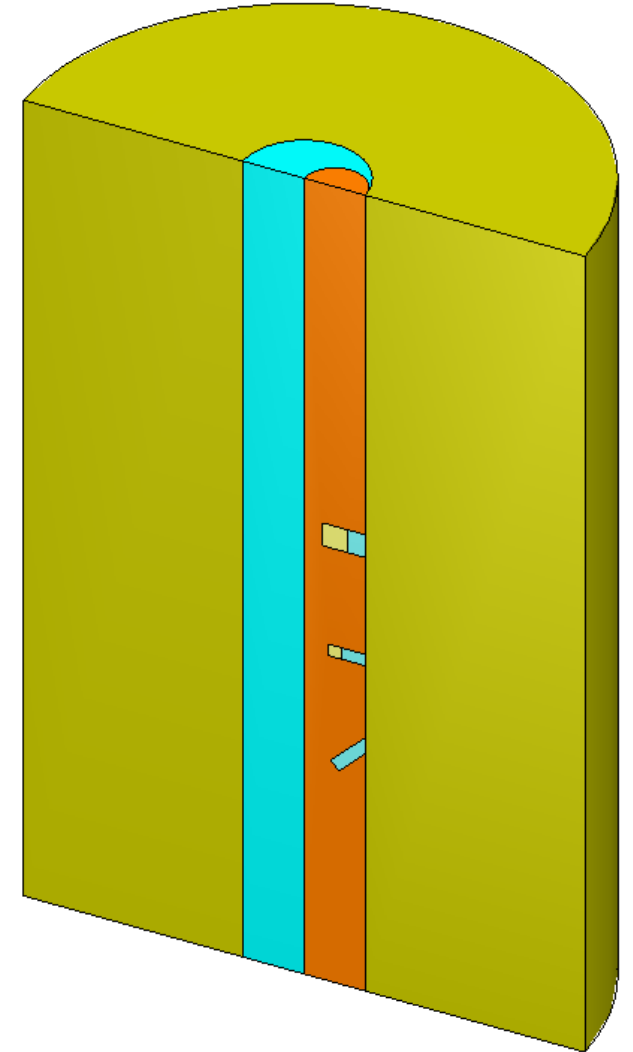
- Provides consistent relationships for calculating source & transport biasing parameters
- Eliminates the incompatibility between source & transport biasing that has been problematic in other approaches
- Large speed-up for source/detector problems
- Described in more detail in:
 - *Nuclear Science & Engineering*, 128 186-208, 1998
 - *Progress of Nuclear Energy*, 42(1), 2003
- Guidance on mesh planes for the importance map
 - Mesh planes bound
 - Material changes
 - Source
 - Tally region(s) / Adjoint source(s)
 - More mesh planes where adjoint flux changes quickly
 - Point sources should be at cell centers
 - Point adjoint sources should be at cell centers

Questions?



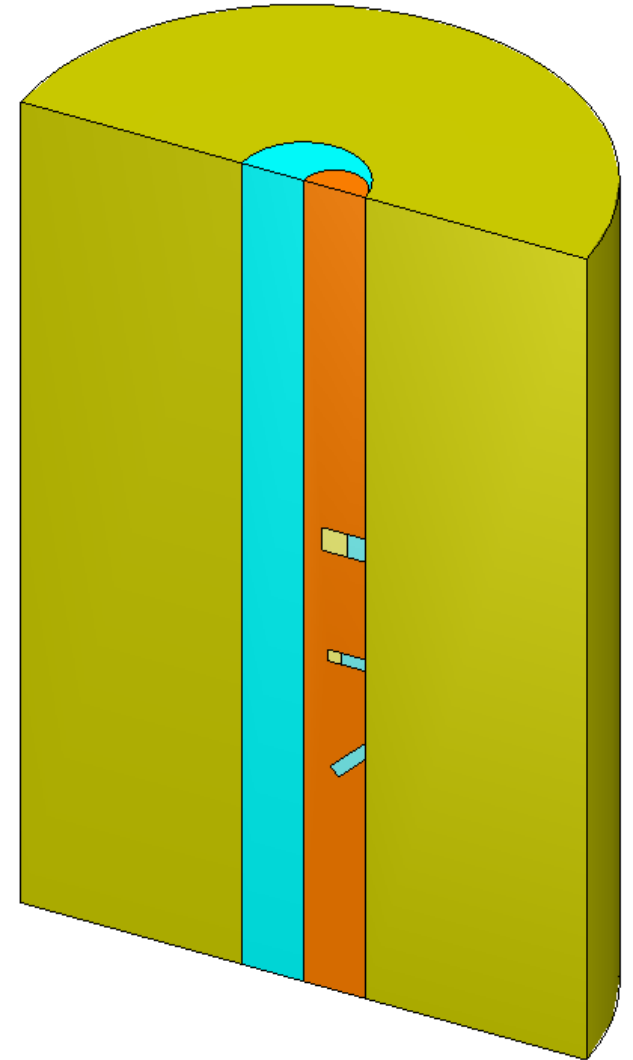
How To Improve Uncertainties (1/2)

- CADIS works
 - Improves the FOM for one detector
 - At the expense of tracking particles deep into the formation
 - At the expense of the other detector
- Can we get both detectors simultaneously?
- Try adjoint source in both detectors



How To Improve Uncertainties (2/2)

- Adjoint source in both detectors:
 - Recall that the adjoint source locations act like particle attractors in the MC.
 - MC particles will tend to go to the “easiest” adjoint source location.
 - Need to put more adjoint source in the far detector so that the same number of particles get to each.
- How much adjoint source strength to put into the far detector relative to the near?
- Ratio needs to be same as ratio of the responses!

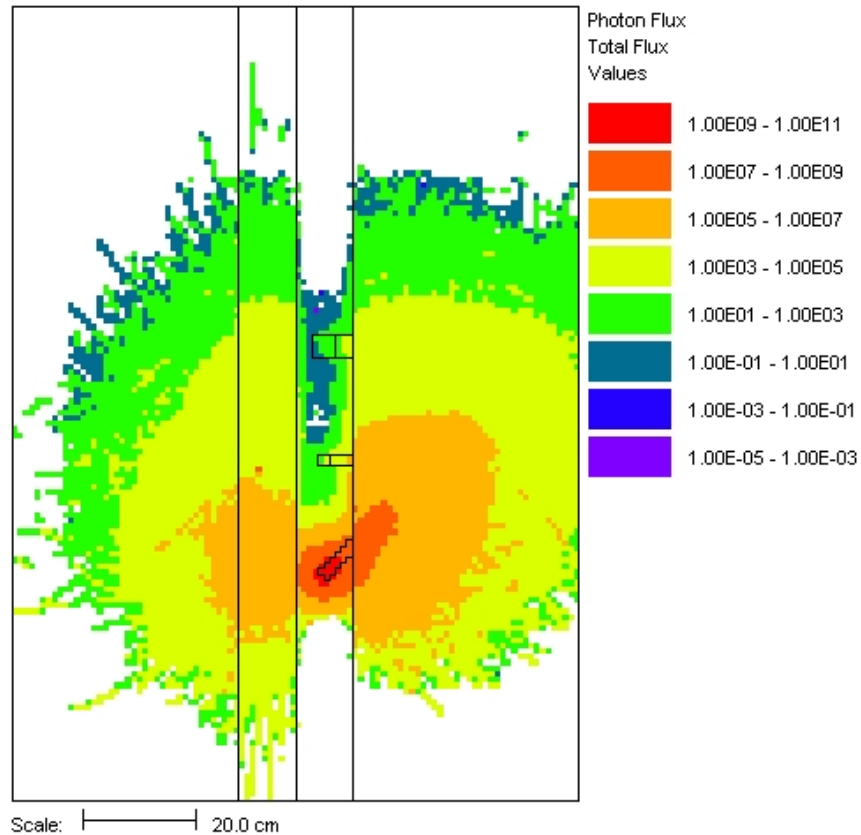


Forward Weighted CADIS in MAVRIC

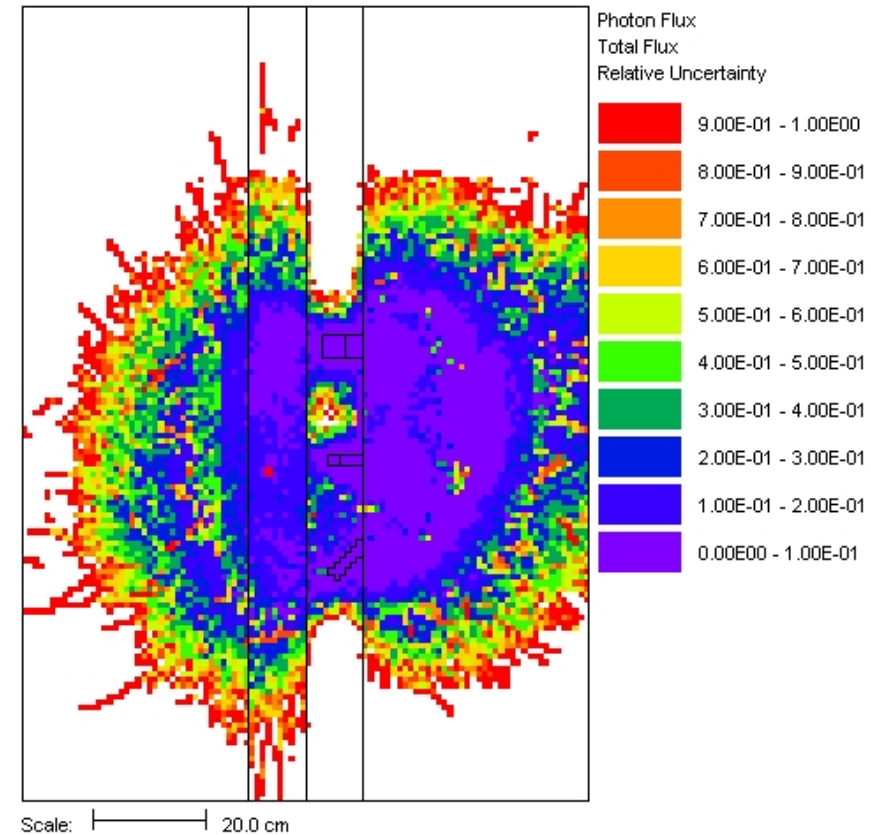
- Perform a forward discrete ordinates calculation
 - Estimate the responses $R(\vec{r}, E)$ everywhere
 - Construct the CADIS adjoint source but weight the source strength with $1/R(\vec{r}, E)$
-

- Perform the adjoint discrete ordinates calculation
- Create the weight windows and biased source
- Perform the Monte Carlo calculation

FW-CADIS – for both Detectors



Total Neutron Flux



Relative Uncertainty

Calculation	Minutes
Forward DO	6
Adjoint DO	7
Monte Carlo	126

Results

Near 1.54×10^3 ($\pm 0.6\%$)
Far 5.56×10^1 ($\pm 0.4\%$)