MAVRIC-S/U Development: Fixed Source Multi-group Sensitivity and Uncertainty Analysis

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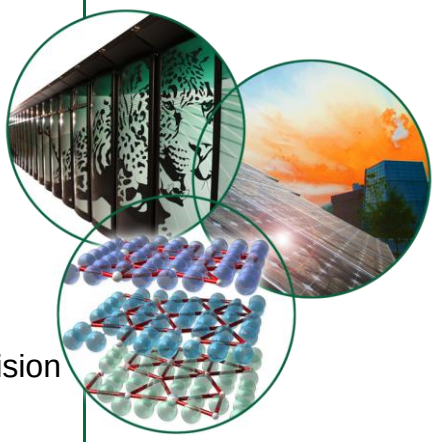

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Outline

- Motivation
- Background and the path forward
- Progress on MAVRIC S/U development
  - Adjoint Monaco
  - Analogous implementation of CADIS for adjoint Monte Carlo calculations
- Future work (FY 2012 and 2013)

Motivation

- Desire to perform S/U analysis for fixed source calculations in the same manner that SCALE can for eigenvalue calculations (TSUNAMI)
  - SILENE benchmark
  - Other benchmarks currently in the C_EdT process

Background (1)

- TSUNAMI can…
  - Produce sensitivity of neutron multiplication, k_{eff}, and reactivity to neutron cross section data
  - Compute uncertainty in responses due to uncertainties tabulated in cross section covariance data
  - Use S/U data in code validation for system-to-system similarity quantification, bias assessment, and gap analysis
- This can all be done in 1-D with XSDRN and 3-D with KENO
- The TSUNAMI tools need a transport solver to provide forward and adjoint flux moments and uses a numerical differentiation algorithm to calculate sensitivity coefficients

Background (2)

- MAVRIC can…
  - Use multiple complex fixed sources entered by the user and/or calculated by KENO to calculate any number of detector responses, region tallies, point detectors, or mesh tallies (arrays of region tallies)
  - Provide a biased source and importance map to optimize the Monte Carlo simulation of a single detector response (CADIS) or multiple detector responses (FW-CADIS)
- MAVRIC applies the multi-group fixed-source Monte Carlo code Monaco and uses the 3-D S_N Denovo to produce particle importances (adjoint flux) to bias the forward Monte Carlo transport simulation

Path forward

- In order to use the S/U tools already included in SCALE a code must provide multi-group forward and adjoint flux moments tallied on a spatial grid
- Monaco has always been able to tally multi-group forward scalar flux on a mesh tally
- MAVRIC provides the biasing parameters so Monaco can perform Monte Carlo simulations for complex and/or deep penetration shielding problems
- In order to create a SCALE MAVRIC S/U sequence
  - Monaco must be modified to perform adjoint transport calculations
  - Monaco mesh tallies must be modified to tally flux moments
  - The MAVRIC sequence must be modified to provide the capability analogous to CADIS and FW-CADIS for adjoint Monte Carlo calculations
  - All of this requires modification to the user input file and SCALE manual, and needs to be accompanied by some training materials and test problems

MAVRIC S/U development progress (1)

- Monaco has been modified to perform adjoint neutron transport calculations

Forward Cross Sections, Water, 3 Neutron Groups

```
mixture id =          1          mixture index =     1     mixture number 1

                   neutron cross sections

group     sigt        sigs        siga        sum         signu       chi
    1  2.37552E-01 9.98258E-01 1.74004E-03 9.99998E-01 0.00000E+00 0.00000E+00
    2  6.68495E-01 9.99868E-01 1.32083E-04 1.00000E+00 0.00000E+00 0.00000E+00
    3  2.88633E+00 9.95338E-01 4.66214E-03 1.00000E+00 0.00000E+00 0.00000E+00
```

Adjoint Cross Sections, Water, 3 Neutron Groups

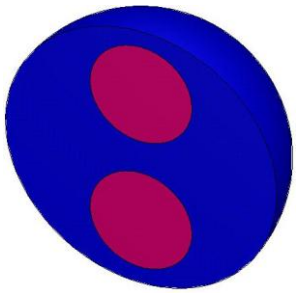
```
mixture id =          1          mixture index =     1     mixture number 1

                   neutron cross sections

group     sigt        sigs        siga        sum         signu       chi
    1  2.88633E+00 1.00696E+00 4.66214E-03 1.01162E+00 0.00000E+00 0.00000E+00
    2  6.68495E-01 1.10743E+00 1.32083E-04 1.10756E+00 0.00000E+00 0.00000E+00
    3  2.37552E-01 5.54405E-01 1.74004E-03 5.56145E-01 0.00000E+00 0.00000E+00
```


MAVRIC S/U development progress (2)

- Simple adjoint test problem
  - Sphere of HEU that contains 2 smaller spheres of water
  - Lower water sphere contains evenly distributed <u>forward</u> neutron source
  - Therefore, the water lower sphere must be an <u>adjoint</u> region tally
  - <u>Forward</u> region tally in the upper water sphere and <u>forward</u> point detector tally 10 cm above HEU sphere
  - Therefore, the upper water sphere must be an <u>adjoint</u> distributed source and at the point detector location there must be an <u>adjoint</u> point source



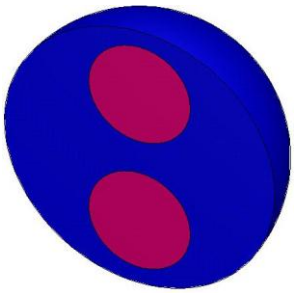
MAVRIC S/U development progress (2)

- Simple adjoint test problem
  - Sphere of HEU that contains 2 smaller spheres of water
  - Lower water sphere contains evenly distributed forward neutron source
  - Therefore, the water lower sphere must be an adjoint region tally
  - Forward region tally in the upper water sphere and forward point detector tally 10 cm above HEU sphere
  - Therefore, the upper water sphere must be an adjoint distributed source and at the point detector location there must be an adjoint point source

Remember there are 2 ways to calculate a detector response, $\Re$

$$\Re = \iint \sigma_d(\vec{r},E)\phi(\vec{r},E)d\vec{r}dE$$

$$= \iint q(\vec{r},E)\phi^+(\vec{r},E)d\vec{r}dE$$



MAVRIC S/U development progress (2)

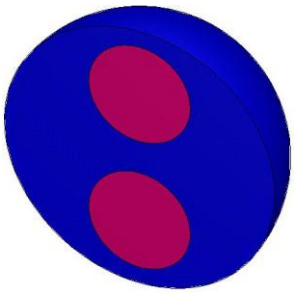
- Simple adjoint test problem
  - The source and response functions were made up, so the units are completely arbitrary

Response	Mean	Relative Error
Forwad Region Tally	1.1489E+05	0.00475
Adjoint Region Tally with Adjoint Distributed Source	1.1457E+05	0.00383
Forward Point Detector	1.0153E+05	0.00414
Adjoint Region Tally with Adjoint Point Source	1.0149E+05	0.00745

Remember there are 2 ways to calculate a detector response, $\Re$

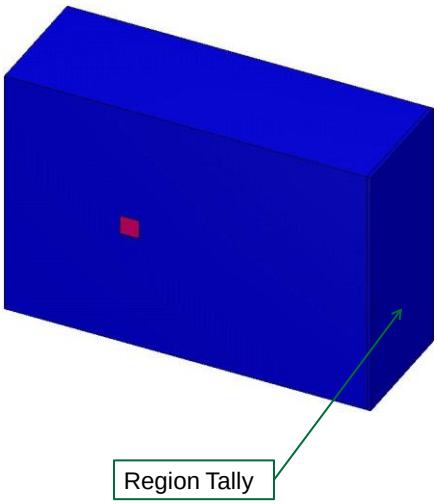
$$\Re = \iint \sigma_d(\vec{r},E)\phi(\vec{r},E)d\vec{r}dE$$

$$= \iint q(\vec{r},E)\phi^+(\vec{r},E)d\vec{r}dE$$



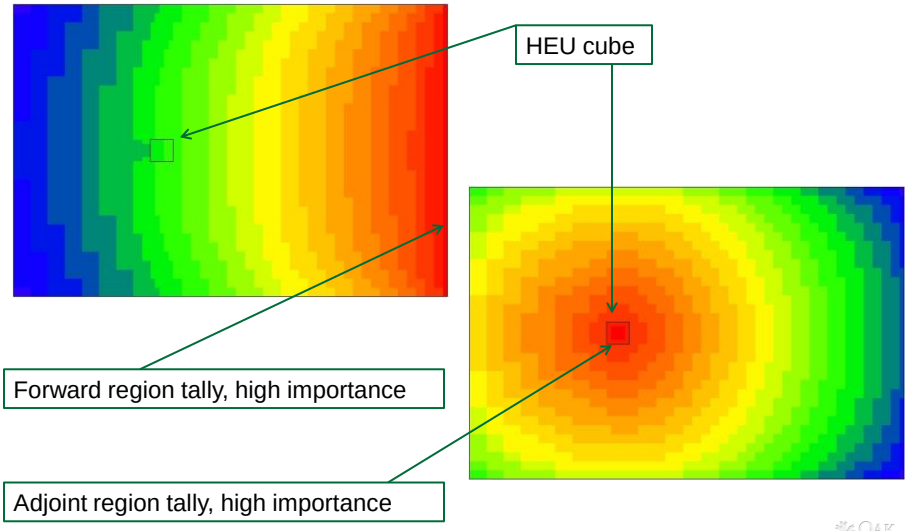
MAVRIC S/U development progress (3)

- More complex adjoint test problem using MAVRIC and methodology analogous to CADIS for adjoint Monte Carlo
  - Small cube of HEU contained in a larger cube of water
  - HEU contains evenly distributed <u>forward</u> neutron source
  - Therefore, the HEU cube must be an <u>adjoint</u> region tally
  - <u>Forward</u> region tally on the outer +x surface of the water cube
  - Therefore, the outer +x surface of the water cube must contain an <u>adjoint</u> distributed source



MAVRIC S/U development progress (3)

- Forward and adjoint importance maps

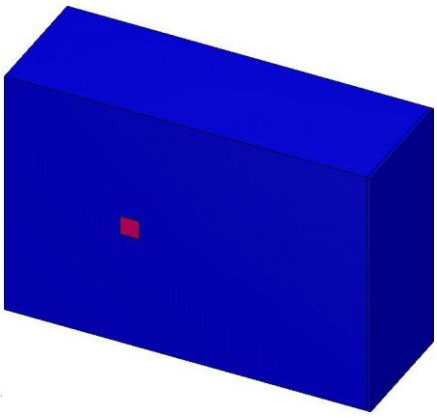


MAVRIC S/U development progress (3)

- More complex adjoint test problem

Response	Mean	Relative Error	FOM	Speed Up
Forwad Semi-Analog	6.0248E-07	0.01727	1.29	1
Forward CADIS	6.2197E-07	0.00041	4938	3828
Adjoint Semi-Analog	6.1506E-07	0.01255	1.43	1
Adjoint CADIS	6.2115E-07	0.00206	445	311

- ^{235}U watt fission spectrum, 10^6 n/sec
- Response is ANSI 1977 flux-to-dose conversion factor
- Response units of rem/hr



Future work (FY 2012 and 2013)

- Modify Monaco mesh tallies to also calculate flux moments
- Implement a methodology in MAVRIC that is analogous to FW-CADIS for adjoint Monte Carlo simulations
- Finish modifying the MAVRIC and Monaco input files to handle these new capabilities and modify the SCALE manual to describe these new features
- Ensure that MAVRIC S/U produces files in the correct format to use the existing TSUNAMI tools
- Add a few problems to the SCALE regression test suite to continuously test these new features
- Create some training materials to provide instruction about these new features