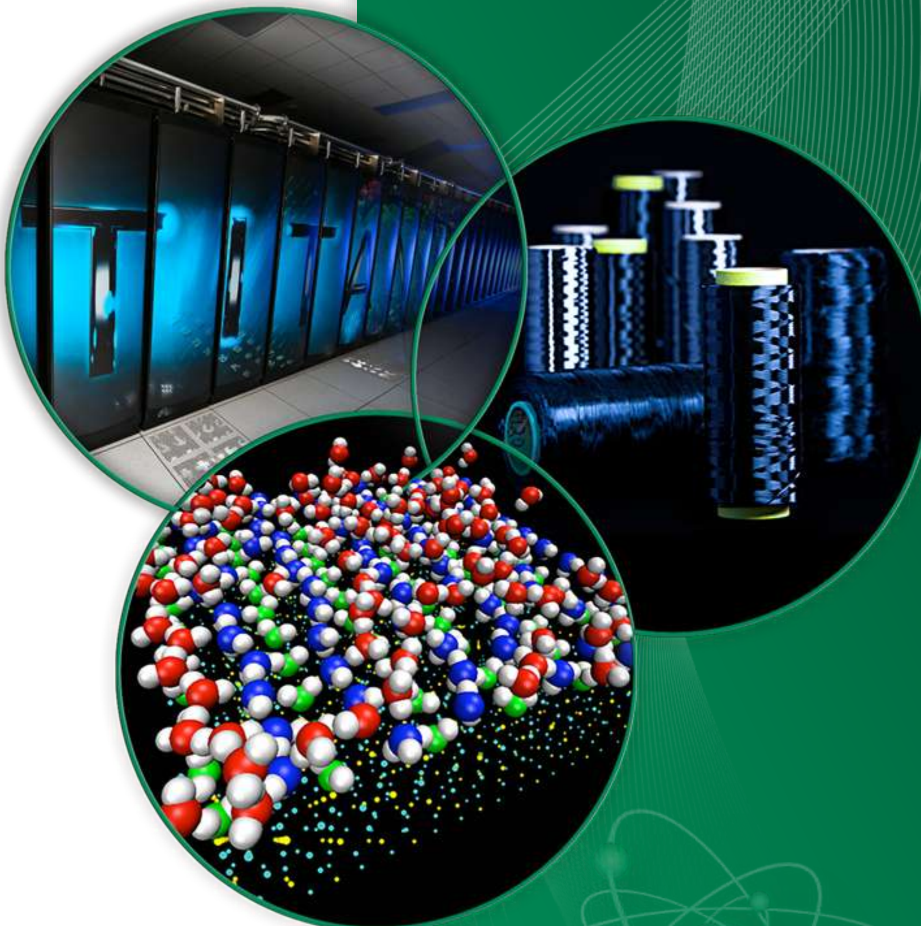
Corrected User Guidance for 3-D CAAS Modeling with SCALE



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Outline

- Fission photons in nuclear data
- SCALE CAAS analysis historical perspective
  - Previous guidance
  - New guidance
- Comparison of previous and new guidance
  - Minimum accident of concern
  - CAAS detector response
- Summary and Conclusions

Fission Photons in Nuclear Data

- Fission photon production is not uniquely identified in ENDF/B at all incident neutron energies
- ENDF/B references that illustrate this
  - LA-4918, Stewart and Hunter, ^{235}U and ^{238}U
  - LA-4901, Hunter and Stewart, ^{239}Pu and ^{240}Pu

Upper Neutron Energy Cutoffs of Fission Photon Production for Some of the Fissionable Isotopes in ENDF/B-VII.1	
Isotope	**Upper Neutron Energy Cutoff (MeV)**
^{233}U	1.09
^{235}U	1.09
^{238}U	30
^{237}Np	0.54923
^{239}Pu	1.09
^{241}Pu	0.1

SCALE CAAS Guidance Historical Perspective

- CSAS1X (nuclear criticality slide rule)
  - XSDRNPM models a 1-D critical assembly and generates a fission neutron source (eigenvalue)
  - That fission neutron source is used in a second 1-D XSDRNPM model to calculate dose outside the critical assembly (fixed source)
- MAVRIC (introduced in SCALE 6.0)
  - KENO-VI used to generate a fission neutron source
  - MAVRIC/Monaco used to calculate a CAAS detector response
    - Option to generate fission photon source
    - SCALE 6.1 includes method to avoid double counting fission photons
    - REALITY: this method does not avoid double counting all fission photons

Previous SCALE 3-D CAAS Guidance

- Calculate the spatial and energy dependent distribution of neutrons created by fission using KENO-VI
- Convert the KENO neutron mesh tally to a Monaco mesh source using the MAVRIC utility MT2MSM
- Calculate the CAAS detector response using MAVRIC/Monaco
  - Use the `noFissions` parameter
  - If no photon CAAS detector response is needed use the `noSecondaries` parameter
  - If a photon CAAS detector response is needed
    - In the `celldata` block set the `moredata` parameter `nFisFot` equal to 1 to remove photon yields from the fission cross sections
    - Set the source keyword `fissPhotonZAID` to the primary fission isotope ZAID to add fission photon data to the neutron source

New SCALE 3-D CAAS Guidance

- KENO-VI … MT2MSM … MAVRIC/Monaco
  - Use the `noFissions` parameter
  - If no photon CAAS detector response is needed use the `noSecondaries` parameter
  - ~~If a photon CAAS detector response is needed~~
    - ~~In the `celldata` block set the `moredata` parameter `nFisFot` equal to 1 to remove photon yields from the fission cross sections~~
    - ~~Set the source keyword `fissPhotonZAID` to the primary fission isotope ZAID to add fission photon data to the neutron source~~
  - If a photon CAAS detector response is needed
    - Do <u>NOT</u> use the keywords `noSecondaries`, `nFisFot`, or `fissPhotonZAID`
- The difference in the previous and new guidance is not the result of an error in the coding of SCALE
- The difference is due to an incorrect interpretation/use of ENDF/B data

Comparison of Previous and New Guidance – Thermal System

- Critical sphere of ^{239}Pu and water, radius=29.06 cm, Pu density=0.01324 g/cm^3, water density=0.9982 g/cm^3
- Compare neutron and photon air kerma rate per fission rate 2 meters from sphere

Calculated Dose Rates for a Critical Sphere of ^{239}Pu and Water[a]				
Dose Rates (Air Kerma – Gy/hr/fiss/sec)	XSDRN	MCNP5	MAVRIC CAAS	
			Previous Guidance	Revised Guidance
Neutron	1.21e-14	1.21e-14	1.22e-14	1.21e-14
Photon	1.18e-13	1.18e-13	1.18e-13	1.18e-13

[a] All Monte Carlo results have relative uncertainty less than 0.4%.

- Not an issue for thermal systems

Comparison of Previous and New Guidance – Fast System

- Critical sphere of ^{239}Pu, radius=4.946 cm, density=19.82 g/cm^3
- Compare neutron and photon air kerma rate per fission rate 2 meters from sphere

Calculated Dose Rates for a Critical ^{239}Pu Sphere[a]

Dose Rates (Air Kerma – Gy/hr/fiss/sec)	XSDRN	MCNP5	MAVRIC CAAS	
			Previous Guidance	Revised Guidance
Neutron	6.00e-14	5.99e-14	5.99e-14	5.99e-14
Photon	2.23e-14	2.23e-14	3.31e-14	2.23e-14

[a] All Monte Carlo results have relative uncertainty less than 0.3%.

- Previous guidance over estimated photon dose by ~50%

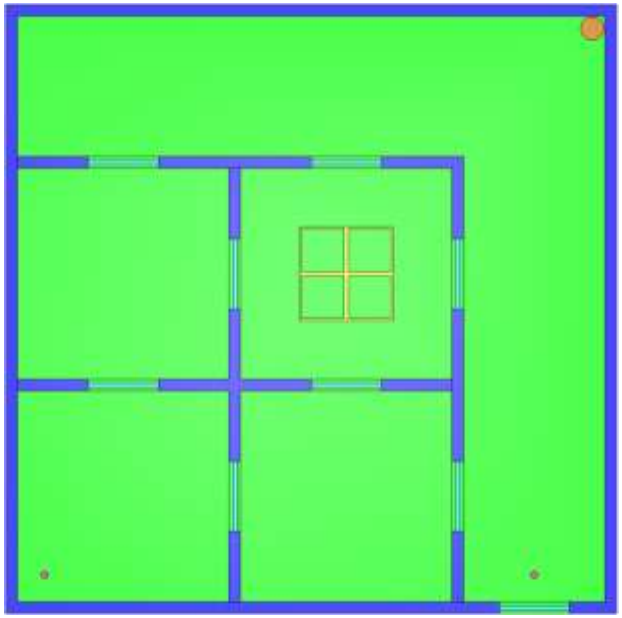
Minimum Accident of Concern – Fast System

- Use the calculated dose rate per fission rate for the fast system to calculate the minimum accident of concern based on ANSI/ANS-8.3 (0.2 Gy/min at 2 meters)

Determination of the Minimum Accident of Concern	
MAOC Previous Guidance (fissions/sec)	1.29E+14
MAOC New Guidance (fissions/sec)	1.46E+14

- The previous guidance underestimates the minimum accident of concern by ~13%

CAAS Detector Response – Fast System



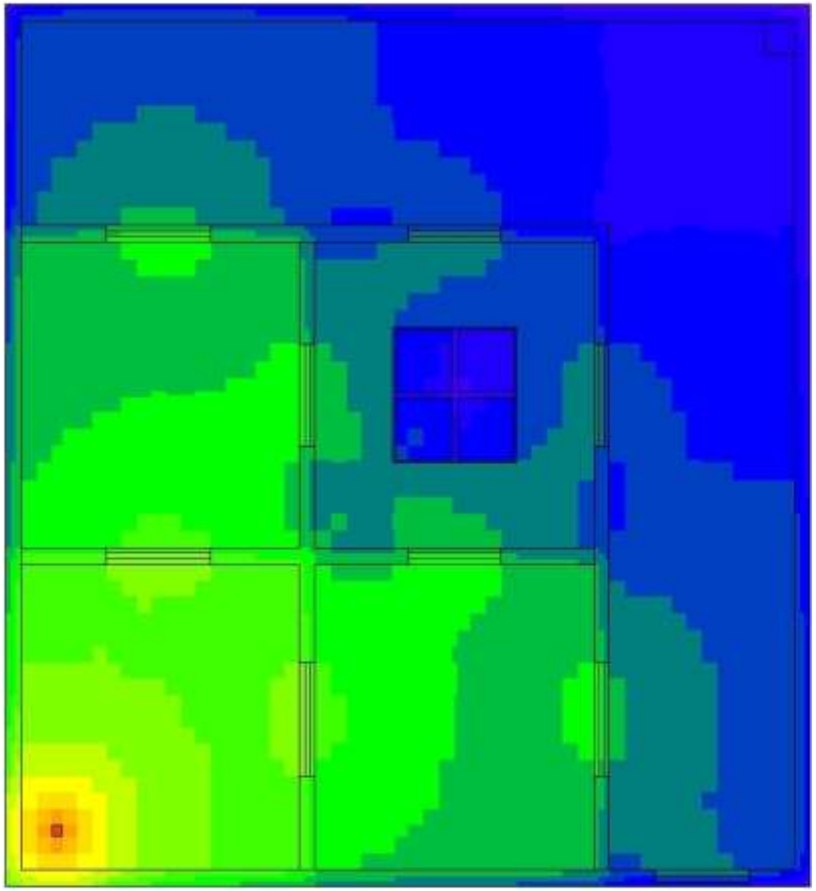
- What impact does the new guidance have on a CAAS detector response?
- Place ^{239}Pu sphere at two locations in a concrete building (dark blue), with steel doors (light blue), and lead glove boxes (yellow). Green is air.
- Calculate air kerma at CAAS detector (large sphere) in corner
- First location: small sphere bottom left, shielded location
- Second location: small sphere bottom right, unshielded location

Details About Building Model

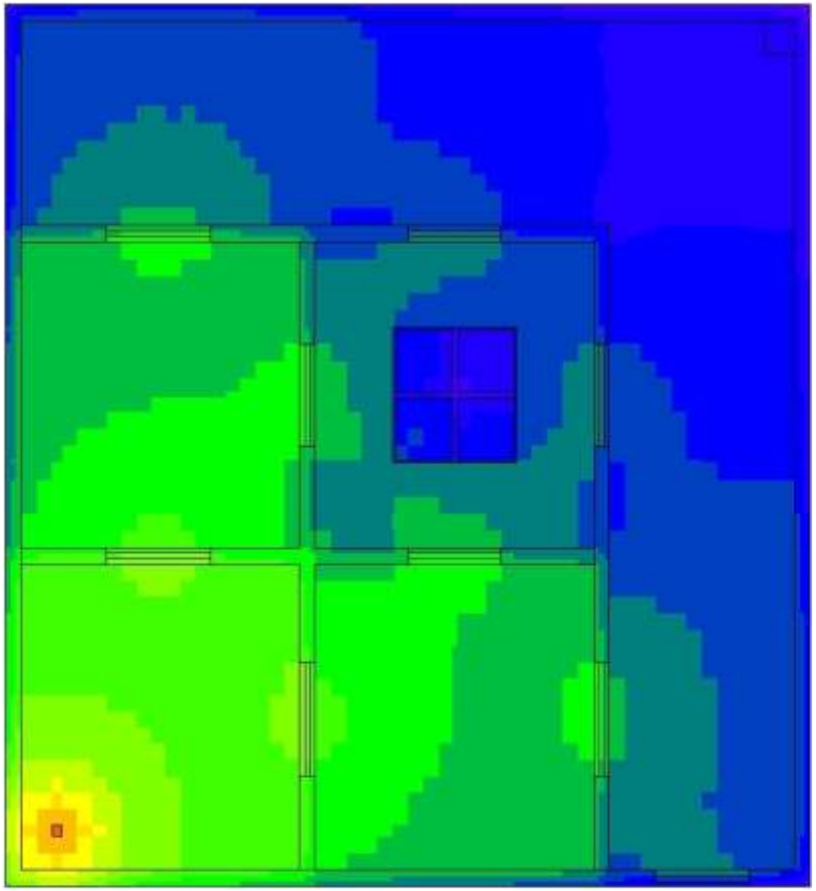
- Walls & ceiling: Oak Ridge concrete, 6 inches thick
  - Outside of building: 26 ft × 26 ft × 10.5 ft
  - 4 Rooms interior dimensions: 9 ft × 9 ft × 9 ft
- Floor: Oak Ridge concrete, 1 ft thick
- Doors: Stainless steel 304, 2 inches thick
  - Width: 3 ft
  - Height: 7 ft
- Glove boxes: Lead
  - External dimensions: 2 ft × 2 ft × 2ft
  - Wall thickness: 1 inch
- CAAS detector: sphere of air, 6 inch radius
- Center of CAAS, rooms, and glove boxes all at the same height

CAAS Detector Response – Fast System Dose Rate Mesh Tallies
(per fission)

Previous guidance



New guidance



CAAS Detector Response – Fast System Dose Rate Region Tallies

- Unshielded location
  - The difference in dose rate is ~4%, so the results are statistically the same on 95% confidence interval
  - Using the previous guidance the MAOC was low, but the photon dose rate per fission was high.
  - Therefore, the error in the previous CAAS guidance compensates for itself in unshielded scenarios (i.e., largely unaltered spectrum)
- Shielded location
  - The photon dose rate using the new CAAS guidance is ~15% greater
  - On the 95% confidence interval the difference between the previous and new dose rate is the same as the difference between the previous and new MAOC (~13%)
  - The dose is dominated by photons produced by neutrons near the CAAS detector, so for the shielded scenario the difference is driven by the difference in the MAOC

Calculated Photon CAAS Detector Reponse[a]

Photon Dose Rates (Air Kerma – Gy/min)	Previous Guidance	Revised Guidance
Shielded location	2.04e-3	2.35e-3
Unshielded location	3.14e-2	3.26e-2

[a] All Monte Carlo results have relative uncertainty less than 1%

Summary and Conclusions

- The new guidance for performing 3-D CAAS modeling with SCALE is the result of an incorrect interpretation/use of ENDF/B data
  - Fission photon production is not uniquely identified at all incident neutron energies
- This error has no impact on neutrons, and only effects photons in fast systems
- In the examples discussed…
  - The photon dose rate per fission rate was over estimated by ~50%
  - The MAOC is underestimated by the previous guidance by ~13%
  - An unshielded CAAS detector in a fast system is largely unaffected by this new guidance because the error compensates for itself
  - A shielded CAAS detector response, with dose dominated by secondary photons, underestimated the dose by ~15% with the previous guidance
    - This difference is driven by the difference in the MAOC