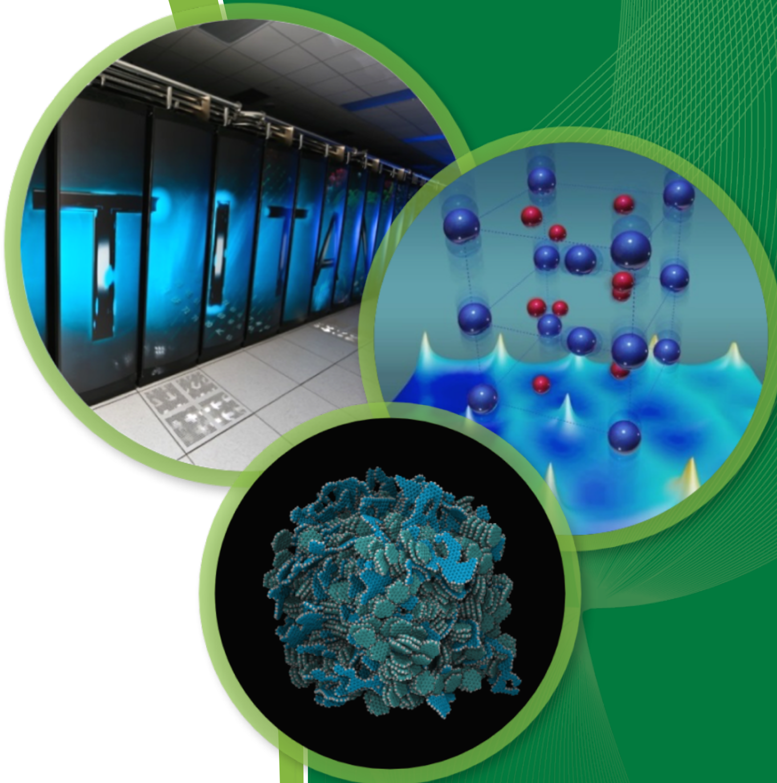
MAVRIC/Monaco Neutron Activation Simulations with Critical Sources



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2017 SCALE Users' Group

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Overview

- Introduction
- KENO and MAVRIC/Monaco input requirements
- Discussion of photons from critical sources
- Example results
  - ORNL Pool Critical Assembly (PCA), thanks to Bruce Patton
  - SILENE, assisted by Cihangir Celik
- Summary and conclusions

- Also, thanks to Douglas Peplow – I stole about half of this presentation from training slides he created

Introduction

- This capability makes it easy to simulate a critical source with Monaco
  - Coupling between KENO-VI and Monaco
  - KENO-VI writes mesh tally of fission neutron production
  - Monaco reads mesh tally data as fission neutron source
- Capability added to SCALE 6.0
- Primary reason for development of this capability
  - 3D Criticality Accident Alarm System (CAAS) analysis
- 3D replacement of CSAS1X
  - XSDRNPM eigenvalue simulation saves energy and angular dependent leakage
  - Leakage spectrum fixed source of second XSDRNPM simulation

Coupling between KENO-VI and Monaco

- KENO-VI (through CSAS6 sequence, MG or CE)
  - Calculates k_{eff}
  - Calculates $\bar{\boldsymbol{\nu}}$
  - Creates “fissionSource.3dmap”
- MAVRIC Utility: mt2msm converts mesh tally to mesh source
- MAVRIC
  - Uses “fissionSource.msm” as source
  - Transports neutrons and photons
  - Region tallies, point detector tallies, mesh tallies
  - Can use CADIS and FW-CADIS variance reduction

KENO-VI Criticality Calculation

Tell KENO-VI to store fissionSource.3dmap

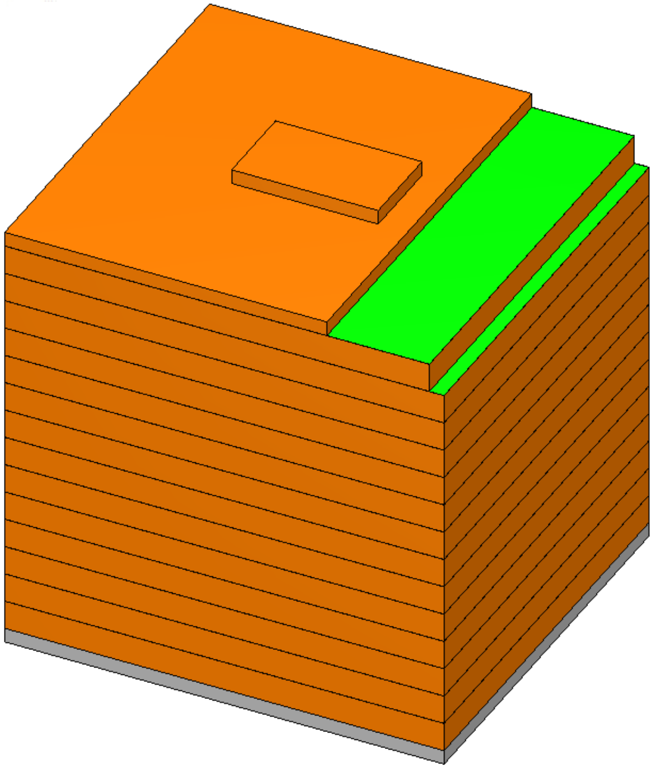
```
'----------------------------------------------------------------------------
' Parameters Block
'----------------------------------------------------------------------------
read parameters
    ...
    cds=yes  **or**  cds=1
` cds=# if you specify more than one grid geometry
end parameters
```

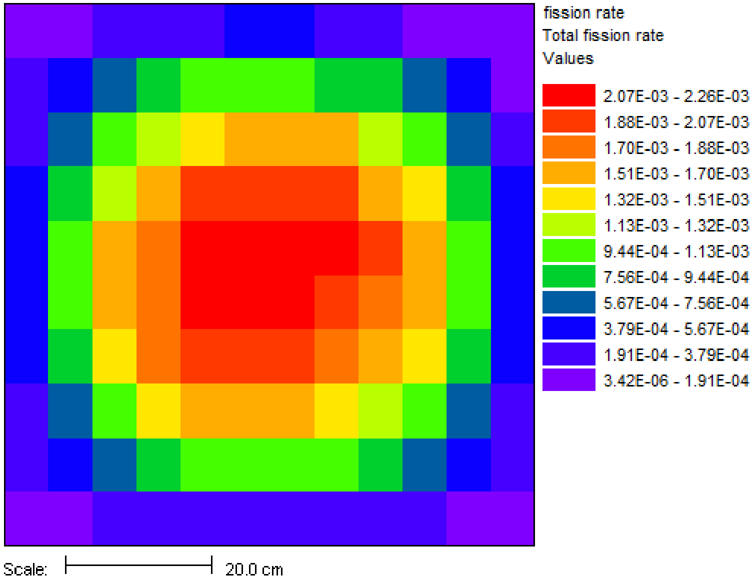
Specify the grid geometry for fissionSource.3dmap

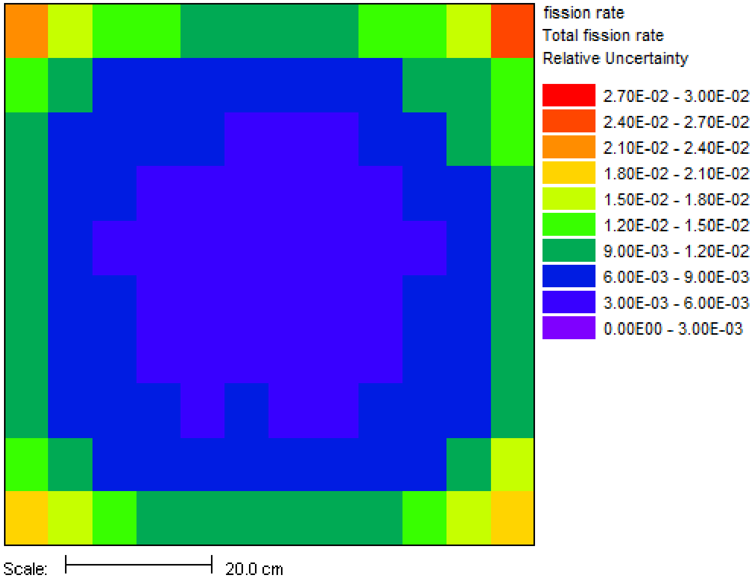
```
'----------------------------------------------------------------------------
' Grid Block - mesh grid for source
'----------------------------------------------------------------------------
read grid 1
    xLinear 10  -10.0 10.0
    yLinear 10  -10.0 10.0
    zPlanes -10.0 -8 -6 -4 -2 0 2 4 6 8 10 end
    title="easy grid"
end grid
```

KENO-VI Results

- KENO-VI calculates $\bar{\nu}$ and stores it in a file `kenoNuBar.txt`
- Use the Mesh File Viewer or Fulcrum to visualize the fission source neutron distribution *.3dmap





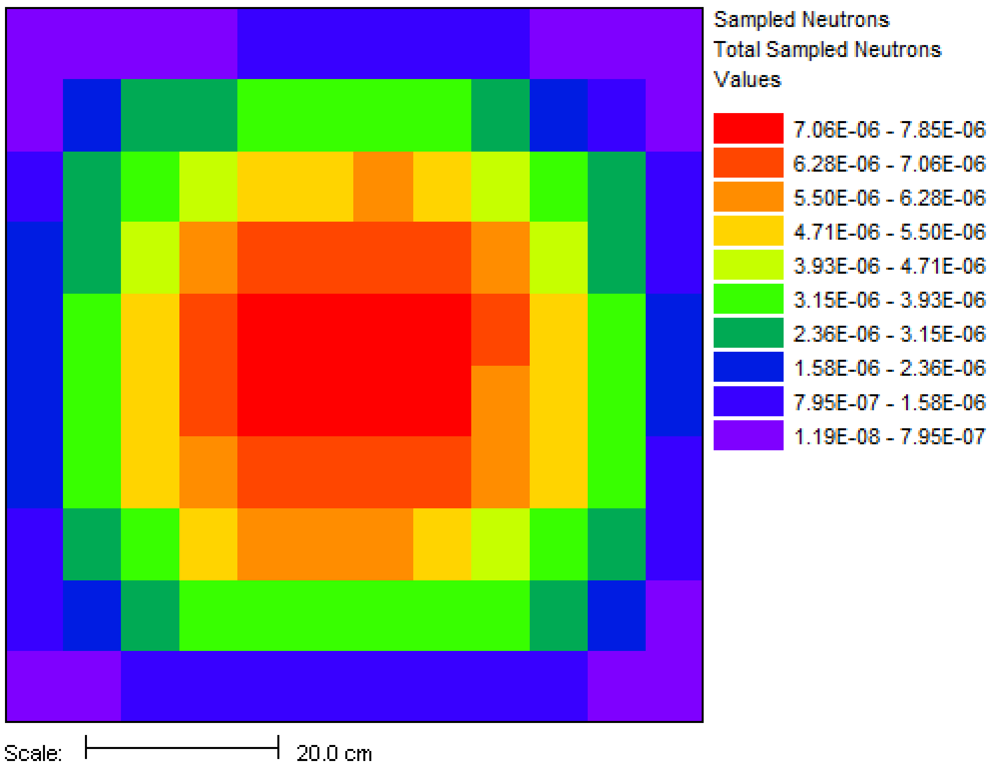


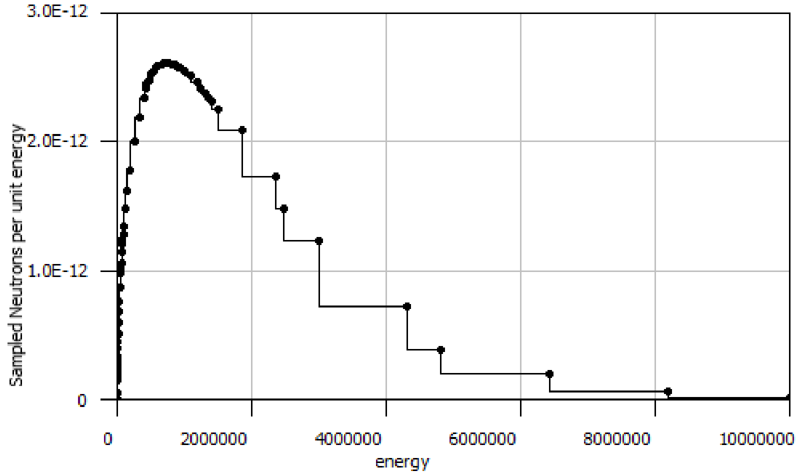
MAVRIC Utility: mt2msm

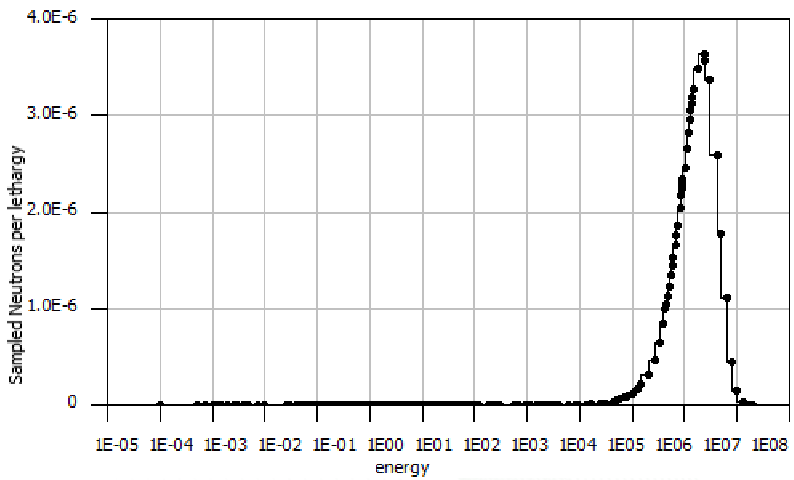
- Convert a *.3dmap into a *.msm file

```
'========================================================================
' Convert the mesh tally into a mesh source
'========================================================================
=mt2msm
‘C:\documents\fissionSource.3dmap‘    ! Mesh tally name
1                                     ! Family 1 of mesh tally
-1                                    ! -1 use all energy groups
1                                     ! Source: 1-neutron, 2-photon
'C:\documents\fissionSource.msm‘      ! Mesh source map name
end
```

Mesh Source Map







MAVRIC Shielding Calculation

Use the fissionSource.msm

```
'-----------------------------------------------------------------------
' Source Block - for 1e18 fissions
'-----------------------------------------------------------------------
read sources
    src 1
        meshSourceFile="fissionSource.msm"
           origin x=280 y=300 z=100
        fissions=1.0e18
           nu-bar=2.6
    end src
end sources
read parameters
    ...
' turn off neutron multiplication, turn on photon production
    fissionMult=0 secondaryMult=2
end parameters
```

Use importance map block for biasing. MAVRIC will create importance map and biased source using its cross section library group structure.

Neutron Activation Response Functions

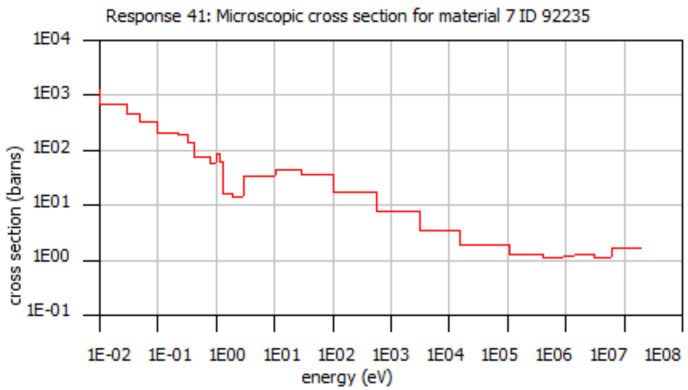
```
response 41
   title="Cross section from the library"
   material=7  ZAID=92235  MT=18
end response
```

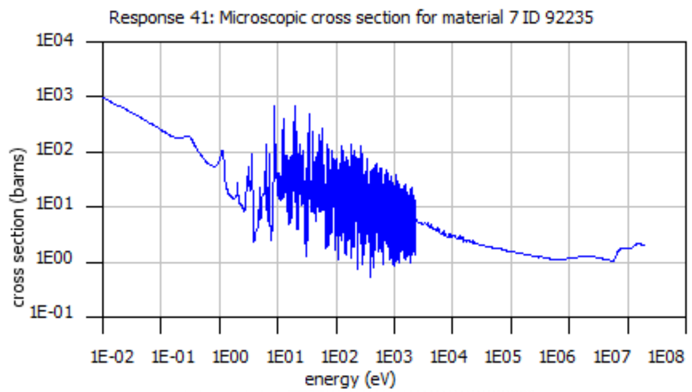
Or

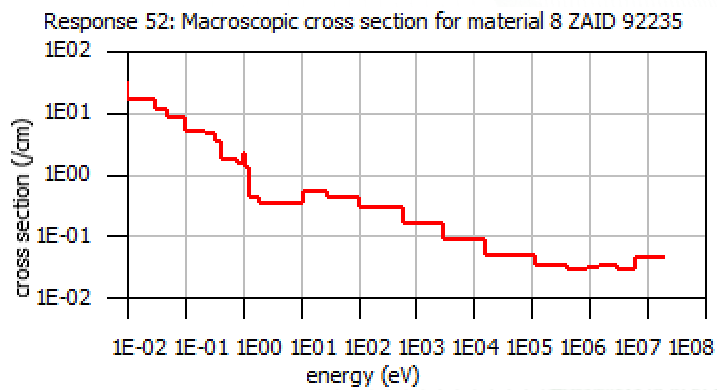
```
response 46
   title="Cross section from the library"
   material=7  MT=18  macro
end response
```

Or

```
response 52
   title="Cross section from the library"
   material=8  nuclide=U-235
     reaction=fission   macro
end response
```







Tally Examples – Neutron Activation Usually a Region Tally

```
read tallies
    pointDetector 7
        neutron
        locationID=2
        responseID=9029
    end pointDetector

    regionTally 8
        title="most important region in problem"
        photon   unit=2  region=8
        responseIDs 24 30 end
    end regionTally

    meshTally 1
        title="Mesh Tally with two responses"
        photon  gridGeometryID=1
        responseIDs 24 30 end
    end meshTally

end tallies
```

Common Items: KENO-VI and MAVRIC

- Cross Section Library
  - Can be the same, can be different
  - KENO-VI fissionSource group structure is converted when loaded by MAVRIC
- Materials
  - Can be the same, can be different
- Geometry
  - Can be the same, can be different
  - Origins can be offset, but not rotated
- Mesh grid
  - Can be the same, can be different
  - KENO-VI fissionSource grid geometry is converted when loaded by MAVRIC

Optional Fission Photons

- To model fission photons, the user needs
  - Keyword `secondaryMult>0` in the parameters block
- This is necessary because
  - KENO knows nothing about photons
  - Fission photon production can not always be fully correlated to fission events with ENDF/B-VII.1 (and earlier) data
- Fission photon production data for U-235 (ENDF/B-VII.1)
  - Neutrons <= 1.09 MeV that cause fission (MT 18) produce photons via MT 18 production channel
  - Neutrons > 1.09 MeV produce no photons via MT 18
  - Photon production for Neutrons > 1.09 MeV all via MT 3, non-elastic neutron interactions

Example 1: ORNL Pool Critical Assembly (PCA, Bruce Patton)

- The PCA was one of ORNL's "swimming pool" reactors over in the 3000 area (next to the graphite reactor)
- In the same pool as the Bulk Shielding Reactor (BSR)
- Could use Material Test Reactor (MTR) AND Oak Ridge Research Reactor (ORR) fuel elements
- Could operate up to 10 kW
- In 1981 NRC published a report on LWR Pressure Vessel Surveillance Dosimetry experiments at the PCA with the Pressure Vessel Wall Benchmark Facility (PVWBF)
- In 1997 Igor Remec published an ORNL TM providing a benchmark model of these experiments

Images of the PCA PVWBF

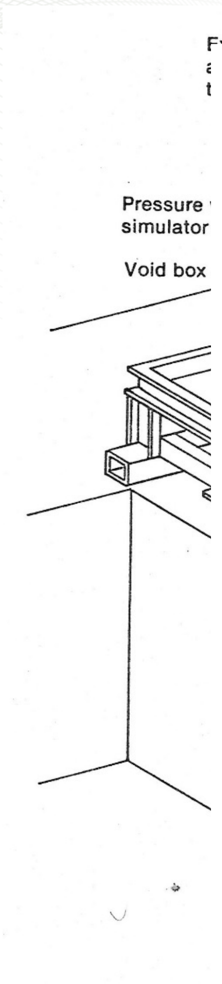
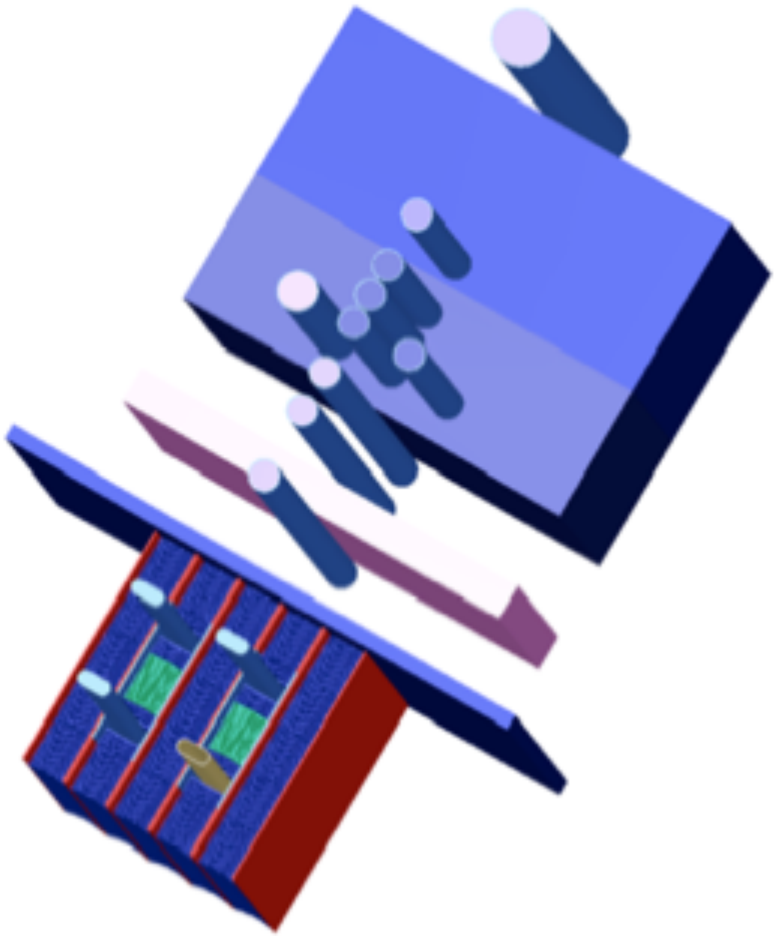


FIGURE 1.1.1. PCA



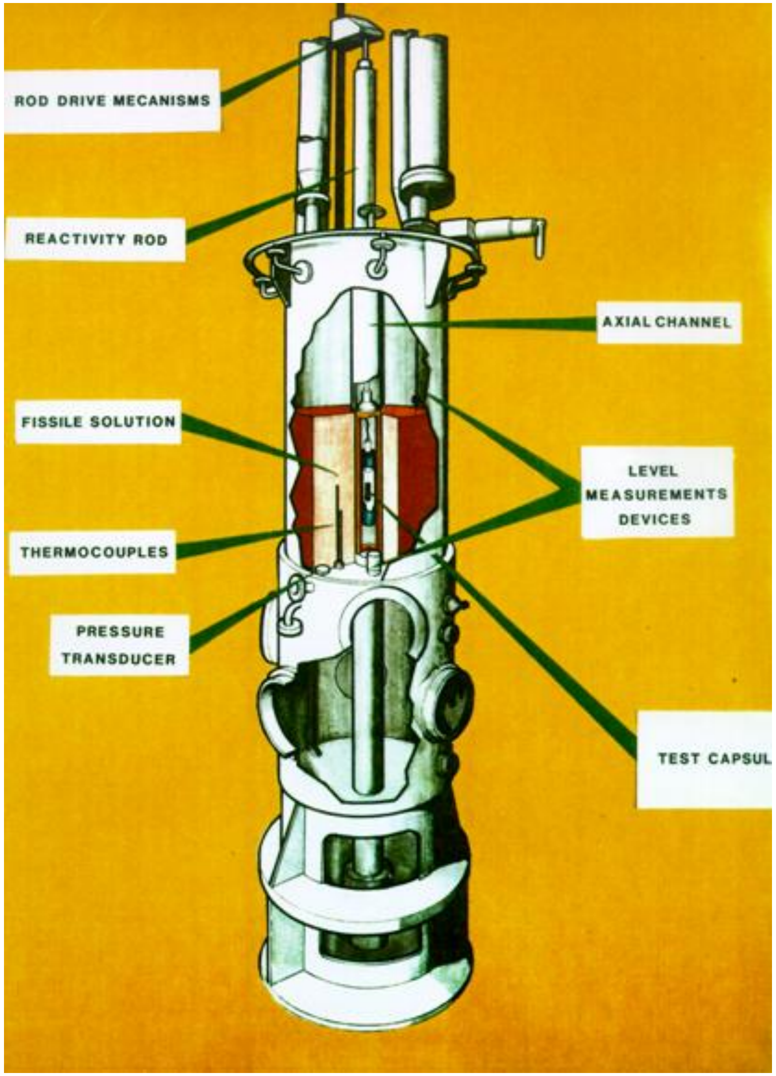
Compare Simulation and Measurement
(Some of the “worst” results that are actually very good)

$^{237}Np(n,f)^{137}Cs$ Results				
Experiment tube position	Distance from core (cm)	Experimental fission equivalent flux	MAVRIC/Monaco fission equivalent flux VITAMIN-B7	VITAMIN-B7 C/E ratio
A1	12.0	6.64E-06	6.92E-06 (0.55%)	1.04
A3	29.7	2.27E-07	2.66E-07 (0.61%)	1.17
A4	39.5	9.27E-08	9.69E-08 (0.46%)	1.05
A5	44.7	5.18E-08	5.37E-08 (0.45%)	1.04
A6	50.1	2.70E-08	2.78E-08 (0.54%)	1.03
A7	59.1	7.25E-09	8.12E-09 (1.3%)	1.12

$^{115}In(n,n')^{115m}In$ Results				
Experiment tube position	Distance from core (cm)	Experimental fission equivalent flux	MAVRIC/Monaco fission equivalent flux VITAMIN-B7	VITAMIN-B7 C/E ratio
A1	12.0	5.61E-06	5.92E-06 (0.74%)	1.06
A2	23.8	6.06E-07	6.49E-07 (0.75%)	1.07
A3	29.7	1.99E-07	2.26E-07 (0.84%)	1.14
A4	39.5	5.87E-08	6.63E-08 (0.63%)	1.13
A5	44.7	2.76E-08	3.08E-08 (0.64%)	1.12
A6	50.1	1.17E-08	1.34E-08 (0.81%)	1.15

Introduction to SILENE

- Annular core
  - Internal cavity diameter 7 cm
  - Outer fuel diameter 36 cm
  - Typical critical height ~35 – 45 cm
- Uranyl Nitrate fuel Solution
  - ~93% ^{235}U
  - ~71 g of uranium per L
- Power level ranges from 10 mW to 1000 MW
- Three operating modes
  - Single pulse
  - Free evolution
  - Steady State

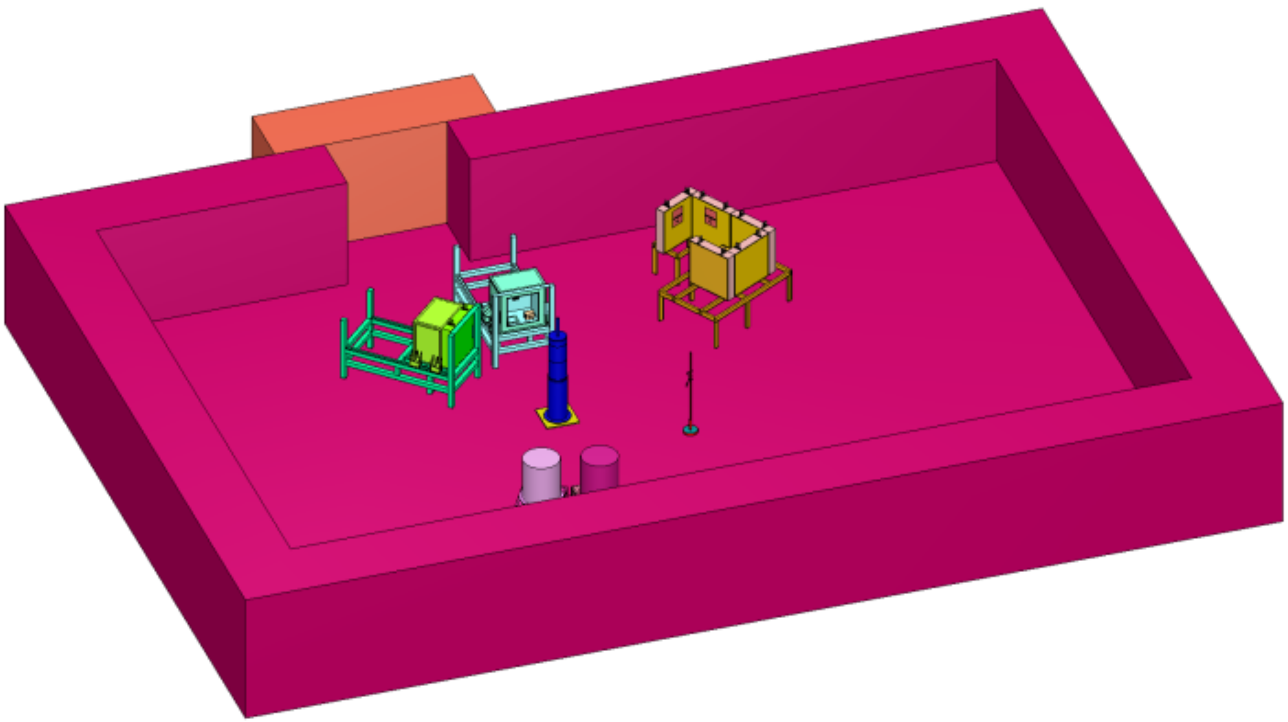


Photographs of bare SILENE and pulse 1 cell configuration

Experimental configuration

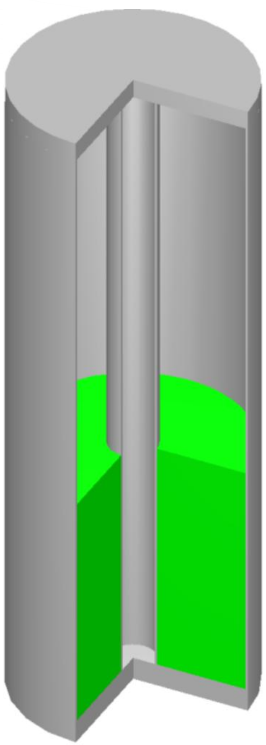
- Pulse 1
  - SILENE bare (no reflector)
  - Collimator A – unshielded
    - Full set of neutron activation foils
    - Valduc Al_2O_3, ORNL HBG & DXT TLDs
    - CIDAS and Rocky Flats CAAS

Scale model of pulse 1 geometry

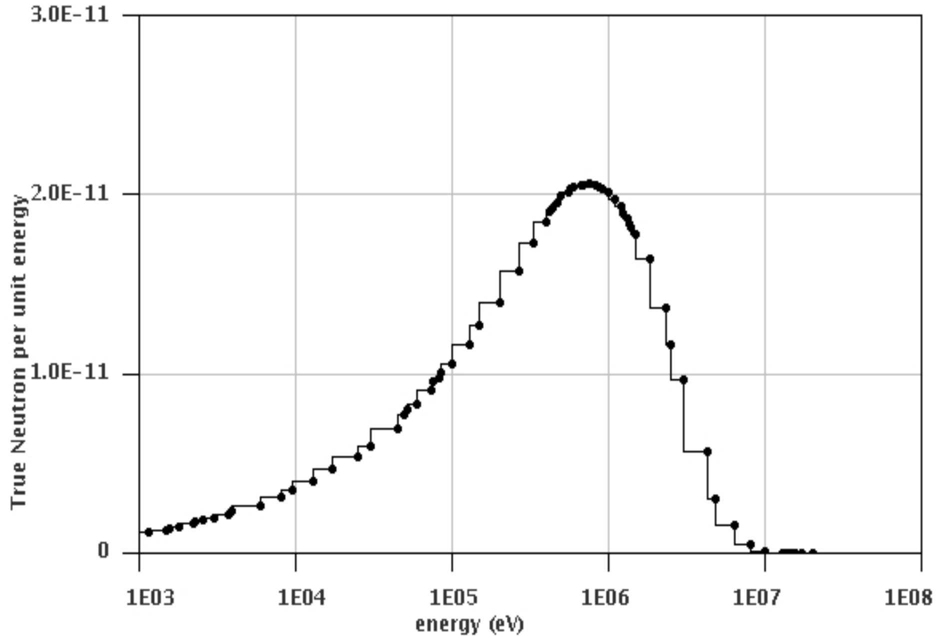


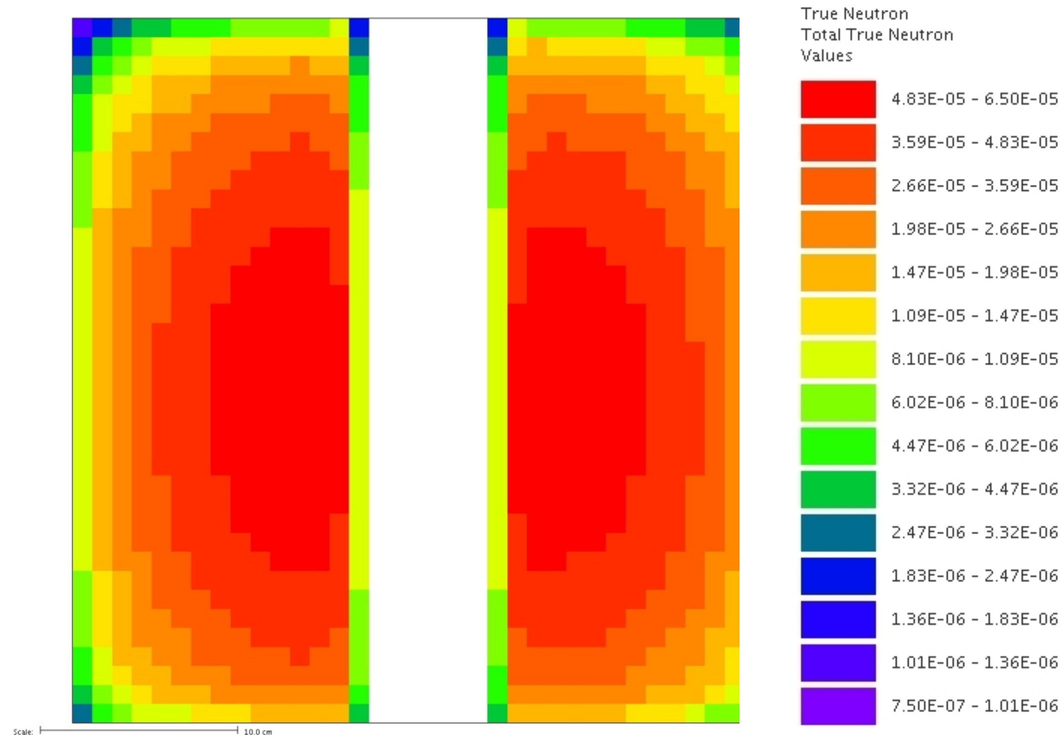
KENO-VI Calculation

Quantity	Value	Uncertainty
k_{eff}	1.02320	0.00002
$\bar{\nu}$	2.43755	2.51e-7

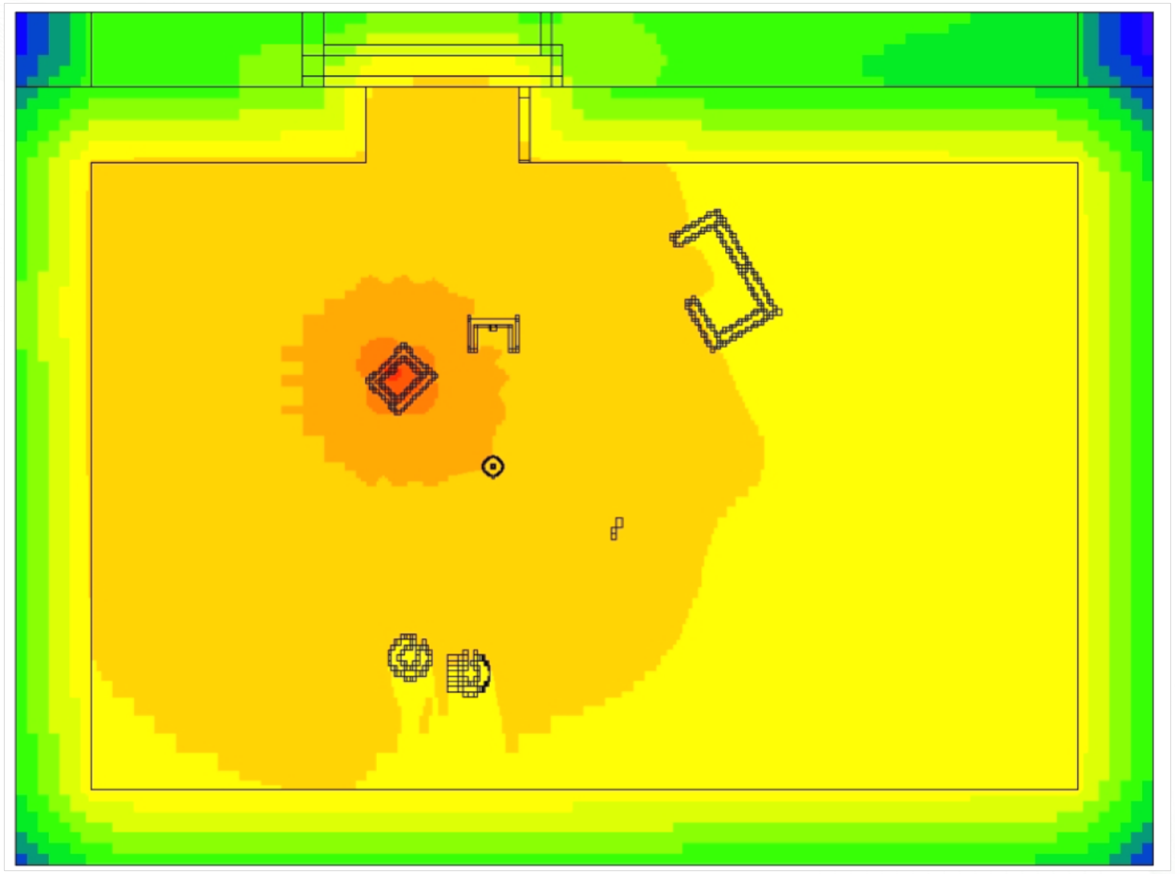


SILENE critical height ~ 37.36 cm

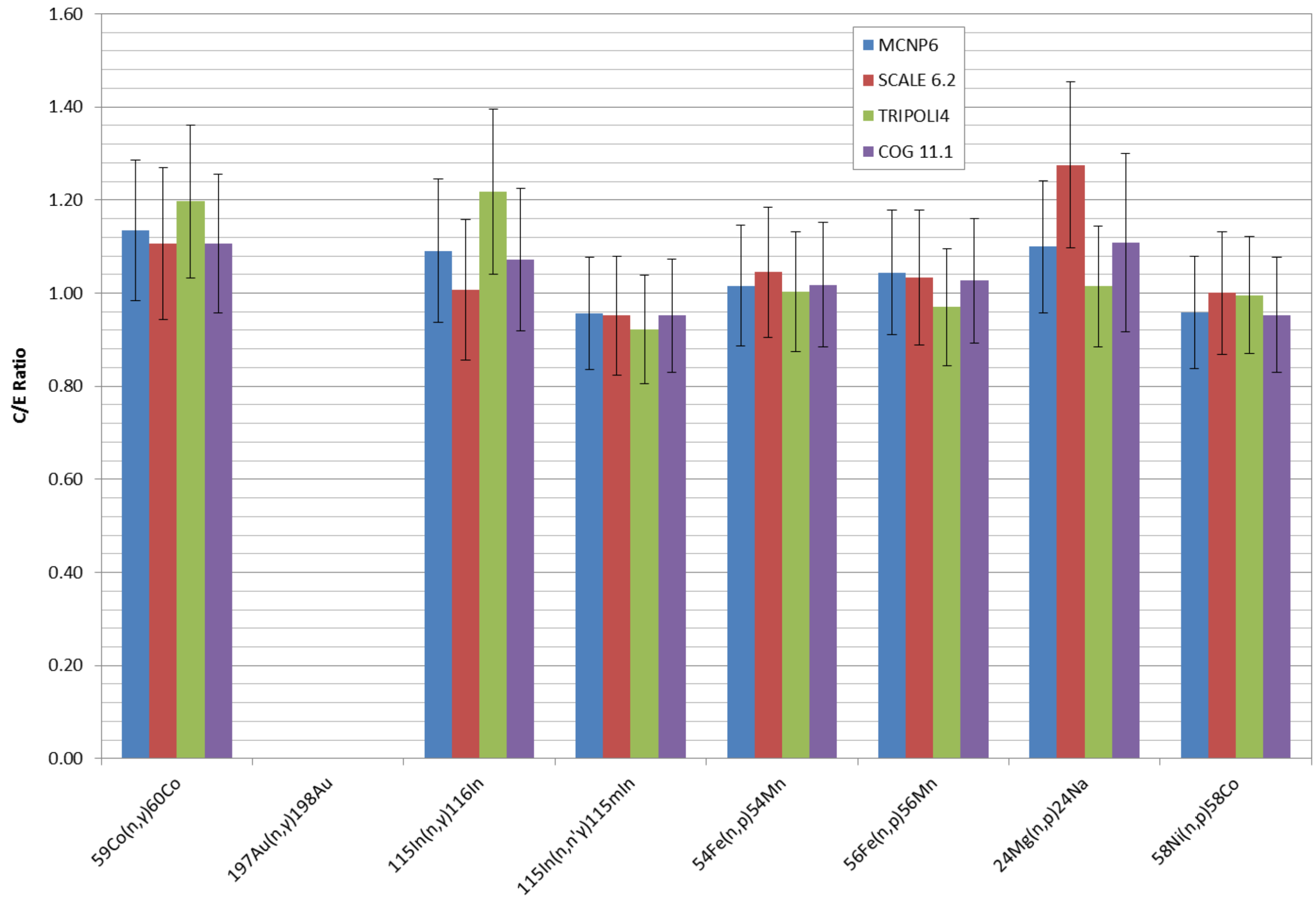




MAVRIC/Monaco Calculation
(Importance map)



Compare Simulation and Measurement
(Some of the best results)



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Summary and Conclusions

- “Shielding” simulations with a critical source are problematic if variance reduction is needed
  - Initial reaction by some is to apply variance reduction to an eigenvalue simulation
  - However, one must be careful to not interfere with convergence of the fission source
  - In other words, you cannot use source biasing
- Coupling KENO-VI and MAVRIC/Monaco allows you to
  - Accurately calculate a fixed sourced for a critical system
  - Apply CADIS or FW-CADIS
- At this point KENO, like ORIGEN, is just one more subroutine in SCALE to generate sources for MAVRIC/Monaco