

MAVRIC/Monaco

SCALE 6.3.1

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

Learning goals

- Introduce attendees to fixed-source / shielding simulations
- Introduce attendees to variance reduction (VR) techniques
- Introduce attendees to the MAVRIC sequence
- Identify the information required to build a computational model of a fixed-source / shielding problem
- Introduce the attendees to the text-based MAVRIC/Monaco input
- Review the different MAVRIC/Monaco output files and plotting packages

Shielding calculations: Monte Carlo basics



Learning goals

- Review the statistical nature of Monte Carlo simulations
- Review the strengths and weaknesses of Monte Carlo simulations for shielding problems
- Introduce attendees to VR techniques commonly available in Monte Carlo codes and identify which are available in MAVRIC/Monaco

Shielding calculations

- Calculation of radiation transport through materials
- Usually a fixed source; can involve multiplication
- Desired output – usually dose or dose equivalent rates
- Can be very deep penetration (fluxes may be attenuated by many orders of magnitude)
- Methods
 - Point kernel (historical)
 - Discrete ordinates
 - Monte Carlo

Monte Carlo simulation

- Simulates individual particles interacting (e.g., scattering or being absorbed) in materials by random sampling
- History: start with a source particle, follow it as it makes contributions to various responses (random walk)

- Final answer is an average of all histories $\bar{x} = \frac{1}{N} \sum x_i$
- Final answer has statistical uncertainty; similar to detector counting statistics $\sigma_{\bar{x}} = \frac{1}{\sqrt{N}} \sqrt{\frac{1}{N} \sum x_i^2 - \bar{x}^2}$

Monte Carlo simulation (cont.)

- 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 the problem, number of results (tallies), level of geometry detail
- Difficult problems
 - Streaming
 - Highly scattering
 - Deep penetration

Examples of Monte Carlo (MC) codes

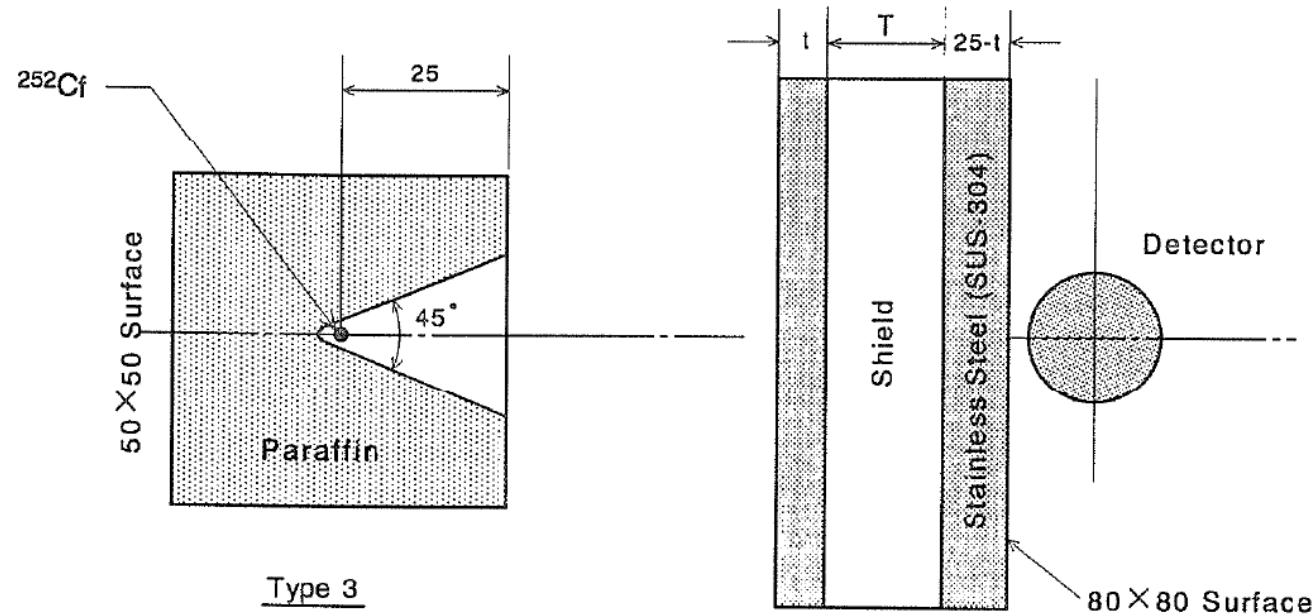
- Monaco/KENO/Shift – Oak Ridge National Laboratory
- MCNP/MCNPX – Los Alamos National Laboratory
- VIM – Argonne National Laboratory
- COG, TART – Lawrence Livermore National Laboratory
- ITS – Sandia National Laboratory
- Serpent – VTT Technical Research Centre of Finland
- OpenMC – Computational Reactor Physics Group at MIT
- EGS, EGSnrc – SLAC National Accelerator Laboratory
- FLUKA – The FLUKA team
- Geant – Geant4 Collaboration

Monte Carlo codes (cont.)

- Different geometry descriptions
- Different energy treatments (continuous versus multi-group)
- Different energy regimes
- Different particles (neutrals, charged, exotic)
- Different levels of user programming

Variance reduction (VR)

- Changes to the physical random walk to get more particles to add score to the result
- Scores are now weighted to account for the probability of this history occurring in an analog simulation

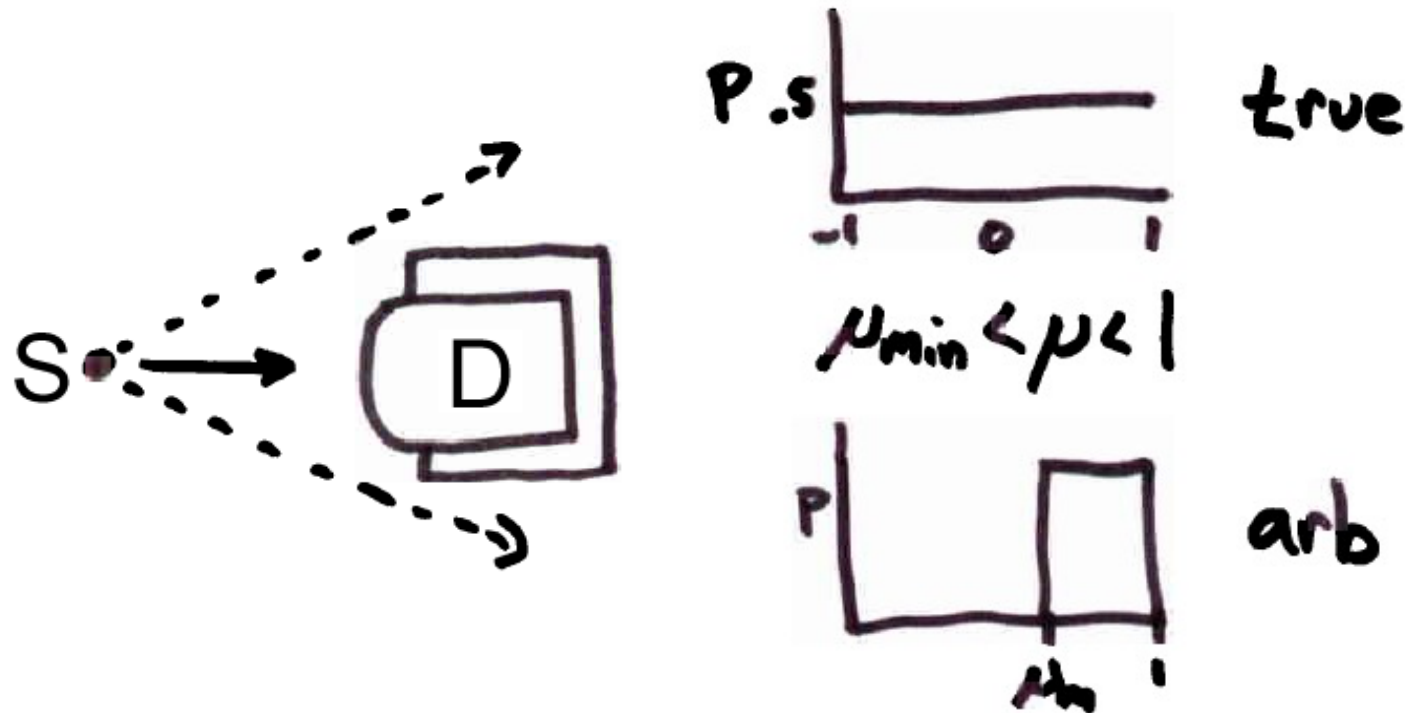


Ueki shielding measurements
K. Ueki et al.,
"Systematic Evaluation of Neutron Shielding Effects
for Materials," Nuclear Science and Engineering, vol.
124, no. 3, pp. 455-464, 1996.

VR methods – forcing

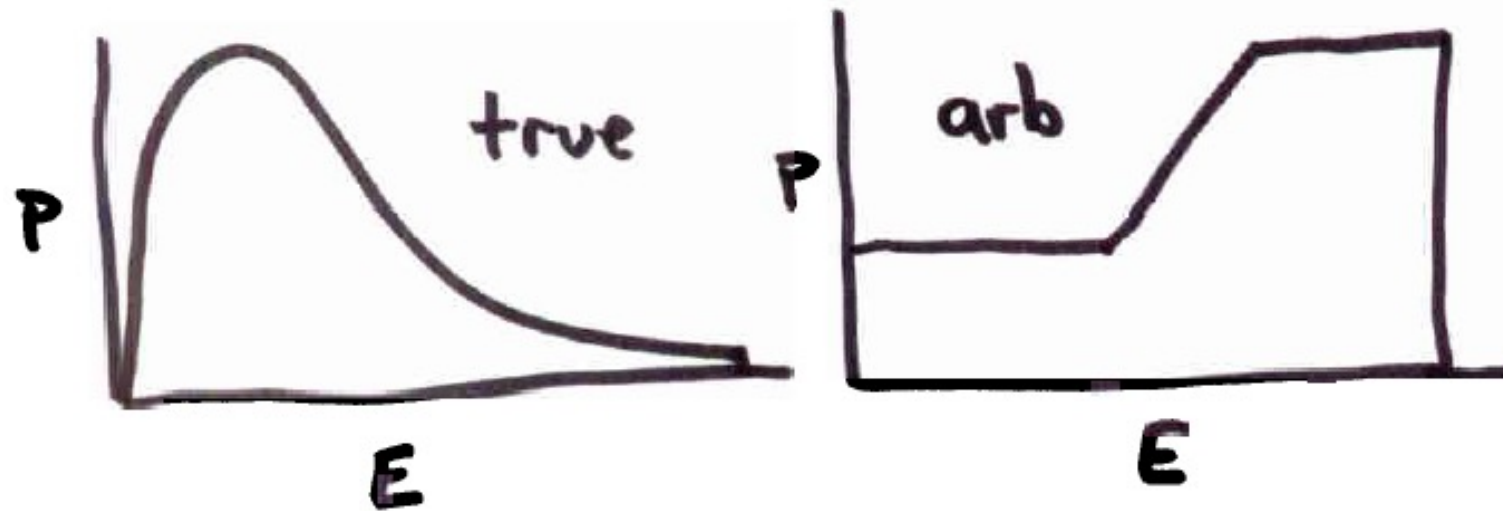
- Force a particle to do something when the alternative never leads to a score

Example – only start source particles in “direction of interest”



VR methods – source biasing

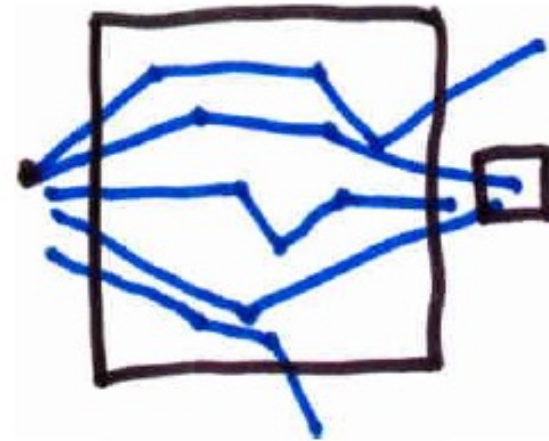
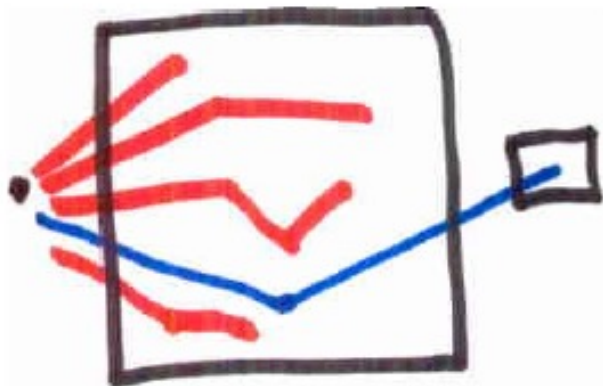
- Pick more source particles with desired energy, direction, and starting location
- Weight is true probability density function (pdf)/arbitrary pdf



VR methods – Implicit capture

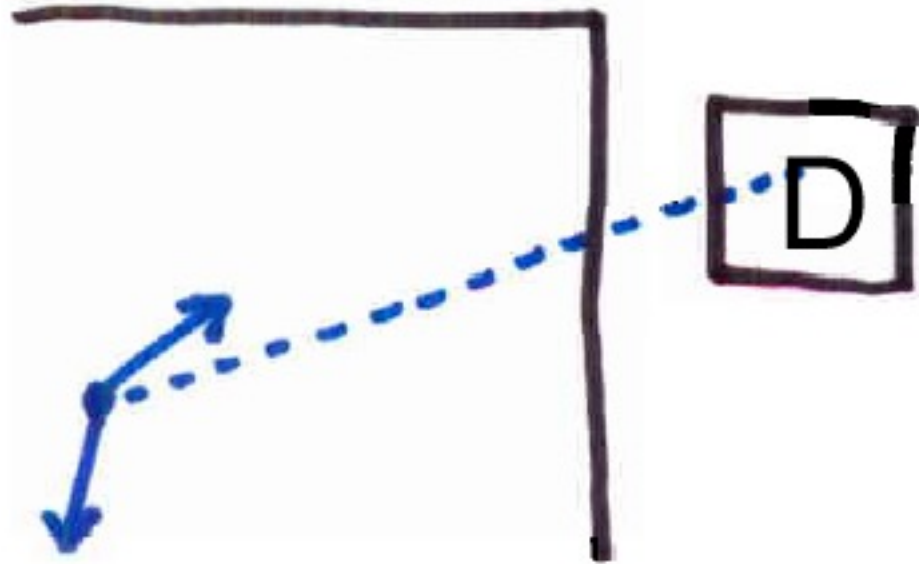
- Do not let particles get absorbed
- Instead, reduce weight and keep tracking
- This requires roulette to handle very low weight particles: either remove them or increase their weights

$$w' = w \frac{\sigma_s}{\sigma_a + \sigma_s}$$



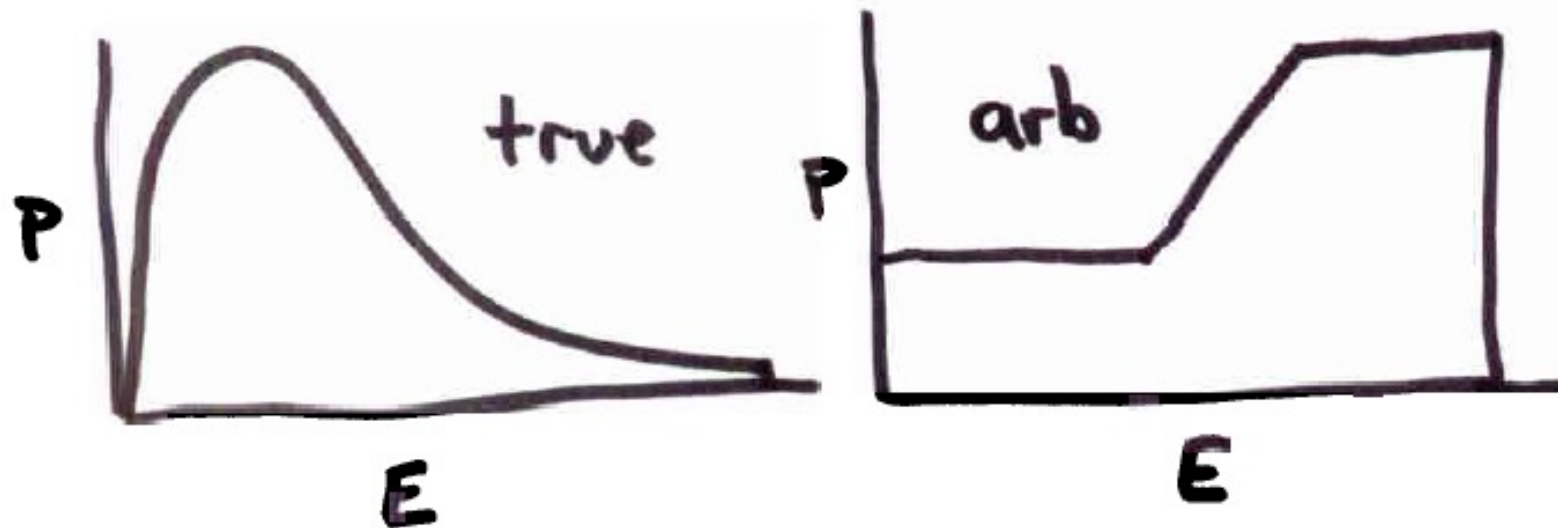
VR methods – path length stretching

- Also known as exponential transform
- If a particle is going toward the response area, then reduce the cross section (to increase the mean free path length) and reduce the particle weight



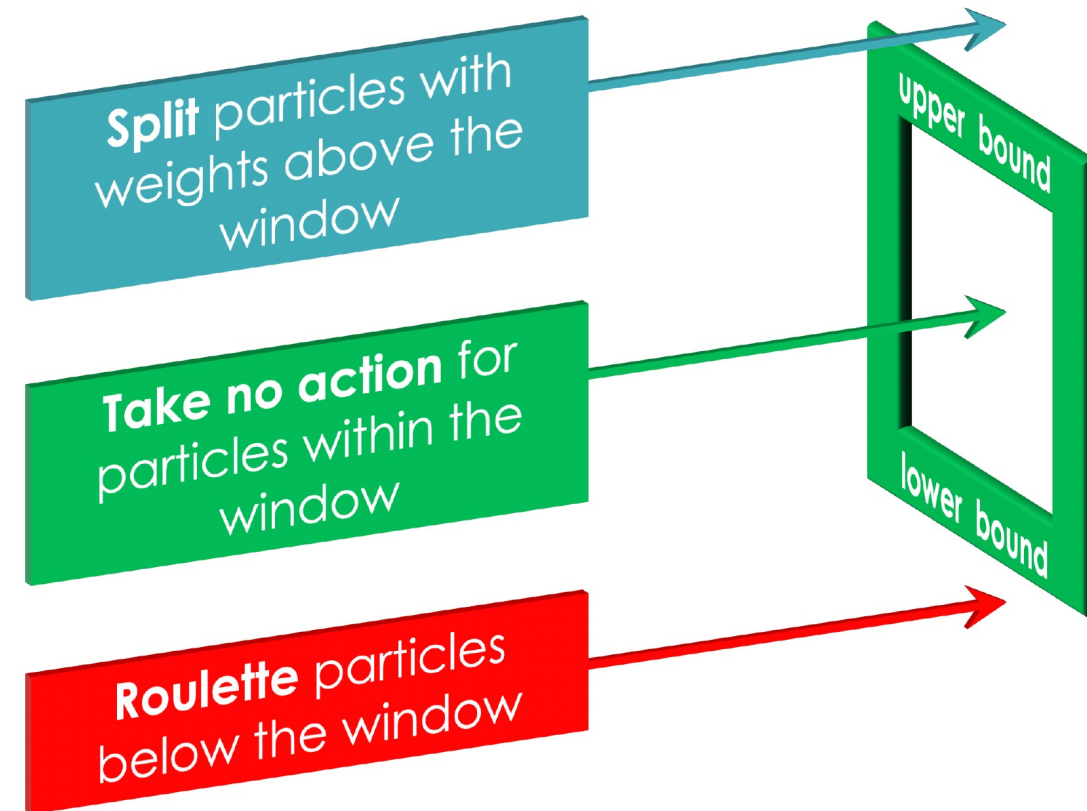
VR methods – PDF biasing

- Change certain PDFs (scattering angle, energy change, etc.) to get more particles to score
- Weight is true PDF/arbitrary PDF
- Must be careful not to use competing methods



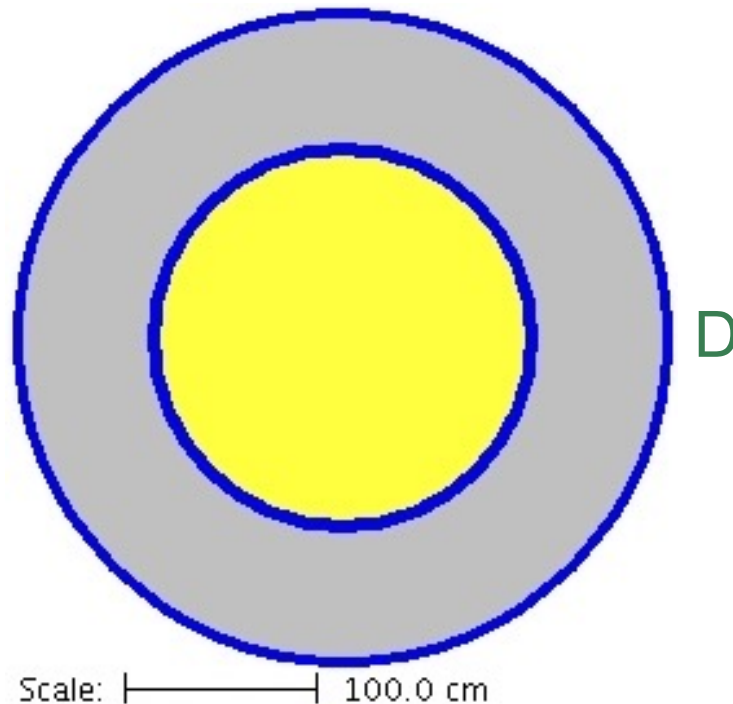
VR methods – weight windows

- Assign spatial and energy region importance
- As a particle crosses a boundary, the weight is compared to the weight target
- High-weight particles are ‘split’ into multiple lower-weight particles
- Low-weight particles are rouletted (either the history is terminated, or it is continued with an increased particle weight)

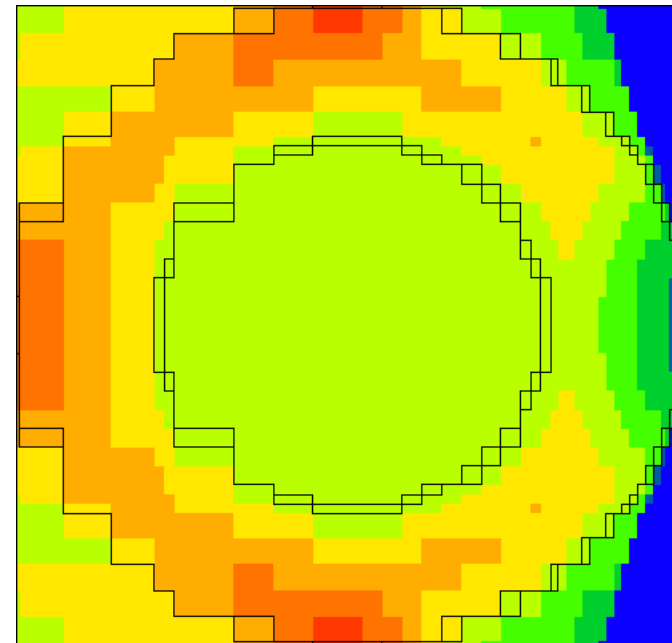


VR methods – importance map (adjoint)

- Uses the importance of a particle (i.e., space, energy, direction) to set weight windows: high importance → low target weight



Particle Weights



VR methods – summary

- Requires knowledge about how the calculation will most likely proceed
- May require an iterative process to tune biasing
- “Bad” biasing can slow the rate of convergence
- Automated VR would be nice

Importance sampling

- If the exact importance is known, then we do not need a Monte Carlo simulation — we could just convolve the true source distribution with the adjoint function
- True importance (adjoint) is just as difficult to compute as the original problem
- Fortunately, an approximate importance map can be used as weight window targets to greatly accelerate the convergence of the forward MC simulation
- CADIS, Consistent Adjoint Driven Importance Sampling, creates an importance map and source biasing that work together

Importance sampling (cont.)

- MCNP – stochastic weight window generator
- ADVANTG – uses 3D TORT, CADIS methodology, and MCNP
- MAVRIC – uses 3D Denovo, CADIS methodology, and Monaco
- ADVANTG 3.0 – uses 3D Denovo, CADIS methodology, and MCNP

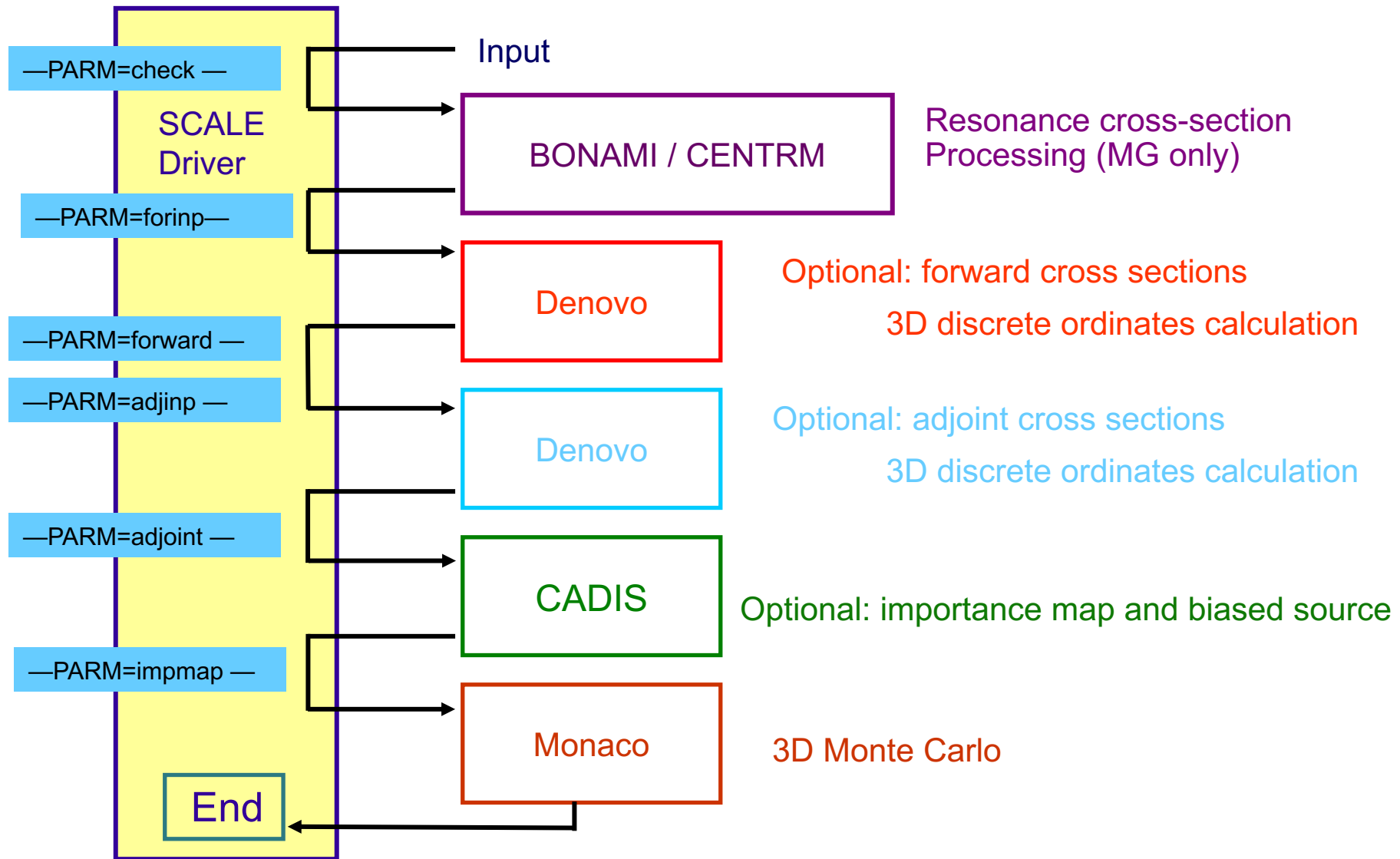
SCALE: Monaco/MAVRIC

Introduced in SCALE 6 (released: Jan 2009)

- Monaco – multi-group Monte Carlo transport
 - Based on MORSE physics (predates SCALE and later included in SCALE)
 - SCALE General Geometry Package (SGGP), same as KENO-VI
 - Continuous-energy physics added for 6.2 (Jun 2016)
 - Parallel processing enabled for MAVRIC-Shift in 6.3 (Jan 2022)
- MAVRIC – Monaco with Automated Variance Reduction using Importance Calculations
 - Computes cross sections
 - Performs a Denovo adjoint calculation, forms an importance map and biased source distribution
 - Runs Monaco



Sequence MAVRIC calls Monaco



Elements of a shielding calculation

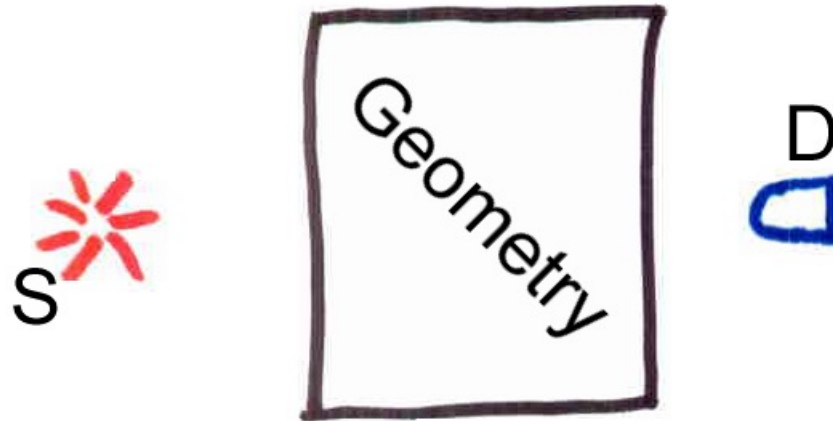
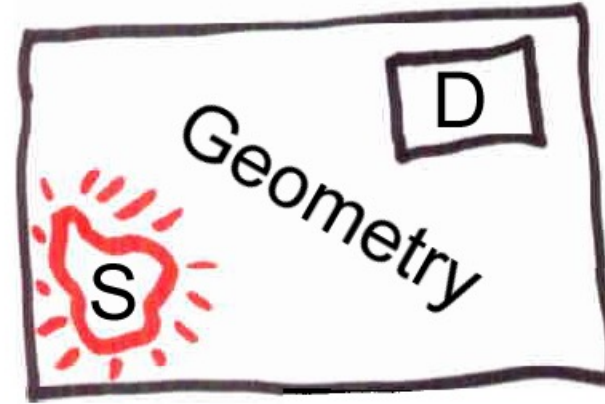


Learning goals

- Identify the information required to build a computational model of a fixed source / shielding problem

Elements of a shielding calculation

- Physical model
- Source
- Response
- Computational parameters

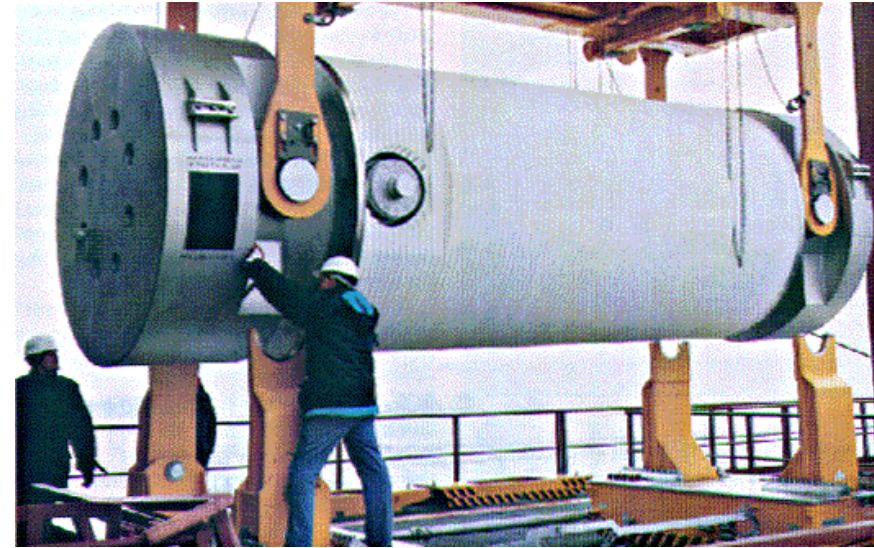


Physical model

- Geometry description
 - Boolean operation of solid and surface equations
 - CAD format – faceted surfaces
- 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



Example of a transportation container for radioactive materials
BMT, CargoHandBook, www.cargohandbook.com



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 (x,y,z) , E , Ω , etc.



Computational parameters

- Minimum accuracy
- Maximum runtime
- Problem truncation
- VR

MAVRIC Input



Learning goals

- Introduce attendees to the text-based MAVRIC/Monaco input file when using standard biasing techniques
 - Identify where in the MAVRIC/Monaco input file to enter information required to build a computational model of a shielding problem
 - Additionally, identify the MAVRIC/Monaco syntax used to enter information required to build a computational model of a shielding problem
- Review the different MAVRIC/Monaco output files and identify the location of different types of requested output
- Introduce attendees to the SCALE plotting packages applicable to MAVRIC/Monaco output and demonstrate how to create commonly used output plots

MAVRIC input

- Material compositions, CellData processing (XSProc)
- Geometry: Regions made of intersections of solids, arrays, volumes (same as KENO-VI)
- Definitions: Locations, Response Functions, Grid Geometries, Distributions
- Sources description: spatial, energy, direction
- Tallies: region tallies, point detectors, mesh tallies
- Basic calculational parameters
- VR parameters

MAVRIC input: Block format

```
=mavric      parm=keyword  
Some title for this problem  
v7.1-28n19g
```

```
read compositon  
  ...  
end composition  
read celldata  
  ...  
end celldata
```

```
read geometry  
  ...  
end geometry  
read array  
  ...  
end array  
read volume  
  ...  
end volume  
read plot  
  ...  
end plot
```

```
read definitions  
  ...  
end definitions  
read sources  
  ...  
end sources  
read tallies  
  ...  
end tallies  
  
read parameters  
  ...  
end parameters  
read biasing  
  ...  
end biasing  
read importanceMap  
  ...  
end importanceMap  
  
end data  
end
```

MAVRIC input: Keyword input style

- Single values

- `batches=1000`
- `strength=6.7e15`

- Array values

- `abscissa 27r1.0 19r0.0 end`
- `yPlanes 15.0 20.0 25.0 50.0 end`

- Fixed-length parameter list

- `cuboid 10 0 20 0 30 0`
- `xShellCylinder 0 10 -35 35`

- Keywords without values

- `firstCollision`

- Text Strings

- `title="cool program, eh?"`
- `sourceMeshFile="C:\My Documents\source.msm"`

**SCALE is not
case sensitive***

***except in places
where it is**

MAVRIC input: Basics

Format:

=Sequence name

Problem title

SCALE Library name

- Denovo **always** uses this library;
Monaco **might** use this library
- “library” or “ceLibrary” keywords in
parameters block override this library for
Monaco, which is useful for coarse
group Denovo and fine group Monaco
(mixing group structures for speed)

Example:

```
=mavric
```

```
Some long title for this particular  
problem
```

```
v7.1-28n19g
```

Always a multigroup library!

Material composition block

- Standard composition – from SCALE library
- Arbitrary compound – using any isotope from SCALE library
 - Atomic fractions (atom)
 - Weight percents (wtpt)
- Solution (soln) – mixture of SCALE library solutions

Composition block example

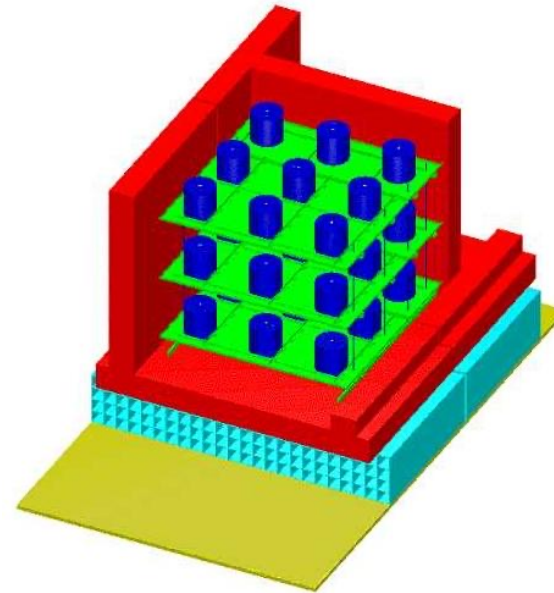
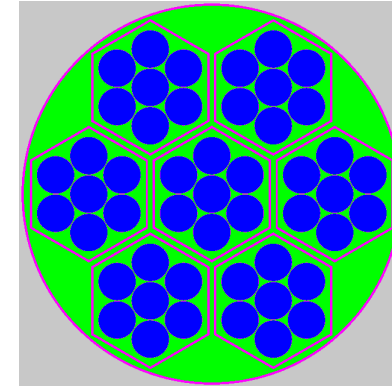
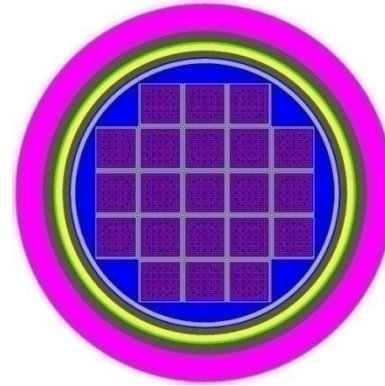
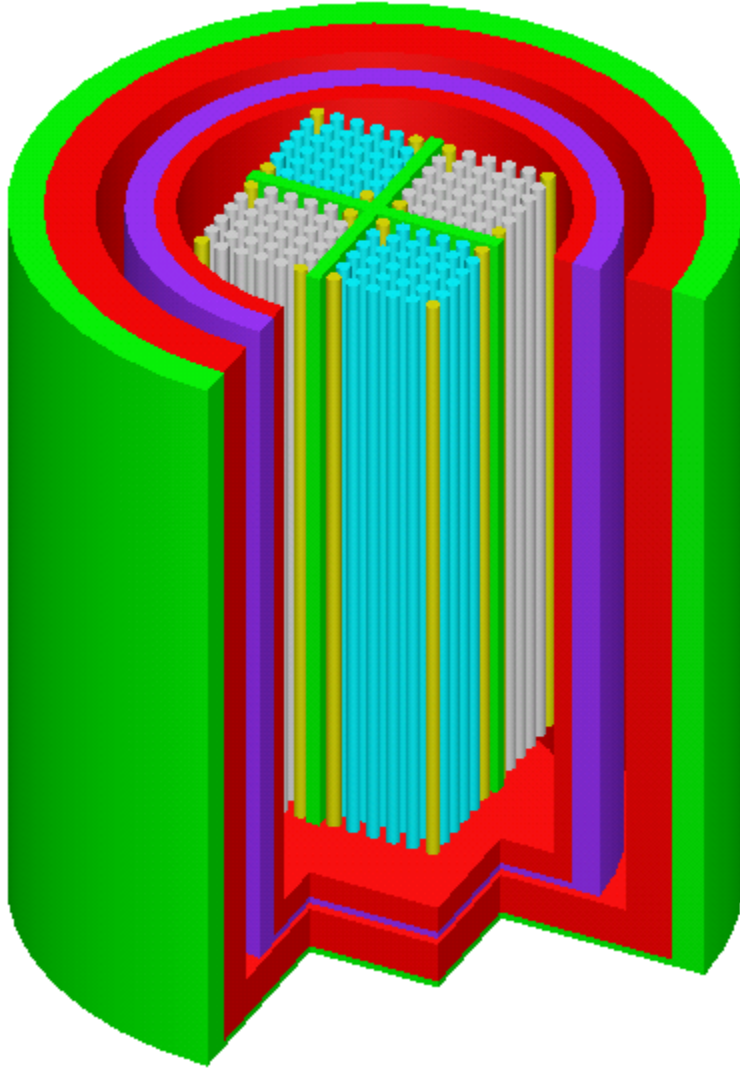
```
read composition
  para(h2o)    1 1.0 293    end

  wtptkrafton 2 1.7 16
    1000 4.21    3000 1.82    5000 7.12    6000 24.07
    7014 0.6     8016 28.38   12000 6.16   13000 3.7
    14000 0.46   16000 0.43   19000 0.52   22000 3.44
    26000 6.75   28000 4.98   56138 4.32   64000 3.04
    1 293    end
end composition
```

Physical geometry blocks

- Uses the SCALE General Geometry Package
 - Shared with KENO-VI
- Solids: cuboids, cylinders, spheres, cones, etc.
- Regions: intersections of solids
- Units: regions sharing the same coordinates
- Boundary: limits of a unit
- Holes/Arrays: embed other units into a given unit
- Global unit: top-level unit
- Blocks: Geometry, Array, Volume

Physical geometry visuals

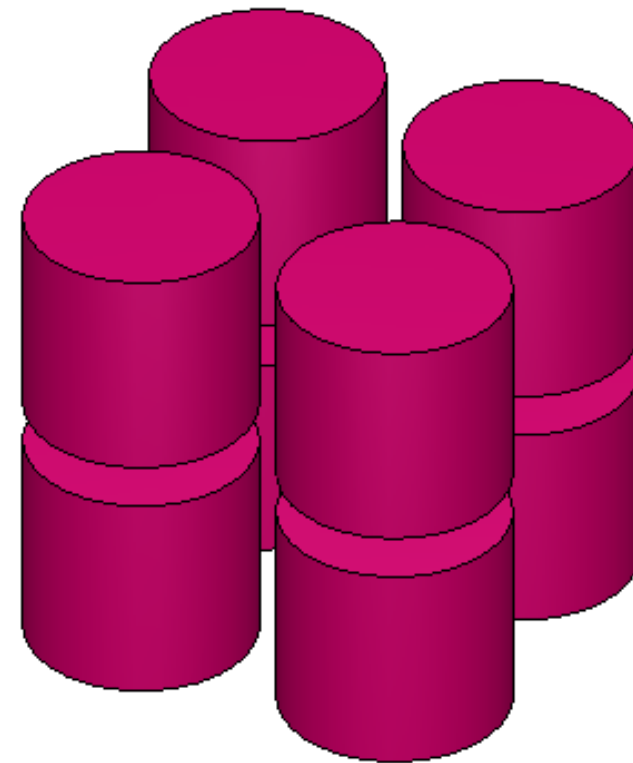


Physical geometry example

```
read geometry
  unit 1
    cylinder 10 5.748 5.3825 -5.3825
    cuboid 20 6.87 -6.87 6.87 -6.87 6.505 -6.505
    media 1 1 10
    media 0 1 20 -10
  boundary 20

  global unit 2
    cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
    array 1 10 place 1 1 1 -6.87 -6.87 -6.505
  boundary 10
end geometry

read array
  ara=1 nux=2 nuy=2 nuz=2 typ=square gbl=1
  fill 1 1 1 1 1 1 1 1 end fill
end array
```



Definitions block

- Items used multiple times in other blocks
 - Locations
 - Responses
 - Grid geometries
 - Cylindrical geometries
 - Distributions
 - Spatial
 - Energy
 - Direction
 - EnergyBounds
 - TimeBounds

```
read definitions
  location 1
  ... end location

  response 19
  ... end response

  gridGeometry 1
  ... end gridGeometry

  distribution 7
  ... end distribution

  energyBounds 2
  ... end energyBounds

  cylGeometry 2
  ... end cylGeom
end definitions
```

Location format

```
location id
    title="Optional title in double quotes"
    position x y z
end location
```

Light gray is an optional keyword
Red is a value to be entered

Examples:

```
location 1
    title="Radial detector"
    position 162.0 0.0 0.0
end location
```

```
location 47
    position 0.0 0.0 295.6
end location
```

```
location 2
    title="Corner detector"
    position 162.0 0.0 295.6
end location
```

Response formats

```
response id
  title="Standard multi-group response definition"
  neutron/photon
  values v1 v2 v3 ... vG end
end response
```

Or

```
response id
  title="Use a dose response from the cross section library"
  doseData=mt
end response
```

Or

```
response id
  title="Histogram response using energy bins (eV)"
  neutron/photon
  bounds E1 E2 E3 ... En En+1 end -or- energyBoundsID=id
  values v1 v2 v3 ... vn end
end response
```

Or

```
response id
  title="Value/function pair using energy bins (eV)"
  neutron/photon
  bounds E1 E2 E3 ... En end -or- energyBoundsID=id
  values v1 v2 v3 ... vn end
end response
```

This method does not work when Denovo and Monaco use different group structures.

Response formats (cont.)

```
response id
  title="Cross section from the library"
  material=m ZAID=zaid MT=mt
end response
```

Or

```
response id
  title="Cross section from the library"
  material=m MT=mt macro
end response
```

Or

```
response id
  title="Cross section from the library"
  material=m nuclide=Sy-XYZ reaction=Rx_name
end response
```

With any response:

```
multiplier=m
makeChart
eHigh=E
eLow=E
```

Outside all responses:

```
multiplier=m
makeCharts
```

Response examples

```
response 19
  title="ANSI standard (1977) photon flux-to-dose-rate factors"
  values 27r0.0          1.1620E-05  8.7446E-06  7.4597E-06
        6.3506E-06  5.3995E-06  4.6017E-06  3.9523E-06  3.4588E-06
        3.0131E-06  2.6200E-06  2.1944E-06  1.8270E-06  1.5149E-06
        1.1595E-06  8.7045E-07  6.2187E-07  3.7081E-07  2.6878E-07
        5.9327E-07  end
```

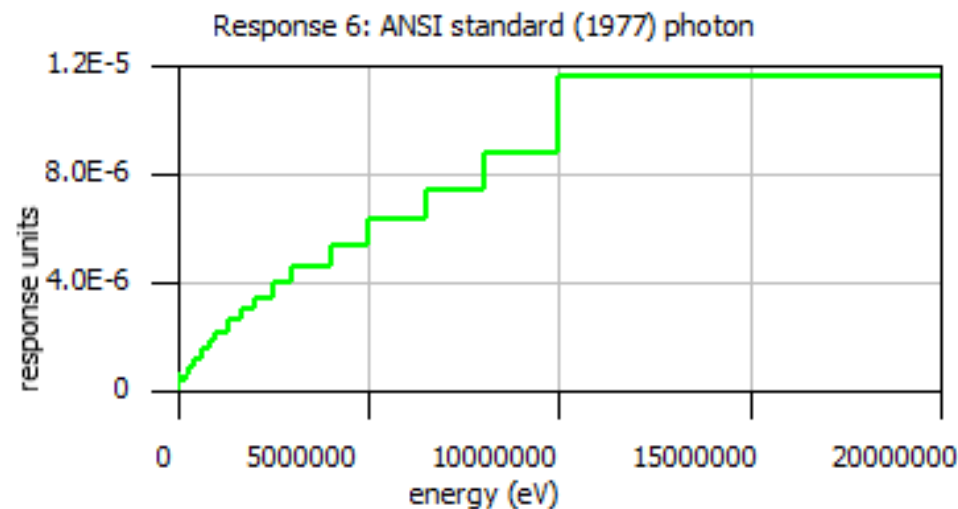
end response

Or

```
response 6
  doseData=9504
end response
```

Or

```
response 24
  photon
  bounds 10e6  8e6  6e6  4e6  3e6  2e6  1e6  0.5e6  end
  values 1.0  2.0  3.0  4.0  3.0  2.0  1.0  end
end response
```



Response examples (cont.)

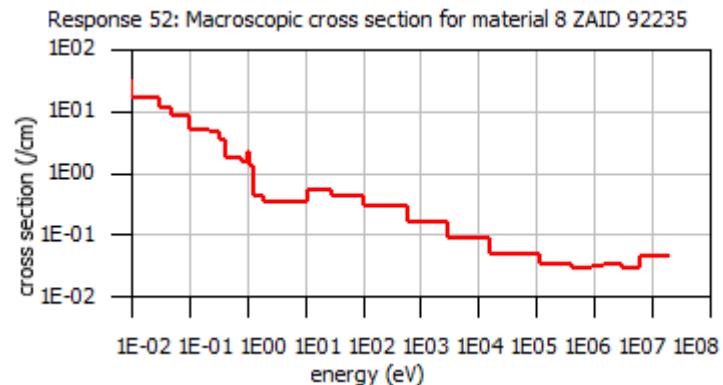
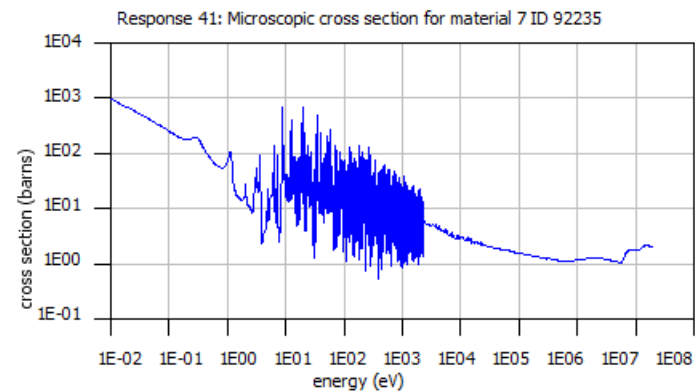
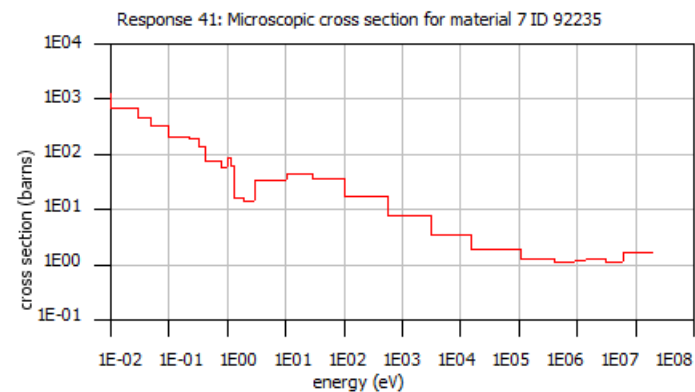
```
response 41
  title="Cross section from the library"
  material=7  ZAID=92235  MT=18
end response
```

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
```



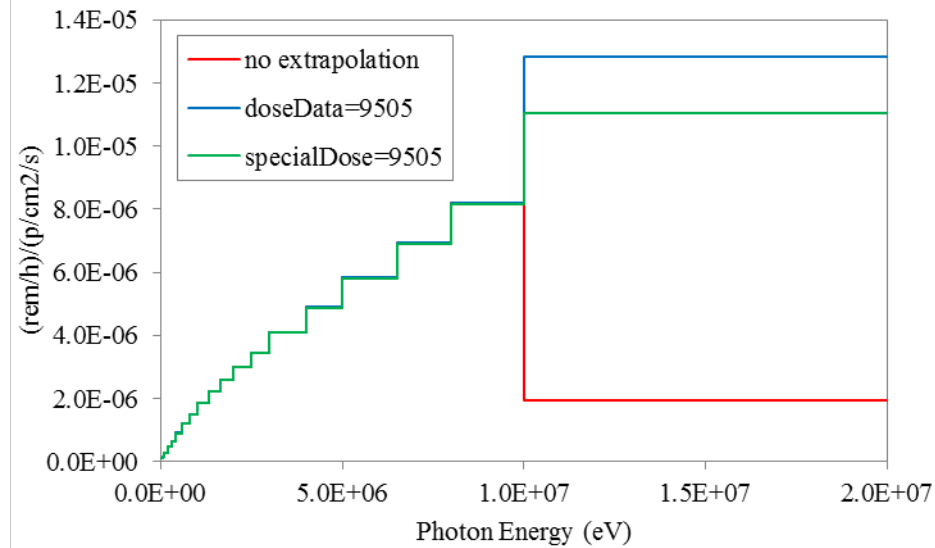
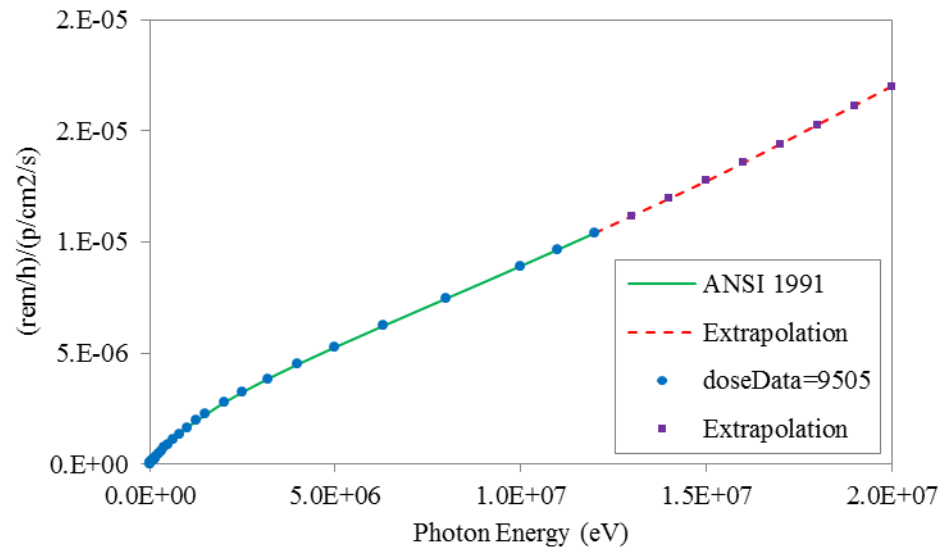
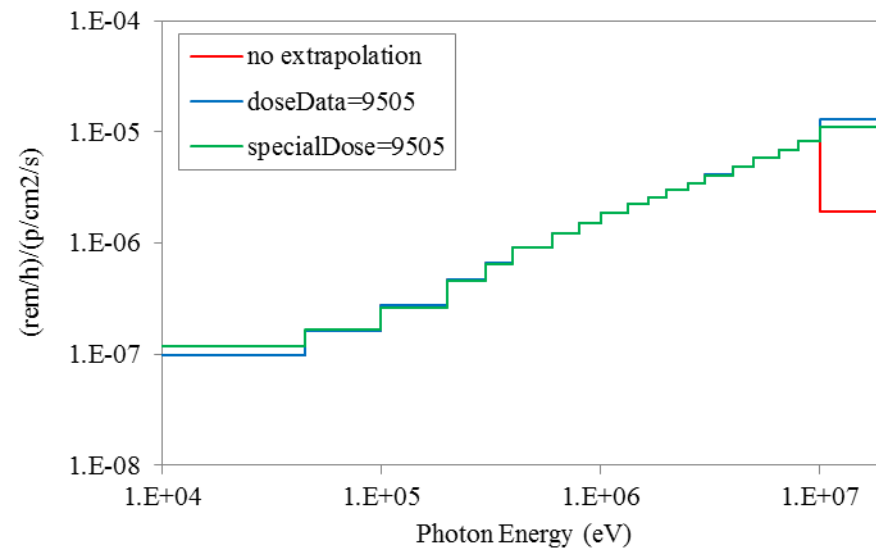
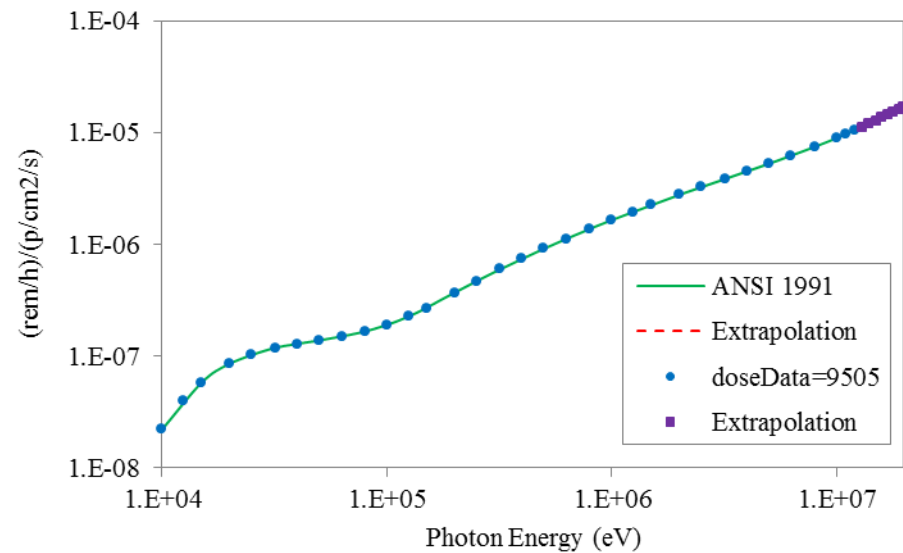
Keyword *doseData* (*specialDose* is obsolete)

$$\dot{D} = \int f(E)\phi(E)dE$$

Response	MT	Neutron Units	MT	Photon Units
Henderson conversion factors	9027	(rad/h)/(n/cm ² /s)	9502	(rad/h)/(p/cm ² /s)
Claiborne-Trubey conversion factors			9503	(rad/h)/(p/cm ² /s)
ANSI standard (1977) flux-to-dose-rate factors	9029	(rem/h)/(n/cm ² /s)	9504	(rem/h)/(p/cm ² /s)
ANSI standard (1991) flux-to-dose-rate factors	9031	(rem/h)/(n/cm ² /s)	9505	(rem/h)/(p/cm ² /s)
ICRU-44 Table B.3 (air) Kerma	9032	(Gy/h)/(n/cm ² /s)		
	9033	(rad/h)/(n/cm ² /s)		
ICRU-57 Table A.21 (air) Kerma			9506	(Gy/h)/(p/cm ² /s)
			9507	(rad/h)/(p/cm ² /s)
Ambient dose equivalent (ICRU-57)	9034	(Sv/h)/(n/cm ² /s)	9508	(Sv/h)/(p/cm ² /s)
	9035	(rem/h)/(n/cm ² /s)	9509	(rem/h)/(p/cm ² /s)
Effective dose (ICRU-57)	9036	(Sv/h)/(n/cm ² /s)	9510	(Sv/h)/(p/cm ² /s)
	9037	(rem/h)/(n/cm ² /s)	9511	(rem/h)/(p/cm ² /s)
Dosimetry for Criticality Accidents	8001	(Gy/h)/(n/cm ² /s)	8511	(Gy/h)/(p/cm ² /s)
(ANSI/HPS N13.3-2013, Table B1 & B2)	8002	(Gy/h)/(n/cm ² /s)	8512	(Gy/h)/(p/cm ² /s)
Personal absorbed dose			8501	(Gy/h)/(p/cm ² /s)
Ambient absorbed dose				
(air) Kerma				



Keyword doseData=9505



specialDose vs. doseData

keyword(s)	Multi-Group (MG)	Continuous Energy (CE)
<i>specialDose=MT</i>	uses pre-computed responses contained in the MG library: data points from reference, extrapolated to energy range of the library and collapsed to the library group structure using a weighting spectrum	this keyword is not allowed since there are no pre-computed dose responses contained within the CE libraries
<i>doseData=MT</i>	data points from reference, extrapolated over the range of 1.0d-11 to 20.0 MeV and collapsed to the library group structure without a weighting spectrum	data points from reference, extrapolated over the range of 1.0d-11 to 20.0 MeV
<i>doseData=MT</i> <i>noExtrapolation</i>	data points from reference and collapsed to the library group structure without a weighting spectrum	data points from reference using only the original energy range

Reaction rate MT values

$$R = \int \Sigma(E) \phi(E) dE$$

MT	Description
1	Total cross section
18	Total fission cross section
27	Absorption cross section (MT=18 and 101)
101	Neutron disappearance
102	(n, γ) radiative capture cross section
103	(n,p) cross section
104	(n, ^2H) cross section
105	(n, ^3H) cross section
106	(n, ^3He) cross section
107	(n, ^4He) cross section
1452	Product of ν times the fission cross section

MT	Description
501	Total photon interaction cross section
502	Photon coherent scattering
504	Photon incoherent scattering
516	Pair production, nuclear and electron field
518	Photofission (γ ,f)
522	Photoelectric

Grid geometry format

List (x,y,z) planes in each dimension separately:

1. By specifying n uniform cells from the min to max
2. By listing all the plane values

```
gridGeometry id
  title="Optional title in double quotes"
  xLinear nx xmin xmax
  yPlanes y0 y1 y2 ... yn end
  zLinear nz zmin zmax
  make3dMap
end gridGeometry
```

Use *Linear and *Planes multiple times; duplicates will be removed.

Grid geometry example

```
gridGeometry 7
  title="large meshes in paraffin, 5 cm mesh for shield thicknesses"
  xLinear 5 -25 25
  xLinear 12 30 90
  xplanes 100 110 120 -30 end

  yplanes -50 -40 40 50 end
  yLinear 7 -35 35

  zplanes -50 -40 40 50 end
  zLinear 7 -35 35
end gridGeometry

make3dMaps
```

Cylindrical geometry format

List (r, θ, z) values in each dimension separately:

1. By specifying n uniform steps from the min to max
2. By listing all the values

```
cylGeometry id
  title="Optional title in double quotes"
  radii  $r_0$   $r_1$   $r_2$  ...  $r_n$  end      radiusLinear  $n_r$   $r_{\min}$   $r_{\max}$ 
  thetas  $\theta_0$   $\theta_1$   $\theta_2$  ...  $\theta_n$  end    thetaLinear  $n_\theta$   $\theta_{\min}$   $\theta_{\max}$ 
  degrees  $\theta_0$   $\theta_1$   $\theta_2$  ...  $\theta_n$  end  degreeLinear  $n_\theta$   $\theta_{\min}$   $\theta_{\max}$ 
  zPlanes  $z_0$   $z_1$   $z_2$  ...  $z_n$  end      zLinear  $n_z$   $z_{\min}$   $z_{\max}$ 
  make3dMap
  zaxis  $u$   $v$   $w$       xaxis  $u$   $v$   $w$ 
end cylGeometry
```

Use *Linear and *Planes multiple times; duplicates will be removed.

For angle, theta is $0-2\pi$; degrees are $0-360^\circ$.

Cylindrical geometry example

```
cylGeometry 12
  radiusLinear 20 100.0 168.0
  radiusLinear 10 168.0 368.0
  thetaLinear 12 0 6.283
  zLinear 25 255.2 -255.2
  zPlanes -45.0 -40. -35.0 end
end cylGeometry
```

```
cylGeometry 14
  title="degenerate: emulate surface tally over partial angle range"
  radiusLinear 1 367.5 368.5
  degreeLinear 1 45 135
  zLinear 25 255.2 -255.2
  zaxis 0 0 1
  xaxis 0 -1 0
end cylGeometry
```

```
make3dMaps
```

For Tallies only –
not importance maps

Distribution formats

```
distribution id
  title="a binned histogram"
  abscissa x1 x2 x3 ... xn xn+1 end
-or-
  energyBoundsID=id
  truePDF f1 f2 f3 ... fn end
end distribution
```

Or

```
distribution id
  title="value/function pairs"
  abscissa x1 x2 x3 ... xn end
-or-
  energyBoundsID=id
  truePDF f1 f2 f3 ... fn end
end distribution
```

Optional – with either type

```
distribution id
  biasedPDF f1 f2 f3 ... fn end
  importance f1 f2 f3 ... fn end
  runSampleTest
end distribution
```

Or

use keywords "trueCDF", "biasedCDF"

Additional keywords that can be used with binned histograms instead of the abscissa keyword:

```
neutronGroups
photonGroups
```

However, these keywords cannot be used when Denovo and Monaco use different group structures.

zDistributions to sample the axial dimension of a cylinder are relative to the bottom of the cylinder, i.e., bottom of cylinder at $z = 0$.

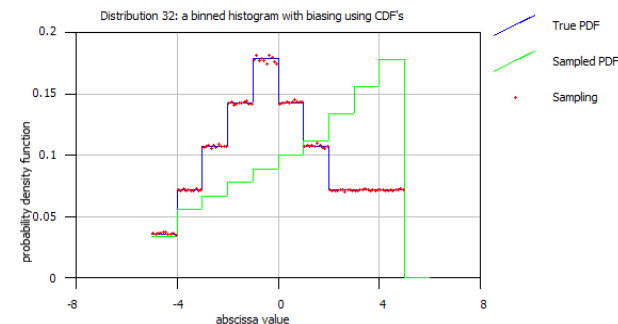
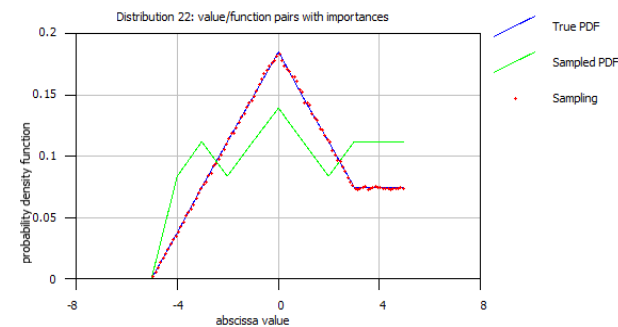
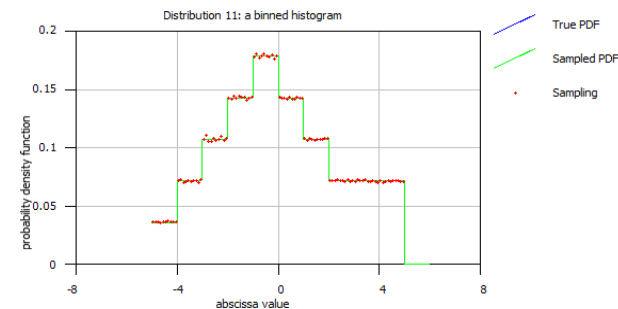
Distribution examples

```
distribution 11
  title="a binned histogram"
  abscissa -5 -4 -3 -2 -1 0 1 2 3 4 5 end
  truePDF  1  2  3  4  5 4 3 2 2 2  end
end distribution
```

```
distribution 22
  title="value/function pairs with importances"
  abscissa  -5 -4 -3 -2 -1 0 1 2 3 4 5  end
  truePDF   0  1  2  3  4 5 4 3 2 2 2  end
  importance 4  3  2  1  1 1 1 1 2 2 2  end
end distribution
```

```
distribution 32
  title="a binned histogram with biasing using CDF's"
  abscissa -5 -4 -3 -2 -1 0 1 2 3 4 5 end
  trueCDF  1  3  6 10 15 19 22 24 26 28  end
  biasedPDF 3  5  6  7  8  9 10 12 14 16  end
end distribution
```

```
runSampleTests
```



Distribution formats

```
distribution id
  title="discrete probabilities"
  discrete E1 E2 E3 ... En end
  truePDF  p1 p2 p3 ... pn    end
end distribution
```

Example:

```
distribution 11
  title="Cobalt-60 discrete"
  discrete 1173228 1332492 end
  truePDF   0.9985 0.999826 end
end distribution
```

Optional

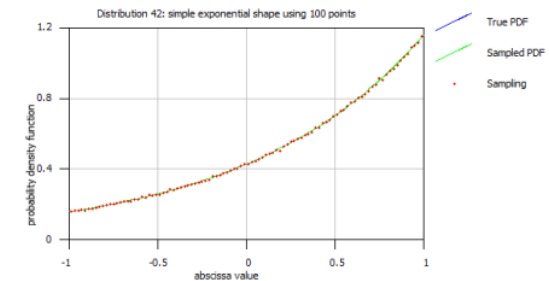
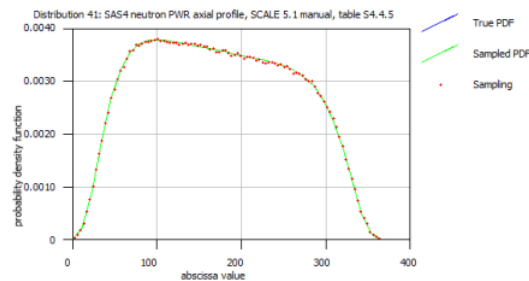
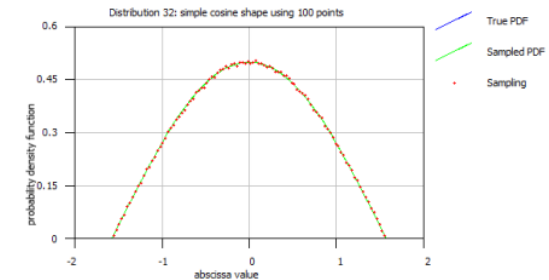
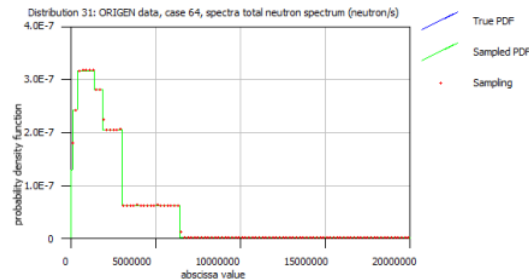
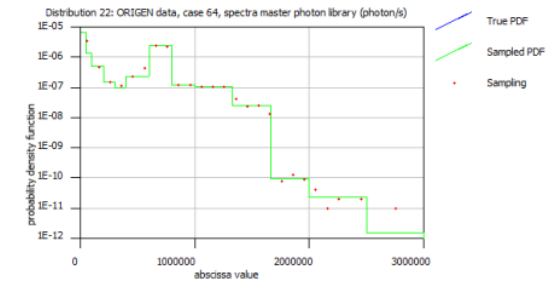
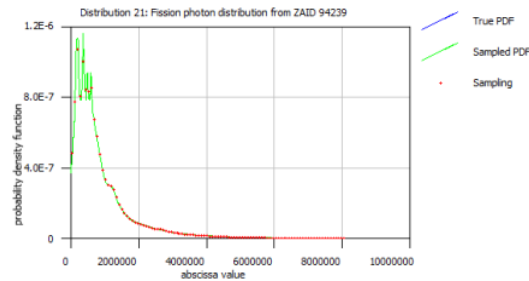
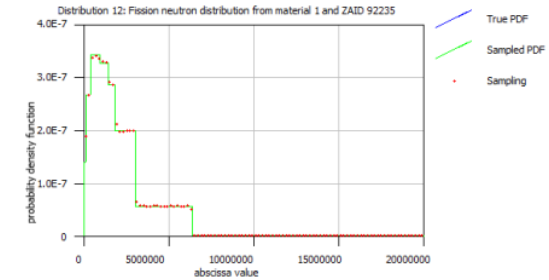
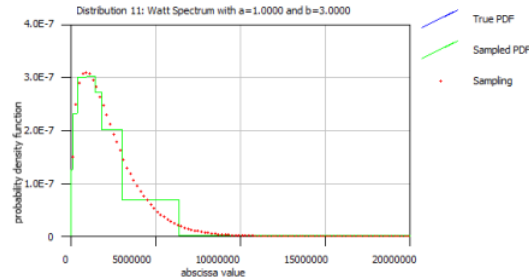
```
distribution id
  biasedPDF  p1 p2 p3 ... pn end
  importance f1 f2 f3 ... fn end
  weight    w1 w2 w3 ... wn end
  runSampleTest
end distribution
```

Or
use keywords “trueCDF”, “biasedCDF”

Built-in distributions

```
distribution id
  title="a built-in distribution"
  special="distributionName"
  parameters p1 p2 ... pn end
end distribution
```

Distribution	Parameters
"wattSpectrum"	a b n
"fissionNeutrons"	m $ZAID$
"fissionPhotons"	$ZAID$
"origensBinaryConcentrationFile"	c s
"cosine"	n
"pwrNeutronAxialProfile"	none
"pwrGammaAxialProfile"	none
"pwrNeutronAxialProfileReverse"	none
"pwrGammaAxialProfileReverse"	none
"exponential"	a n
"origensDiscreteGammas"	z a m



EnergyBounds/TimeBounds format

```
energyBounds id
  title="energy bin boundaries"
  bounds  $E_1$   $E_2$   $E_3$  ...  $E_n$  end
  linear n  $E_{\min}$   $E_{\max}$ 
  logarithmic n  $E_{\min}$   $E_{\max}$ 
  tolerance=t
end energyBounds
```

Or

```
energyBounds id
  252n 238n 200n 56n 44n 27n
  47p 19p
end energyBounds
```

```
timeBounds id
  title="time bin boundaries"
  bounds  $t_1$   $t_2$   $t_3$  ...  $t_n$  end
  linear n  $t_{\min}$   $t_{\max}$ 
  logarithmic n  $t_{\min}$   $t_{\max}$ 
  tolerance=t
end timeBounds
```

Sources block

Each Monaco source uses separable distributions in space, energy, and direction.

```
read sources
```

```
src id
```

(source basics)

(spatial distribution)

(energy distribution)

(directional distribution)

```
end src
```

```
end sources
```



Multiple sources
allowed

Source basics

Optional title and source strength in particles/sec.

```
read sources
  src id
    title="Optional title in double quotes"
    neutron/photon
    strength=S
    biasedStrength=B

    (spatial distribution)
    (energy distribution)
    (directional distribution)
  end src
end sources
```

Source spatial shape format

- Spatial – uniform density over a shape:

Keyword	Parameters	Possible degenerate cases
cuboid	$x_{max} \ x_{min} \ y_{max} \ y_{min} \ z_{max} \ z_{min}$	rectangular plane, line, point
xCylinder	$r \ x_{max} \ x_{min}$	circular plane, line, point
yCylinder	$r \ y_{max} \ y_{min}$	circular plane, line, point
zCylinder	$r \ z_{max} \ z_{min}$	circular plane, line, point
xShellCylinder	$r_1 \ r_2 \ x_{max} \ x_{min}$	cyl., planar annulus, cyl. surface, line, ring, point
yShellCylinder	$r_1 \ r_2 \ y_{max} \ y_{min}$	cyl., planar annulus, cyl. surface, line, ring, point
zShellCylinder	$r_1 \ r_2 \ z_{max} \ z_{min}$	cyl., planar annulus, cyl. surface, line, ring, point
sphere	r	point
shellSphere	$r_1 \ r_2$	sphere, spherical surface, point

- Limited by unit, region, or material

unit=**u** region=**r** or mixture=**m**

- Optional translation: origin $x=\mathbf{x}$ $y=\mathbf{y}$ $z=\mathbf{z}$

- Optional rotation: axis **u v w** (cylinders)

rotate $a_1=\theta_1$ $a_2=\theta_2$ $a_3=\theta_3$ (cylinders)

Source spatial distribution

- Cuboids

```
xDistributionID=id  xScaleDist  
yDistributionID=id  yScaleDist  
zDistributionID=id  zScaleDist
```

- Cylinders

```
rDistributionID=id  rScaleDist  
zDistributionID=id  zScaleDist
```

zDistributions to sample the axial dimension of a cylinder are relative to the bottom of the cylinder, i.e., bottom of cylinder at $z = 0$

- or -

use *zScaleDist*

- Spheres

```
rDistributionID=id  rScaleDist
```

Source spatial distribution example

```
read sources
  src 1
    title="Uniform over cask cylinder but only in spent fuel (7)"
    strength=3.7e18
    neutrons
    zCylinder 95.0 228.6 -228.6
    zDistributionID=4 zScaleDist
    mixture=7
    (energy distribution)
    (directional distribution)
  end src
end sources
```

Source energy and direction

- Specify the energy distribution

```
eDistributionID=id  
useNormConst  (do not use strengh= keyword)
```

- Specify the optional directional distribution (in μ)

```
direction u v w  
dDistributionID=id  
dScaleDist
```

Full source example

```
read definitions
  distribution 4 special="cosine" end distribution
  distribution 10
    special="wattSpectrum" parameters 1.0 3.0 end
  end distribution
  distribution 21
    abscissa -1.0 0.0 0.8 0.9 1.0 end
    truePDF 0.5 0.4 0.05 0.05 end
    biasedPDF 0.2 0.2 0.2 0.4 end
  end distribution
end definitions
read sources
  src 1
    title="Uniform over cask cylinder but only in spent fuel (7)"
    neutrons
    strength=3.7e18
    zCylinder 95.0 228.6 -228.6
    zDistributionID=4 zScaleDist
    mixture=7
    eDistributionID=10
    direction 0.0 0.0 1.0
    dDistributionID=21
  end src
end sources
```

MAVRIC input: Mesh file source

Use a Monaco Mesh Source (*.msm) file for the spatial and energy components of a source.

```
read sources
  src 1
    meshSourceFile="c:\mydocu~1\previouslyMadeSource.msm"
    strength=S
    biasedStrength=B
    origin x=x y=y z=z
    direction u v w
    dDistributionID=id
    dScaleDist
    allowResampling
  end src
end sources
```

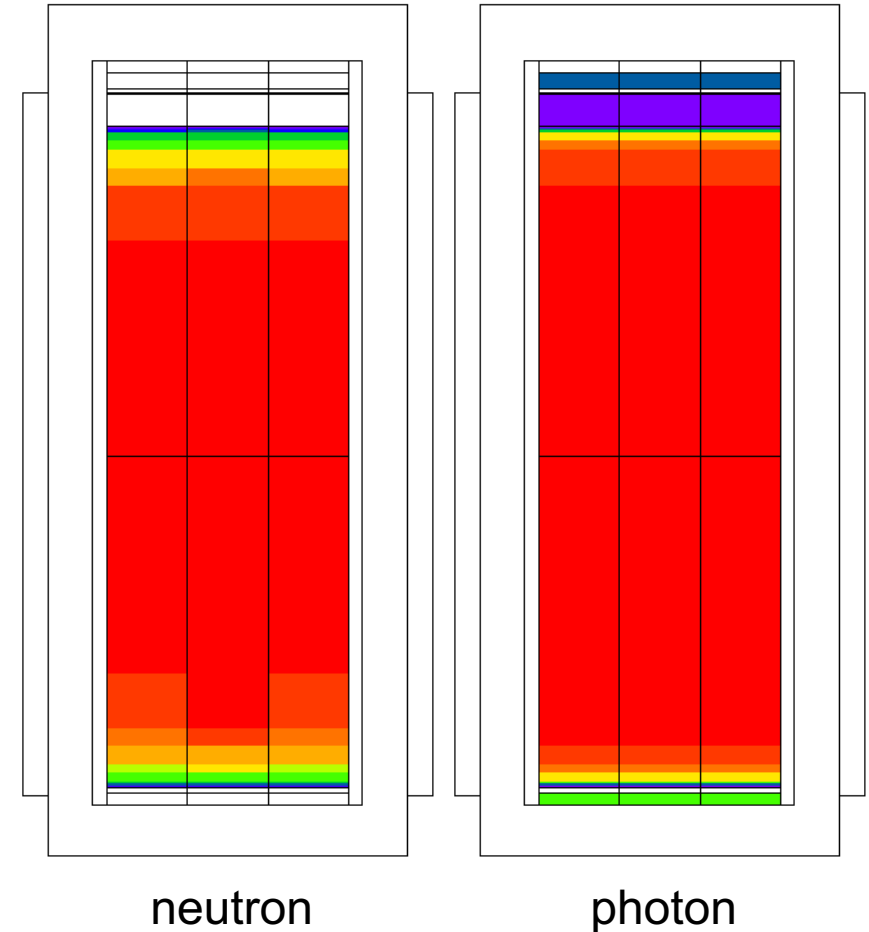
Mesh source saver

- Make a mesh-based version of the source

- Viewable in Fulcrum

```
read sources
  src 1 ... end src
  ...
  src 7 ... end src
meshSourceSaver
  gridGeometryID=1
  filename="meshed.msm"
  subCells=3
  sourceTrials=1000000
  reduce
  makeTotal

  nEnergyBoundsID=
  pEnergyBoundsID=
end meshSourceSaver
end sources
```



Tallies in Monaco

- Point detectors
 - Estimates flux at a point
 - Can integrate flux with a response function(s)
 - Gives both uncollided and total response
 - Gives uncertainties
- Region tallies
 - Estimates flux over a region (or material)
 - Gives the track-length and collision density estimates
 - Can integrate flux with a response function(s)
- Mesh tallies
 - Gives the group fluxes and optional responses using a grid geometry

Tallies block

```
read tallies
  pointDetector 1
  ...
end pointDetector

regionTally 7
  ...
end regionTally

meshTally 1
  ...
end meshTally

regionTally 1
  ...
end regionTally

meshTally 2
  ...
end meshTally

end tallies
```

Tally formats

```
pointDetector id
  title="optional title goes here"
  locationID=p
  minSampProb=m
end pointDetector

regionTally id
  title="optional title goes here"
  unit=u region=r -OR- unit=u mixture=m
end regionTally

meshTally id
  title="optional title goes here"
  gridGeometryID=g
  unit=u region=r -OR- unit=u mixture=m
  noGroupFluxes
  saveRespDetails
  weightless
end meshTally
```

Tally formats (cont.)

```
tallyType id
  title="optional title goes here"

  neutron/photon

  responseID=R
  responseIDs R1 R2 ... Rn end

  multiplier=m

  energyBoundsID=i
  timeBoundsID=j
end tallyType

multiplier=m
```

Tally examples

```
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

  `  convert responses from rem to mrem (doesn't change flux)
    multiplier=1000.0
end tallies
```

Parameters block

- Random seed = 16 character hexadecimal
- Cross section library used by Monaco can be set by *library="name"*
- Total histories = *batches*perBatch*

```
read parameters
  randomSeed=00003ecd7b4e3e8b
  perBatch=10000
  batches=100
  maxMinutes=1440.0

  fissionMult=0,1
  secondaryMult=0,1,2

  voidAllRegions

  library="name"   Or   ceLibrary="name"
end parameters
```

For Multi-Group
(default is all particles in library)

noNeutrons noPhotons

For Continuous-Energy
(default is none)

neutrons photons

Standard biasing block format

- Weight windows by region and path length stretching – everything is optional

```
read biasing
  windowRatio=R
  lowerWeights  w1 w2 w3 ... wn end
  targetWeights w1 w2 w3 ... wn end
  upperWeights  w1 w2 w3 ... wn end

  pathStretch  p1 p2 p3 ... pn end
  direction="globalZp"
end biasing
```

- Number of entries should match one of the following:
 - Number of regions
 - Number of groups
 - Regions*groups
- Number of entries equal to the number of groups or regions*groups does not work when Denovo and Monaco use different group structures

Standard biasing block examples

Weight windows by region and path length stretching

```
read biasing
  windowRatio=10.0
  targetWeights 46r1.0 46r2.0 46r3.0 46r1.0 46r2.0 46r3.0
                46r1.0 46r2.0 46r3.0 46r1.0 46r2.0 46r3.0
                46r1.0 46r2.0 46r3.0 end

  pathStretch 46r0.5 46r0.6 46r0.75 end
  direction="globalZp"
end biasing
```

For CE

```
nEnergyBoundsID=i
pEnergyBoundsID=j
```

Or, using a Monaco Importance Map File

```
read biasing
  meshImpMapFile="c:\mydocu~1\previouslyMadeImpMap.mim"
end biasing
```

MAVRIC input: After all blocks

end data	(no more data blocks to read)
end	(ends the “=mavric”)

Known issues with file names in Denovo

- In general, SCALE can handle spaces in file names
- However, Denovo cannot handle spaces in file names, so do not include spaces in your MAVRIC input file names

MAVRIC output

- Output from each module stitched together
 - *outputName.out*
- Diagnostic files – from definitions block
 - Grid geometry: *outputName.gridid.3dmap*
 - Cylindrical geom: *outputName.cylid.3dmap*
 - Response: *outputName.respid.chart*
 - Distribution: *outputName.distid.chart*
- Plots – from plot block
 - *outputName.plotxxxx.png*



Fulcrum



MAVRIC output

- Main output text file: *outputName.out*
 - Monaco part is at the end
 - Summary tables for region tallies and point detectors
- Separate files – group-wise results for flux and integrated results for each optional response
 - Mesh tallies: *outputName.mtid.3dmap*
 - Region tallies:
 - Table of results: *outputName.rtid.txt*
 - Convergence plot: *outputName.rtid.chart*
 - Point detector tallies:
 - Table of results: *outputName.pdid.txt*
 - Convergence plot: *outputName.pdid.chart*

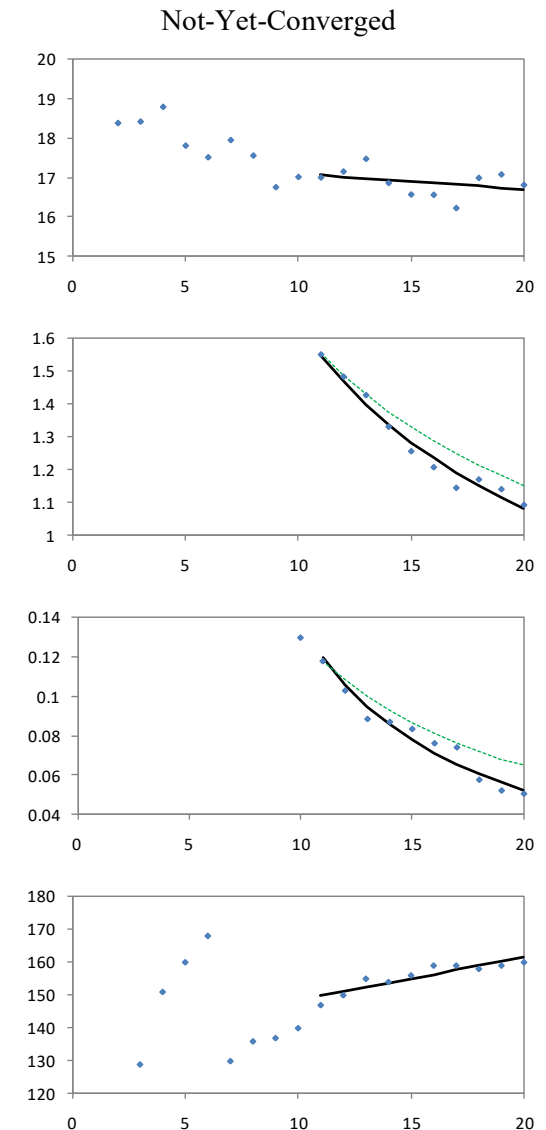
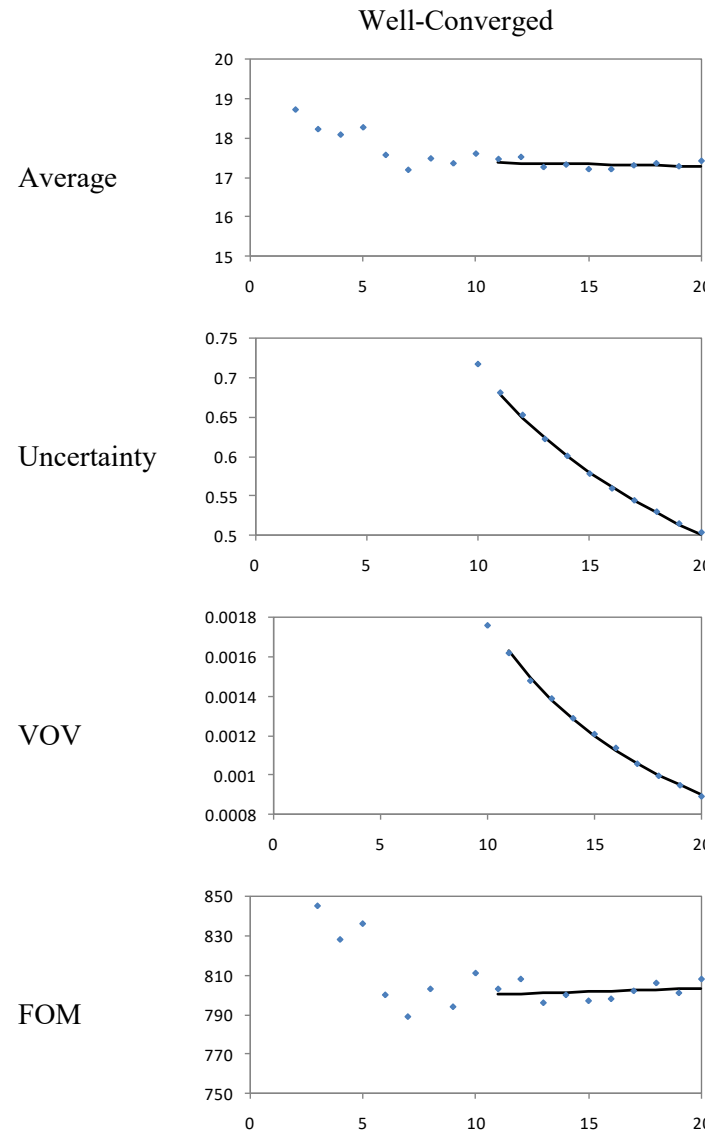


Fulcrum



MAVRIC output – Statistical checks

Quantity/Test	Goal	Within
1. mean relative slope of linear fit	= 0.00	0.10
2. standard deviation exponent of power fit	= -0.50	$R^2 > 0.99$
3. relative uncertainty final value	< 0.05	
4. relative VOV exponent of power fit	= -1.00	$R^2 > 0.95$
5. relative VOV final value	< 0.10	
6. figure-of-merit relative slope of linear fit	= 0.00	0.10



MAVRIC output – Statistical checks

- Tally detail file (*outputName.pdid.txt*, *outputName.rtid.txt*)

Response 1 (using flux by track-length)

ANSI standard (1977) neutron flux-to-dose-rate factors (rem/h)/(neutrons/cm2/s)

Tally Values as the Simulation Progressed

batch	average value	standard deviation	relat uncert	rel VOV	FOM (/min)	stats check					
						1	2	3	4	5	6
1	7.55738E-05	7.07675E-08	0.00094	3.69E-06	1.11E+06			X		X	
2	7.55214E-05	5.00518E-08	0.00066	1.84E-06	1.10E+06			X		X	
3	7.55393E-05	4.08808E-08	0.00054	1.23E-06	1.10E+06			X		X	
4	7.55475E-05	3.54003E-08	0.00047	9.21E-07	1.10E+06			X		X	
5	7.55304E-05	3.16769E-08	0.00042	7.36E-07	1.09E+06			X		X	
6	7.55107E-05	2.89240E-08	0.00038	6.14E-07	1.09E+06			X		X	
7	7.55152E-05	2.67798E-08	0.00035	5.26E-07	1.09E+06			X		X	
8	7.55141E-05	2.50501E-08	0.00033	4.61E-07	1.09E+06			X		X	
9	7.55300E-05	2.36183E-08	0.00031	4.09E-07	1.09E+06			X		X	
10	7.55335E-05	2.24068E-08	0.00030	3.68E-07	1.09E+06	X	X	X	X	X	X

Final Statistical Check (fits are over the last half of the simulation)

quantity	check	goal	actual	pass
1 mean	rel slope of linear fit	= 0.00	0.0008	yes
2 standard deviation	exponent of power fit	= -0.50	-0.4998	yes
3 relative uncertainty	final value	< 0.05	0.0003	yes
4 relative VOV	exponent of power fit	= -1.00	-0.9989	yes
5 relative VOV	final value	< 0.10	0.0000	yes
6 figure-of-merit (FOM)	rel slope of linear fit	= 0.00	-0.0029	yes

MAVRIC output – Statistical checks

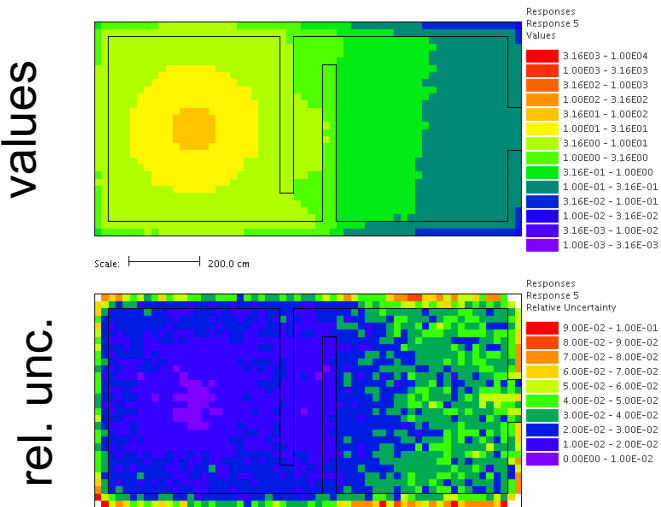
- Tally summary (main text output file, *outputName.out*)

Region Tally 4. example region tally

tally/quantity	average value	standard deviation	relat uncert	FOM (/min)	stat checks 1 2 3 4 5 6
-----	-----	-----	-----	-----	-----
neutron flux (tl)	9.75686E-01	5.47382E-05	0.00006	3.04E+07	X X X X X X
photon flux (tl)	0.00000E+00				
neutron flux (cd)	0.00000E+00				
photon flux (cd)	0.00000E+00				
response 1	7.55335E-05	2.24068E-08	0.00030	1.09E+06	X X X X X X
-----	-----	-----	-----	-----	-----

MAVRIC output – Mesh tally StatChecks

- Tough to make checks, since there are I×J×K tallies



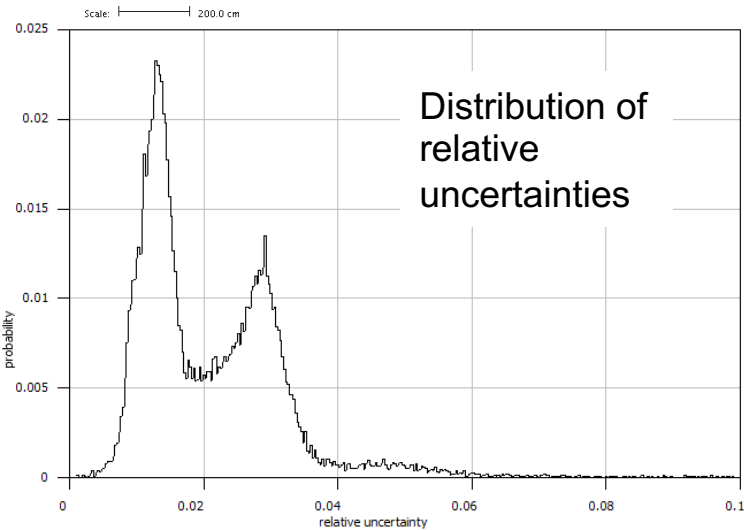
Distribution of relative uncertainties R_i and its mean, $\bar{r}$, of the voxels, V with score

$$\bar{r} = \frac{1}{V} \sum R_i \qquad FOM = \frac{1}{\bar{r}^2 T}$$

If each voxel $R_i \propto 1/\sqrt{N}$, then $\bar{r} \propto 1/\sqrt{N}$

Four Tests:

Quantity	Test	Goal	Within
1. ζ , fraction with score	relative slope of linear fit	= 0.00	± 0.10
2. $\bar{r}$, mean relative uncertainty	exponent of power fit	= -0.50	$R^2 > 0.99$
3. variance of $\bar{r}$	exponent of power fit	= -1.00	$R^2 > 0.95$
4. figure-of-merit	relative slope of linear fit	= 0.00	± 0.10

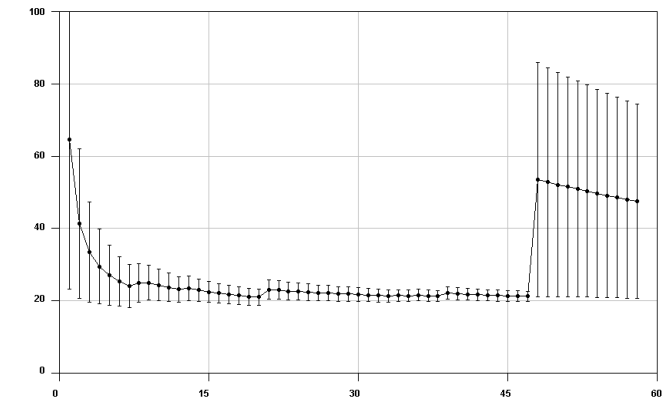
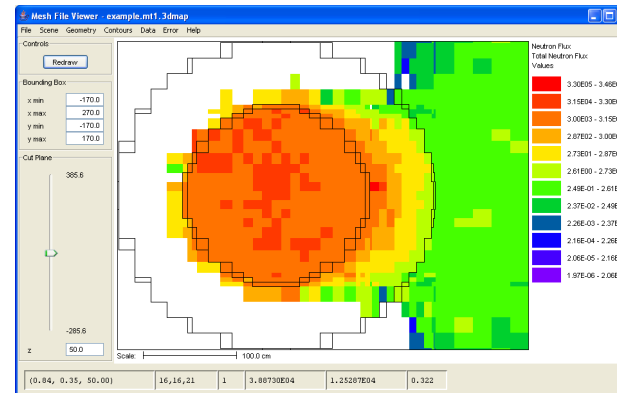
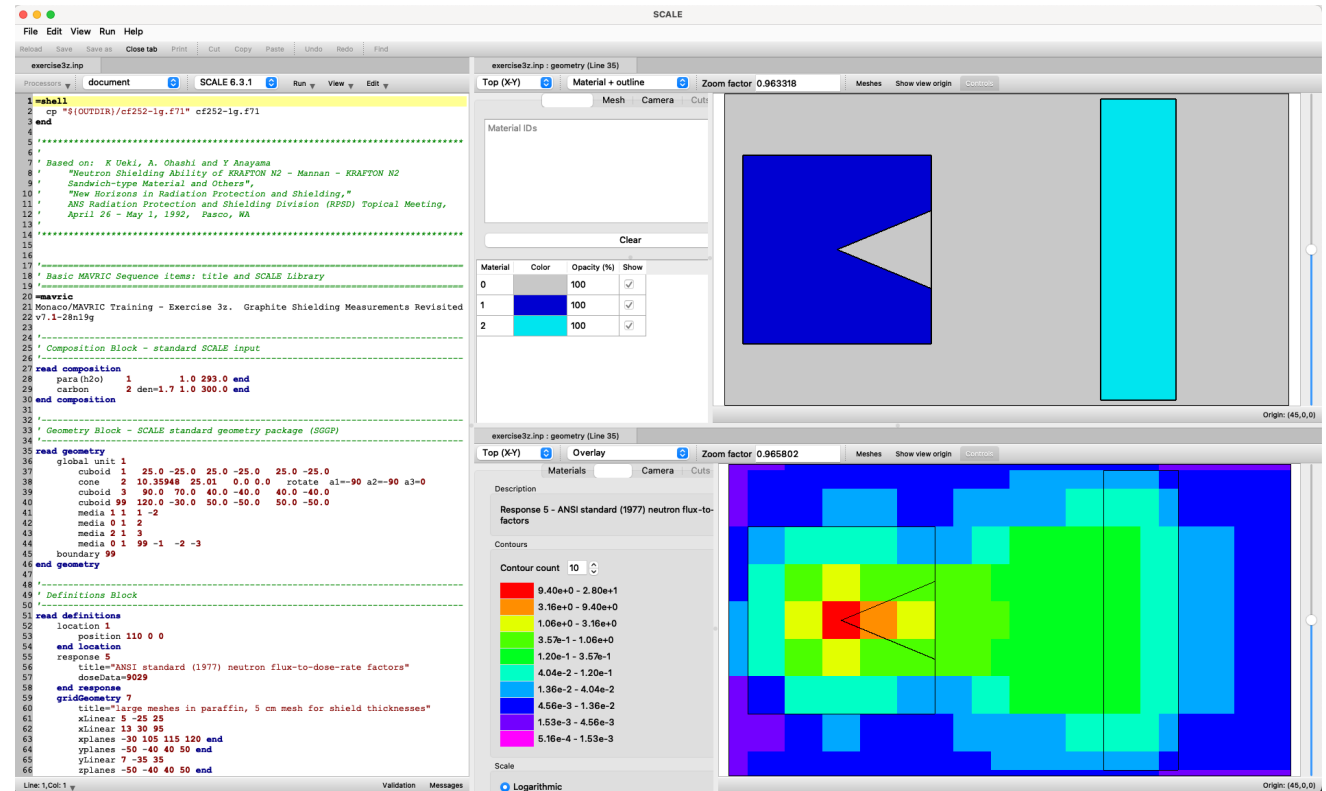


Neutron Mesh Tally 30.

tally/quantity	zeta	mean	var of	FOM	passed			
	value	rel unc	rel unc	(/min)	1	2	3	4
flux, bin 0	0.9991	1.46E-01	1.44E-08	2.38E-01	X	-	X	X
tot flux, bin 0	1.0000	2.14E-02	4.71E-09	1.11E+01	X	X	X	X
resp 5/bin 0	1.0000	3.06E-02	1.07E-08	5.47E+00	X	-	X	X

MAVRIC output

- Fulcrum
 - Mesh tallies
 - Denovo fluxes
 - Importance maps
 - Mesh Sources
- Interactive plotter
 - Distributions
 - Responses
 - Convergence checks
 - Line plots from mesh



In-class example: Iron sphere benchmark problem



Learning goals

- The trainees and instructor will work an example problem together, which will allow attendees to apply what they have learned about running MAVRIC/Monaco using standard biasing techniques
- Also introduce the trainees to the SCALE GUI, Fulcrum, and identify how the different Fulcrum tabs are used to enter the information required to build a computational model of a shielding problem

Iron sphere benchmark problem

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).

