TRITON Workshop

M&C+SNA-2007, Monterey

April 15, 2007

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

TRITON Workshop

M&C+SNA-2007, Monterey

April 15, 2007

Mark D. DeHart, PhD

Senior R&D Staff, Reactor Analysis Group

Nuclear Science and Technology Division

Oak Ridge National Laboratory

Overview

- **Introduction to SCALE**
- **TRITON Functionality**
  - **Modular Nature**
  - **TRITON Sequences**
  - **Key Components (CENTRM/PMC, NEWT, ORIGEN-S)**
  - **Reactor Physics Capabilities**
- **Developing Models in TRITON**
  - **NEWT Transport Models**
  - **TRITON Depletion Input**
  - **Branch Calculations**
  - **Cross Section Assignment**
  - **Examples and Results**

Overview (Cont'd)

- **Taming the Beast**
  - **GeeWiz and KENO 3D**
  - **Model development and execution using GeeWiz**
  - **Depletion using ORIGEN-ARP**
- **Ongoing Development and Future Capabilities**
  - **Continuous Energy KENO**
  - **Generalized Adjoint in NEWT**
  - **Double-Het. Depletion**

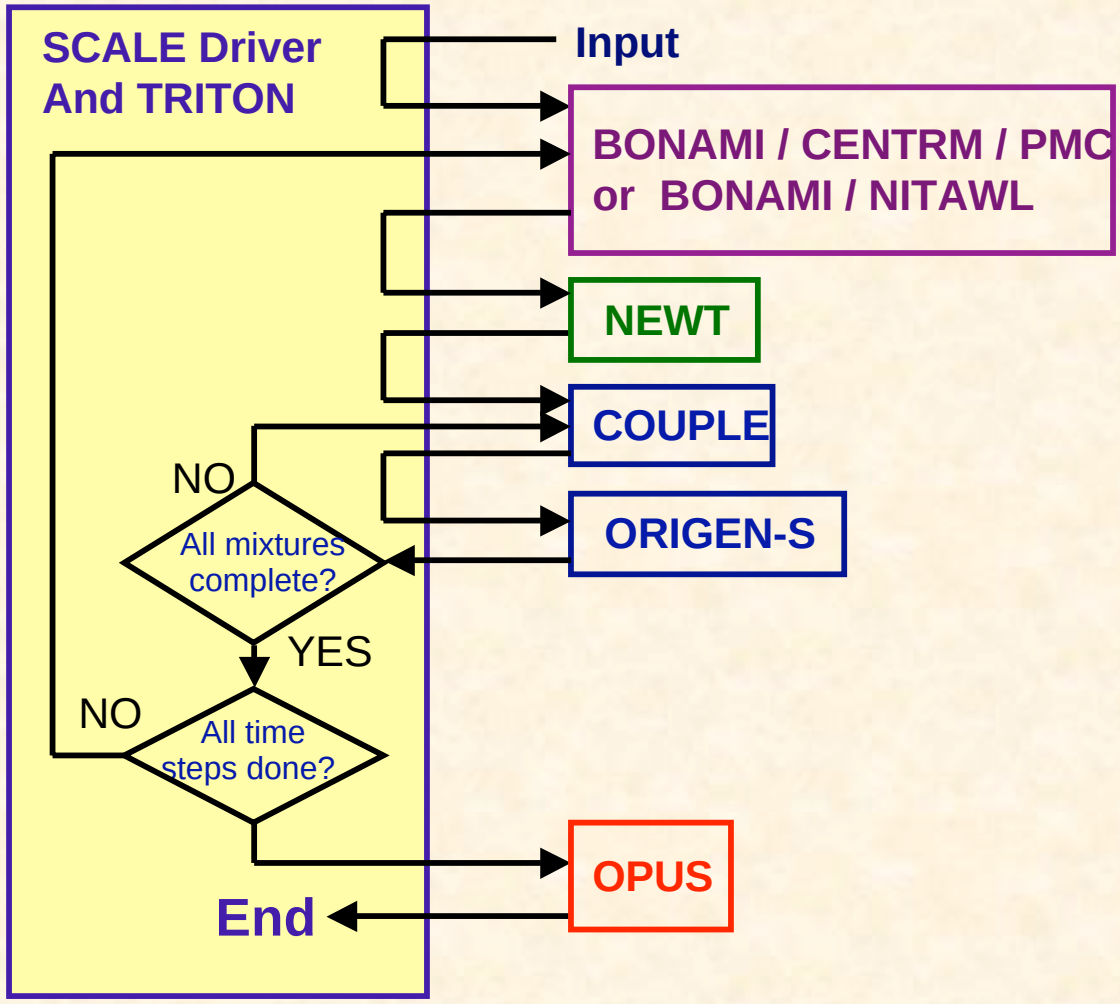
Modular Analysis using SCALE

- **SCALE - Standardized Computer Analysis for Licensing Evaluation**
  - **Developed at Oak Ridge National Laboratory for the Nuclear Regulatory Commission (NRC)**
  - **Maintained/enhanced under co-sponsorship of NRC and Department of Energy (DOE)**
  - **A multi-purpose computational system for analyses of nuclear facilities and packages:**
    - **Criticality safety**
    - **Radiation source terms and shielding**
    - **SNF/HLW characterization (e.g., nuclide inventory)**
    - **Lattice physics**

SCALE Features and Terminology

- **Modular system of well-established and well-tested programs (functional modules) and data**
- **Control modules automate data processing and functional (system) analysis into sequences**
- **Engineering (not physics) parameters input with keywords and free format**
- **Designed for ease of use by new/occasional users, but with flexibility for expert users**

SCALE Is Built on a Modular Concept



Resonance cross-section processing (repeat for all cells)

2-D discrete ordinates

Fuel depletion/decay (repeat for all depletion mixtures)

Output edits (repeat for all requested mixtures)

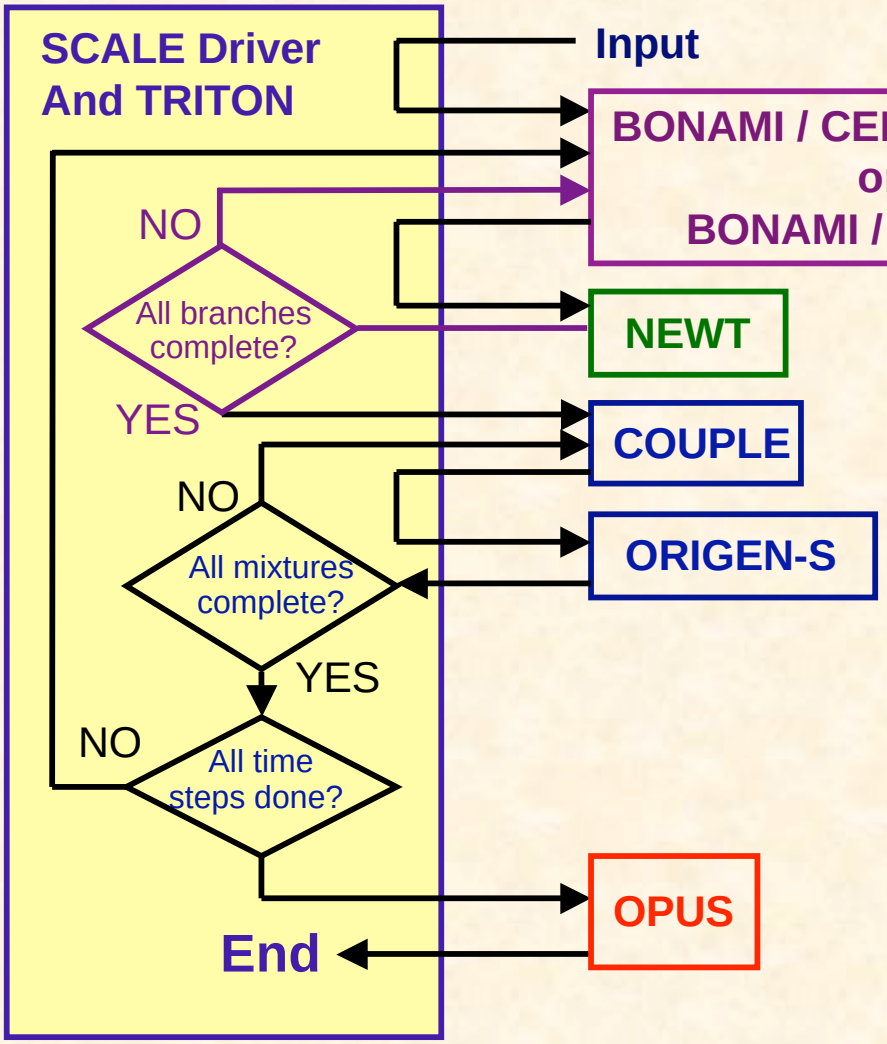
TRITON

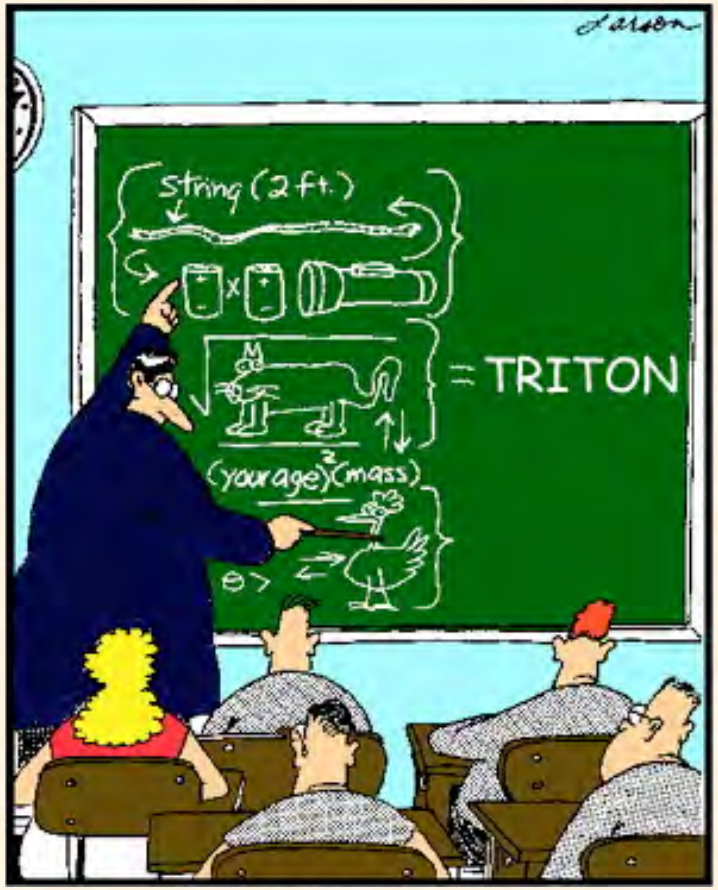
- **TRITON (Transport Rigor Implemented with Time-dependent Operation for Neutronic depletion) is a multipurpose transport sequence**
  - **SCALE 5 control module**
  - **Drives five sequences**
    - **t-xsec - cross-section processing**
    - **t-newt - NEWT transport calculation**
    - **t-depl - NEWT/ORIGEN-S depletion calculation**
    - **t5-depl - KENO V.a/ORIGEN-S depletion calculation**
    - **t6-depl - KENO-VI/ORIGEN-S depletion calculation**
    - ***t-sunami/tsunami-2d - 2D sensitivity/uncertainty calculations (under development)***
  - **Generation of lattice physics cross sections is currently supported only in the NEWT-based t-depl sequence.**

TRITON Functionality

- **TRITON processes input, prepares data, and handles calling sequence for each calculation type.**
  - **Material processing**
  - **Generation of problem-dependent cross sections**
  - **Transport solution (NEWT, KENO V.a, or KENO-VI)**
  - **Cross section update**
  - **Depletion and decay calculations**
  - **Update isotopic number densities**
  - **Iterate as required**
- **Remainder of this workshop will focus primarily on t-depl**

t-depl Sequence With Branches





Capabilities of t-depl Depletion Sequence

- **Independent depletion of multiple materials.**
- **Isotopic prediction with rigorous transport model.**
- **Source terms.**
- **Decay heat.**
- **Depletion based on assembly power, local power, or region power.**

Capabilities of t-depl Depletion Sequence (continued)

- **Treatment of time-dependent changes in configuration (boron concentration, poison rod removal, etc.).**
- **Branch calculations.**
- **Database of burnup/branch cross-sections.**
- **Limited restart capabilities.**

Multiregion depletion

- **TRITON has the ability to deplete each fuel location in a system using local fluxes.**
- **A unique mixture must be specified for each region to be depleted.**
- **ORIGEN-S depletion is performed based on the average flux within each mixture, irrespective of location(s).**
- **One fuel element can be modeled as multiple mixtures (rings or regions within a contiguous volume).**
- **Conversely, large discontinuous regions (i.e., sets of pins) can be modeled as a single mixture.**

Key Components of TRITON

- **Cross section processing**
  - **Default is BONAMI/CENTRM/PMC with 2-region approximation**
  - **Other options are:**
    - **BONAMI/CENTRM/PMC in spatial (S_n) solution mode**
    - **BONAMI/NITAWL**
- **Transport solution**
  - **t-depl: NEWT 2D arbitary-geometry discrete ordinates (more on NEWT later)**
  - **t5-depl: KENO V.a 3D Monte Carlo**
  - **t6-depl: KENO VI 3D Monte Carlo**
- **Depletion/Decay**
  - **COUPLE/ORIGEN-S**

Division of Labor

- **Multigroup cross section processing:**
  - **Cross sections are created for each pin type**
  - **Cross sections may be generated for subregions (e.g., rings) within a cell (CENTRM S_n mode only)**
- **The transport solution couples all cross sections in generating a detailed multidimensional solution**
  - **NEWT is fully converged everywhere**
  - **KENO has stochastic and spatially-varying uncertainties.**
- **The local spatial flux and cross sections from transport solution are used to independently deplete each spatial region.**
- **Isotopic concentrations are updated and the process is repeated.**

CENTRM/PMC Methodology

- **CENTRM: Continuous ENergy TRansport Module**
  - **Computes space-dependent, continuous-energy neutron spectra for 1-D model of critical system**

- **PMC: Process Multigroup Cross sections**
  - **Computes problem-dependent cross sections using flux spectrum from CENTRM**

Features of CENTRM

- **Solves 1-D discrete ordinates transport equation using pointwise cross section data to obtain continuous-energy angular flux spectra**
- **Computes full energy-range spectrum (not just in resolved range)**
  - **pointwise in resonance energy range**
  - **multigroup in fast and thermal ranges**
  - **pointwise is an option in thermal ranges**
- **Pointwise data pre-processed directly from ENDF/B specs (no assumption of SLBW)**

Features of CENTRM (Cont.)

- **Generates problem-specific energy mesh that accounts for resonance overlap**
- **Includes general space and temperature variation in materials**
- **Point cross sections are automatically temperature-corrected.**
- **Computes anisotropic scatter source for s-wave elastic & inelastic reactions using pointwise flux and analytical scatter kernel**
- **Includes pointwise thermal spectrum calculation**

Benefits of CENTRM

- **CENTRM/PMC expands traditional resolved resonance self-shielding capabilities in NITAWL**
- **Removes several approximations in NITAWL**
  - **Accurate calculation of slowing-down sources with resonance interference effects**
  - **Includes resonance overlap effects**
  - **Accurate treatment of clad, moderator flux spectrum**
  - **Includes impact of scatter-anisotropy and leakage on PW spectrum**
- **Treats cases with multiple absorber-zones**
  - **e.g., black absorber rod, or fissionable lump in fissionable solution**

Transport Solution

- **The transport solution performs two functions:**
  - **Spatial flux solution used by TRITON to calculate power distributions:**
    - **ORIGEN-S may deplete using powers or fluxes**
    - **Powers are scaled according to user input**
  - **Multigroup cross section collapsed to update ORIGEN three-group cross sections.**

Transport Flux Weighting

- **NEWT automatically performs a 3-group collapse to thermal/resonance/fast energies expected by COUPLE**
  - **COUPLE is a utility to convert AMPX-format cross section to update ORIGEN data**
  - **Cross sections are collapsed based on the average flux in each mixture**
  - **Collapsed cross sections are created for each depletion mixture**
  - **A loop over COUPLE/ORIGEN-S is performed, processing each mixture one at a time, for all mixtures being depleted**

Transport Flux Weighting (cont'd)

- **The NEWT transport solution uses the flux distribution to calculate the power generation in each mixture.**
  - **fluxes are used to calculate fission and n-γ reaction rates, and obtain power generation rates in all mixtures**
  - **TRITON obtains powers and fluxes from NEWT**
    - **Powers are used to normalize fluxes for ORIGEN-S**
    - **NEWT uses the same flux-to-power conversions as ORIGEN-S for consistency**
    - **Depletion by flux is was default in SCALE 5, but depletion by power was added and made default in SCALE 5.1.**

Transport Flux Weighting (cont'd)

- **User-requested flux collapse is also available - if requested, two independent group collapses are performed**
  - **required 3-group collapse**
  - **user-specified collapse**
- **This feature is most commonly used in generating reactor physics parameters in a few-group structure.**
- **Weighted microscopic cross sections are saved in AMPX Working Library Format**
- **Homogenized macroscopic cross sections, if requested, are saved in same format**

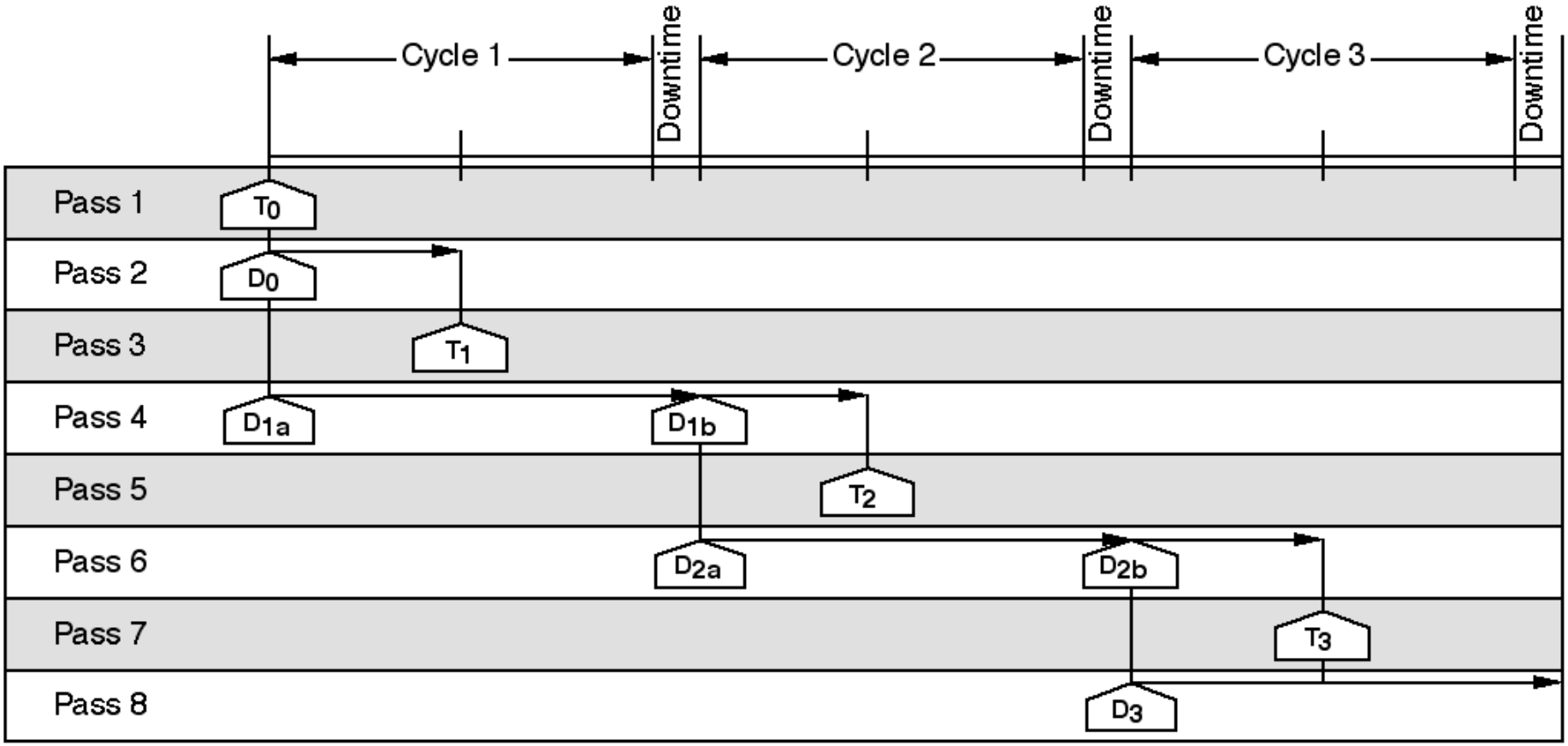
Library Updates

- **COUPLE reads 3-group working format libraries and updates the ORIGEN-S library database.**
- **Only those nuclides used in the transport calculation are updated on the ORIGEN-S library**
  - **By default, in addition to input trace quantities of nuclides a set of 66 additional nuclides are automatically added to all fuel mixtures.**
  - **Optionally, another 150 nuclides may be added.**
    - **Additional nuclides are necessary to accurately predict eigenvalues at higher burnups**
    - **Incurs increased computational effort**

Library Updates (cont'd)

- **TRITON creates burnup-dependent cross-section libraries that are used by ORIGEN-S for depletion calculations**
  - **Multigroup cross sections change with time as inventories vary.**
  - **Changes are generally second-order so cross-section updates are not needed on a fine temporal basis.**
  - **Cross-section updates are required more often when properties change rapidly, e.g., Gd depletion.**

t-depl Predictor/Corrector Approach



TRITON Reactor Analysis Capabilities

- **Generation of libraries for ORIGEN-ARP**
- **Restart to simulate fuel shuffling**
- **Generation of broad group master libraries**
- **Cross sections for nodal analysis**
- **Faster CENTRM processing and mixed methods**
- **Reduced cross section processing for large problems**

ORIGEN-ARP Methodology

- **Generates ORIGEN-S cross-section libraries by interpolation of existing cross section data**
- **Interpolation parameters for uranium fuels are burnup, enrichment, and moderator density (optional)**
- **MOX interpolation parameters are total Pu content, ^{239}Pu concentration, burnup, and moderator density**

Restart to Simulate Fuel Shuffling, etc.

- **At the end of a depletion calculation, TRITON saves the concentrations of all nuclides (for which master library x-secs exist) in a preformatted file.**
- **The file can be automatically or manually included in a subsequent calculation.**
- **Can be used for any kind of change - the results on one calculation are readily available and formatted for the next calculation.**

Generation of Broad Group Master Libraries

- **SCALE 44-group ENDF/B-V library was collapsed from the 238-group library using an LWR spectrum.**
  - **This library was (is) often misused and abused**
  - **SCALE 5.1 includes an ENDF/B-VI 238-group library, but no collapsed 44-group library.**
- **TRITON now provides the ability to create a new, <u>appropriately-weighted</u> broad-group library from a fine-group master**
- **This library may be produced only by the t-newt sequence.**

Cross sections for nodal analysis

- **T-DEPL (only) generates a database of cross sections any time branch calculations are requested.**
  - **Archive of cross sections and data for each reference case and branch, for each depletion step.**
  - **Saved in user-specified collapsed and homogenized format.**
  - **Other data (D, ADFs, pin form factors, neutron velocity, etc. are also saved)**
- **The database is a a simple binary file intended for subsequent post-processing.**

Cross sections for nodal analysis

- **TRITON can produce pin-power edits for comparison to other results**
- **The TRANSFORMER utility is currently used to process this file and generate cross sections for PARCS.**
- **ORNL hopes to eventually extend TRANSFORMER to support other nodal codes**
- **The format of the binary file is available and other translators may be independently developed.**

Faster CENTRM Processing

- **The default cross section processing mode in t-depl is CENTRM two-region processing**
  - **Still continuous energy**
  - **Lacks spatial resolution**
  - **Fast and appropriate for most fuel cells**
- **A full spatial S_n solution mode may be selected in place of the two-region approximation.**
- **TRITON allows one to "mix and match" CENTRM cross section processing**
- **Two-region can be used globally, but more rigorous S_n solution can be applied when needed, e.g., Gd poison rods.**

Reduced Cross Section Processing

- **TRITON can be used to deplete every fuel pin in an assembly**
  - **Symmetry generally allows depletion of an assembly subset**
- **Each fuel pin is individually resonance-processed**
  - **Rigorous but slow**
- **An alternate approach has been developed for TRITON depletion to reduce this computational penalty.**

Reduced Cross Section Processing

- **Macroscopic cross sections for depleted materials are more sensitive to number densities that cross sections.**
- **It is a reasonable approximation to generate a single set of cross sections for similar rods by using an averaged set of isotopics.**
- **Local number densities in each rod are retained and combined with average cross sections.**
- **User determines which fuel mixtures are "similar."**

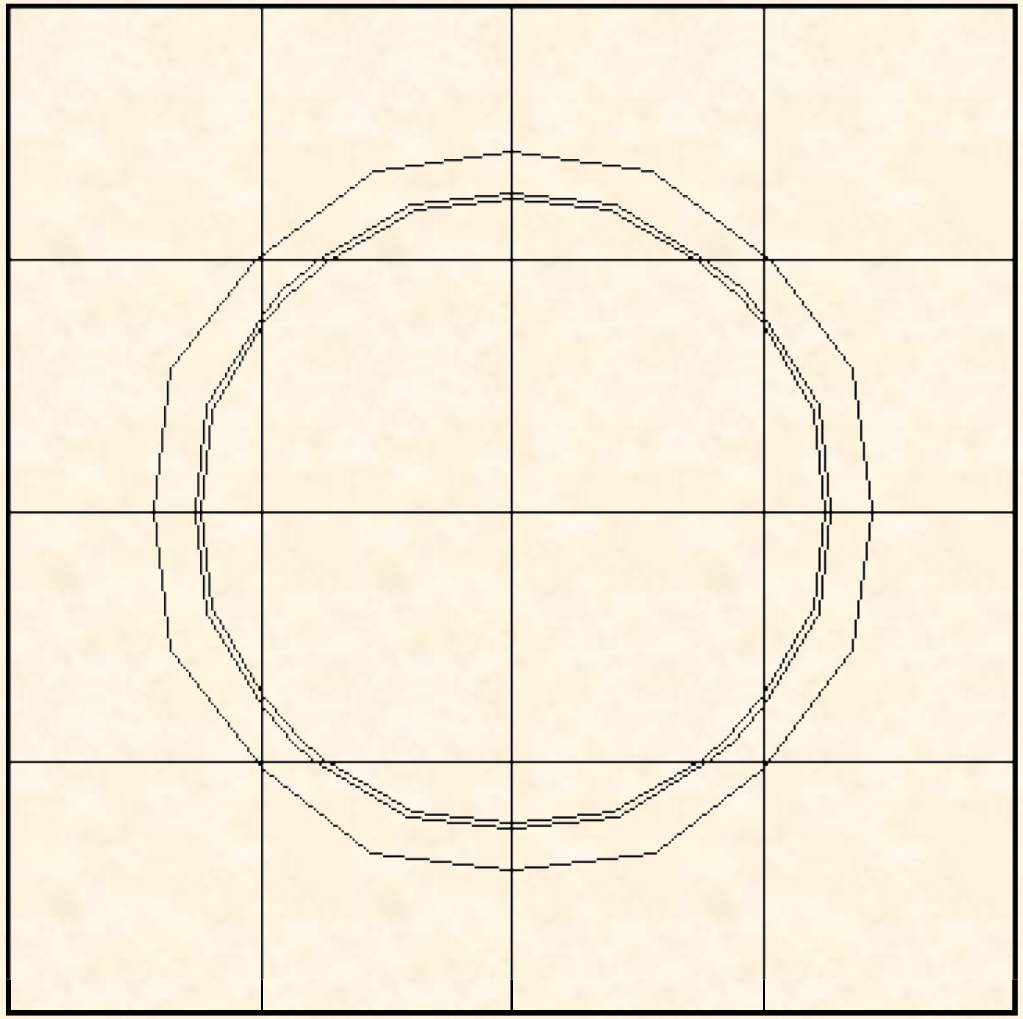
Developing Models in TRITON

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

NEWT - Introduction

- **NEWT provides a discrete ordinates solution for arbitrary, non-orthogonal configurations**
  - **Discrete ordinates methods are the most rigorous approximation to the transport equation**
  - **Direct solution of angular fluxes allows capture of important anisotropic effects**
- **NEWT uses Extended Step Characteristic discretization:**
  - **Allows cells in the form of arbitrary polygons**
  - **Able to closely approximate any curved surface (with volume conserved)**
  - **Able to exactly represent any straight-sided body**

NEWT - Introduction



Automatic Grid Generation

- **The NEWT solution grid is generated automatically from a body-based combinatorial geometry spec (SGGP).**
- **Grid generator converts curved surfaces (cylinders) to regular polygons, then places bodies on an underlying rectangular grid.**
- **NEWT analyzes each line segment for each angle to:**
  - **Determine required solution sweep order**
  - **Calculate and save side-to-side transport factors**

Solution method

- **"Standard" S_n approach:**
  - **Iterative solution uses cross-section, source, and transport factors to solve all line segment angular fluxes according to direction-dependent sweep order.**
  - **Balance eqn. used for cell-averaged angular flux, numerical integration gives scalar flux.**
  - **Cells are solved iteratively in an inner loop for each energy group, based on a guessed source Q.**
  - **An outer loop iterates on energy groups to update the source as energy groups converge**

Features and Capabilities

- **NEWT uses the discrete ordinates method, allowing detailed angular and spatial resolution of fluxes.**
  - **Arbitrary order of scattering (P_n approximation)**
  - **Arbitrary quadrature order**
  - **Automated grid generation (fast and easy)**
  - **Multigroup energy solution**
  - **A rigorous and highly accurate deterministic solution for non-trivial configurations**

Features and Capabilities

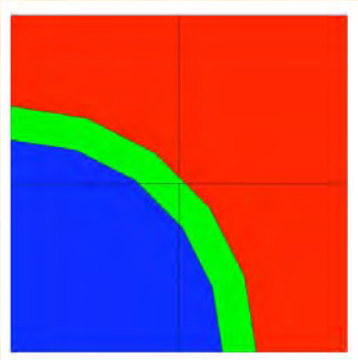
- **Although the characteristic form of the transport eqn. is integrated in the NEWT derivation, NEWT is <u>not</u> a Method of Charactistics code.**
- **Ray tracing is done only within a cell, to obtain angular fluxes on boundaries and the cell average.**
- **Rays are not uniformly distributed - only used where needed.**

NEWT Input

- **Keyword-based input**
- **Data is input in data blocks:**
- **Basic model must include these data blocks:**
  - **control parameters**
  - **mixture identification**
  - **geometry description**
- **Additional optional data blocks are used for special operations**

NEWT Input - Example

```
=newt
Infinite lattice PWR pin cell
read parm
collapse=yes outers=100 epsilon=1.0e-5 kguess=1.34 prtxsec=yes
   prtmxsec=yes prtbroad=yes
end parm
read materials
  3  2  'moderator' end
  2  1  'clad'  end
  1  1  'fuel' end
end materials
read geom
global unit 1
cylinder 10  0.41000 com='fuel' chord +x=0 chord +y=0 sides=20
cylinder 20  0.4750  com='clad' chord +x=0 chord +y=0 sides=20
cuboid 30 0.65635 0.0 0.65635 0.0 com='moderator'
media 1 1 10
media 2 1 20 -10
media 3 1 30 -20
boundary 30 2 2
end geom
read bounds all=reflect end bounds
end
```

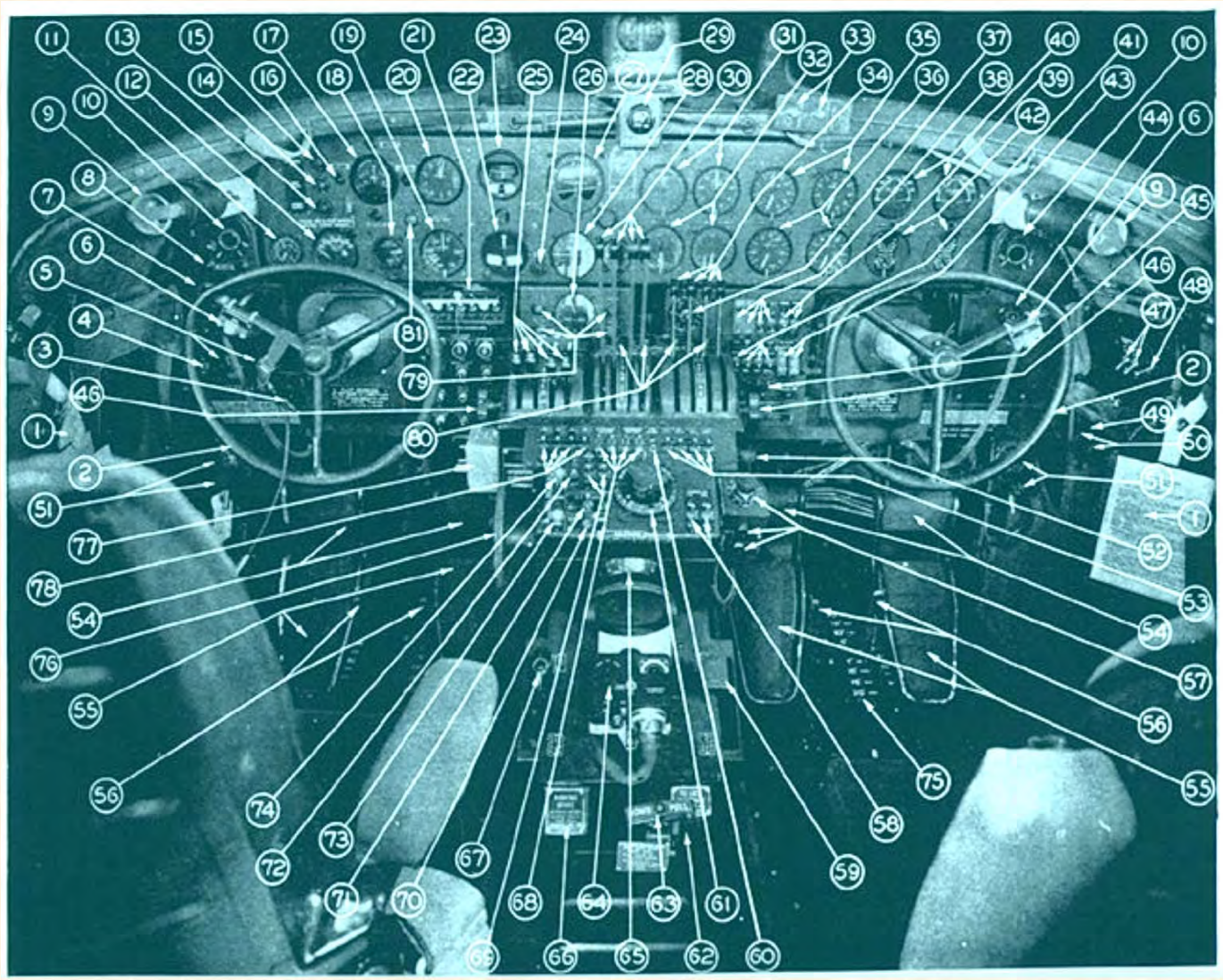


Data Blocks

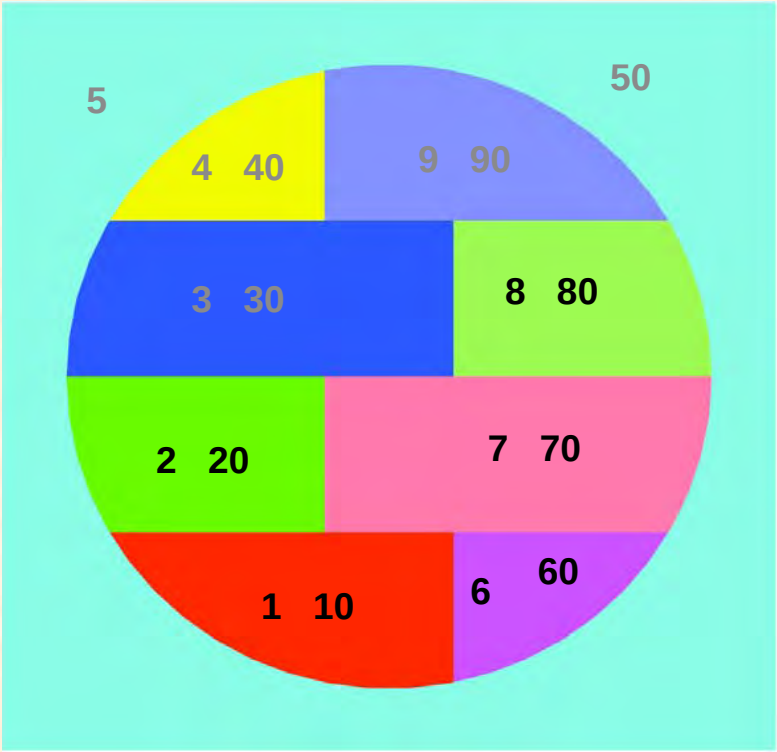
READ PARAM	problem control data	END PARAM
READ MATERIAL	material data	END MATERIAL
READ GEOMETRY	model geometry specifications	END GEOMETRY
READ COLLAPSE	energy collapse data	END COLLAPSE
READ BOUNDS	boundary conditions	END BOUNDS
READ HOMOG	spatial homogenization data	END HOMOG
READ MIXT	mixing table data	END MIXT
READ ARRAY	arrays	END ARRAY
READ ADF	discontinuity factor data	END ADF
READ FLUXPLANE	flux and current edit	END FLUXPLANE

Data Blocks

So many controls, so little time!



Partial Bodies Using Chords

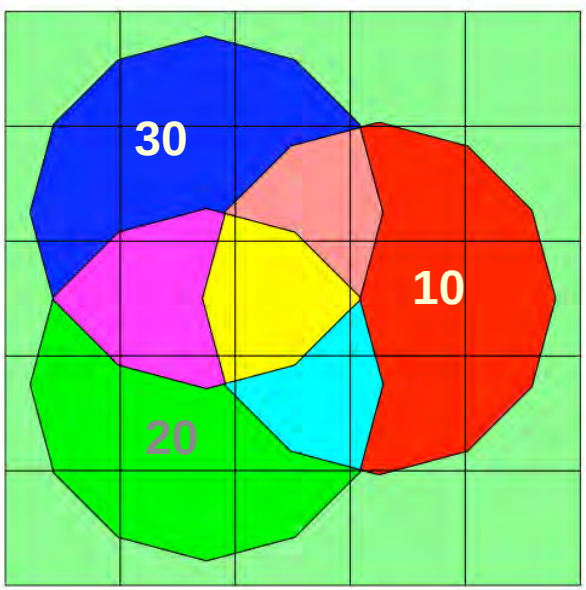



```
global unit 1
cylinder  10  10.0  chord -y=-5.0 chord -x=2.0 sides=50
cylinder  20  10.0  chord +y=-5.0 chord -y=0.0
          chord -x=-2.0 sides=50
cylinder  30  10.0  chord +y=0.0 chord -y=5.0
          chord -x=2.0 sides=50
cylinder  40  10.0  chord +y=5.0 chord -x=-2.0 sides=50
cylinder  60  10.0  chord -y=-5.0 chord +x=2.0 sides=50
cylinder  70  10.0  chord +y=-5.0 chord -y=0.0
          chord +x=-2.0 sides=50
cylinder  80  10.0  chord +y=0.0 chord -y=5.0
          chord +x=2.0  sides=50
cylinder  90  10.0  chord +y=5.0 chord +x=-2.0 sides=50
cuboid  50  4p12.0
media  5  1  50 -10 -20 -30 -40 -60 -70 -80 -90
media  1  1  10
media  2  1  20
media  3  1  30
media  4  1  40
media  6  1  60
media  7  1  70
media  8  1  80
media  9  1  90
boundary  50 12 12
```

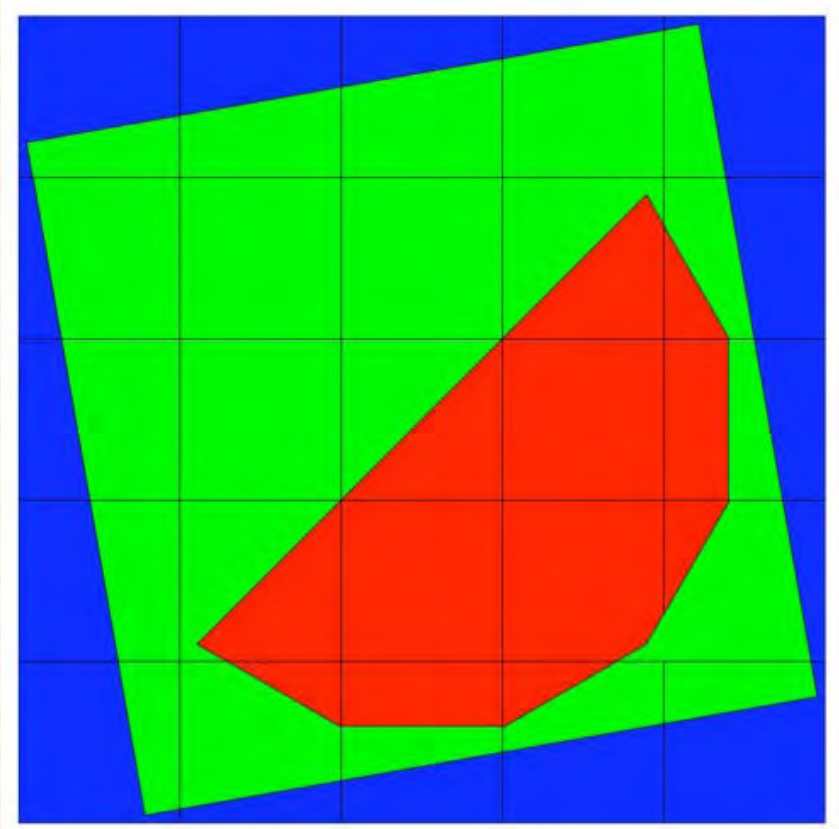
Geometry Block - Unit:media

- **Media specifications use a logical AND to define regions. This allows intersections and specification of intersecting regions**

```
global unit 1
cylinder 10 9.0 origin x=4.5
cylinder 20 9.0 origin y=-4.5 x=-4.5
cylinder 30 9.0 origin y=4.5 x=-4.5
cuboid 40 4p15
media 1 0 10 -20 -30
media 2 0 20 -10 -30
media 3 0 30 -10 -20
media 4 0 10 20 30
media 5 0 10 20 -30
media 6 0 20 30 -10
media 7 0 10 30 -20
media 8 0 40 -10 -20 -30
```



ROTATE Example



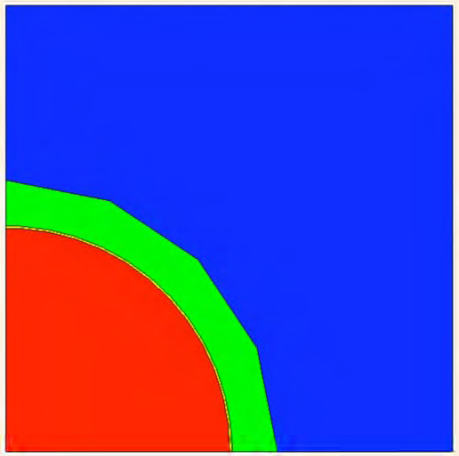
```
read geom
unit 1
cylinder  10  10.0 chord +x=0.0
media 1 1 10
boundary 10

global unit 2
cuboid  20  4p11.0 rotate a1=10
cuboid 30 4p13.0
hole 1 rotate a1=-45
media  2  1  20
media  3  1  30 -20
boundary  30 5  5
end geom
```

User Control of Polygonal Approximation

- **Example:**

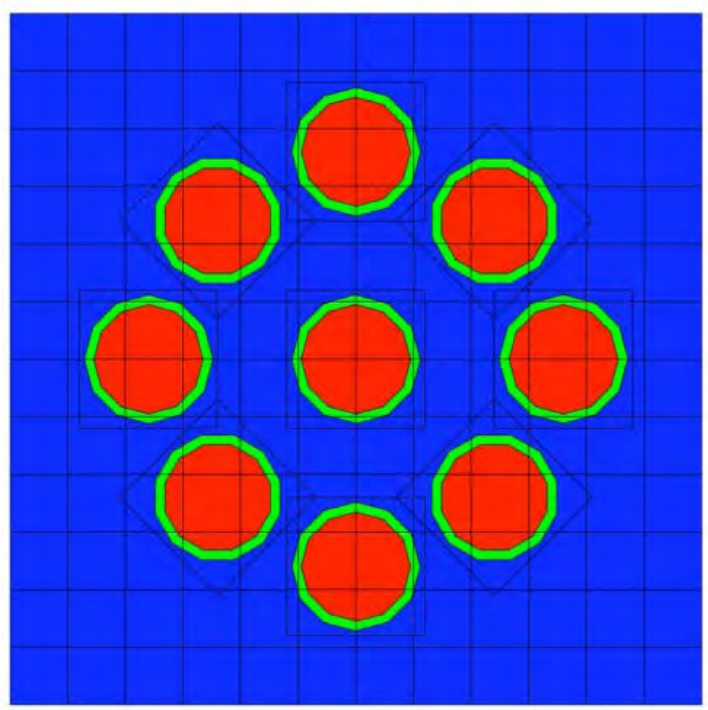
```
global unit 1
   cylinder 10 0.5 sides=50 chord +x=0 chord +y=0 com='fuel'
   cylinder 20 0.505 sides=50 chord +x=0 chord +y=0 com='gas gap'
   cylinder 30 0.600 sides=16 chord +x=0 chord +y=0 com='clad'
   cuboid 40 1.0 0.0 1.0 0.0 com='moderator'
```



Holes for Irregular Body Placement

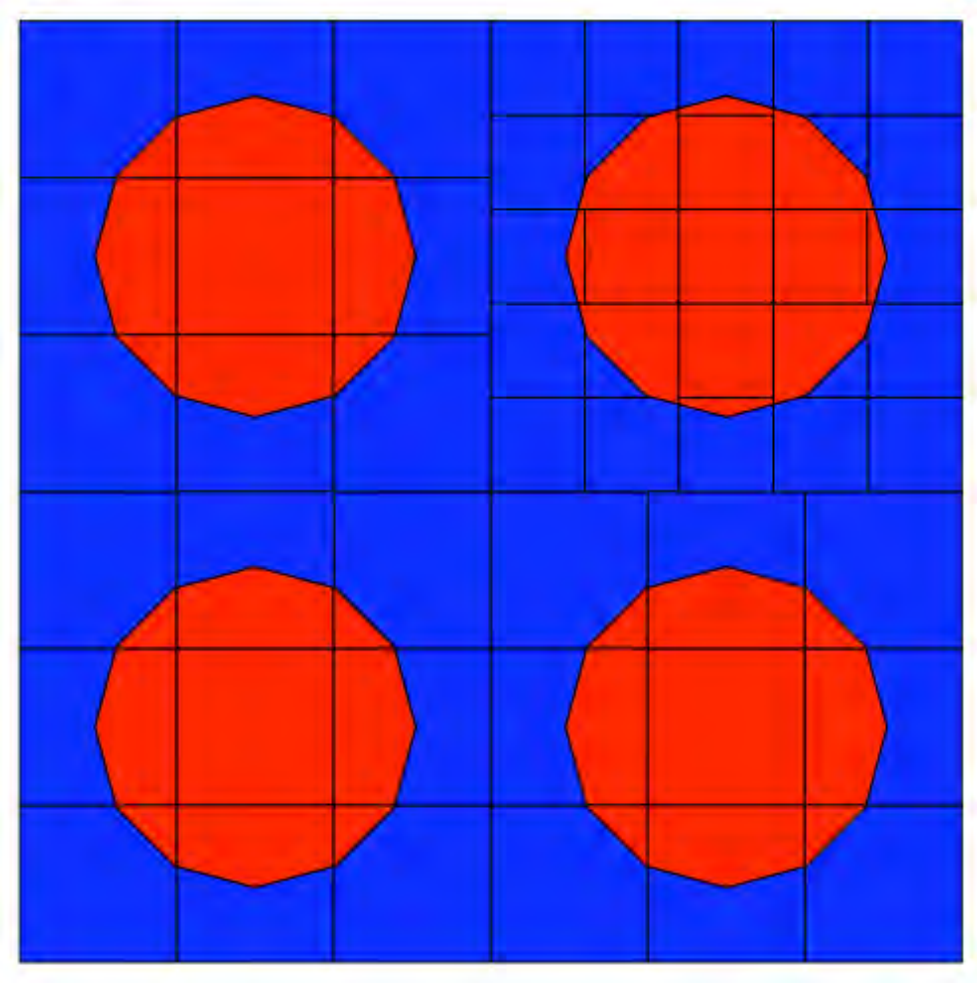
```
unit 1
cylinder 30 .3860
cylinder 40 .4550
cuboid   50 4p0.5
…

global unit 2
hole 1
hole 1 origin x=1. y=1. rotate a1=45
hole 1 origin x=-1. y=1. rotate a1=45
hole 1 origin x=-1. y=-1. rotate a1=45
hole 1 origin x=1. y=-1. rotate a1=45
hole 1 origin x=0 y=1.5
hole 1 origin x=0 y=-1.5
hole 1 origin x=1.5 y=0
hole 1 origin x=-1.5 y=0
cuboid 10 4p2.5
…
```

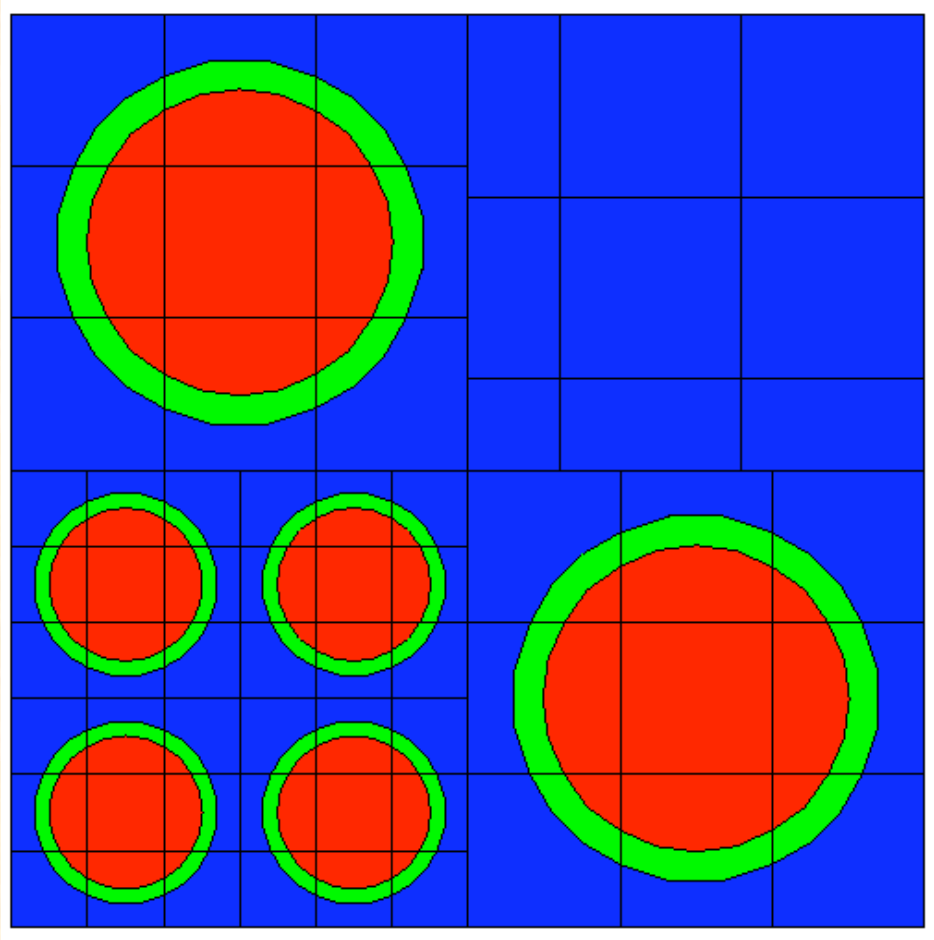


Arrays

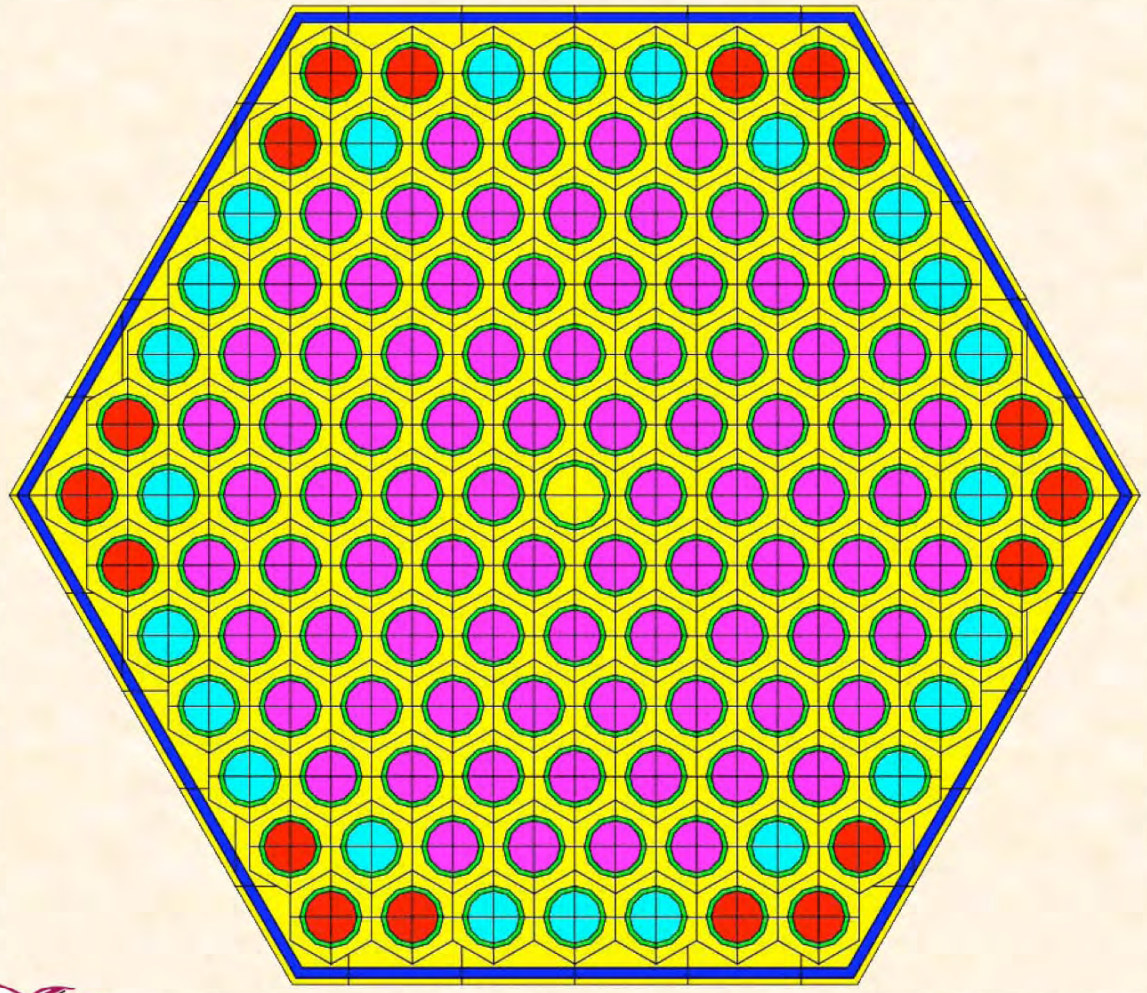
```
read geom
unit 1
cylinder 10 0.5
cuboid 20 0.75 -0.75 0.75 -0.75
media 1 0 10
media 3 0 20 -10
boundary 20 5 5
unit 2
cylinder 10 0.5
cuboid 20 0.75 -0.75 0.75 -0.75
media 1 0 10
media 3 0 20 -10
boundary 20
global unit 3
rectangle 10 3.0 0.0 3.0 0.0
array 1 10  place 1 1 0.75 0.75
media 3 0 10
boundary 10 6 6
end geom
```



Arrays of Arrays

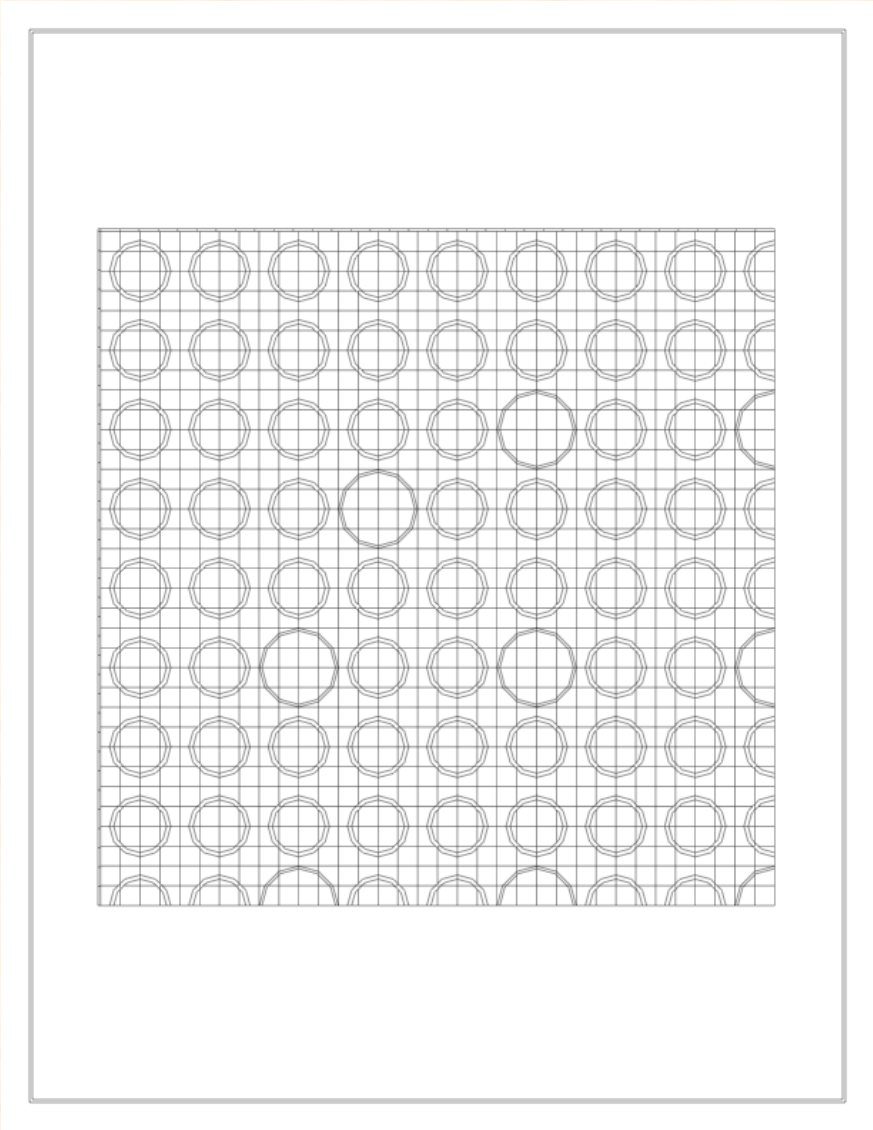


Hexagonal Arrays



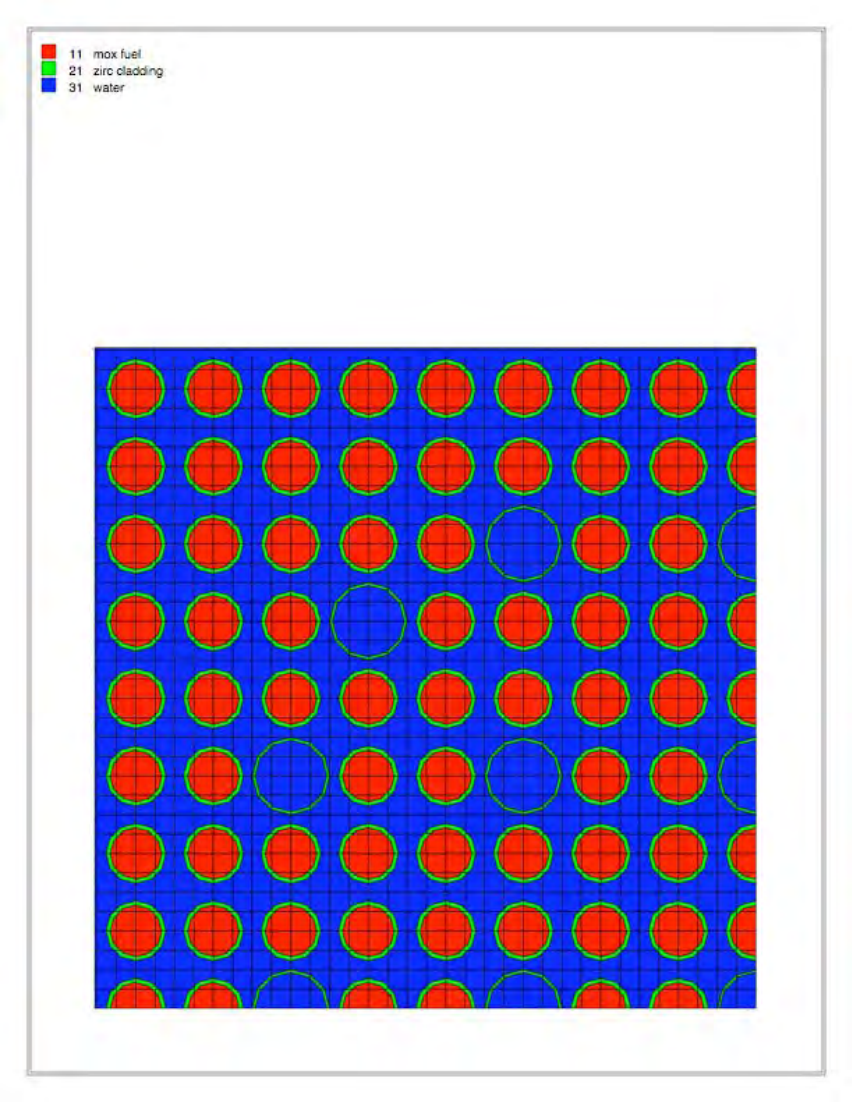
PostScript Output Graphics: newtgrid.ps

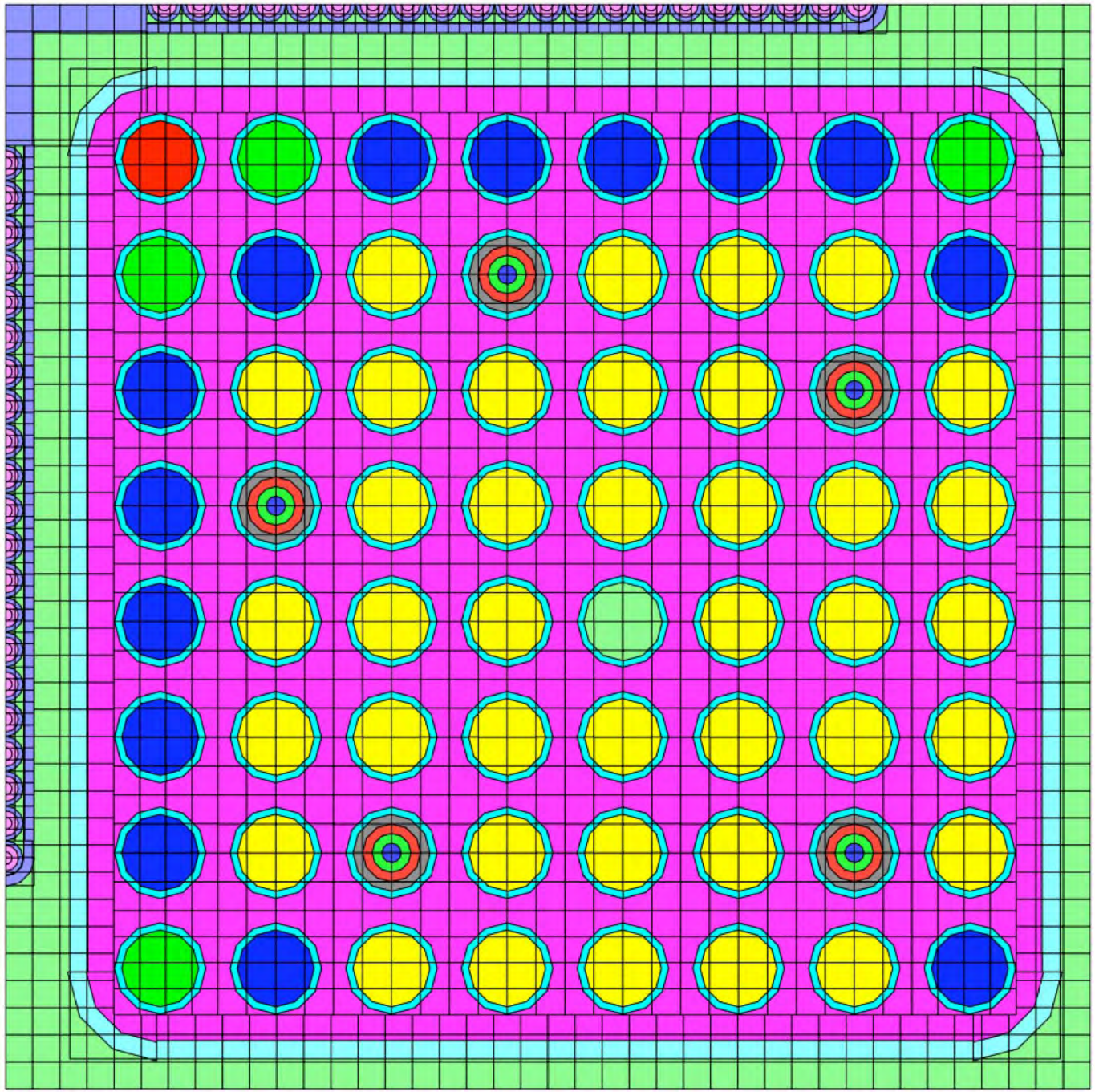
Generated first, if a consistent geometry model is read.



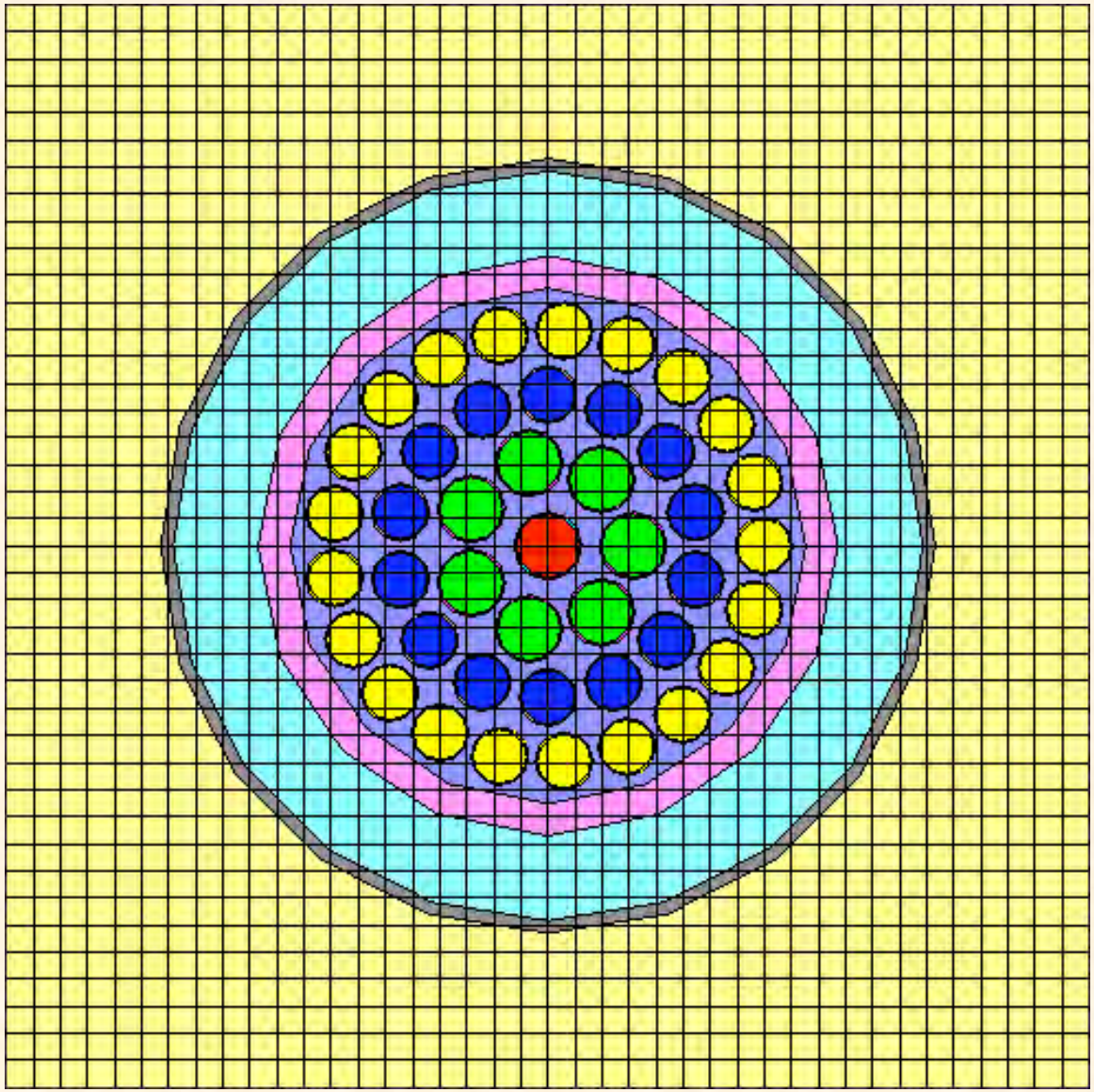
PostScript Output Graphics: newtmatl.ps

Generated second, after media placement operations are completed.

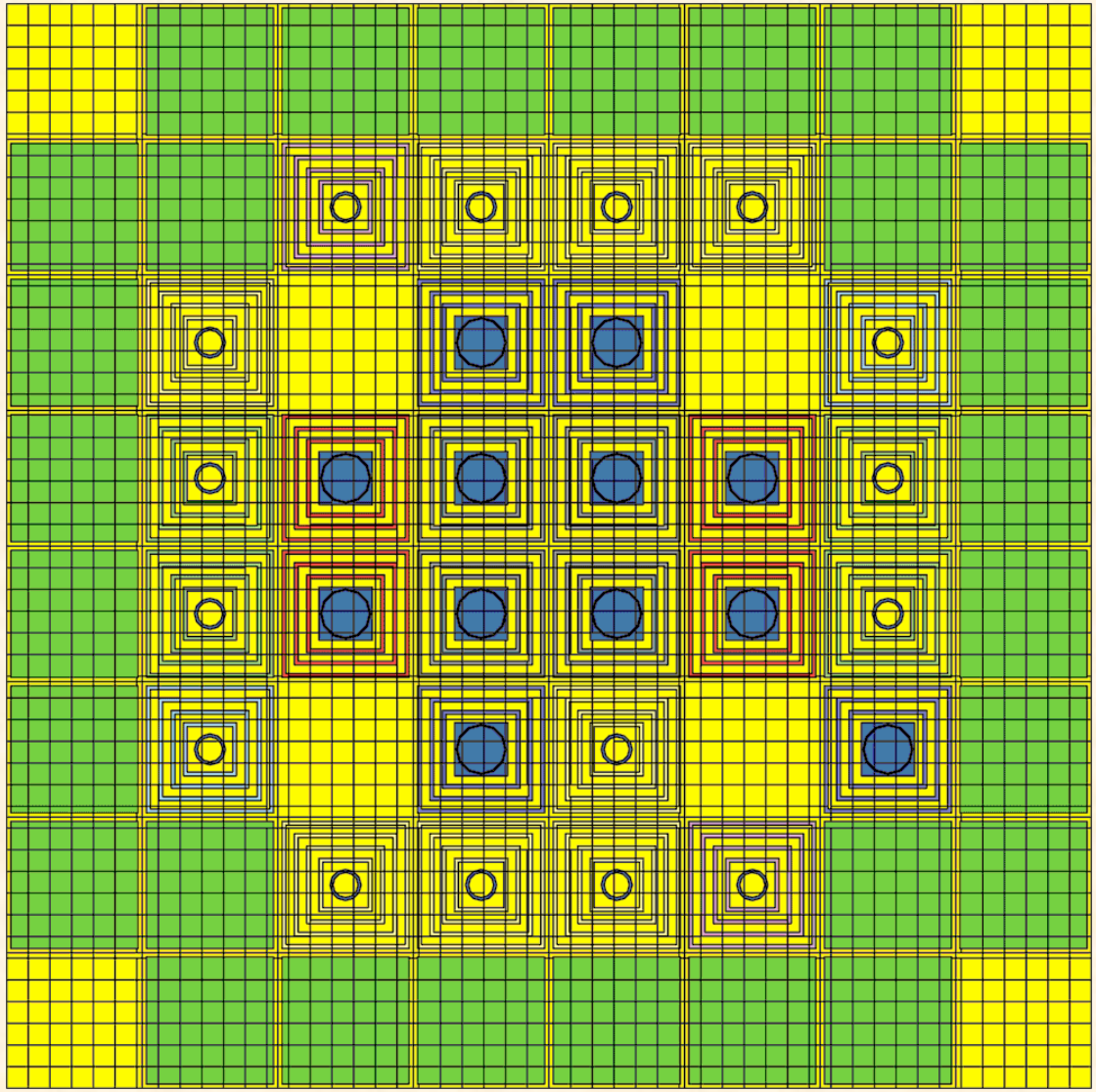




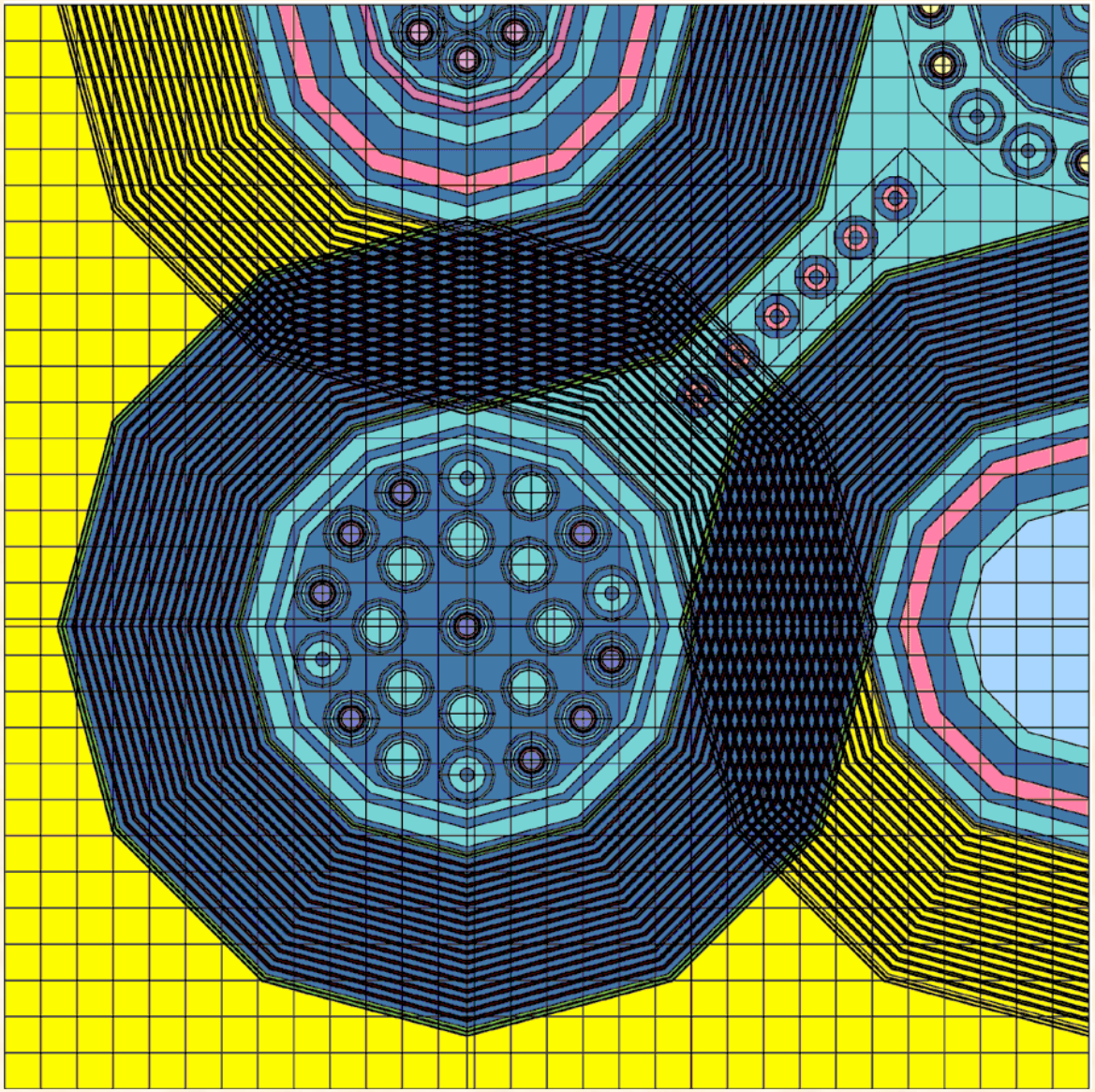
ACR-700 Assembly



IRT Core



ATR 1/4 Core



Depletion Model Development

- **Depletion models are most easily developed by developing a t-newt model first**
  - **t-newt does cross-section processing and transport solution only.**
  - **Add *depletion* and *burndata* blocks to specify**
    - **Materials to be depleted**
    - **Depletion history (powers, burn times, down times)**
  - **Add other optional control blocks as needed.**
    - ***timetable***
    - ***alias***
    - ***branch***
    - ***opus***

Depletion Model Development

- **Not all materials are depleted - generally only fuel, poisons, and occasionally structural mat'ls**
- **Depletion block lists materials to be depleted**
- **Depletion block also allows:**
  - **Specification of power normalization**
  - **Mixture assignments for simplified cross section processing (more later)**
- **Current limit of 255 depletion materials**

Depletion Model Development

- ***burndata*** **data block allows specification of power history in histogram form.**
  - **Control of cross section update frequency over burnup period**
  - **Optional down time after burn period**
  - **Specific power is distributed to a pin, set of pins, or an entire assembly, as defined in *depletion* data block.**
- **Current limit of 255 burn periods.**

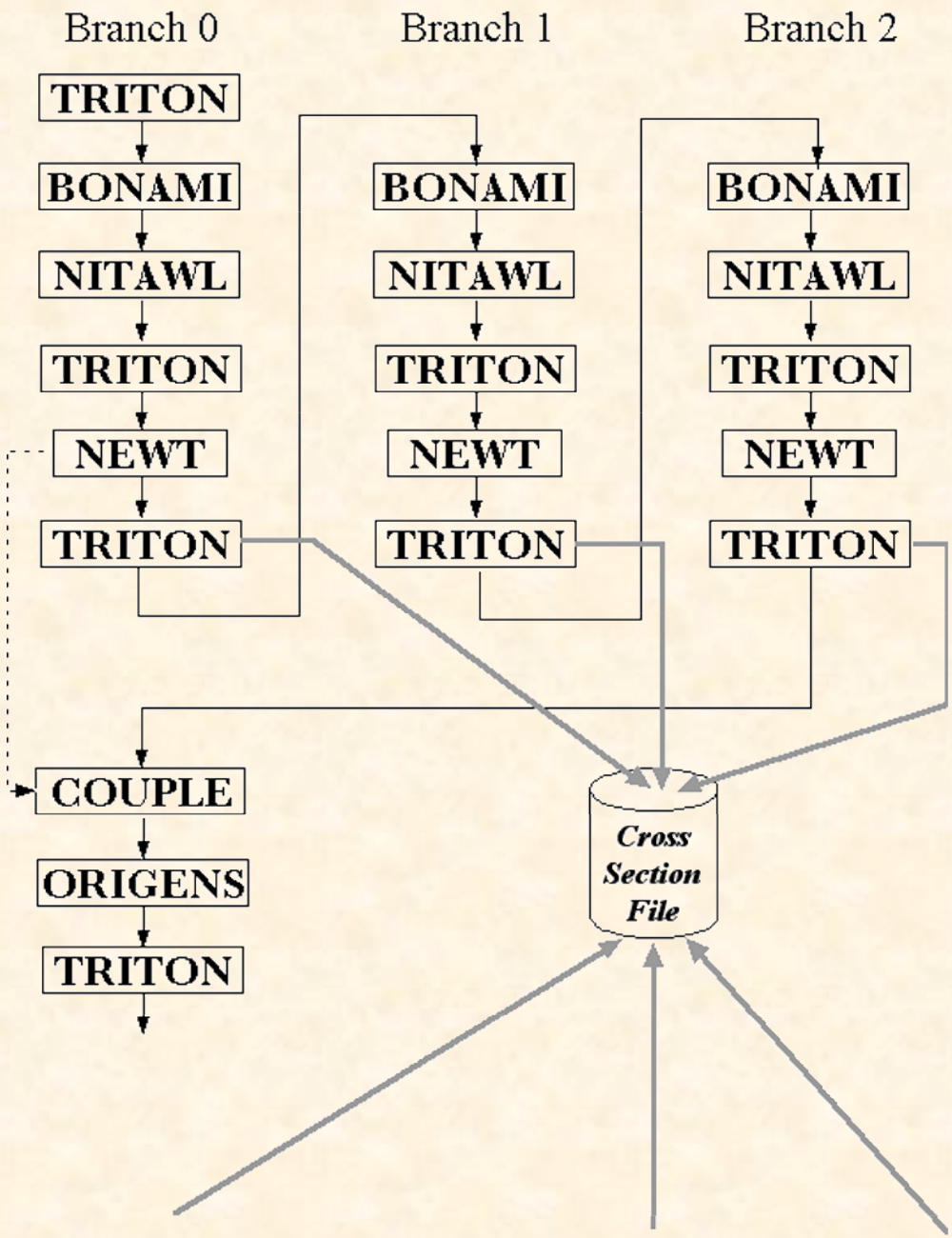
BRANCH Calculations

- **Branch calculations are supported in TRITON for lattice physics analysis (t-depl only)**
- **Branch calculations allow for a nominal condition transport calculation followed by perturbation of one or more of the following parameters:**
  - **fuel temperature**
  - **moderator temperature**
  - **moderator density**
  - **soluble boron concentration**
  - **control rod insertion**

BRANCH Calculations

- **Branch calculations yield cross sections computed for one or more perturbed states for each depletion step.**
- **Cross sections are saved in a single database file for a user-specified collapsing scheme.**
- **Cross sections may be subsequently extracted from this file and converted for use by core simulation codes.**

BRANCH Calculations



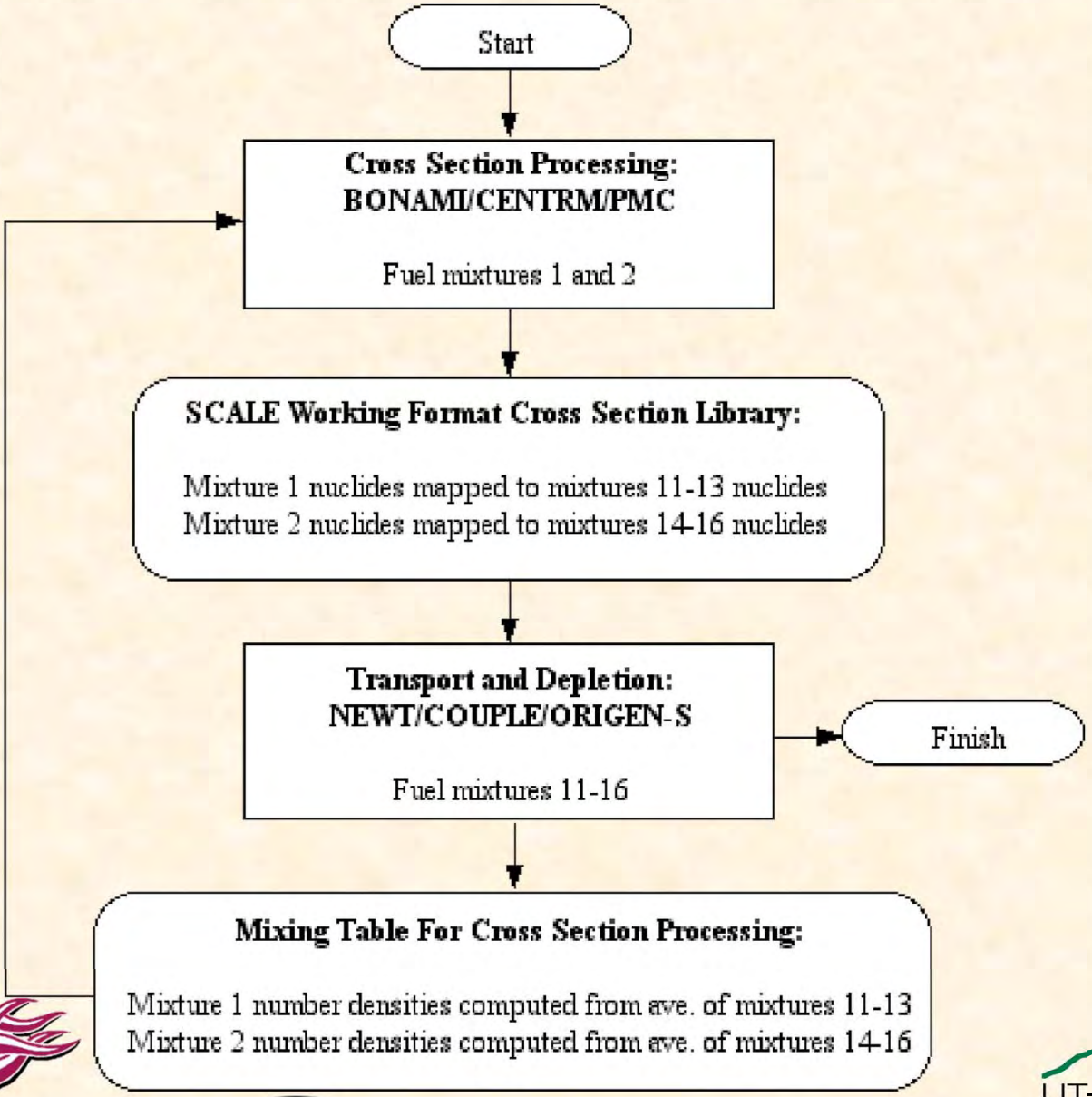
Use of TRITON ASSIGN Statements

- **For each transport pass, CENTRM (or NITAWL) performs cell calculations for each fuel cell.**
- **If one chooses to track unique isotopics in each fuel cell location, then a cell calculation is required for each of a number of pins.**
  - **with symmetry, a Westinghouse 17x17 PWR can be reduced to 24 unique locations**
  - **24 cell calculations can consume a great deal of time - even more than the transport calculation**
- **Although fuel pin isotopic concentrations vary by location, fuel pin cross sections are less sensitive to small isotopic changes**

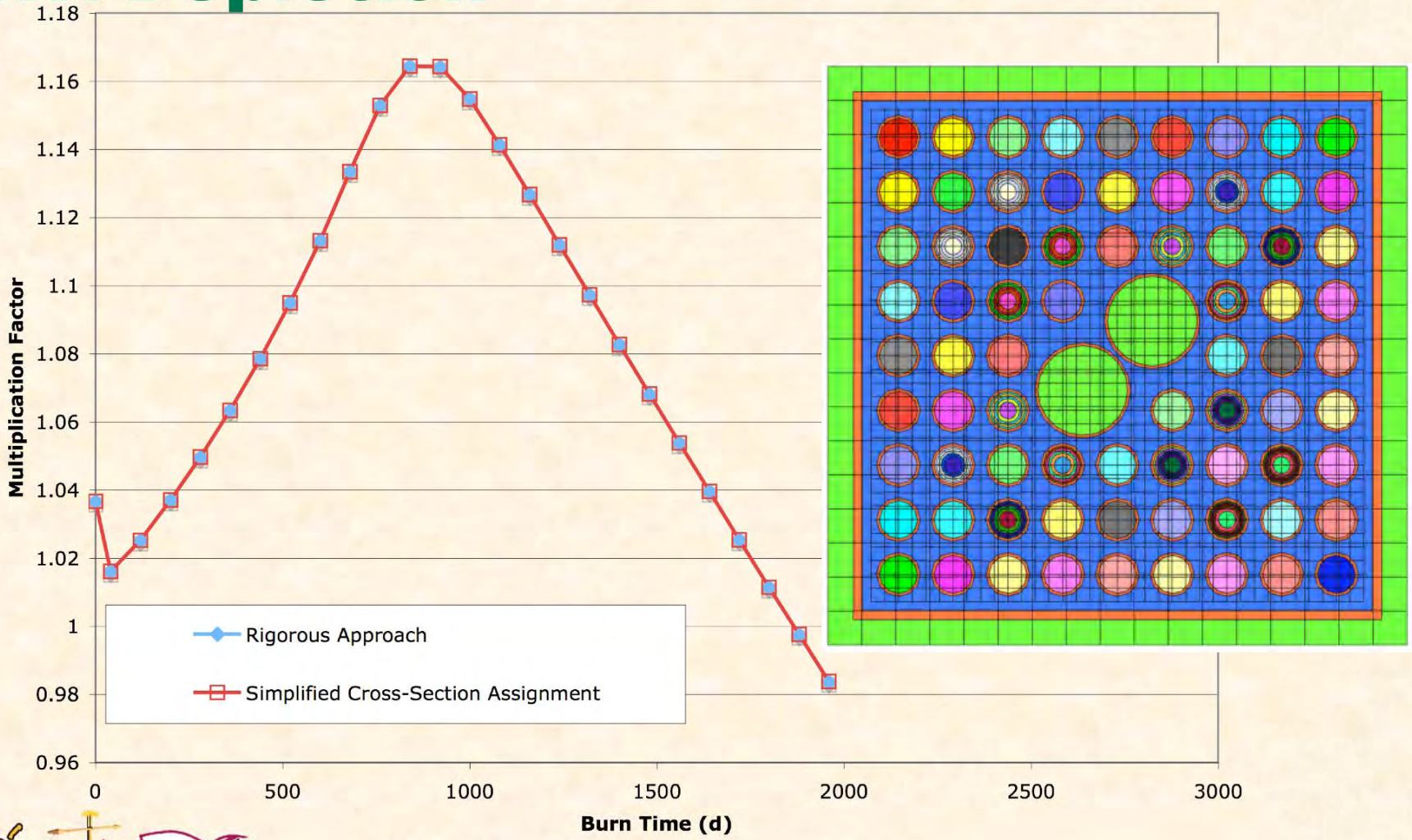
Use of TRITON ASSIGN Statements

- **Cross-section "assignments" take advantage of second-order differences in cross sections.**
- **Effectively, mixture numbers used in depletion calculations are "assigned" to mixture numbers used in cell calculations.**
- **Only available in depletion calculations.**
- **Assignment statements are an optional part of the *depletion* data block.**

Use of TRITON *ASSIGN* Statements



TRITON *ASSIGN* Approximation for BWR Depletion



Relative Error of TRITON *ASSIGN* Approximation

Isotopics and Timings

Nuclide	Rigorous standard approach	Cross Section Assignment	Nuclide	Rigorous standard approach	Cross Section Assignment
^{235}U	3.26E-04	3.26E-04	^{99}Tc	6.45E-05	6.45E-05
^{238}U	2.02E-02	2.02E-02	^{101}Ru	6.08E-05	6.08E-05
^{238}Pu	6.01E-06	6.01E-06	^{103}Rh	3.14E-05	3.14E-05
^{239}Pu	1.22E-04	1.22E-04	^{143}Nd	4.32E-05	4.32E-05
^{240}Pu	5.96E-05	5.96E-05	^{145}Nd	3.70E-05	3.70E-05
^{241}Pu	3.11E-05	3.11E-05	^{147}Sm	6.20E-06	6.20E-06
^{242}Pu	1.47E-05	1.47E-05	^{150}Sm	1.50E-05	1.50E-05
^{241}Am	1.72E-06	1.72E-06	^{151}Sm	6.14E-07	6.14E-07
^{242m}Am	3.56E-08	3.55E-08	^{152}Sm	4.89E-06	4.89E-06
^{245}Cm	7.23E-08	7.25E-08	^{153}Eu	6.02E-06	6.02E-06
^{95}Mo	5.94E-05	5.94E-05	^{155}Gd	4.57E-08	4.57E-08

Model	Time (hours)
Rigorous (reference) approach	117.62
Simplified cross-section assignment	12.08

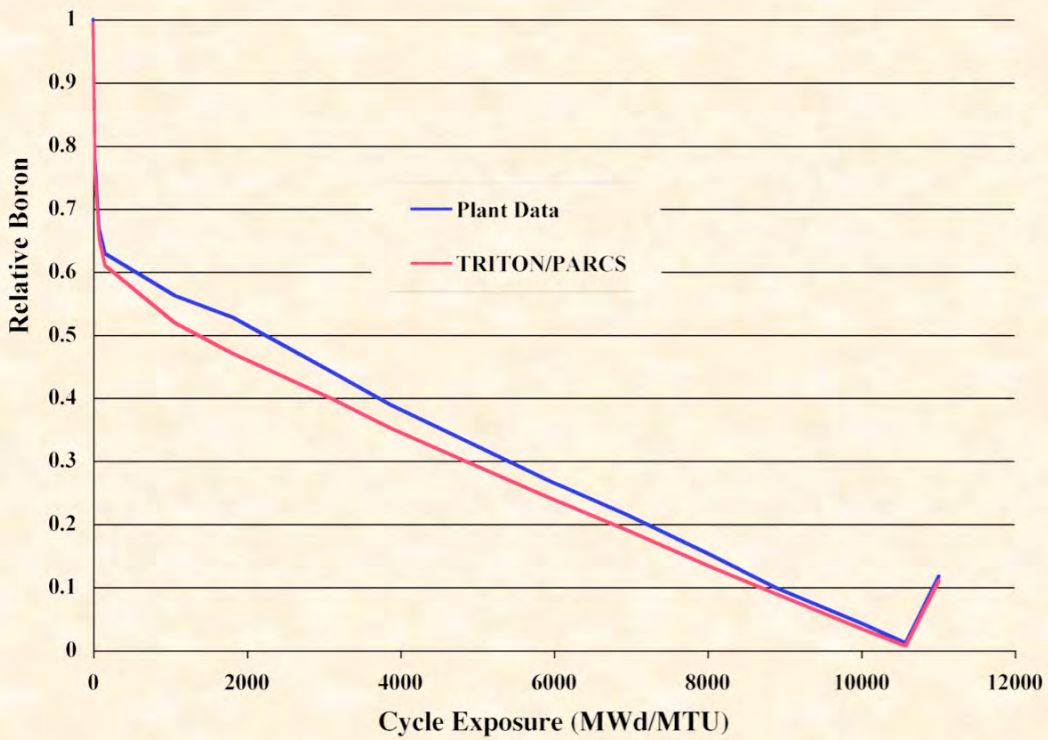
Assessment using St. Laurent core data

- **TRITON was used to calculate cross sections for each of four assembly types (3 MOX, 1 UO_2) plus reflected UO_2 assemblies, for burnups of 0 → 50 GWd/t.**
- **PARCS was used to model the time-dependent behavior of the core:**
  - **Beginning of Cycle 9 as a known state (first loading of MOX fuel) to predict core behavior for Cycle 10.**
  - **Control rod bank positions, power, and inlet temperatures were input to PARCS to simulate the reactor's operating history.**
  - **Results were boron letdown curve and assembly power distribution**

St. Laurent PWR with MOX Fuel

3.03%	–0.14%	–1.19%	–0.38%	–0.87%	–1.56%	–1.37%	0.98%
–0.16%	–1.67%	–1.32%	–0.19%	0.37%	0.93%	–2.17%	–1.30%
–1.23%	–2.14%	0.35%	0.91%	–0.65%	0.75%	1.55%	
0.74%	–1.86%	0.52%	–0.08%	1.60%	1.10%	1.60%	
–0.88%	0.09%	–1.08%	1.39%	0.66%	0.32%		
–0.74%	0.58%	0.63%	1.11%	–0.57%			
–1.39%	–2.29%	1.41%	2.05%				
1.99%	–2.05%						

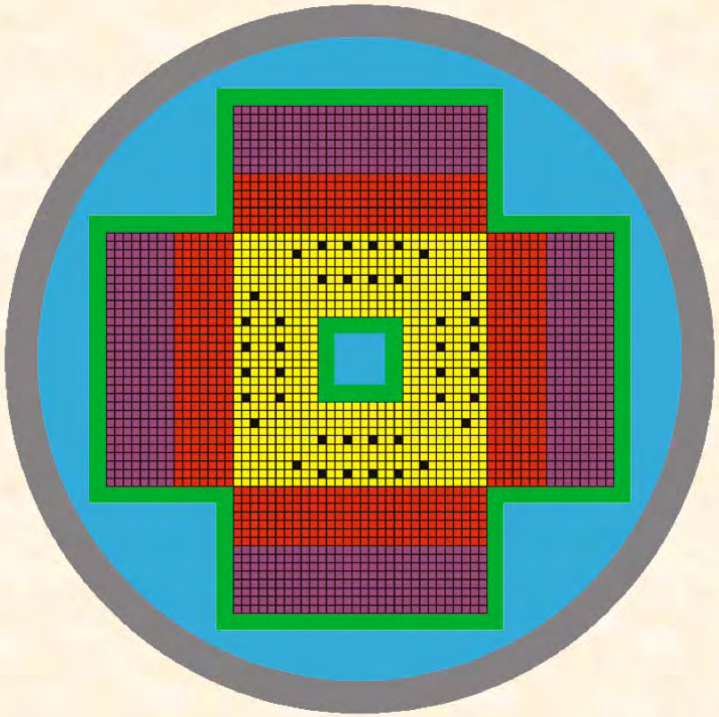
RMS	1.26%
RMS (UO_2)	1.20%
RMS (MOX)	1.38%



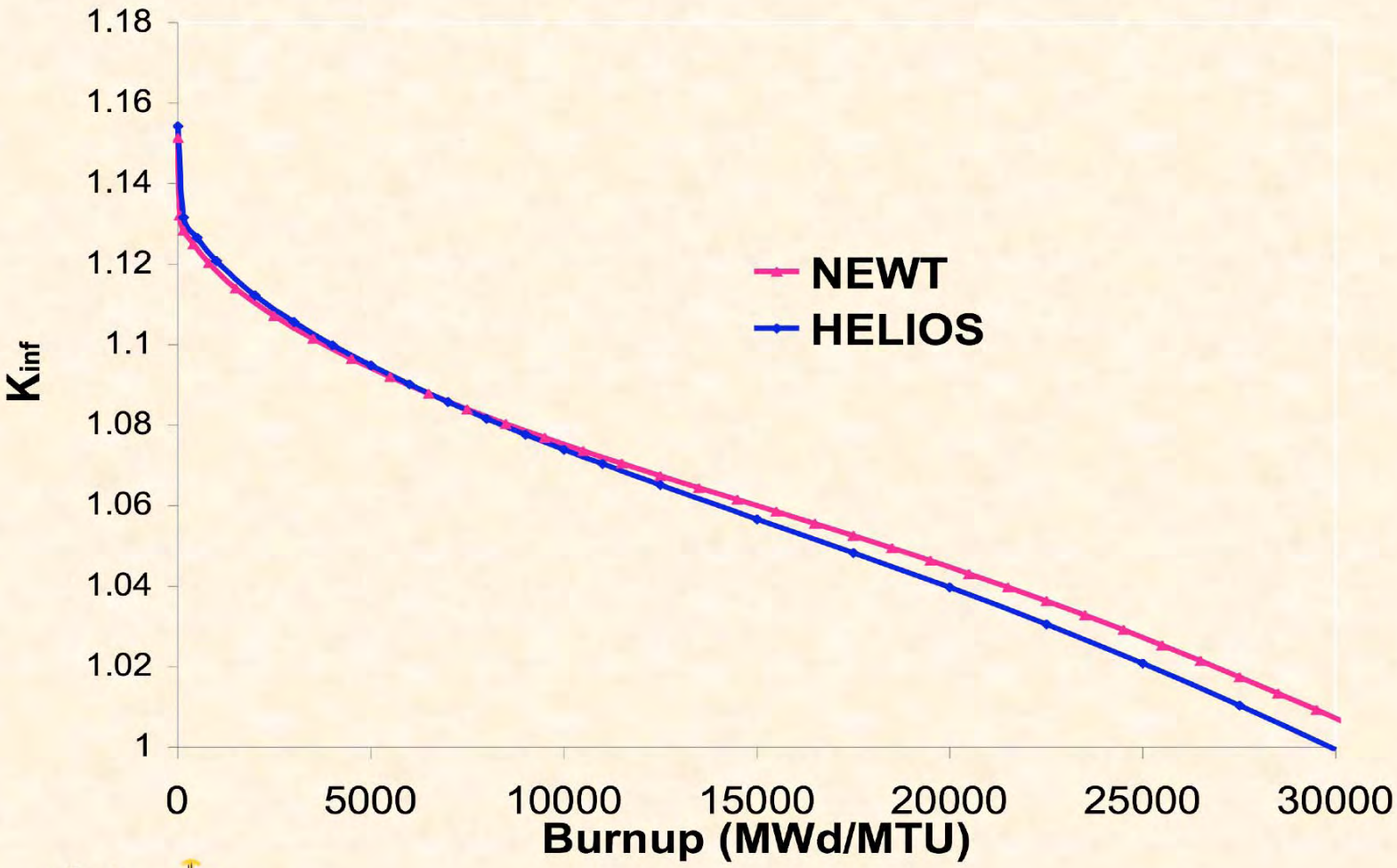
VENUS-2 Critical Experiment

	3.3% UO_2	4.0% UO_2	MOX	UO_2 assm.	UO_2/MOX assm.	UO_2/MOX assm. + refl.	Full core	Full core, buckled
HELIOS 1.7 (190g)	1.4085	1.34331	1.26339	1.17477	1.29886	1.15295	1.08969	0.99870
HELIOS 1.7 (45g)	1.40691	1.34189	1.26332	1.17502	1.29843	1.1542		0.99817
NEWT (44g)	1.40385	1.33303	1.25345	1.17309	1.28986	1.14419	1.08829	0.99945
XSDRNPM (44g)	1.40385	1.33366	1.25345					
MCNP 4B	1.40650 (0.04%)	1.33640 (0.04%)	1.26310 (0.05%)		1.29478 (0.04%)	1.14637 (0.05%)		1.00050 (0.03%)
KENO V.a (44g)					1.29179 (0.04%)	1.14655 (0.05%)		
Benchmark ave.	1.40593	1.33726	1.25673					0.99796

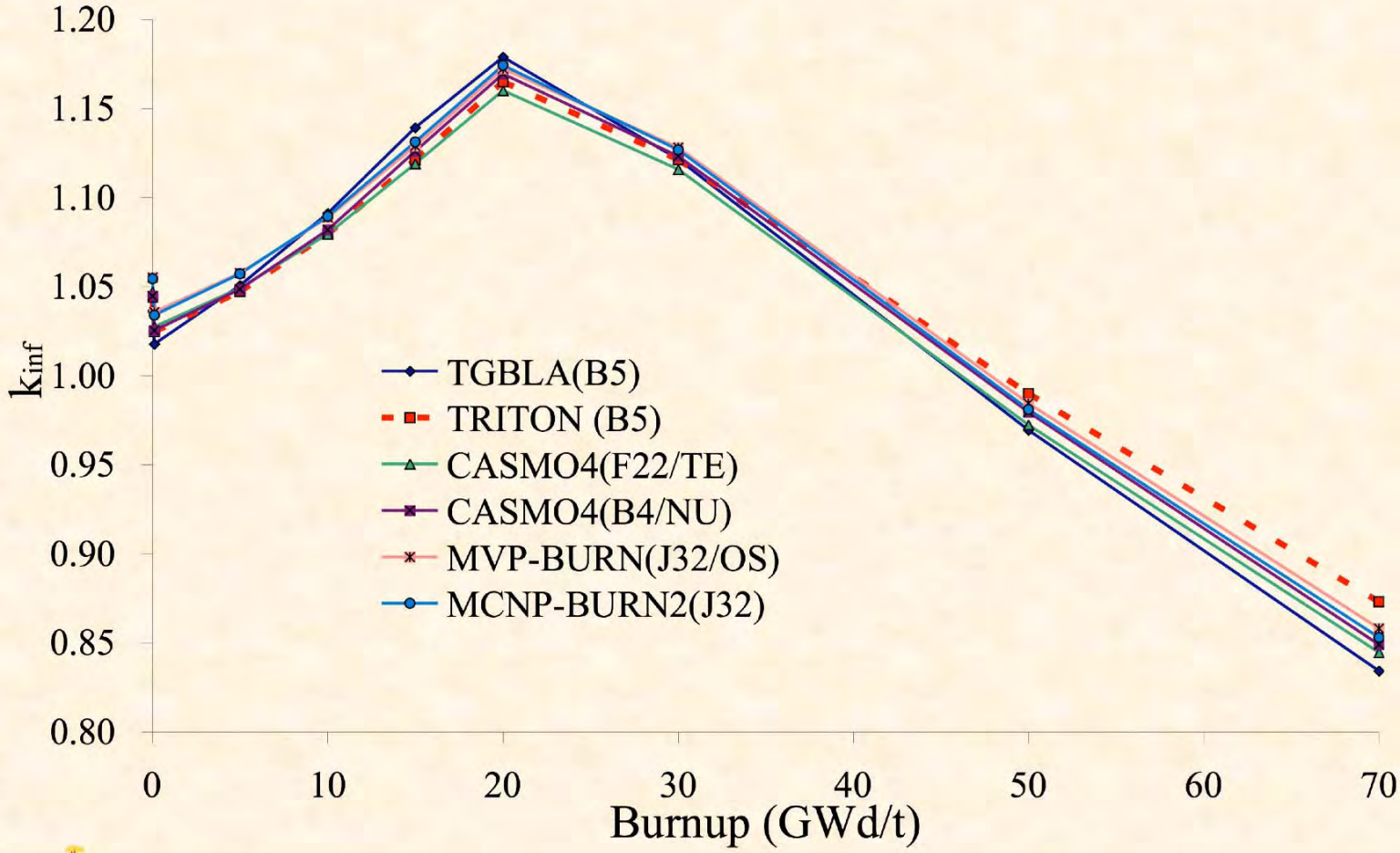
	UO_2 assm.	UO_2/MOX assm.	UO_2/MOX Assm. + refl.	Full core
*TRITON 44g**	*1.17309*	*1.28986*	*1.14419*	*1.08829*
PARCS 2g (TRITON XS)	1.17492	1.28956	1.17620	
PARCS 8g (TRITON XS)	1.17307	1.28946	1.14772	1.08108
*HELIOS 45g**	*1.17477*	*1.29886*	*1.15295*	*1.08969*
PARCS 2g (HELIOS XS)	1.16891	1.29742	1.16689	
PARCS 8g (HELIOS XS)	1.17447	1.29744	1.16558	1.08561



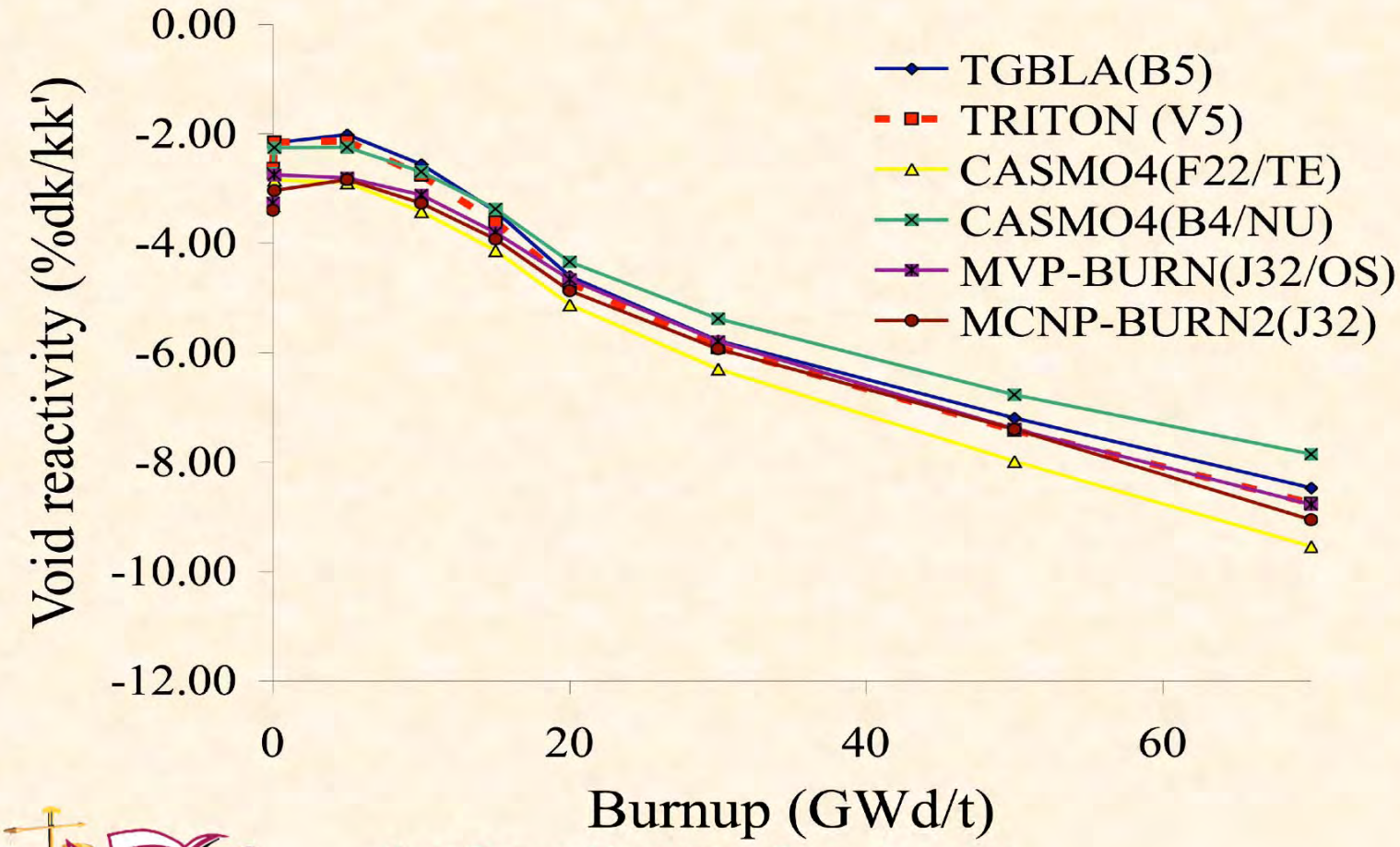
k_{inf} vs. Burnup for MOX5.0-WABA Assembly

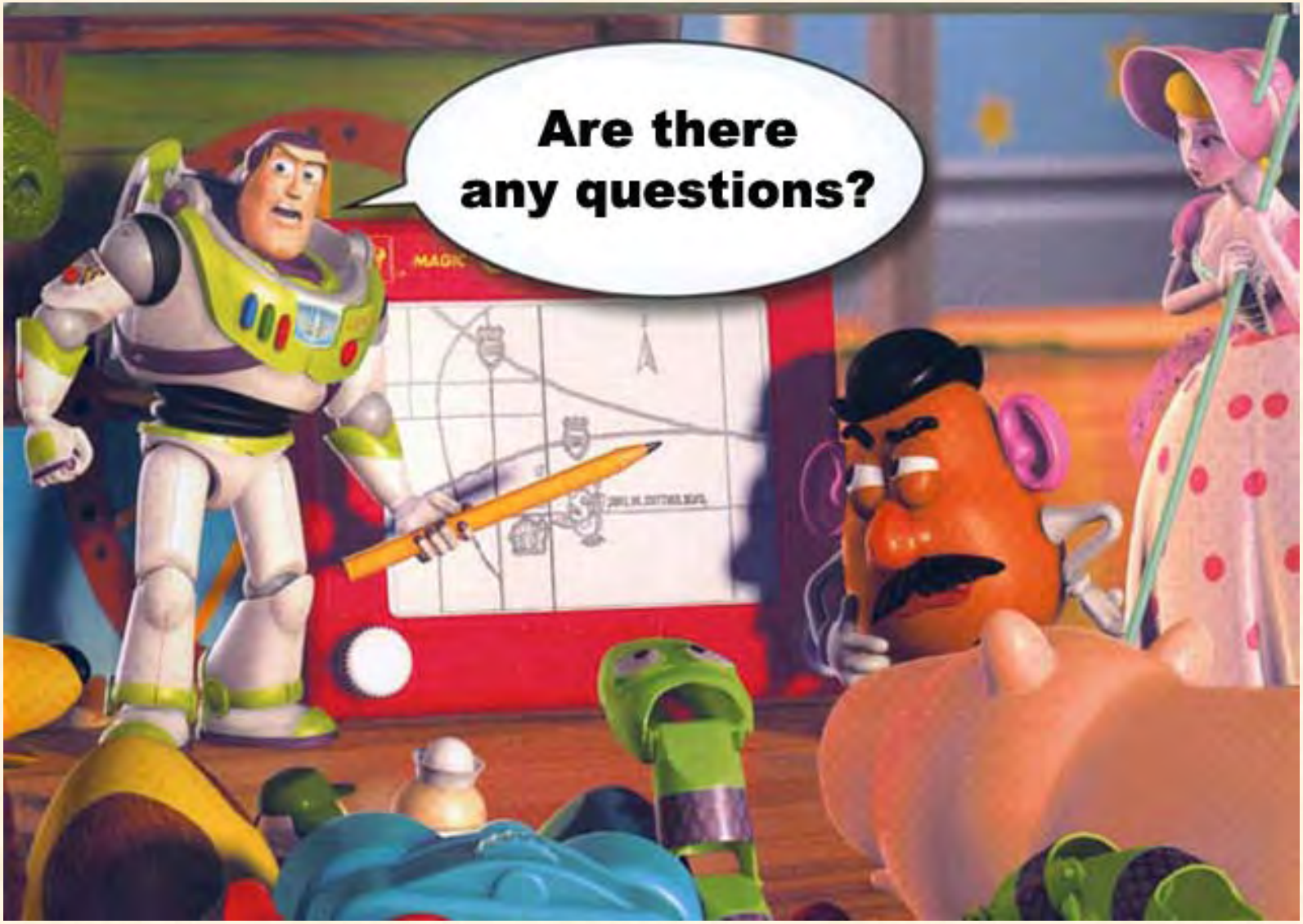


JAERI 9x9 BWR Problem: k-eff



JAERI 9x9 BWR Problem: Void Reactivity (0-70%)




Are there any questions?

Taming the Beast

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Overview

- **Taming the Beast - GUIs and Visualization**
  - **GeeWiz**
  - **KENO 3D**
  - **ORIGEN-ARP**
- **Demo of GeeWiz**
  - **Model setup**
  - **Execution**
  - **KENO 3D**
- **Demo of ORIGEN-ARP**

GUIs and Visualization

- **SCALE was originally designed to be simple to use for the novice and occasional user.**
- **Increasing complexity of SCALE and SCALE models has necessitated the development of graphical user interfaces (GUIs).**
  - **GeeWiz provides model development and execution capabilities for most SCALE sequences**
  - **KENO 3D provides a 3D visualization tool for KENO V.a and KENO-VI models**
    - **Rotations, zooms, cut-aways, etc.**
  - **ORIGEN-ARP provides a simple GUI and rapid means for depletion calculations for assemblies with precalculated cross section libraries.**

GeeWiz

- **GeeWiz is a Windows-based GUI for simplified model development and execution**
- **Because NEWT is "new" kid on the block, GeeWiz does not yet support NEWT modeling.**
- **GeeWiz DOES support TRITON t5-depl and t6-depl analysis sequences (KENO V.a and KENO-VI)**
- **NEWT models are very similar to KENO-VI models (albeit 2D); GeeWiz *can* be used to partially develop t-depl input.**

ORIGEN Depletion

- **The challenge in depletion modeling is generation of time-dependent cross sections.**
- **In TRITON, NEWT (and KENO) are used to generate a library of time-dependent cross sections for a given lattice/configuration.**
- **Such a library can used "after the fact" by ORIGEN for rapid depletion calculations.**
- **Libraries can be generated for a range of burnups, enrichments, moderator densities, etc.**

ORIGEN Depletion

- **ARP (Automatic Rapid Processing) is a utility developed to access cross sections from a set of libraries and interpolate to a specific state point or set of state points.**
- **ORIGEN can then be run to perform rapid depletion calculations for the system of interest.**
- **ORIGEN-ARP is a Windows-based GUI used to perform calculations using one of a set of precalculated libraries for fixed configurations**

ORIGEN-ARP

- **Fast, Easy, and Accurate Fuel Depletion, Decay, and Source Terms**
- **Allows easy setup of ORIGEN-S depletion and decay cases**
- **Interactive Windows program with on-line help**
- **Generates input files for ARP, ORIGEN-S, and OPUS that can be run on a PC or workstation**
- **Executes code sequence on a PC**
- **Runs extremely fast – on the order of a few seconds**

ORIGEN-ARP Libraries in SCALE 5.1

- **UO2 LWR Fuel types**
  - **7 x 7 BWR, 8 × 8 BWR**
  - **14 × 14 PWR, 15 × 15 PWR, 17 × 17 PWR**
- **Enrichments - 1.5 to 5.0 wt %**
- **Burnups - 0 to 60 GWd/MTU**
- **CANDU reactor (natural UO_2)**
- **MAGNOX (natural U metal)**
- **Advanced Gas-Cooled Reactor (AGR)**
- **Russian VVER 440, VVER 1000**
- **MOX fuels (PWR and BWR assemblies)**
  - **8x8-2, 9x9-9, 9x9-1, 10x10-9**
  - **14x14, 15x15, 16x16, 17x17, 18x18**
  - **Variable moderator density for BWR designs**

GeeWiz, KENO 3D, and Origen-ARP Demos

Run GeeWiz Demo

Run Origen-ARP Demo

Ongoing Developments and Future Capabilities

Current Development Status

- **Continuous-Energy solution mode in KENO V.a and KENO-VI**
- **Continuous energy libraries for ENDF/B-V and ENDF/B-VI data**
- **Doubly-Heterogeneous depletion treatment in TRITON**
- **t-sunami (tsunami-2d) sensitivity/uncertainty sequence in TRITON using NEWT**
- **Generalized adjoint solution in TRITON using NEWT**

Upcoming Developments

- **TRITON depletion using CE solution modes in KENO V.a and KENO-VI**
- **Continuous energy libraries for ENDF/B-VII**
- **Extension of Bondarenko factor data for all energies**
- **Fast reactor libraries for ORIGEN-S**
- **Extended quadrature sets in NEWT to allow 30° and 45° outer boundaries**
- **New Krylov-based acceleration scheme in NEWT**

Upcoming Developments

- **New shielding code (MONACO) and sequence driver (MAVERIC)**
- **Extension of GeeWiz to support NEWT and MONACO**
- **Incorporation of DORT and TORT into SCALE**

Availability

- **Hopefully, all these features (and more) will be available with the next major release of SCALE: *SCALE 6***
- **Time frame: ??? Your guess is as good as mine…**

Congratulations! You've made it to the end of this workshop!

NEWT

TRITON