SCALE 6.2 Reactor Physics Capabilities

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Matthew A. Jessee (presenter)

Reactor Physics Methods Team

Brian Ade
Kursat Bekar
Ben Betzler
Greg Davidson
Tom Evans
Cole Gentry
Steven Hamilton
Matthew Jessee
Rob Lefebvre
Ugur Mertyurek
Doro Wiarda
Will Wieselquist
Mark Williams

Reactor Physics Capabilities in SCALE 6.2

High-Fidelity Neutronics

- **TRITON**:
  - modular (1D/2D/3D)
  - general geometry
- **Polaris**:
  - easy-to-use LWR lattice physics (LP)
- TRITON and Polaris create lattice physics output and prepare reactor-specific data for Spent Nuclear Fuel (SNF) analysis a

SNF Characterization

- **ORIGEN:**
  - state-of-the-art transmutation module
- **ORIGAMI:**
  - easy-to-use assembly depletion analysis tool

Uncertainty Quantification

- **Sampler:**
  - computes uncertainties in LP and SNF quantities of interest due to input uncertainties

User Interfaces

- **Fulcrum:**
  - model development interface
  - output visualization

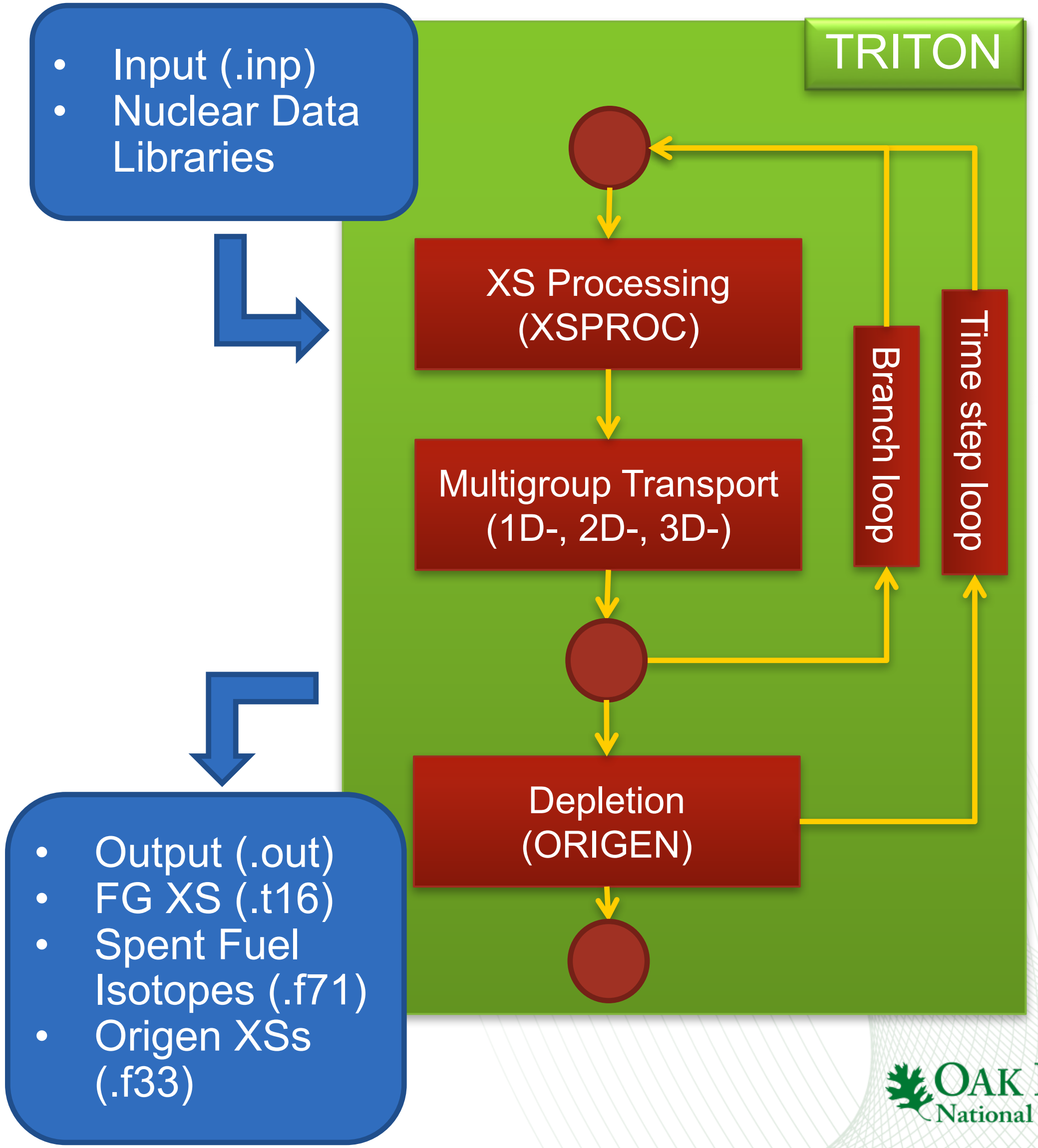
New 6.2 capabilities

TRITON: Modular General-Purpose Reactor Physics Sequence

OAK RIDGE
National Laboratory

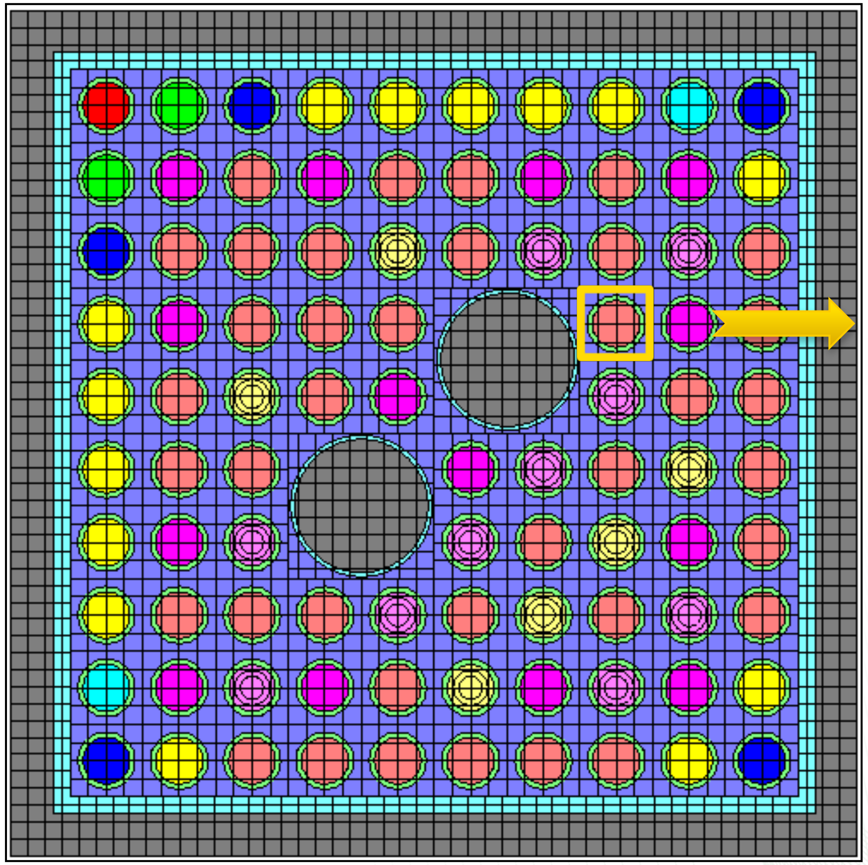
TRITON

- XSPROC
  - Wide range of self-shielding options
  - Same module used in criticality safety and shielding sequences
- Multigroup Transport:
  - 1-D SN (XSDRNPM)
    - slab
    - cylinder
    - spherical
  - 2-D ESC-SN (NEWT)
  - 3-D Monte Carlo (KENO-V.a, KENO-VI)
- TRITON in SCALE 6.2 also supports 3D CE-KENO depletion



SCALE Cross Section Processing

- User defines XS processing calculations based on unit cells
- XSs are assigned to geometry materials for transport/depletion calculations
- XS processing options:
  - Equivalence-theory self-shielding (BONAMI)
  - PW slowing down calculation (CENTRM/PMC)
    - 1D SN (slab, sphere, cylinder)
    - 2D MOC (square-pitched lattice)
    - 2-region, several others
  - Double Heterogeneous treatment for TRISO particle fuel


BWR 10x10 lattice


unit cell

TRITON Timeline

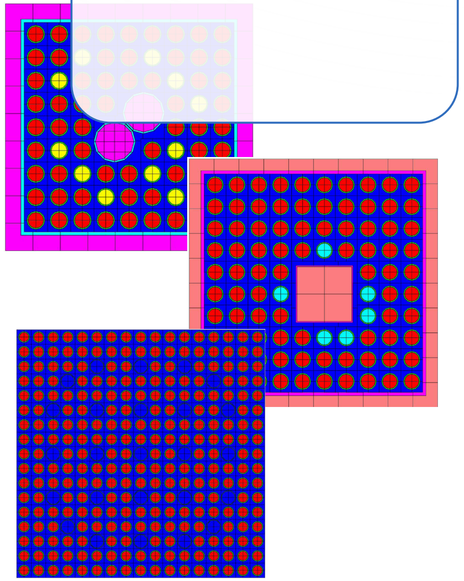
SCALE 5.0 (2004)
- Initial release of TRITON
- 2D-only
- 238g/44g group structures
- ENDF/B5

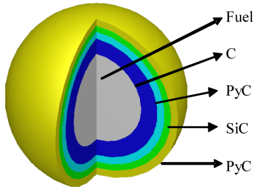
SCALE 5.1 (2006)
- Added double-het XS processing
- Added 3D Monte Carlo depletion sequences
- ENDF/B5 & 6

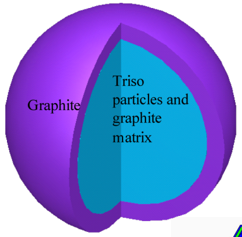
SCALE 6.0 (2008)
- Added hex boundary (2D)
- Removed SAS2H
- ENDF/B 5, 6, 7
- 44g to 49g

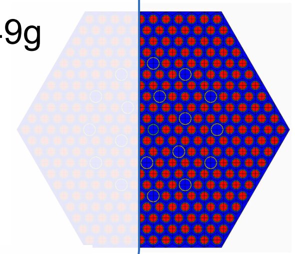
SCALE 6.1 (2011)
- Several lattice physics enhancements
- Parallel branching
- 1D depletion
- 2D S/U
- ENDF/B 5, 6, 7

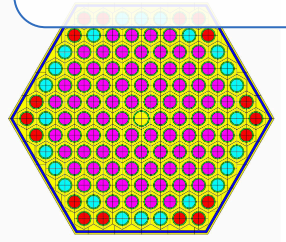
SCALE 6.2 (2016)
- XSPROC
- NEWT speedups
- CE-KENO depletion
- Accuracy improvements
- 252g/56g libraries
- ENDF/B 7 and 7.1

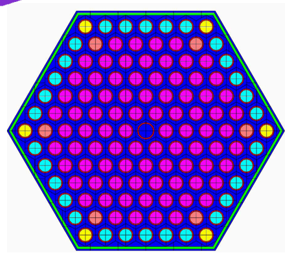


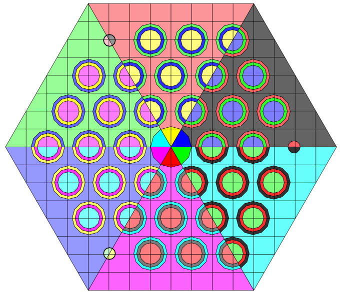


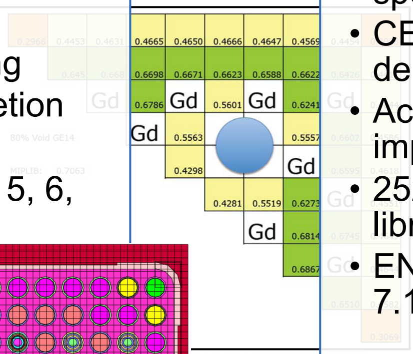


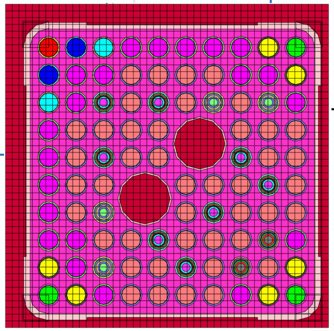


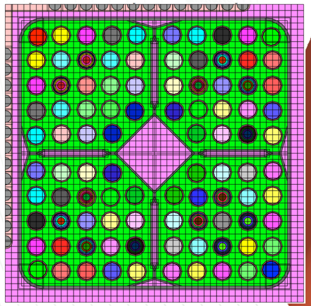


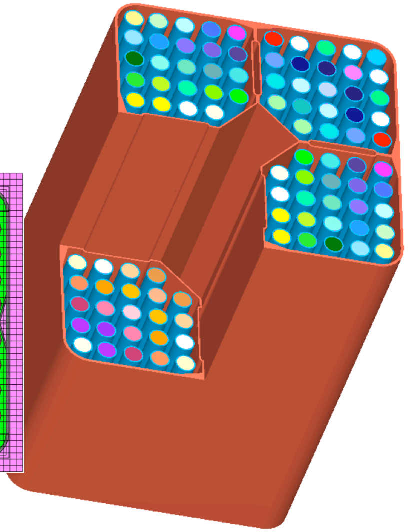




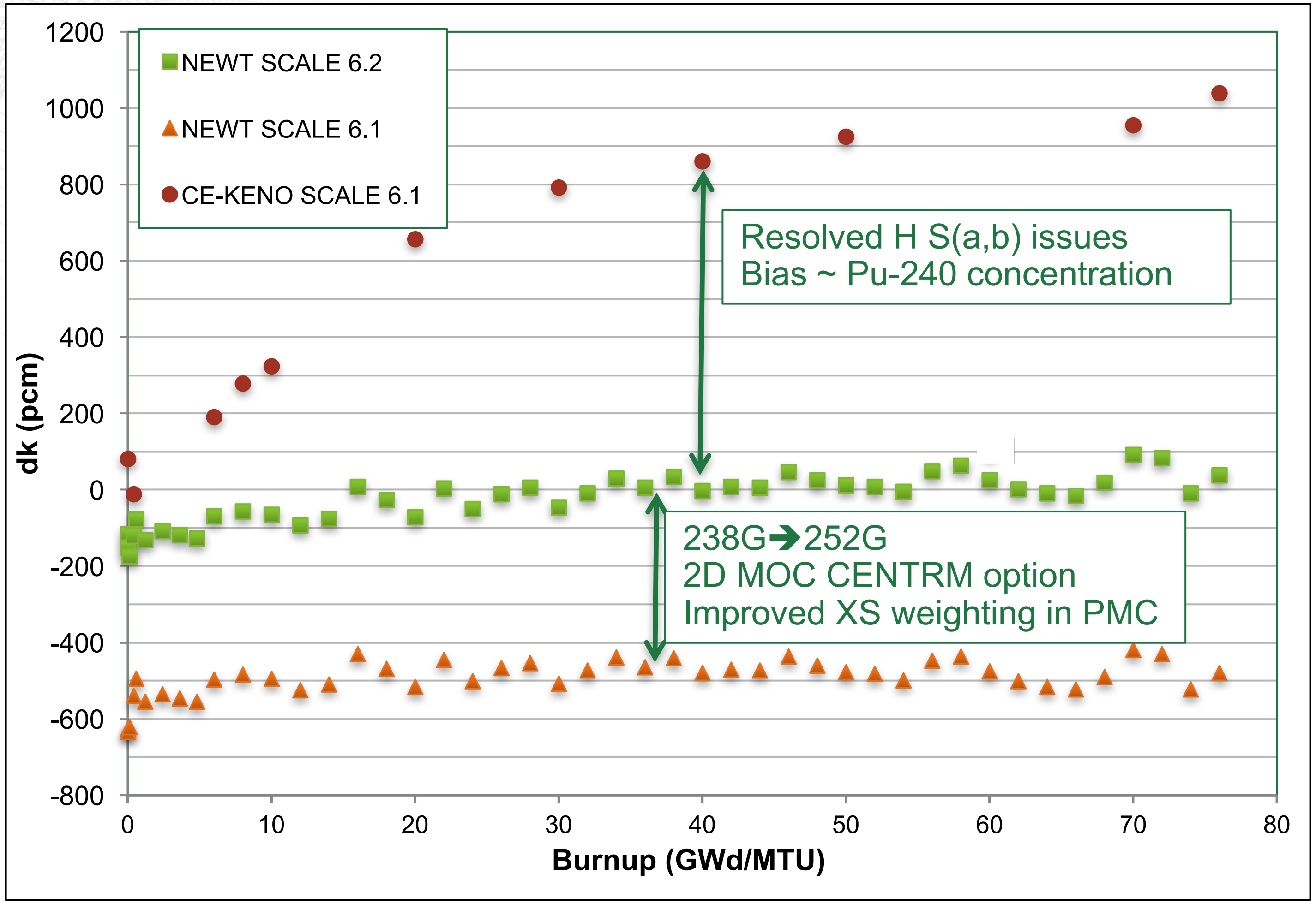








SCALE 6.2 Accuracy Improvements

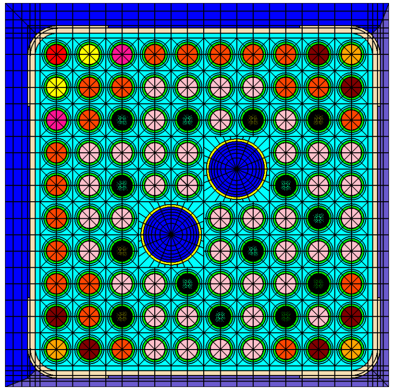


- Westinghouse 17x17 pin cell depletion benchmark
- Reference depletion calculation with CE-KENO
- Assess k-eff calculation accuracy at different burnups
- All codes uses same fuel composition vs burnup

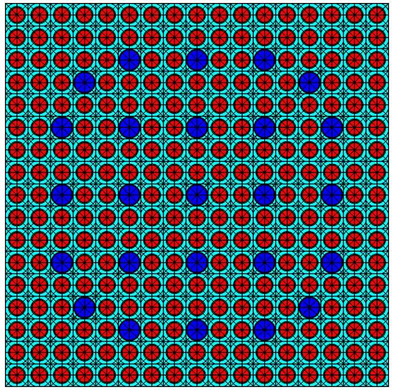
Polaris: LWR Lattice Physics

Polaris

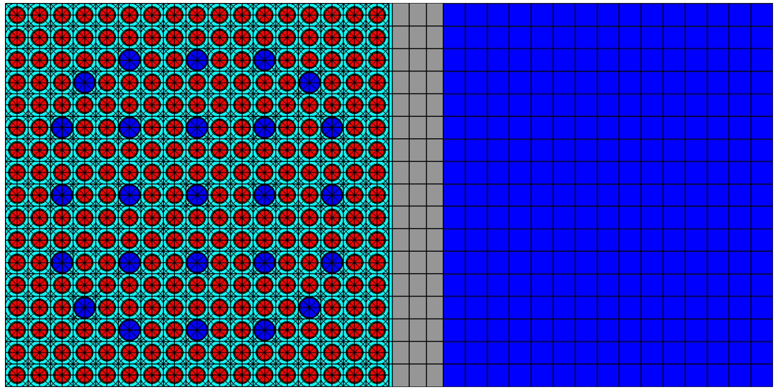
- Fast 2-D lattice physics
- Simple Input
  - Assembly geometry
  - Material definitions
  - Range of system conditions
- Output
  - Lattice physics parameters (.t16 file)
  - GENPMAXS converts .t16 file to .PMAX file
  - Spent Fuel Isotopics file (.f71 file)
- Goals
  - Fast: < 1 CPU minute per statepoint
  - Simple Input: 100 - 200 lines
  - Target accuracy compared to Monte Carlo:
    - 200 pcm dk
    - BWR: 1% RMS, 1.5% Max pin fission rate error
    - PWR: 0.5% RMS, 1.0% Max pin fission rate error
  - Good agreement with radiochemical assay data



BWR GE 10x10



PWR W 17x17

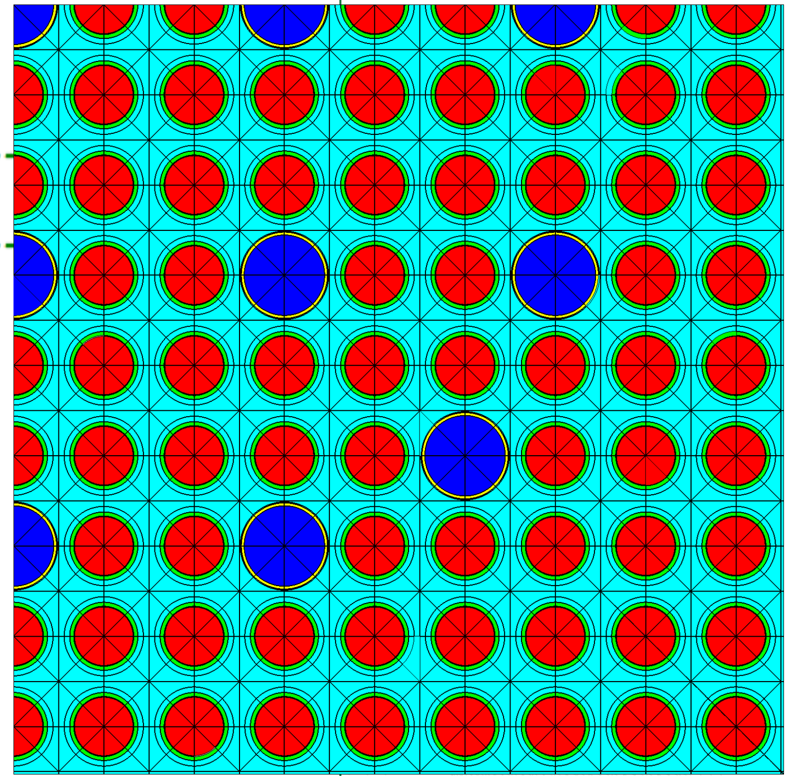


Reflector Model

Example Input

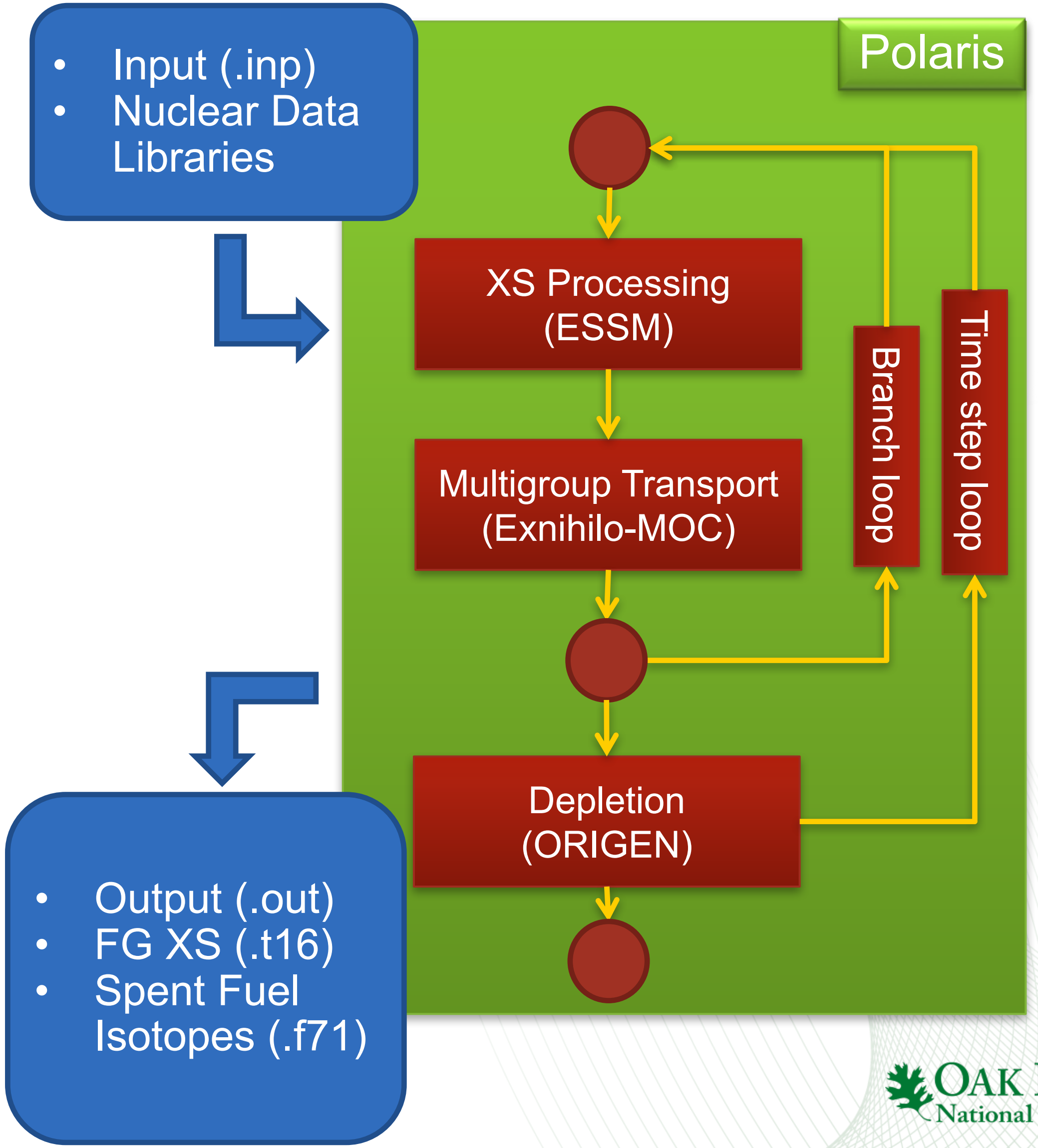
```
=polaris
%-----------------------------------------%
% general options
%-----------------------------------------%
title "W17x17" "Polaris training"
lib "v7.1-56n"  %v7.1-252n is default
system PWR
%-----------------------------------------%
% geometry
%-----------------------------------------%
geom W17 : ASSM 17 1.26 SE
hgap 0.04
%-----------------------------------------%
% comps and mats
%-----------------------------------------%
comp F31    : UOX 3.1
mat FUEL.1 : F31 10.26
%-----------------------------------------%
% pins
%-----------------------------------------%
pin F : 0.4096 0.418 0.475
      : FUEL.1 GAP.1 CLAD.1
pin I : 0.559 0.605
      : MOD.1 TUBE.1
pin G : 0.561 0.602
      : MOD.1 TUBE.1
```

```
%----------------------------------
% maps
%-----------------------------------------%
pinmap
I
F F
F F F
G F F G
F F F F F
F F F F F G
G F F G F F F
F F F F F F F F
F F F F F F F F F
%----------------------------
% state
%----------------------------
state ALL   : temp=590
state COOL  : dens=0.68
              boron=1300
state MOD   : dens=0.71
              boron=1300
              temp=575
state FUEL  : temp=900
state CLAD  : temp=700
state TUBE  : temp=580
end
```



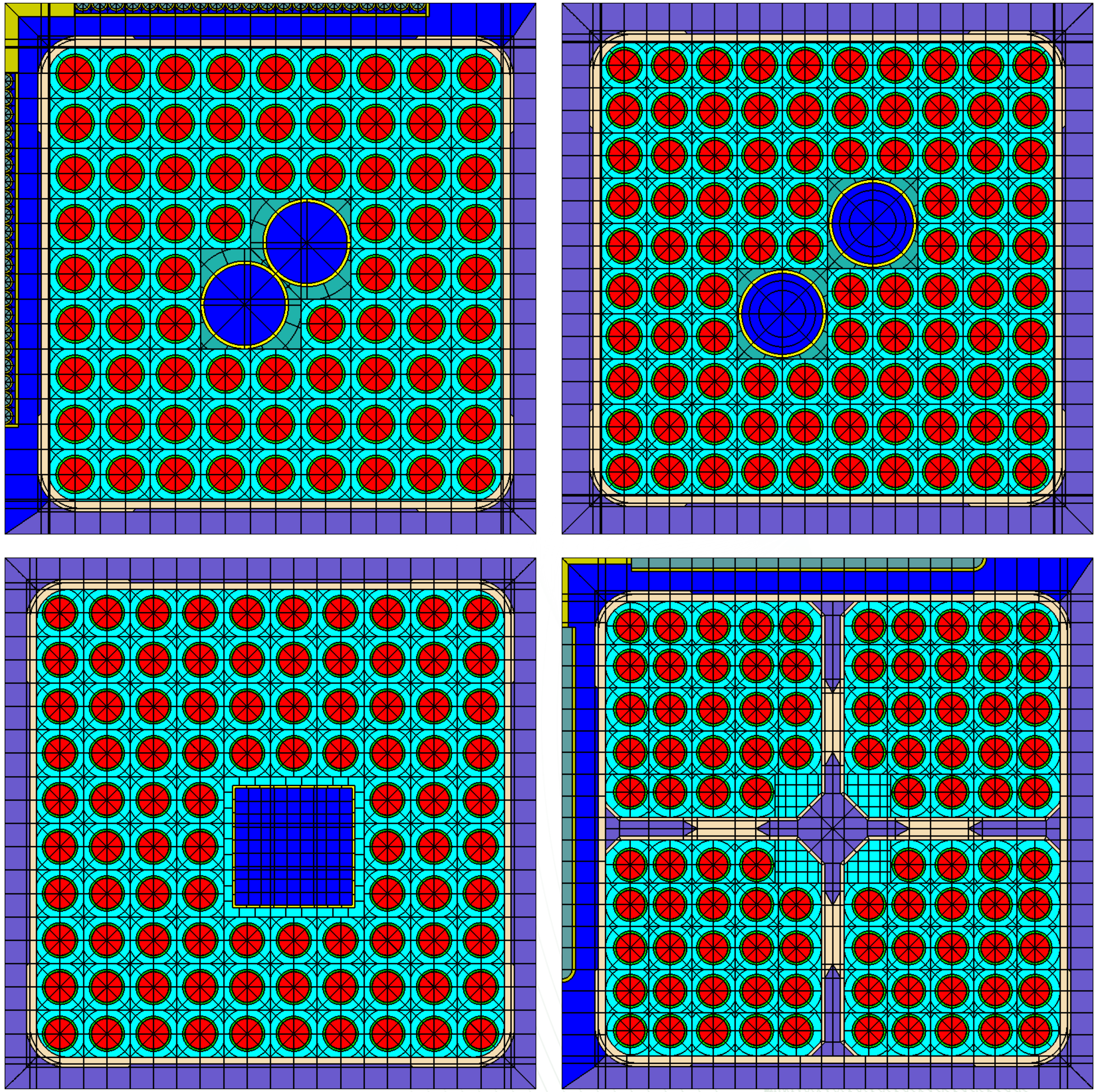
The Polaris Lattice Physics Sequence

- Nuclear Data Libraries:
  - ENDF/B-V7.1 252G and 56G
- XS Processing (ESSM)
  - Embedded Self-Shielding Method
  - Novel ORNL-developed XS processing method
  - XS processing is "embedded" into 2D geometry
  - No input requirements
  - Mark L. Williams and Kang Seog Kim. "The Embedded Self-Shielding Method." *PHYSOR 2012*. Knoxville, Tennessee, USA
- Multigroup Transport
  - 2-D Assembly Calculation
  - New Method-of-Characteristics (MoC) solver



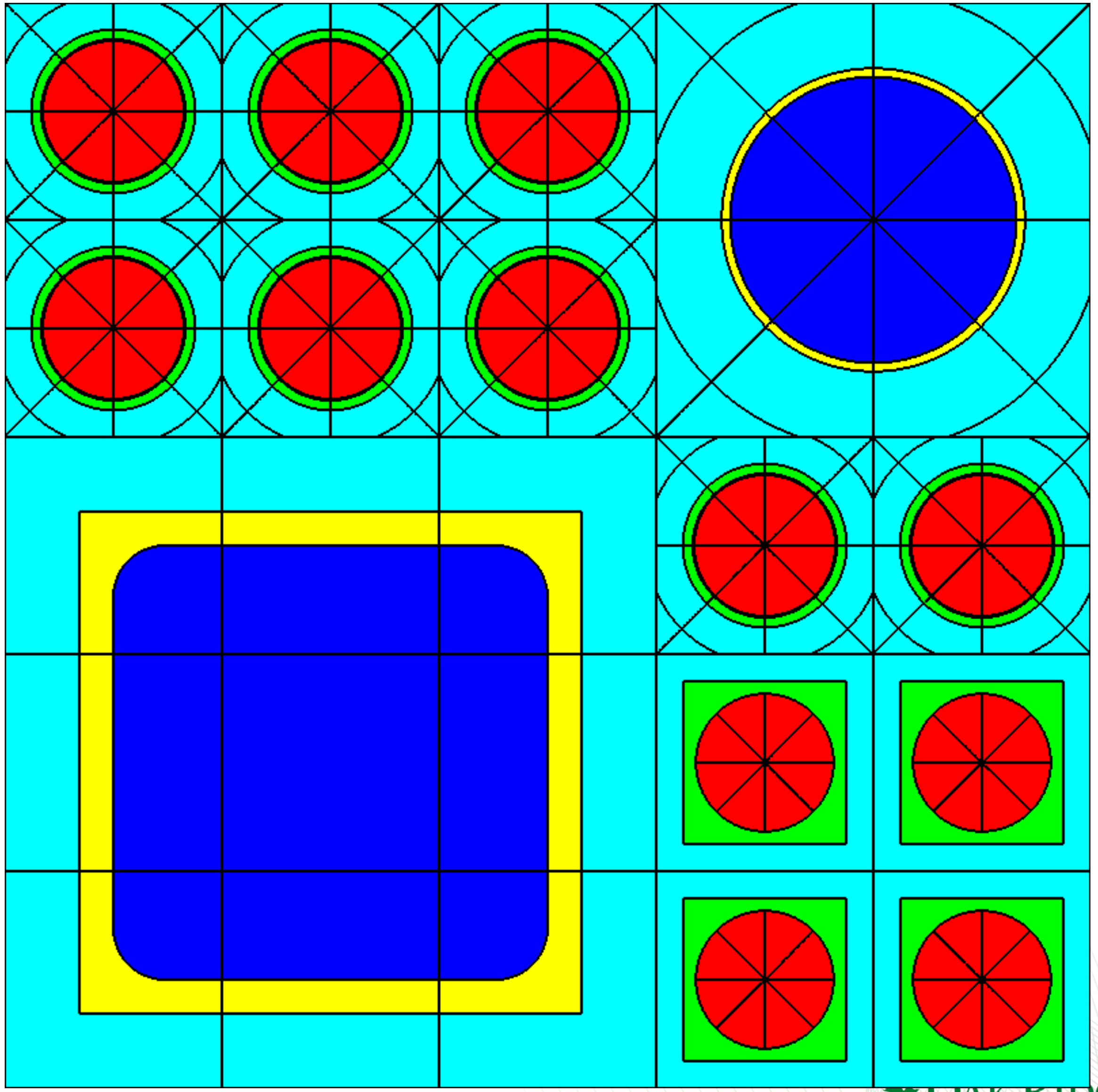
New BWR Capabilities

- SCALE 6.2.2 contains several updates to Polaris to support BWR lattice physics analysis
- BWR input cards
  - **box:** upgraded for more geometry detail
  - **pin:** upgraded to support square pins
  - **mesh**
  - **cross**
  - **dxmap, dymap**
  - **control : BLADE**
- New **history** capability



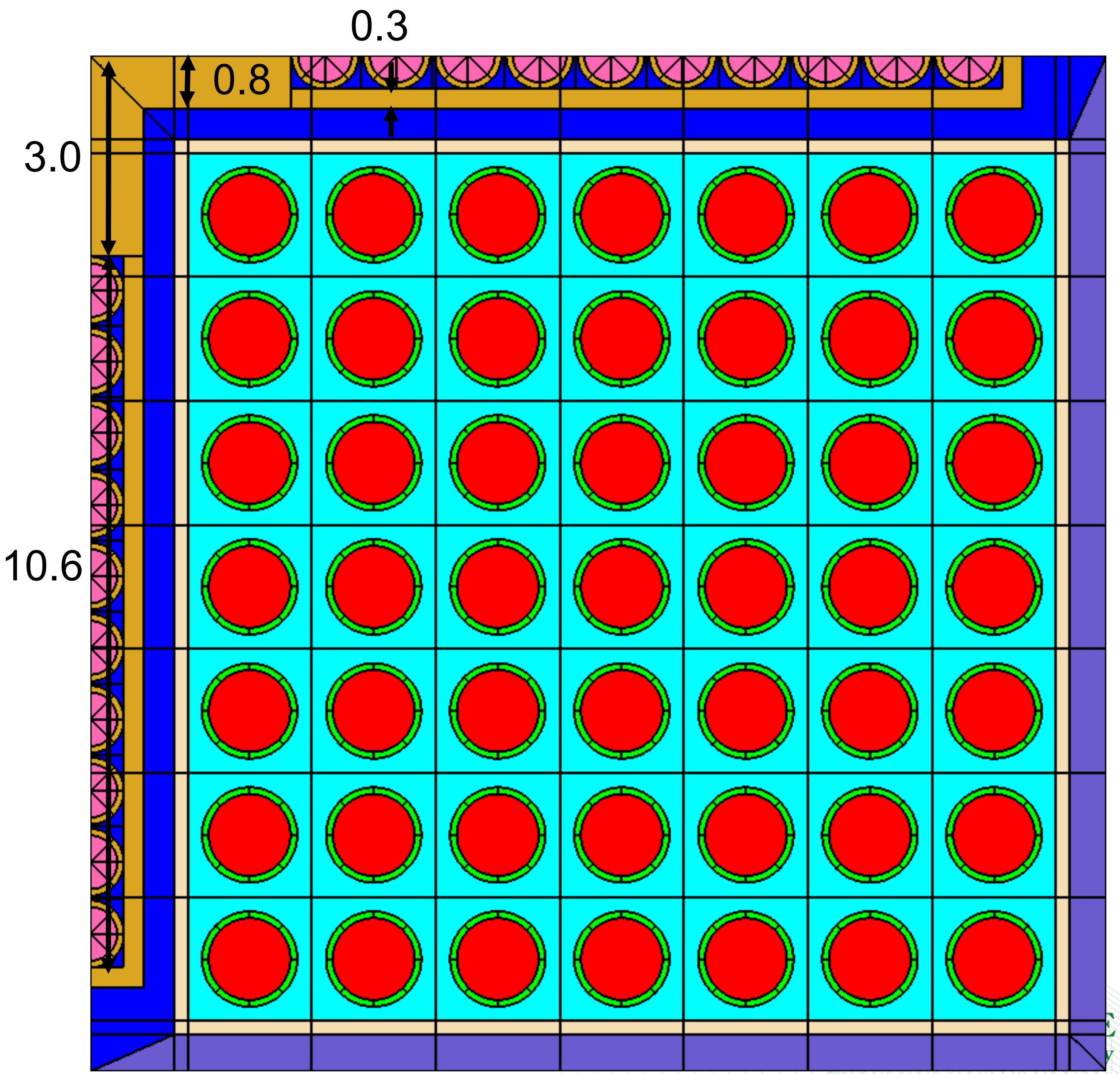
pin example

```
=polaris_6.3
title "W17x17"
lib "broad_n"
system PWR
geom W17 : ASSM 5 1.26
%-----------------------------------------%
% comps and mats
%-----------------------------------------%
comp c_e31 : UOX 3.1
mat FUEL.1 : c_e31  10.26
%-----------------------------------------%
% pins
%-----------------------------------------%
pin A : 0.4096 0.418 0.475
      : FUEL.1 GAP.1 CLAD.1
pin B 2 : 0.83   0.88   : MOD.1      TUBE.1
                        : CIR        CIR
pin C 3 : 1.26   1.46   : MOD.1      TUBE.1
                        : SQR(0.3)  SQR
pin D : 0.4    0.475
      : FUEL.1 CLAD.1
      : CIR    SQR
pinmap
 A A A B B
 A A A B B
 C C C A A
 C C C D D
 C C C D D
end

```



blade example

```
=polaris_6.3
lib "broad_n"
sys BWR
geom myBWR : ASSM 7 1.85
hgap 0.55 1.25 : MOD.2 MOD.1
box  0.2
pin 1 : 0.61 0.71 : FUEL.1 CLAD.1
mesh FUEL ns=1
mesh COOL nr=1 ns=1
mesh MOD  nf=1 nd=1 ns=1
pinmap
  1
  1 1
  1 1 1
  1 1 1 1
comp c_e293 : UOX 2.93
mat  FUEL.1 : c_e293 10.32
%---------------------------------------%
% control blade
%---------------------------------------%
pin B : 0.4 0.5
      : CNTL.1 STRUCT.1 MOD.1
control blade1 : BLADE 0.8 0.3 3.0
               : B
               : 10.6
               : 10
state blade1 : in=yes


end
```



history example

- history block allows for time-dependent operational changes
- similar to TIMETABLE block in TRITON

```
=polaris_6.3
lib "broad_n"
sys PWR
geom taka : ASSM 1 1.26
comp u411 : UOX 4.11
mat FUEL.1 : u411 10.412
pin 1 : .4025  .475  : FUEL.1 CLAD
state ALL  : temp=600
      COOL : dens=0.6 boron=1100
      FUEL : temp=900
read history
%-------------------------------------%
% cycle 1
%-------------------------------------%
pow 39
state COOL : boron=900 850 700 600 400
      FUEL :  temp=900 910 920 890 880
dt                  50  50 100 100 200
pow 0
ti 70
%-------------------------------------%
% cycle 2
%-------------------------------------%
pow                 42  41  38  39  37
state COOL : boron=900 850 700 600 300
dt                  50  50  50 100 250
pow 0
ti 80
end history
end
```

history example

```
=polaris_6.3
lib "broad_n"
sys PWR
geom taka : ASSM 1 1.26
comp u411 : UOX 4.11
mat FUEL.1 : u411 10.412
pin 1 : .4025  .475  : FUEL.1 CLAD
state ALL  : temp=600
      COOL : dens=0.6 boron=1100
      FUEL : temp=900
read history
%-------------------------------------%
% cycle 1
%-------------------------------------%
pow 39
state COOL : boron=900 850 700 600 400
      FUEL :  temp=900 910 920 890 880
dt                  50  50 100 100 200
pow 0
ti 70
%-------------------------------------%
% cycle 2
%-------------------------------------%
pow                 42  41  38  39  37
state COOL : boron=900 850 700 600 300
dt                  50  50  50 100 250
pow 0
ti 80
end history
end
```

- history block allows for time-dependent operational changes
- similar to TIMETABLE block in TRITON
- outside of history block
  - one state card to initialize state variables

- inside history block
  - power, state, and burnup/time cards are entered together
    - power – single value or array
    - state – single value or array
    - burnup/time – array
    - all arrays must be same size
  - multiple power/state/time cards may be stacked together

- convenient for RCA benchmarks

history example 2

```
=polaris_6.3
sys BWR
lib 'broad_n'
geom bwr7x7 : ASSM 7 1.85
hgap 0.75 1.05
box  0.2
comp c_e293 : UOX 2.93
mat  FUEL.1 : c_e293 10.32
pin 1 : 0.61 0.715 : FUEL.1 CLAD.1
pinmap
 1
 1 1
 1 1 1
 1 1 1 1
pin B : 0.18 : CNTL.2 MOD.1
control cb : BLADE .4 .1 2 : B : 9. : 19
state ALL : temp=600 COOL : void=40
      FUEL : temp=900 cb : in=no
power 40
opt PRINT xfile16=yes
opt FG : 0 10 20 30 40 50 60 70
read branch
 add COOL : void=0  FUEL : temp=950  cb : in=no
 add COOL : void=40 FUEL : temp=950  cb : in=no
 add COOL : void=70 FUEL : temp=950  cb : in=no
 add COOL : void=0  FUEL : temp=950  cb : in=yes
 add COOL : void=40 FUEL : temp=950  cb : in=yes
 add COOL : void=70 FUEL : temp=950  cb : in=yes
 add COOL : void=0  FUEL : temp=1500 cb : in=no
 add COOL : void=40 FUEL : temp=1500 cb : in=no
 add COOL : void=70 FUEL : temp=1500 cb : in=no
end branch
read history VF40
  state COOL : void=40 cb : in=no
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
read history VF00
  state COOL : void=0  cb : in=no
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
read history VF70
  state COOL : void=70 cb : in=no
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
read history VF40CR
  state COOL : void=40 cb : in=yes
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
read history VF00CR
  state COOL : void=0  cb : in=yes
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
read history VF70CR
  state COOL : void=70 cb : in=yes
  bu 0 .5 1 2.5 5 7.5 10 12.5 15 20 25 30 35
     40 45 50 55 60 65 70
end history
end
```

Summary

- SCALE 6.2 Reactor Physics Capabilities
  – TRITON: modular, general-geometry, reactor physics sequence
  – Polaris: Fast, easy-to-use LWR lattice physics
  – ORIGAMI: Fast, easy-to-use depletion interface for ORIGEN
  – Sampler: Automates uncertainty quantification for TRITON, Polaris, and ORIGAMI
- Significant enhancements for SCALE 6.2
  – Accuracy improvements through new libraries and XS processing methods
  – Run-time improvements through modernization
- ~50 RNSD contributors to development and testing
- SCALE RP capabilities enabling new R&D
  – Continuous Energy Monte Carlo depletion
  – Uncertainty quantification using Sampler