

KENO-VI geometry

SCALE 6.3.3

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Learning Objectives

- Describe the KENO-VI geometry syntax and logic
- Apply geometry modifications in KENO-VI inputs
- Apply holes and arrays for repetitive and advanced geometries
- Apply KENO and Shift Monte Carlo codes capabilities

Outline

- Sub-Module 1: KENO-VI geometry basics
 - Exercises: Lady Godiva, Green Block, Rocky Flats
- Sub-Module 2: Geometry modification data
 - Exercises: Y30, Hopper, Cross
- Sub-Module 3: HOLES in KENO-VI
 - Exercise: 2c8
- Sub-Module 4: Arrays in KENO-VI
 - Exercises: 2c8, Pins in a Tank, 4A-4M, GOSLAR cask, CASTOR cask
- Sub-Module 5: Randomgeom block
 - Exercise: HTGR pebble

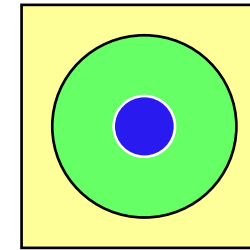
Sub-Module 1

- KENO-VI geometry basics

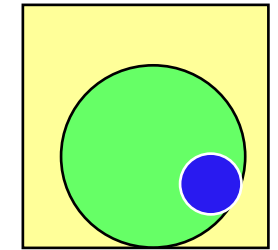


KENO-VI geometry basics

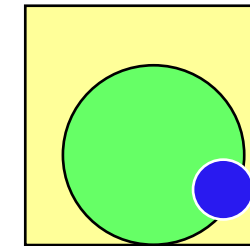
1. *Volumes are built in sections called UNITS.* Each UNIT is independent of all other units and has its own coordinate system.
2. *Units are built using REGIONS.* Regions are made using available KENO-VI geometry shapes. The unit boundary fully encloses all defined regions in the unit; it may truncate regions in the unit.
3. *Regions may share boundaries and may intersect.* (Not allowed in KENO V.a.)
4. *Regions may be rotated.* (Not allowed in KENO V.a.)



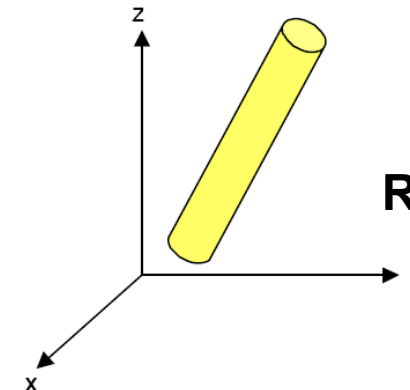
Regions in a unit



Shared boundaries



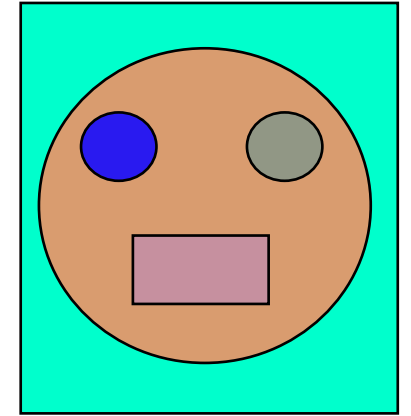
Intersecting regions



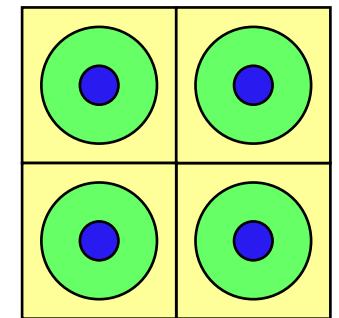
Rotated cylinder

KENO-VI geometry basics (cont.)

5. *A HOLE is used to place a unit within a region of a different unit.* The HOLE must be completely contained within the unit and may not intersect other holes or nested arrays. As many HOLES as required may be placed in a unit.
6. *An ARRAY is an ordered stack of units.* The touching faces of adjacent units in an array must be the same shape and same size. Multiple arrays may be placed directly in a UNIT, and arrays can also be placed within a unit using HOLES. The BOUNDARY record of each unit must be appropriate for the selected array type.
7. *A GLOBAL UNIT that encloses the entire system must be specified.* All geometry data used in a problem are correlated by the global unit coordinate system.



**Unit Containing
HOLES**



Array of units

KENO-VI input records

- Three types of records are used to define the volume, position, and material contents of the regions in a unit
 - Geometry record
 - Contents record
 - Boundary record
- Each unit may have as many Geometry and Contents records as needed but must have **one and only one** Boundary record

Unit geometry keywords

- GLOBAL
 - Specifies global/outer-most unit in problem
 - Precedes the keyword UNIT
- UNIT
 - Specifies a new independent set of geometries and materials
- COM=
 - Specifies a comment record, one per unit
 - Must begin and end with the same delimiter

Example input layout for a UNIT

GLOBAL UNIT 1

COM=!This is a comment field!

Geometry Records

Media Records

Boundary Record*

*It is a best practice (and more or less required for Fulcrum) to put the boundary record at the end of the unit.

Geometry record

- Specifies the volumes that make up the unit
- Comprises the following components:
 - Geometry keyword
 - Geometry record label
 - Geometry boundary definitions
 - Geometry modification data

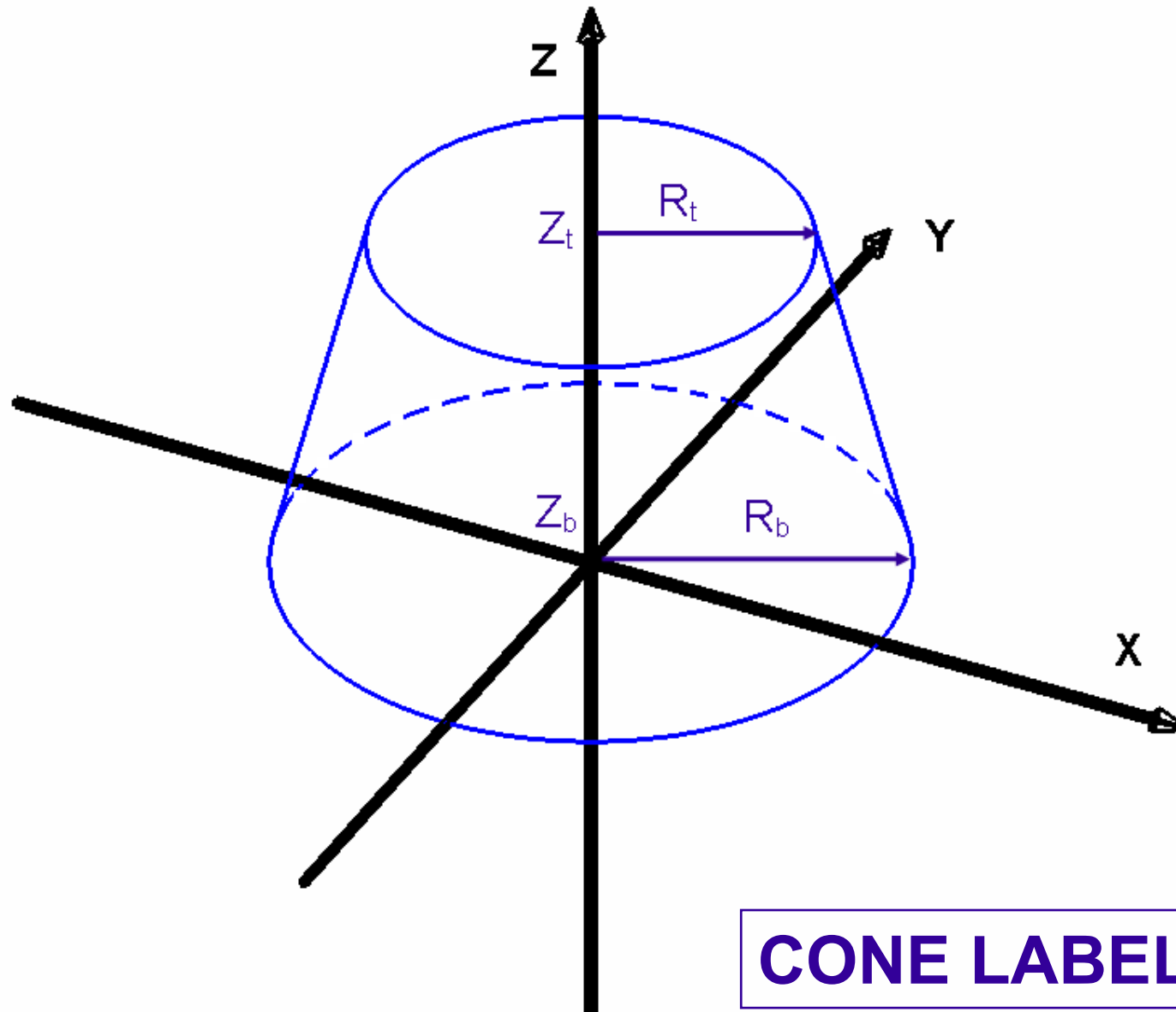
KENO-VI geometry input

KENO-VI Geometry Keyword	Geometry Record Input
CONE	Label, Top and Bottom Radius, Top and Bottom Z-Positions
CUBOID	Label, +X, -X, +Y, -Y, +Z, -Z, Positions
CYLINDER (also XCLYINDER or YCYLINDER)	Label, Radius, Top and Bottom Z-Position
DODECAHEDRON	Label, Inner Radius
ECYLINDER	Label, X-Radius, Y-Radius, Top and Bottom Z-Positions
ELLIPSOID	Label, X-Radius, Y-Radius, Z-Radius
HEXPRISM, RHEXPRISM	Label, Inner Radius, Top and Bottom Z-Positions
HOPPER	Label, Top Half Length along X & Y axis, Bottom Half length along X & Y axis, Top and Bottom Z-Positions

KENO-VI geometry input (cont.)

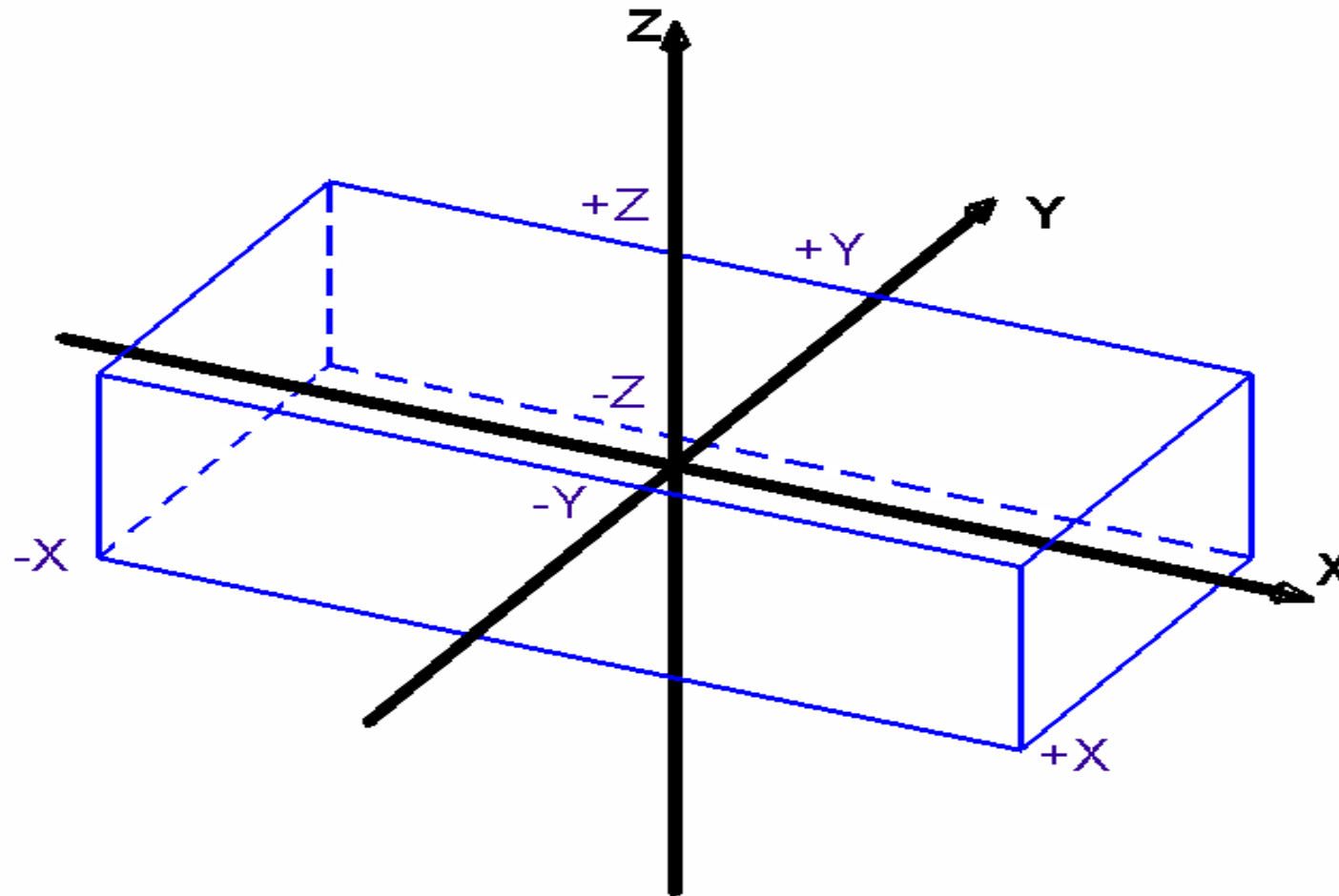
KENO-VI Geometry Keyword	Geometry Record Input
PARALLELPIPED (PPIPED)	Label, Distance along X, Y, and Z axes Angles between the X, Y, and Z faces and axes
PENTAGON	Label, Radius, Top and Bottom Z-Position
PLANE	Label, Non-Zero Coefficients of the Quadratic
QUADRATIC	Label, Non-Zero Coefficients of the Quadratic
RHOMBOID	Label, Length of a Side, Angle between the Y-Edge of the Base and the Y-axis
SPHERE	Label, Radius
WEDGE	Label, Length of triangle base along X-axis X & Y position of the triangle top Length of the Wedge along the Z-axis
XPPLANE, YPPLANE, ZPPLANE	Label, Max. and Min. positions on axis
RING	Inner and outer radii, +Z –Z positions

Cone



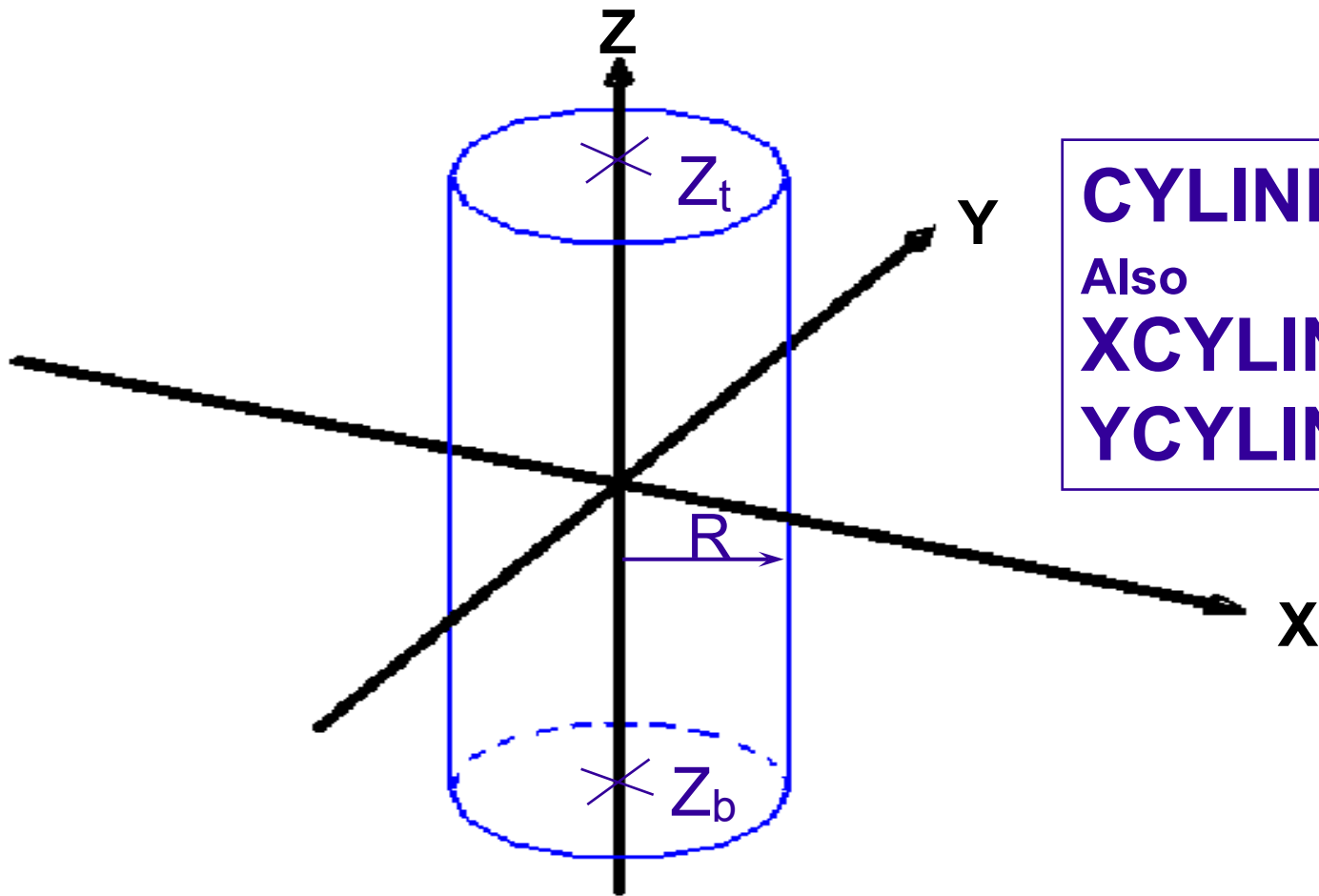
CONE LABEL R_t z_t R_b z_b

Cuboid



CUBOID LABEL +X -X +Y -Y +Z -Z

Cylinder



CYLINDER LABEL R Z_t Z_b

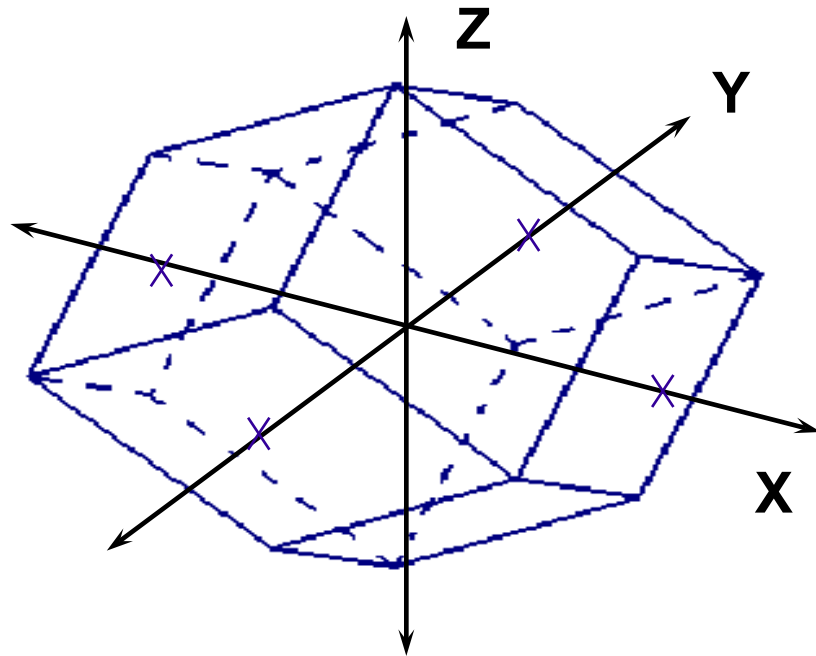
Also

XCYLINDER LABEL R X_t X_b

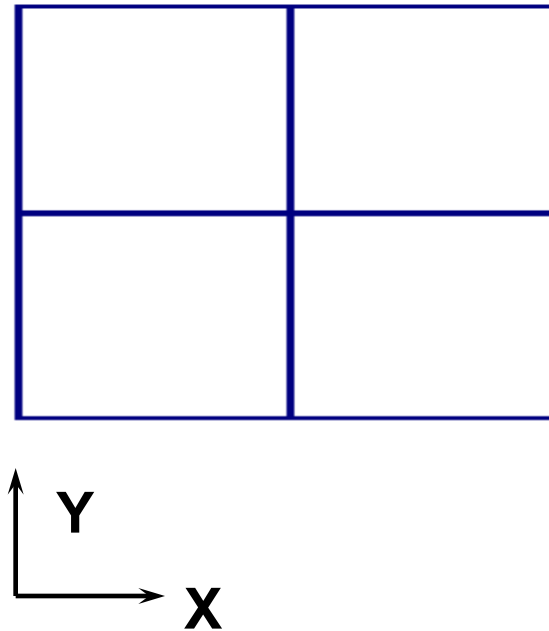
YCYLINDER LABEL R Y_t Y_b

Dodecahedron

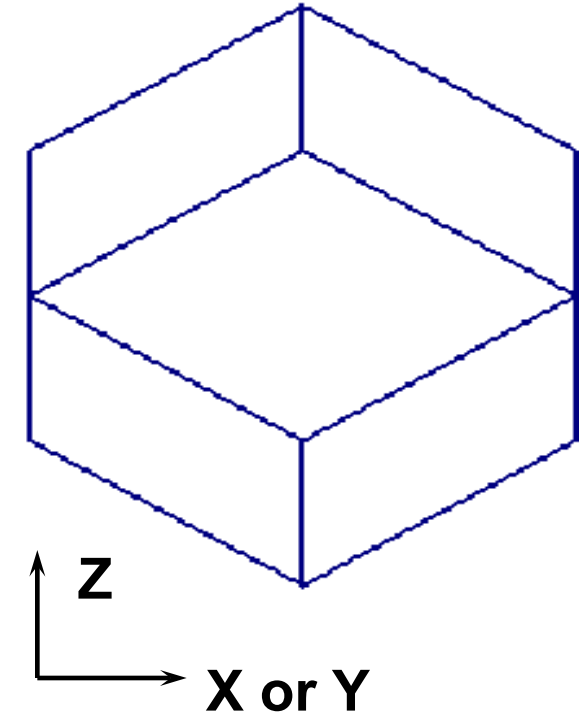
OVERALL VIEW



TOP VIEW

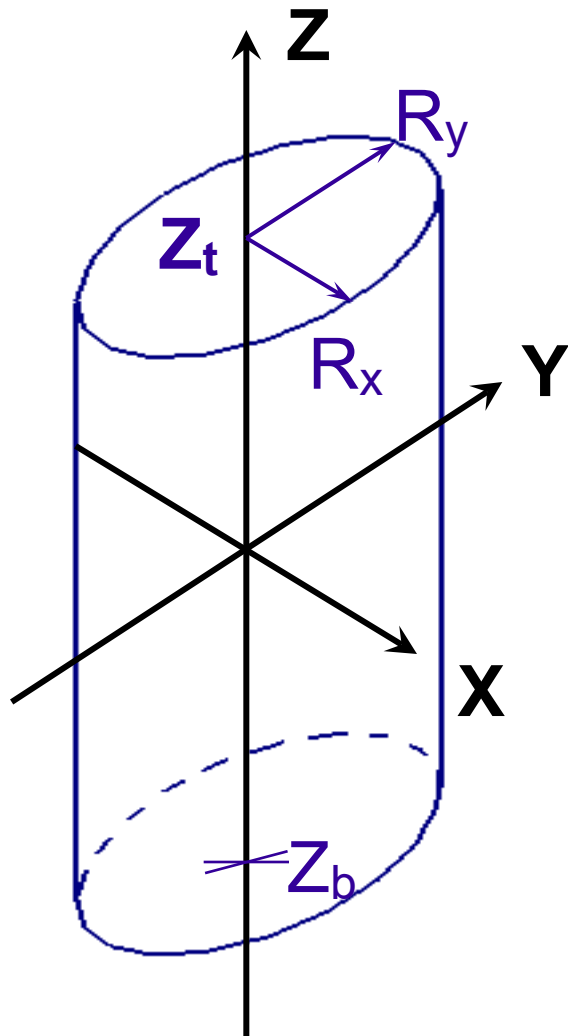


SIDE VIEW



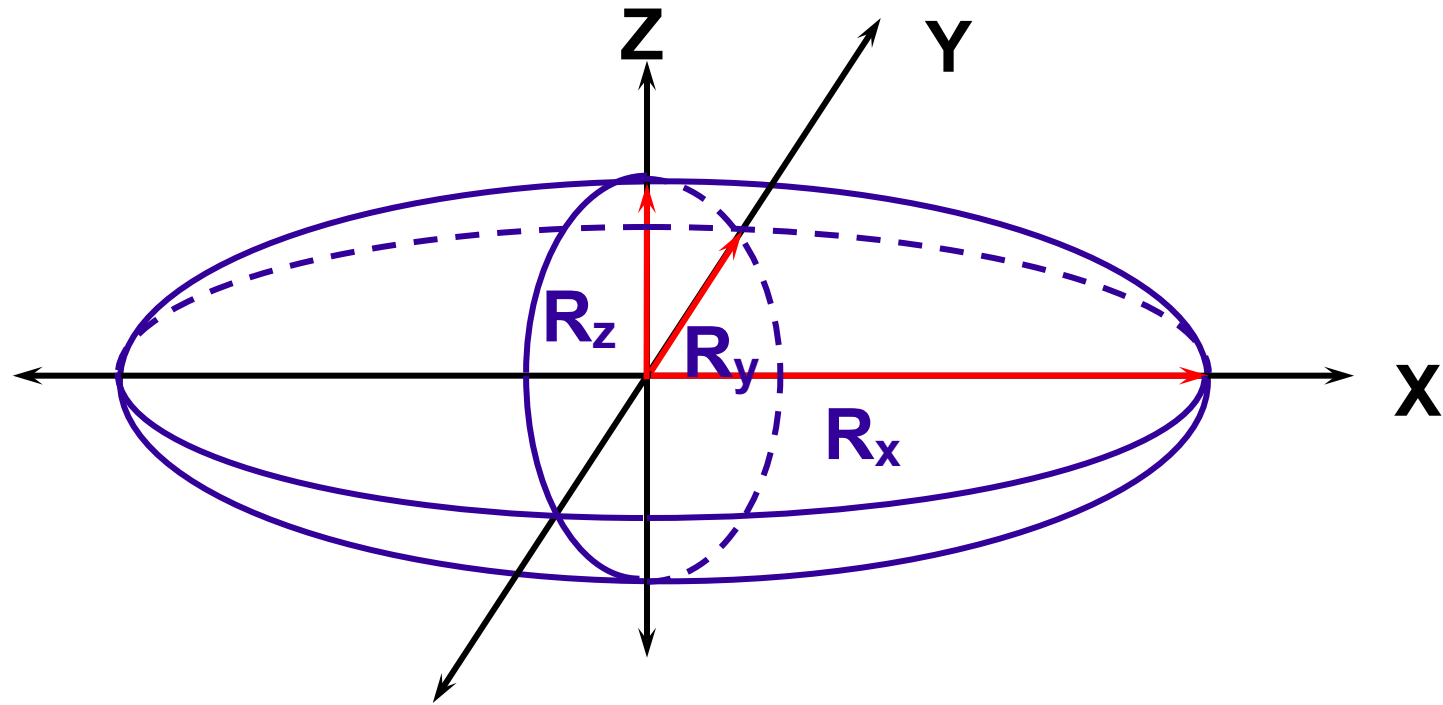
DODECAHEDRON LABEL R
(R is the Inscribed Radius)

Elliptical cylinder



ECYLINDER LABEL R_x R_y Z_t Z_b

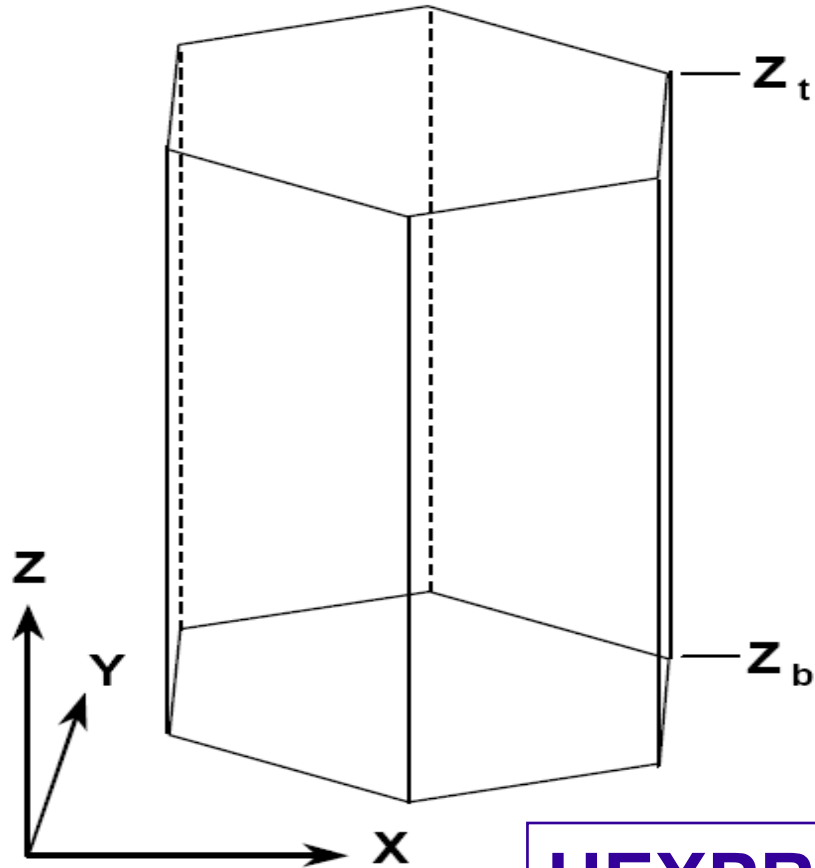
Ellipsoid



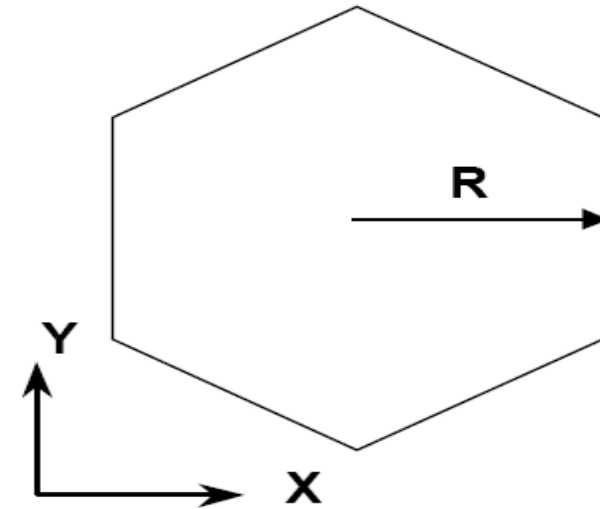
ELLIPSOID LABEL R_x R_y R_z

Hexagonal prism

OVERALL VIEW

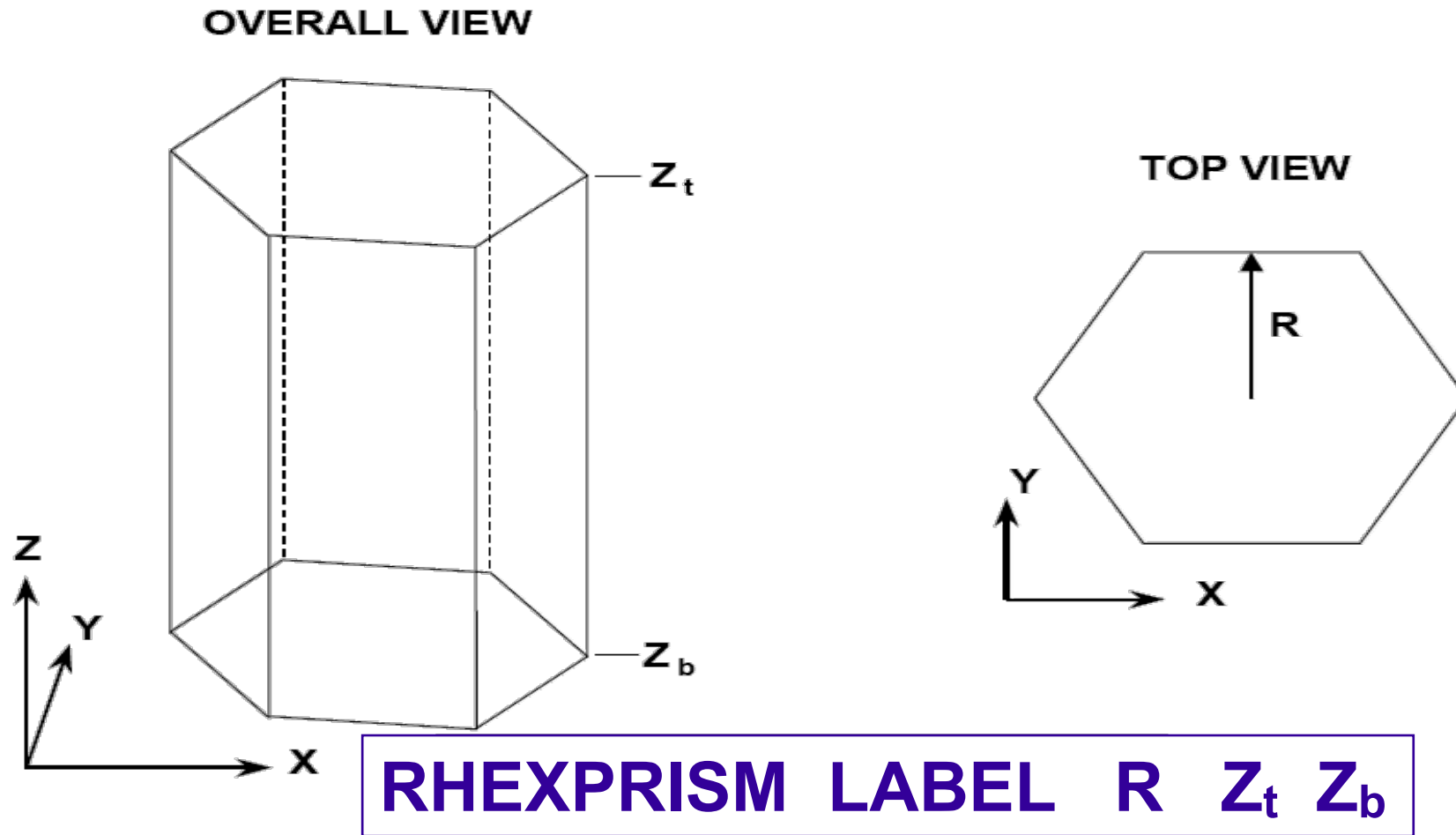


TOP VIEW

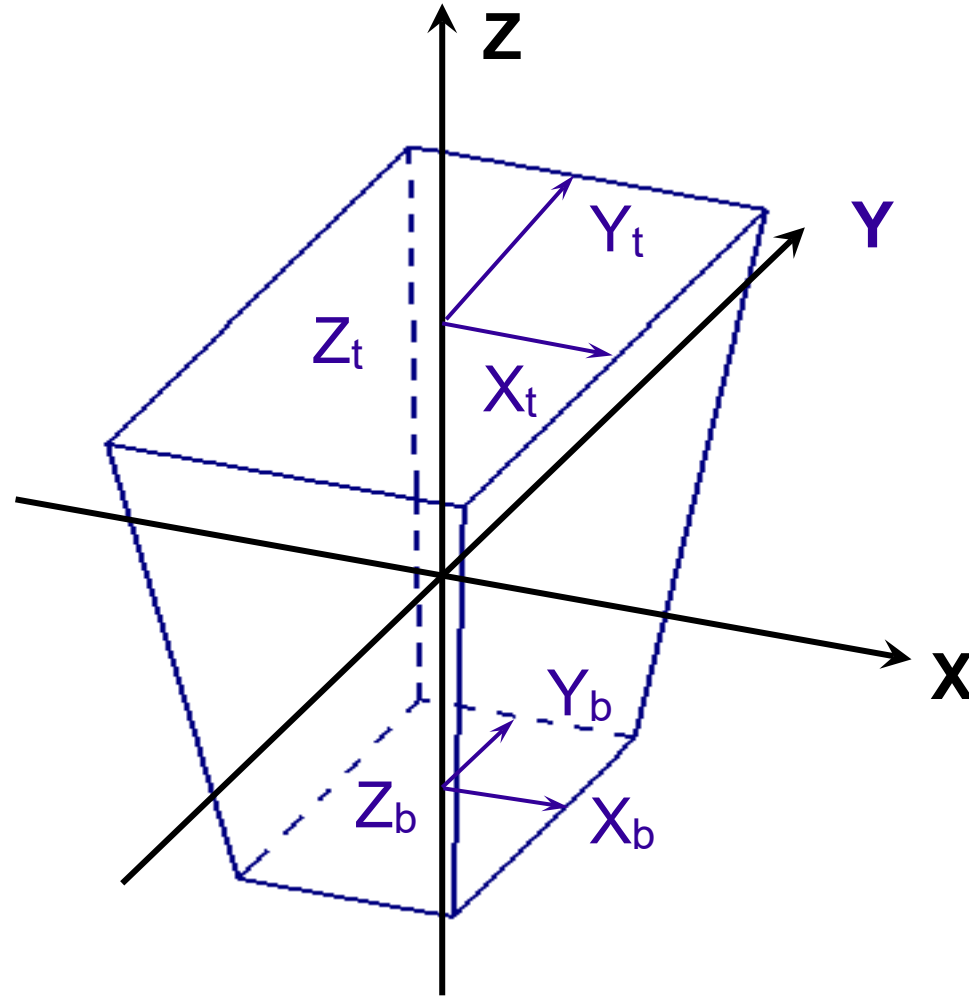


HEXPRISM LABEL R Z_t Z_b

Rotated hexprism

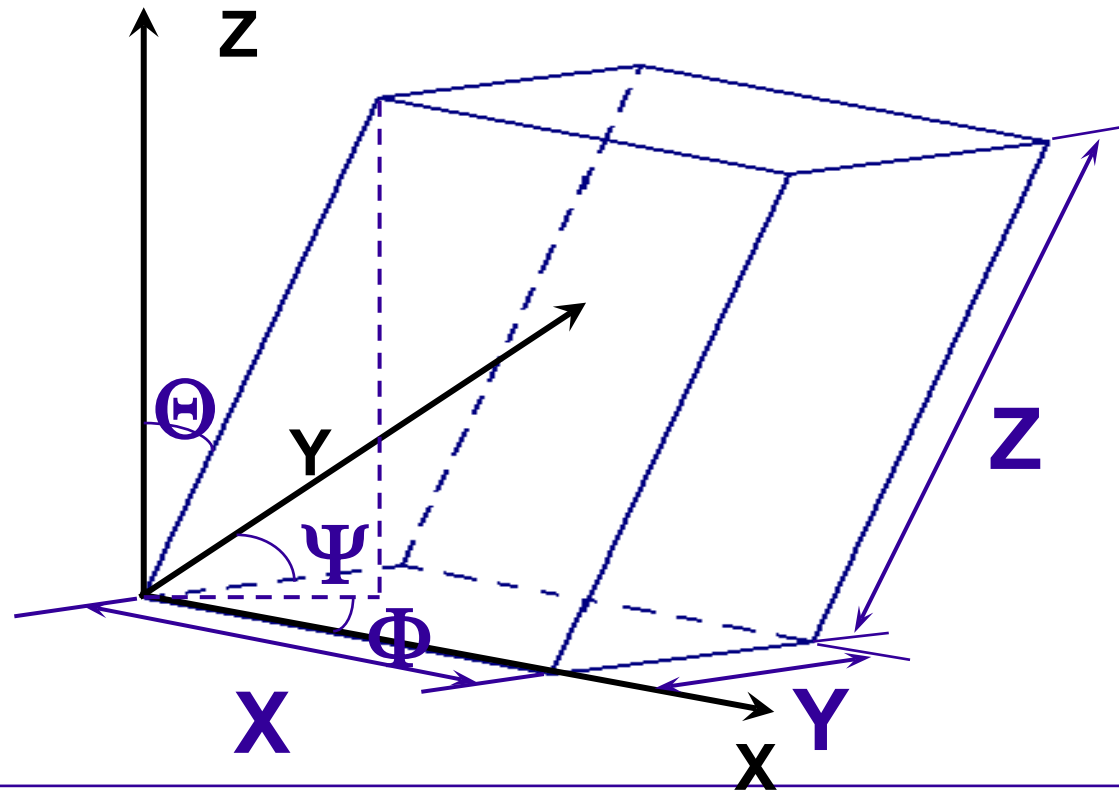


Hopper



HOPPER LABEL X_t Y_t Z_t X_b Y_b Z_b

Parallelepiped

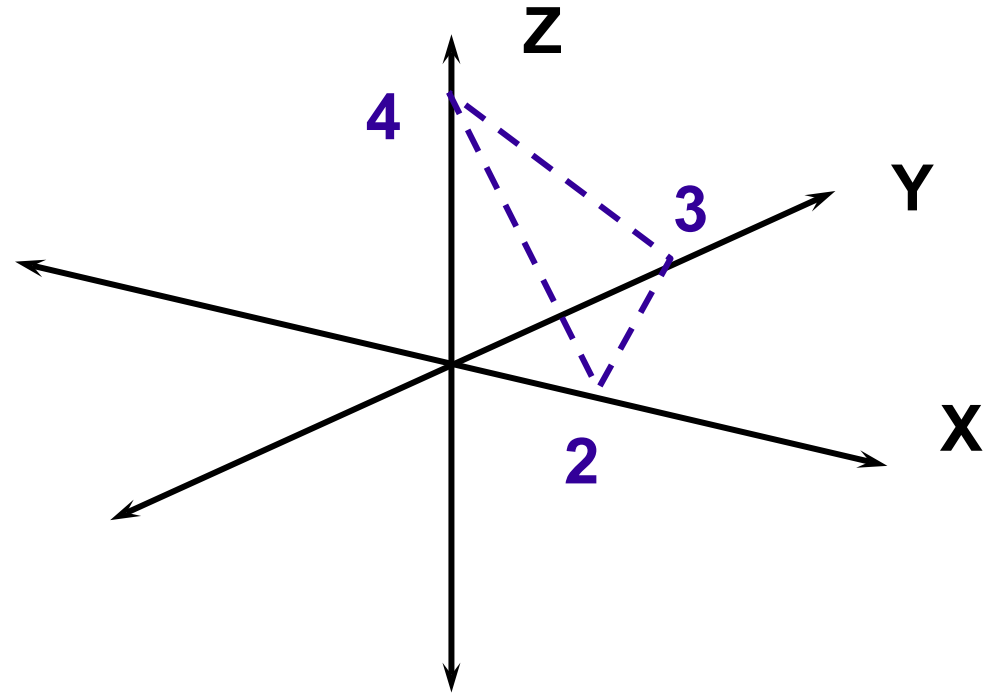


PPIPED LABEL X Y Z Ψ Θ Φ

or

PARALLELEPIPED LABEL X Y Z Ψ Θ Φ

Plane

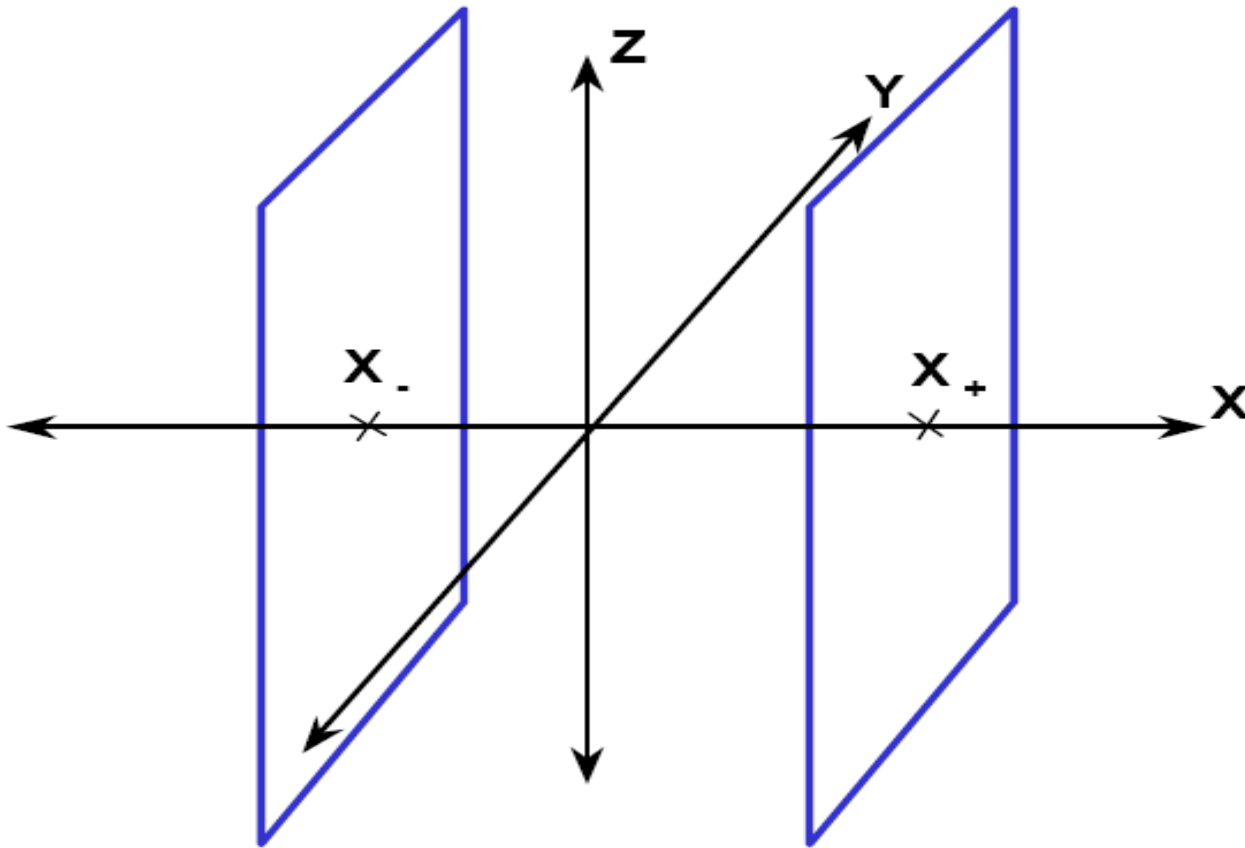


PLANE LABEL XPL=a YPL=b ZPL=c CON=d

$$aX + bY + cZ + d = 0$$

$$6X + 4Y + 3Z - 12 = 0$$

Paired planes



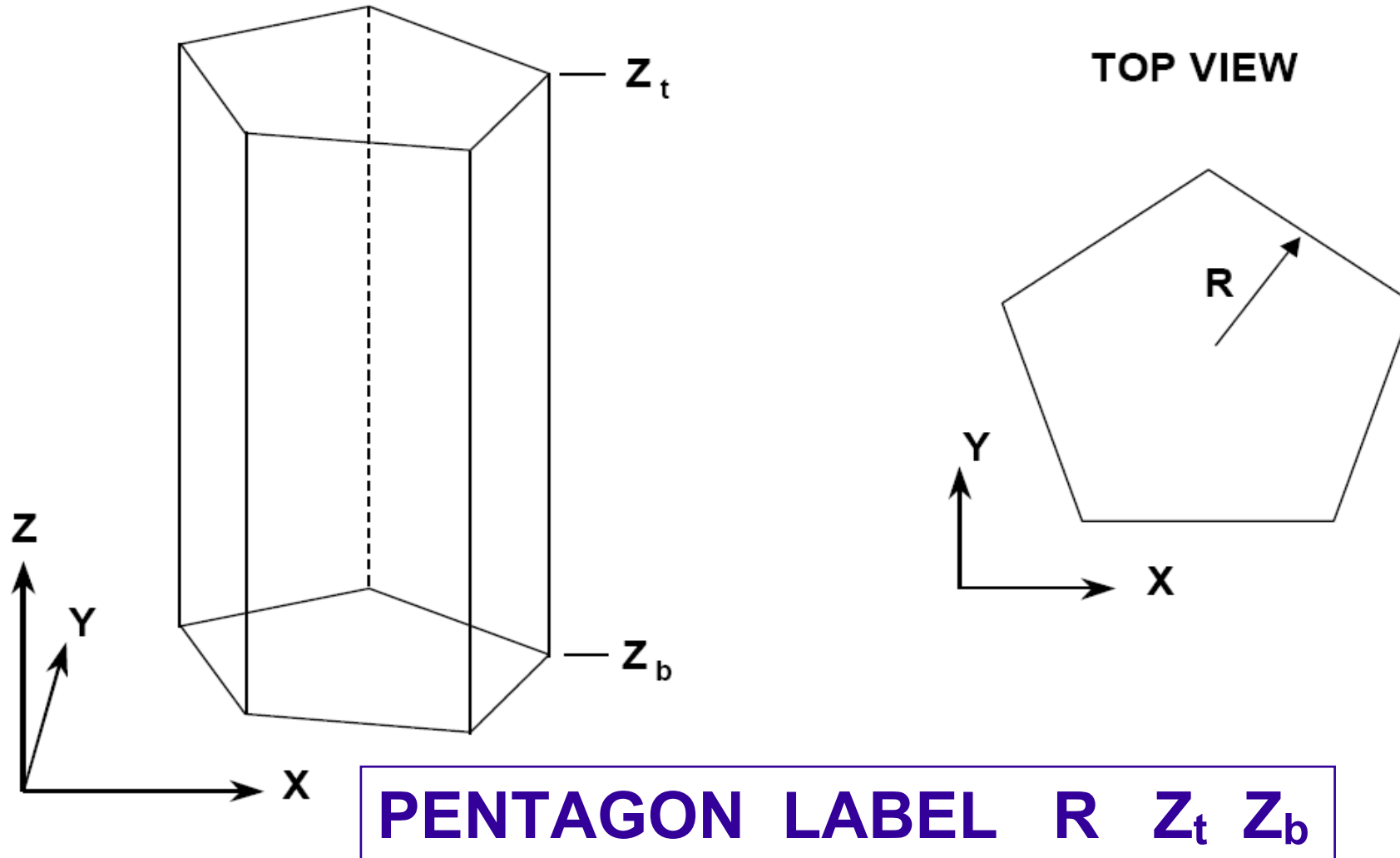
XPPLANE LABEL X+ X-

Also

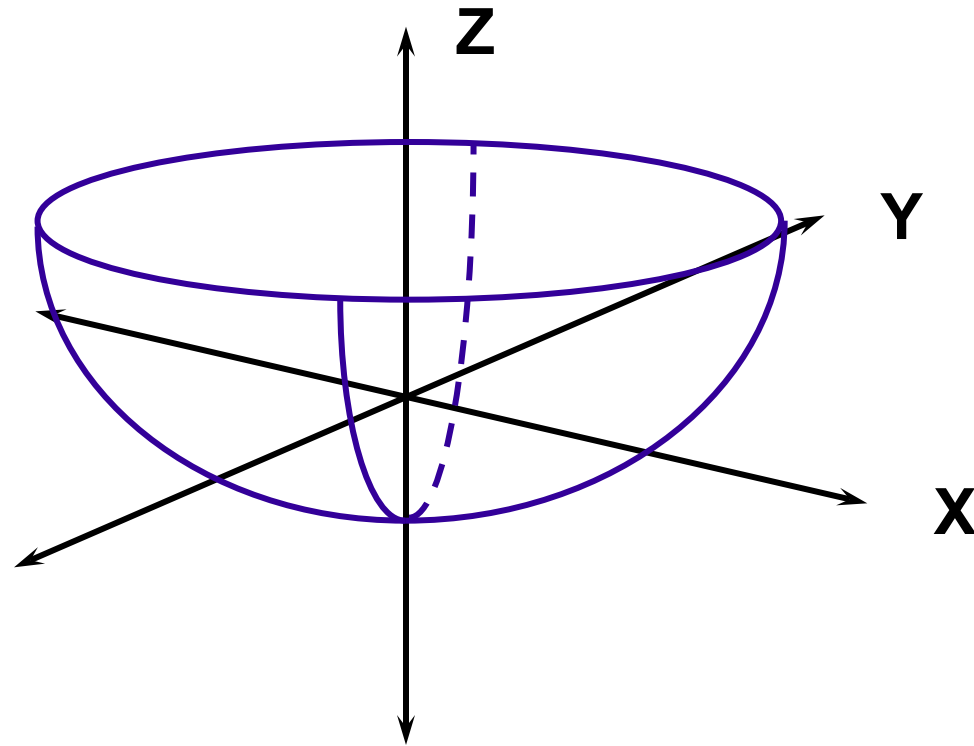
YPPLANE LABEL Y+ Y-

ZPPLANE LABEL Z+ Z-

Pentagonal prism



Quadratic surface

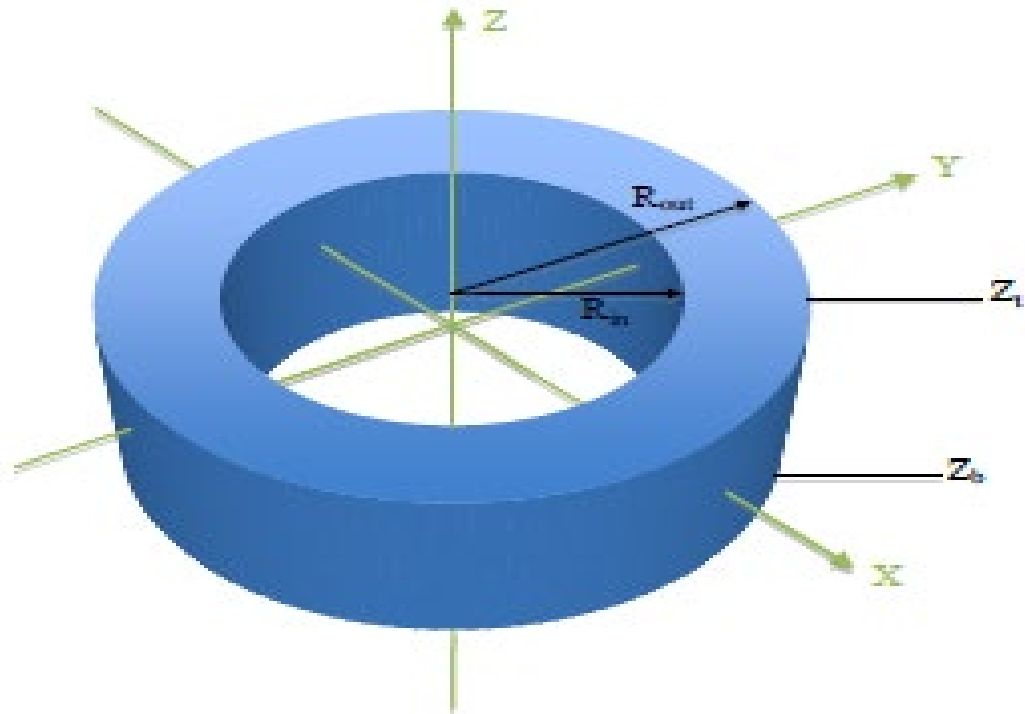


**QUADRATIC LABEL AQU=a BQU=b CQU=c DQU=d
EQU=e FQU=f GQU=g HQU=h IQU=i JQU=j**

$$aX^2 + bY^2 + cZ^2 + dXY + eXZ + fYZ + gX + hY + iZ + J = 0$$

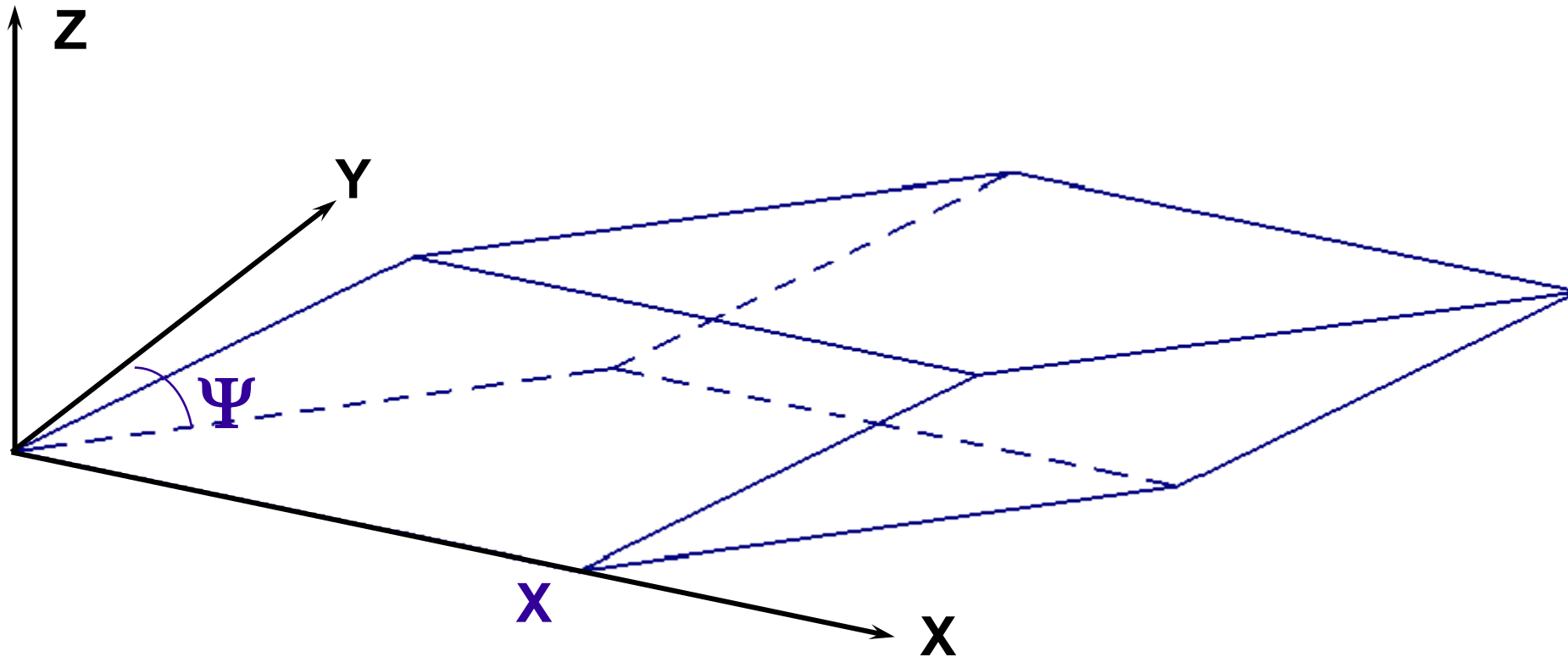
(Only non-zero values need to be entered)

Ring



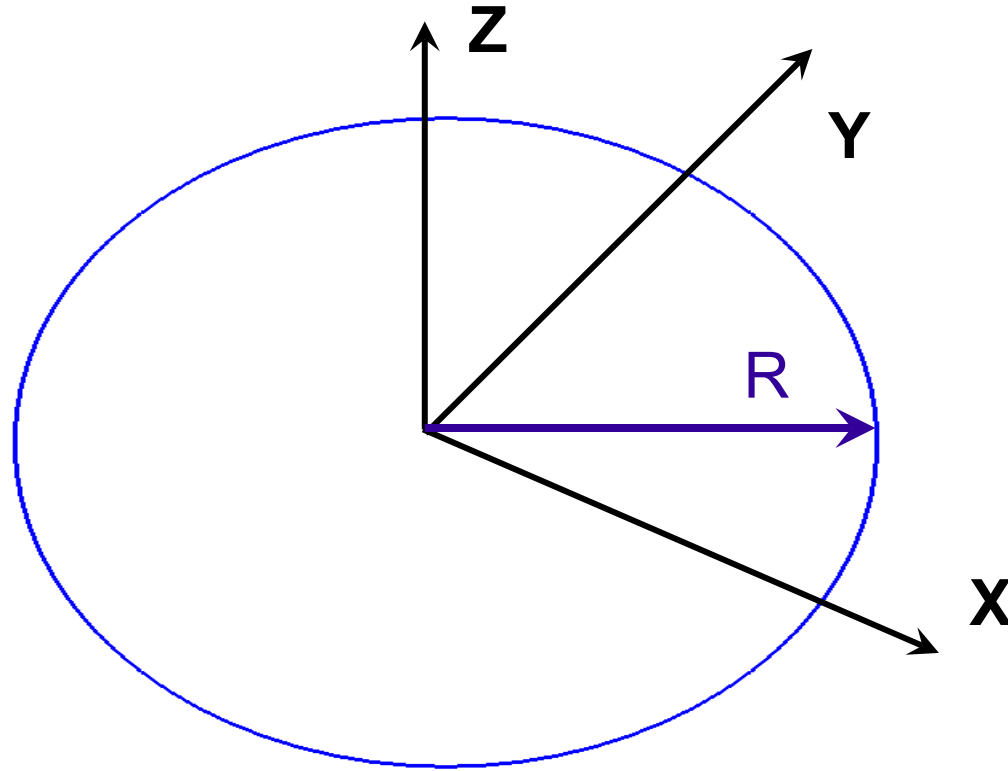
RING LABEL R_{in} R_{out} Z_t Z_b

Rhomboid



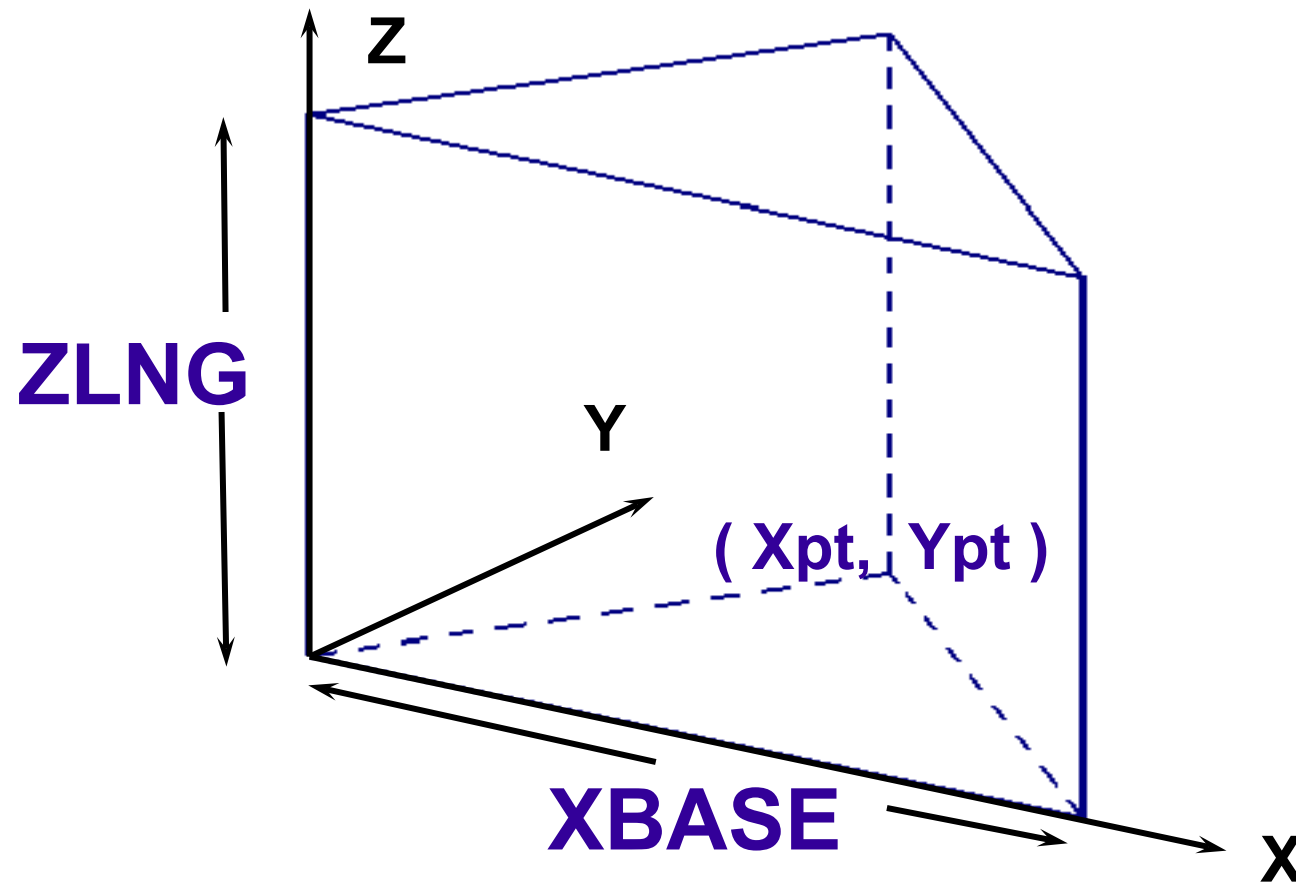
RHOMBOID LABEL X Ψ

Sphere



SPHERE LABEL R

Wedge



WEDGE	LABEL	XBASE	Xpt	Ypt	ZLNG
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Questions on geometry records?



Contents record

- Specifies the contents of a volume defined relative to the Geometry records in that unit
- Three types of Contents records:
 1. **Media** – Places a mixture in the specified volume
 2. **Hole** – Places a previously defined unit at the specified position
 3. **Array** – Places an array in the specified volume

Contents record types

Keyword	Contents Record Input
MEDIA	Mixture Number Bias ID Number Region Definition Vector
ARRAY	Array Number Region Definition Vector Keyword PLACE followed by the X, Y, Z position of the unit used to place the array and the X, Y, Z coordinates of the unit with respect to the origin of the outer region
HOLE	Unit number Keywords ORIGIN and ROTATE, if desired

Will be discussed in
a dedicated lecture

Will be discussed in
a dedicated lecture

Contents record types (cont.)

- Comprises the following components
 - Contents keyword (**Array**, **Hole**, **Media**)
 - ID number (**Array #**, **Unit #**, **Mixture #**)
 - Bias ID number (**Media** only)
 - Region definition vector (**Array**, **Media** only)
 - PLACE (**Array** only)
 - ORIGIN and/or ROTATE (**Hole** only)

- Examples:

```
media 4 1 20 -15
```

```
hole 1 origin x=5 y=5 z=10 rotate a1=45
```

```
array 6 10 PLACE 7 7 1 0 0 0
```

Media Contents record

- Places mixture into a region defined in the current unit
- Comprises the following components:
 - MEDIA keyword
 - Mixture ID number
 - Bias ID number (essentially always 1)
 - Biased tracking not recommended for use in KENO
 - Historically only available for some reflector materials
 - Bias weights may not be accurate anymore, leading to wrong answers
 - Region definition vector
 - VOL keyword
 - Necessary for region-averaged tallies, not eigenvalue

Region definition vector

- Composed of Geometry Record Labels used to specify the volume and location of a region in a unit
- The sign associated with each geometry label in the region definition vector specifies the relative location of the region in the unit using Boolean logic
 - Inside Geometry: Positive Label (AND)
 - Outside Geometry: Negative Label (NOT)
 - NO union operator

Region definition vector examples

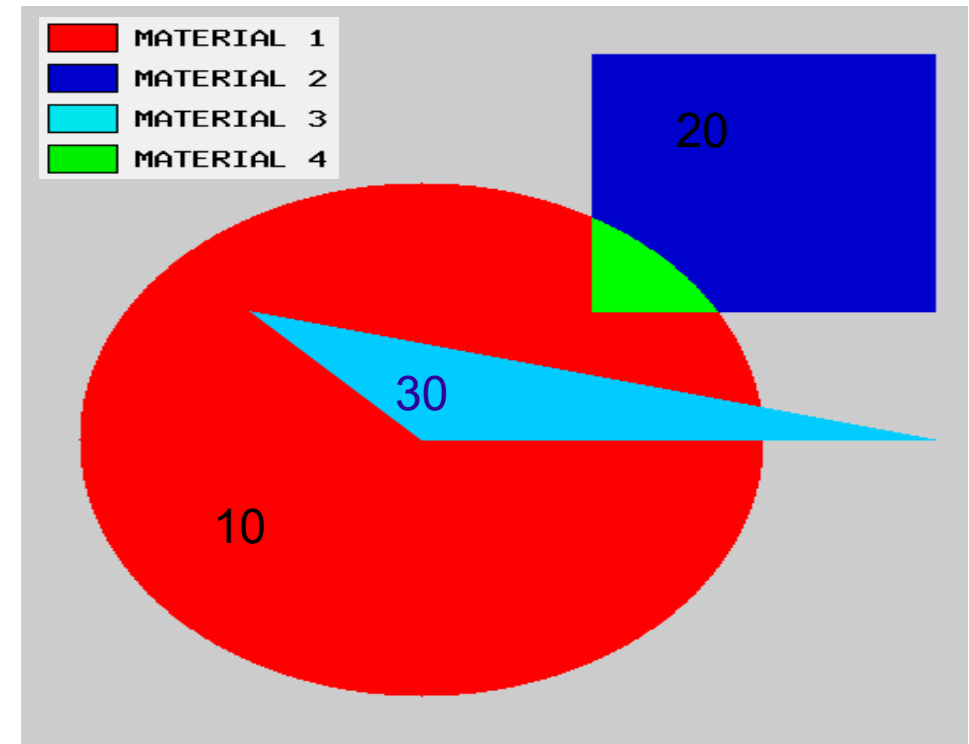
media 1 1 10 -20 -30

media 2 1 20 -10

media 4 1 20 10

media 3 1 30

Region Definition Vectors

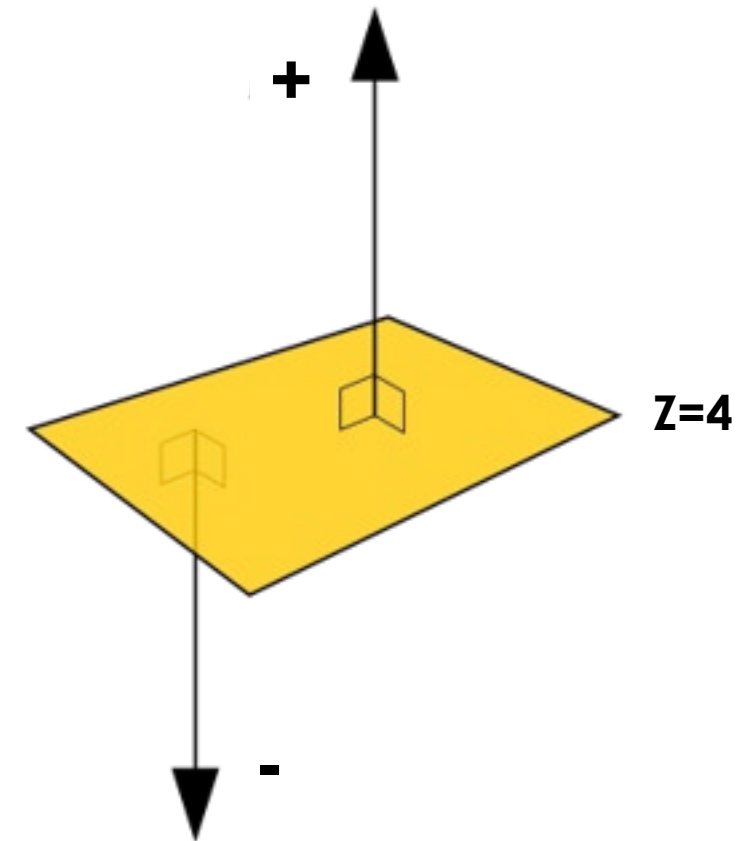


Region definition vector for planes

- How can a particle be inside a plane?
- The positive side (inside) of the plane is the side that the normal points to or where $aX + bY + cZ + d > 0$
 - Positive label: $aX + bY + cZ + d > 0$
 - Negative label: $aX + bY + cZ + d < 0$

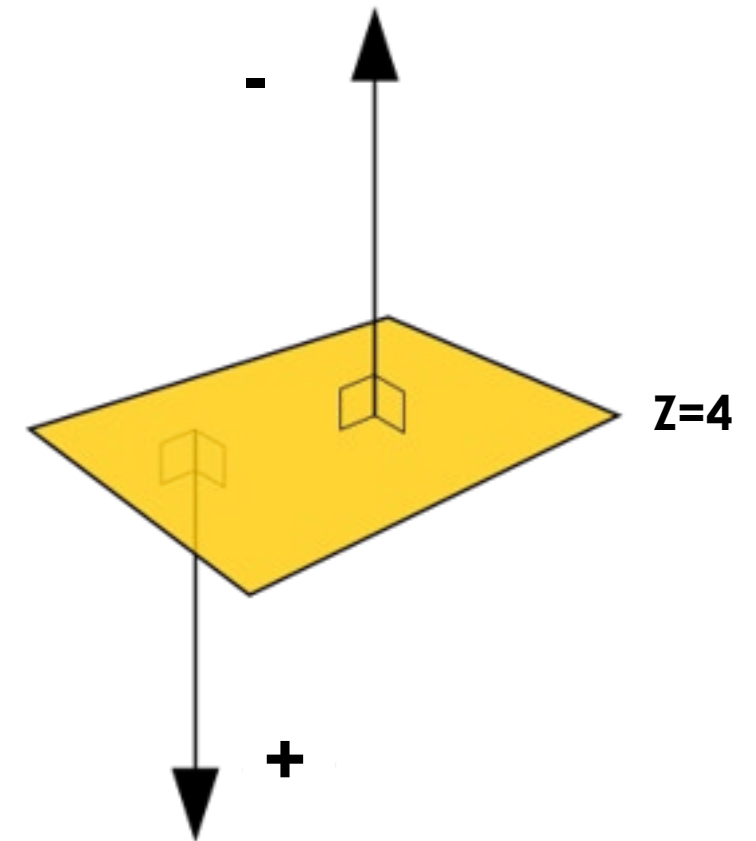
Example for plane at $Z=4$

- Option 1: Set $ZPL = 1$, $CON = -4$
 - $0X + 0Y + 1Z + (-4) > 0$, or $Z = 4$
 - This makes volume above plane inside (+)
 - A point on $Z = 5$ is + relative to the plane
 - This is intuitive, but the constant has the opposite sign of the plane coordinate ($CON=-4$)
- No “best” choice; pick the lesser evil for you



Example for plane at $Z=4$

- Option 2: Set $ZPL = -1$, $CON = 4$
 - $0X + 0Y + (-1)Z + 4 > 0$, or $Z = 4$
 - This makes the volume above the plane outside (-)
 - A point on $Z = 5$ is - relative to the plane
 - This is counterintuitive, but the constant has the same sign as the plane coordinate ($CON=4$)
- No “best” choice; pick the lesser evil for you



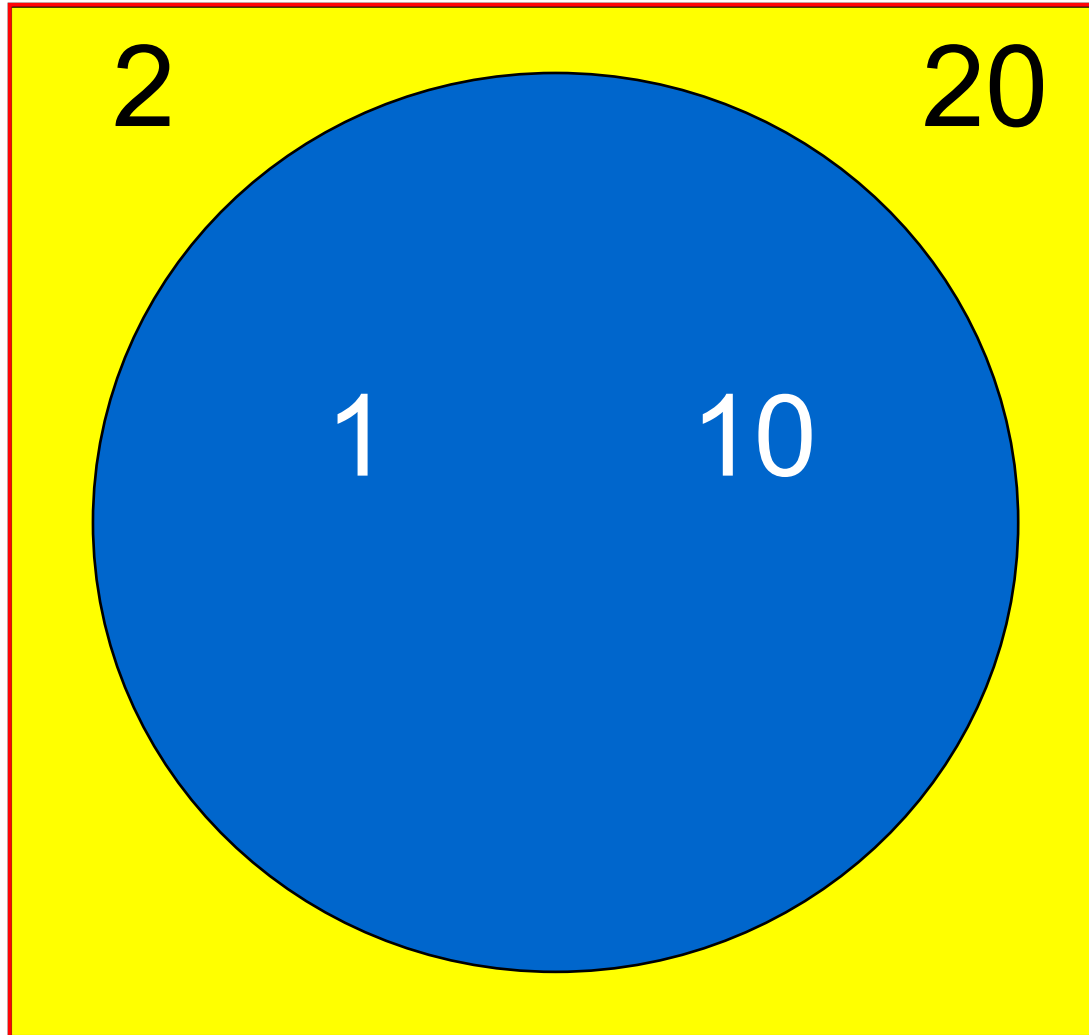
Questions on contents
records?
Aside from HOLES and
ARRAYs, which are later...



Boundary record

- Specifies the overall volume of a unit
 - One and only one Boundary record is required for each unit
 - Only the volume defined in the region definition vector of the unit's boundary record is contained within the unit
 - Other specified volumes outside the boundary record's region definition vector are not included in the unit
- Composed of a Region definition vector

Single unit example



```
read geometry
global unit 1
  sphere 10 10.0
  cuboid 20 6p12.0
  media 1 1 10
  media 2 1 20 -10
boundary 20
end geometry
```

Free-form input in geometry definitions

Count Field	Option Field	Operand Field	Comment
<i>i</i>	r, *, \$	<i>j</i>	Stores <i>j</i> in the next <i>i</i> positions and, if in an array, increments the array position by position <i>i</i> .
<i>i</i>	p	<i>j</i>	Stores <i>j</i> in the next <i>i</i> positions, alternating the sign each time.
<i>i</i>	z		Stores zero in the next <i>i</i> positions.

Examples:

3R2.5 is equivalent to: 2.5 2.5 2.5

4P3 is equivalent to: 3 -3 3 -3

5Z is equivalent to: 5R0 or 0 0 0 0 0

Building a unit in KENO-VI

unit 1

com='simple unit example'

Geometry
Record

sphere 10 4

cylinder 20 6 6.5 -6.5

cylinder 30 7 7 -7

cuboid 40 6p7.2

Contents
Record

media 1 1 10

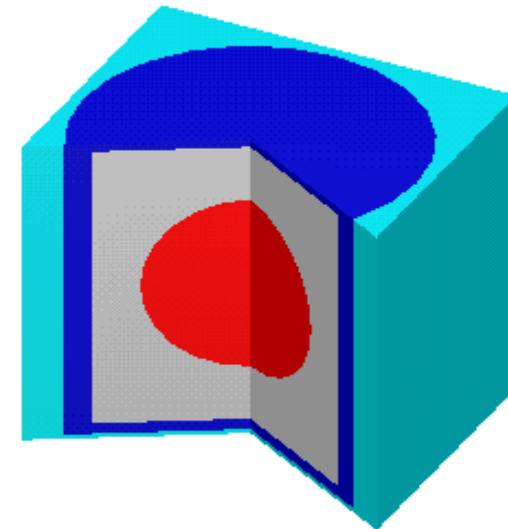
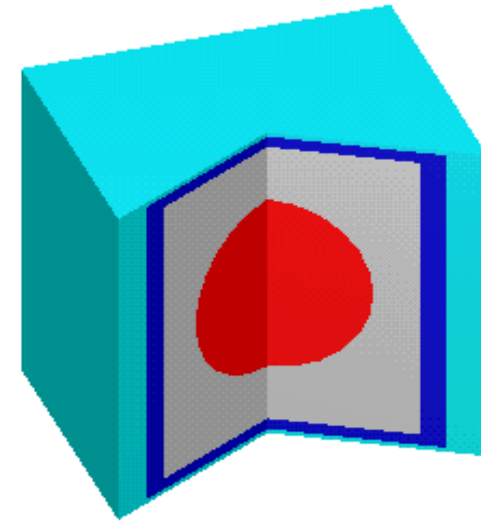
media 2 1 20 -10

media 3 1 30 -20

media 4 1 40 -30

Boundary
Record

boundary 40



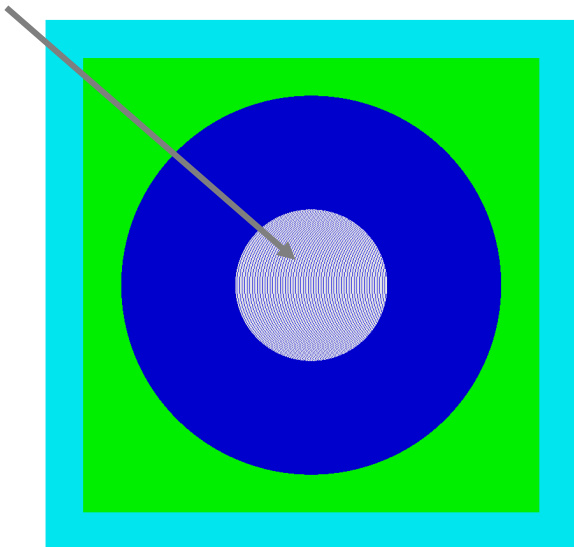
Error message for RDV problem: csas6

```
***** error ***** keno message number k6-106 follows:  
posit error --- unit 1 has multiply defined space at  
x = -1.65087E+00    y = -8.89616E-01    z = -3.63992E-01  
sector inside
```

1	T
2	F
3	F
4	T

- Sector number is contents record number – just counted
- T/F is true/false for inside or outside of sector

Doubly defined space in 6.3.3 Fulcrum



Input

Contents
Record #

```
global unit 1  
sphere 10 5  
cuboid 20 6p6  
cuboid 30 6p7  
sphere 40 2  
'  
1 media 1 1 10  
2 media 3 1 20 -10  
3 media 2 1 30 -20  
4 media 0 1 40  
'  
boundary 30
```

Sphere 40 is smaller than (and completely inside) sphere 10. This is doubly defined space; thus, the particle is inside 1 and 4 at the same time.

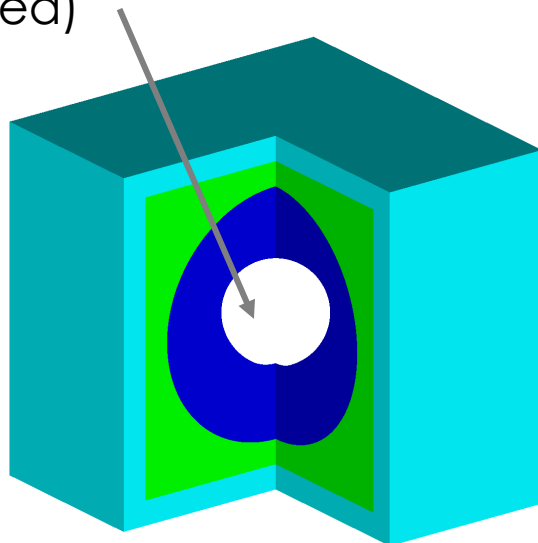
Error message for RDV problem: csas6-Shift

```
!!! Geometry error in particle 0:11: Multiple overlapping cells found at -1.88819
0.47528 0.456992 along 0.90074 -0.296867 0.317076 in 'unit 1': inside '1.4' (<inp>:65,
local cell ID 4) and '1.1' (<inp>:59, local cell ID 1)
!!! Geometry error in particle 0:19: Multiple overlapping cells found at -1.28204
1.16206 1.00299 along 0.882639 -0.422375 0.20627 in 'unit 1': inside '1.4' (<inp>:65,
local cell ID 4) and '1.1' (<inp>:59, local cell ID 1)
```

- Shift provides location of overlapping cell instance
- Provides unit regions that overlap (cell ID 1 and cell ID 4) as well as input location of overlapping media instance (line 65 and 59)

Doubly defined space in 6.3.3 Fulcrum:

- Less obvious than in 6.2.4
- Hard to distinguish from void (if expected)



Input

Contents Record

```
global unit 1
sphere 10 5
cuboid 20 6p6
cuboid 30 6p7
sphere 40 2
'
1 media 1 1 10
2 media 3 1 20 -10
3 media 2 1 30 -20
4 media 0 1 40
'
boundary 30
```

Sphere 40 is smaller than (and completely inside) sphere 10. This is doubly defined space; thus, the particle is inside 1 and 4 at the same time.

Volume block



Volumes in Monte Carlo models

- Region volumes are not needed in CSAS/KENO-VI or CSAS/Shift for criticality calculation
 - However, region/mixture averaged tallies, i.e., reaction, flux, and others, require region volumes
- **Volumes are always required in TRITON/KENO-VI and TRITON/Shift depletion calculations**
 - If your fuel volumes are incorrect, then the power generated from the fuel is incorrect, and your whole depletion calculation is wrong
- Options:
 - Specify volume via “vol=” after each **MEDIA** record
 - Example: `media 10 1 3 -4 vol=2.0e-2`
 - Add VOLUME block to enable volume calculation (next slide)
- CSAS skips the volume calculation if not enabled
- TRITON enables a volume calculation if no volume block is specified and if volumes are missing
- Units for volume definitions are cm³

Volume calculation via VOLUME block

- Use the **VOLUME** block to calculate region and mixture volumes
- Volume calculation is performed before each neutron transport calculation, and also if **parm= (check)**
- KENO-VI:
 - Monte Carlo integration (point sampling):
type=random nbatches=500 npoints=1000
 - Trapezoidal integration (ray-tracing):
type=trace nrays=100000
- Shift:
 - Ray tracer: **type=trace nrays=100000**
- Check volumes and corresponding errors in output

See details on VOLUME block in SCALE manual [section 8.1.3.13](#)

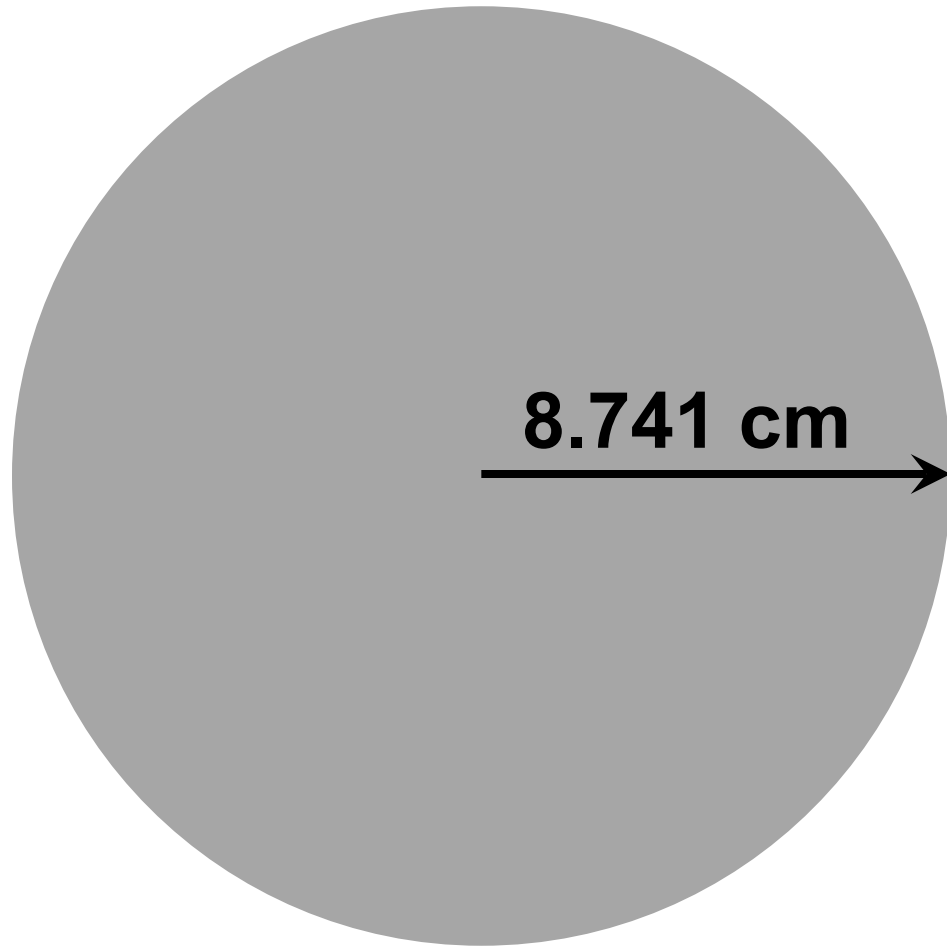
Volume calculation with Fulcrum

- Use Fulcrum to calculate volumes for simple geometries
- Hit arrow next to “Run” and select “Calculate volumes”
- Message window will contain input with volumes added for each MEDIA record
- Note:
 - Behavior of Fulcrum is slightly different between SCALE versions: addition of *all* vol= records, replacement of existing vol= records, etc.
 - This only works for simple geometries
 - Uncertainty of volumes is not reported
 - **Recommended only to double-check your own calculated volumes**

Class exercise: Lady Godiva



Lady Godiva



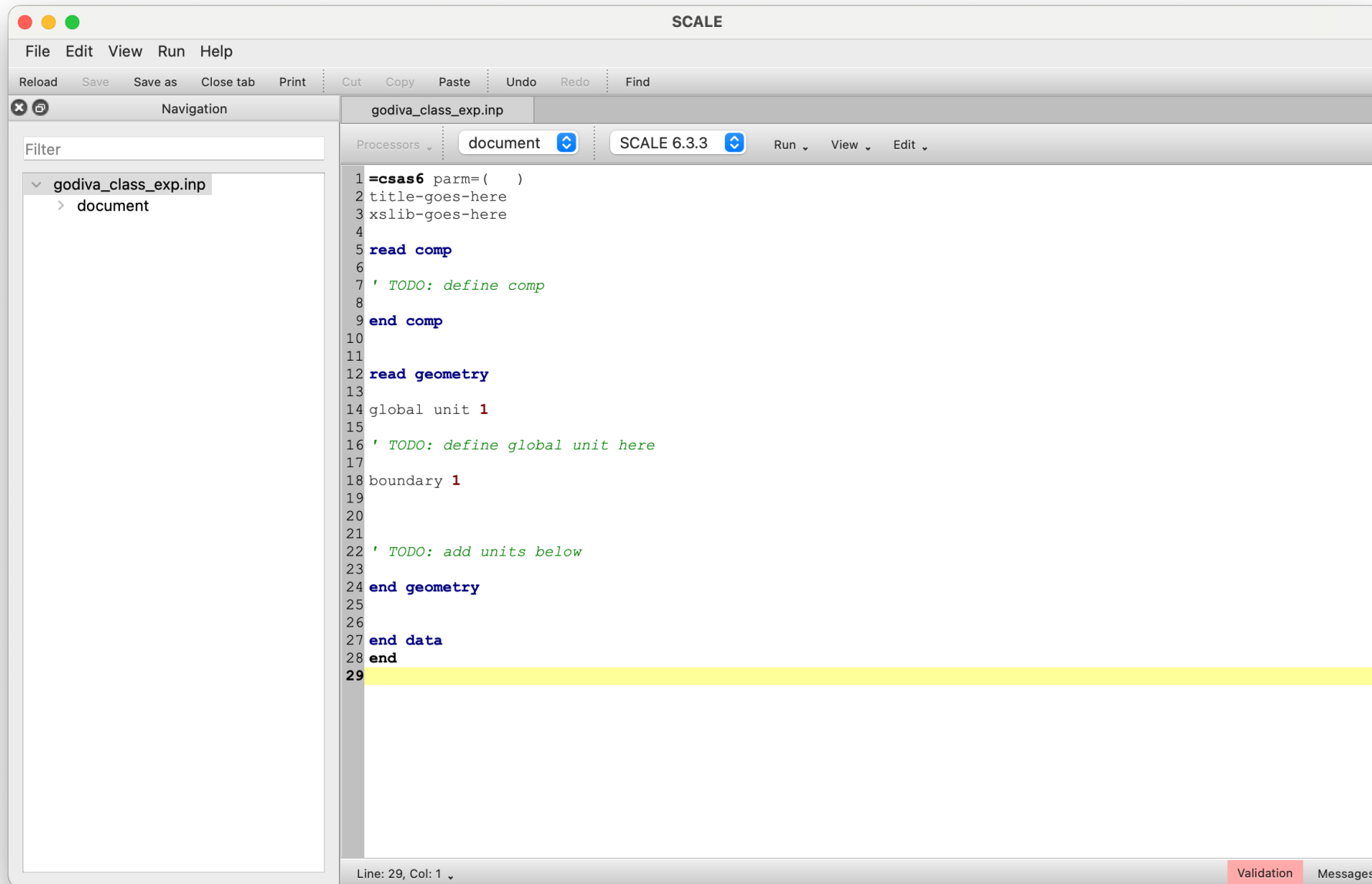
Bare Uranium Metal Sphere

Density 18.74 g/cc

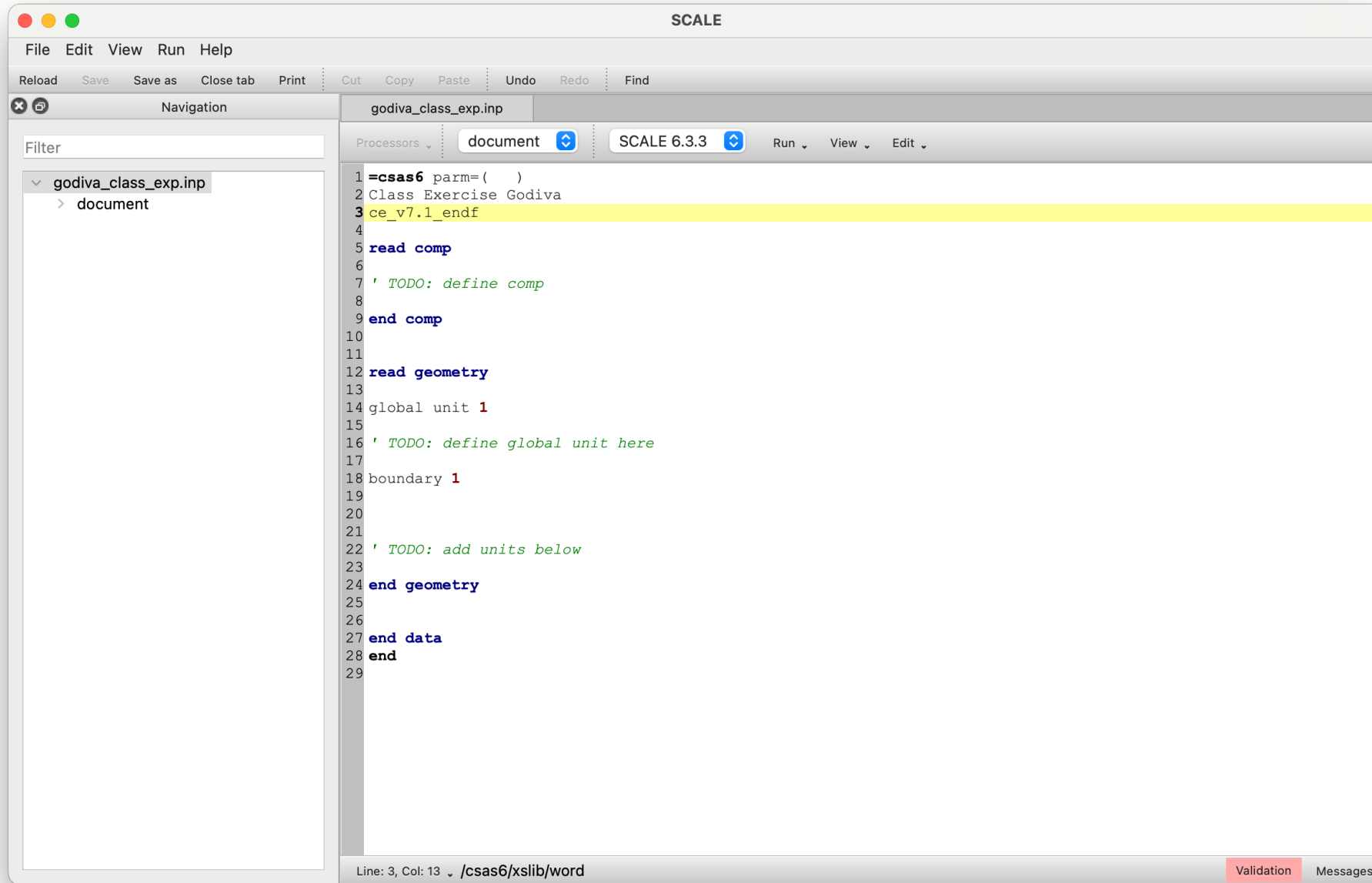
Enrichment:

U-235	93.7112 wt%
U-238	5.2686 wt%
U-234	1.0202 wt%

Input skeleton



General problem data



The screenshot displays the SCALE 6.3.3 application window. The title bar reads "SCALE". The menu bar includes "File", "Edit", "View", "Run", and "Help". Below the menu bar is a toolbar with buttons for "Reload", "Save", "Save as", "Close tab", "Print", "Cut", "Copy", "Paste", "Undo", "Redo", and "Find". A "Navigation" panel on the left shows a tree view with "godiva_class_exp.inp" expanded, revealing a sub-entry "document". The main editor area displays the contents of "godiva_class_exp.inp", which is a Fortran input file. The code is as follows:

```
1 =csas6 parm=( )
2 Class Exercise Godiva
3 ce_v7.1_endf
4
5 read comp
6
7 ' TODO: define comp
8
9 end comp
10
11
12 read geometry
13
14 global unit 1
15
16 ' TODO: define global unit here
17
18 boundary 1
19
20
21
22 ' TODO: add units below
23
24 end geometry
25
26
27 end data
28 end
29
```

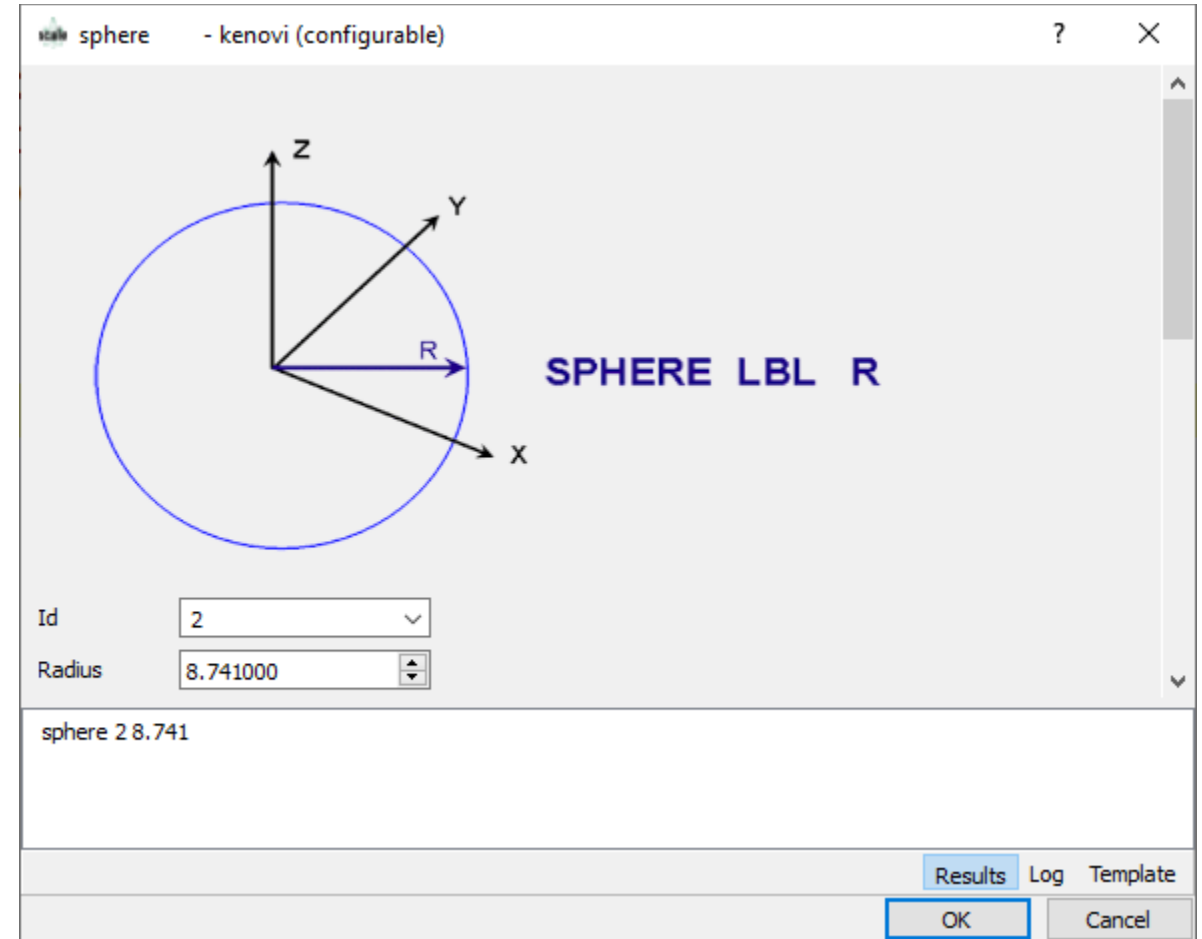
The status bar at the bottom indicates "Line: 3, Col: 13" and the file path "/csas6/xslib/word". On the right side of the status bar are buttons for "Validation" and "Messages".

Create U metal composition

```
5 read comp
6
7 u 10 den=18.74 1 293 92234 1.0202
8                               92235 93.7112
9                               92238 5.2686 end
10 end comp
```

Create sphere geometry record

```
11 read geometry
12 global unit 1
13 com='the whole thing'|
14 sphere 2 8.741
```



Create Media record

```
11 read geometry
12 global unit 1
13 com='the whole thing'
14 sphere 2 8.741
15 media 10 1 2
```

media - kenovi (configurable) ? X

Material 0 ▾

Regions

	+/-	Id	State
1	+ -	2 ▾	inside ▾

Add row

media 10 1 2

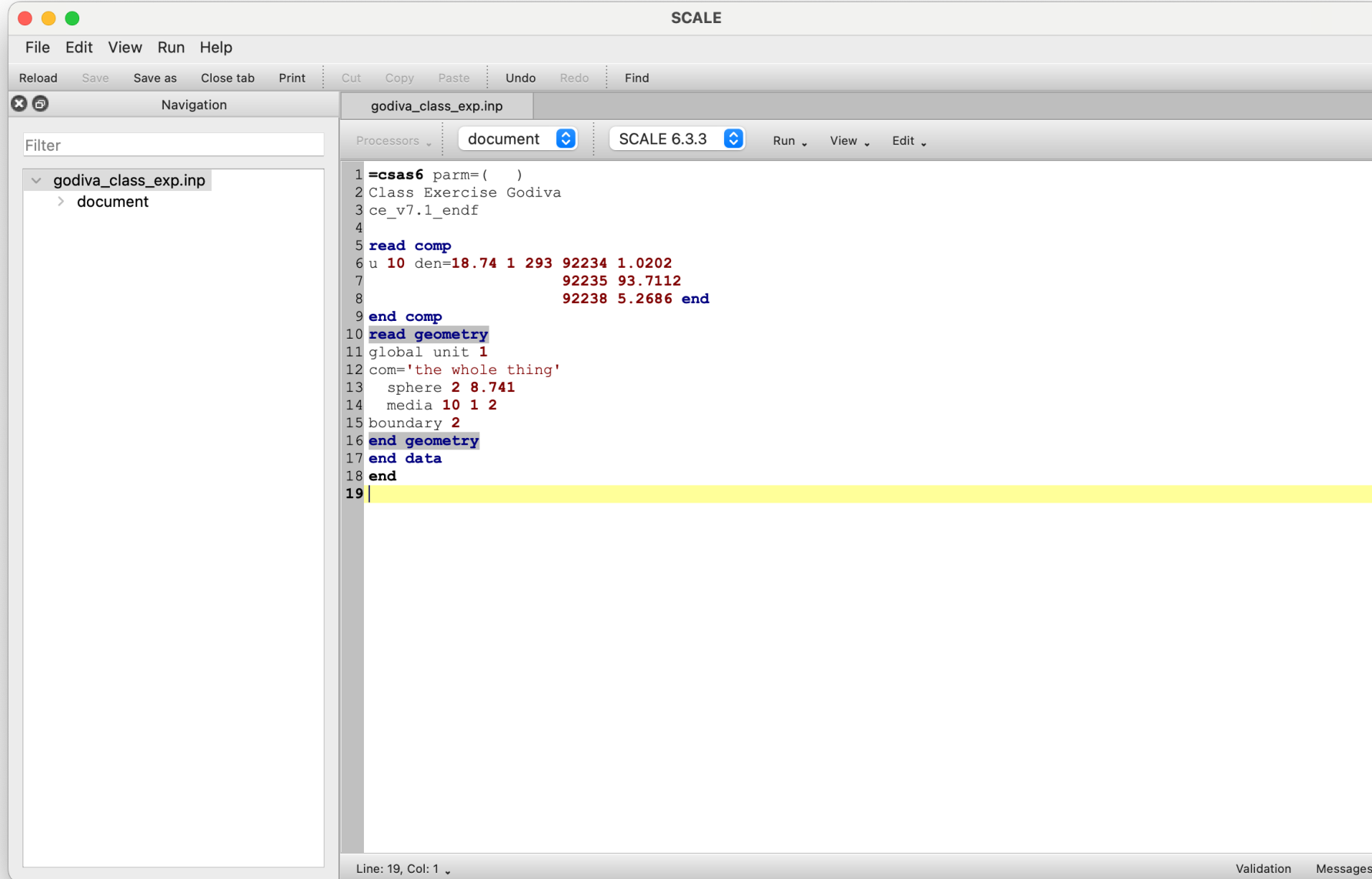
Results Log Template

OK Cancel

Create Boundary record

```
11 read geometry
12 global unit 1
13 com='the whole thing'
14   sphere 2 8.741
15   media 10 1 2
16 boundary 2
17 end geometry
```

Entire problem description



The screenshot displays the SCALE 6.3.3 application window. The title bar reads "SCALE". The menu bar includes "File", "Edit", "View", "Run", and "Help". Below the menu bar is a toolbar with buttons for "Reload", "Save", "Save as", "Close tab", "Print", "Cut", "Copy", "Paste", "Undo", "Redo", and "Find". The interface is divided into three main sections. On the left is a "Navigation" pane with a "Filter" input field and a tree view showing the file structure: "godiva_class_exp.inp" expanded to show "document". The central pane displays the contents of "godiva_class_exp.inp" as a text file. The text is as follows:

```
1 =csas6 parm=( )
2 Class Exercise Godiva
3 ce_v7.1_endf
4
5 read comp
6 u 10 den=18.74 1 293 92234 1.0202
7                                     92235 93.7112
8                                     92238 5.2686 end
9 end comp
10 read geometry
11 global unit 1
12 com='the whole thing'
13 sphere 2 8.741
14 media 10 1 2
15 boundary 2
16 end geometry
17 end data
18 end
19
```

The status bar at the bottom indicates "Line: 19, Col: 1" and includes "Validation" and "Messages" buttons.

Save and run

```
1 =csas6 parm=( )
2 Class Exercise Godiva
3 ce_v7.1_endf
4
5 read comp
6 u 10 den=18.74 1 293 92234 1.0202
7 92235 93.7112
8 92238 5.2686 end
9 end comp
10 read geometry
11 global unit 1
12 com='the whole thing'
13 sphere 2 8.741
14 media 10 1 2
15 boundary 2
16 end geometry
17 end data
18 end
19
```

Mon Sep 22 15:30:04 2025						
515	200	9.98126E-01	1.00091E+00	2.20216E-03	6.09856E+00	7.43333E-02
516						
517	201	1.00250E+00	1.00091E+00	2.19012E-03	6.12360E+00	7.46667E-02
518						
519	202	1.04687E+00	1.00114E+00	2.17090E-03	6.10447E+00	7.48333E-02
520						
521	203	1.03456E+00	1.00131E+00	2.18457E-03	6.11159E+00	7.51667E-02
522						
523						
524	class exercise godiva					
525	***** final results table *****					
526	best estimate system k-eff 1.0013 + or - 0.0021					
527						
528	Energy of average lethargy of Fission (eV) 8.14672E+05 + or - 2.28879E+03					
529	k-effective satisfies the chi**2 test for normality at the 95 % level					
530						
531	Scale job /Users/6tg/godiva_class_exp.inp is finished.					
532	Output is stored in /Users/6tg/godiva_class_exp.out					
533						
534	Process finished with 0 return code; ran in 26 secs, finished at Mon Sep 22 15:30:31 2025					

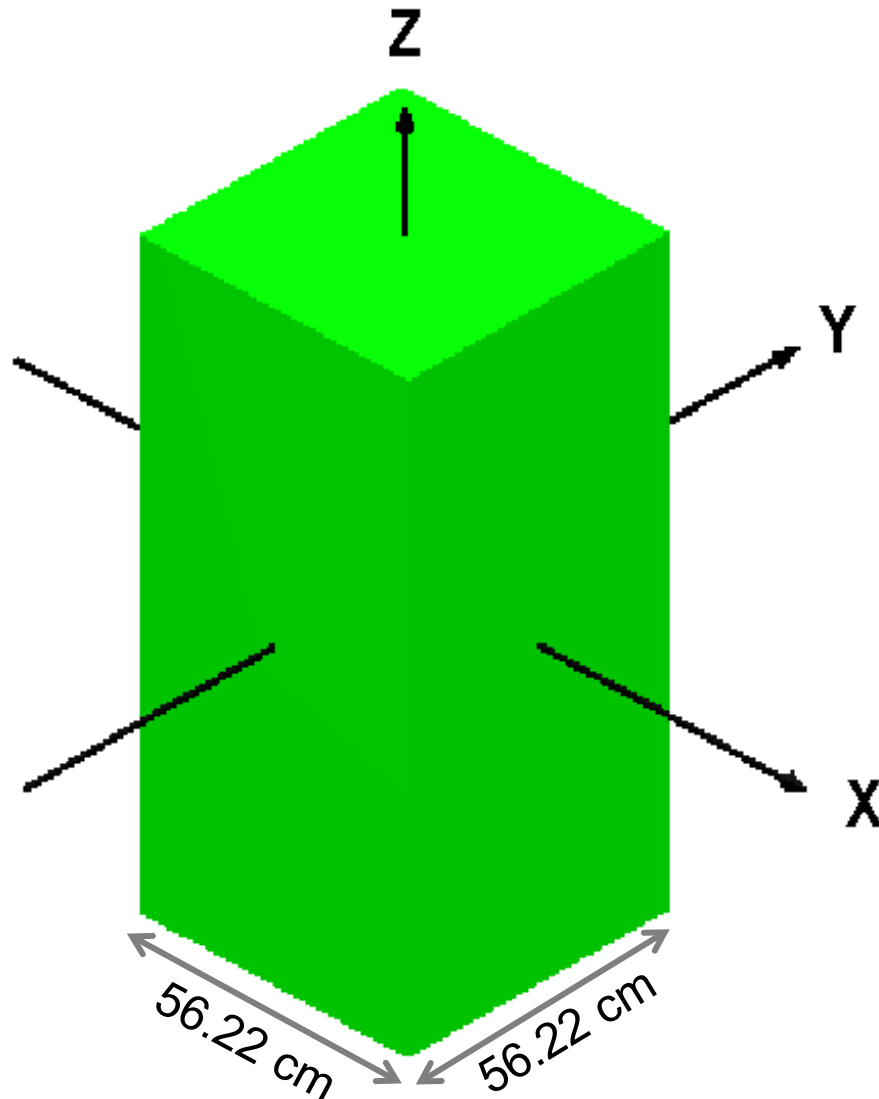
Best estimate k_{eff} :
 1.0013 ± 0.0021

Exercises for sub-module 1

- Simple KENO-VI geometry exercises
 - Set 1: Green block and Rocky Flats



Problem: Green block



Material

Temperature = 293 K

UF₄ – 51.13 vol%

U-235 2.0 wt%

U-238 98.0 wt%

Paraffin – 48.87 vol%

Hint: remember that if DEN is not the same for both components of a mixture, the density multiplier works as a *volume fraction*.

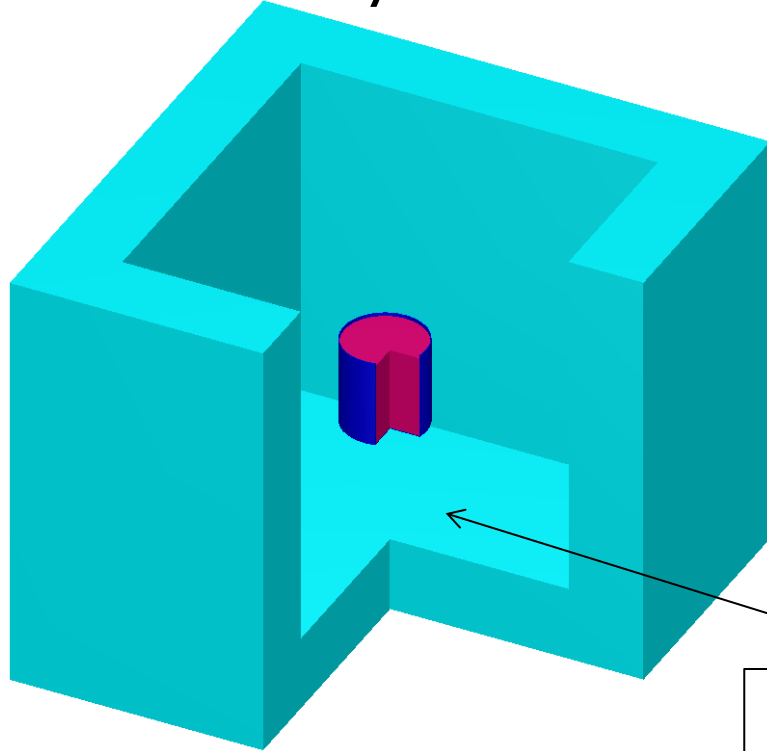
Dimensions

X : 56.22 cm

Y : 56.22 cm

Z : 122.47 cm

Problem: Rocky Flats



Al Tank

14.005 cm inner radius, solution height 28.6 cm

0.32 wall and bottom thickness

30.0 cm total tank height

Distance **from the tank inside bottom center**

to the 25.7 cm thick Concrete walls, floor, and ceiling

+ X: 64.6 cm -X: -57.4 cm

+ Y: 57.4 cm -Y: -64.8 cm

+ Z: 80.0 cm -Z: -41.1 cm

Materials: Room Temperature

uo2(no3)2 Solution default density

g U/l: 334.77

Acid Molarity: 0.521

U-234: 1.022 wt%

U-235: 93.172 wt%

U-236: 0.434 wt%

U-238: 5.372 wt%

Al density = 2.702 g/cc

Concrete density = 2.32 g/cc

oxygen: 48.49 wt%

calcium: 23.31 wt%

silicon: 15.5 wt%

carbon: 5.52 wt%

aluminum: 2.17 wt%

potassium: 1.37 wt%

magnesium: 1.25 wt%

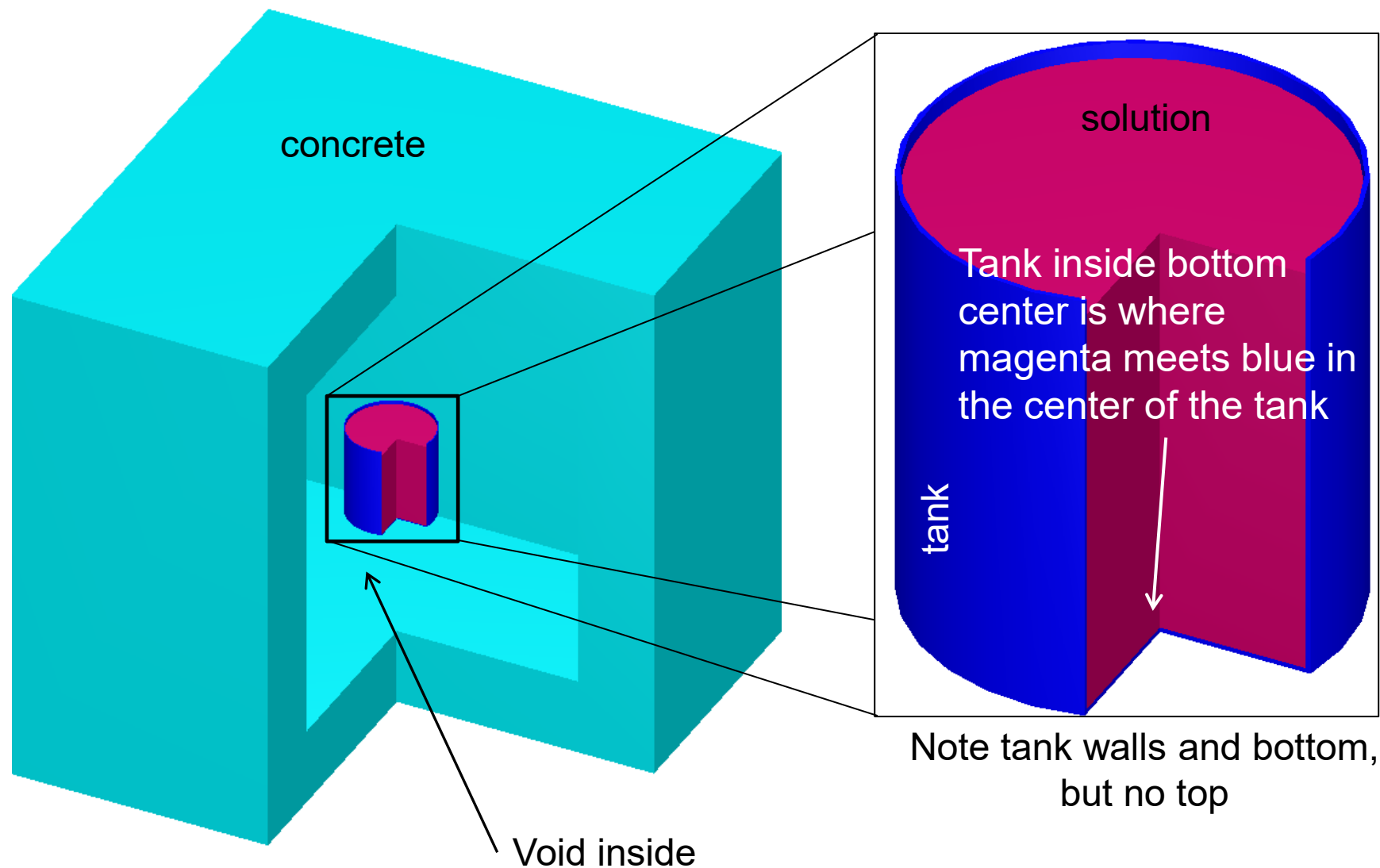
iron: 1.01 wt%

hydrogen: 0.75 wt%

sodium: 0.63 wt%

Room filled
with void

Problem: Rocky Flats (cont.)



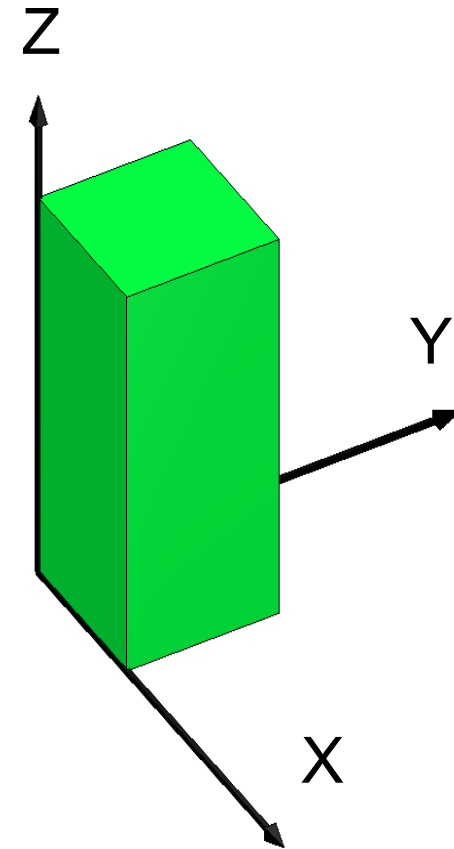
Calculated k-eff values

	KENO-VI	Shift
Green block	1.0070 +/- 0.0017	1.000393 +/- 0.002452
Rocky Flats	1.0060 +/- 0.0025	1.001669 +/- 0.004153

Your results may differ based on the options and computer used

Solution: Green block

```
=csas6
raffety and mihalczo u(2)f4-2 unreflected green block
ce_v7.1_endf
read composition
  uf4          1 0.5113 293  92235 2  92238 98  end
  paraffin     1 0.4887 293  end
end composition
read geometry
global unit 1
  cuboid 1     56.22 0.0    56.22 0.0   122.47 0.0
  media 1 1 1
  boundary 1
end geometry
end data
end
```

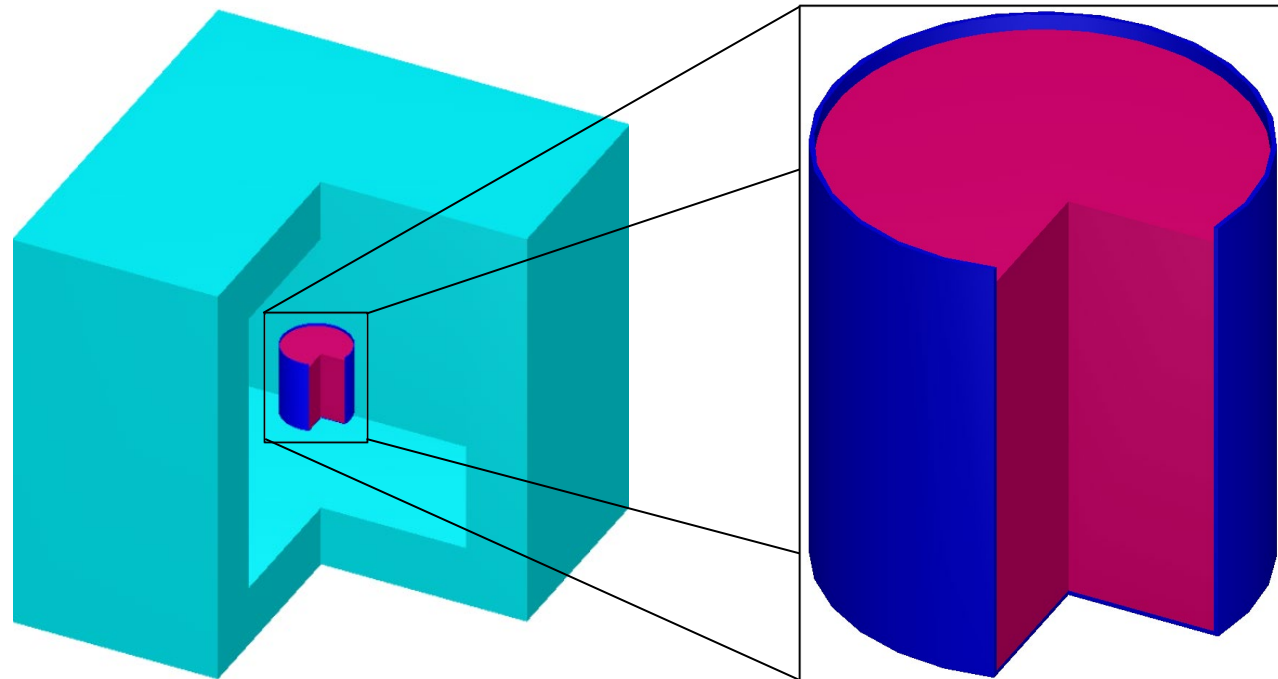


Solution: Rocky Flats

```
=csas6
rocky flats uo2(no3)2 soln 334.77 g u/l 28.01 cm diam conc refl
ce_v7.1_endf
read composition
  solution    mix=1    rho[uo2(no3)2]=334.77 92234 1.022
                                           92235 93.172
                                           92236 0.434
                                           92238 5.372
                                molar[hno3]=0.521
                                density=? vol_frac=1
  end solution
al          2  end
wtptconcrete 3 2.32 10
  8000 48.49
  20000 23.31
  14000 15.5
  6000 5.52
  13027 2.17
  19000 1.37
  12000 1.25
  26000 1.01
  1000 0.75
  11000 0.63  end
end composition
```

Solution: Rocky Flats (cont.)

```
read geometry
global unit 1
com='global unit 1'
cylinder 5 14.005 29.68 28.6
cylinder 10 14.005 28.6 0
cylinder 20 14.325 29.68 -0.32
cuboid 30 64.6 -57.4 57.4 -64.8 80.0 -41.1
cuboid 40 90.3 -83.1 83.1 -90.5 105.7 -66.8
media 0 1 5
media 1 1 10
media 2 1 20 -10 -5
media 0 1 30 -20
media 3 1 40 -30
boundary 40
end geometry
end data
end
```



Summary of Sub-Module 1

- KENO-VI rules and restrictions
- Geometry region descriptions and definitions
- Godiva example, Green Block and Rocky Flats exercises

Sub-Module 2

- Geometry modification data



Geometry modification data

- These options modify the previous geometric volume and are always performed sequentially, **in the order listed below**:
 1. Chord: Truncates the volume with a plane perpendicular to a major axis
 2. Rotate: Rotates the volume
 3. Origin: Translates the volume origin, thus translating the volume

Note that the order matters: If all three geometry modifiers are present, first "chord" is performed, then "rotate", and then "origin". Use Fulcrum to double-check your modifications.

Geometry modification keywords

Keyword

CHORD

ROTATE

ORIGIN

Input Values

+X=, -X=, +Y=, -Y=, +Z=, -Z=

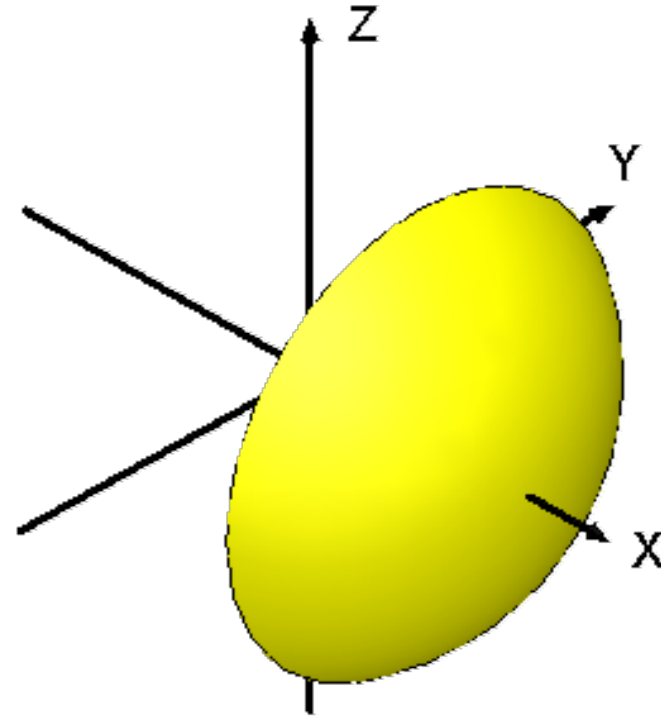
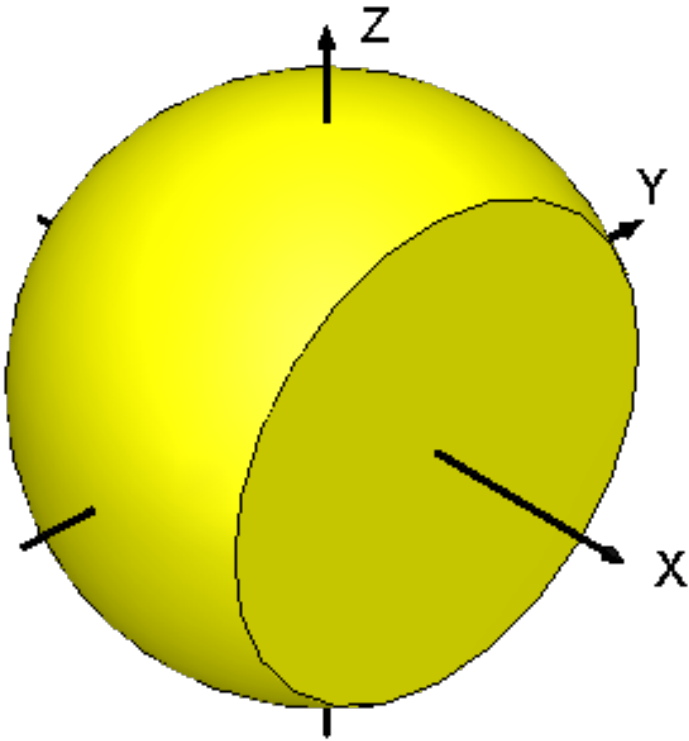
A1=, A2=, A3=

X=, Y=, Z=

CHORD data

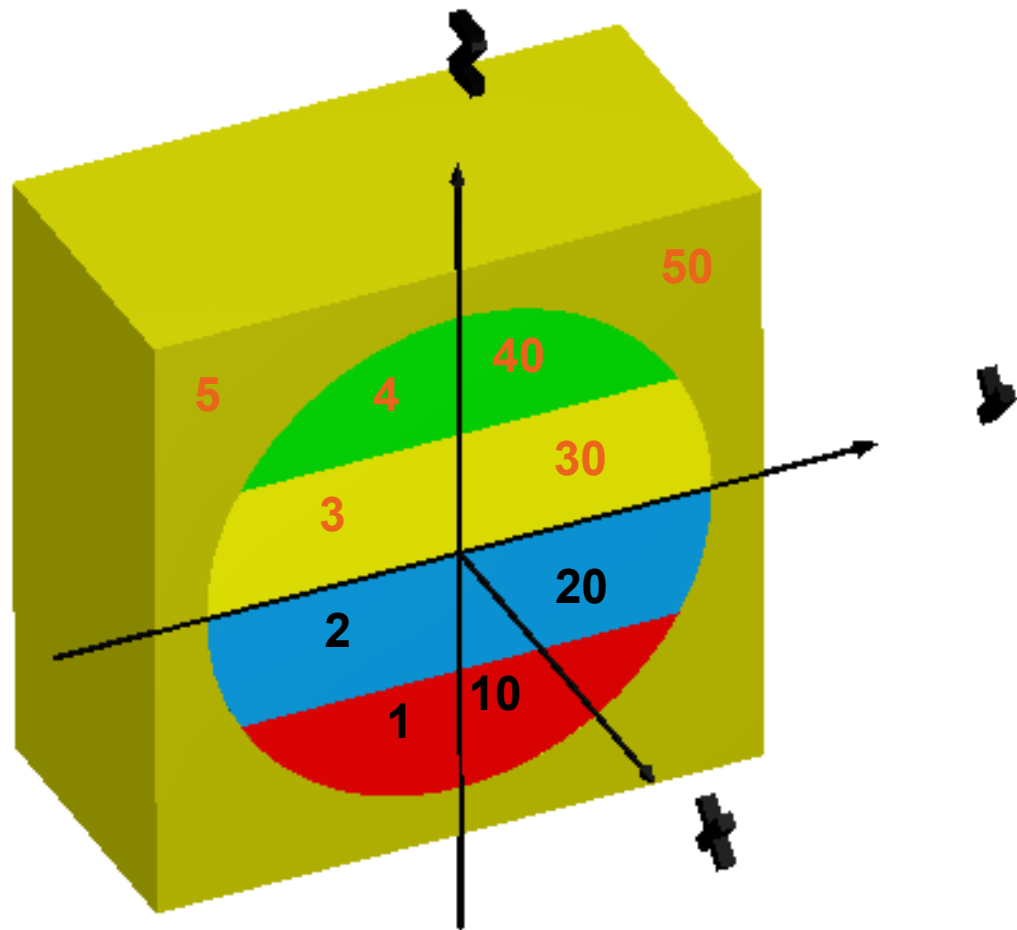
- Truncates a geometric volume with a plane perpendicular to a major axis
- Applies to the Geometry record that immediately precedes it
- Contains the following components
 - CHORD keyword
 - Subordinate keywords
 - +X=, -X=, +Y=, -Y=, +Z=, -Z=
 - Unlike KENO V.a, the subordinate keyword determines which side will be kept

CHORD examples



SPHERE 1 10.0 CHORD -X=5.0 SPHERE 2 10.0 CHORD +X=5.0

Sphere cut into four regions using CHORDs



global unit 1
sphere 10 10.0 chord -z=-5.0
sphere 20 10.0 chord +z=-5.0
 chord -z=0.0
sphere 30 10.0 chord +z=0.0
 chord -z=5.0
sphere 40 10.0 chord +z=5.0
cuboid 50 6p12.0
media 1 1 10
media 2 1 20
media 3 1 30
media 4 1 40
media 5 1 50 -10 -20 -30 -40
boundary 50

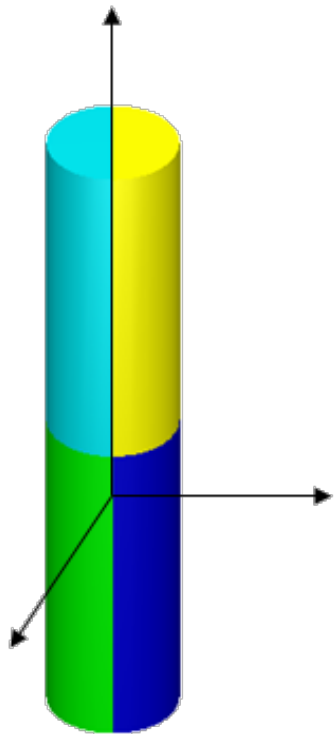
Questions about CHORD?



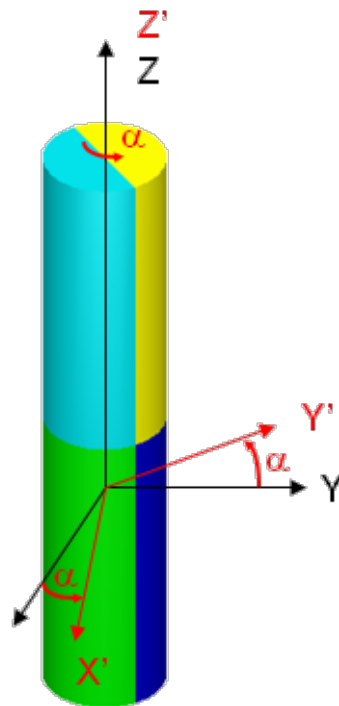
ROTATE Data

- Rotates a volume about the origin using the Euler angle x-convention
- Applies to the Geometry or HOLE record that immediately precedes it
- Contains the following components
 - ROTATE keyword
 - Subordinate keywords
A1=, A2=, A3=

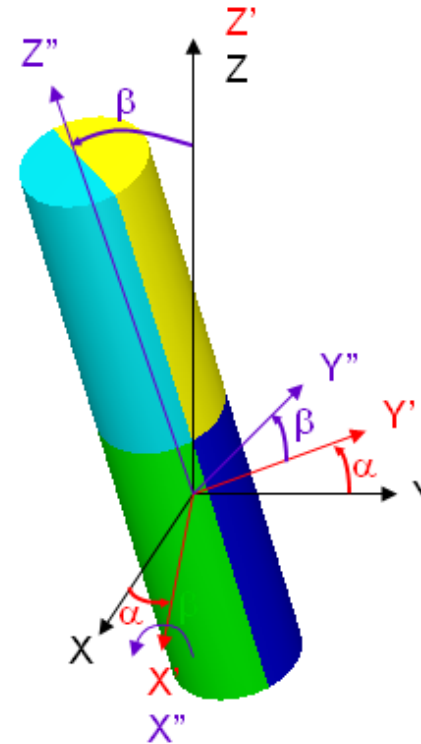
CYLINDER Label R Zt Zb ROTATE $A1=\alpha$ $A2=\beta$ $A3=\gamma$



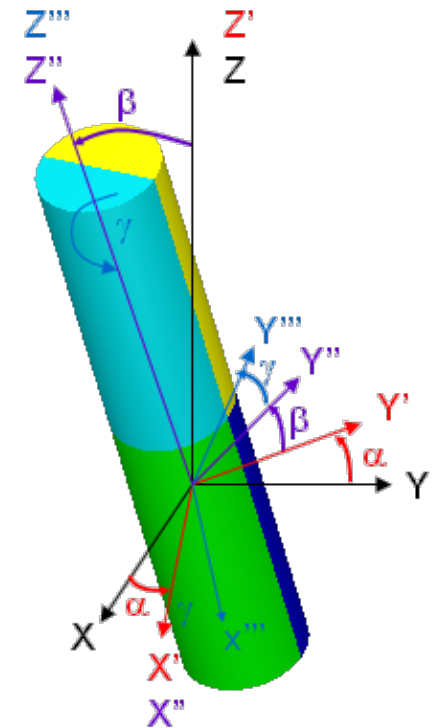
Cylinder before rotation



First rotation, $A1 = \alpha$ is counter-clockwise about the Z axis



Second rotation, $A2 = \beta$ is counter-clockwise about the X' axis



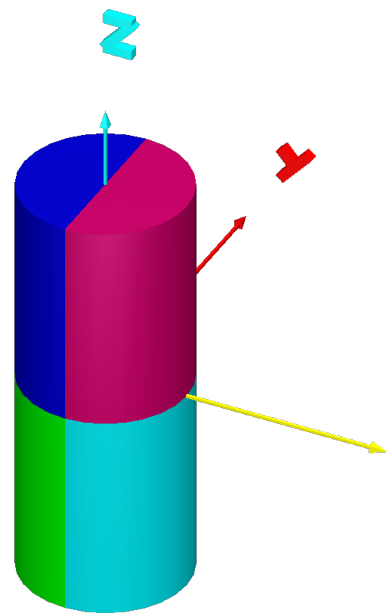
Third rotation, $A3 = \gamma$ is counter-clockwise about the Z'' axis

Right-handed coordinate system: thumb as axis pointing positive, fingers rotate in positive direction.

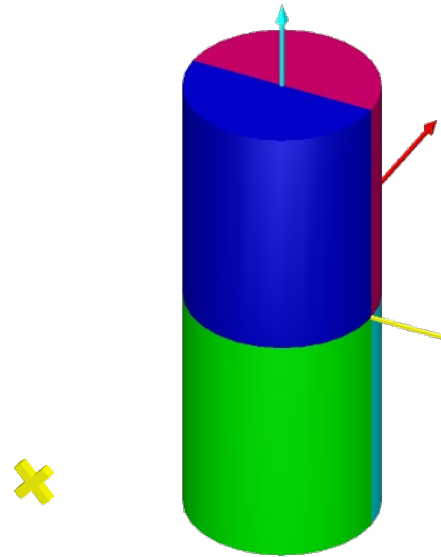
Another way of thinking about it...

CYLINDER Label R Zt Zb ROTATE A1= α A2= β A3= γ

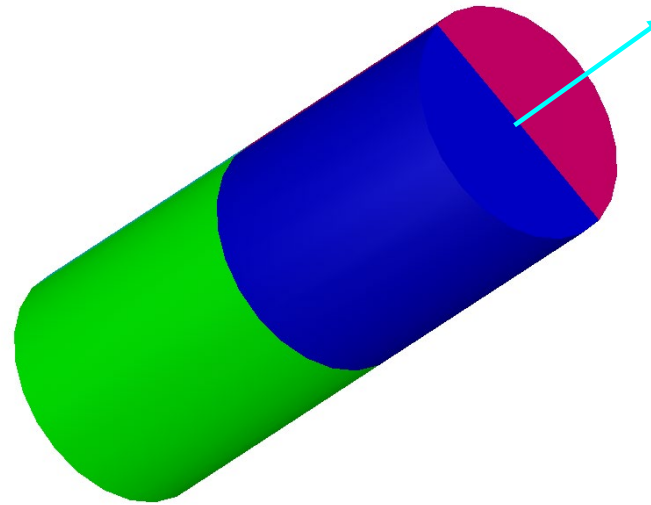
- A1 rotates about Z to position the next axis of rotation for A2
- A2 rotates about X' and positions next axis of rotation for A3



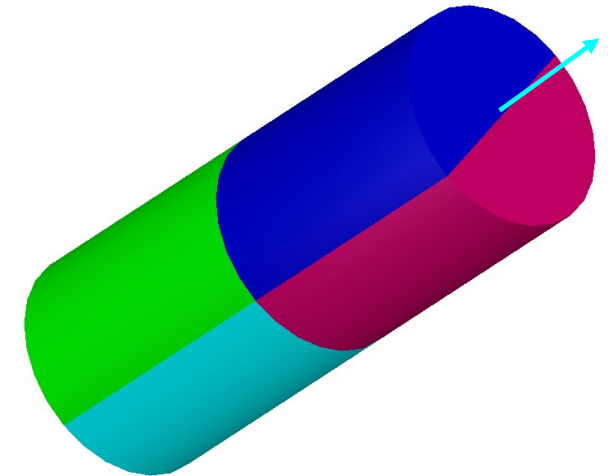
Initial object



A1=90°
A2 is now about red
axis

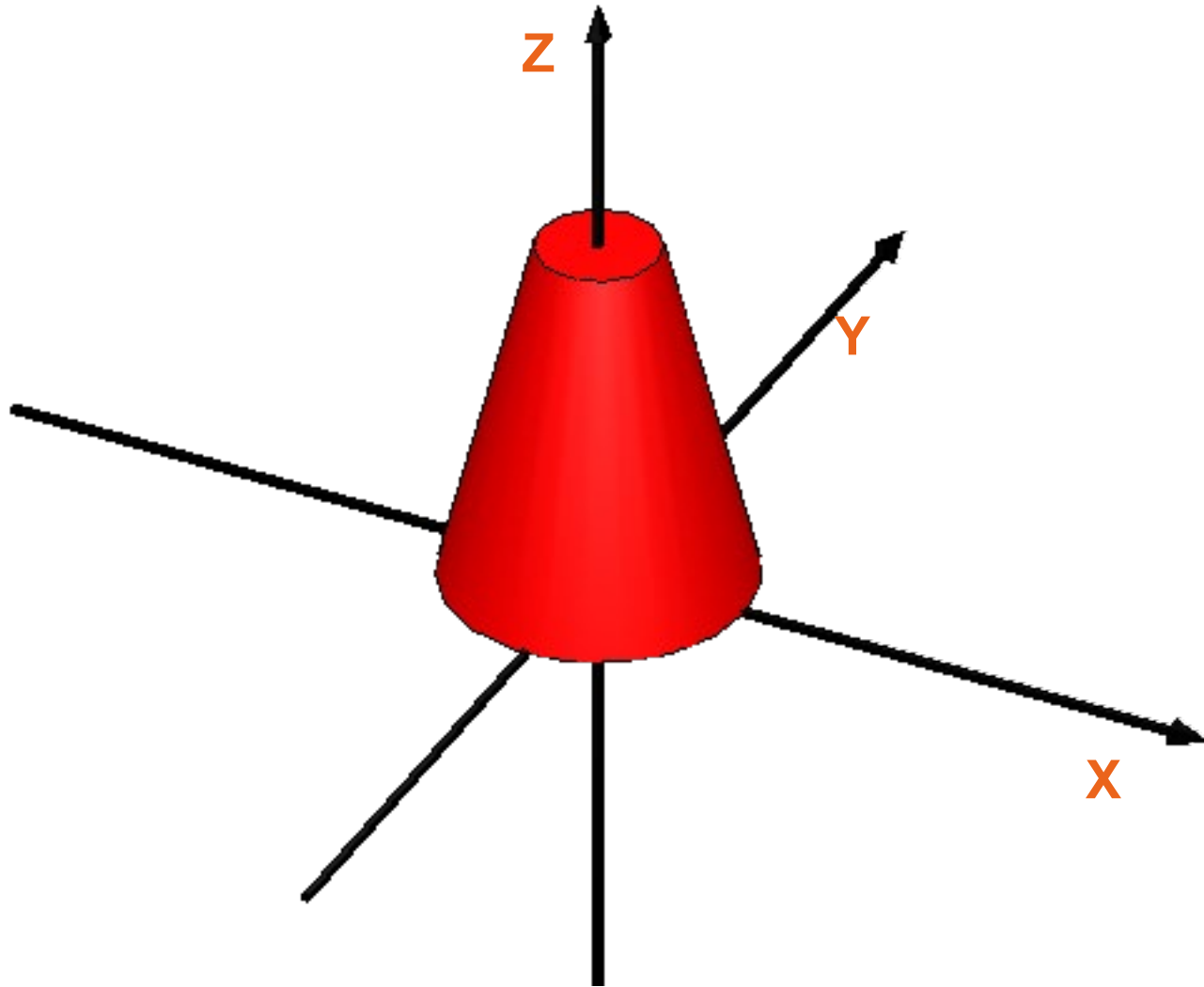


A1=90° A2=45° A3 is
now about axis out the
top



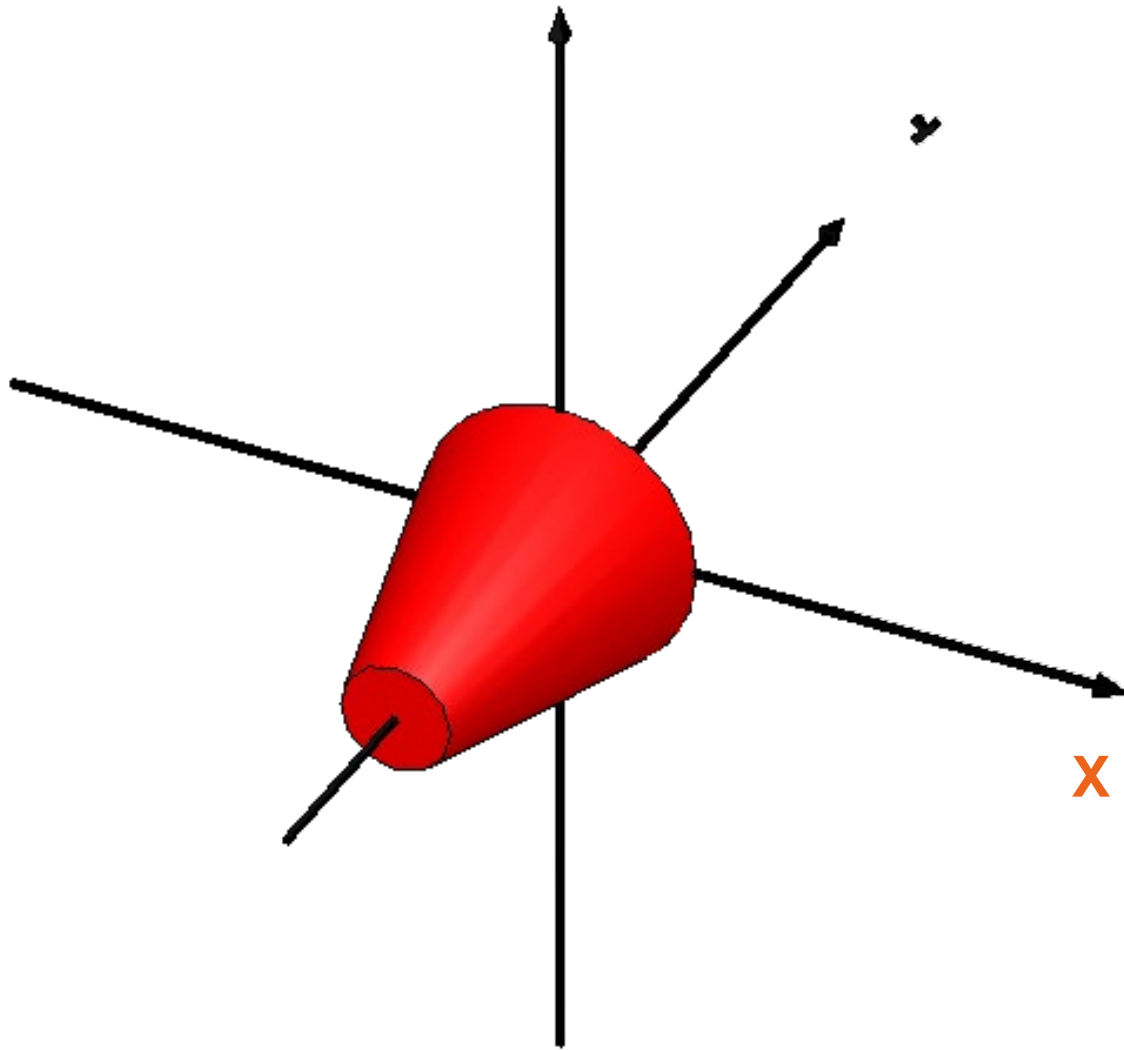
A1=90° A2=45° A3=-90°

Unrotated cone



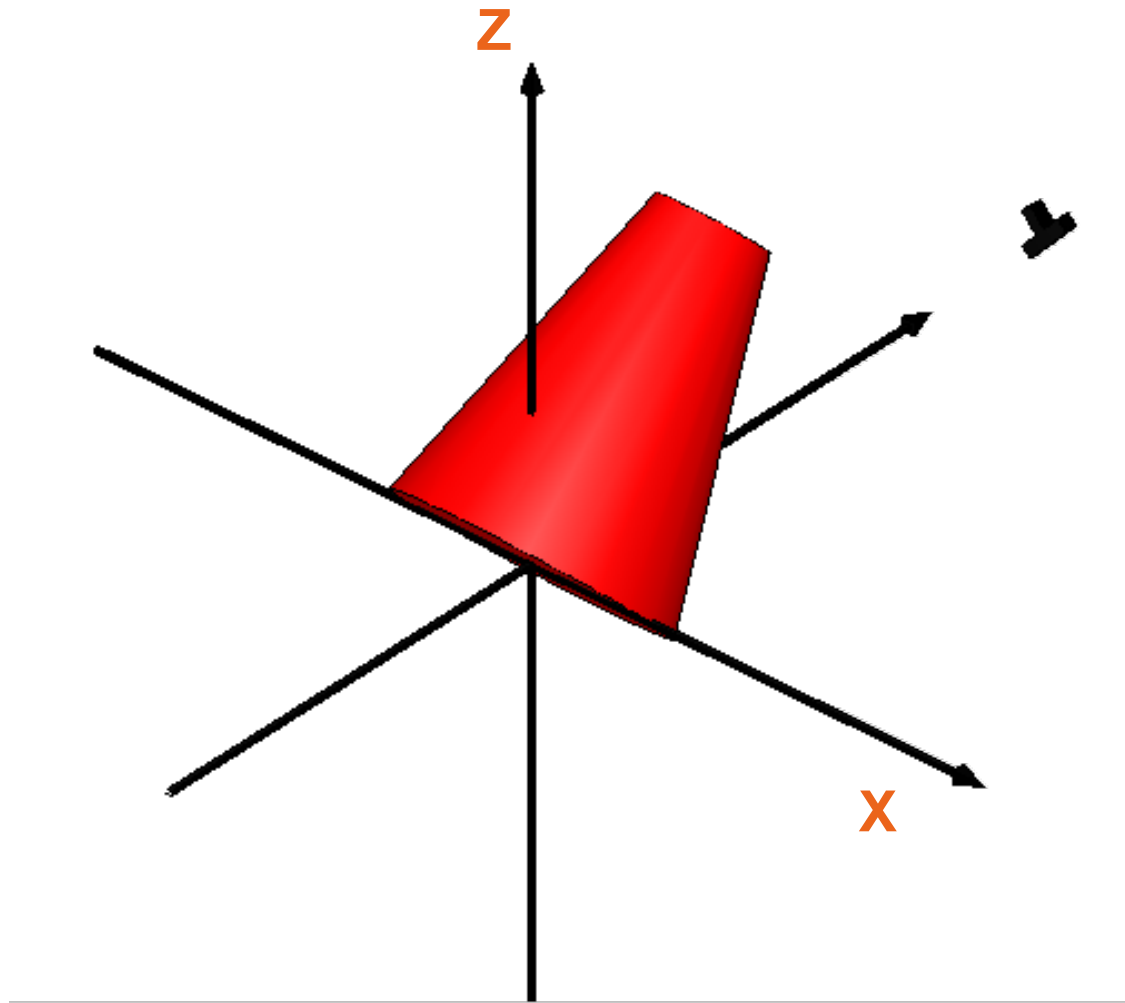
```
read geometry
global unit 1
com='cone'
cone 1    2    12    5    0
media 1 1 1
boundary 1
end geometry
```

Cone rotated to Y-axis



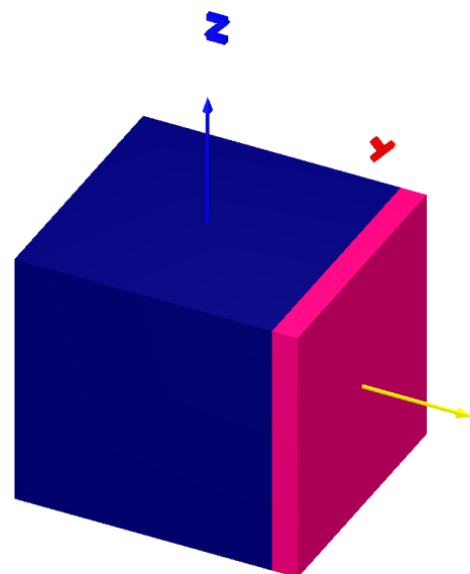
```
read geometry
global unit 1
com='y cone'
cone 1 2 12 5 0
    rotate a2=90
media 1 1 1
boundary 1
end geometry
```

45 ° rotation around X-axis

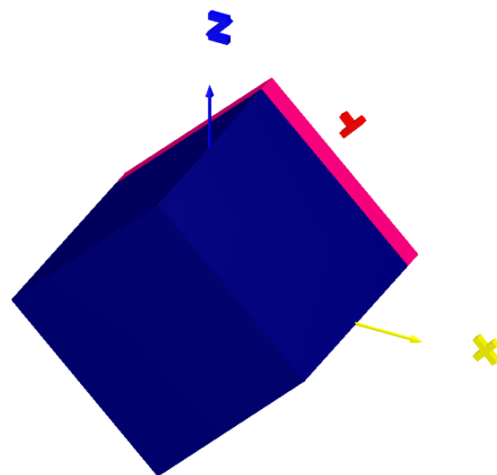


```
read geometry
global unit 1
com='45 deg rotation'
cone 1 2 12 5 0
    rotate a2=-45
media 1 1 1
boundary 1
end geometry
```

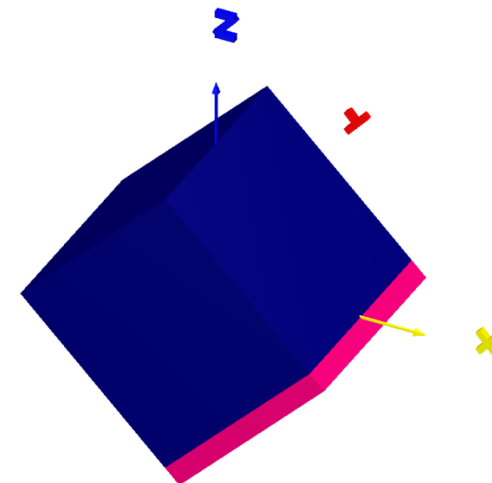
Cuboid examples



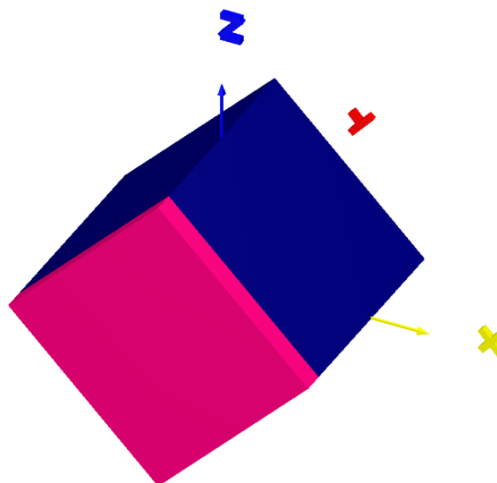
Initial object



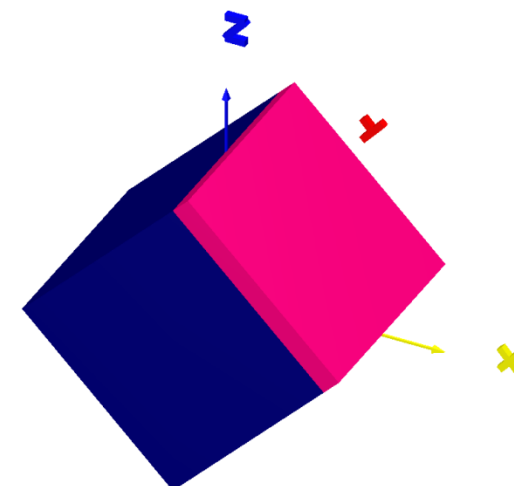
$A1=90$ $A2=45$ $A3=0$



$A1=90$ $A2=45$ $A3=-90$



$A1=-90$ $A2=45$ $A3=0$



$A1=-90$ $A2=45$ $A3=90$

Rotations and CHORDs

unit 1

com='1/4 cylinder'

cylinder 10 9.0 5.0 0 chord +x=0 rotate a1=45

cylinder 20 9.0 5.0 0 chord +x=0 rotate a1=-45

cuboid 30 4p9.0 5.0 0

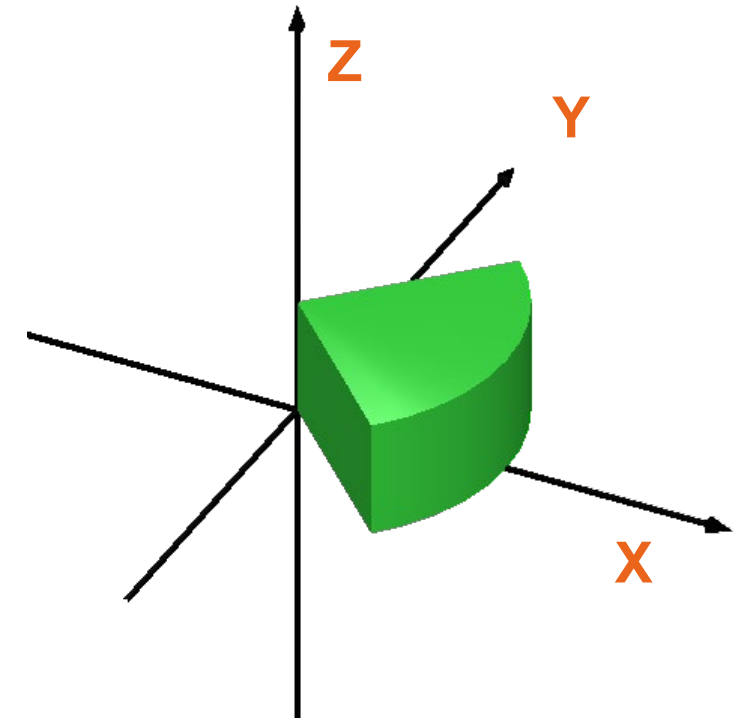
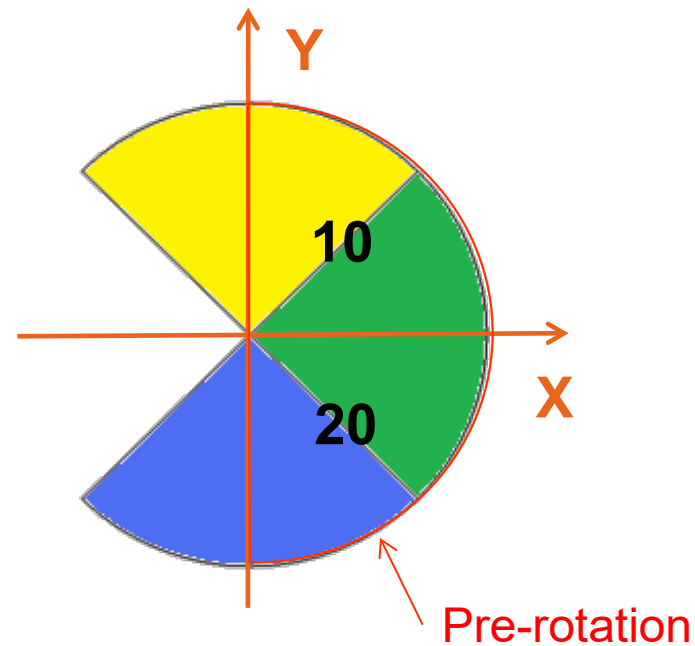
media 1 1 10 20

media 0 1 10 -20

media 0 1 20 -10

media 0 1 30 -10 -20

boundary 30



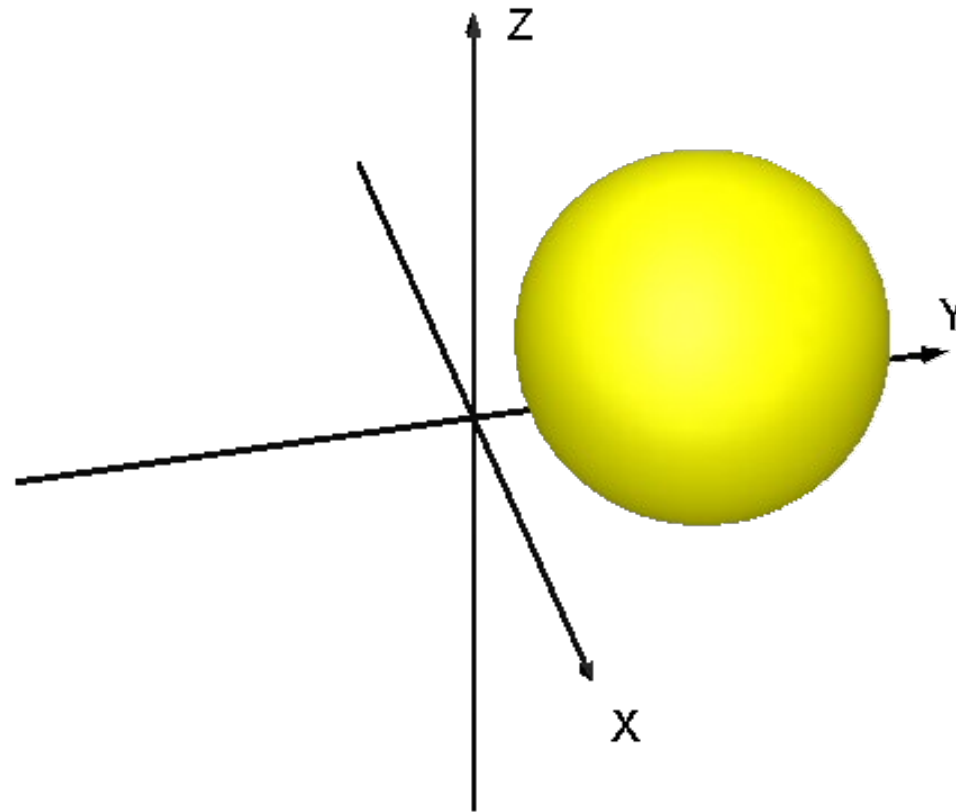
Questions about ROTATE?



ORIGIN data

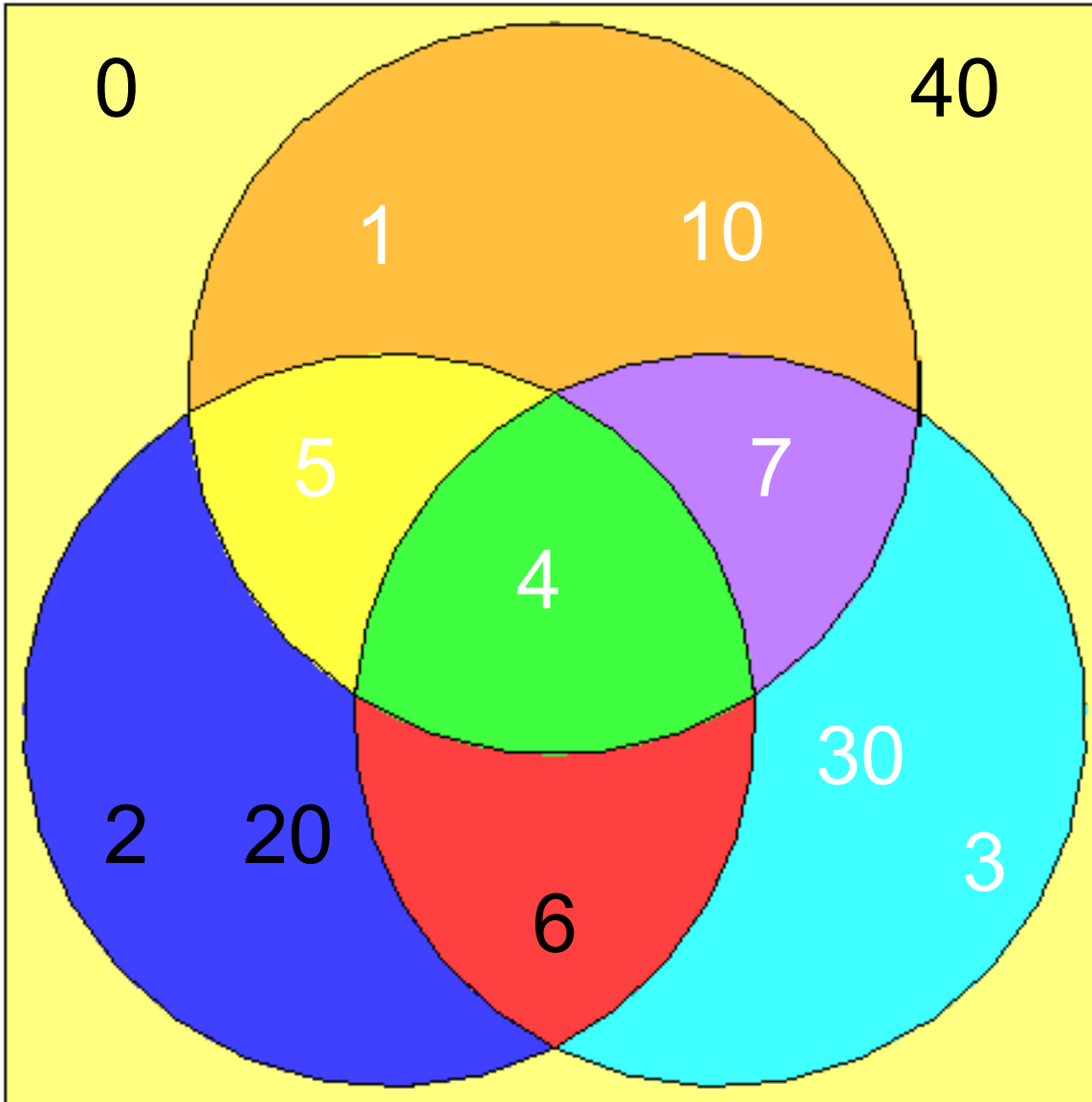
- Translates the origin of a volume to a new specified position
 - Only non-zero data need to be entered
- Applies to the Geometry or Hole record that immediately precedes it
- Contains the following components:
 - ORIGIN keyword
 - Subordinate keywords
X=, Y=, Z=

ORIGIN example



SPHERE 1 10.0 ORIGIN X=10.0 Y=10.0 Z=10.0

Three intersecting spheres



global unit 1

sphere 10 10.0 origin z=4.5

sphere 20 10.0 origin y=-4.5 z=-4.5

sphere 30 10.0 origin y=4.5 z=-4.5

cuboid 40 6p15.0

media 1 1 10 -20 -30

media 2 1 20 -10 -30

media 3 1 30 -10 -20

media 4 1 10 20 30

media 5 1 10 20 -30

media 6 1 20 30 -10

media 7 1 10 30 -20

media 0 1 40 -10 -20 -30

boundary 40

Questions about ORIGIN?

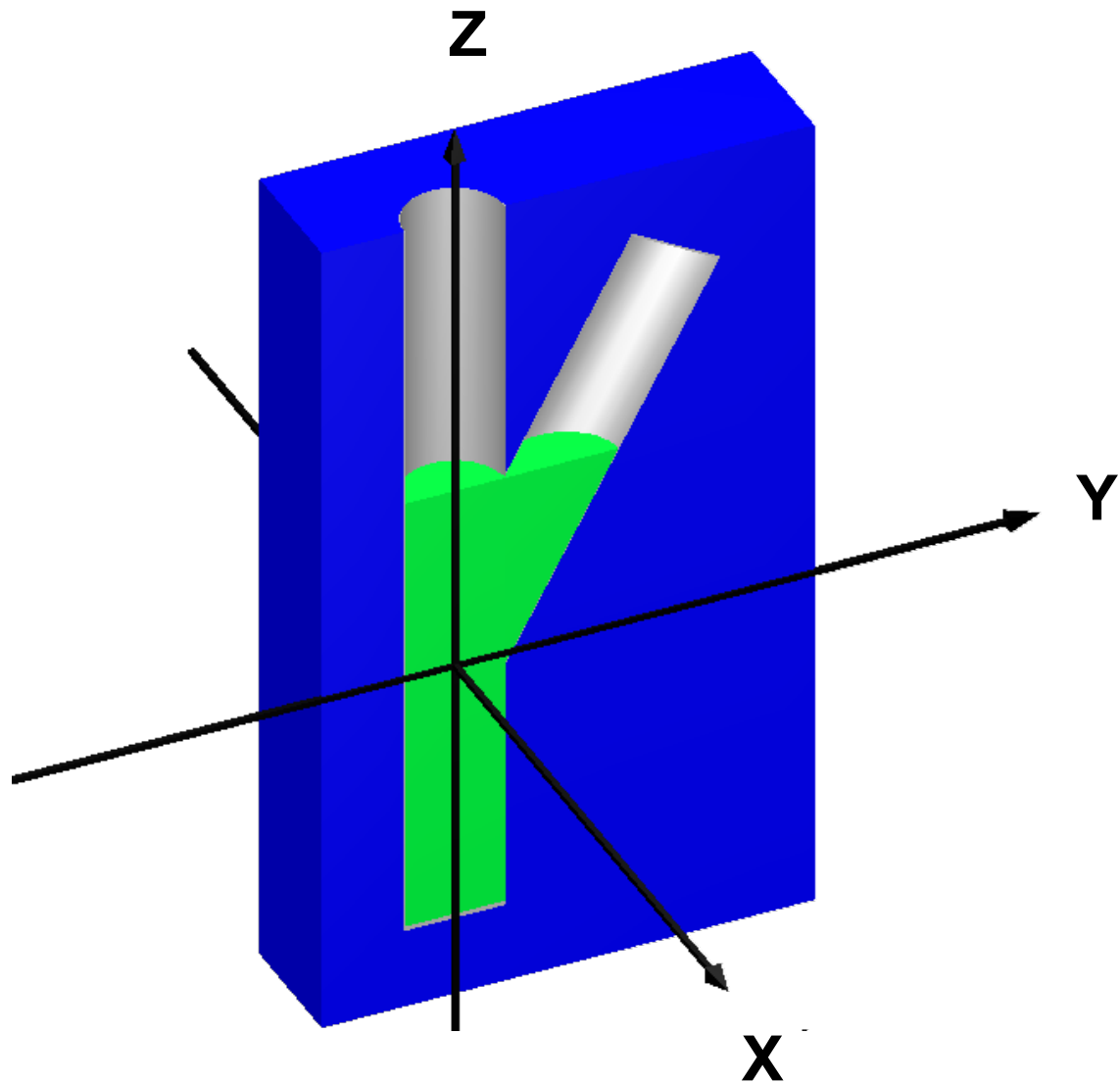


Demo: Geometry modification data

- Y30



Y30



UO₂F₂ solution

specific gravity 2.0289

907.01 g U/l

Enrichment:

U-235 5.0 %

U-238 95.0 %

Aluminum Y-Pipe

(Dimensions taken from center of Y intersection)

13.95 cm inner radius

14.11 cm outer radius

1.30 cm bottom thickness

Side leg at 29.26° angle from vertical

Top of vertical pipe: 135.4 cm

Bottom of vertical pipe: -76.7 cm

Side leg length: 126.04 cm

Side leg sealed top: 0.64 cm thick

UO₂F₂ Solution Height: 52.8 cm

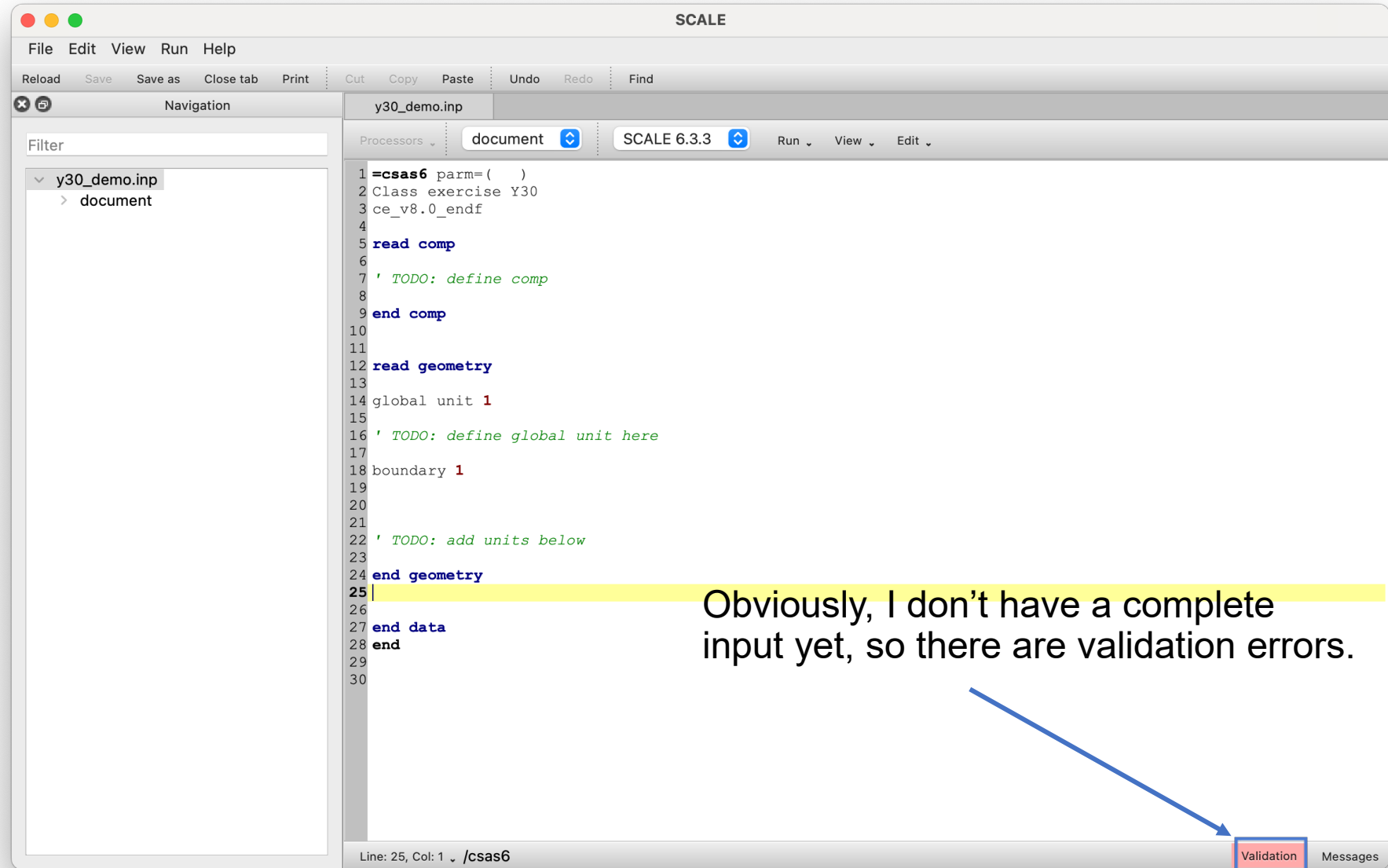
Water Reflector

+X = 37.0 cm; -X = -37.0 cm

+Y = 100.0 cm; -Y = -37.0 cm

+Z = 135.4 cm; -Z = -99.6 cm

General problem data



Create UO_2F_2 solution

```
5 read composition
6 solution mix=1 rho[uo2f2]=907.01 92235 5 92238 95
7           density=2.0289 temperature=293 vol_frac=1
8   end solution
9
```

Create Al and H₂O compositions

```
8  al      2  1  293  end
9  h2o     3  1  293  end
10 end composition
11
```

Create Geometry records

1. Inside of vertical pipe
2. Vertical pipe wall
3. Inside of angled pipe
4. Angled pipe wall
5. Z-plane for level of solution
6. Cuboid for water reflector

```
14 global unit 1
15 cylinder 10 13.95 135.4 -75.4
16 cylinder 20 14.11 135.4 -76.7
17 cylinder 30 13.95 125.4 0 rotate a2=-29.26
18 cylinder 40 14.11 126.04 0 rotate a2=-29.26
19 plane 50 zpl=-1 con=52.8
20 cuboid 60 37 -37 100 -37 135.4 -99.6
21
```

Create Media records

1. Solution in vertical pipe
2. Vertical pipe wall
3. Solution in angled pipe
4. Angled pipe wall
5. Void in vertical pipe
6. Void in angled pipe
7. Water reflector

```
21 ,
22 media 1 1 10 50
23 media 2 1 20 -10 -30
24 media 1 1 30 -10 50
25 media 2 1 40 -30 -20
26 media 0 1 10 -50
27 media 0 1 30 -50 -10
28 media 3 1 60 -40 -20
29
```

Create Boundary record

```
12 read geometry
13
14 global unit 1
15 cylinder 10 13.95 135.4 -75.4
16 cylinder 20 14.11 135.4 -76.7
17 cylinder 30 13.95 125.4 0 rotate a2=-29.26
18 cylinder 40 14.11 126.04 0 rotate a2=-29.26
19 plane 50 zpl=-1 con=52.8
20 cuboid 60 37 -37 100 -37 135.4 -99.6
21 '
22 media 1 1 10 50
23 media 2 1 20 -10 -30
24 media 1 1 30 -10 50
25 media 2 1 40 -30 -20
26 media 0 1 10 -50
27 media 0 1 30 -50 -10
28 media 3 1 60 -40 -20
29 '
30 boundary 60
31 end geometry
32
```

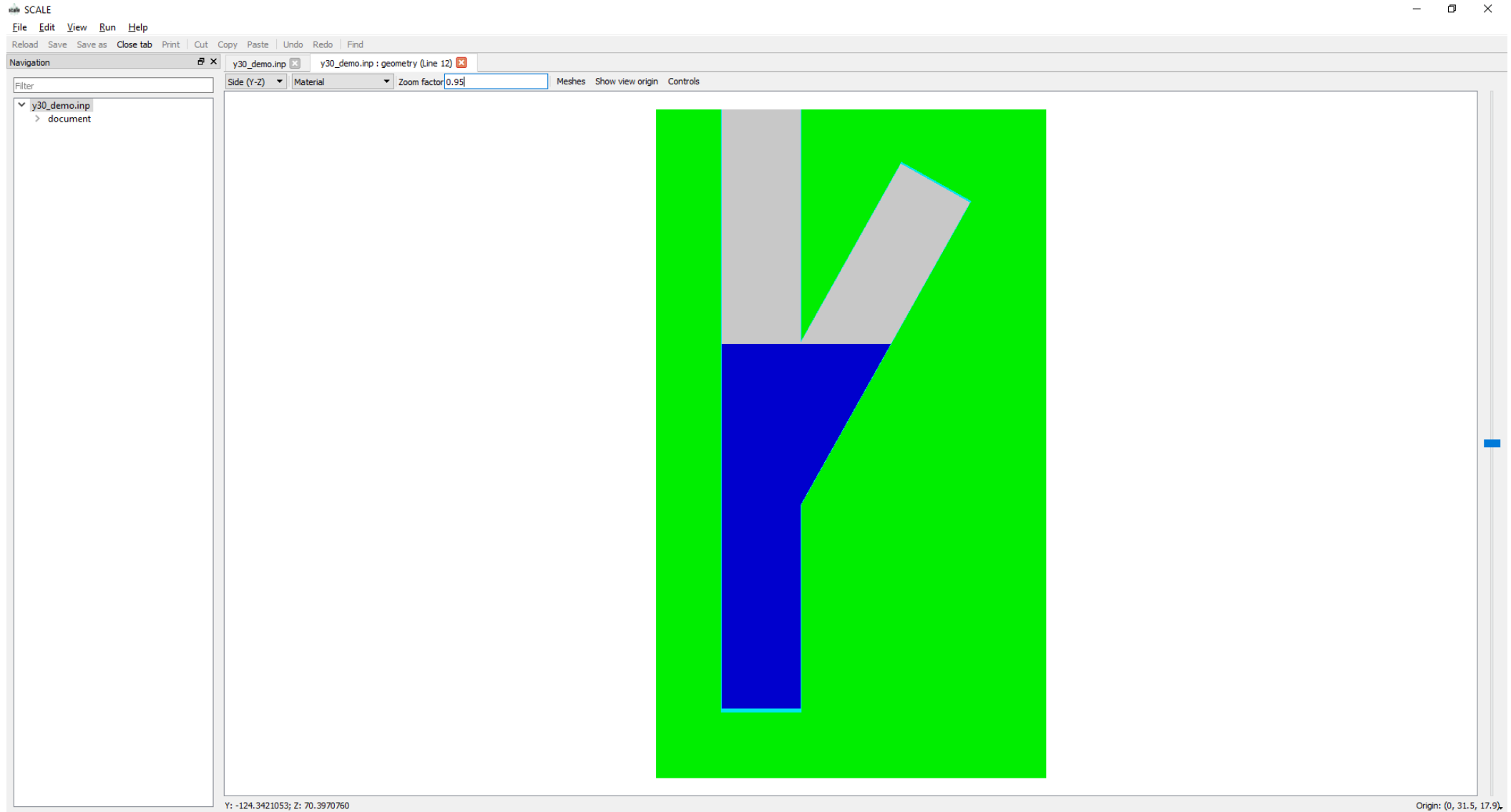
End Geometry block and input

```
read geom
global unit 1
cylinder 10 13.95 135.4 -75.4
cylinder 20 14.11 135.4 -76.7
cylinder 30 13.95 125.4 0 rotate a2=-29.26
cylinder 40 14.11 126.04 0 rotate a2=-29.26
plane 50 zpl=-1 con=52.8
cuboid 60 37 -37 100 -37 135.4 -99.6
'

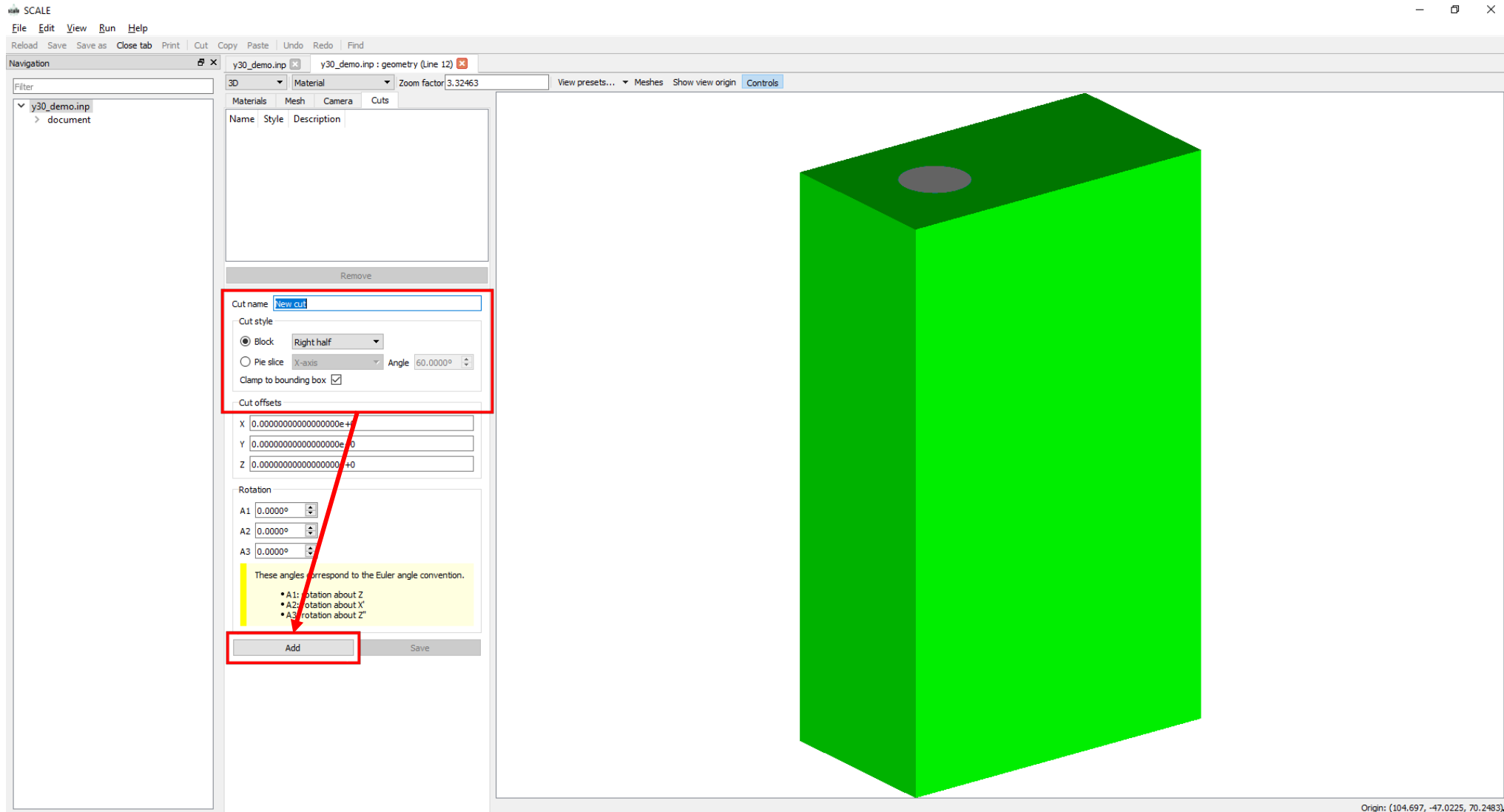
media 1 1 10 50
media 2 1 20 -10 -30
media 1 1 30 -10 50
media 2 1 40 -30 -20
media 0 1 10 -50
media 0 1 30 -50
media 3 1 60 -40 -20
'

boundary 60
end geom
end data
end
```

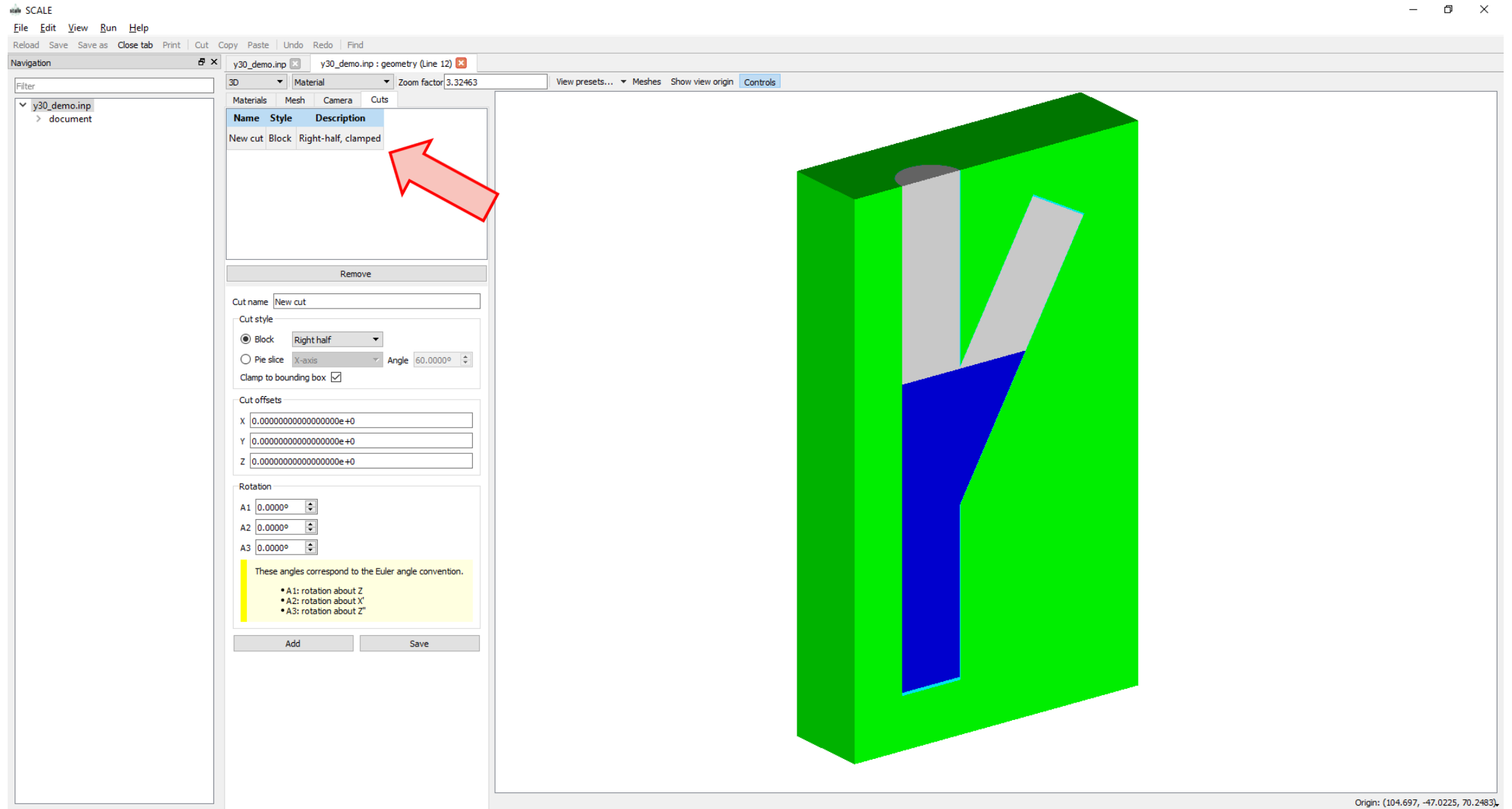
Visualize in Fulcrum: 2D (side)



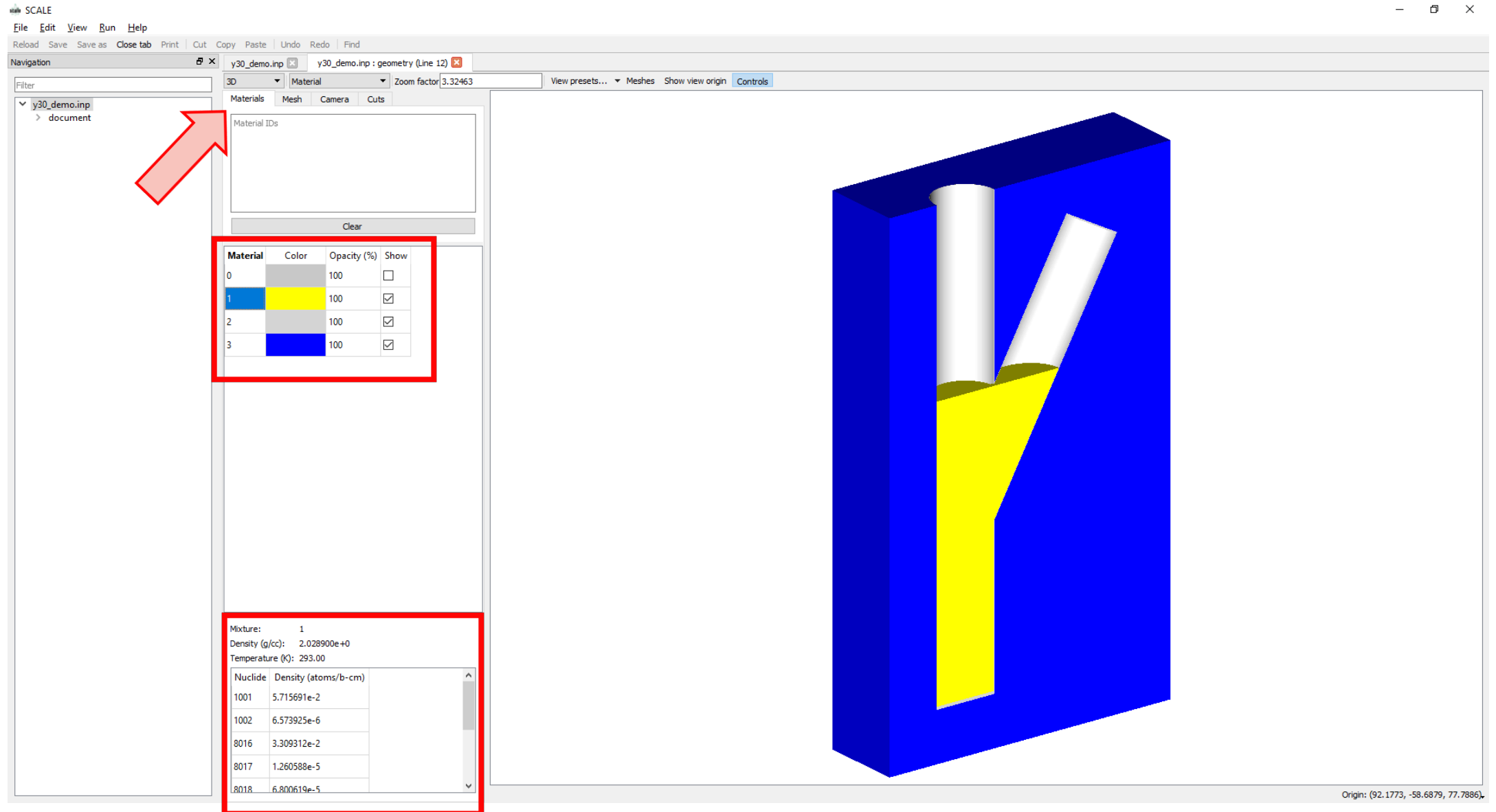
Visualize in Fulcrum: 3D



Visualize in Fulcrum: 3D Part 2



Visualize in Fulcrum: 3D Part 3



Run!

The screenshot displays the SCALE 6.3.3 application window. The interface includes a menu bar (File, Edit, View, Run, Help), a toolbar (Reload, Save, Save as, Close tab, Print, Cut, Copy, Paste, Undo, Redo, Find), and a navigation pane on the left. The navigation pane shows a tree structure with 'K6_y30.inp' selected. The main window displays the input file 'K6_y30.inp' with the following content:

```
1 =csas6 parm=( )
2 Class Exercise: Y30
3 ce_v7.1
4
5 read comp
6 solution mix=1 rho[uo2f2]=907.01 92235 5 92238 95
7 density=2.0289 temperature=293 vol_frac=1
8 end solution
9 al 2 1 293 end
10 h2o 3 1 293 end
11
12 end comp
13
14 read geometry
15
16 global unit 1
17 cylinder 10 13.95 135.4 -75.4
18 cylinder 20 14.11 135.4 -76.7
19 cylinder 30 13.95 125.4 0 rotate a2=-29.26
20 cylinder 40 14.11 126.04 0 rotate a2=-29.26
21 plane 50 zpl=-1 con=52.8
22 cuboid 60 37 -37 100 -37 135.4 -99.6
23
24 media 1 1 10 50
25 media 2 1 20 -10 -30
26 media 1 1 30 -10 50
27 media 2 1 40 -30 -20
28 media 0 1 10 -50
29 media 0 1 30 -50 -10
30 media 3 1 60 -20 -40
31
32 boundary 60
33 end geometry
34 end data
35 end
```

Below the input file, the output window shows the results of the simulation. The output includes a table of results for the class exercise 'Y30' and a final results table. The table of results shows the following data:

Line	Col	1	2	3	4	5	6	7
536	201	1.00686E+00	1.00401E+00	1.85703E-03	3.12646E+00	7.63035E-01		
538	202	1.04248E+00	1.00421E+00	1.85936E-03	3.08561E+00	7.67167E-01		
540	203	9.93659E-01	1.00415E+00	1.84509E-03	3.13061E+00	7.70667E-01		

The final results table shows the following data:

Line	Col	1	2	3	4	5	6	7
544	class exercise: y30							
545	***** final results table							
546	best estimate system k-eff	1.0052						
547								
548	Energy of average lethargy of Fission (eV)	5.26154E-02						
549	k-effective satisfies the chi**2 test for normality at the 95 % level							

At the bottom of the output window, a message states: 'Scale job /Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/class_exercises/K6_Y30/K6_y30.inp is finished. Output is stored in /Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/class_exercises/K6_Y30/K6_y30.out'. Two red arrows point to the 'final results table' and the 'Scale job' message.

Exercises for Sub-Module 2

- KENO-VI geometry exercises for geometry modification data
 - Set 1: Hopper and cross



Hopper filled with UO_2 powder

Top section of hopper

SS304

Inside dimensions:

91.44 x 91.44

138.43-cm-tall

Top and walls: 0.635-cm-thick

Reducer section of hopper

SS304 – 0.635-cm-thick

Top inside : 91.44 x 91.44

Bottom inside: 20.32 x 20.32

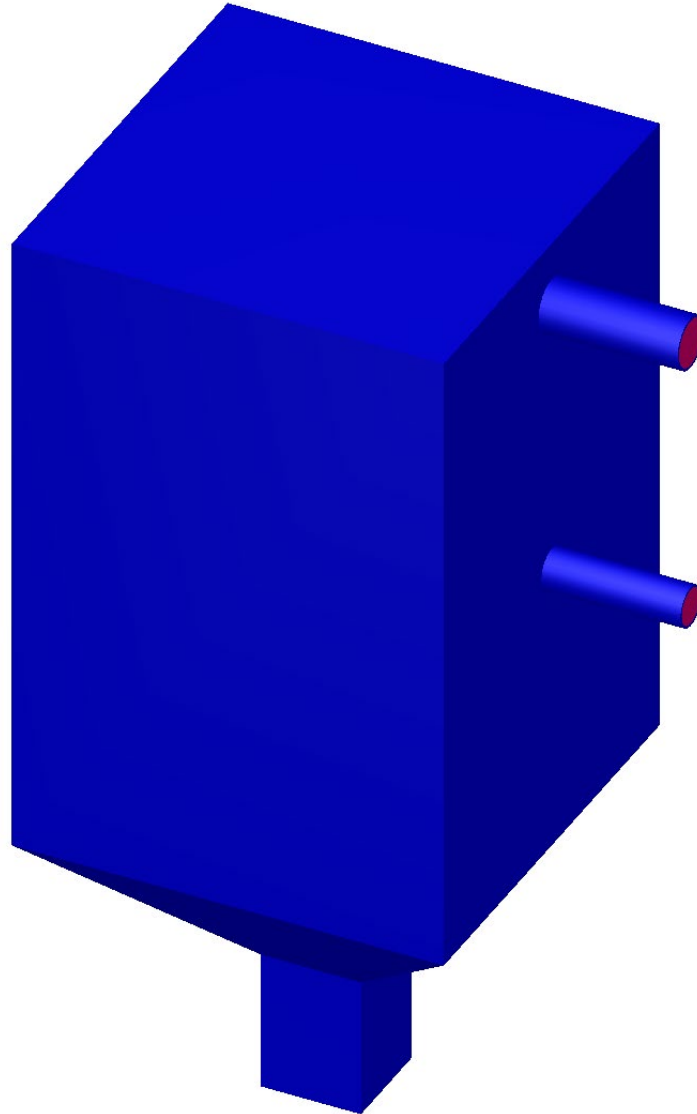
Length: 35.8775

Bottom section of hopper

SS304 – 0.635-cm-thick

Inside: 20.32 x 20.32

30.48-cm-tall



Top side pipe

SS304

Outer diameter: 11.43

Wall thickness: 0.60198

Center is 13.97 cm from the top
of the top hopper section

Length: 30.48 cm

Bottom side pipe

SS304

Outer diameter: 8.89

Wall thickness: 0.54864

Center is 60.96 cm from
center of top pipe

Length: 30.48 cm

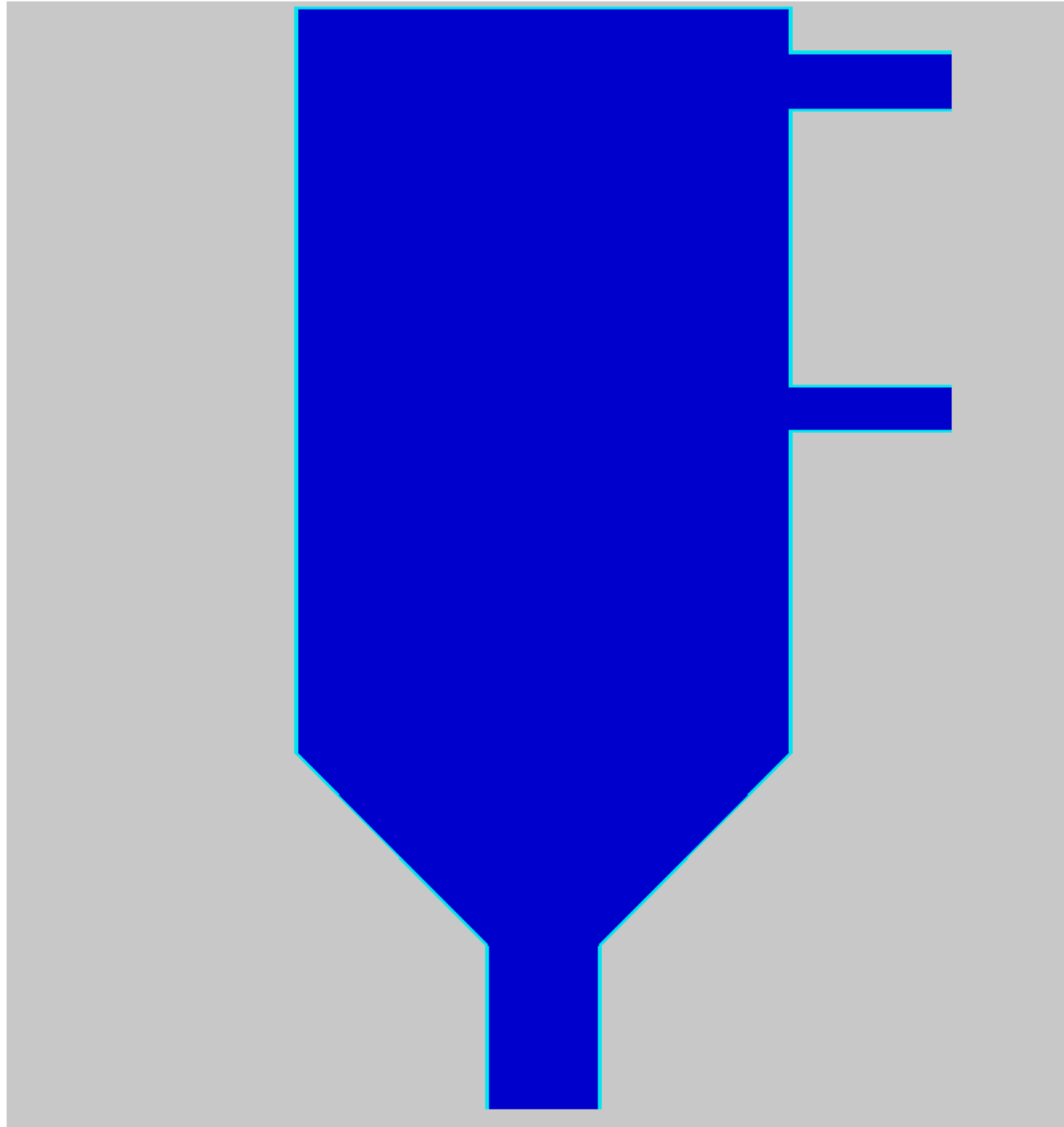
UO_2 Powder

1.5 wt% U-235

98.5 wt% U-238

Density: 2.1 g/cc

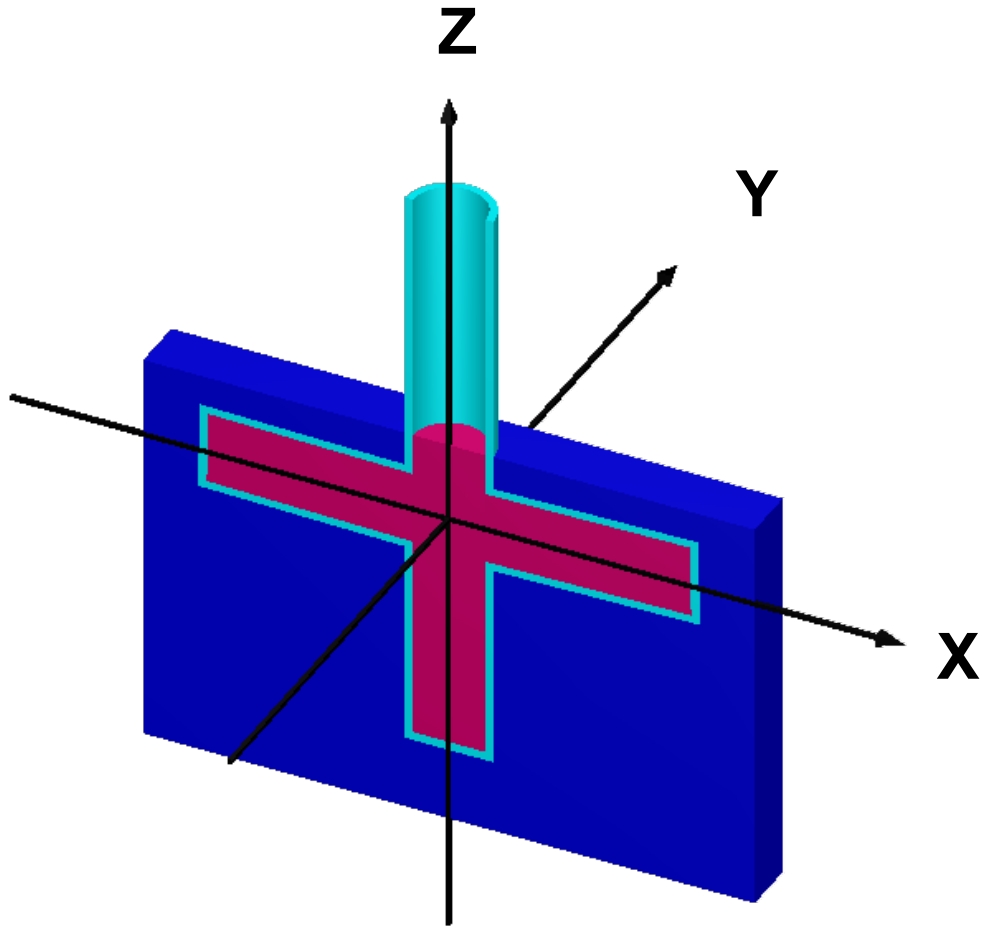
Side view



Notes:

- No internal obstructions to powder flow
- Steel around the outside except for the bottom surface and outer side of both pipes

Cross



UO₂F₂ solution

specific gravity 2.0150

896.1 g U/l

Enrichment:

U-235 5.0 %

U-238 95.0 %

Plexiglas cross

(Dimensions taken from center of cross intersection)

13.335 cm inside radius

3.17 cm thick ends

2.855 cm thick walls

2 side and bottom legs are 91.44 cm long from center to outer surface

Side legs at 89 degree angle from vertical

Top leg is 121.92 cm long

UO₂F₂ solution height 28.93 cm

Water reflector thickness

+X = 111.74 cm; -X = -111.74 cm

+Y = 20.64 cm; -Y = -20.63 cm

+Z = 29.03 cm; -Z = -118.428 cm

Calculated k_{eff} values

	KENO-VI	Shift
Hopper	0.16369 +/- 0.00051	0.163801 +/- 0.000596
Cross	1.0065 +/- 0.0018	1.006680 +/- 0.002980

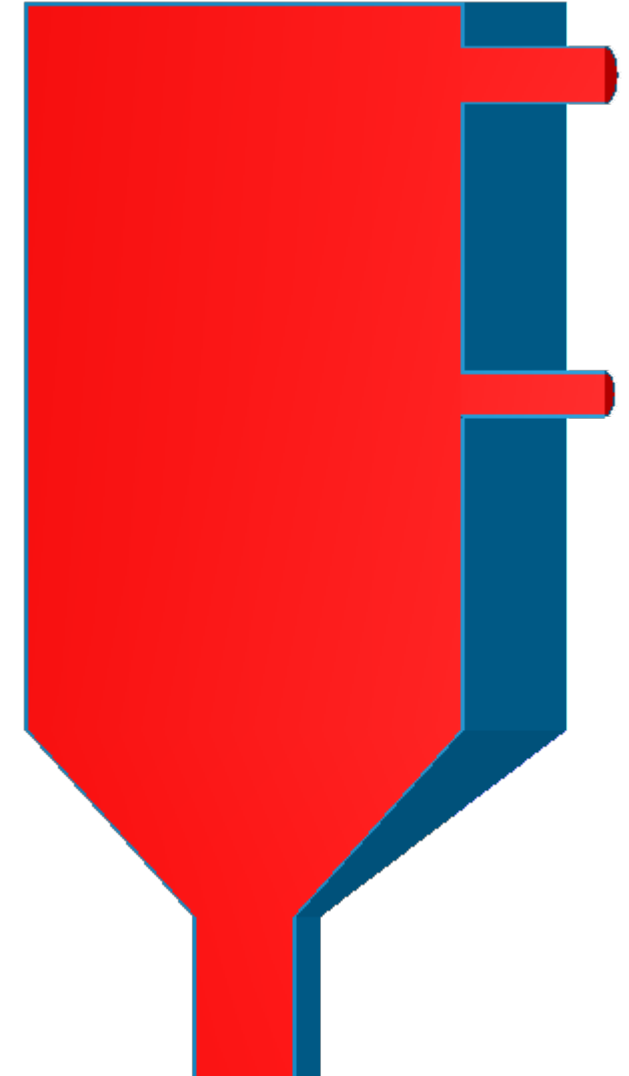
Your results may differ based on the options and computer used

Hopper with UO₂ powder

```
=csas6
hopper
ce_v7.1_endf
read composition
  uo2          1 den=2.1 1 293      92235 1.5      92238 98.5      end
  ss304        2 end
end composition
```

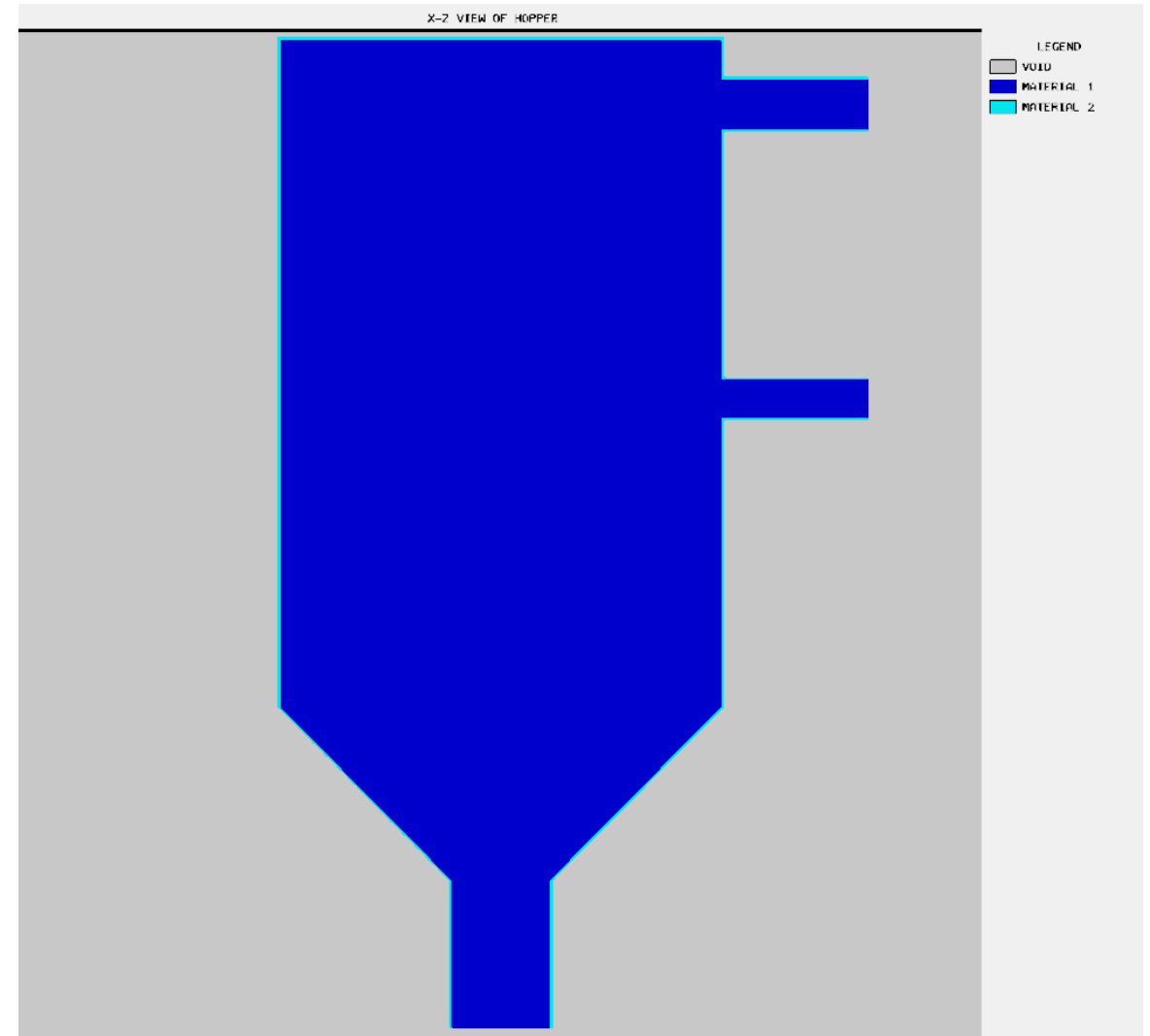
Hopper with UO₂ powder (cont.)

```
read geometry
global unit 1
com='hopper in 3 sections with 2 pipes'
cuboid 1      45.72   -45.72   45.72   -45.72   138.43      0
cuboid 2      46.355  -46.355  46.355  -46.355  139.065      0
hopper 11      45.72    45.72      0    10.16    10.16   -35.8775
hopper 12      46.355   46.355      0    10.795   10.795   -35.8775
cuboid 21      10.16   -10.16    10.16   -10.16   -35.8775   -66.3575
cuboid 22      10.795  -10.795   10.795  -10.795   -35.8775   -66.3575
xcylinder 31     5.113    76.2    45.72  origin  z=125.095
xcylinder 32     5.715    76.2    45.72  origin  z=125.095
xcylinder 41     3.896    76.2    45.72  origin  z=64.135
xcylinder 42     4.444    76.2    45.72  origin  z=64.135
cuboid 50      100     -100     100     -100     140      -70
```



Hopper with UO_2 powder (cont.)

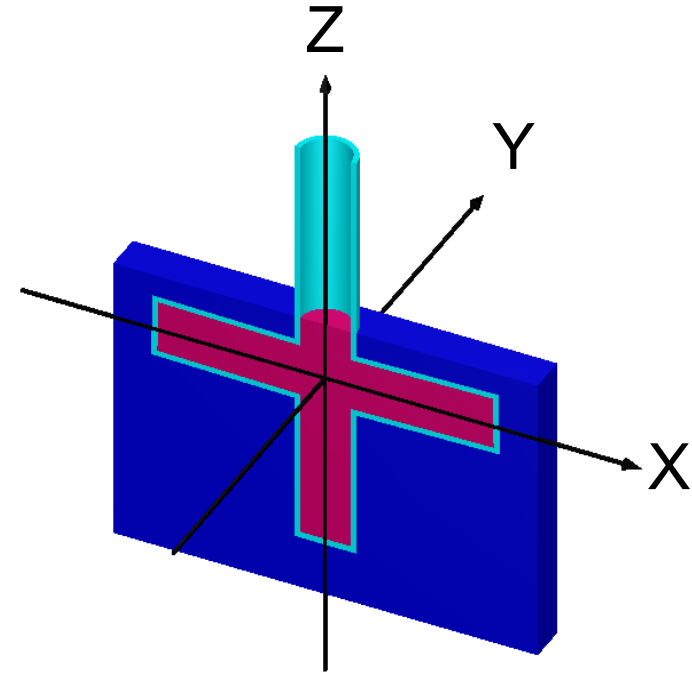
```
media 1 1 1
media 1 1 11
media 1 1 21
media 1 1 31
media 1 1 41
media 2 1 2 -1 -32 -42
media 2 1 12 -11
media 2 1 22 -21
media 2 1 32 -31
media 2 1 42 -41
media 0 1 50 -2 -12 -22 -32 -42
boundary 50
end geometry
end data
end
```



Cross

```
=csas6
kenovi 89 deg cross 5% uo2f2 soln, plexiglass pipes, h2o refl.
ce_v7.1_endf
read composition
  solution    mix=1    rho[uo2f2]=896.1    92235 5    92238 95
              density=2.015
    end solution
  h2o          2 end
  plexiglass   3 end
end composition
```

Cross (cont.)

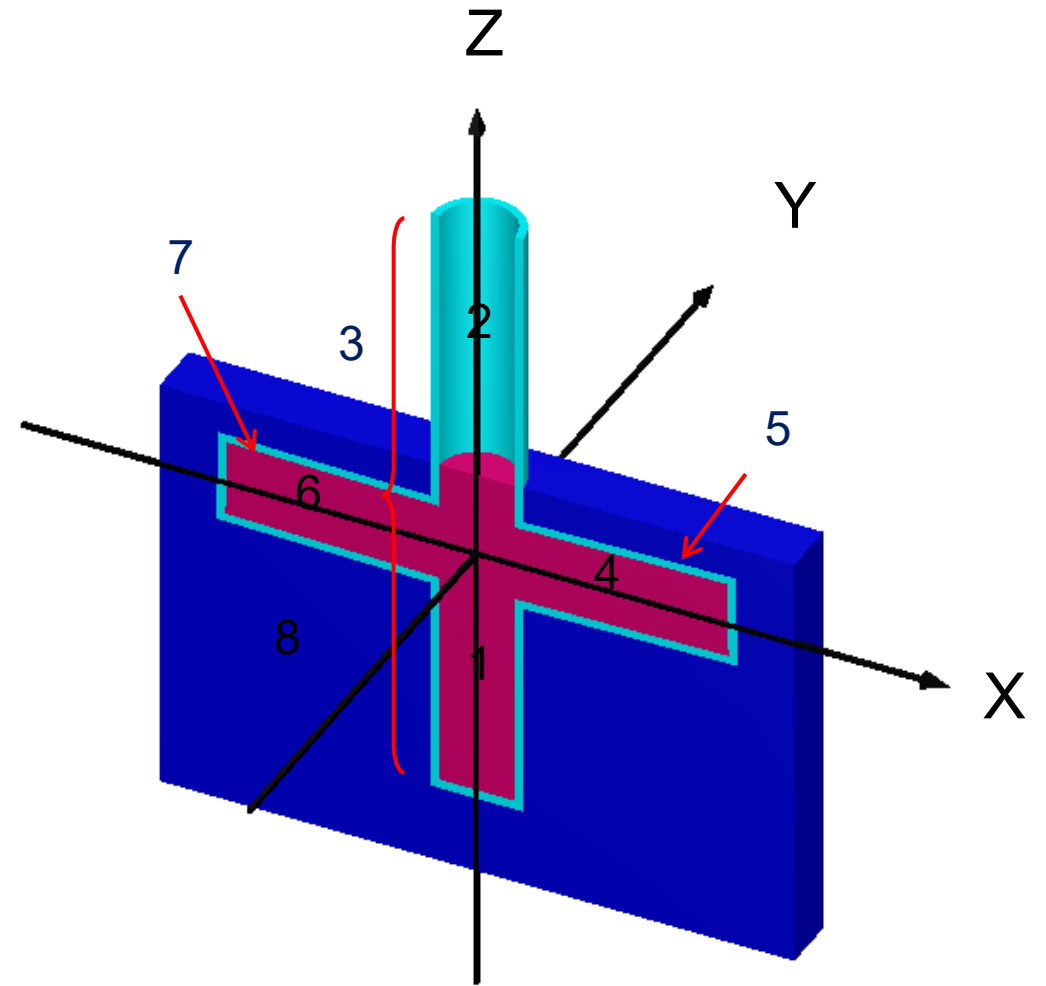


```

read geometry
global unit 1
cylinder 10    13.335    28.93    -88.27
cylinder 20    13.335    121.92   -88.27
cylinder 30    16.19     121.92   -91.44
cylinder 40    13.335    88.27     0    rotate    a1=90    a2=89    a3=0
cylinder 50    16.19     91.44     0    rotate    a1=90    a2=89    a3=0
cylinder 60    13.335    88.27     0    rotate    a1=-90   a2=89    a3=0
cylinder 70    16.19     91.44     0    rotate    a1=-90   a2=89    a3=0
cuboid 80      111.74    -111.74    20.64    -20.64    29.03    -118.428
cuboid 90      111.74    -111.74    20.64    -20.64    121.92    -118.428
    
```

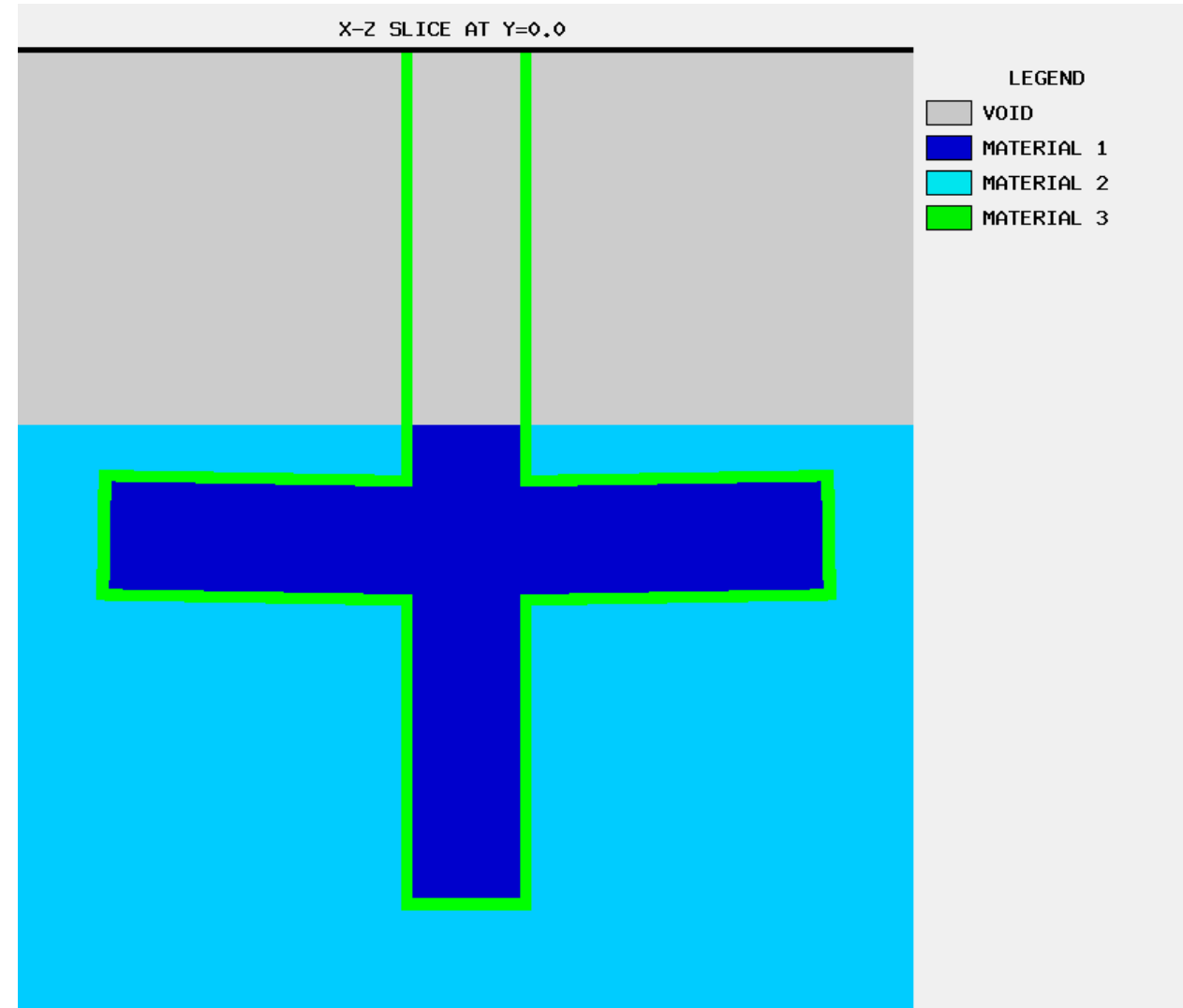
Cross (cont.)

```
media 1 1 10
media 0 1 20 -10
media 3 1 30 -20 -50 -70
media 1 1 40 -20
media 3 1 50 -40 -20
media 1 1 60 -20
media 3 1 70 -60 -20 -50
media 2 1 80 -30 -50 -70
media 0 1 90 -30 -80
boundary 90
end geometry
```



Cross (cont.)

```
read plot
  ttl=' x-z slice at y=0.0 '
  xul=-111  yul=0  zul=121
  xlr=111    ylr=0  zlr=-118
  nax=640  typ=xz  end
end plot
end data
end
```



Summary of Sub-Module 2

- Overview of modification options and syntax
- Geometry modifications are always performed sequentially; first "chord", then "rotate", and then "origin"
- Y30 example, Hopper and Cross exercises

Sub-Module 3

- HOLES in KENO-VI



Contents record types

- Specifies the contents of a volume defined relative to the Geometry records in that unit
- Three types of contents records
 1. **Media**: places a mixture in the specified volume
 2. **Hole**: places a previously defined unit at the specified position
 3. **Array**: places an array in the specified volume

Contents records

Keyword	Contents Record Input
MEDIA	Mixture Number Bias ID Number Region Definition Vector Discussed previously in the geometry lecture
HOLE	Unit number Keywords ORIGIN and ROTATE, if desired
ARRAY	Array Number Region Definition Vector Keyword PLACE followed by the X, Y, Z position of the unit used to place the array and the X, Y, Z coordinates of the unit with respect to the origin of the outer region Will be discussed in the next lecture

HOLE contents record

- Used to place a unit into a different unit
- Consists of the following components:
 - HOLE Keyword
 - Unit ID number placed in HOLE
 - Modification data (ORIGIN, ROTATE) used to place the origin of the unit being inserted to the desired position and orientation

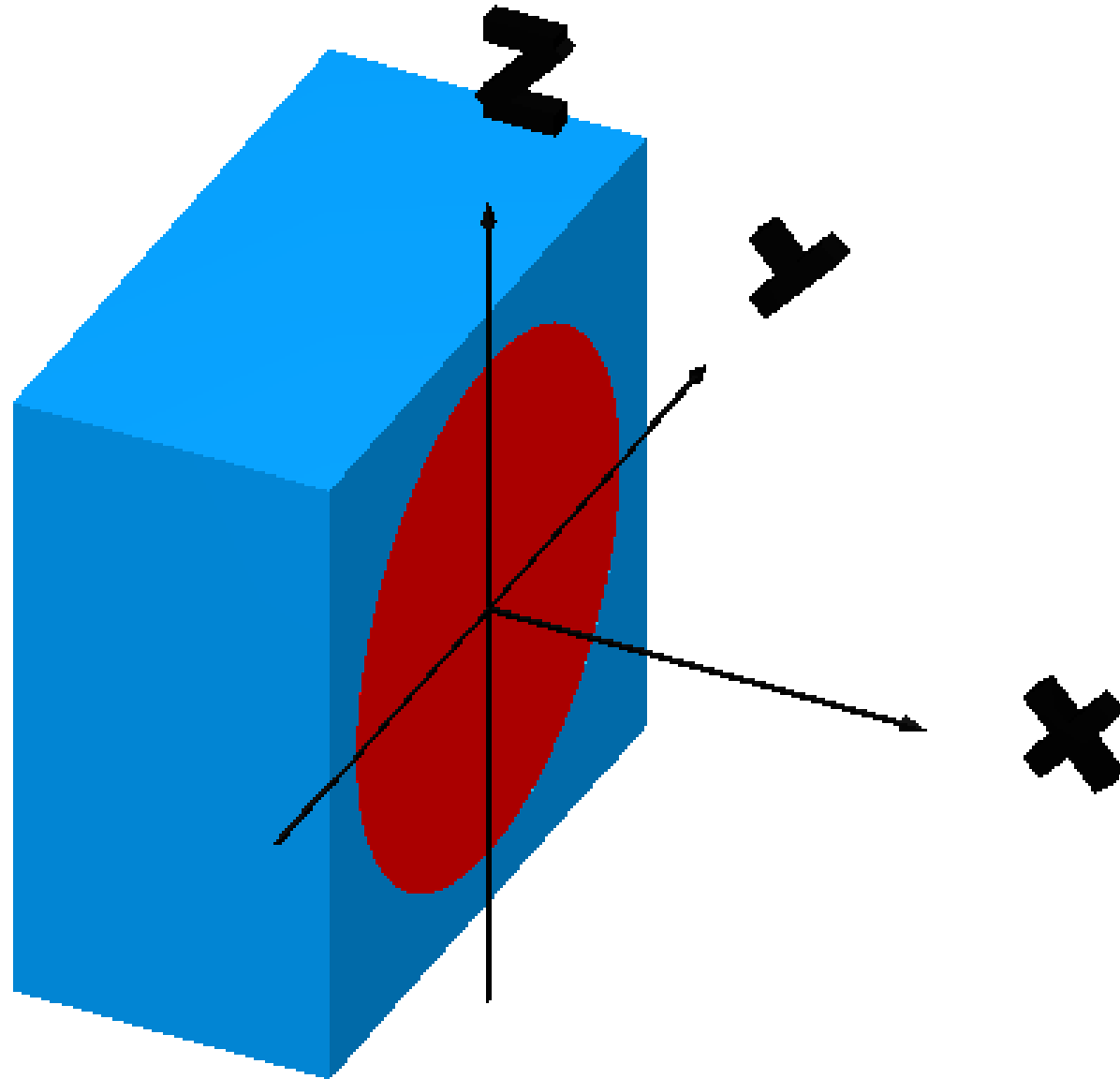
Advantages and disadvantages of HOLES

- Advantages
 - Allows for better modularization of input
 - Can simplify region definition vectors for units
 - Can decrease run time
- Disadvantages
 - Arrays are a better option for repeated structures
 - Depending on viewpoint, adds complexity to input
 - More units, but each unit is simpler

Restrictions on holes

- Holes cannot intersect other holes
 - Two holes may share boundaries
- Holes cannot intersect the boundary of the unit into which they are placed
- Holes may not be truncated by an array boundary
 - We'll come back to this in the next lecture on arrays...
- All geometry labels on the boundary record of the unit being inserted as the hole must be positive
 - The hole must be *inside* the hole boundary
 - This is the reason for the RING shape

Simple HOLE example



read geometry

unit 1

sphere 10 10.0

media 1 1 10

boundary 10

\

global unit 2

cuboid 10 6p12.0

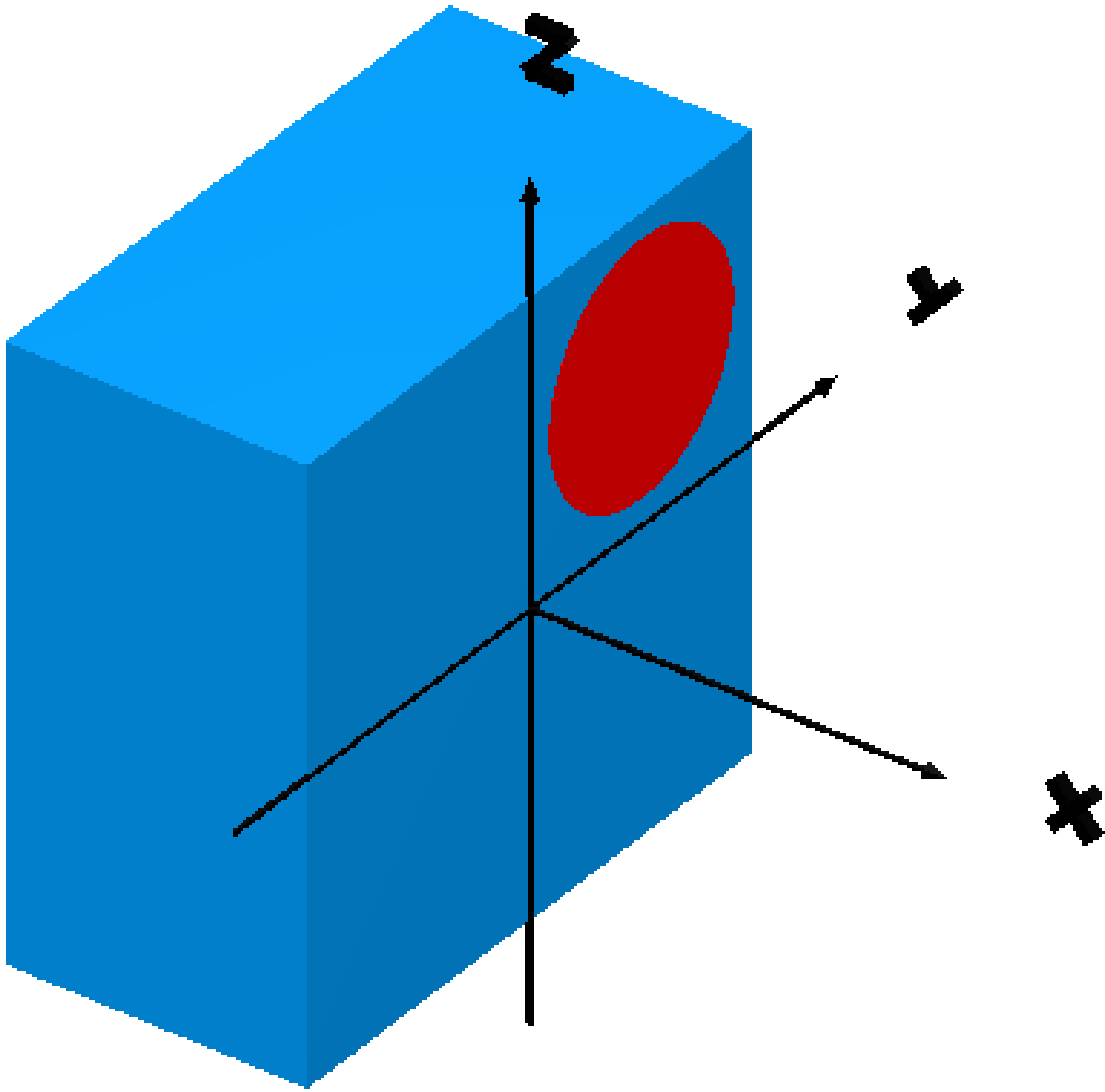
media 2 1 10

hole 1

boundary 10

end geometry

HOLE example with origin



read geometry

unit 1

sphere 10 5.0

media 1 1 10

boundary 10

\

global unit 2

cuboid 10 6p12.0

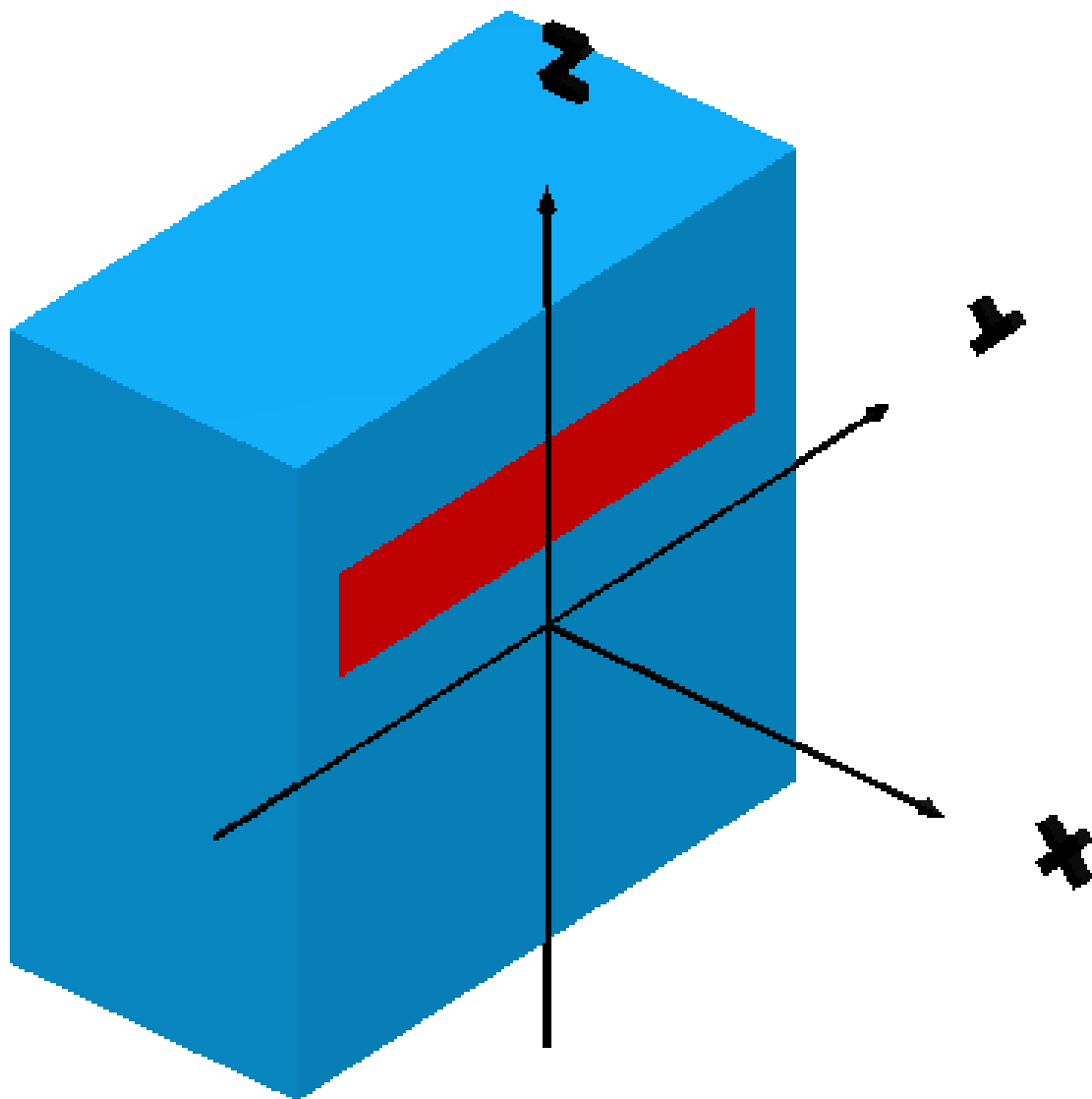
media 2 1 10

hole 1 origin y=6.0 z=6.0

boundary 10

end geometry

HOLE example with rotation



read geometry

unit 1

cylinder 10 2.0 2p10.0

media 1 1 10

boundary 10

\

global unit 2

cuboid 10 6p12.0

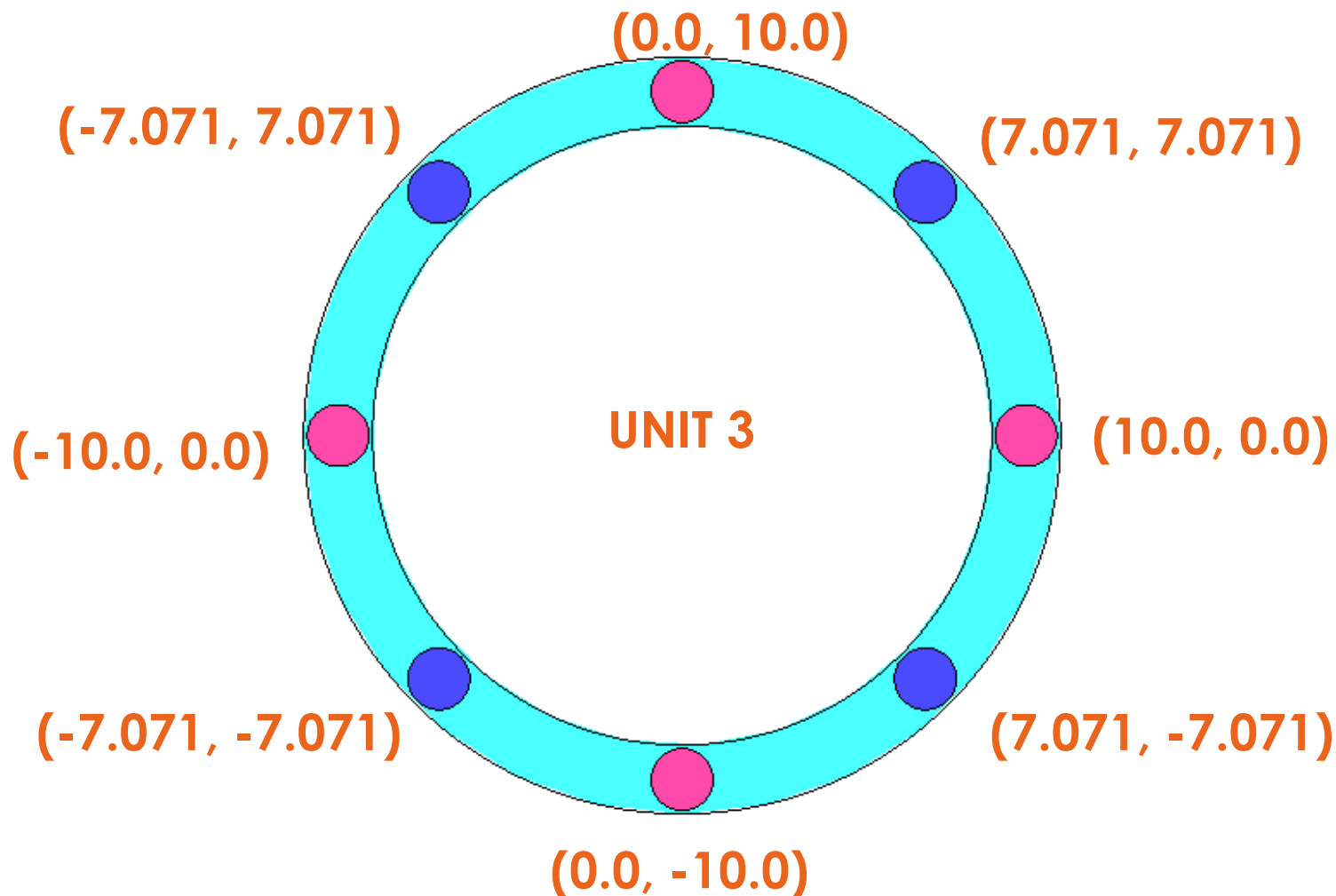
media 2 1 10

hole 1 origin z=5.0 rotate a2=90

boundary 10

end geometry

HOLE placement

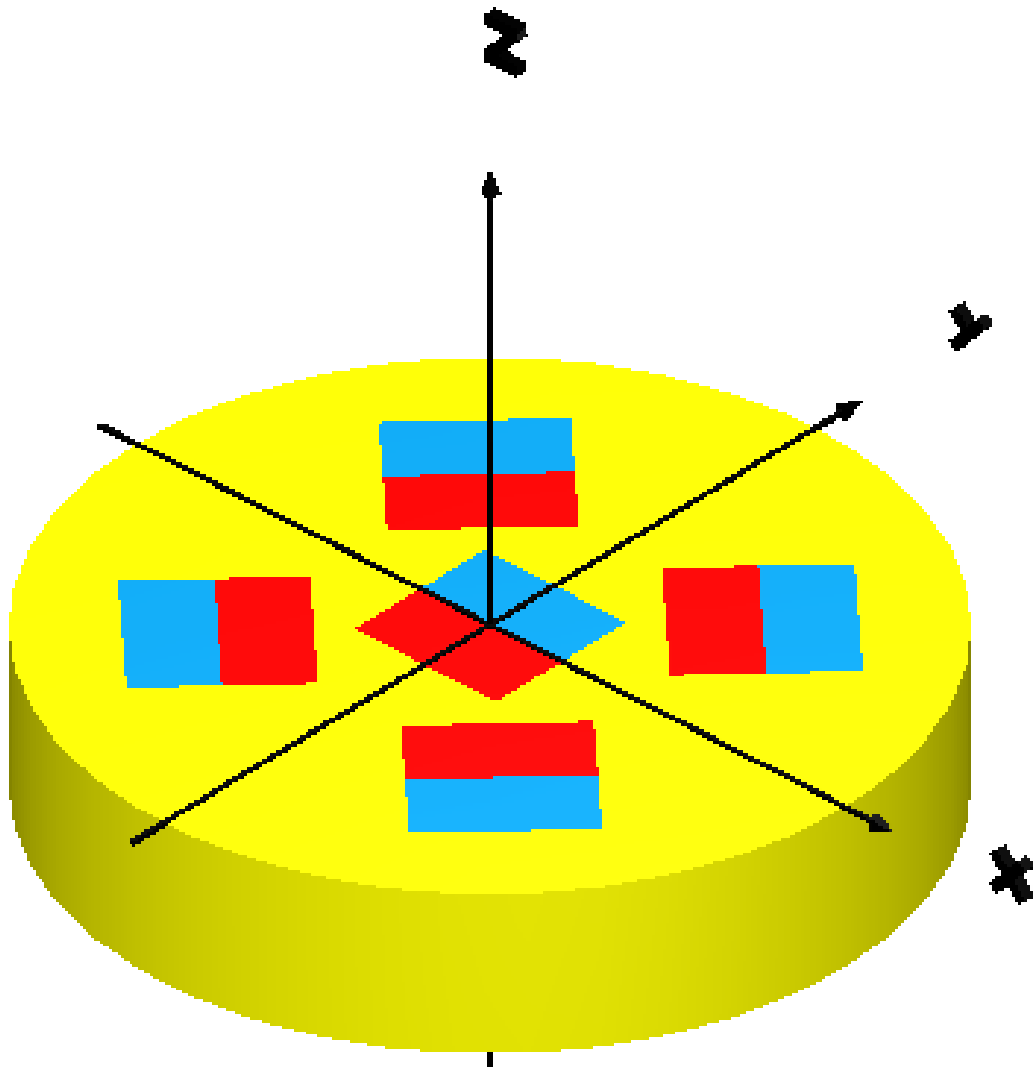


unit 1 ●
cylinder 10 0.9 20.0 0.0
media 1 1 10
boundary 10

unit 2 ●
cylinder 10 0.9 20.0 0.0
media 2 1 10
boundary 10

global unit 3
cylinder 10 9.0 20.0 0.0
cylinder 20 11.0 20.0 0.0
media 0 1 10
media 3 1 20 -10
hole 1 origin x=-10.0 y=0.0
hole 2 origin x=-7.071 y=7.071
hole 1 origin x=0.0 y=10.0
hole 2 origin x=7.071 y=7.071
hole 1 origin x=10.0 y=0.0
hole 2 origin x=7.071 y=-7.071
hole 1 origin x=0.0 y=-10.0
hole 2 origin x=-7.071 y=-7.071
boundary 20

HOLEs with modification data



read geometry

unit 1

cuboid 10 2p6.0 0.0 -6.0 2p10.0

cuboid 20 2p6.0 6.0 -6.0 2p10.0

media 1 1 10

media 2 1 20 -10

boundary 20

global unit 2

cylinder 10 30.0 2p12.0

media 3 1 10

hole 1

hole 1 origin x=12.0 y=12.0 rotate a1=-45

hole 1 origin x=12.0 y=-12.0 rotate a1=-135

hole 1 origin x=-12.0 y=-12.0 rotate a1=135

hole 1 origin x=-12.0 y=12.0 rotate a1=45

boundary 10

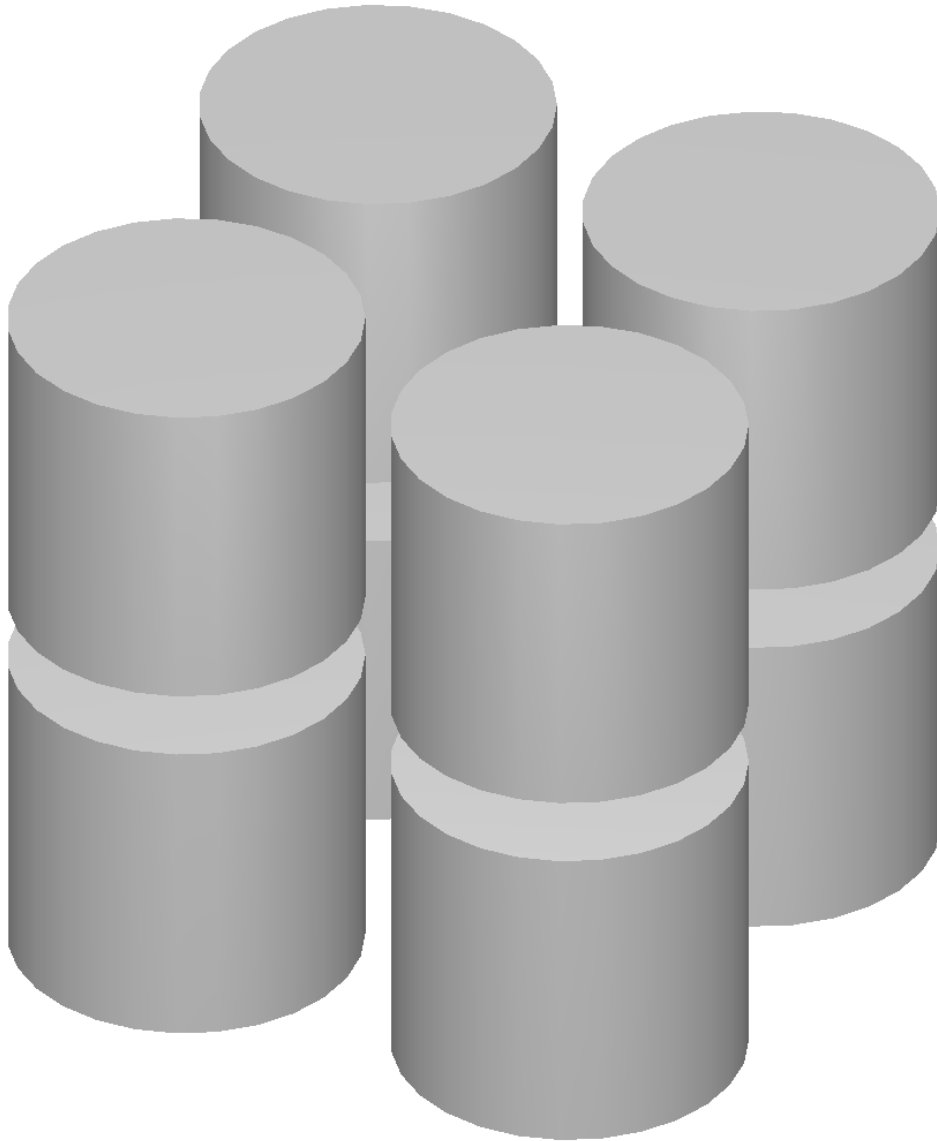
end geometry

Demo: HOLEs

- 2c8 – Take 1



2c8



8 Uranium Cylinders

5.748 cm radius

10.765 cm length

13.74 cm center to center spacing in X and Y dimensions

13.01 cm center to center spacing in Z dimension

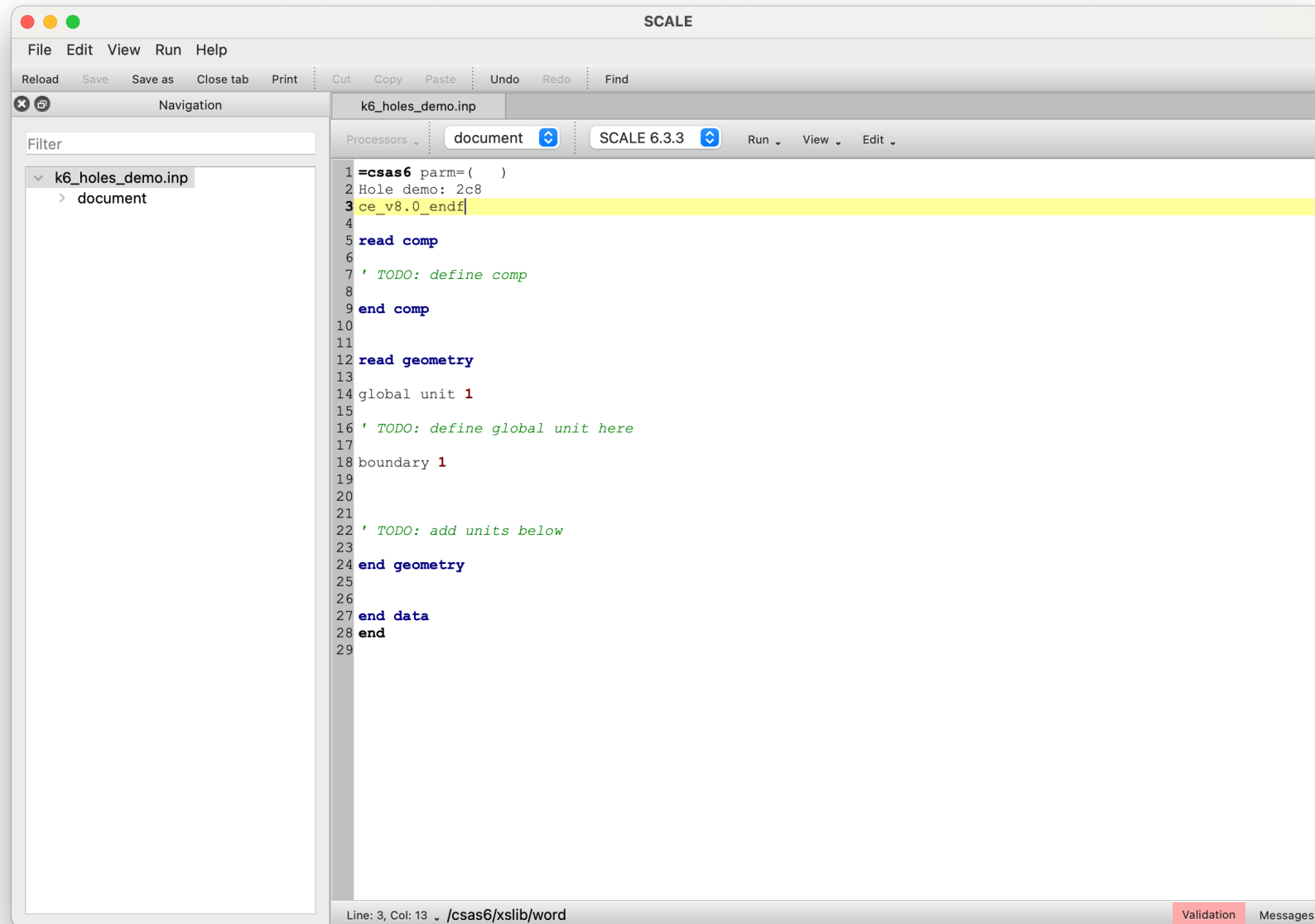
Uranium Metal

Density = 18.764 g / cc

Enrichment:

93.2%	U-235
5.6%	U-238
1.0%	U-234
0.2%	U-236

General problem data



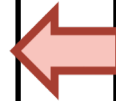
The screenshot displays the SCALE 6.3.3 application window. The title bar reads "SCALE". The menu bar includes "File", "Edit", "View", "Run", and "Help". Below the menu bar is a toolbar with buttons for "Reload", "Save", "Save as", "Close tab", "Print", "Cut", "Copy", "Paste", "Undo", "Redo", and "Find". The main interface is divided into three panes. The left pane, titled "Navigation", shows a tree view with "k6_holes_demo.inp" expanded, revealing a sub-entry "document". The middle pane, titled "k6_holes_demo.inp", shows the text of the input file. The text is as follows:

```
1 =csas6 parm=( )
2 Hole demo: 2c8
3 ce_v8.0_endf
4
5 read comp
6
7 ' TODO: define comp
8
9 end comp
10
11
12 read geometry
13
14 global unit 1
15
16 ' TODO: define global unit here
17
18 boundary 1
19
20
21
22 ' TODO: add units below
23
24 end geometry
25
26
27 end data
28 end
29
```

The right pane is currently empty. At the bottom of the window, a status bar shows "Line: 3, Col: 13" and the file path "/csas6/xslib/word". To the right of the status bar are two buttons: "Validation" and "Messages".

Composition data

```
5 read comp
6 uranium 1 den=18.764000 1.0 293.0
7      92234 1.0
8      92235 93.2
9      92236 0.2
10     92238 5.6 end
11 end comp
```



stdcomp - basic (configurable)

Composition: uranium

Mixture: 1

☒ Theoretical Density: 18.764000

☒ Volume Fraction: 1.000000

☒ Temperature: 293.000000

☒ Isotopic Weight Percents

	+/-	Isotope	Weight Percent
1	+ -	92234	1.000000
2	+ -	92235	93.200000
3	+ -	92236	0.2
4	+ -	92238	5.600000

Add row

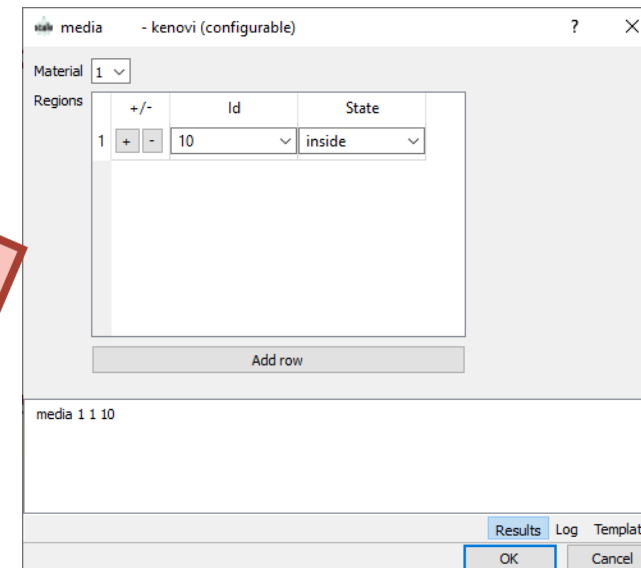
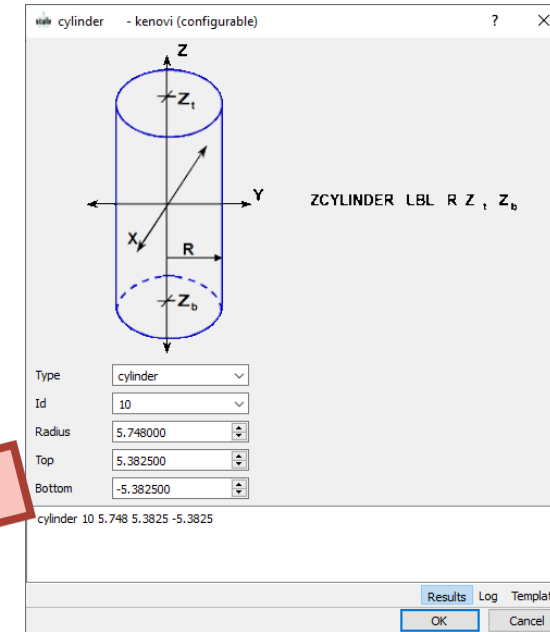
uranium 1 den=18.764000 1.0 293.0
92234 1.0
92235 93.2
92236 0.2
92238 5.6 end

Results Log Template

OK Cancel

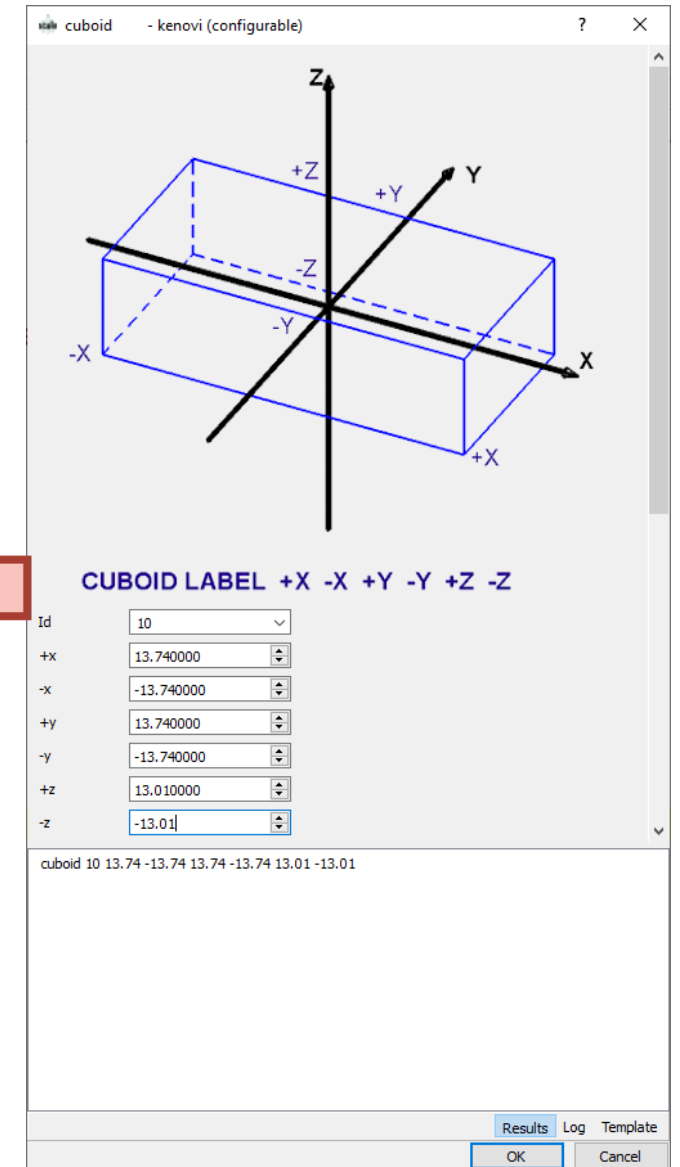
Unit 1: Metal casting

```
15 unit 1
16   cylinder 10 5.748 5.3825 -5.3825
17   media 1 1 10
18 boundary 10
```



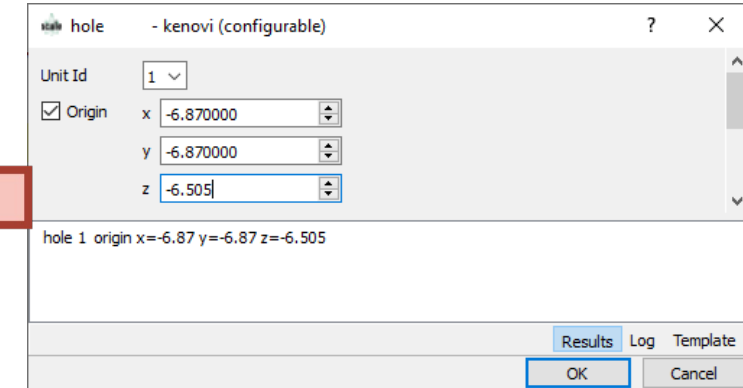
Global unit 2: Void space

```
19 global unit 2
20 cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
21 media 0 1 10
22
23 boundary 10
```



Global unit 2: Add first hole

```
19 global unit 2
20   cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
21   media 0 1 10
22   hole 1 origin x=-6.87 y=-6.87 z=-6.505
23
24 boundary 10
```



hole - kenovi (configurable)

Unit Id: 1

☒ Origin

x: -6.870000

y: -6.870000

z: -6.505

hole 1 origin x=-6.87 y=-6.87 z=-6.505

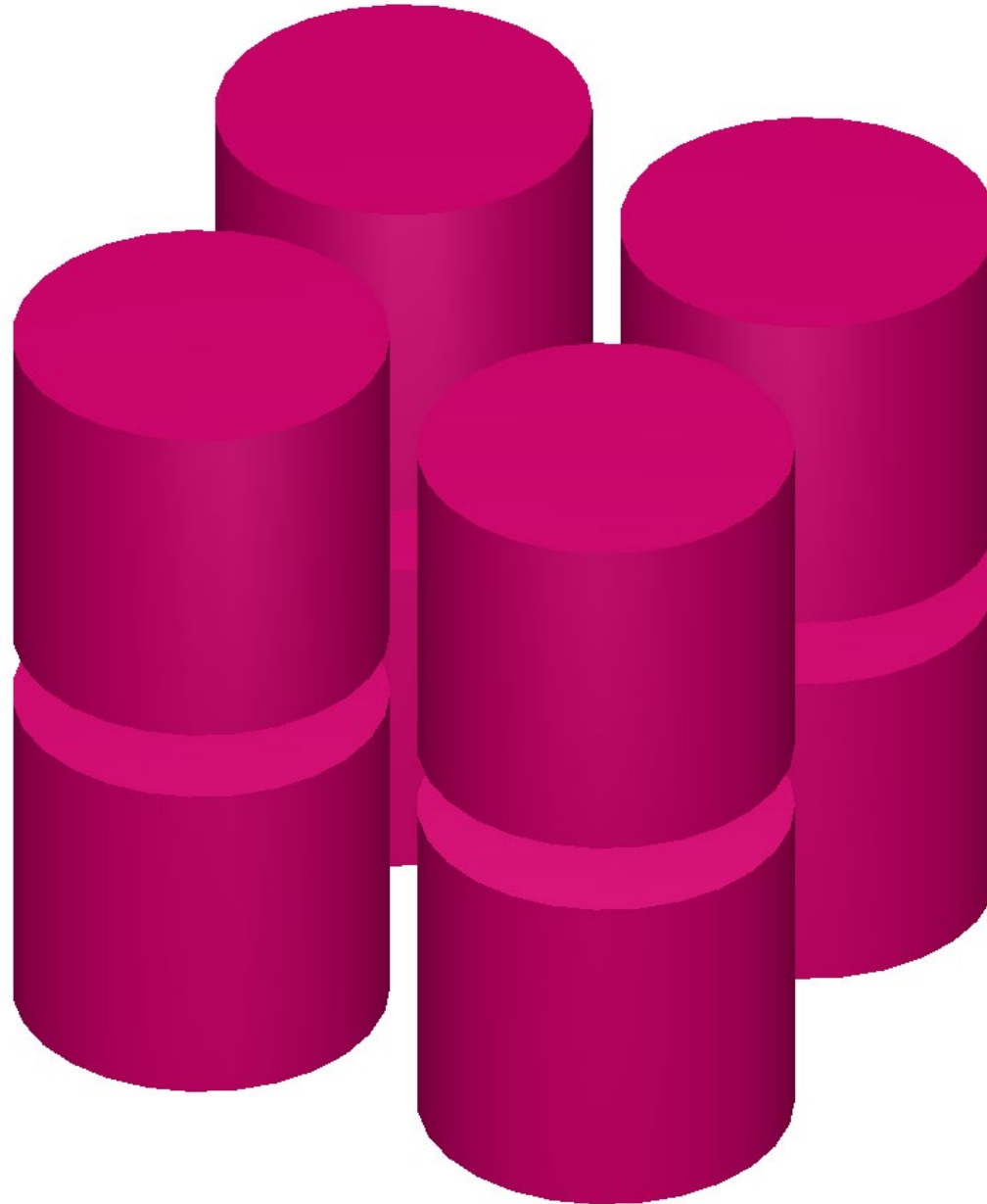
Results Log Template

OK Cancel

Global unit 2: Add remaining holes

```
19 global unit 2
20   cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
21   media 0 1 10
22   hole 1 origin x=-6.87 y=-6.87 z=-6.505
23   hole 1 origin x=6.87 y=-6.87 z=-6.505
24   hole 1 origin x=-6.87 y=6.87 z=-6.505
25   hole 1 origin x=6.87 y=6.87 z=-6.505
26   ,
27   hole 1 origin x=-6.87 y=-6.87 z=6.505
28   hole 1 origin x=6.87 y=-6.87 z=6.505
29   hole 1 origin x=-6.87 y=6.87 z=6.505
30   hole 1 origin x=6.87 y=6.87 z=6.505
31 boundary 10
```

3D rendering



Click run:

The screenshot shows the SCALE 6.3.3 application window. The title bar reads "SCALE". The menu bar includes "File", "Edit", "View", "Run", and "Help". Below the menu bar is a toolbar with buttons for "Reload", "Save", "Save as", "Close", "Print", "Cut", "Copy", "Paste", "Undo", "Redo", and "Find".

The left sidebar contains a "Navigation" pane with a "Filter" input field. Below it, a tree view shows the file structure: "k6_holes_demo.inp" and "document".

The main editor area displays the input file "k6_holes_demo.inp" with the following content:

```
1 =csas6 parm=( )
2 Hole demo: 2c8
3 ce_v8.0_endf
4
5 read comp
6 uranium 1 den=18.764000 1.0 293.0
7          92234 1.0
8          92235 93.2
9          92236 0.2
10         92238 5.6 end
11 end comp
12 read geometry
13 unit 1
14   cylinder 10 5.748 5.3825 -5.3825
15   media 1 1 10
16 boundary 10
17 global unit 2
18   cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
19   media 0 1 10
20   hole 1 origin x=-6.87 y=-6.87 z=-6.505
21   hole 1 origin x=6.87 y=-6.87 z=-6.505
22   hole 1 origin x=-6.87 y=6.87 z=-6.505
23   hole 1 origin x=6.87 y=6.87 z=-6.505
24 ,
25   hole 1 origin x=-6.87 y=-6.87 z=6.505
26   hole 1 origin x=6.87 y=-6.87 z=6.505
27   hole 1 origin x=-6.87 y=6.87 z=6.505
28   hole 1 origin x=6.87 y=6.87 z=6.505
29 boundary 10
30 end geometry
31
32
33 end data
34 end
```

Below the editor is a status bar showing the date and time: "Mon Sep 22 16:04:52 2025".

The bottom pane displays the output of the calculation, starting with a table of results:

1405						
1406	202	9.93557E-01	9.98292E-01	2.15526E-03	6.41787E+00	5.93333E-02
1407						
1408	203	1.02168E+00	9.98409E-01	1.91247E-03	6.38596E+00	5.96667E-02
1409						
1410						
1411	hole demo: 2c8					
1412	*****	final results table	*****			
1413	best estimate system k-eff	0.9984	+ or -	0.0019		
1414						
1415	Energy of average lethargy of Fission (eV)	8.40138E+05	+ or -	2.40868E+03		
1416	k-effective satisfies the chi**2 test for normality at the 95 % level					
1417						
1418	Scale job	/Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/k6_holes_demo.inp	is finished.			
1419	Output is stored in	/Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/k6_holes_demo.out				
1420						
1421	Process finished with 0 return code; ran in 6 secs, finished at	Mon Sep 22 16:04:59 2025				

The status bar at the bottom of the output pane shows "Line: 35, Col: 1" and "Validation Messages".

k-eff: 0.9984 +/- 0.0019

Summary of Sub-Module 3

- Overview of KENO VI holes
- Can simplify geometry construction
- Consists of the following components:
 - HOLE Keyword
 - Unit ID number placed in HOLE
 - Modification data (ORIGIN, ROTATE) used to place the origin of the unit being inserted to the desired position and orientation

Sub-Module 4

- Arrays in KENO-VI



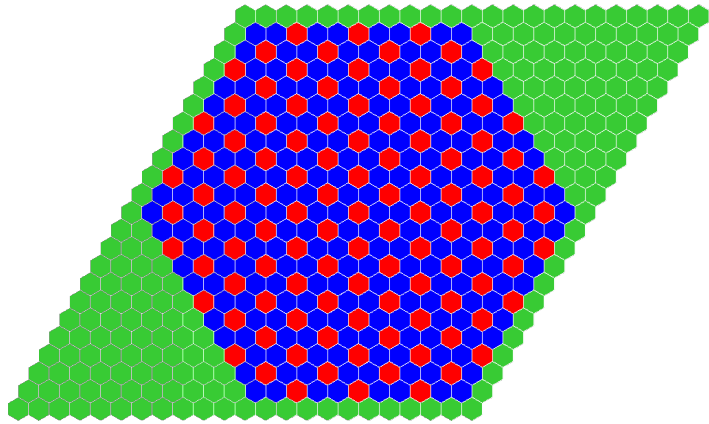
Contents record types

- Specifies the contents of a volume defined relative to the Geometry records in that unit
- Three types of Contents records
 1. **Media** – Places a mixture in the specified volume
 2. **Hole** – Places a previously defined unit at the specified position
 3. **Array** – Places an array in the specified volume

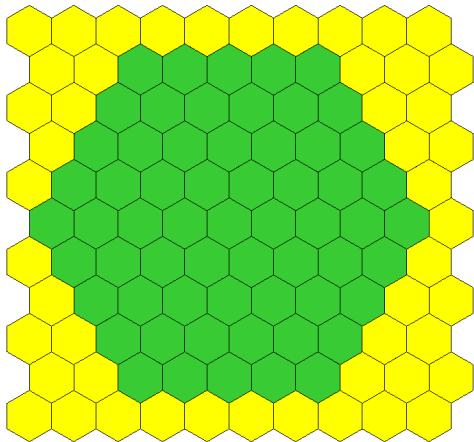
Contents records

Keyword	Contents Record Input
MEDIA	Mixture Number Bias ID Number Region Definition Vector Discussed in previous geometry lecture
HOLE	Unit number Keywords ORIGIN and ROTATE, if desired Discussed in previous holes lecture
ARRAY	Array Number Region Definition Vector Keyword PLACE followed by the X, Y, Z position of the unit used to place the array and the X, Y, Z coordinates of the unit with respect to the origin of the outer region

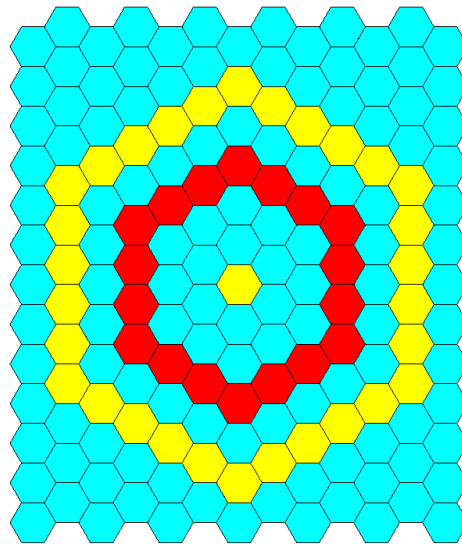
KENO-VI array types



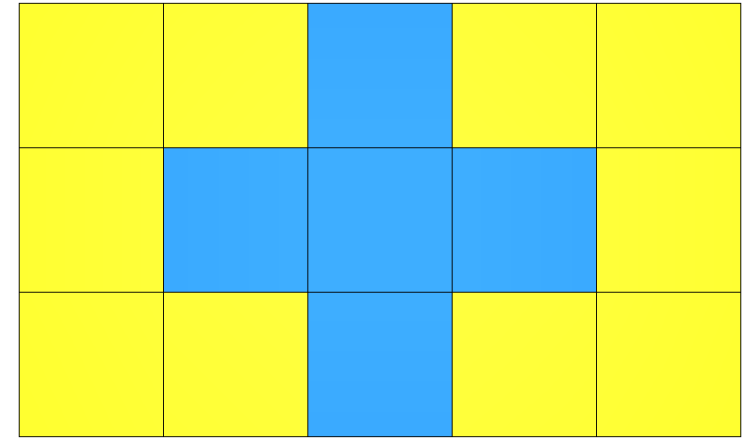
Hexagonal (or Triangular)



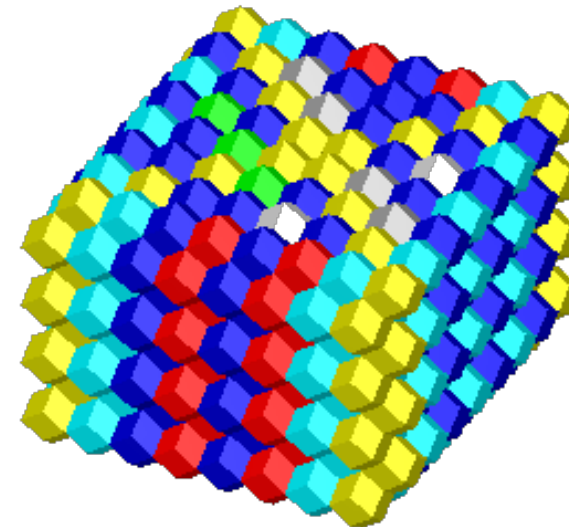
Standard hex



Rotated hex



Rectangular



Dodecahedral

Basic flow of using arrays in KENO-VI

1. Build the units you need to construct the array
2. Specify the array in the array block
 - All adjacent faces must have the same dimensions
3. Place the array within another unit in the problem geometry in the geometry block
 - Position origin of specified unit in the array at specific point in new unit

Array parameters

Keyword	Default	Type of Data
ARA=	1	Number defining the array
TYP=	Square	Square (cuboidal) Hexagonal (triangular) Shexagonal Rhexagonal Dodecahedral
COM=	none	<i>delimiter comment delimiter</i> 132 character maximum

Array parameters

Keyword	Default	Type of Data
NUX=	1	No. of units in the X direction
NUY=	1	No. of units in the Y direction
NUZ=	1	No. of units in the Z direction

FILL data

- Fills the array with the unit numbers in the specified order
- Begins with keyword “fill”
- Ends with keywords “end fill”
- Fills the array by incrementing
 - X from 1 to NUX
 - then Y from 1 to NUY
 - then Z from 1 to NUZ

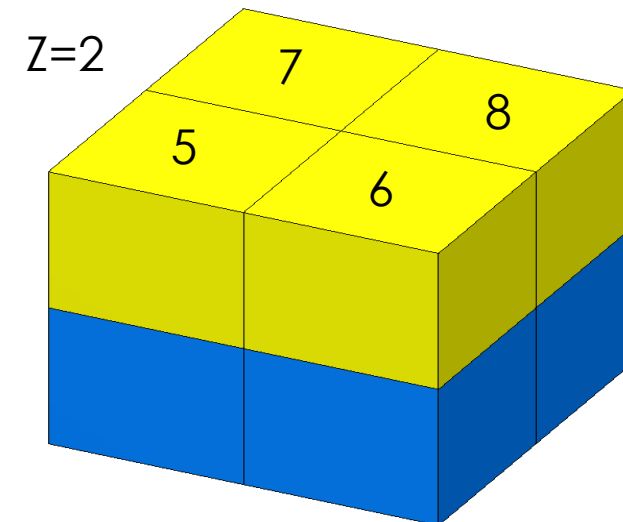
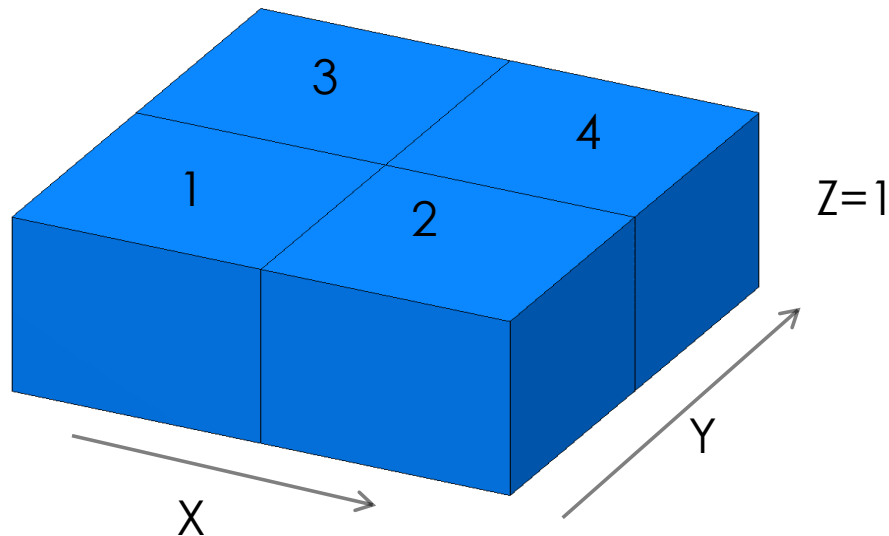
FILL data

- For a $2 \times 2 \times 2$ array, the order of the units stored in the array using the FILL is:

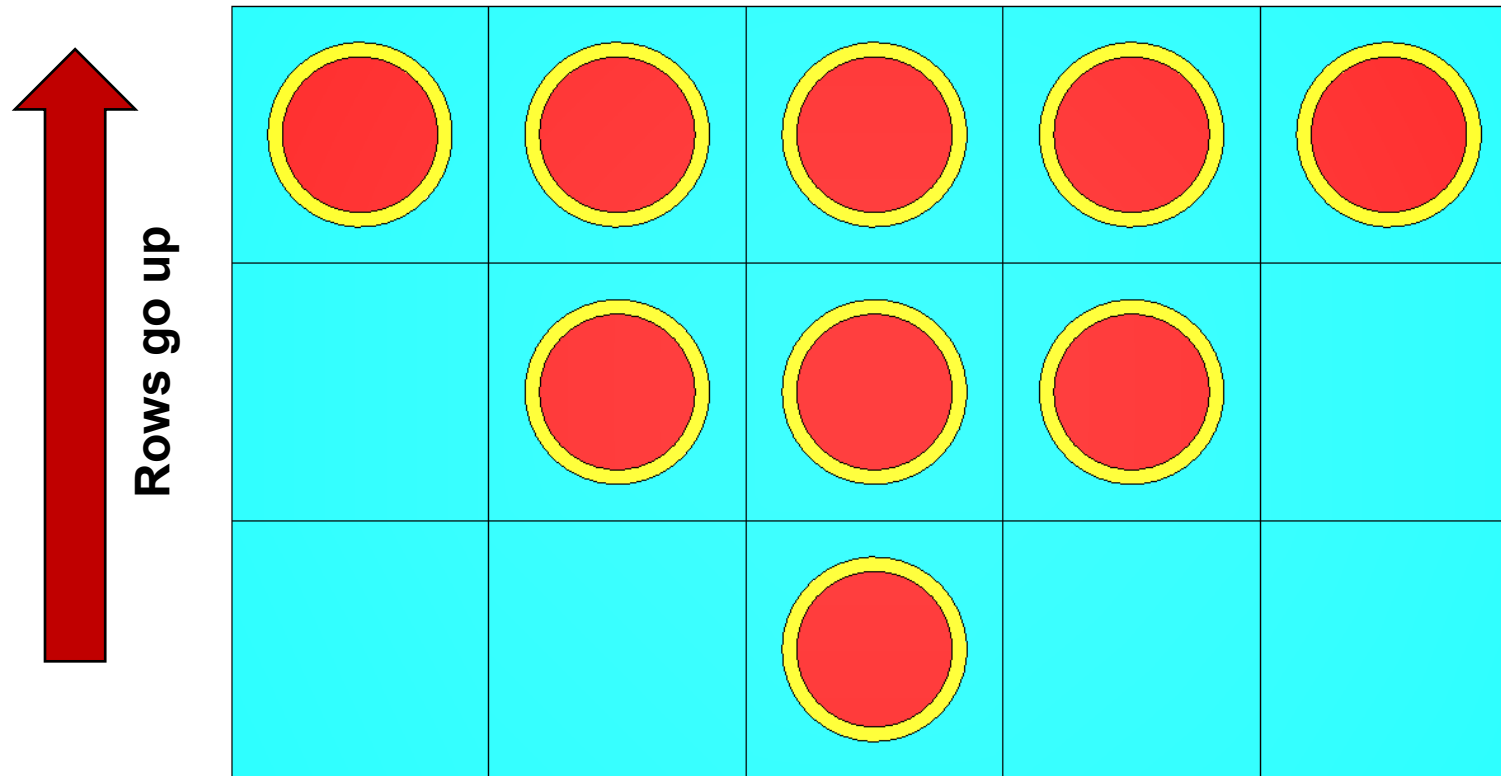
(1,1,1) (2,1,1) (1,2,1) (2,2,1)

(1,1,2) (2,1,2) (1,2,2) (2,2,2)

```
fill
  1 1 1 1
  2 2 2 2
end fill
```



Rectangular array



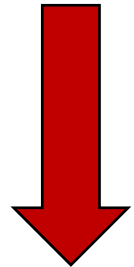
read array
ara=1 nux=5 nuy=3
typ=square

fill

2 2 1 2 2
2 1 1 1 2
1 1 1 1 1

end fill

end array



Rows go down

FIDO-like shortcuts for FILL

Count Field	Option Field	Operand Field	Comment
		j	Stores <i>j</i> in current array position
	f	j	Fills the remainder of the array with <i>j</i> starting with the current position
i	r or *	j	Repeats entry <i>j</i> a total of <i>i</i> times
i	q	j	Repeats the previous <i>j</i> entries <i>i</i> times

Refer to Table 8.1.19 for a complete list of options

Examples:

<code>fill 5 5 5 5 5 end fill</code>	is identical with	<code>fill f5 end fill</code>
<code>fill 10 10 5 5 5 end fill</code>	is identical with	<code>fill 2r10 3r5 end fill</code>
<code>fill 1 2 3 1 2 3 1 2 3 end fill</code>	is identical with	<code>fill 1 2 3 2q3 end fill</code>

ARRAY Contents record

- Used to place an array into a region defined in the current unit
- Consists of the following components:
 - ARRAY keyword
 - Array ID number
 - Region definition vector
 - Keyword PLACE followed by data to position the array in the region

Array PLACE data

- Data following the keyword PLACE used to position the array in a region consist of
 - Element i, j, k in the array used to establish the location of the array
 - the X, Y, Z coordinates of the origin of the unit in that array element, in the coordinate system of the unit into which the array is being placed

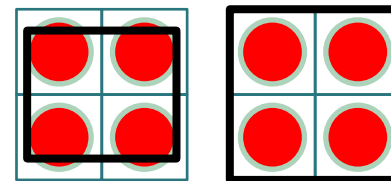
In other words:

PLACE the origin of the unit that is the ijk^{th} element in the array at position (X, Y, Z) in the current unit coordinate system

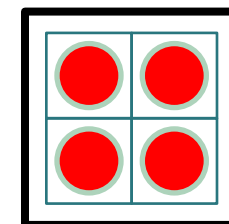
Restrictions on arrays

- Array boundaries cannot intersect holes
 - A hole entirely inside of an array is OK
- Array boundary *MAY* intersect boundary of lower-level units (elements) within array
- Array must **AT LEAST** fill the region into which it is **PLACED**
 - Region can be smaller than array
 - Region cannot be larger than array
 - Different treatment from TRITON/NEWT

Either of these is OK

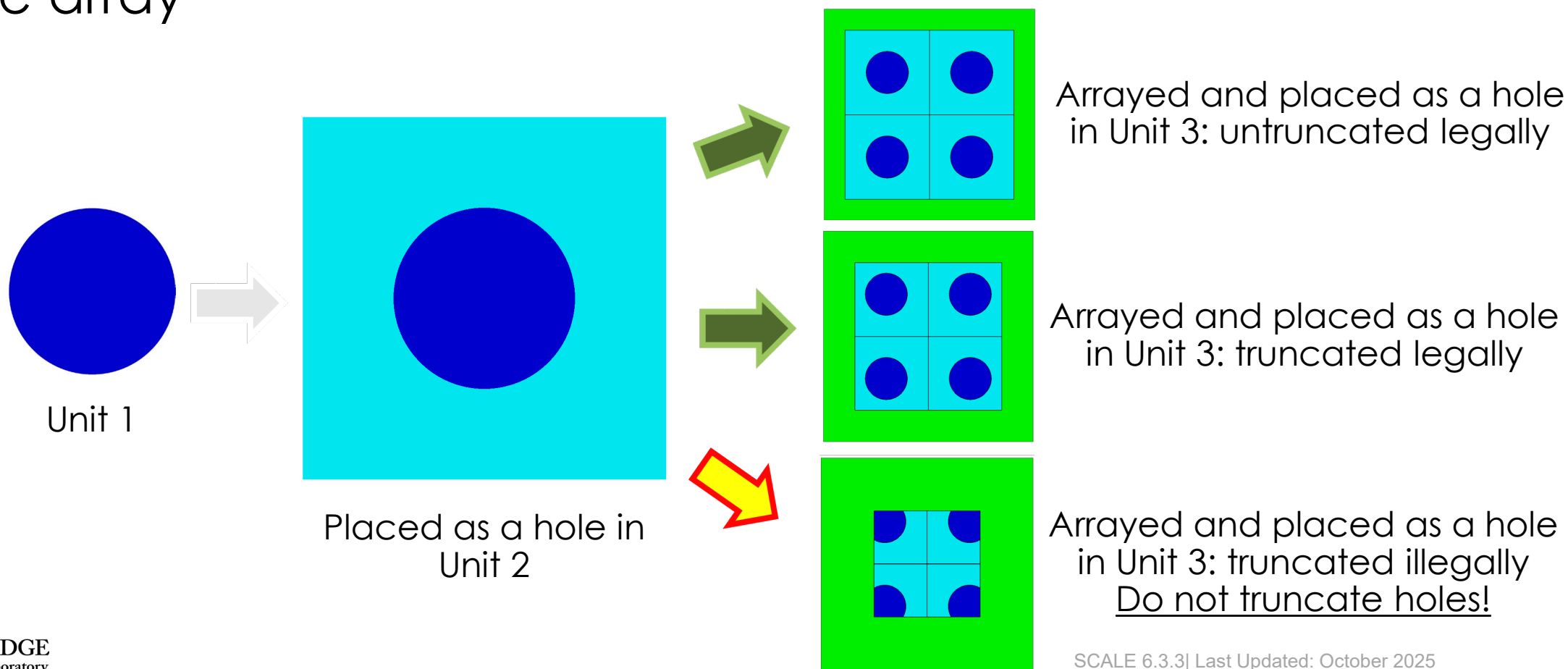


This is not

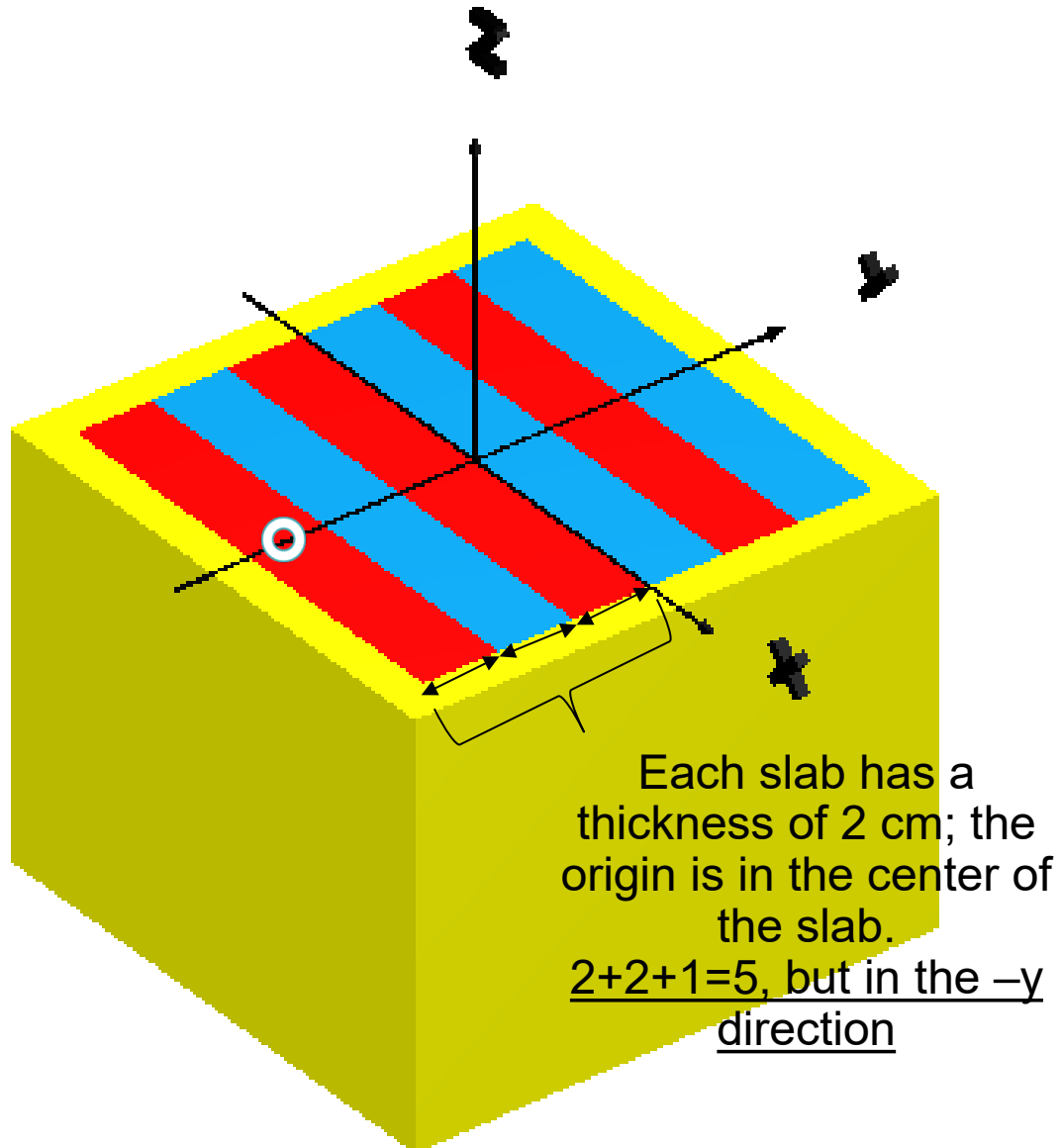


Restrictions on arrays related to holes

- Array boundary cannot truncate a hole contained in a unit in the array



1D array



read geometry

unit 1

cuboid 10 2p6.0 1.0 -1.0 2p10.0

media 1 1 10

boundary 10

unit 2

cuboid 10 2p6.0 1.0 -1.0 2p10.0

media 2 1 10

boundary 10

global unit 3

cuboid 10 4p6.0 2p10.0

cuboid 20 4p7.0 2p11.0

array 1 10 place 1 1 1 0.0 -5.0 0.0

media 3 1 20 -10

boundary 20

end geometry

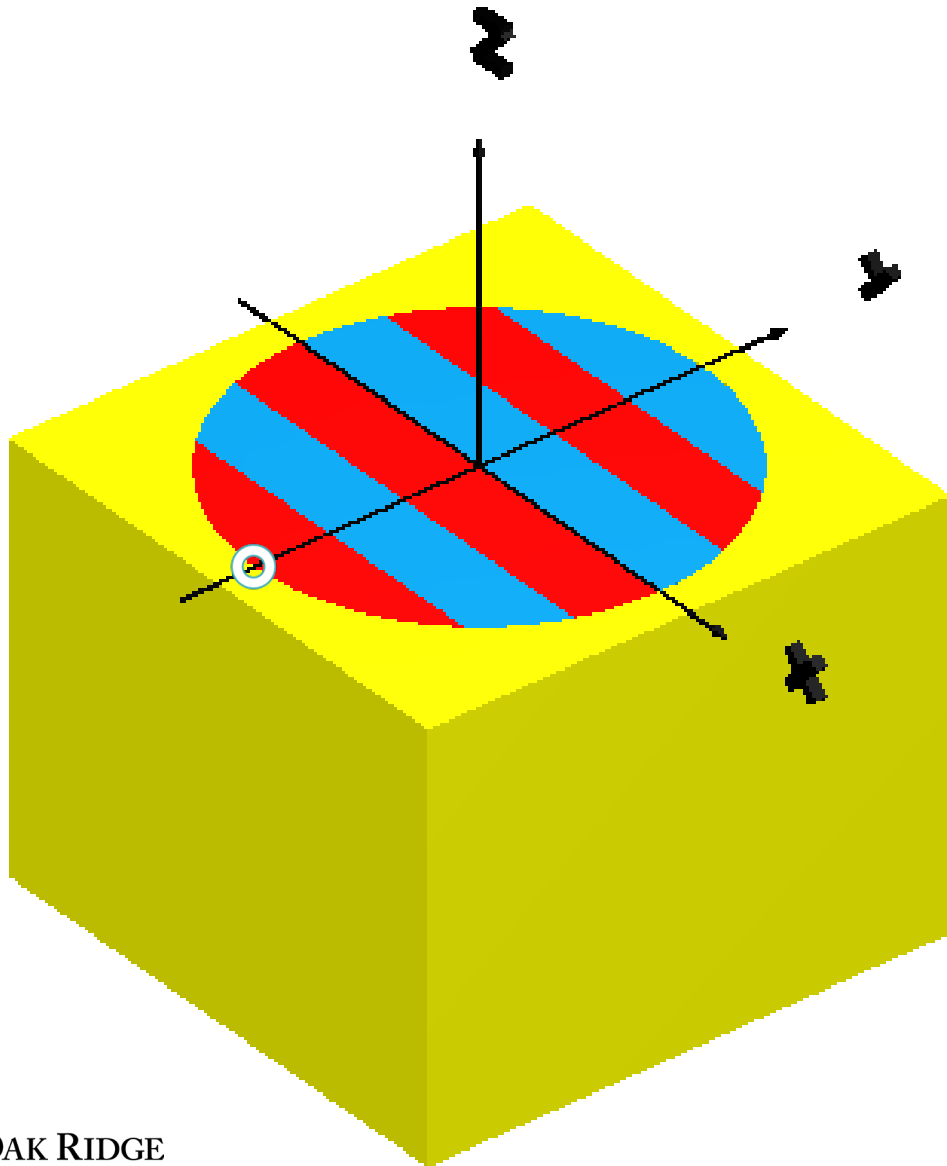
read array

ara=1 nux=1 nuy=6 nuz=1

fill 1 2 1 2 1 2 end fill

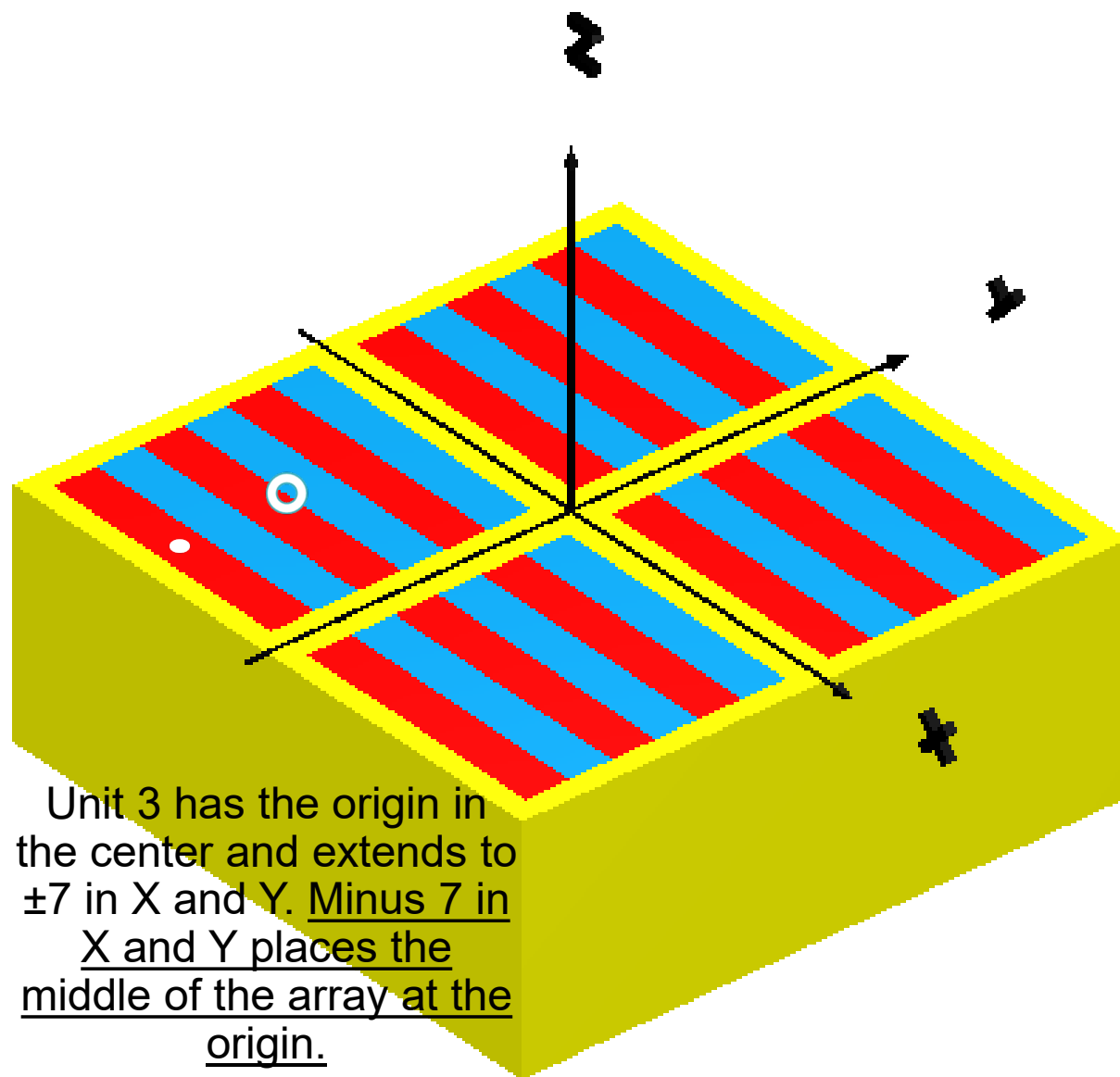
end array

1D array with cylindrical boundary



```
read geometry
unit 1
  cuboid 10 2p6.0 2p1.0 2p10.0
  media 1 1 10
  boundary 10
unit 2
  cuboid 10 2p6.0 2p1.0 2p10.0
  media 2 1 10
  boundary 10
global unit 3
  cylinder 10 6.0 2p10.0
  cuboid 20 4p7.0 2p11.0
  array 1 10 place 1 1 1 0.0 -5.0 0.0
  media 3 1 20 -10
  boundary 20
end geometry
read array
ara=1 nux=1 nuy=6 nuz=1
  fill 1 2 1 2 1 2 end fill
end array
```

Array of arrays



read geometry

unit 1 cuboid 10 2p6.0 2p1.0 2p10.0

media 1 1 10 boundary 10

unit 2 cuboid 10 2p6.0 2p1.0 2p10.0

media 2 1 10 **boundary 10**

unit 3

cuboid 10 4p6.0 2p10.0

cuboid 20 4p7.0 2p11.0

array 1 10 place 1 1 1 0.0 -5.0 0.0

media 3 1 20 -10 **boundary 20**

global unit 4

cuboid 10 4p14.0 2p11.0

array 2 10 **place 1 1 1 -7.0 -7.0 0.0**

boundary 10

end geometry

read array

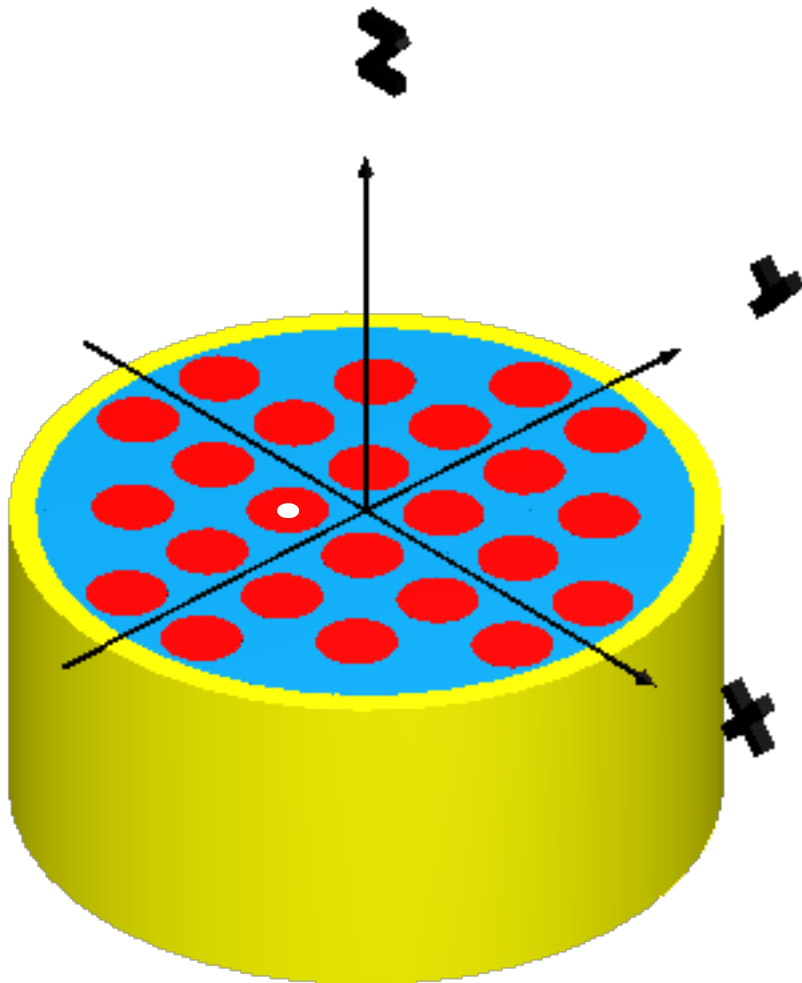
ara=1 nux=1 nuy=6 nuz=1

fill 1 2 1 2 1 2 end fill

ara=2 nux=2 nuy=2 nuz=1

fill f3 end fill end array

Rectangular array with cylindrical boundary



read geometry

unit 1

cylinder 10 0.75 2p5.0

cuboid 20 4p1.0 2p5.0

media 1 1 10

media 2 1 20 -10

boundary 20

unit 2

cuboid 10 4p1.0 2p5.0

media 2 1 10

boundary 10

global unit 3

cylinder 10 6.0 2p5.0

cylinder 20 6.5 2p6.0

array 1 10 place 3 3 1 -0.5 -0.5 0.0

media 3 1 20 -10

boundary 20

end geometry

read array

ara=1 nux=6 nuy=6 nuz=1

fill 2 2 1 1 2 2

2 1 1 1 1 2

1 1 1 1 1 1

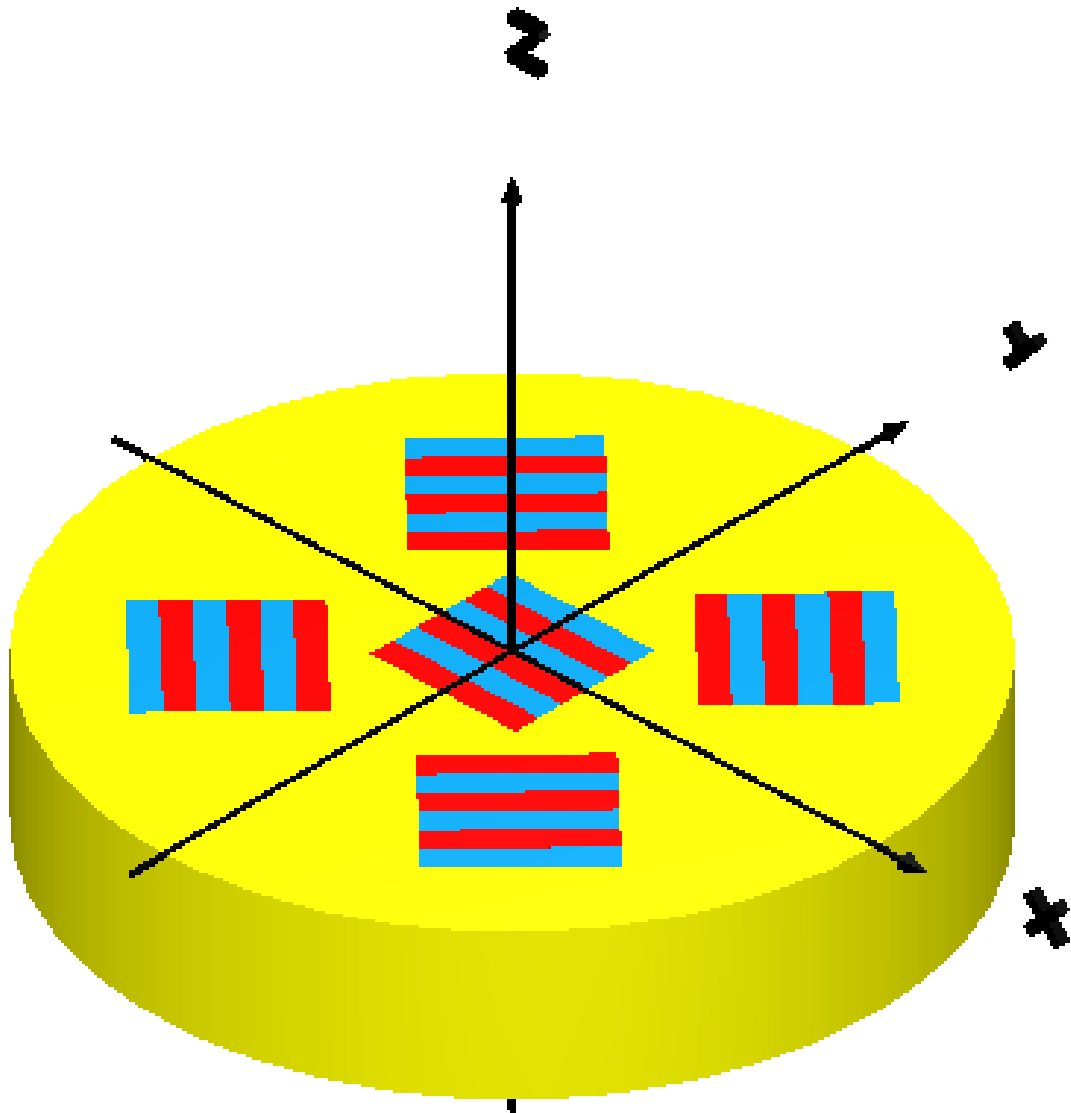
1 1 1 1 1 1

2 1 1 1 1 2

2 2 1 1 2 2 end fill

end array

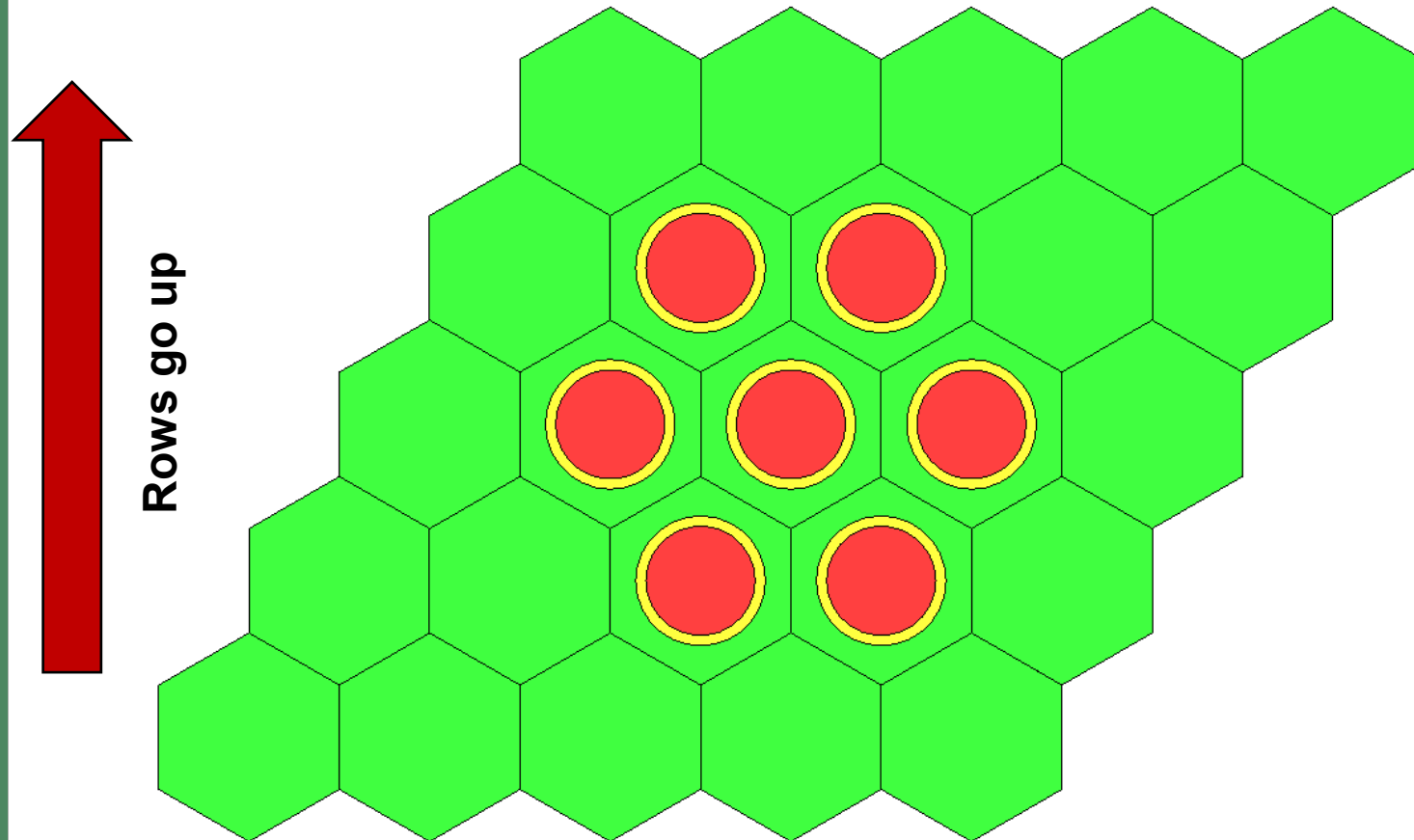
Placing arrays with holes and rotation



```

read geometry
unit 1  cuboid 10 2p6.0 2p1.0 2p10.0
media 1 1 10  boundary 10
unit 2  cuboid 10 2p6.0 2p1.0 2p10.0
media 2 1 10  boundary 10
unit 3  cuboid 10 2p6.0 2p6.0 2p10.0
array 1 10 place 1 1 1 0.0 -5.0 0.0
boundary 10
global unit 4
cylinder 10 30.0 2p12.0
media 3 1 10
hole 3
hole 3 origin x=12.0 y=12.0 rotate a1=-45
hole 3 origin x=12.0 y=-12.0 rotate a1=-135
hole 3 origin x=-12.0 y=-12.0 rotate a1=135
hole 3 origin x=-12.0 y=12.0 rotate a1=45
boundary 10 end geometry
read array  ara=1 nux=1 nuy=6 nuz=1
fill 1 2 1 2 1 2 end fill end array
    
```

Hexagonal array



read array

ara=1 nux=5 nuy=5 nuz=1

typ=hexagonal

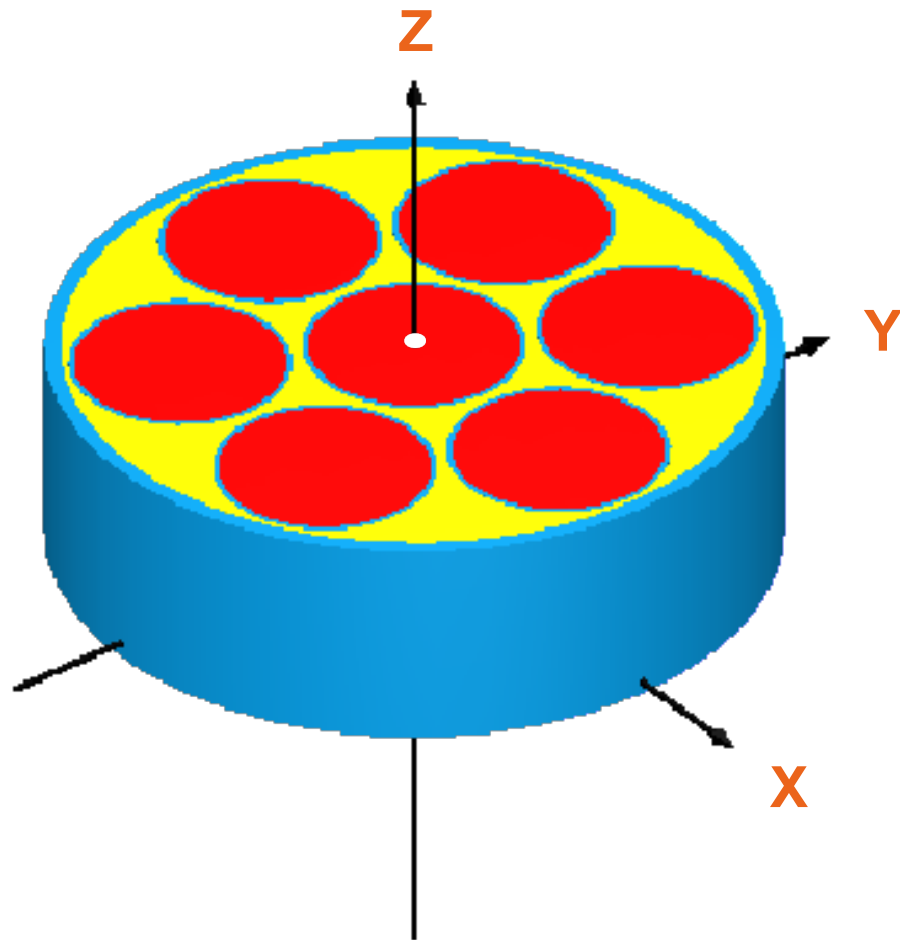
fill

2	2	2	2	2
2	2	1	1	2
2	1	1	1	2
2	1	1	2	2
2	2	2	2	2

end fill

end array

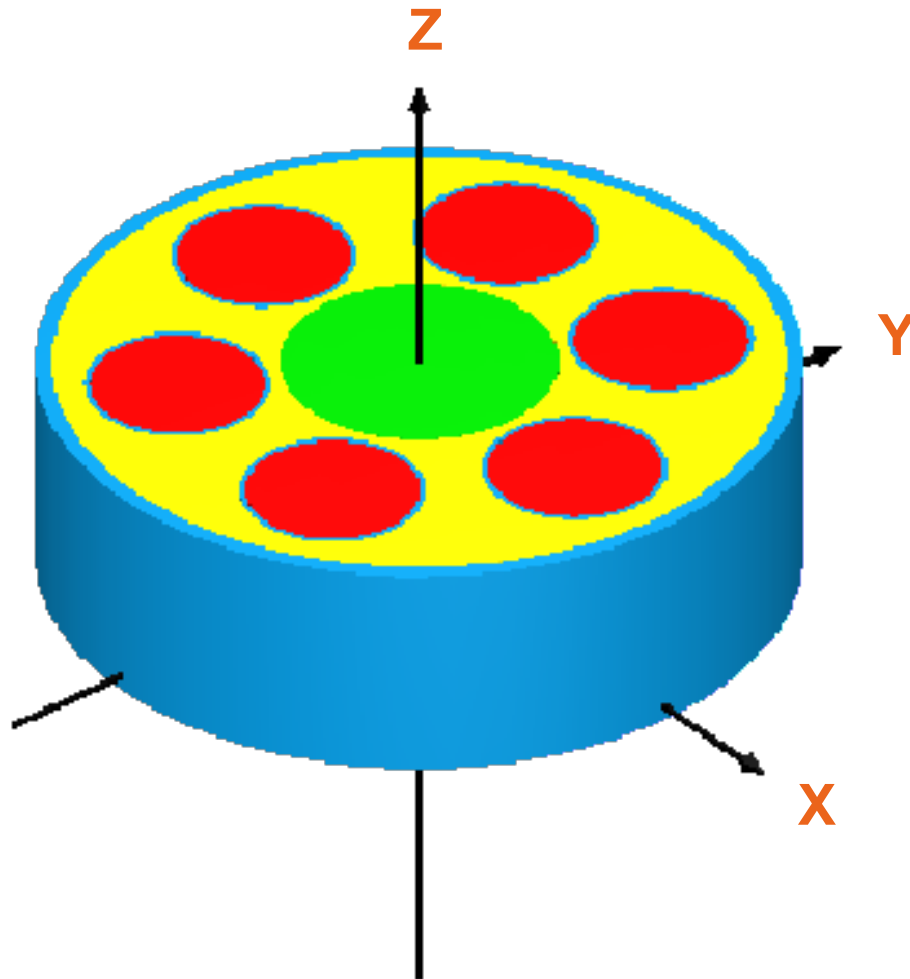
Hexagonal array with cylindrical boundary



```

read geometry
unit 1  cylinder 10  9.5 18.3  0.0
      cylinder 20 10.0 18.3 -0.15
      hexprism 30 10.5 18.3 -0.15
      media 1 1 10
      media 2 1 20 -10
      media 3 1 30 -20 -10  boundary 30
unit 2  hexprism 10 10.5 18.3 -0.15
      media 3 1 10  boundary 10
global unit 3
      cylinder 10 31.5 18.3 -0.15
      cylinder 20 33.0 18.3 -1.45
      array 1 10 place 3 3 1 0 0 0
      media 2 1 20 -10
      boundary 20
end geometry
read array ara=1 typ=triangular
nux=5 nuy=5 nuz=1
fill 2  2  2  2  2  2
      2  2  1  1  2
      2  1  1  1  2
      2  1  1  2  2
      2  2  2  2  2  end fill
end array
    
```

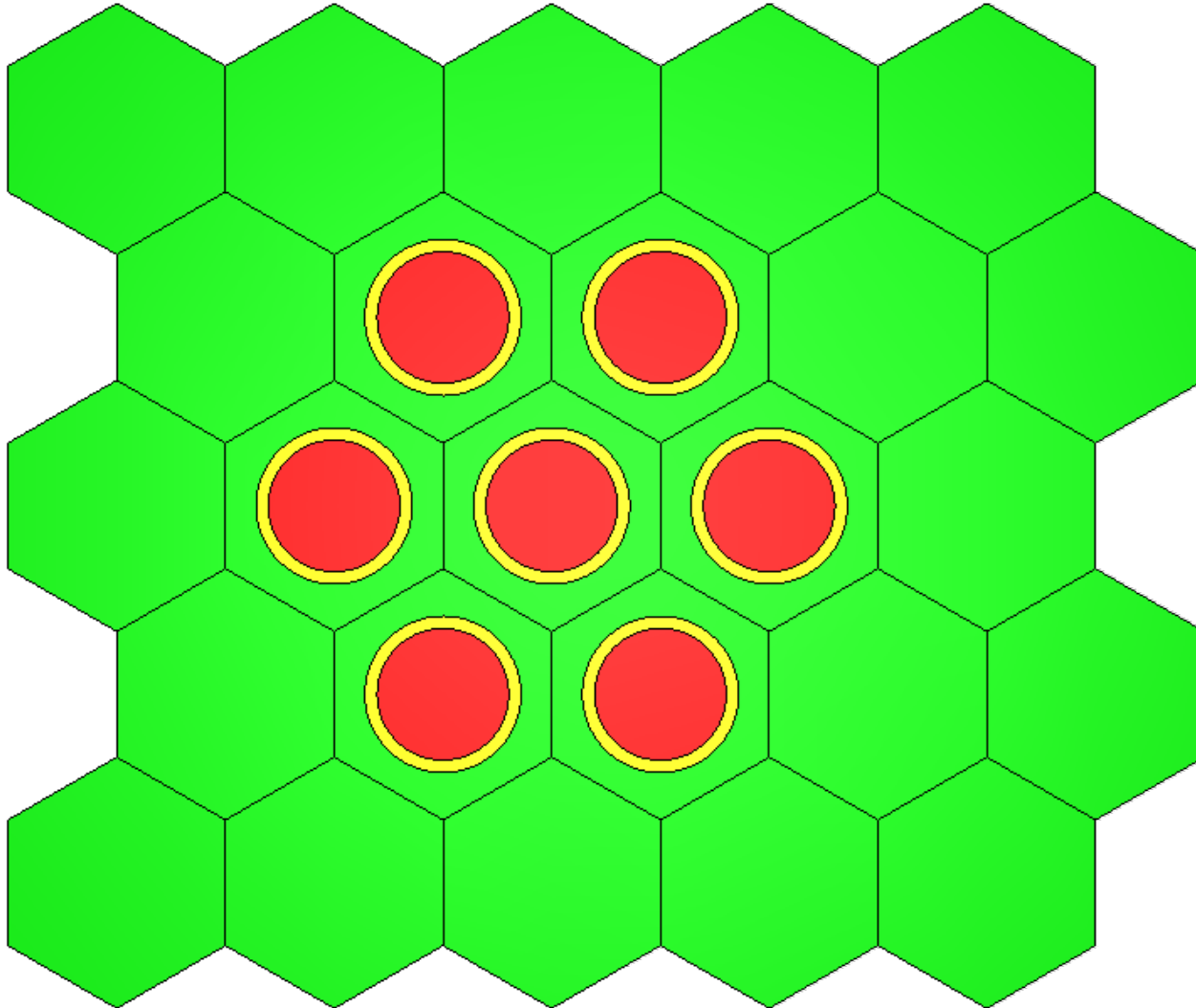
Hexagonal array with inner and outer boundaries



```

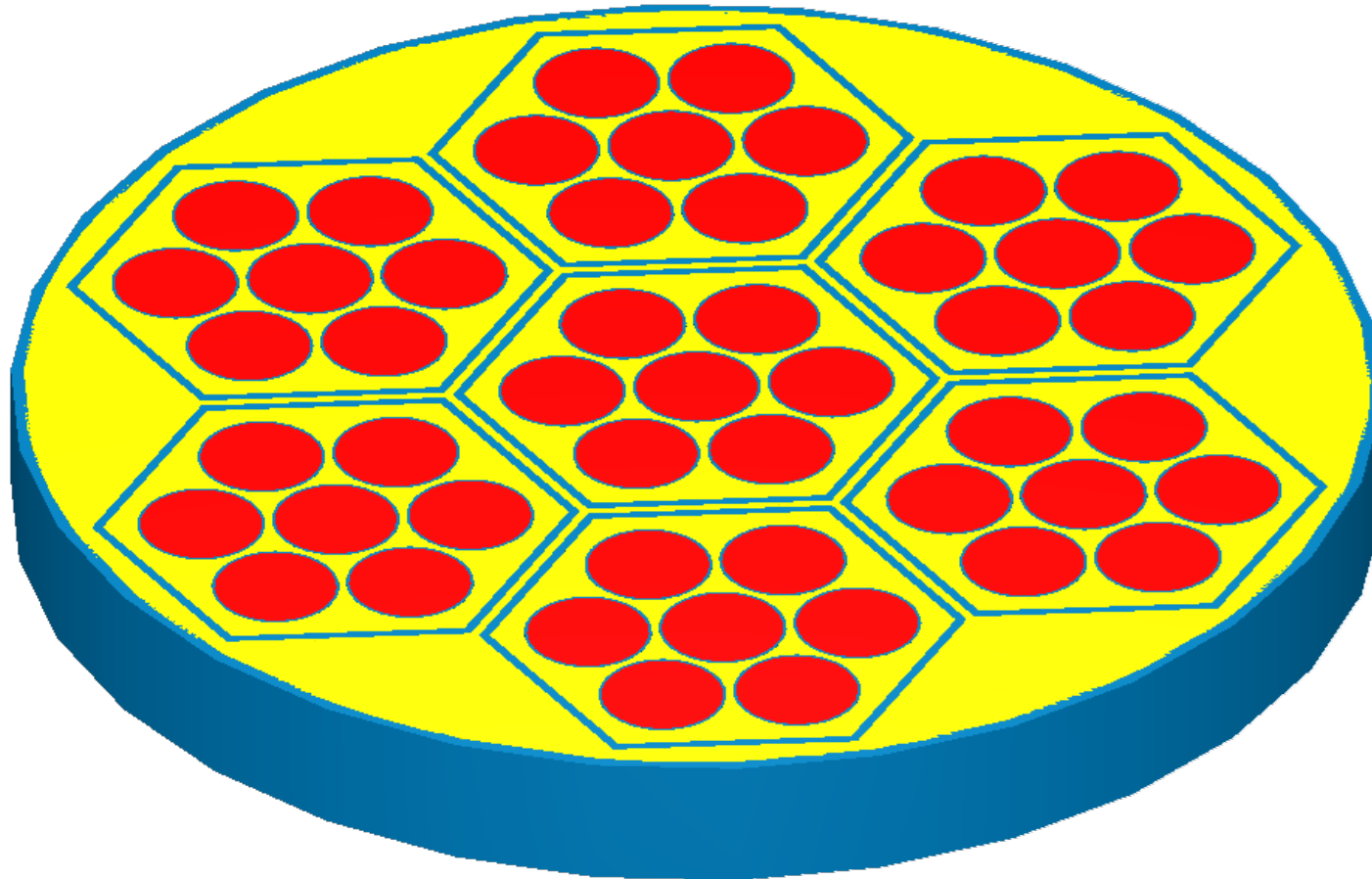
read geometry
unit 1  cylinder 10  7.5 18.3  0.0
      cylinder 20  8.0 18.3 -0.15
      hexprism 30 10.5 18.3 -0.15
      media 1 1 10
      media 2 1 20 -10
      media 3 1 30 -20 -10  boundary 30
unit 2  hexprism 10 10.5 18.3 -0.15
      media 3 1 10  boundary 10
global unit 3
cylinder 10 31.5 18.3 -0.15
cylinder 20 33.0 18.3 -1.45
cylinder 30 12.0 18.3 -0.15
array 1 10 -30 place 3 3 1 3r0.0
      media 2 1 20 -10
      media 4 1 30  boundary 20
end geometry
read array ara=1 typ=triangular
nux=5 nuy=5 nuz=1
fill  2  2  2  2  2
      2  2  1  1  2
      2  1  1  1  2
      2  1  1  2  2
      2  2  2  2  2 end fill
end array
    
```

Standard hexagonal array



```
ara=2 nux=5 nuy=5 nuz=1  
typ=shexagonal  
fill  
  2  2  2  2  2  
    2  1  1  2  2  
  2  1  1  1  2  
    2  1  1  2  2  
  2  2  2  2  2  
end fill  
end array
```

Hexagonal array of arrays



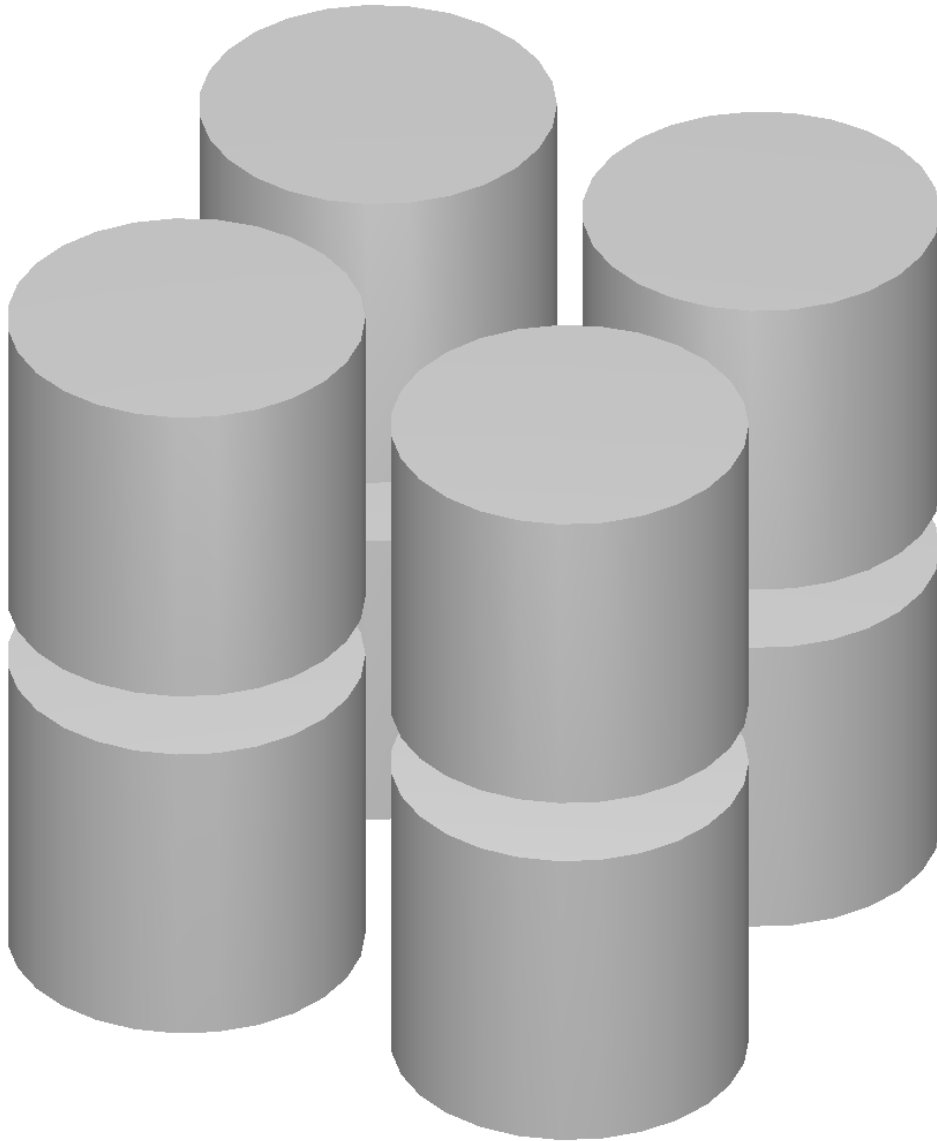
For more of the same, review this demo later...

Demo: Array

- 2c8 – Take 2



2c8



8 Uranium Cylinders

5.748 cm radius

10.765 cm length

13.74 cm center to center spacing in X and Y dimensions

13.01 cm center to center spacing in Z dimension

Uranium Metal

Density = 18.764 g / cc

Enrichment:

93.2%	U-235
5.6%	U-238
1.0%	U-234
0.2%	U-236

Process for this demo

1. Start from hole demo input
2. Modify unit 1 to have a void-filled cuboid boundary
3. Create array
4. Place array in Global Unit 2

Unit 1: Add cuboid for boundary

```
15 unit 1
16   cylinder 10 5.748 5.3825 -5.3825
17   cuboid 20 6.87 -6.87 6.87 -6.87 6.505 -6.505
18 '
19   media 1 1 10
20   media 0 1 20 -10
21 boundary 20
```

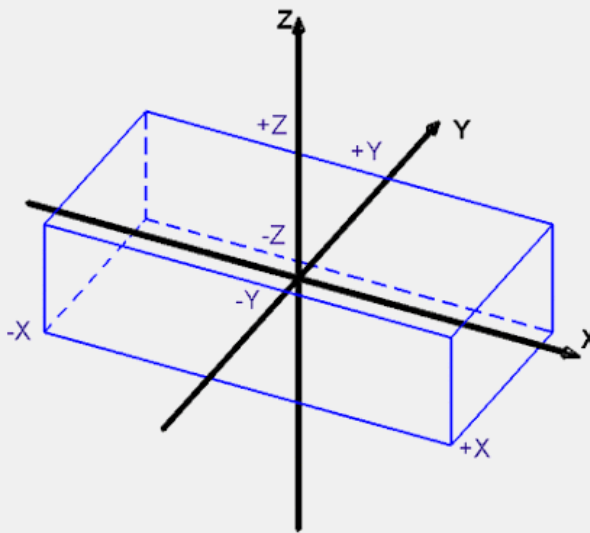
media - kenovi (configurable)

Material

Regions	+/-	Id	State
1	+ -	20	inside
2	+ -	10	outside

media 0 1 20 -10

cuboid - kenovi (configurable)



CUBOID LABEL +X -X +Y -Y +Z -Z

Id

+x

-x

+y

-y

+z

-z

cuboid 20 6.87 -6.87 6.87 -6.87 6.505 -6.505

Add array block, then create array

```
18 '  
19 media 1 1 10  
20 cells 0 1 20 -10  
21 parameters  
22 biasing  
23 start y 20  
24 arrays unit 2  
25 xlds  
26 mixt d 10 13.74 -13.74 13.74 -13.74 13.01 -13.01  
27 volume  
28 energy  
29 grid  
30 bounds y 10  
31 plots  
32 reactions metry  
33  
34 end data  
35 end
```

array - kenovi basic (configurable)

ara 1

gbl

prt yes

typ cuboidal

nux 2

nuy 2

nuz 2

fill id 1

com

ara=1
prt=yes
typ=cuboidal
nux=2
nuy=2
nuz=2
fill
z = 1
1 1
1 1
z = 2
1 1
1 1
end fill

Results Log Template

OK Cancel

Array input

```
27 read array
28   ara=1
29   prt=yes
30   typ=cuboidal
31   nux=2
32   nuy=2
33   nuz=2
34   fill
35 ' z = 1
36   1 1
37   1 1
38 ' z = 2
39   1 1
40   1 1
41   end fill
42 end array
```

Place array in global unit

```
22 global unit 2
23 cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
24 array 1 10 place 1 1 1 -6.87 -6.87 -6.505
25 boundary 10
```

Array element as
reference to position
array

Location of origin of
referenced element in the
array in the current unit

array - kenovi (configurable)

Array Id 1

Regions	+/-	Id	State
1	+ -	10	inside

Add row

Place

xindex 1

yindex 1

zindex 1

x -6.870000

y -6.870000

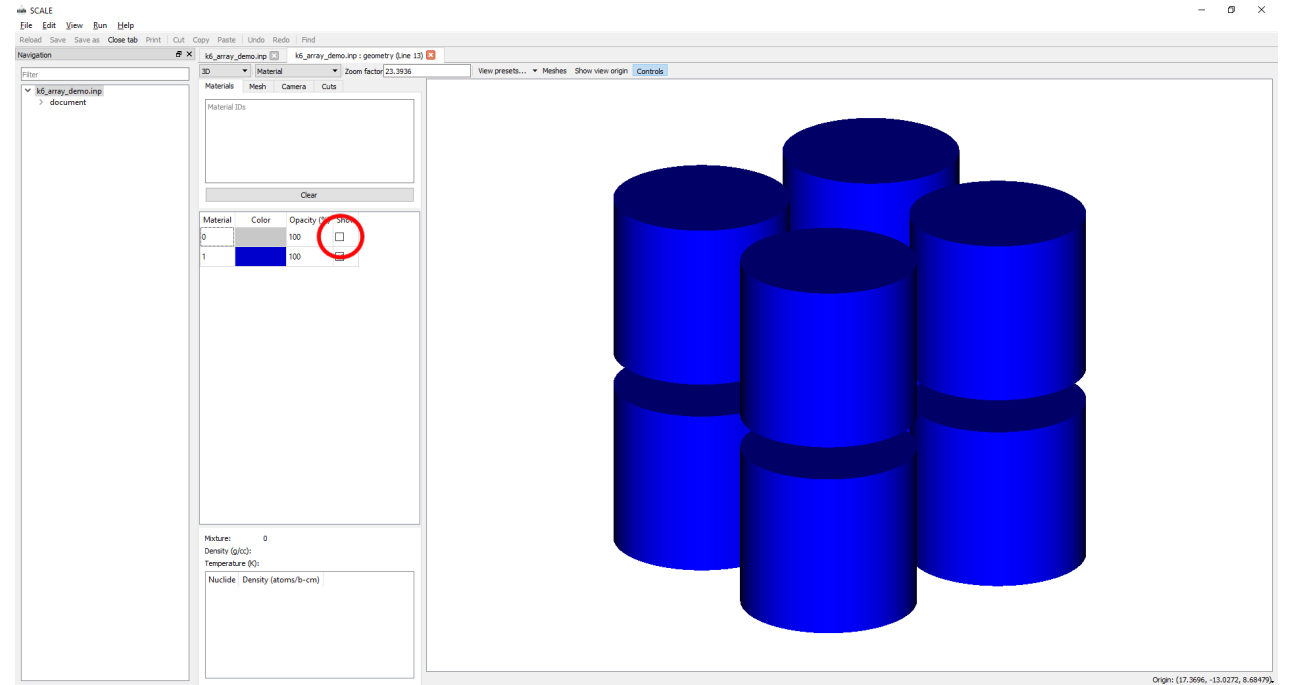
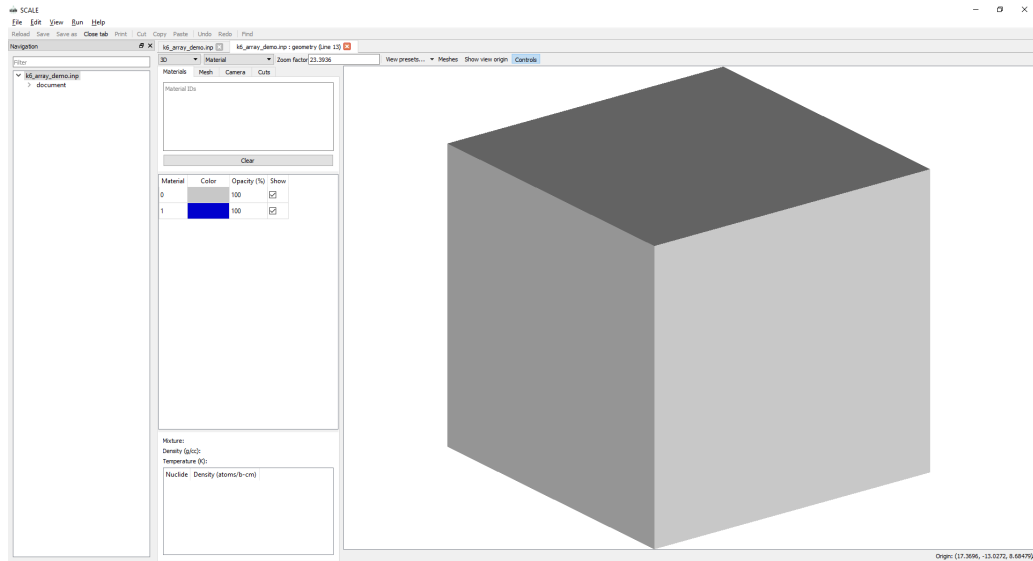
z -6.505

array 1 10 place 1 1 1 -6.87 -6.87 -6.505

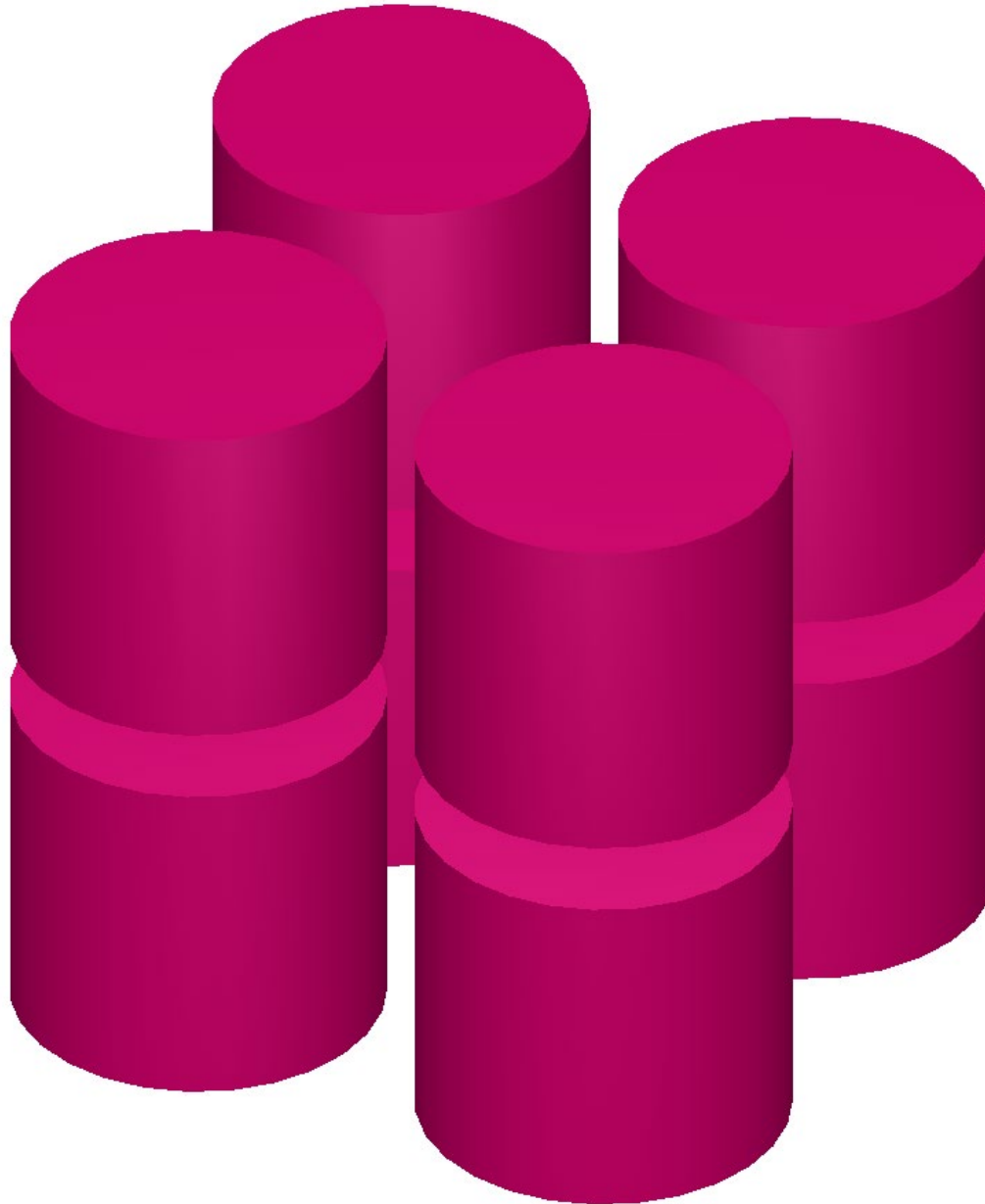
Results Log Template

OK Cancel

3D renderings in Fulcrum



3D rendering



Click run

The screenshot shows the SCALE 6.3.3 application window. The main editor displays an input file named `k6_holes_demo.inp`. The file contains a series of commands for a Monte Carlo simulation, including `read comp`, `read geometry`, `read array`, and `fill`. The output window at the bottom shows the results of the simulation, including a table of data and a summary of the results.

```
2 Hole demo: 2c8
3 ce_v8.0_endf
4
5 read comp
6 uranium 1 den=18.764000 1.0 293.0
7 92234 1.0
8 92235 93.2
9 92236 0.2
10 92238 5.6 end
11 end comp
12 read geometry
13 unit 1
14 cylinder 10 5.748 5.3825 -5.3825
15 cuboid 20 6.87 -6.87 6.87 -6.87 6.505 -6.505
16
17 media 1 1 10
18 media 0 1 20 -10
19 boundary 20
20 global unit 2
21 cuboid 10 13.74 -13.74 13.74 -13.74 13.01 -13.01
22 array 1 10 place 1 1 1 -6.87 -6.87 -6.505
23 boundary 10
24 end geometry
25
26 read array
27 ara=1
28 prt=yes
29 typ=cuboidal
30 nux=2
31 nuy=2
32 nuz=2
33 fill
```

Mon Sep 22 16:08:19 2025						
1401	200	9.66651E-01	9.98489E-01	2.21580E-03	6.34843E+00	6.35000E-02
1402						
1403	201	9.64261E-01	9.98316E-01	2.16955E-03	6.41268E+00	6.36667E-02
1404						
1405	202	9.93557E-01	9.98292E-01	2.15526E-03	6.41787E+00	6.40000E-02
1406						
1407	203	1.02168E+00	9.98409E-01	1.91247E-03	6.38596E+00	6.43333E-02
1408						
1409						
1410	hole demo: 2c8					
1411	***** final results table *****					
1412	best estimate system k-eff 0.9984 + or - 0.0019					
1413						
1414	Energy of average lethargy of Fission (eV) 8.40138E+05 + or - 2.40868E+03					
1415	k-effective satisfies the chi**2 test for normality at the 95 % level					
1416						
1417	Scale job /Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/k6_array.inp is finished.					
1418	Output is stored in /Users/6tg/Documents/Codes/SCALE_NCS_Fall-2025/k6_array.out					
1419						
1420	Process finished with 0 return code; ran in 7 secs, finished at Mon Sep 22 16:08:26 2025					

k-eff: 0.9984 +/- 0.0019

Exercises for Sub-Module 4

- Advanced KENO-VI geometry exercises
 - Set 1: Pins in tank, array of cylinders, GOSLAR cask, CASTOR cask



Problem: Pins in a tank

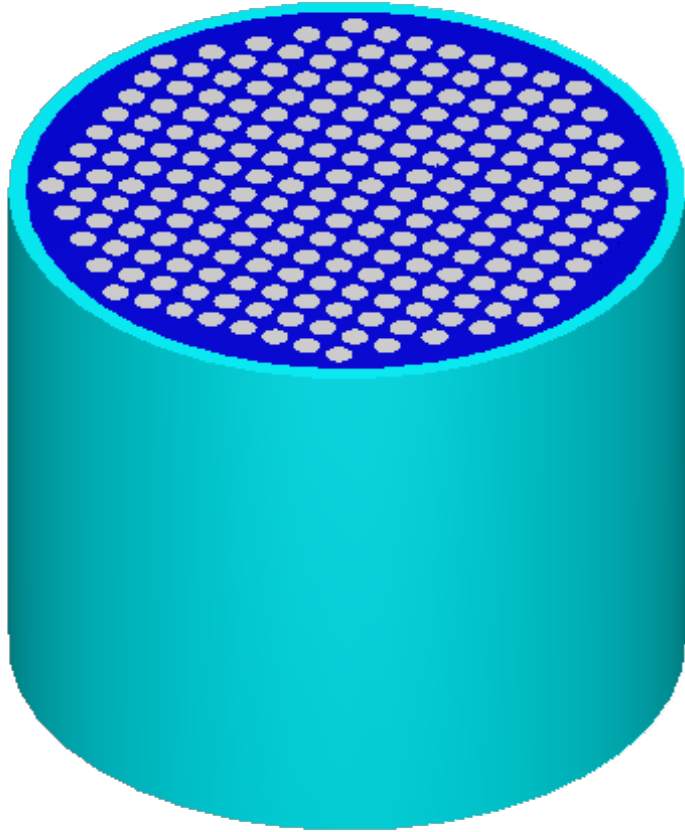


Figure shows tank cut in half
(in Z) without the reflector

RODS

0.75 cm OD X 30.0 cm long

Pitch: 1.0 cm

Fuel: 20 wt% enriched U metal
default density
(No ^{234}U or ^{236}U in fuel)

TANK

18 cm ID

60 cm Inside Height

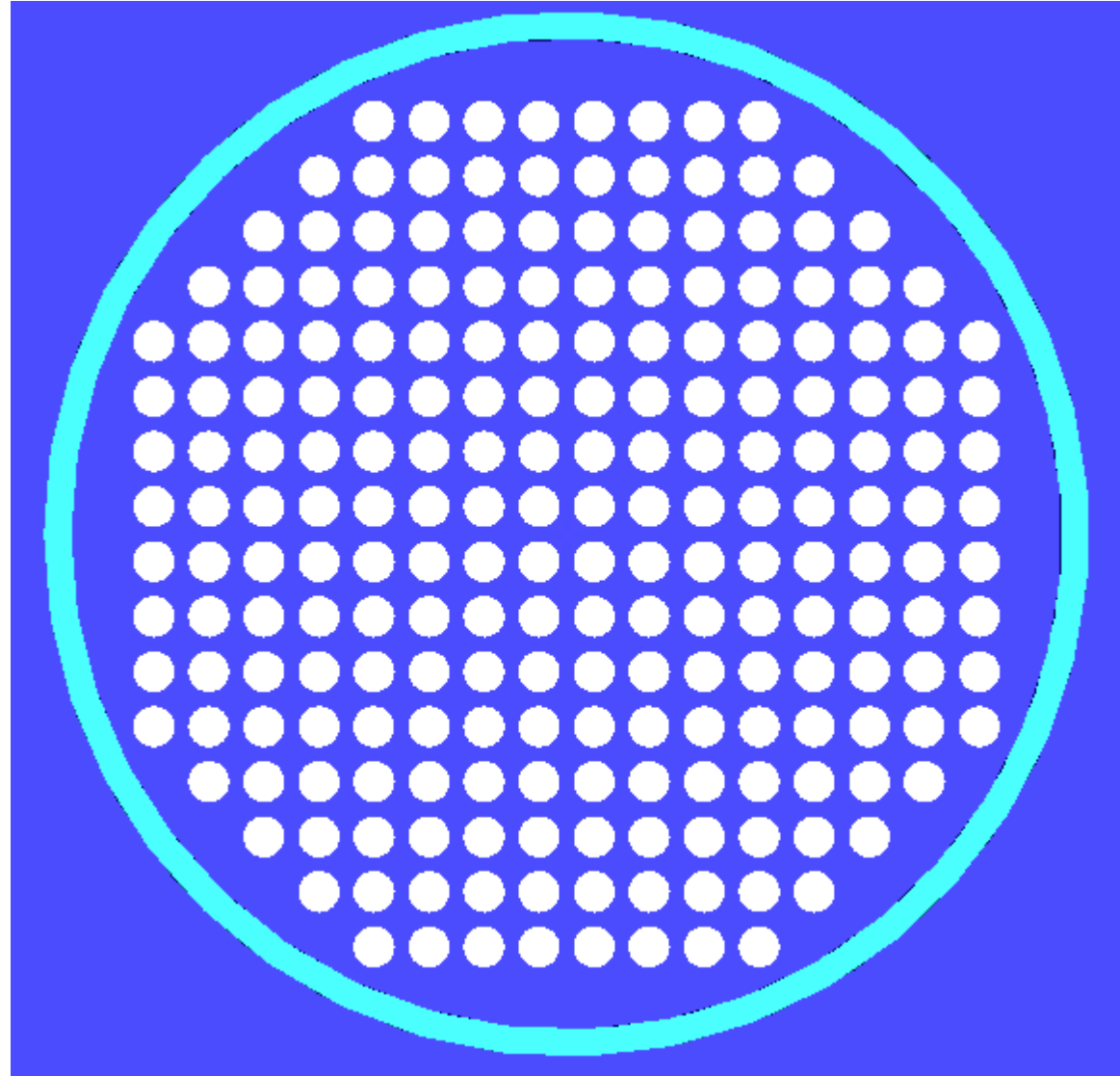
Wall & Bottom 0.5 cm Aluminum

Tank is filled to 45 cm with H_2O

Tank is reflected on the bottom and
sides with 30 cm H_2O

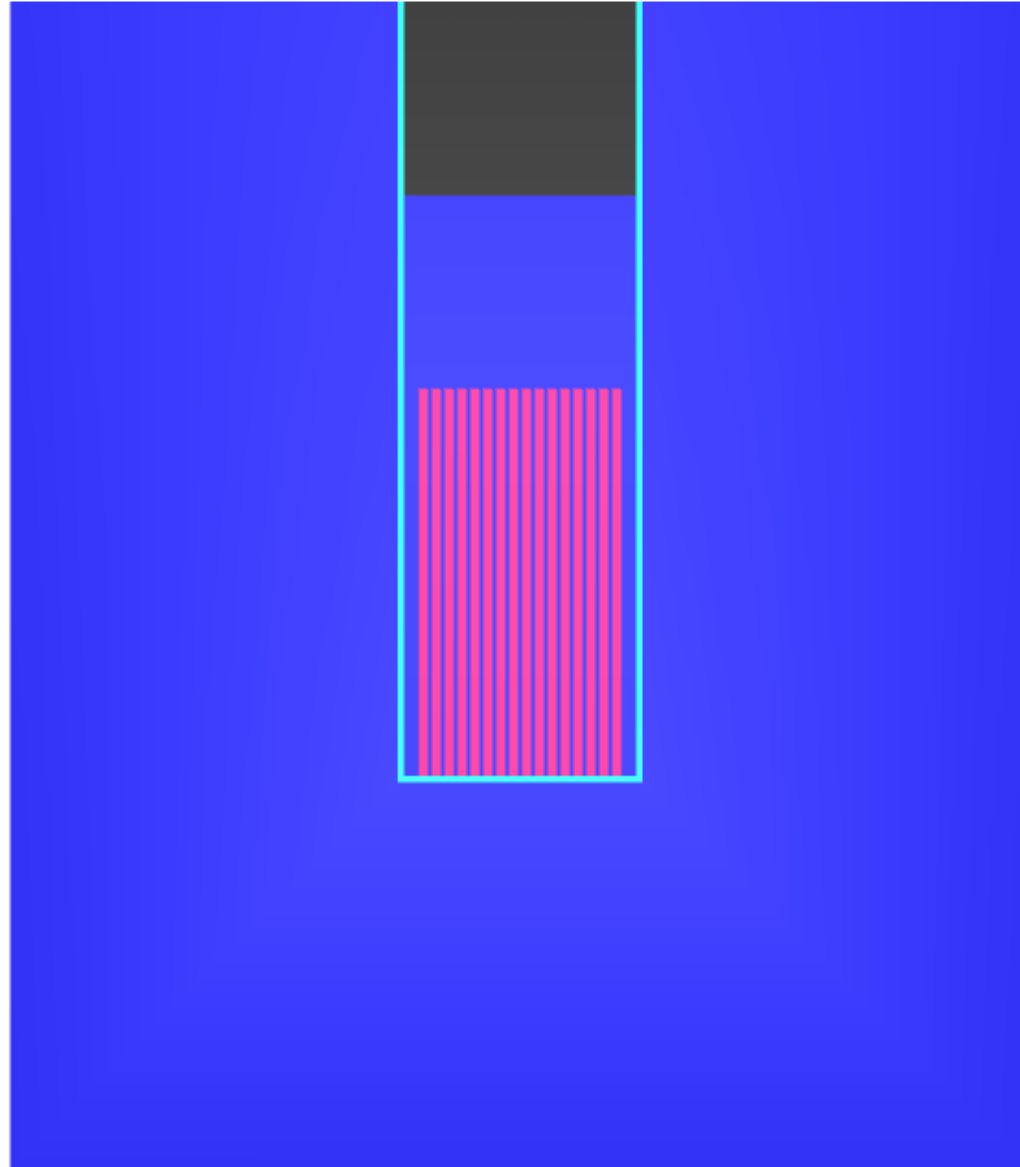
Fuel rods sit on the tank bottom

Problem: Pins in a tank (radial view)

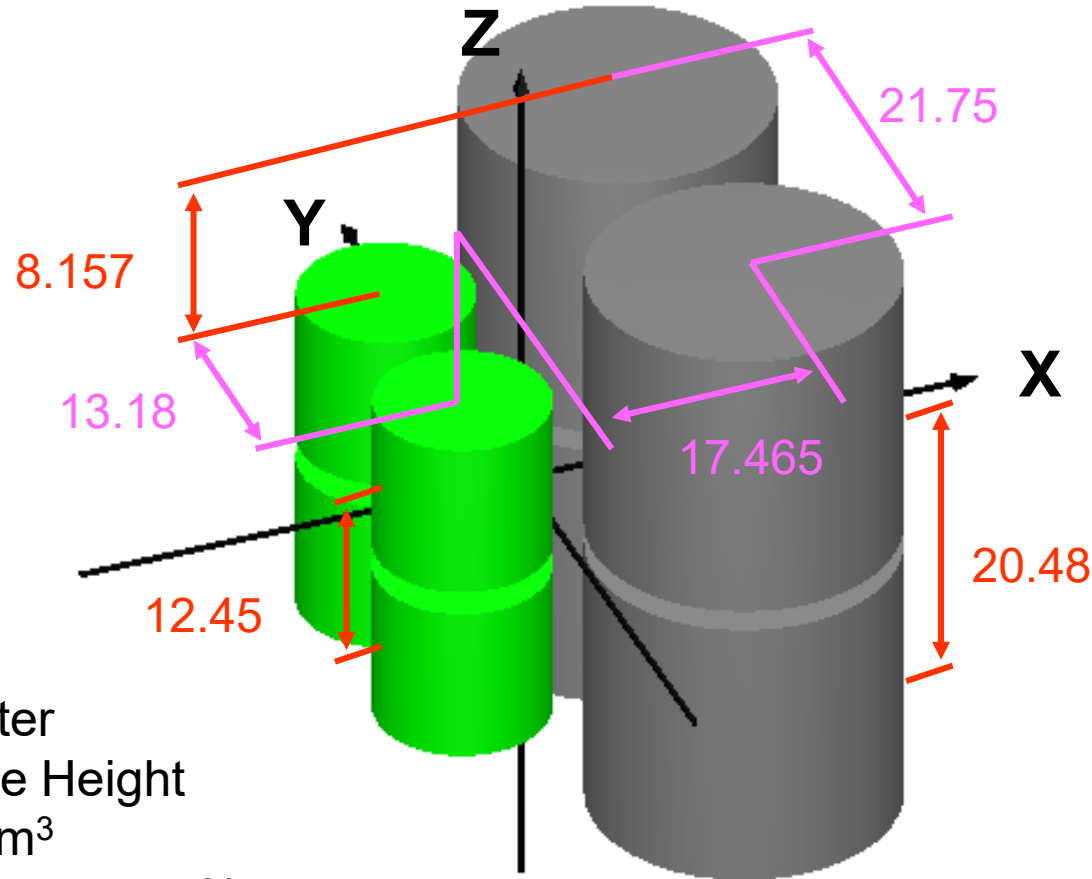


**Reflector is not
shown completely**

Problem: Pins in a tank (axial view)



Problem: 4 aqueous – 4 metal (4A-4M) array



Metal Cylinders

11.496 cm Diameter

10.765 cm Outside Height

Density 18.76 g/cm³

Enrichment: U-234 1.0 wt%

U-235 93.2 wt%

U-236 0.2 wt%

U-238 5.6 wt%

UO₂(NO₃)₂ Solution

415 g U/I Solution

Let SCALE calculate density

0.39 mg excess NO₃ / g solution

NO₃ Molecular weight 61.9895

(0.009783 M excess HNO₃)

Enrichment:

U-234 1.0 wt%

U-235 92.6 wt%

U-236 0.5 wt%

U-238 5.9 wt%

Plexiglass Containers

19.05 cm ID

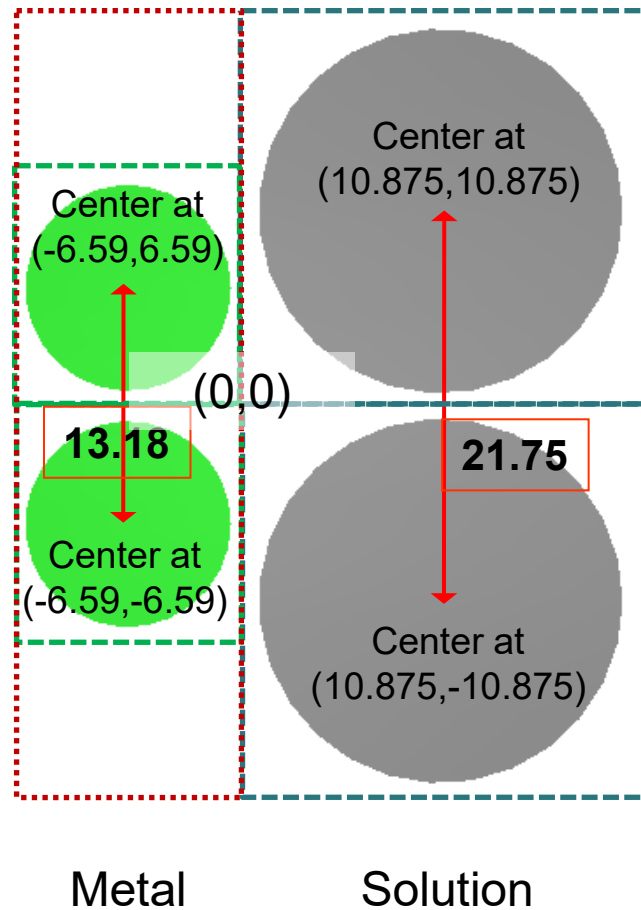
19.05 cm Outside Height

0.635 cm thick wall & ends

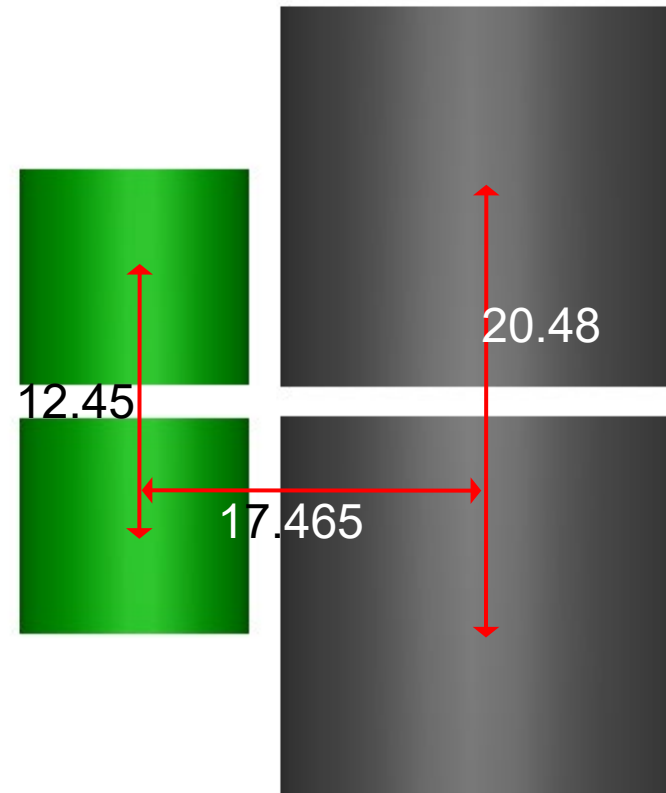
Filled with UO₂ (NO₃)₂ Solution

4A-4M Array

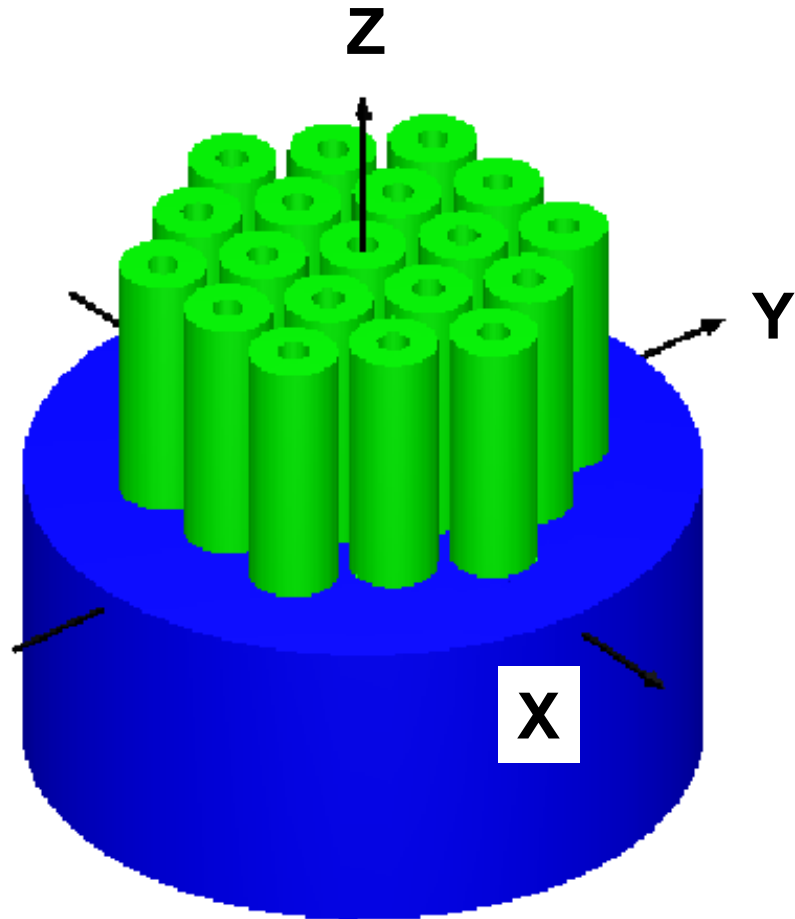
X-Y View



X-Z View



Problem: Hexagonal array of annular rods



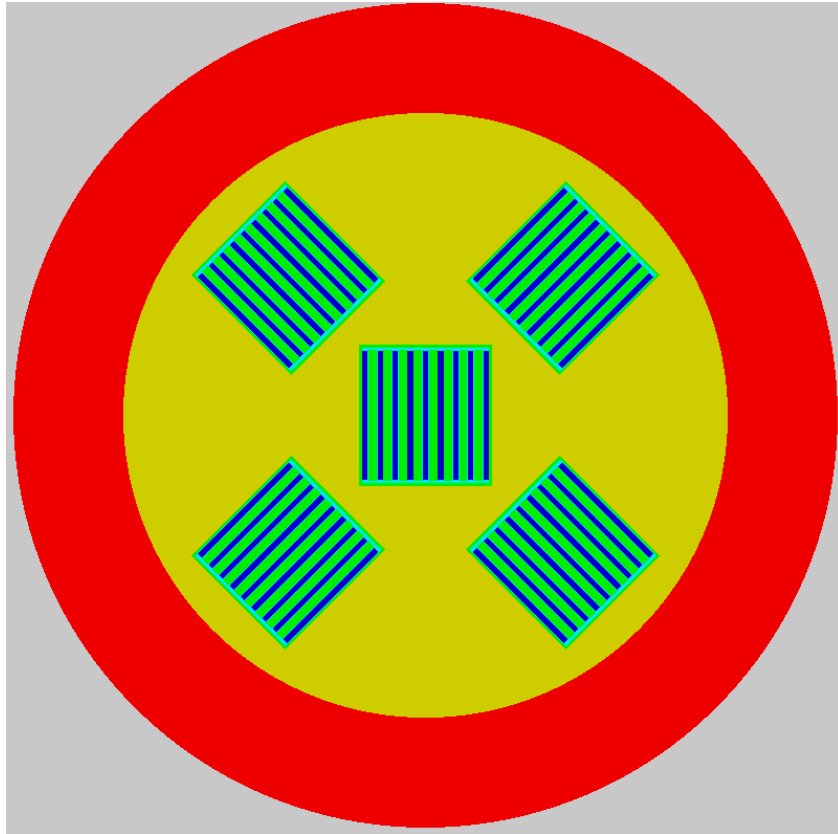
Hexagonal Array of Rods

19 rods in triangular pitched array
20.828 cm pitch (center-to-center)
Water flooded
18 cm below bottom of rods
70.0 cm radius from center
47.1 cm above bottom of rods

Annular Rods

3.302 cm inner radius
9.144 cm outer radius
101.6 cm in length
Uranium Metal
density = 19.0 g / cc
Enrichment:
U-235 1.950 wt %
U-238 98.042 wt %
U-234 0.002 wt %
U-236 0.006 wt %

Problem: GOSLAR cask



U-Al Fuel Plates

density = 3.78 g/cc
93.36 % Al
6.64 % U
Enrichment:
U-235: 92.85 wt %
U-238: 7.15 wt %

Fuel Plate Dimensions:

0.4 cm thickness
9.4 cm width
60.0 cm length
0.05 cm Al cladding on all sides
Al density = 2.7 g/cc

Fuel Assembly

contains 9 fuel plates
0.6 cm H₂O gap between plates
0.2 cm thick Al plate connects
fuel plates along edge
0.2 cm H₂O on X & Y surfaces

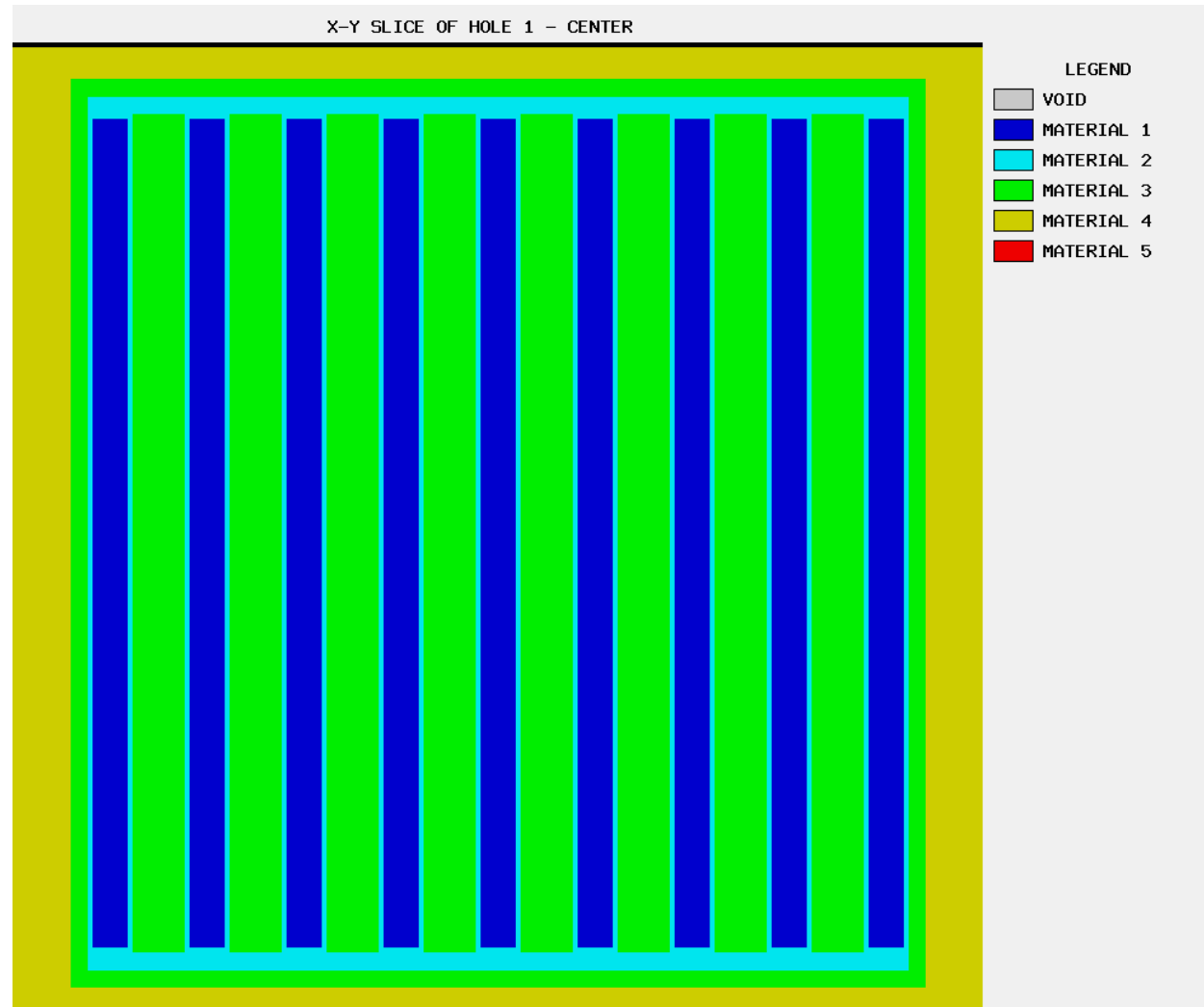
SS304 Fuel Cask

30.0cm radius x 100 cm length (outer)
22 cm radius x 80 cm length (inner)
ss304 density = 7.92 g/cc
Between assemblies: Al at **0.27** g/cc
1 center assembly and
4 outer assemblies rotated 45°

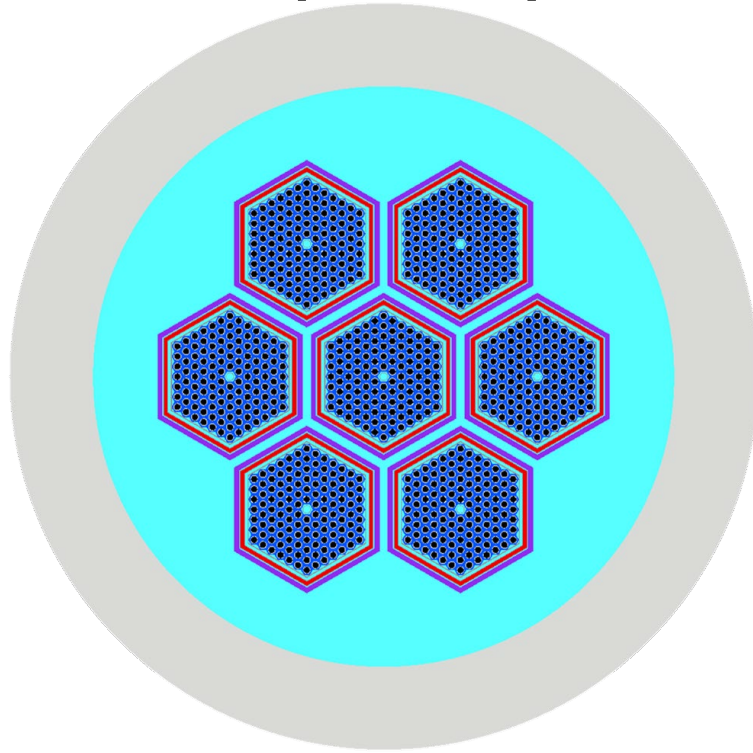
Not a typo

Offset from Center of Cask to the
Center of each Fuel Assembly
X=0.0, Y=0.0, Z=0.0
X=10.0, Y=10.0, Z=0.0
X=10.0, Y=-10.0, Z=0.0
X=-10.0, Y=-10.0, Z=0.0
X=-10.0, Y=10.0, Z=0.0

Problem: GOSLAR cask: Fuel assembly



Problem:(Mini) CASTOR cask



Instrument Tube

0.44 cm inner radius
0.515 cm outer radius
242.0 cm length
Zr density = 6.4369 g / cc
H₂O filled

UO2 Fuel Rods

3.6 % U-235 96.4 % U-238 UO₂
density = 10.192 g / cc
0.38 cm Fuel radius
242.0 cm Fuel length
0.075 cm thick Zr clad
Zr density = 6.088 g / cc

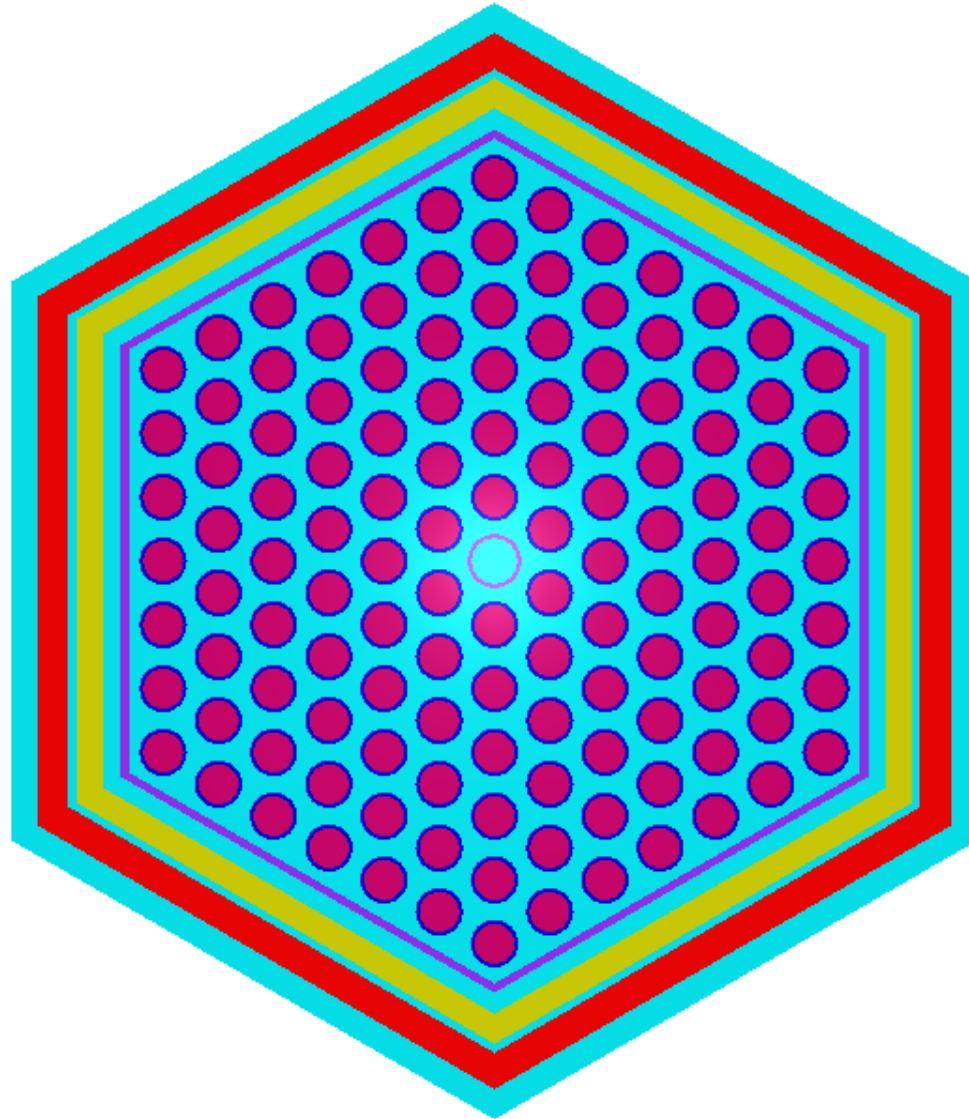
Fuel Assembly

Water Flooded
1.22 cm pitch
126 fuel rods + 1 Instrument Tube
Central position is Instrument Tube
7.0 cm from center, 0.15 cm thick Zr plate
Zr density = 6.4369 g / cc
7.5 cm from center, 0.5 cm thick ss304-b plate
ss304-b density = 8.3157 g / cc
0.938 wt % natural boron
8.15 cm from center, 0.6 cm thick Al plate
Al density = 2.79 g / cc
18.5 cm Assembly Pitch

SS304 Fuel Cask

water flooded
contains 7 fuel assemblies
5 cm water above and below fuel
1.0 cm spacing between fuel assemblies
Inner radius = 35.0 cm
Wall, Top, and Bottom thickness = 10.0 cm
Cask outside length = 272.0 cm
SS304 density = 7.92 g / cc
Fuel positioned in center of cask

Problem: CASTOR cask: Fuel assembly in cell



Calculated k-eff values

KENO-VI	k_{eff}	Std Dev	Run-time (s)	Comparison (MG-CE)
Pins in a tank (CE)	0.8665	0.0017	91.14	-0.0006 $\pm$ 0.0024 (0.3 σ)
Pins in a tank (MG)	0.8659	0.0017	64.04	
4A-4M (CE)	1.0032	0.0022	20.25	-0.0016 $\pm$ 0.0034 (0.5 σ)
4A-4M (MG)	1.0016	0.0026	27.58	

Your results may differ based on the options and computer used

Calculated k-eff values

Shift	k_{eff}	Std Dev	Run-time (s)	Comparison (MG-CE)
Pins in a tank (CE)	0.864878	0.002930	80.84	0.002355 $\pm$ 0.003837 (0.61 σ)
Pins in a tank (MG)	0.867233	0.002478	69.53	
4A-4M (CE)	1.001237	0.003230	21.61	0.003925 $\pm$ 0.004100 (0.96 σ)
4A-4M (MG)	1.005162	0.002526	29.29	

Your results may differ based on the options and computer used

Calculated k-eff values

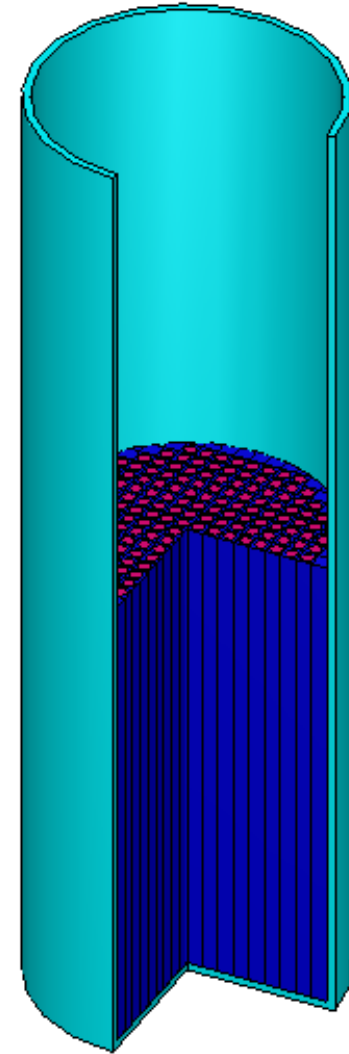
	KENO-VI	Shift
Pins in a tank (CE)	0.8665 +/- 0.0017	0.864878 +/- 0.002930
Pins in a tank (MG)	0.8659 +/- 0.0017	0.867233 +/- 0.002478
4A-4M (CE)	1.0032 +/- 0.0022	1.001237 +/- 0.003230
4A-4M (MG)	1.0016 +/- 0.0026	1.005162 +/- 0.002526

Your results may differ based on the options and computer used

Solution: Pins in a tank

```
=csas6
tank of 20% u rods in aluminum tank
ce_v7.1_endf
read composition
  uranium      1 1 293
                92235 20
                92238 80      end

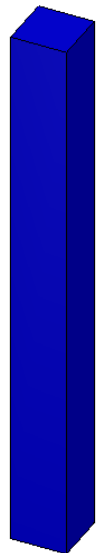
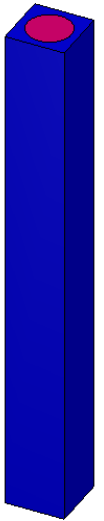
  h2o          2      end
  al           3      end
  h2o          4      end
end composition
read celldata
  latticecell squarepitch fuelr=0.375 1 hpitch=0.5 2 end
end celldata
read parameter
  fdn=yes
end parameter
```



Solution: Pins in a tank (cont.)

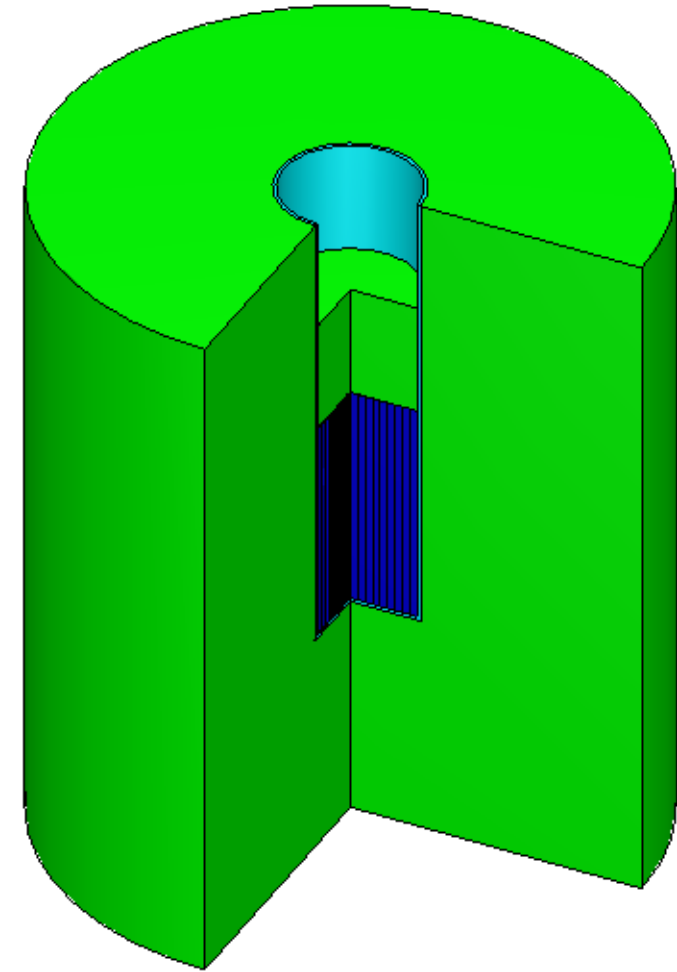
```
read geometry
unit 1
  cylinder 10      0.375      15      -15
  cuboid 20      0.5      -0.5      0.5      -0.5      15      -15
  media 1 1 10
  media 2 1 20 -10
  boundary 20

unit 2
  cuboid 20      0.5      -0.5      0.5      -0.5      15      -15
  media 2 1 20
  boundary 20
```



Solution: Pins in a tank (cont.)

```
global unit 3
cylinder 10      9      15      -15
cylinder 20      9      30      -15
cylinder 30      9      45      -15
cylinder 40      9.5    45      -15.5
array 1 10 place 10 10 1 -0.5 -0.5 0
cylinder 50      39.5    45      -45.5
media 4 1 20 -10
media 0 1 30 -20
media 3 1 40 -30
media 4 1 50 -40
boundary 50
end geometry
read array
ara=1 nux=20 nuy=20 nuz=1 typ=square
```

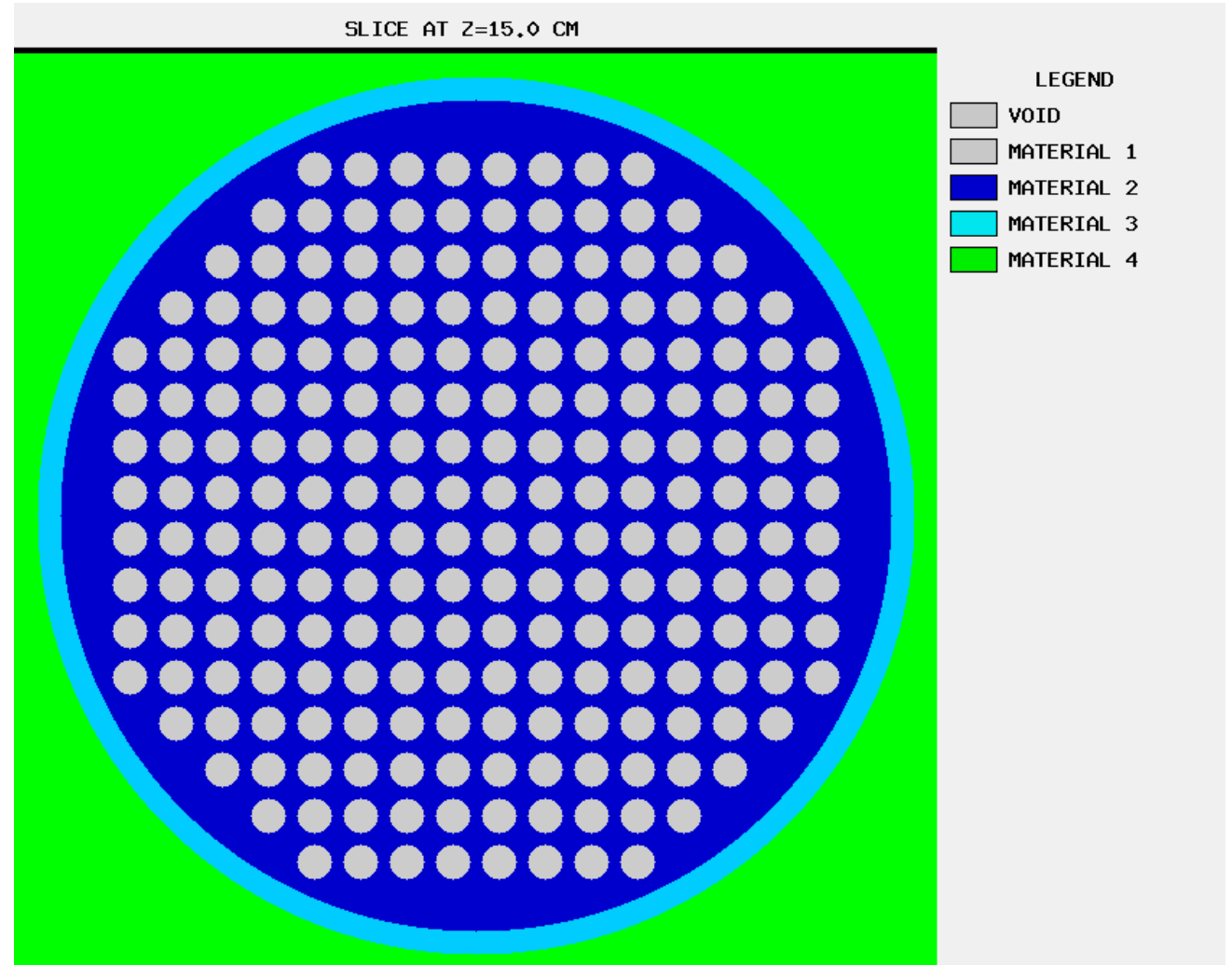


Solution: Pins in a tank (cont.)

```
fill
  2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
  2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
  2    2    2    2    2    2    1    1    1    1    1    1    1    1    2    2    2    2    2    2
  2    2    2    2    2    1    1    1    1    1    1    1    1    1    2    2    2    2    2    2
  2    2    2    2    1    1    1    1    1    1    1    1    1    1    1    1    2    2    2    2
  2    2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2
  2    2    2    1    1    1    1    1    1    1    1    1    1    1    1    1    1    2    2    2
  2    2    2    2    2    1    1    1    1    1    1    1    1    1    2    2    2    2    2    2
  2    2    2    2    2    2    1    1    1    1    1    1    1    2    2    2    2    2    2    2
  2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2    2
end fill
end array
```

Solution: Pins in a tank (cont.)

```
read plot
  ttl='slice at z=15.0 cm '
  xul=-10  yul=10  zul=0
  xlr=10   ylr=-10  zlr=0
  nax=640
  clr=1 200 200 200
        2 0 0 205
        3 0 229 238
        4 0 238 0
  end color
  typ=xy end
end plot
end data
end
```



Solution: 4A-4M array

```
=csas6 parm=( )
```

```
Class exercise: 4a-4m
```

```
ce_v7.1
```

```
read comp
```

```
u 1 den=18.76 1.0 293 92234 1.0 92235 93.2 92236 0.2 92238 5.6 end
```

```
solution mix=2
```

```
    rho[uo2(no3)2]=415.0 92234 1.0 92235 92.6 92236 0.5 92238 5.9
```

```
    molar[hno3]=0.009783
```

```
    density=1.555 temp=293 volfrac=1.0
```

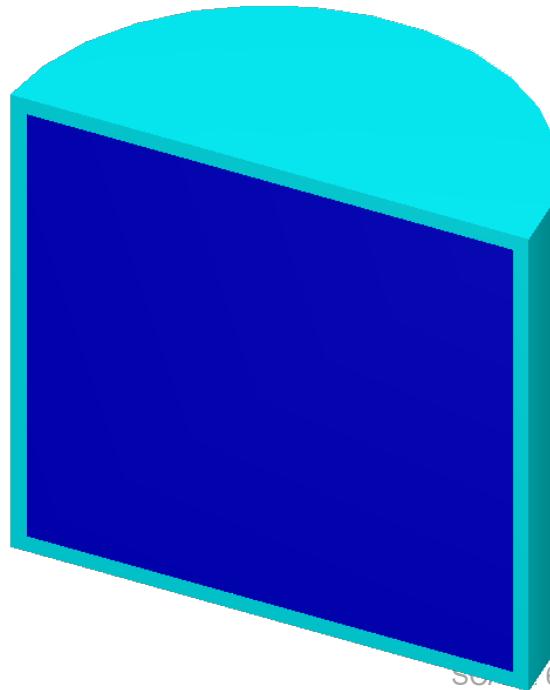
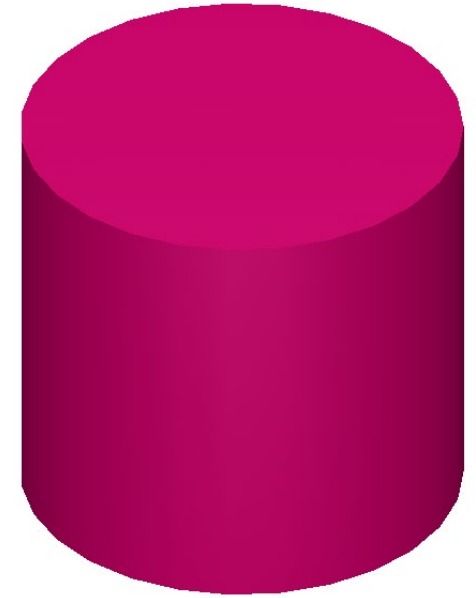
```
end solution
```

```
plexiglas 3 end
```

```
end comp
```

Solution: 4A-4M array (cont.)

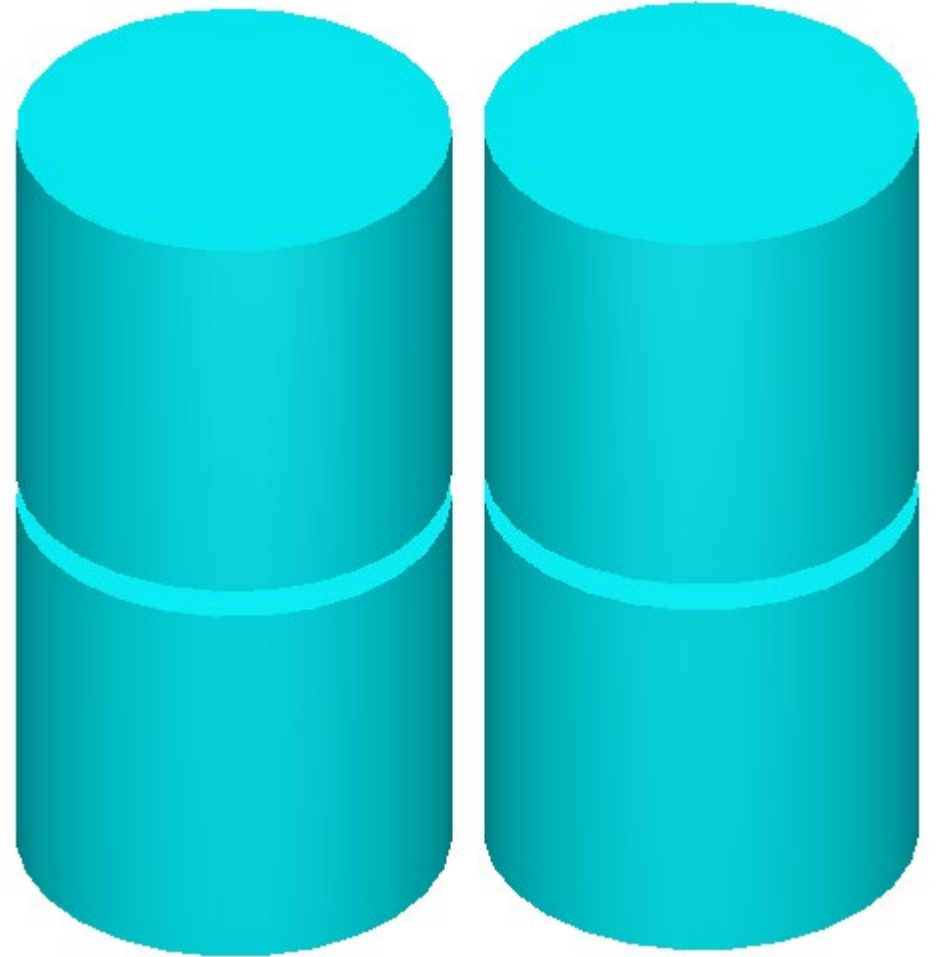
```
unit 1
com='metal cylinders'
  cylinder 10 5.748 5.3825 -5.3825
  cuboid 20 4p6.59 2p6.225
,
  media 1 1 10
  media 0 1 20 -10
boundary 20
unit 2
com='solution cylinders'
  cylinder 20 9.525 8.889 -8.889
  cylinder 30 10.16 9.525 -9.525
  cuboid 40 4p10.875 10.24 -10.24
,
  media 2 1 20
  media 3 1 30 -20
  media 0 1 40 -30
boundary 40
```



Solution: 4A-4M array (cont.)

```
unit 3
com='array of solution tanks'
  cuboid 10 2p10.875 2p21.75 2p20.48
  array 2 10 place 1 1 1 0 -10.875 -10.24
boundary 10
```

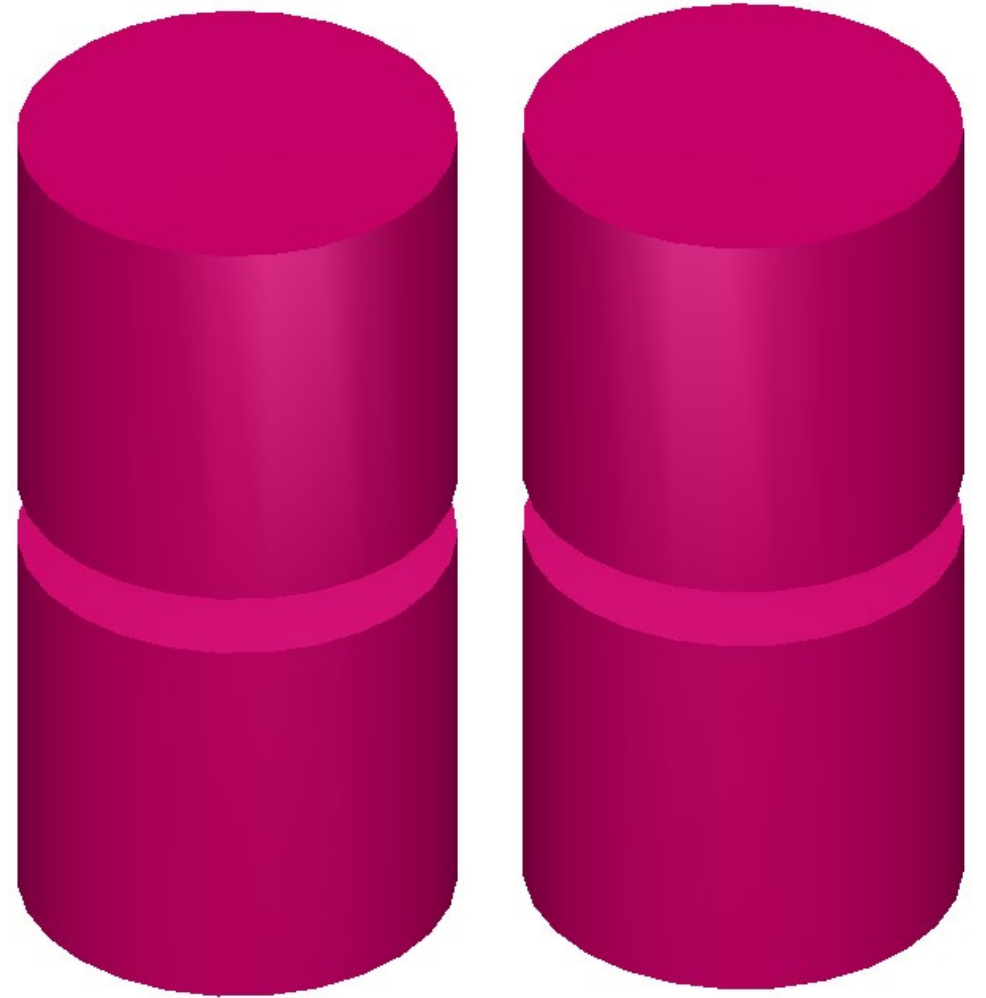
```
ara=2
prt=yes
nux=1
nuy=2
nuz=2
com="Array of solution tanks"
fill
' z = 1
2
2
' z = 2
2
2
end fill
```



Solution: 4A-4M array (cont.)

```
unit 4
com='array of metal cylinders'
  cuboid 10 2p6.59 2p13.18 2p12.45
  cuboid 20 6.59 -6.59 21.75 -21.75 20.48 -20.48
  array 1 10 place 1 1 1 0 -6.59 -6.225
  media 0 1 20 -10
boundary 20
```

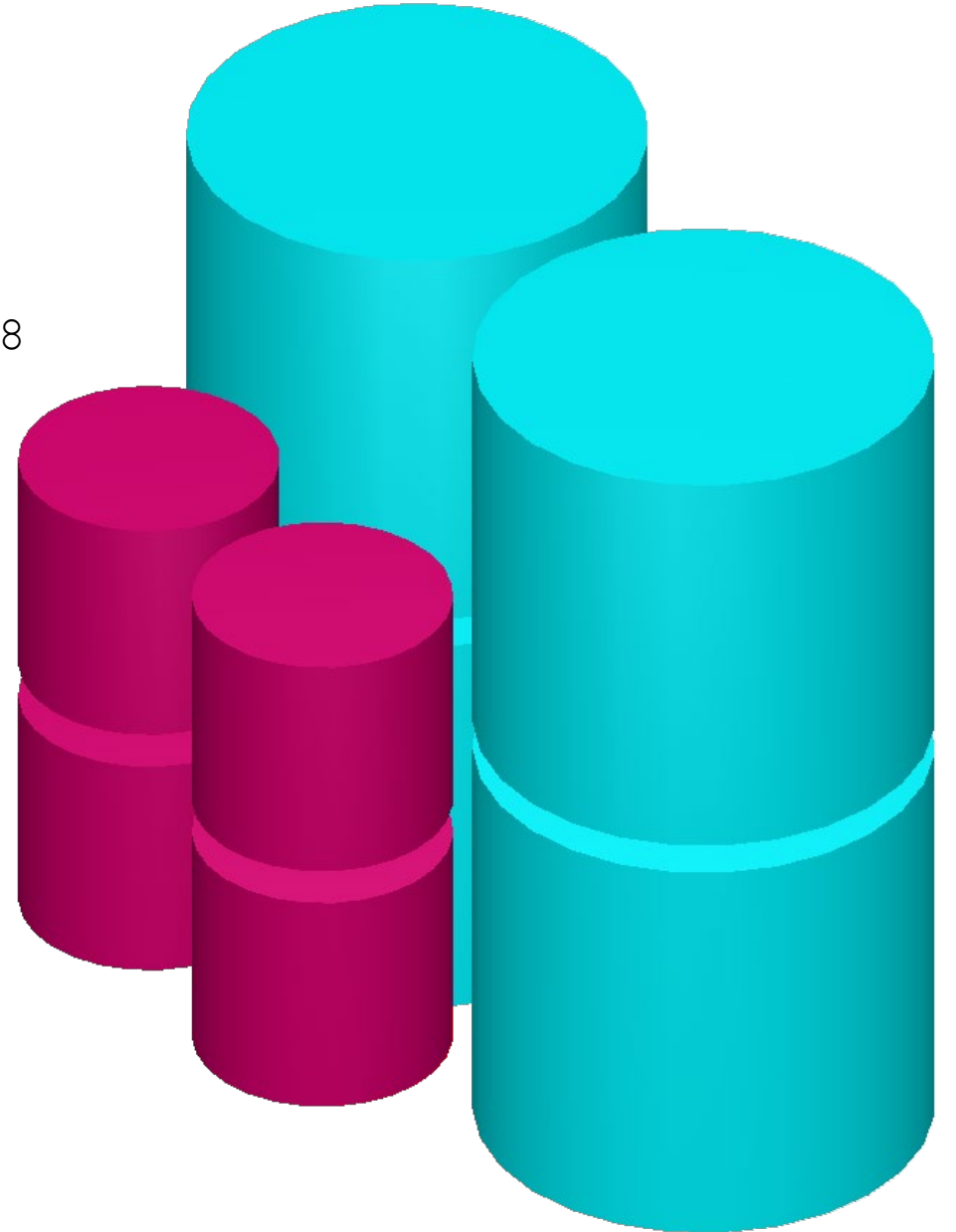
```
ara=1 nux=1 nuy=2 nuz=2
com='array of metal cylinders'
fill 1 1
  1 1 end fill
```



Solution: 4A-4M array (cont.)

```
global unit 5
com='global, containing array of arrays'
  cuboid 10 21.75 -13.18 21.75 -21.75 20.48 -20.48
  array 3 10 place 1 1 1 -6.59 0 0
boundary 10
```

```
ara=3 nux=2 nuy=1 nuz=1
com='array of arrays'
fill 4 3 end fill
```



Calculated k-eff results

KENO-VI	k_{eff}	std. dev.	Run-time (s)	Comparison (MG-CE)
Annular hex array – ce_v7.1	1.0028	0.0014	55.89	-0.0020 ± 0.0021 (0.95 σ)
Annular hex array – v7.1-252	1.0008	0.0016	40.65	
Goslar cask – ce_v7.1	0.4903	0.0019	49.99	0.0003 ± 0.0024 (0.13 σ)
Goslar cask – v7.1-252	0.4906	0.0015	24.14	
Castor cask – ce_v7.1	0.6265	0.0024	51.66	-0.0003 ± 0.0029 (0.10 σ)
Castor cask – v7.1-252	0.6262	0.0017	32.25	

Your results may differ based on the options, geometry, and computer used

Calculated k-eff results

Shift	k _{eff}	std. dev.	Run-time (s)	Comparison (MG-CE)
Annular hex array – ce_v7.1	1.003093	0.002259	52.38	-0.001167 ± 0.003517 (0.33 σ)
Annular hex array – v7.1-252	1.001926	0.002379	47.23	
Goslar cask – ce_v7.1	0.488151	0.002671	63.91	0.002537 ± 0.003342 (0.76 σ)
Goslar cask – v7.1-252	0.490688	0.002009	30.73	
Castor cask – ce_v7.1	0.626487	0.002246	67.66	-0.004000 ± 0.003058 (1.31 σ)
Castor cask – v7.1-252	0.622487	0.002075	40.97	

Your results may differ based on the options, geometry, and computer used

Calculated k-eff values

	KENO-VI	Shift
Annular hex array – ce_v7.1	1.0028 +/- 0.0014	1.003093 +/- 0.002259
Annular hex array – v7.1-252	1.0008 +/- 0.0016	1.001926 +/- 0.002379
Goslar cask – ce_v7.1	0.4903 +/- 0.0019	0.488151 +/- 0.002671
Goslar cask – v7.1-252	0.4906 +/- 0.0015	0.490688 +/- 0.002009
Castor cask – ce_v7.1	0.6265 +/- 0.0024	0.626487 +/- 0.002246
Castor cask – v7.1-252	0.6262 +/- 0.0017	0.622487 +/- 0.002075

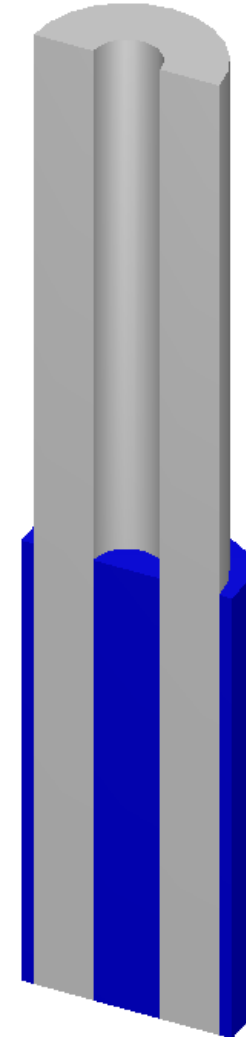
Your results may differ based on the options and computer used

Solution: Hexagonal Array - CE

```
=csas6
critical triangular pitched array of annular rods
ce_v7.1_endf
read composition
  uranium      1 den=19 1 293
                                92234 0.002
                                92235 1.95
                                92236 0.006
                                92238 98.042      end
  h2o           2 1 293      end
end composition
read parameter
  htm=yes
end parameter
```

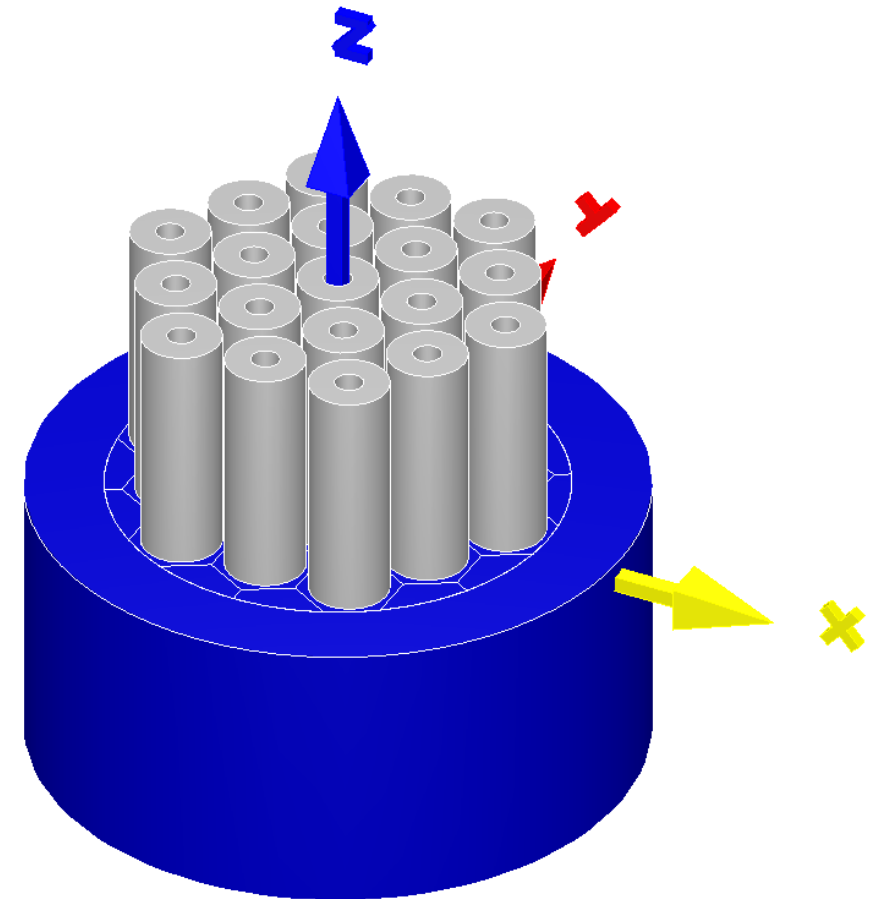
Solution: Hexagonal Array – CE (cont.)

```
read geometry
unit 1
com="flooded annular rod"
cylinder 10      3.302      47.1      0
cylinder 20      9.144      47.1      0
hexprism 30      10.414     47.1      0
cylinder 40      3.302     101.6      0
cylinder 50      9.144     101.6      0
hexprism 60      10.414     101.6      0
media 2 1 10
media 1 1 20 -10
media 2 1 30 -20 -10
media 0 1 40 -10
media 1 1 50 -40 -20
media 0 1 60 -50 -30
boundary 60
```



Solution: Hexagonal Array – CE (cont.)

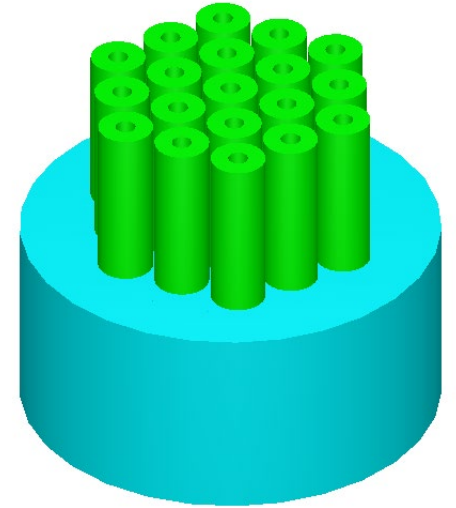
```
unit 2
  hexprism 10    10.414    47.1    0
  hexprism 20    10.414    101.6    0
  media 2 1 10
  media 0 1 20 -10
  boundary 20
global unit 5
com="7x7x1 hexprism array"
  cylinder 10    52    101.6    0
  cylinder 20    70    47.1    -18
  cylinder 30    70    101.6    -18
  array 1 10 place 4 4 1 0 0 0
  media 2 1 20 -10
  media 0 1 30 -20 -10
  boundary 30
end geometry
```



Solution: Hexagonal Array – CE (cont.)

```
read array
ara=1 nux=7 nuy=7 nuz=1 typ=shexagonal gbl=1
  fill
    2      2      2      2      2      2      2
    2      2      1      1      1      2      2
    2      2      1      1      1      1      2
    2      1      1      1      1      1      2
    2      2      1      1      1      1      2
    2      2      1      1      1      2      2
    2      2      2      2      2      2      2
  end fill
end array
end data
end
```

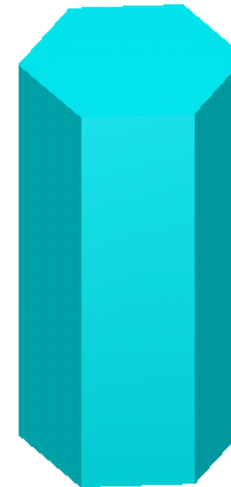
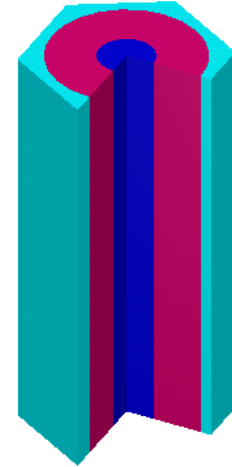
Solution: Hexagonal Array - MG



```
=csas6
critical triangular pitched array of annular rods
v7.1-252n
read composition
  uranium      1 den=19 1 293
                92235 1.95      92238 98.042      92234 0.002      92236 0.006      end
  h2o          2 1 293      end
  h2o          3 1 293      end
  uranium      4 den=19 1 293
                92235 1.95      92238 98.042      92234 0.002      92236 0.006      end
end composition
read celldata
  latticecell atriangpitch imodr=3.302 2 fuelr=9.144 1 hpitch=10.414 3 end
end celldata
```

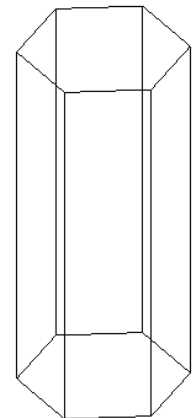
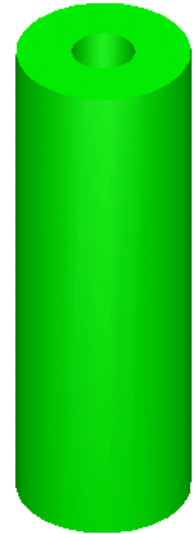
Solution: Hexagonal Array – MG (Cont.)

```
read geometry
unit 1
com='flooded annular rod'
  cylinder 10          3.302          47.1          0
  cylinder 20          9.144          47.1          0
  hexprism 30         10.414          47.1          0
media 2 1 10
media 1 1 20 -10
media 3 1 30 -20
boundary 30
unit 2
  hexprism 10         10.414          47.1          0
media 3 1 10
boundary 10
```



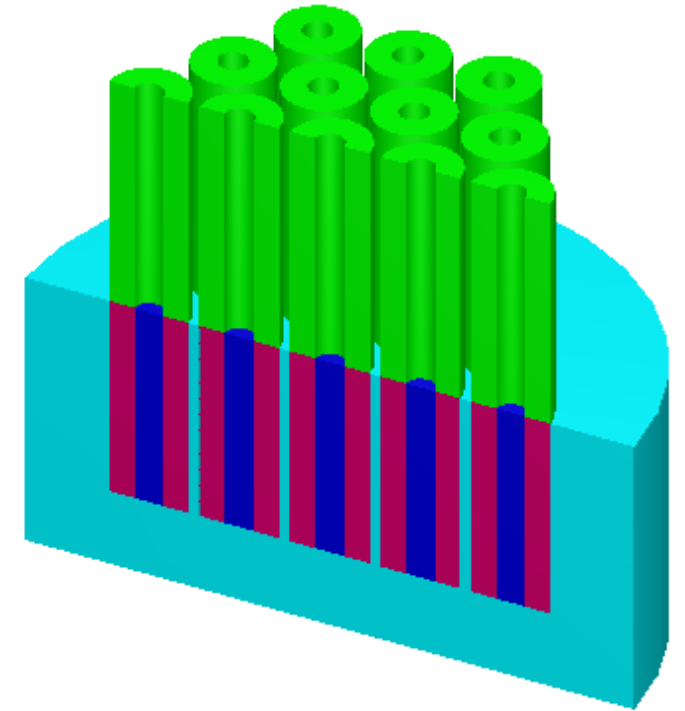
Solution: Hexagonal Array – MG (Cont.)

```
unit 3
com='void annular rod'
  cylinder 10      3.302      54.5      0
  cylinder 20      9.144      54.5      0
  hexprism 30      10.414      54.5      0
  media 0 1 10
  media 4 1 20 -10
  media 0 1 30 -20 -10
  boundary 30
unit 4
  hexprism 10      10.414      54.5      0
  media 0 1 10
  boundary 10
```



Solution: Hexagonal Array - MG (Cont.)

```
global unit 5
com='7x7x2 hexprism array'
cylinder 10      52      101.6      0
cylinder 20      70       47.1     -18
cylinder 30      70      101.6     -18
array 1 10 place 4 4 1 0 0 0
media 3 1 20 -10
media 0 1 30 -20
boundary 30
end geometry
```



Solution: Hexagonal Array - MG (Cont.)

```
read array
ara=1 nux=7 nuy=7 nuz=2 typ=shexagonal
fill
  2      2      2      2      2      2      2
    2      2      1      1      1      2      2
  2      2      1      1      1      1      2
    2      1      1      1      1      1      2
  2      2      1      1      1      1      2
    2      2      1      1      1      2      2
  2      2      2      2      2      2      2
```

Solution: Hexagonal Array - MG (Cont.)

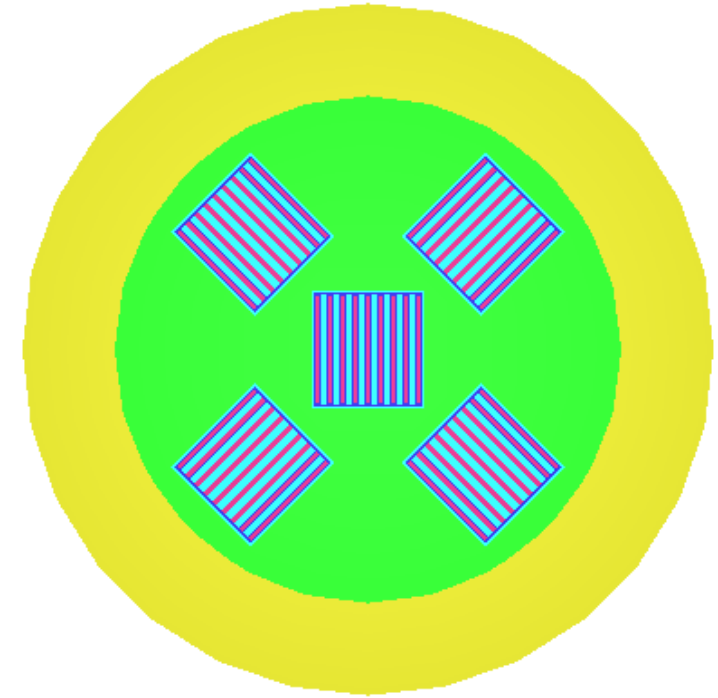
```
4      4      4      4      4      4      4
      4      4      3      3      3      4      4
4      4      3      3      3      3      4
      4      3      3      3      3      3      4
4      4      3      3      3      3      4
      4      4      3      3      3      4      4
4      4      4      4      4      4      4
```

```
end fill
end array
end data
end
```

Solution: Goslar Cask

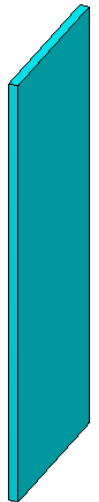
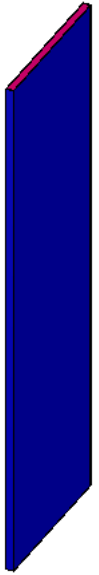
```
=csas6
baby goslar fuel cask  92.85 w% u-235
ce_v7.1_endf
read composition
  uranium      1 den=3.78 0.0664 293
                                     92235 92.85
                                     92238 7.15      end

  al           1 den=3.78 0.9336 293      end
  al           2 den=2.7  1 293      end
  h2o          3 1 293      end
  al           4 den=2.7 0.1 293      end
  ss304        5 1 293      end
end composition
read celldata
  latticecell symmslabcell fuelr=0.2 1 cladr=0.25 2 hpitch=0.55 3 end
end celldata
```



Solution: Goslar Cask (Cont.)

```
read geometry
unit 1
com='fuel slab'
  cuboid 10      0.2      -0.2      4.7      -4.7      30      -30
  cuboid 20      0.25     -0.25     4.75     -4.75     30.05     -30.05
  media 1 1 10
  media 2 1 20 -10
  boundary 20
unit 2
com='h2o slab'
  cuboid 10      0.3      -0.3      4.75     -4.75     30.05     -30.05
  media 3 1 10
  boundary 10
```



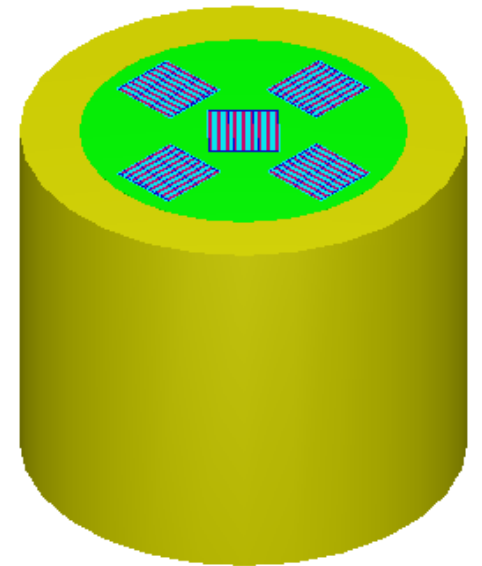
Solution: Goslar Cask (Cont.)

```
unit 3
com='single assembly'
cuboid 10      4.65      -4.65      4.75      -4.75      30.05      -30.05
cuboid 20      4.65      -4.65      4.95      -4.95      30.05      -30.05
cuboid 30      4.85      -4.85      5.15      -5.15      30.05      -30.05
array 1 10 place 9 1 1 0 0 0
media 2 1 20 -10
media 3 1 30 -20 -10
boundary 30
```



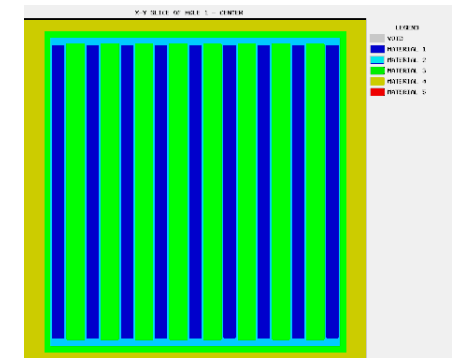
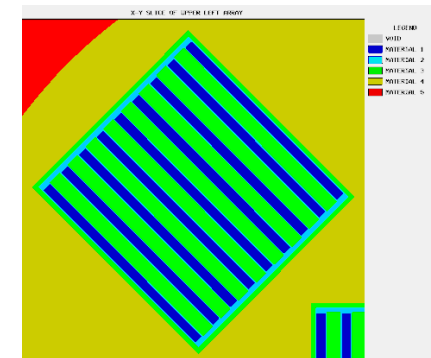
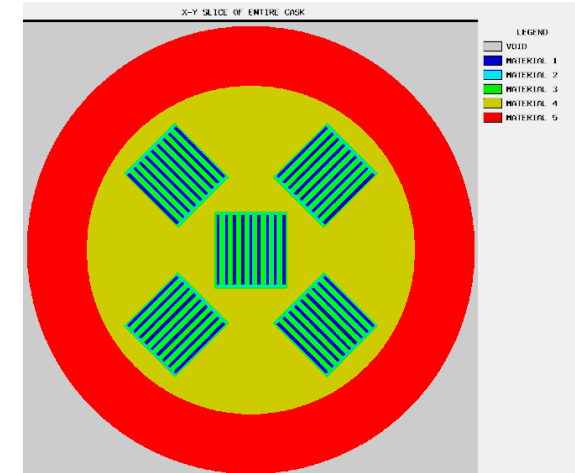
Solution: Goslar Cask (Cont.)

```
global unit 10
cylinder 10      22      40      -40
hole 3
hole 3  origin  x=10 y=10 z=0      rotate  a1=-45 a2=0 a3=0
hole 3  origin  x=10 y=-10 z=0     rotate  a1=-135 a2=0 a3=0
hole 3  origin  x=-10 y=-10 z=0    rotate  a1=135 a2=0 a3=0
hole 3  origin  x=-10 y=10 z=0     rotate  a1=45 a2=0 a3=0
cylinder 20      30      50      -50
cuboid 30      31      -31      31      -31      51      -51
media 4 1 10
media 5 1 20 -10
media 0 1 30 -20
boundary 30
end geometry
read array
ara=1 nux=17 nuy=1 nuz=1 typ=square
fill  1 2 1 2 1 2 1 2 1 2 1 2 1 2 1
end fill
end array
```



Solution: Goslar Cask (Cont.)

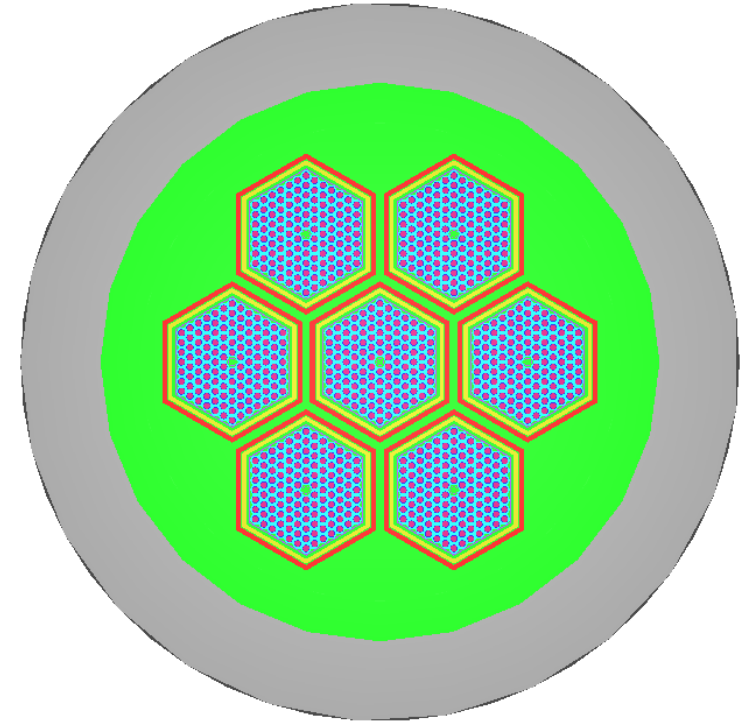
```
read plot
ttl='x-y slice of entire cask'
xul=-30.5  yul=30.5  zul=0
xlr=30.5   ylr=-30.5  zlr=0
nax=800    uax=1  vdn=-1  end
ttl='x-y slice of hole 1 - center'
xul=-5.5   yul=5.5   zul=0
xlr=5.5    ylr=-5.5   zlr=0
nax=800    uax=1  vdn=-1  end
ttl='x-y slice of upper left array'
xul=-17.5  yul=17.5   zul=0
xlr=-2.5   ylr=2.5    zlr=0
nax=800    uax=1  vdn=-1  end
end plot
end data
end
```



Solution: Castor Cask

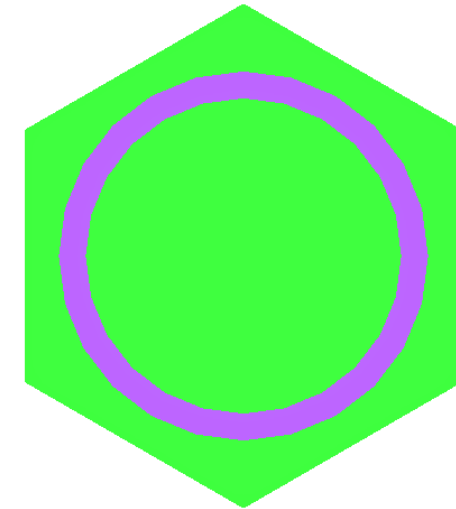
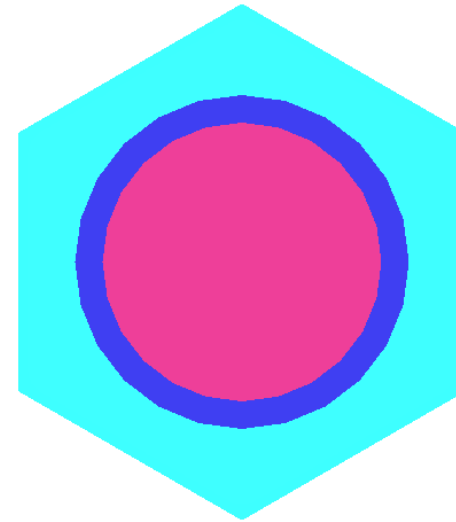
```
=csas6
castor 440/84 - wet infinite lattice
ce_v7.1_endf
read composition
  uo2          1 den=10.192 1 293
                                     92235 3.6
                                     92238 96.4      end

  zirconium    2 den=6.088 1 293      end
  h2o          3 1 293      end
  h2o          4 1 293      end
  b            5 den=0.078 1 293      end
  ss304        5 den=8.2377 1 293      end
  al           6 den=2.7 1 293      end
  zirconium    7 den=6.4369 1 293      end
  ss304        8 1 293      end
end composition
read celldata
  latticecell triangpitch fuelr=0.38 1 cladr=0.455 2 hpitch=0.61 3 end
end celldata
```



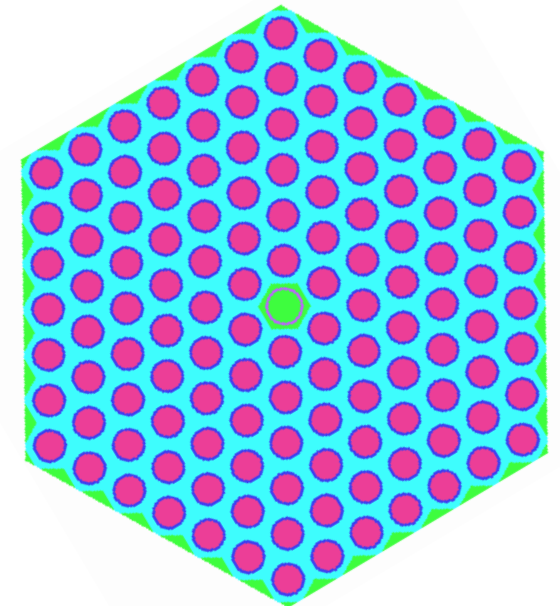
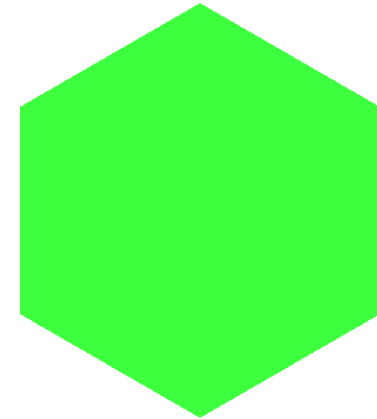
Solution: Castor Cask (Cont.)

```
read geometry
unit 1
com='fuel pin'
  cylinder 10      0.38      242      0
  cylinder 20      0.455     242      0
  hexprism 30      0.61      242      0
media 1 1 10
media 2 1 20 -10
media 3 1 30 -20
boundary 30
unit 2
com='central instrumental tube'
  cylinder 10      0.44      242      0
  cylinder 20      0.515     242      0
  hexprism 30      0.61      242      0
media 4 1 10
media 7 1 20 -10
media 4 1 30 -20
boundary 30
```



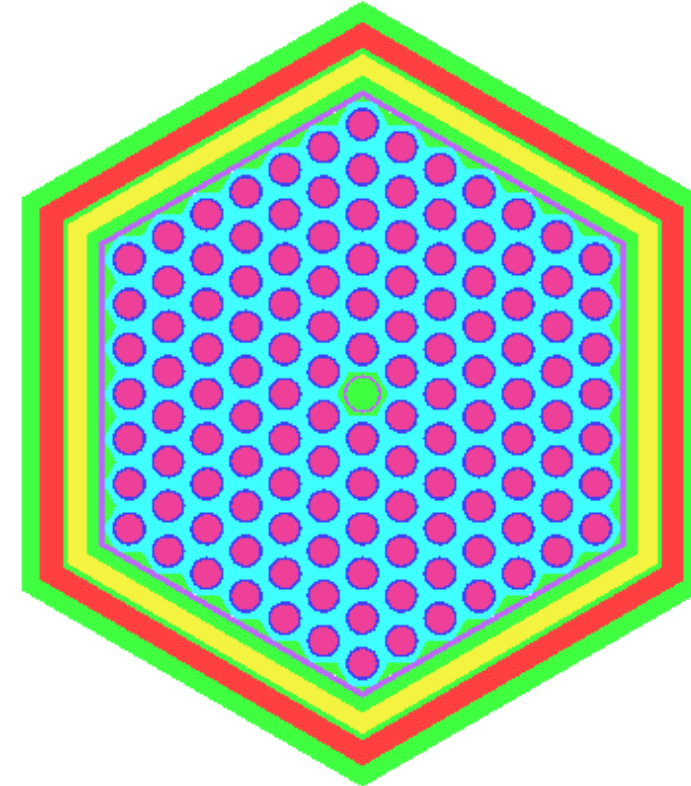
Solution: Castor Cask (Cont.)

```
unit 3
com='empty cell used to fill array'
  hexprism 10      0.61      242      0
  media 4 1 10
  boundary 10
unit 4
com='hexagonal unit of the lattice'
  hexprism 10      7      242      0      rotate      a1=30 a2=0 a3=0
  array 1 10 place 8 8 1 0 0 0
  boundary 10
```



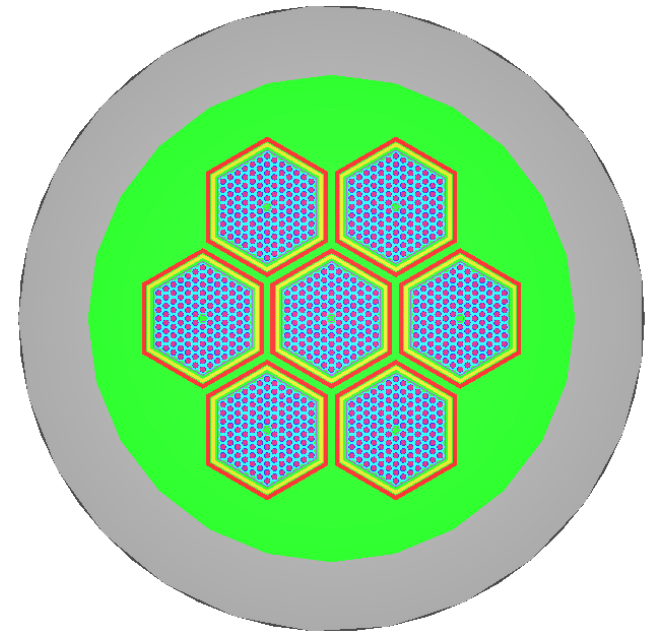
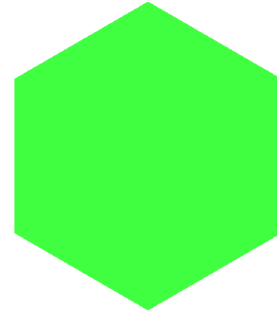
Solution: Castor Cask (Cont.)

```
unit 5
hexprism 20      7.15      242      0
hexprism 30      7.5       242      0
hexprism 40      8         242      0
hexprism 50      8.15      242      0
hexprism 60      8.75      242      0
hexprism 70      9.25      242      0
hole 4    rotate  a1=-30 a2=0 a3=0
media 7 1 20
media 4 1 30 -20
media 5 1 40 -30
media 4 1 50 -40
media 6 1 60 -50
media 4 1 70 -60
boundary 70
```



Solution: Castor Cask (Cont.)

```
unit 6
  hexprism 10      9.25      242      0
  media 4 1 10
  boundary 10
global unit 7
  cylinder 10      30      242      0
  cylinder 20      35      247      -5
  cylinder 30      45      257      -15
  array 2 10 place 3 3 1 0 0 0
  media 4 1 20 -10
  media 8 1 30 -20
  boundary 30
end geometry
```



Solution: Castor Cask (Cont.)

```
read array
ara=1 nux=15 nuy=15 nuz=1 typ=triangular
fill
  3      3      3      3      3      3      3      3      3      3      3      3      3      3      3
  3      3      3      3      3      3      3      1      1      1      1      1      1      1      3
  3      3      3      3      3      3      1      1      1      1      1      1      1      1      3
  3      3      3      3      3      1      1      1      1      1      1      1      1      1      3
  3      3      3      3      1      1      1      1      1      1      1      1      1      1      3
  3      3      3      1      1      1      1      1      1      1      1      1      1      1      3
  3      3      1      1      1      1      1      1      1      1      1      1      1      1      3
  3      1      1      1      1      1      1      1      2      1      1      1      1      1      3
  3      1      1      1      1      1      1      1      1      1      1      1      1      3      3
  3      1      1      1      1      1      1      1      1      1      1      1      3      3      3
  3      1      1      1      1      1      1      1      1      1      1      3      3      3      3
  3      1      1      1      1      1      1      1      1      1      3      3      3      3      3
  3      1      1      1      1      1      1      1      1      3      3      3      3      3      3
  3      3      3      3      3      3      3      3      3      3      3      3      3      3      3
end fill
```

Solution: Castor Cask (Cont.)

```
ara=2 nux=5 nuy=5 nuz=1 typ=triangular
```

```
fill
```

```
  6    6    6    6    6
    6    6    5    5    6
      6    5    5    5    6
        6    5    5    6    6
          6    6    6    6    6
```

```
end fill
```

```
end array
```

```
read start
```

```
nst=1
```

```
xsm=-5 xsp=5 ysm=-5 ysp=5 zsm=0 zsp=242
```

```
end start
```

```
end data
```

```
end
```

Summary of Sub-Module 4

- Overview of KENO VI arrays
- Can simplify geometry construction with repeated structures
- Consists of the following components:
 - Array Keyword
 - Array Type
 - Fill Statement

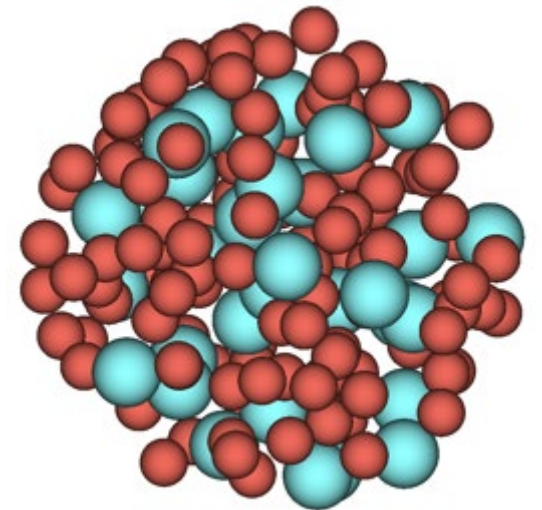
Sub-Module 5

- Randomgeom block



Randomgeom block

- Block available with Shift (not with KENO)
- Enables straightforward generation of reference solutions for stochastic geometry (TRISO fuel particles, FCM, etc.)
- Current capabilities:
 - Automatic generation of random distribution of particles within a geometry
 - Supports multiple particle types with a geometry
 - Placement into spheres, cylinders, and cuboids
 - Visualization in Fulcrum
- Limitations:
 - Distribution of spherical particles
 - Can only be used with a single region
 - Maximum packing fraction of ~20%



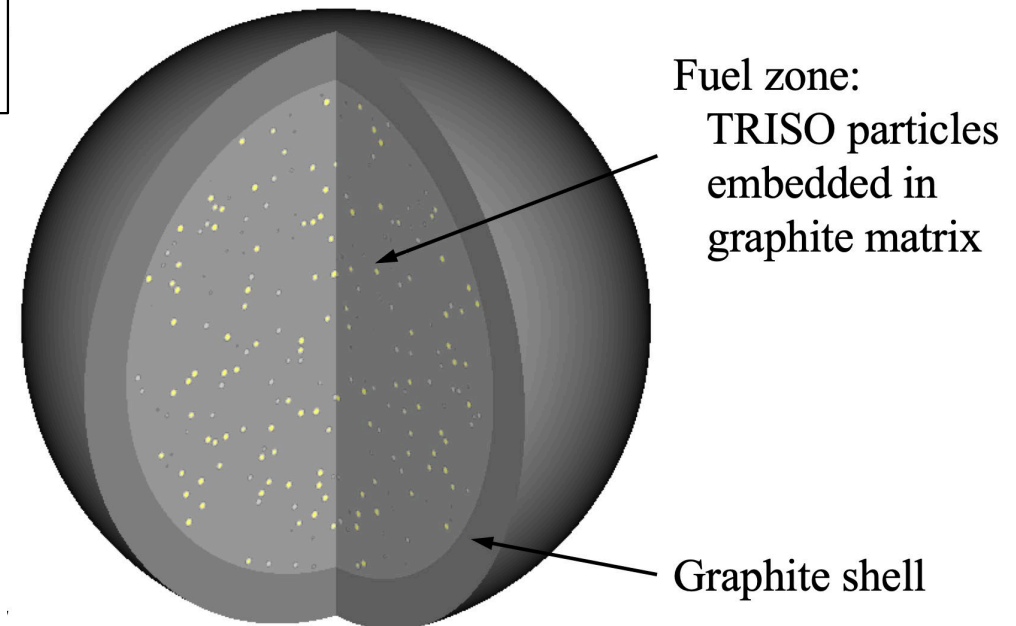
**Random distribution
of 2 particle types**

Randomgeom block input

```
read geometry
unit 1 com='TRISO'
  sphere 1 2.50e-02
  sphere 2 3.40e-02
  ...
  media 100 1 1
  media 101 1 2 -1
  ...
  boundary 5
Global unit 10
com='pebble'
  sphere 1 2.5
  sphere 2 3.0
  cuboid 3 6p3.0
  media 105 1 1 randommix='trisos'
  media 106 1 2 -1
  media 300 1 3 -2
  boundary 3
end geometry
```

```
read randomgeom
  randommix = 'trisos'
  type=random
  units=1 end
  pfs=0.10 end
  clip=no
  seed=1111
end randommix
end randomgeom
```

Fuel pebble with random distribution of TRISO particles



Exercises for Sub-Module 5

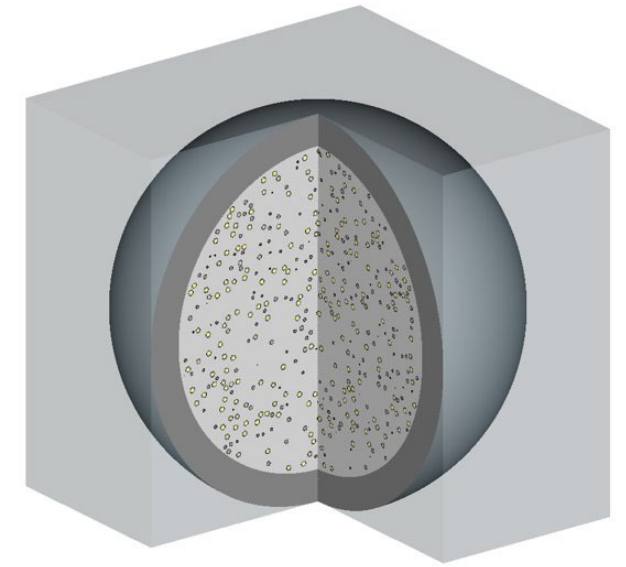
- Randomgeom block



Problem: HTGR pebble

Goal: Develop HTGR fuel pebble model

1. Use “Advanced_Reactors/
htgr_pebble_ce_starter.inp” and
save as “htgr_pebble_ce.inp”
2. Add geometry and randomgeom
block based on details on the right
3. Run calculation and observe runtime



Pebble design details

Pebble outer radius: 3.0 cm
Thickness of fuel-free zone: 0.5 cm
Cube half pitch: 3.0 cm
Fuel kernel diameter: 500 μm
Kernel material: UO_2 with enrichment of 9.6%
Kernel density: 10.4 g/cm^3
Kernel coating material: C/C/SiC/C
Kernel coating thickness: 95/40/35/40 μm
Kernel coating densities: 1.05/1.90/3.18/1.90 g/cm^3
Matrix and shell materials: C
Matrix and shell densities: 1.74
Number of TRISOs per pebble: 15,000
Room temperature

Solution: HTGR pebble

```
' =====  
'   Geometry  
' =====  
read geometry  
  
' =====  
'   TRISO particle  
' =====  
unit 1  
  sphere 1 0.0250  
  sphere 2 0.0345  
  sphere 3 0.0385  
  sphere 4 0.0420  
  sphere 5 0.0460  
  media 10 1 1  
  media 11 1 2 -1  
  media 12 1 3 -2  
  media 13 1 4 -3  
  media 14 1 5 -4  
  boundary 5  
  
' =====  
'   fuel pebble  
' =====  
global unit 10  
  sphere 10 2.5000  
  sphere 11 3.0  
  cuboid 12 6p3  
  media 15 1 10 randommix='trisos'  
  media 16 1 11 -10  
  media 17 1 12 -11  
  boundary 12  
  
end geometry
```

- Geometry:
 - Convert TRISO layer thicknesses to radii
 - Pebble outer radius equals cuboid half length
- Randomgeom:
 - Determine packing fraction from 15,000 TRISO particles with outer radius 0.046 cm in a fuel zone of 2.5 cm radius
 - Define name and use name to fill TRISO particles into fuel zone within the geometry

```
read randomgeom  
  randommix = 'trisos'  
  type=random  
  units=1 end  
  pfs=0.09344256 end  
  clip=no  
  seed=1111  
  end randommix  
end randomgeom
```

Summary of Sub-Module 5

- Introduction to Shift randomgeom capability
- Baseline random geometry capability
 - Limited in volume fraction
 - Limited in allowable shapes
- TRISO pebble example

KENO-VI geometry verification



Tips to verify model

- Use Fulcrum to develop your model and address validation errors
- Visually inspect your geometry with Fulcrum
- Run your geometry using sequence parameter “parm=(check)”
- Calculate volumes of your regions and mixtures and compare them to the expectation
- Common geometry issues:
 - Undefined space
 - Doubly defined space
 - Array incorrectly placed
 - Units in array are of inconsistent outer shape
 - Overlapping holes