Analytical Geometry and Enriched Uranium Solutions in SCALE: Two H-Canyon Studies

Tracy Stover, Ph.D., P.E.

Principle Engineer, Nuclear and Criticality Safety Engineering

SCALE Users' Workshop

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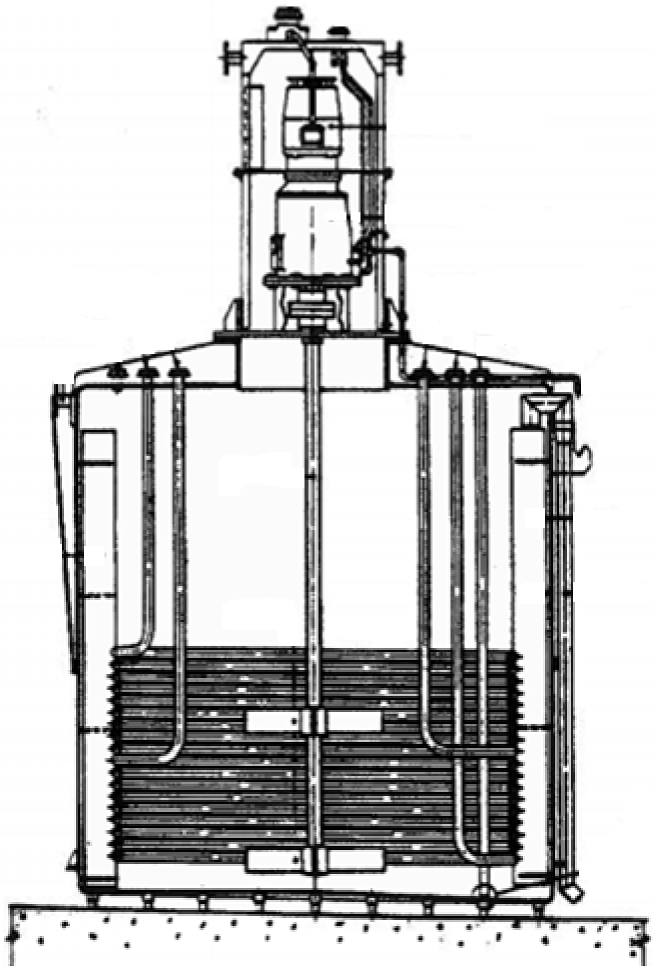
Overview

- Part 1: Simple Model and Complex Physics Behavior
  - HEU Solution stored in sloped bottom tanks
  - Projected Areal Density
    - *Function relationship*
- Part 2: Complex Model and Simple Behavior
  - Section 6 Hot of H-Canyon
    - *Dissolver Operations*
  - Do dissolvers see each other?

Part 1



Motivation for Inquiry

- Investigation was made to establish a mass limit for H-Canyon vessels based on areal density
  - Most vessels have sloped bottoms
  - In some cases, areal density based mass limits were still usable
- Is there a functional relationship between slope of the tank and the use of an areal density based mass?
- What does areal density mean in light of sloped tanks?

Background

- Areal density projects the mass of a 3-D system onto a single plane
  - Physically comparable to infinite slab of certain thickness
  - Well-understood, experimental basis, easily modeled in computational codes
- Assumes that the surface of projection is orthonormal to the remaining dimensions of the system
  - Most commonly project vertical axis onto x-y plane to reference material staged on a floor, tank, table, etc.
- In sloped bottom tanks, the bottom plane is not orthonormal to the remaining dimensions!
  - Flat is not always economic, convenient, available, or safe from a chemical or processing hazard aspect

Background

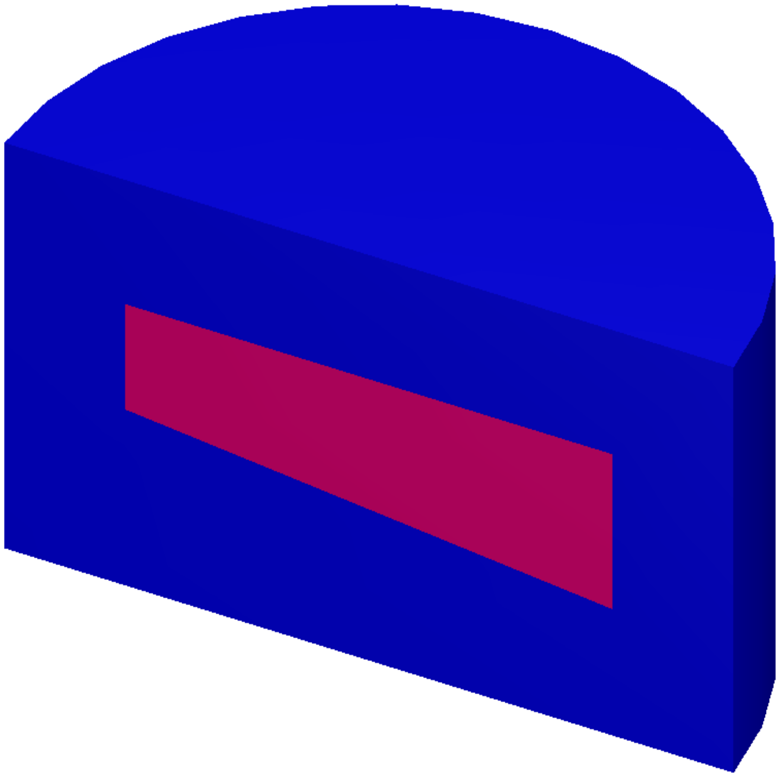
- Is there a relationship between slope, area, and what may be called a *projected* areal density (PAD) where the plane of projection is not orthonormal to the other dimensions?
- Remember: Areal density is a mathematical construct
  - –Modifying the construct in this work, the projection surface is sloped → PAD

Analytical Approach

- Computational modeling performed in KENO-VI of SCALE 6.1
  - Validated internally for use in HEU aqueous systems
- Calculations parallel data available in LA-10860
  - pure $^{235}UO_2(NO_3)_2$
  - no excess nitric acid (removes poisoning effect)
  - full reflection modeled by 60 cm of water in all directions
  - reflective boundary conditions.
- Used the KENO macrobody of a rotated wedge to simulate sloping of the bottom head.

Analytical Approach

- Tank Radii
  - 51.4, 70.5, 121.0, and 150.5 cm
- Slopes
  - 0, 3.15, 5, 7.5, 10, 15 %
- For fixed slope and radius, vary the solution height from 6.35 cm to 300 cm
- Critical concentration search
  - within 1.000 +/- 0.001
  - statistical uncertainty less than 0.001 Δk
- Can back calculate fissile mass, H/fissile, etc.



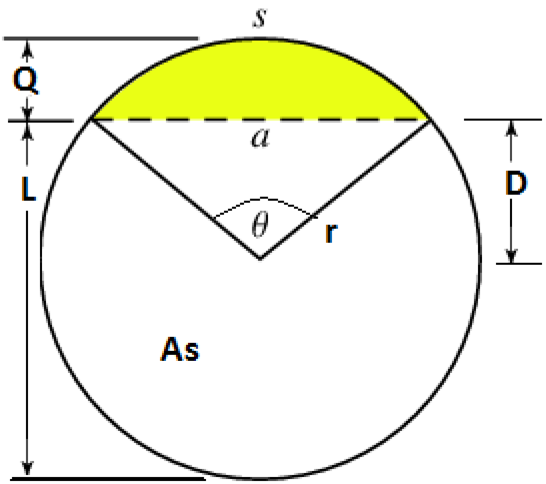
Analytical Approach

- PAD presented here is defined as projected onto the solution surface
  - –Data could easily be renormalized to project onto the sloped tank bottom.
    - *Similar results are obtained from this approach*
- When solution height is less than depth of the “shallow end”, solution takes on shape of a truncated wedge.
  - –No reason limiting PAD would not occur in these conditions

Methodology – Partially Filled Sloped Bottom

- Volume requires numerical integration
  - Integrate area over height
- If deep end depth is *h* and fraction slope of the tank is *l*, then volume of the solution is:

$$V_S = \int_0^h \left\{ \frac{-r^2}{2} \left[\left(2\operatorname{acos}\left(1 - \frac{2r - h'/l}{r}\right)\right) - \sin\left(2\operatorname{acos}\left(1 - \frac{2r - h'/l}{r}\right)\right)\right] + \left[\pi r^2\right] \right\} dh'$$



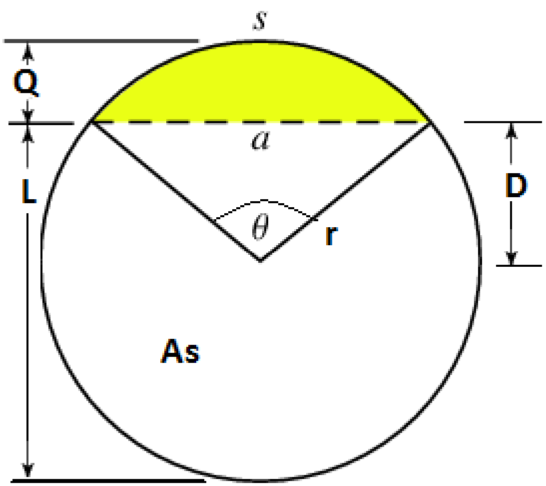
- Line *a* is the line solution makes with the shallow end of the tank

Methodology – Partially Filled Sloped Bottom

- As is the surface area we are interested in
- Area of the yellow segment is

$$\frac{r^2}{2}(\theta - \sin\theta)$$

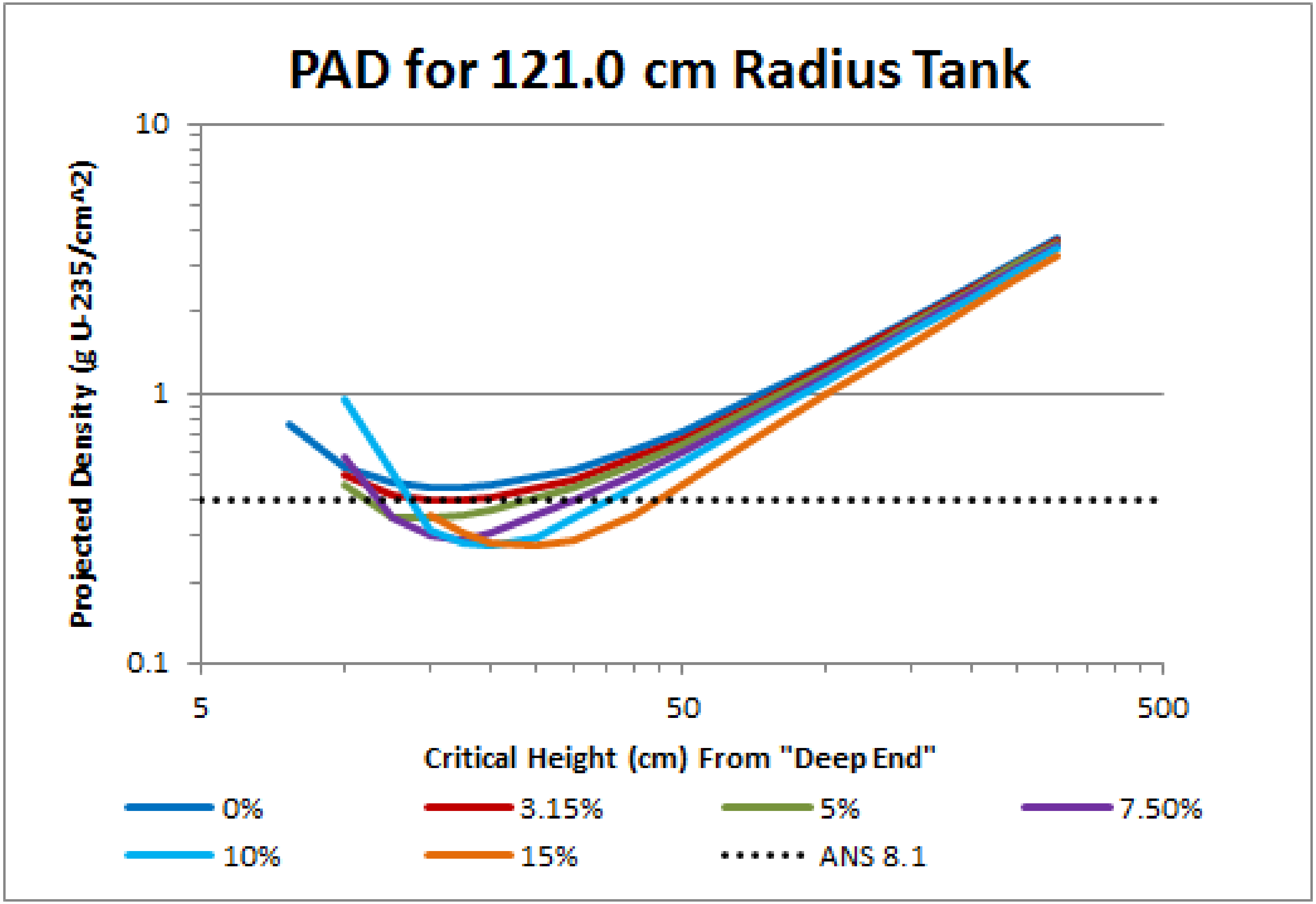
- Knowing 2r = Q + L
- L is determined by depth of solution and fractional slope
- At a solution depth of h' $\theta = 2\mathrm{acos}\left(1 - \frac{2r \quad - h'/l}{r}\right)$



Results - PAD

- For each radius and slope, determined the minimum PAD that would result in a critical configuration
  - As would be done with areal density on flat bottoms tanks
  - Critical heights are measured from the “deep end” of the solution, i.e. the point that would be tangent to the low end tank wall

Results – PAD



PAD for 121.0 cm Radius Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

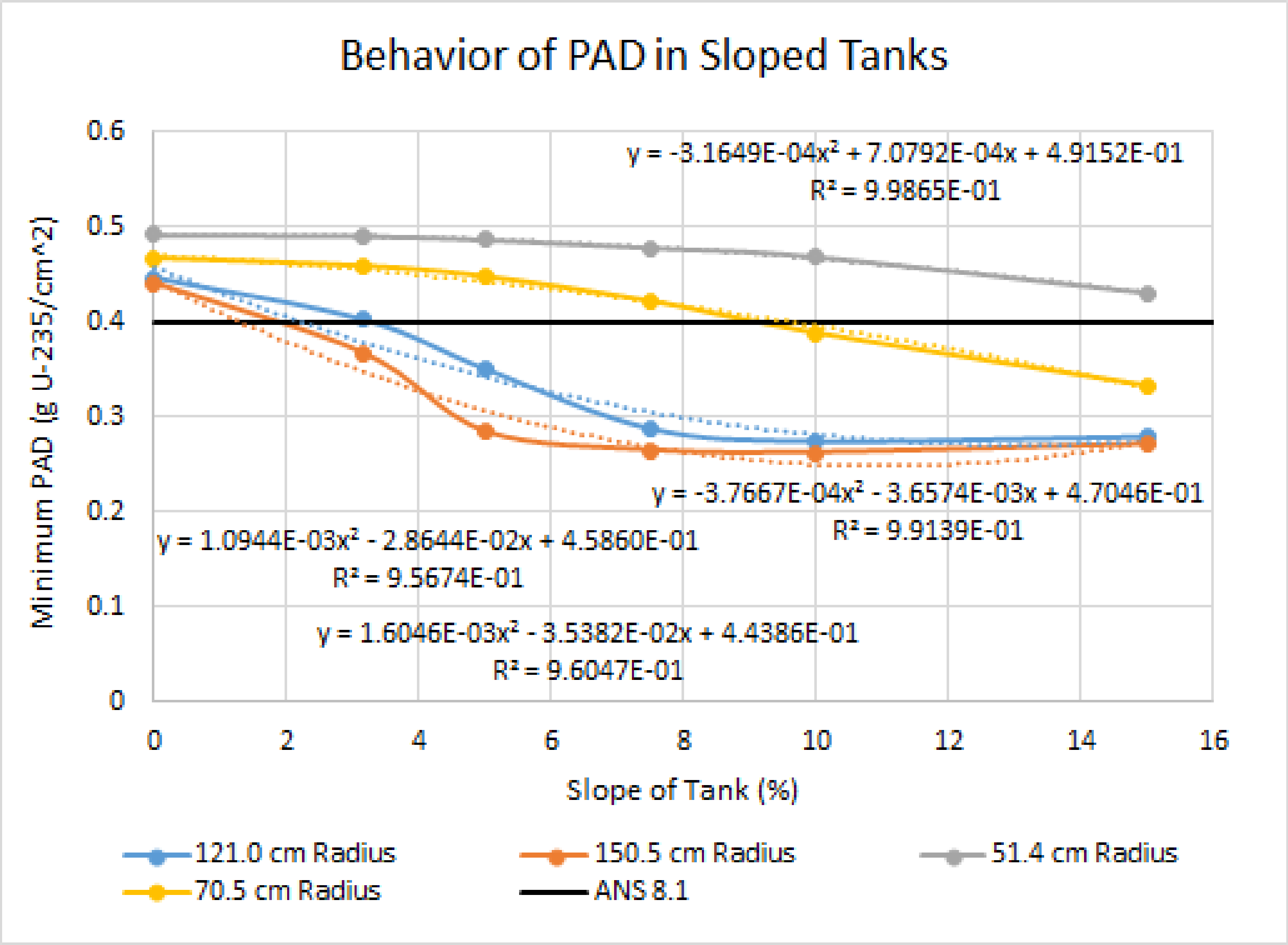
Results – PAD

- Minimum PAD (g U-235/cm^2) for various conditions

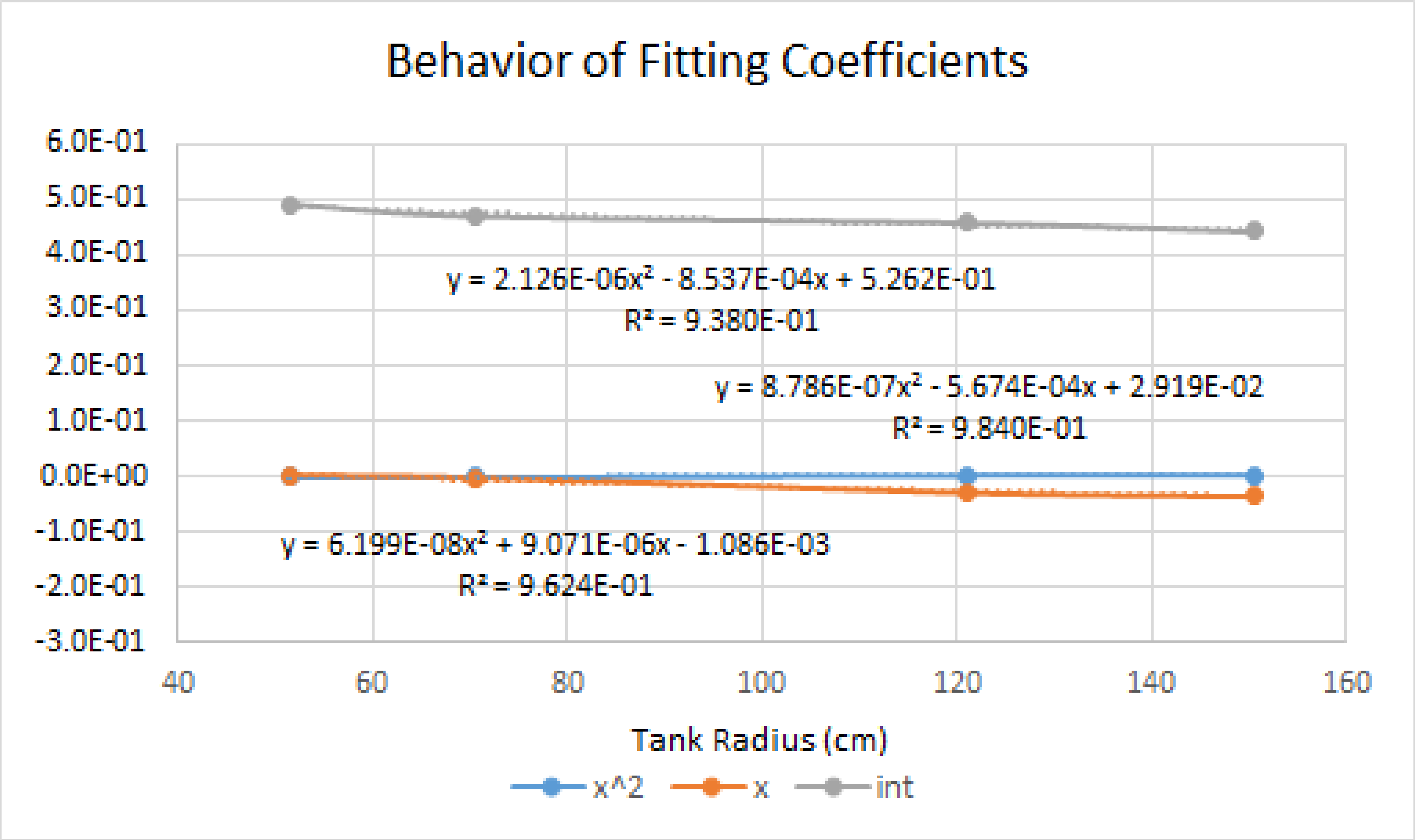
Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
0%	0.4919	0.4669	0.4456	0.4414
3.15%	0.4904	0.4588	0.4022	0.3677
5%	0.4868	0.4476	0.3507	0.2845
7.5%	0.4781	0.4219	0.2886	0.2651
10%	0.4685	0.3887	0.2753	0.2627
15%	0.4305	0.3335	0.2803	0.2713

- Can be translated into more physical quantities
  - Mass (g): 3580 to 31400 depending on tank size
  - Concentration (g U-235/L): 25.5 to 44.0, average 31.6
  - H/U-235: 575 to 1015, average 825

Results – Overall Behavior Fitted



Results – Coefficient Fitting



Results – Function Fit

- PAD = $(6.199*10^{-8})s^2r^2 + (8.786*10^{-7})sr^2 + (2.126*10^{-6})r^2 + (9.071*10^{-6})s^2r – (5.674*10^{-4})sr – (8.537*10^{-4})r – (1.086*10^{-3})s^2 + (2.919*10^{-2})s + (5.262*10^{-1})$

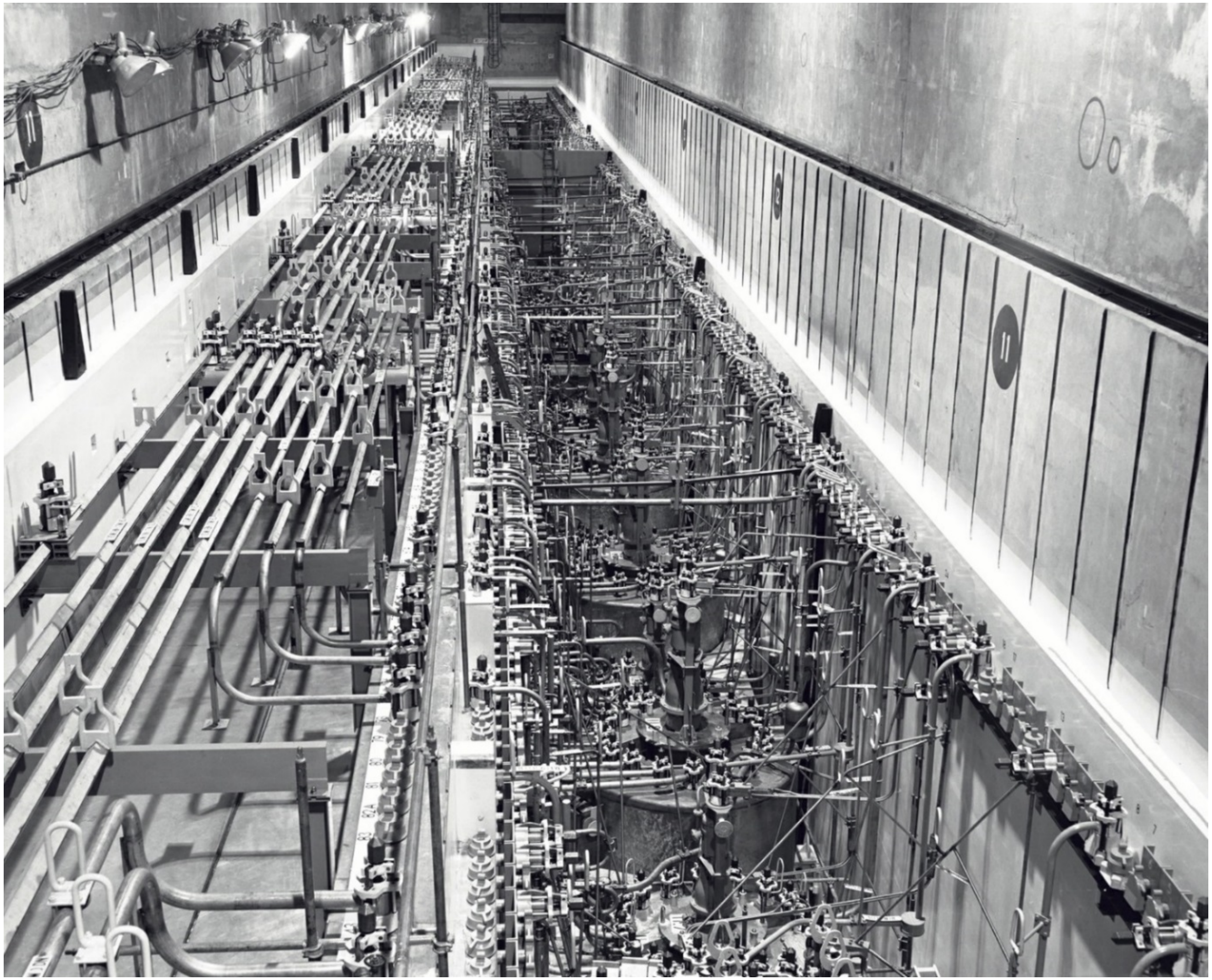
- Fit Predicted PAD Percent Different with Calculated:

Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
0%	-0.81	2.08	1.89	1.02
3.15%	0.06	-0.85	-5.67	-5.30
5%	0.29	-1.50	-1.91	7.70
7.5%	0.36	-0.33	6.13	1.21
10%	-0.60	2.47	1.71	-4.38
15%	-2.35	4.59	-6.60	3.24

Conclusions – Part 1

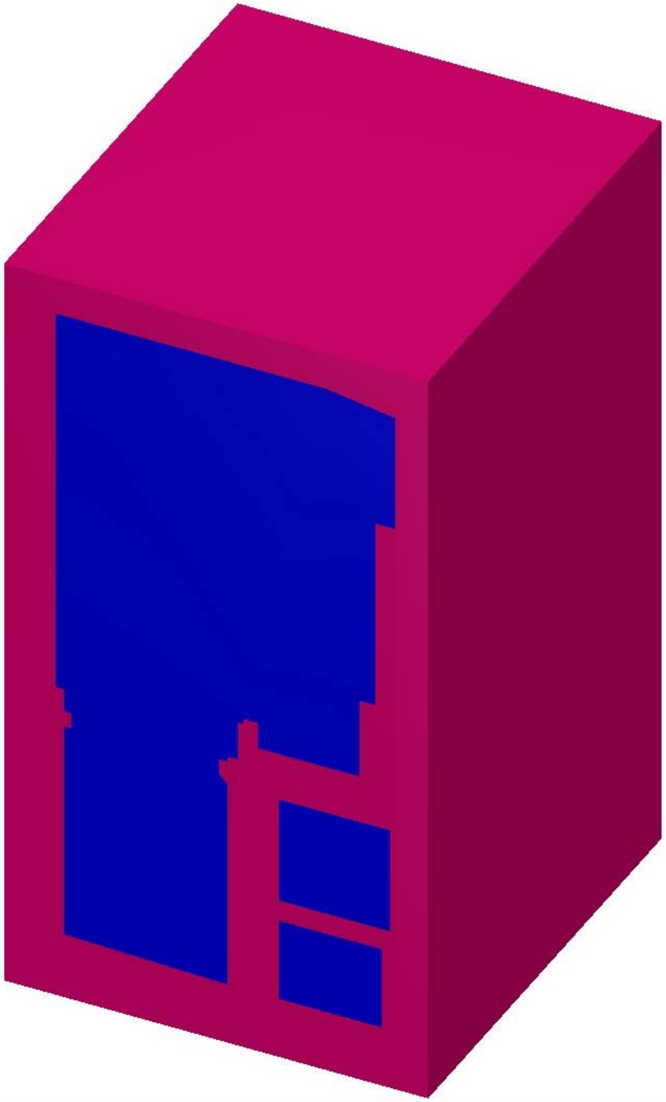
- PAD relationship found to be approximately parabolic in radius and slope
- Could be used to adjust down the ANS 8.1 single parameter areal density by this trend (function or data)
  - apply lower PAD to the cross-sectional area of the tank in question
  - some small additional margin
- Could select the lowest PAD and apply that value
  - Provided radius and slope are bounded by the available data

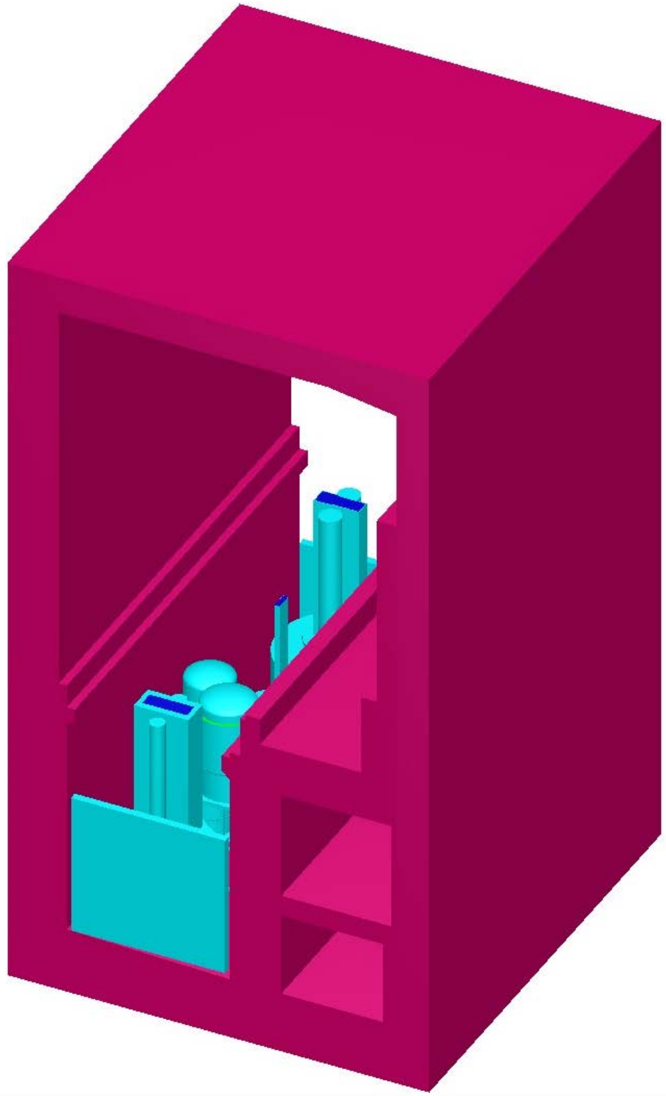
Part 2

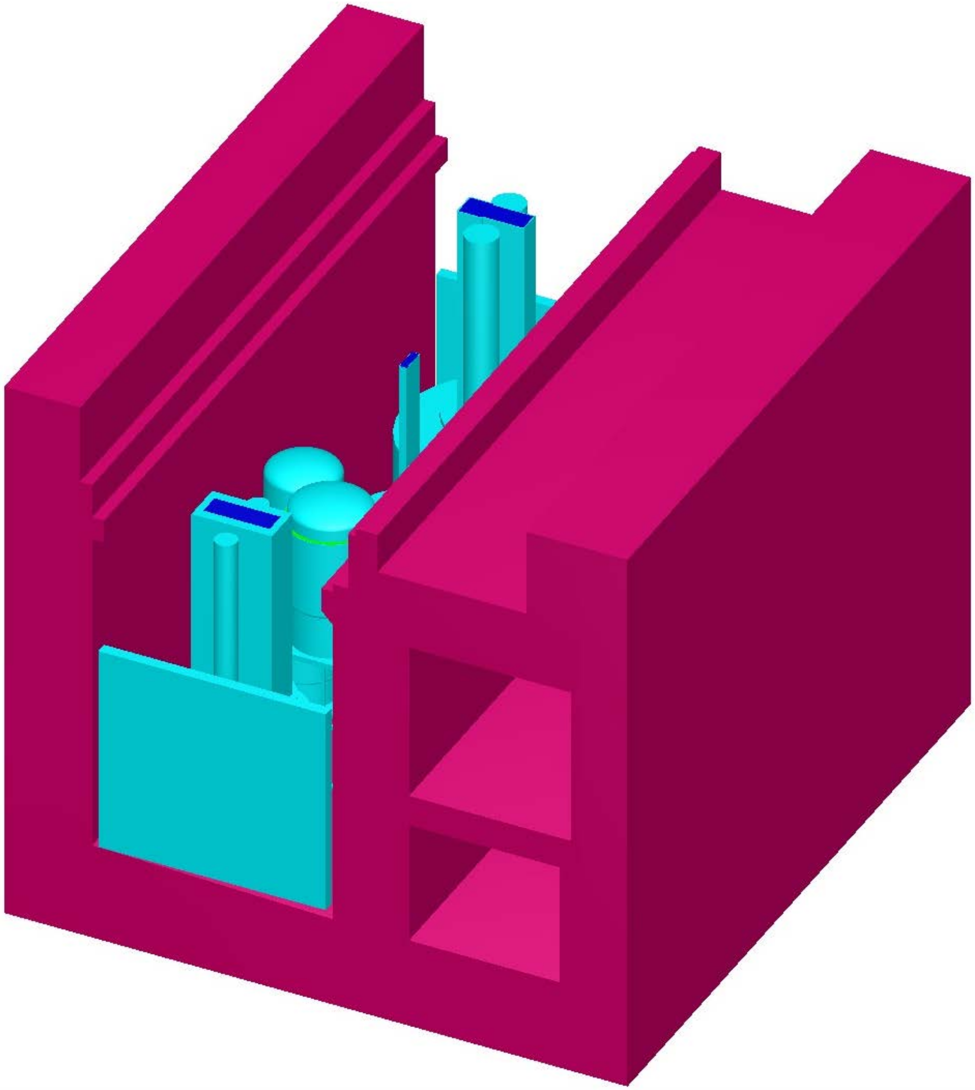


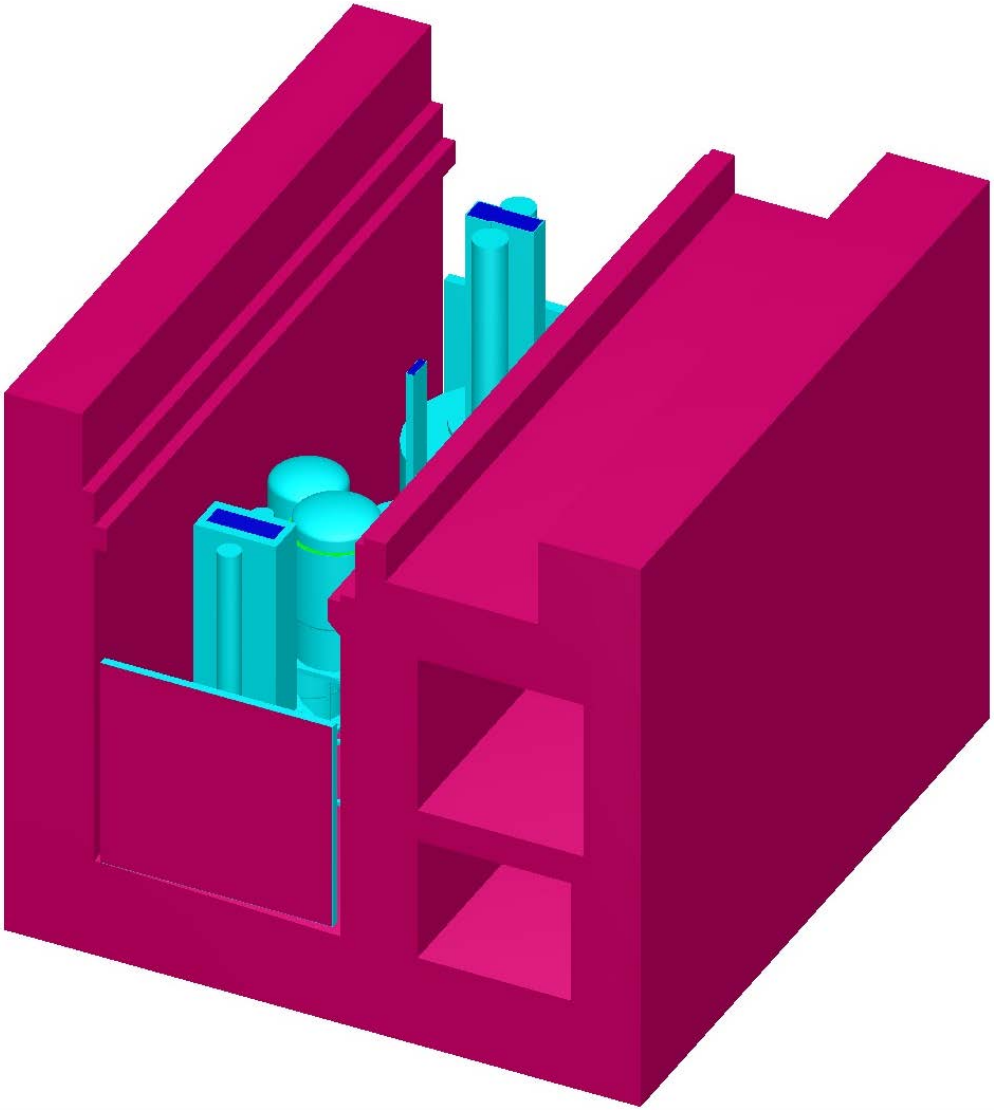
Section 6 Hot – Complex Model for Simple Question

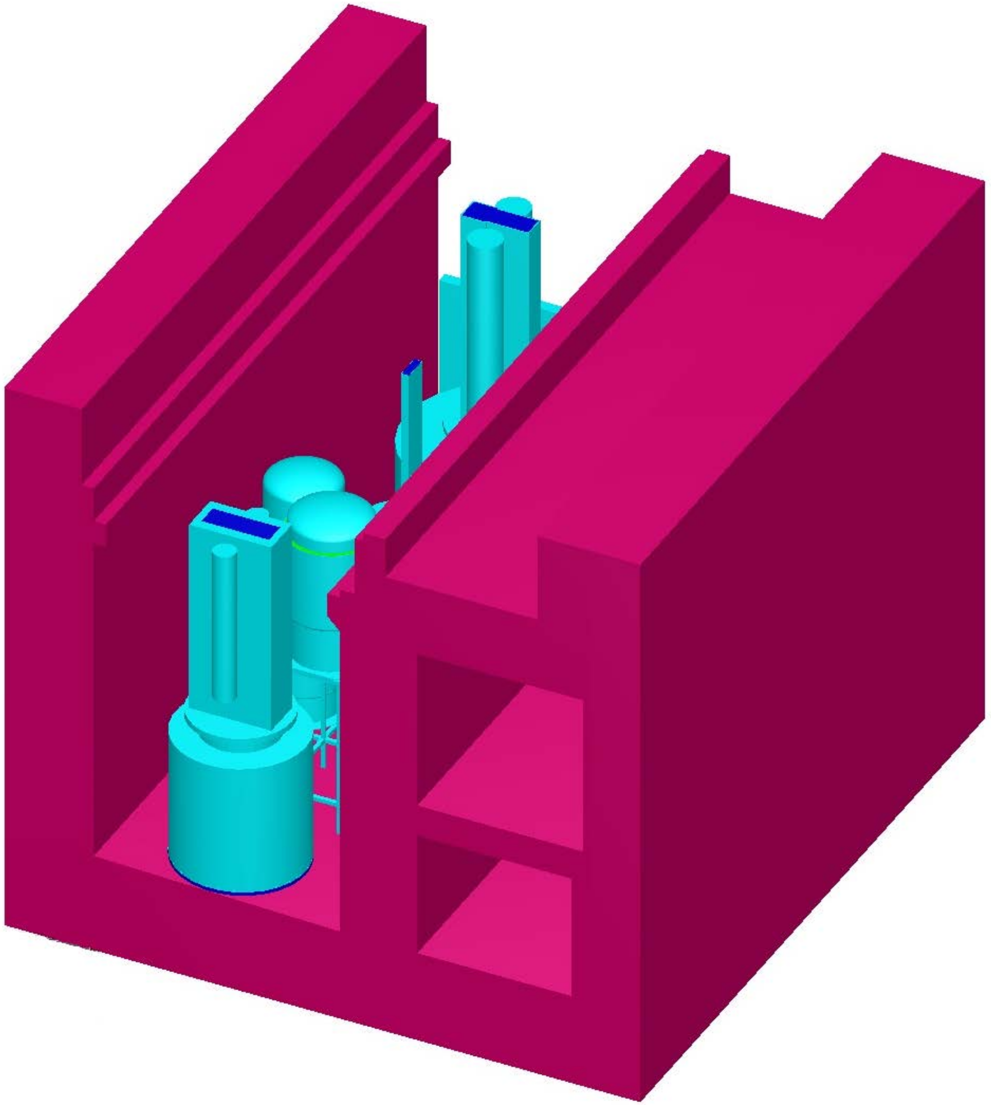
- Canyon is divided into warm and hot sides based on intensity of radiation from the processes
- Divided into 18 sections
- Section 6 Hot contains dissolution operations
- Primary objective to generate highly detailed model of Section 6 Hot
  – Beyond single vessel, homogenous fuel simplified models
- Do the vessels communicate neutronically?

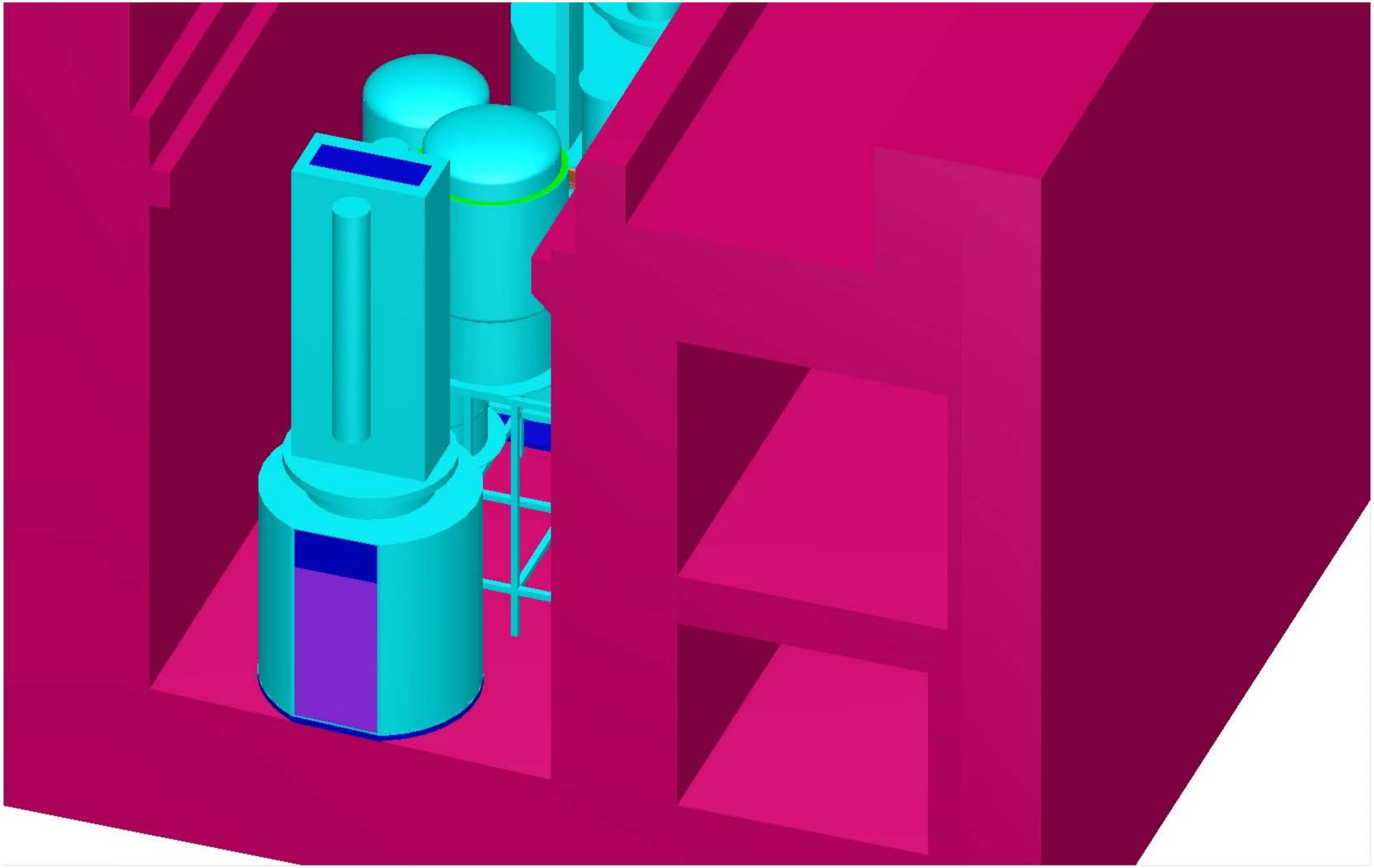


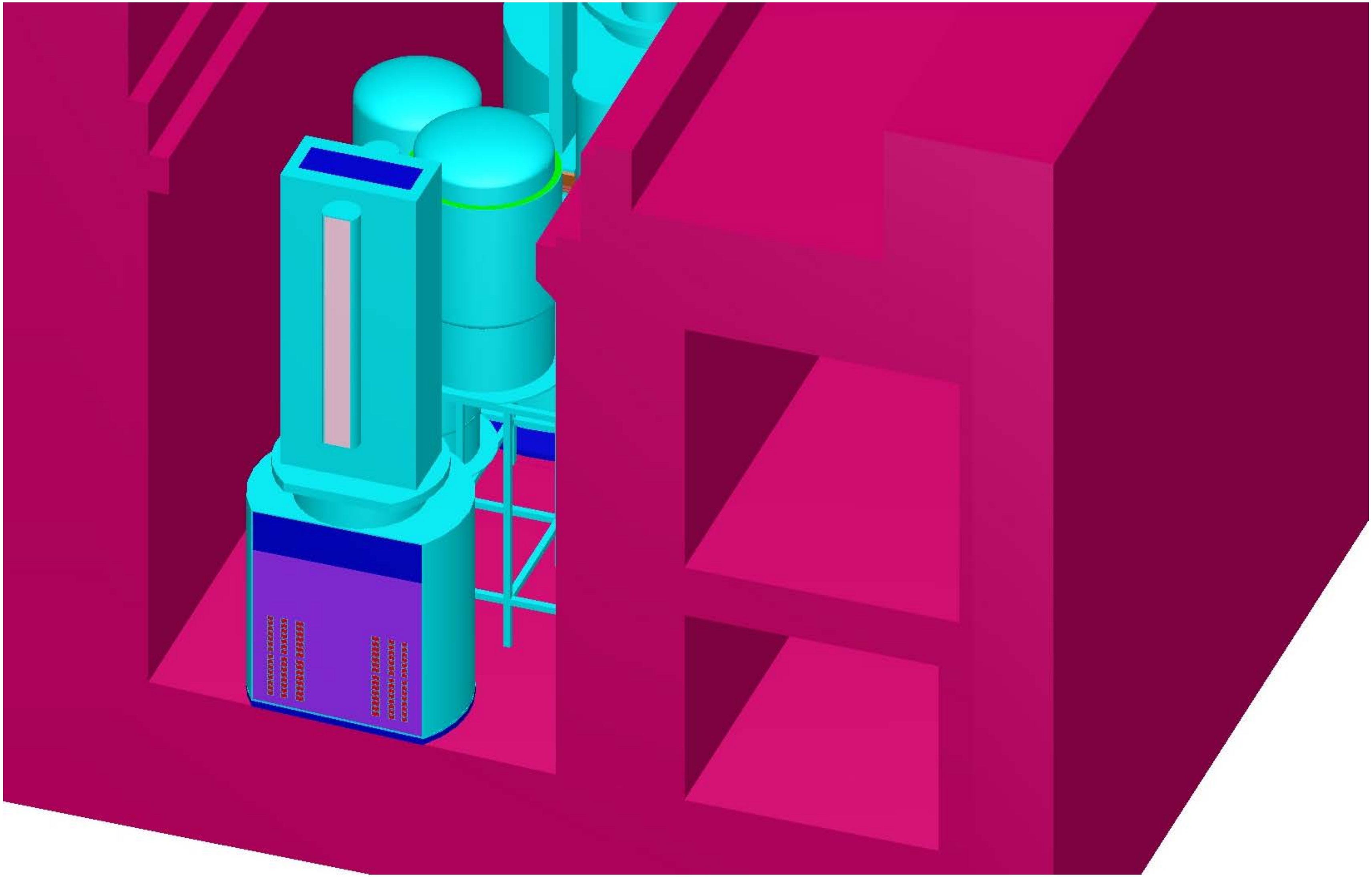


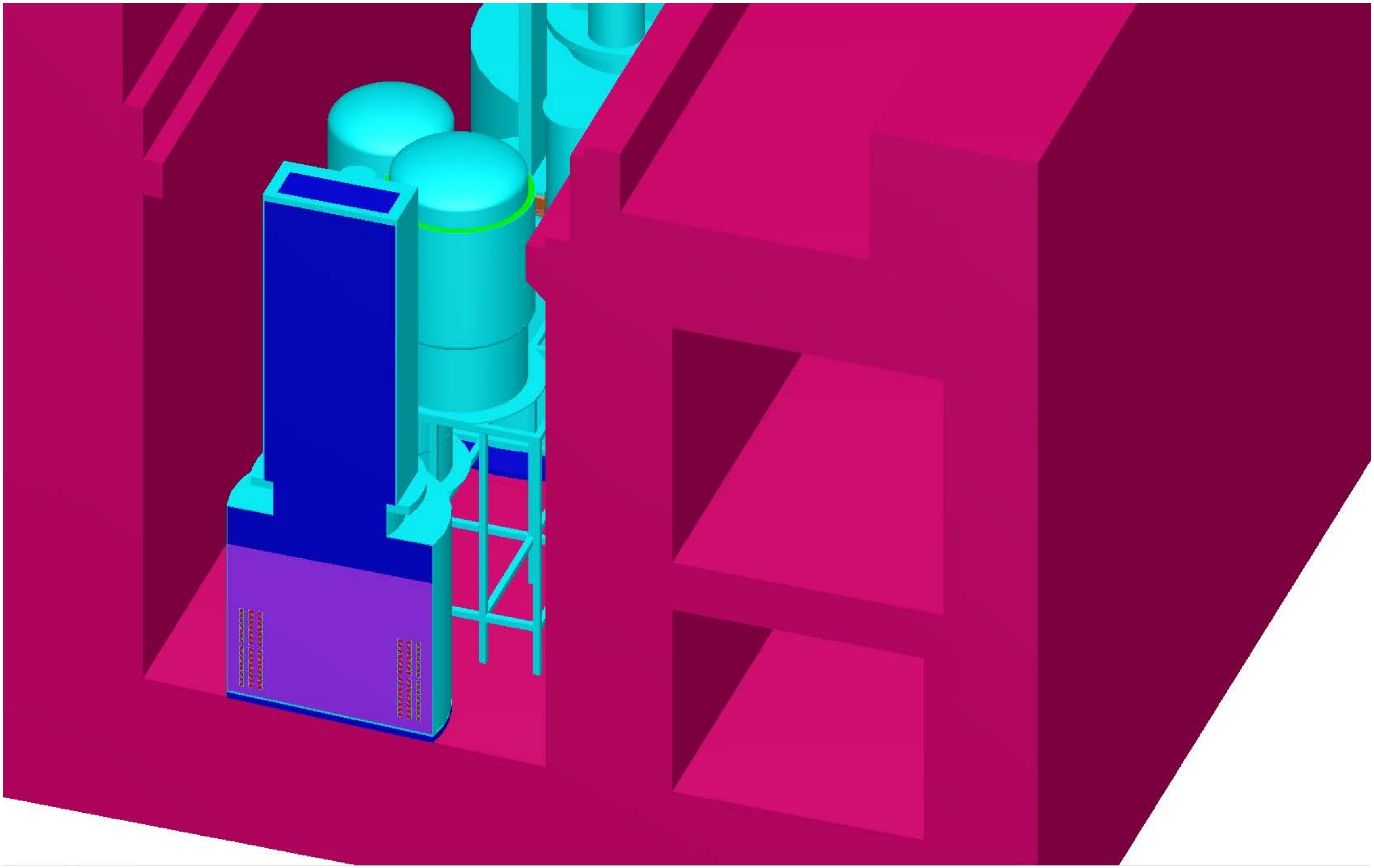


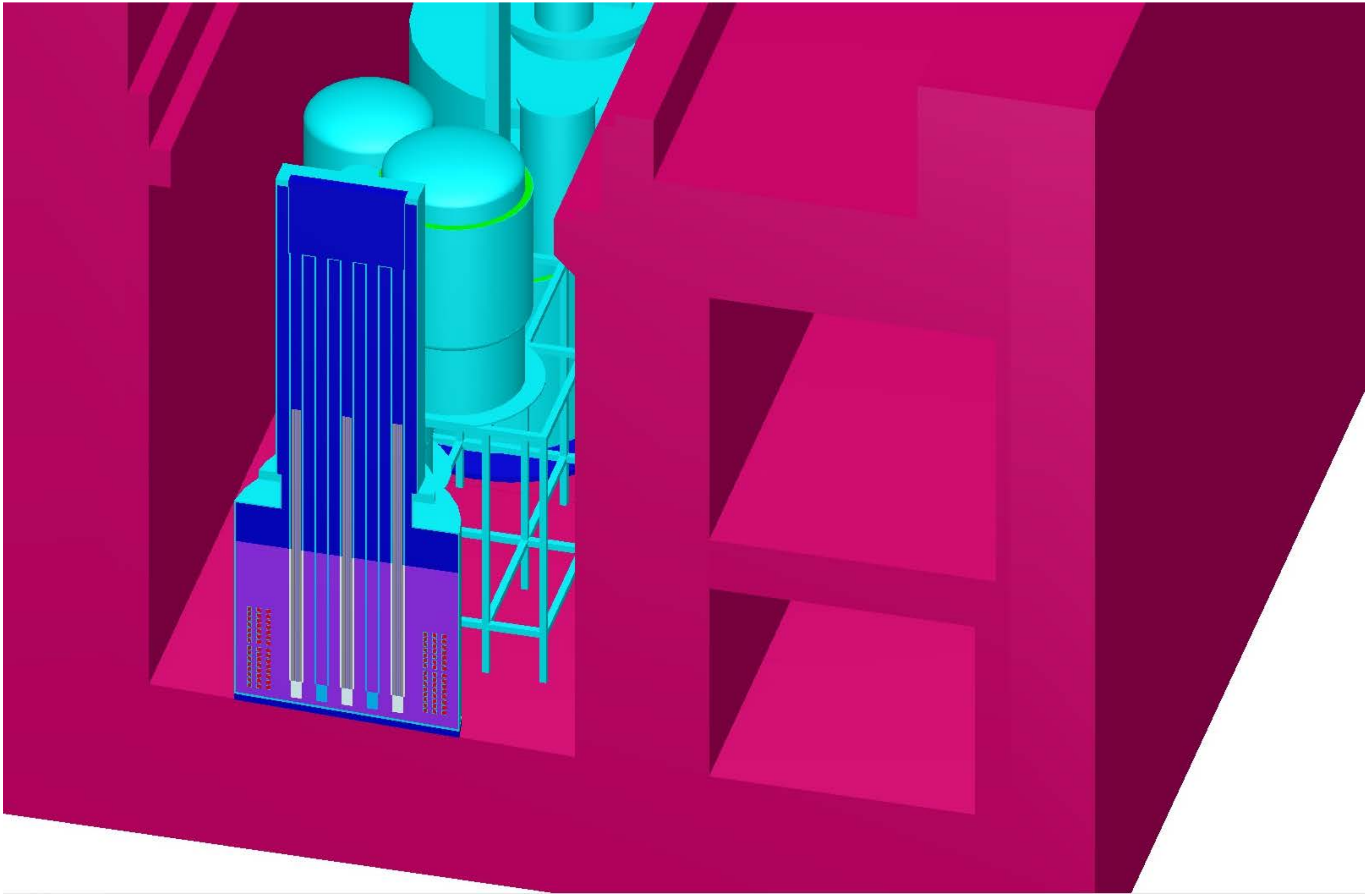


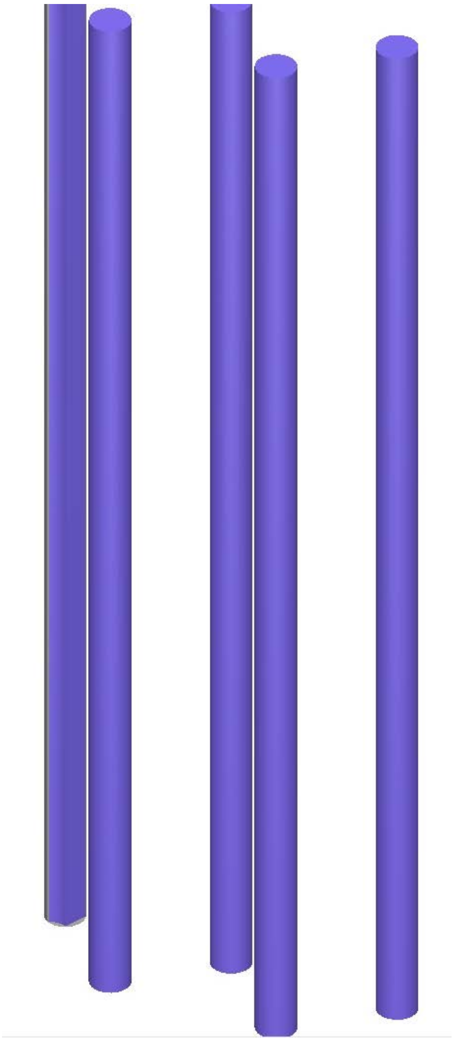


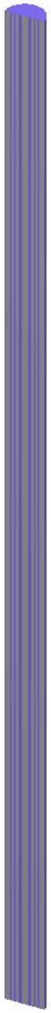


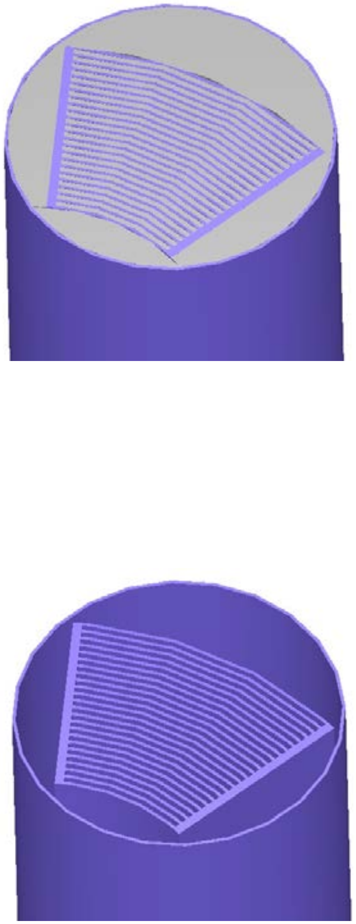


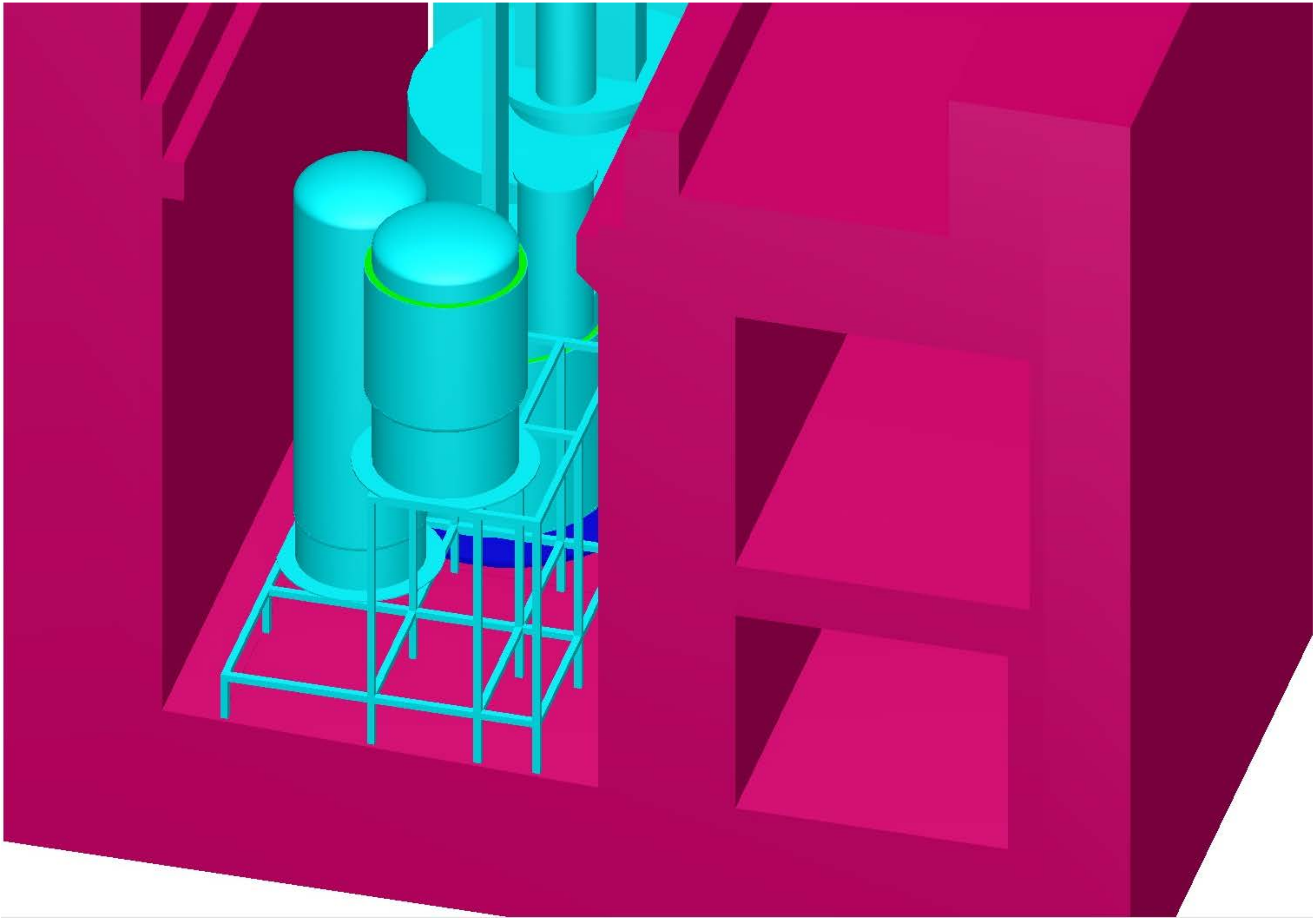


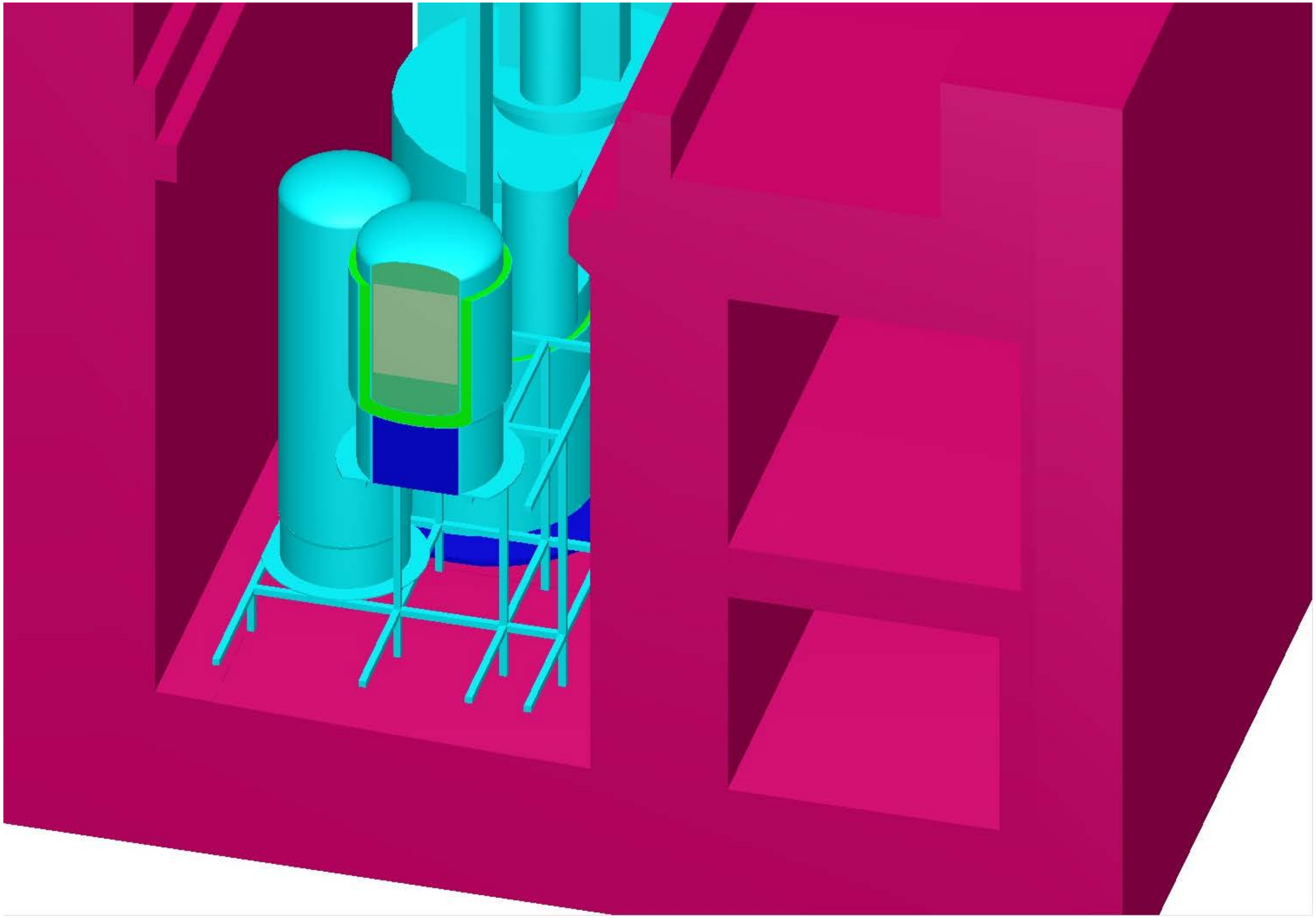


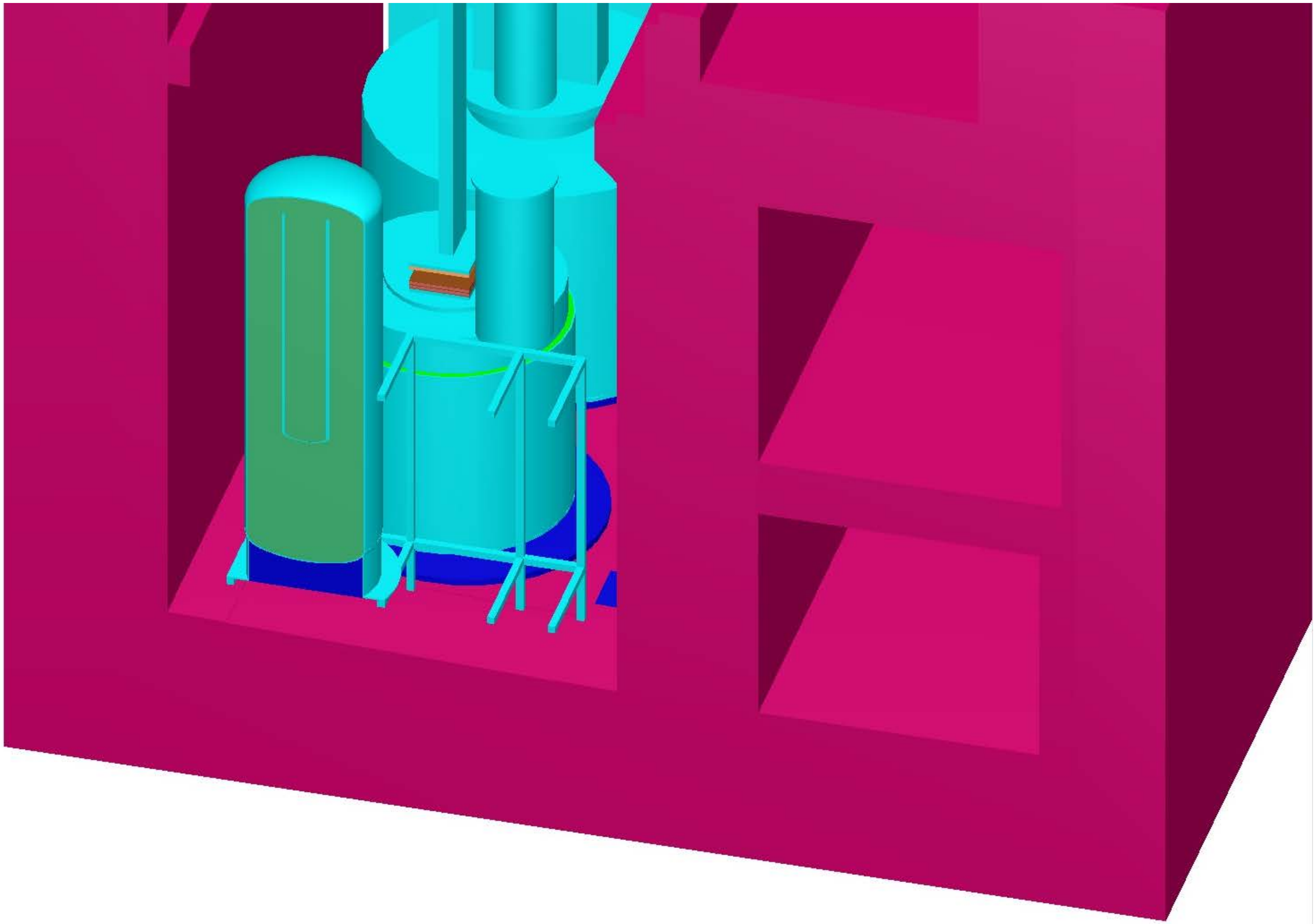


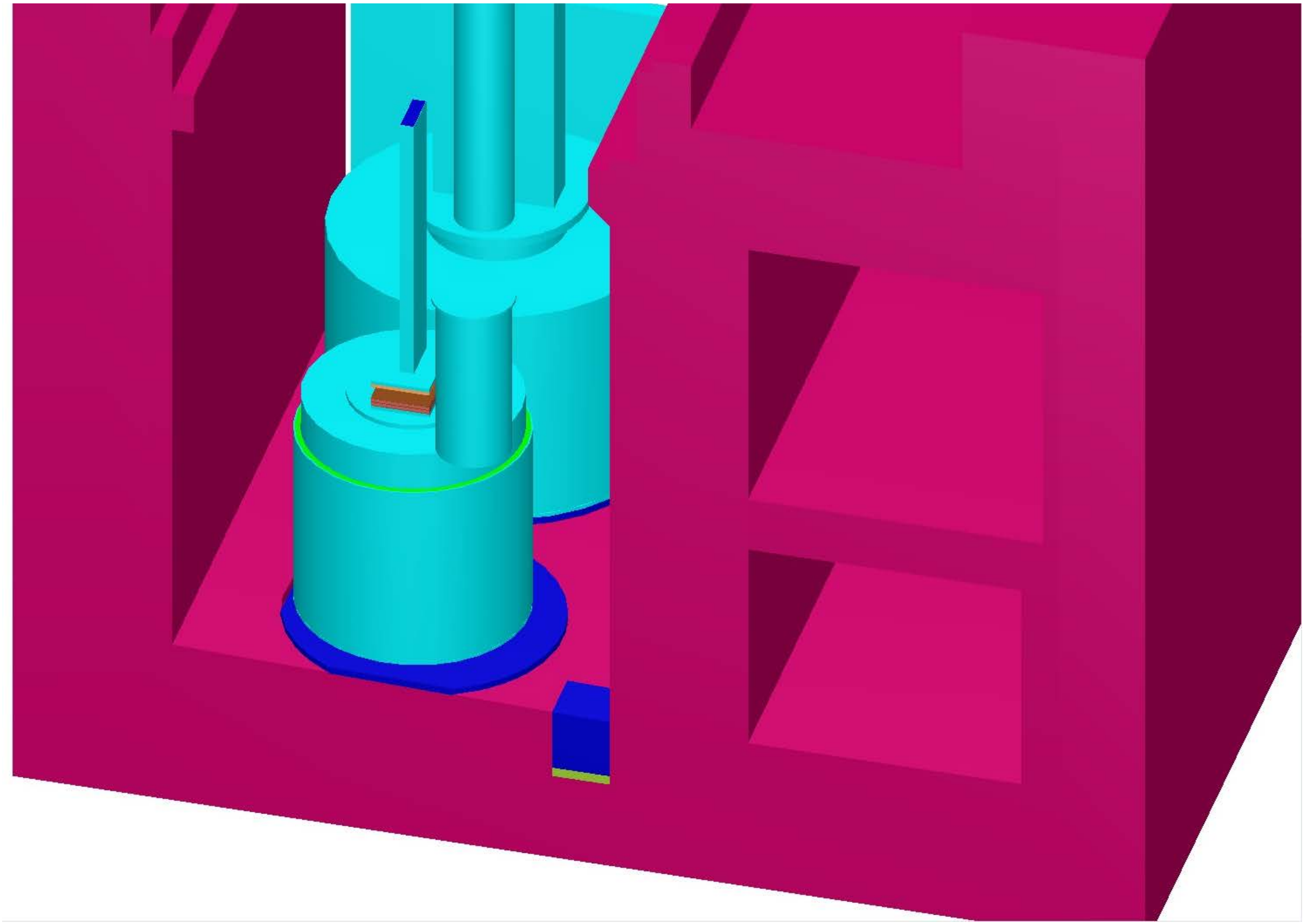


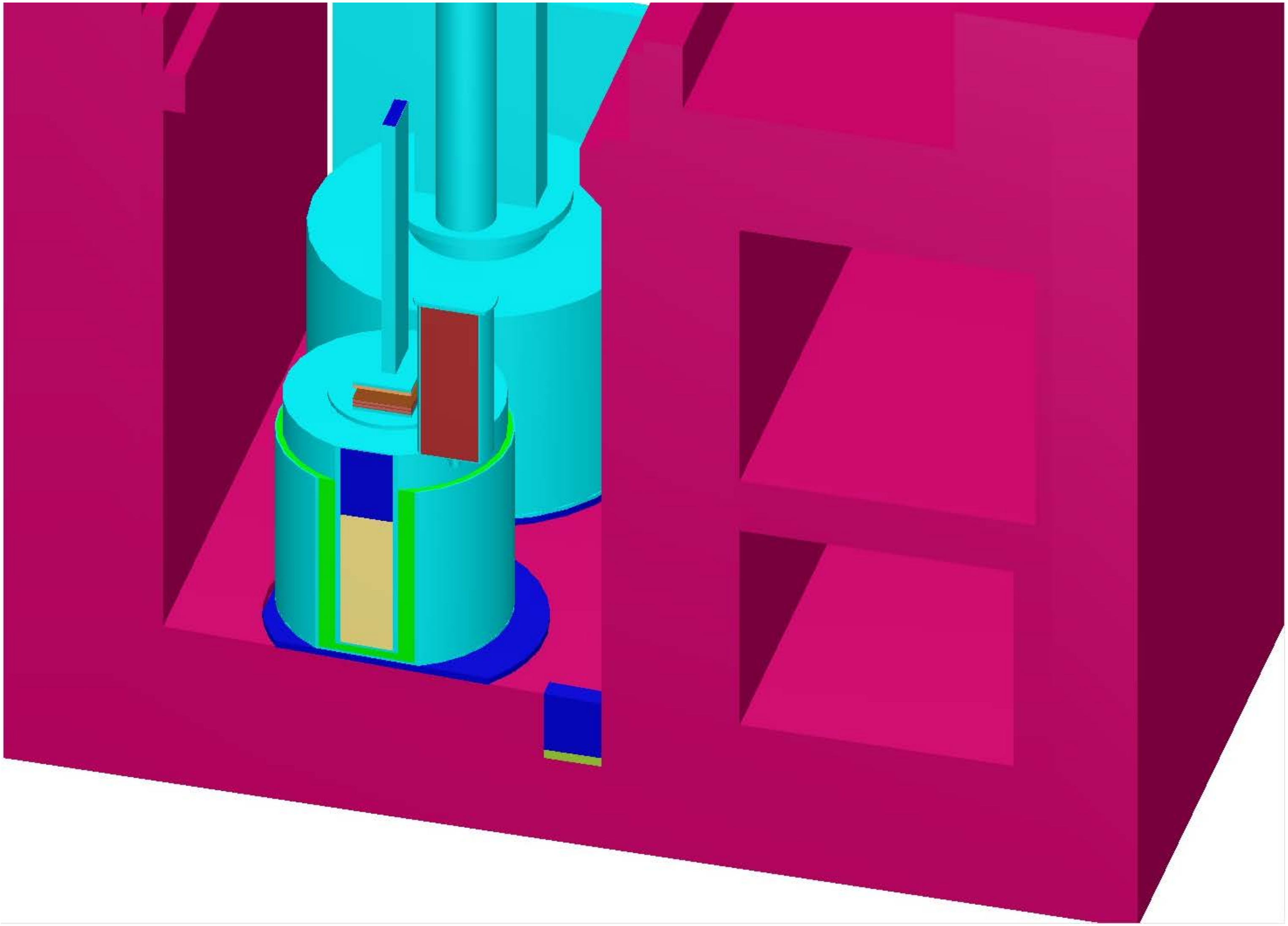


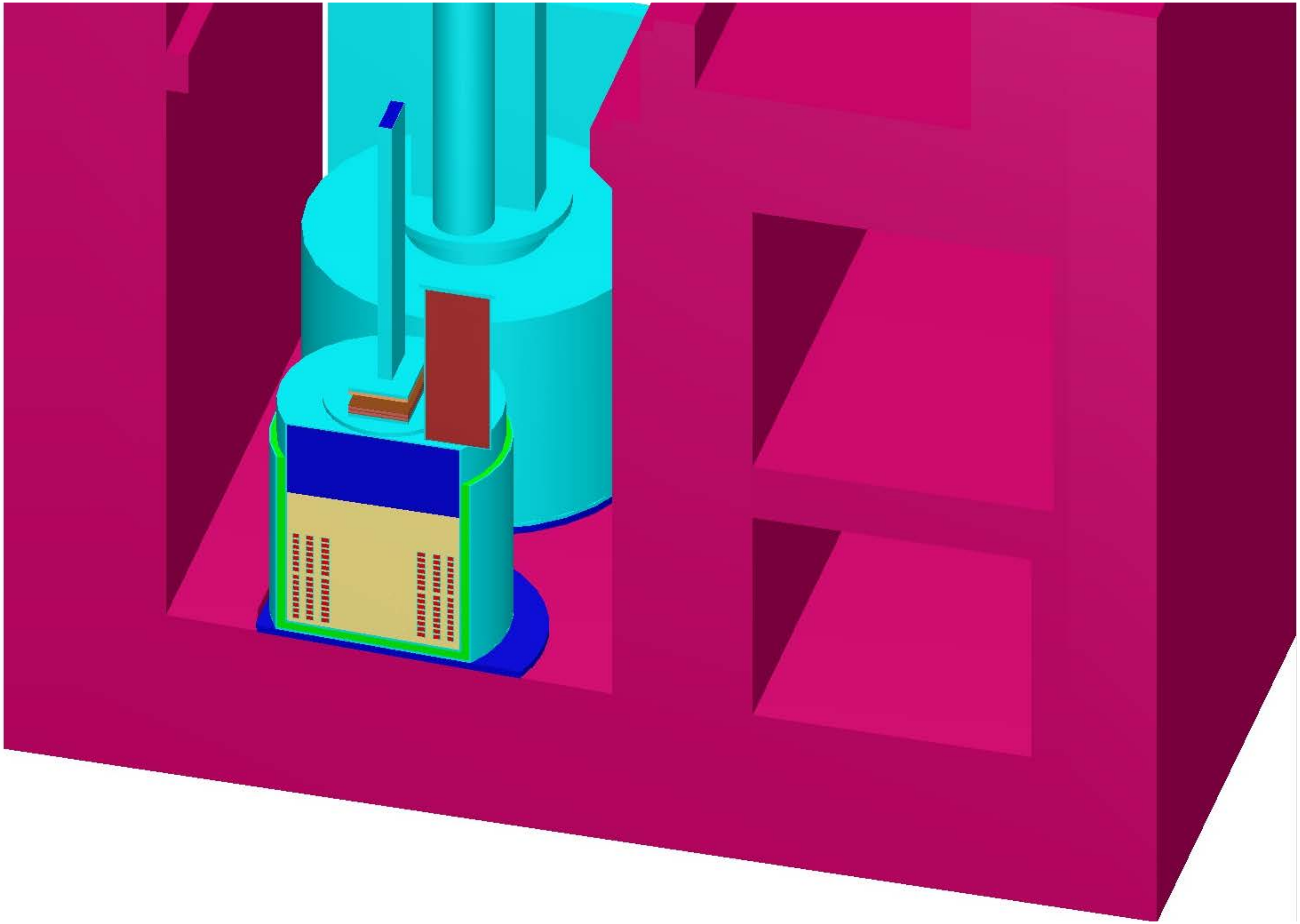


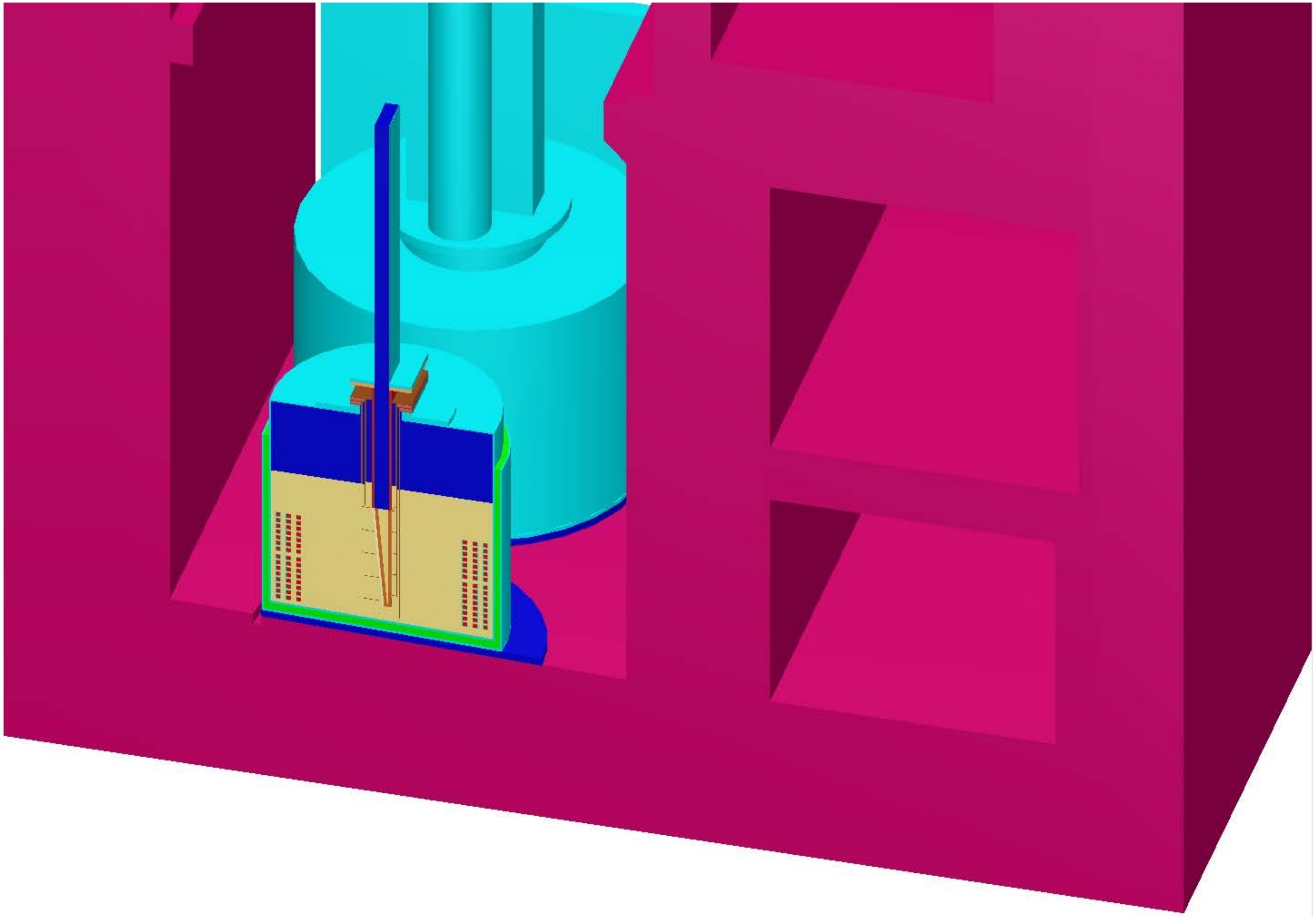


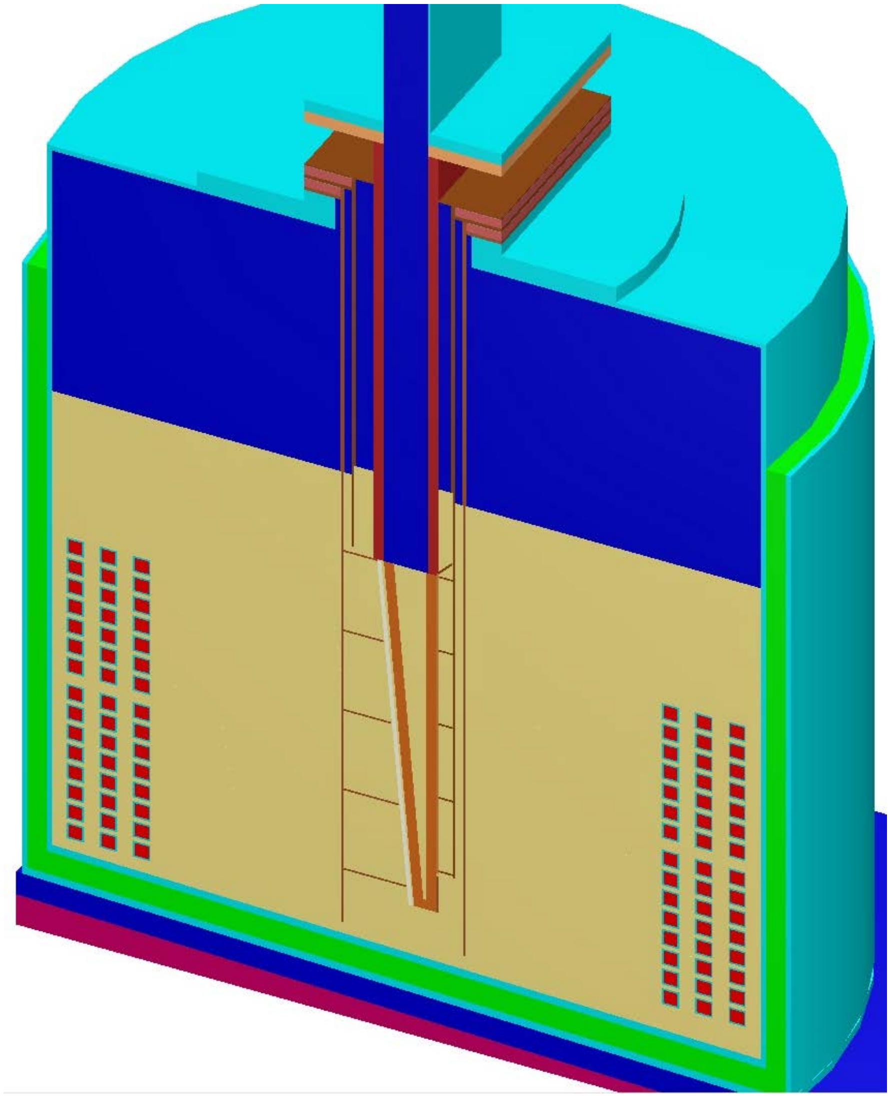


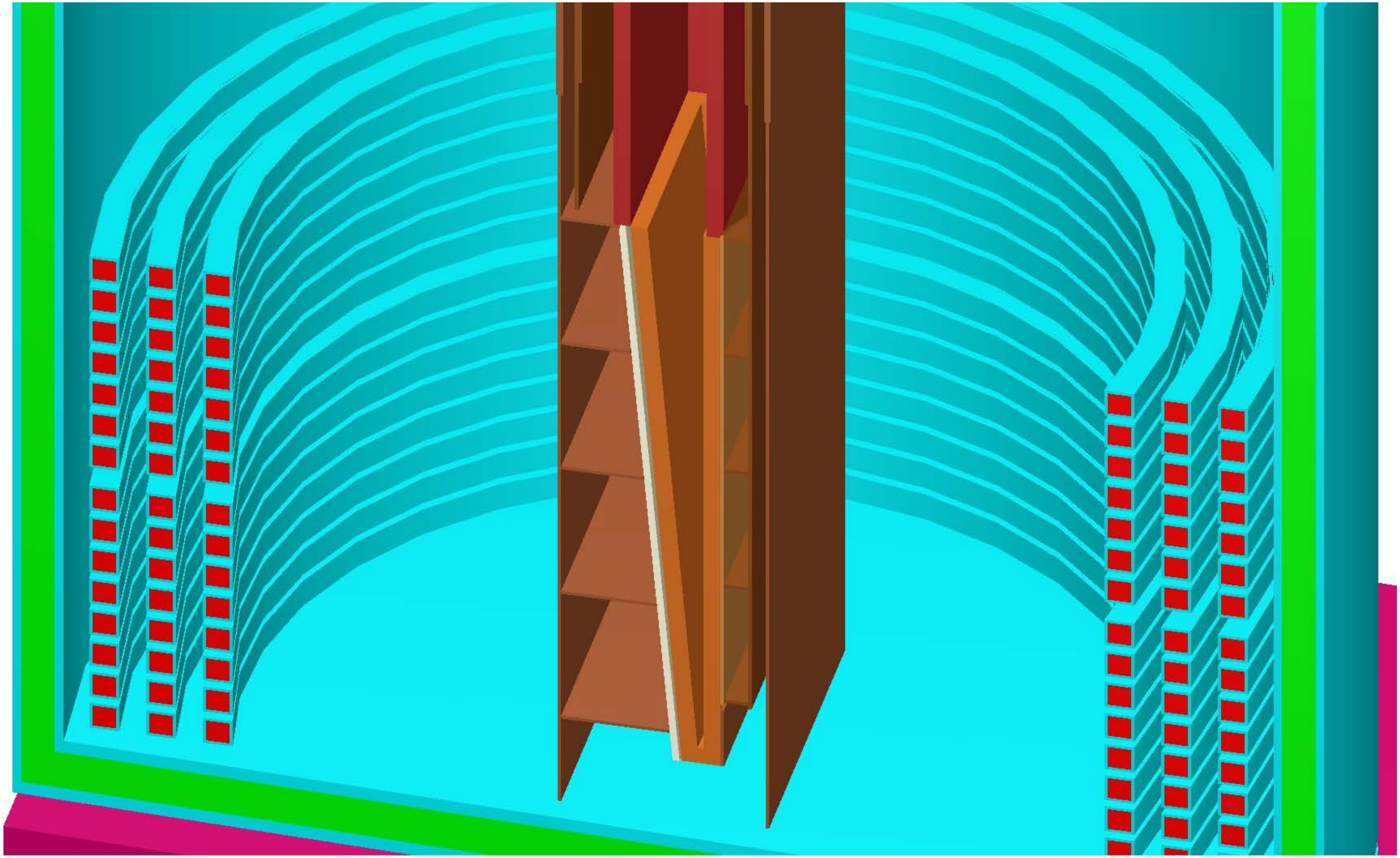


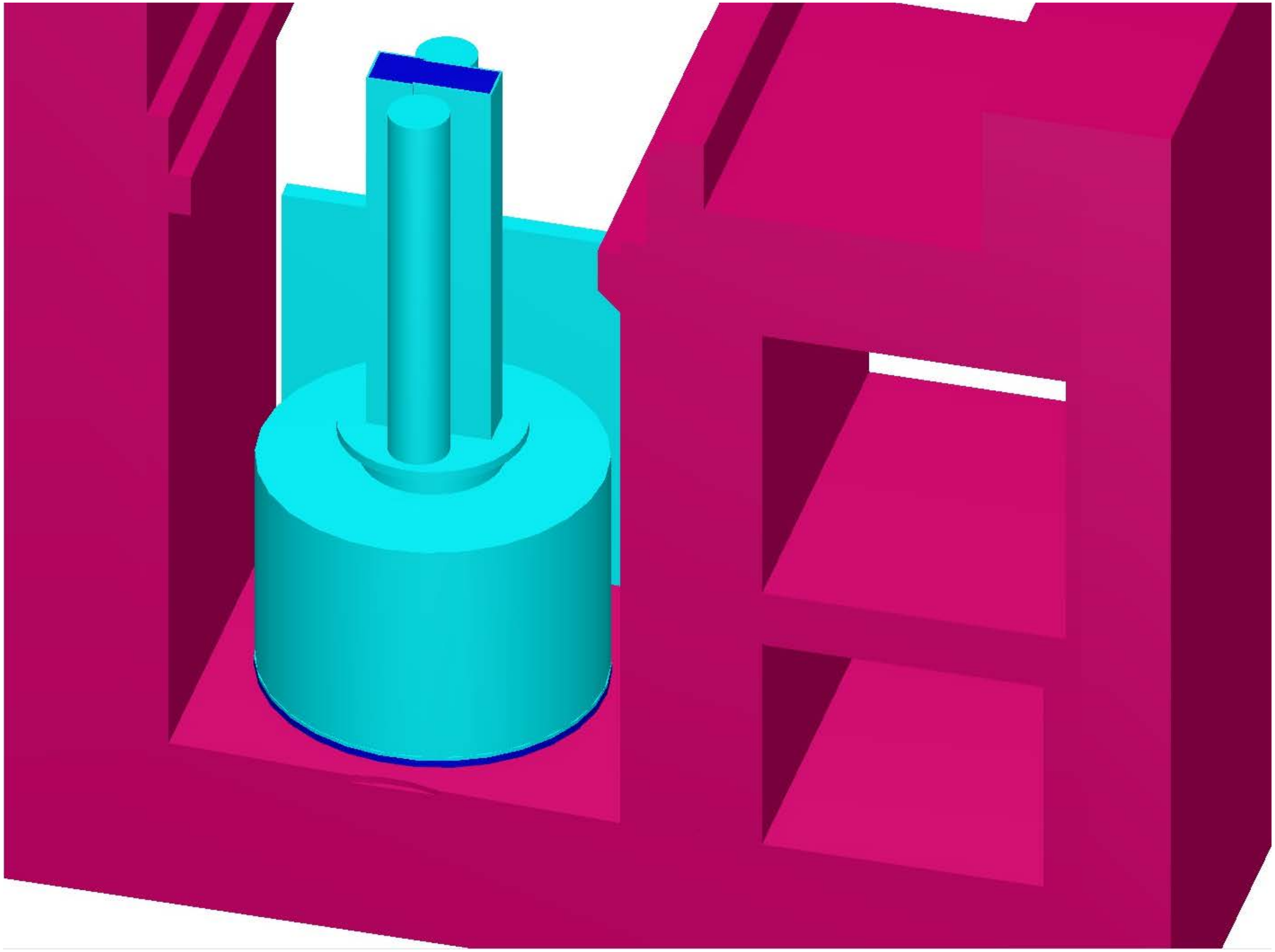


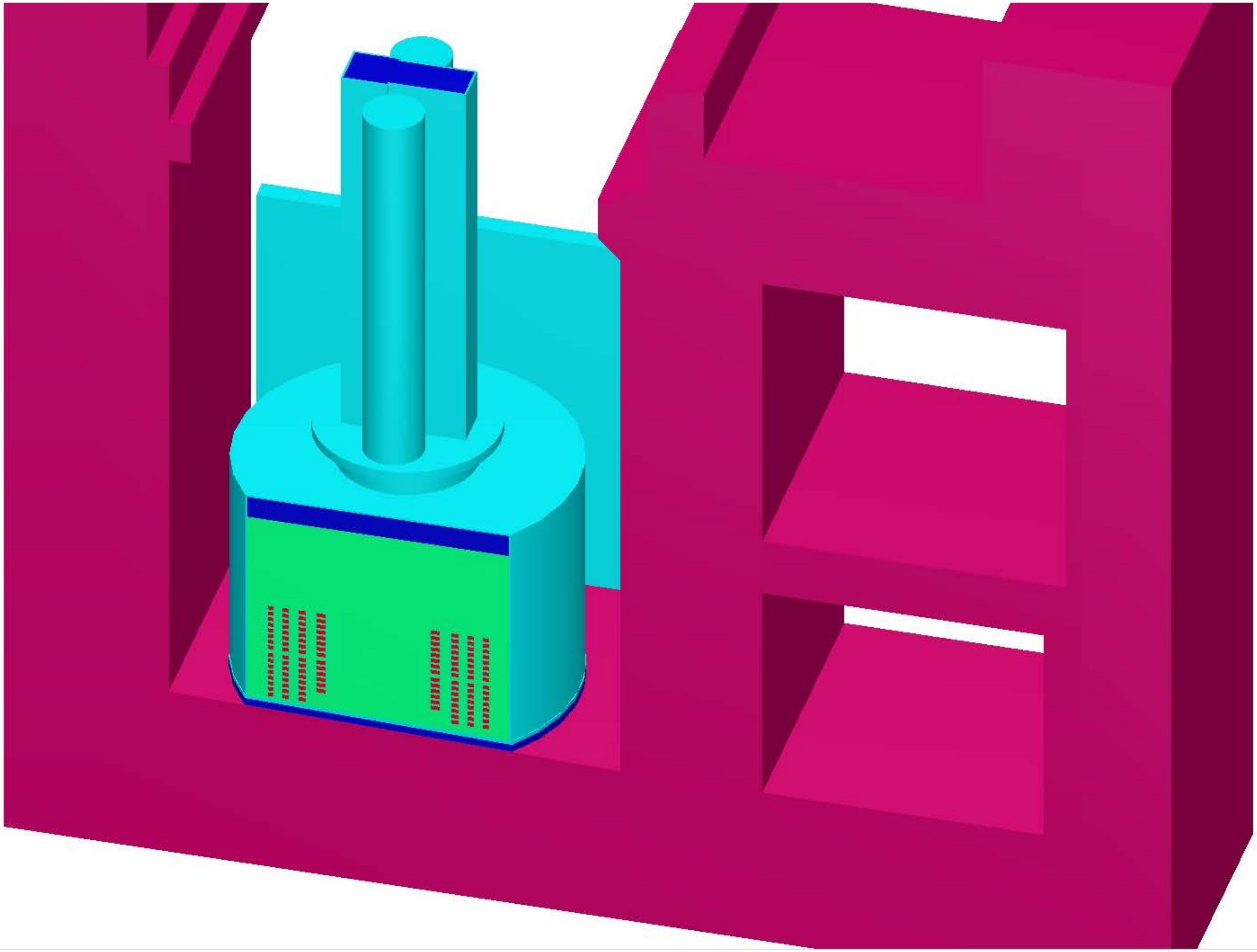


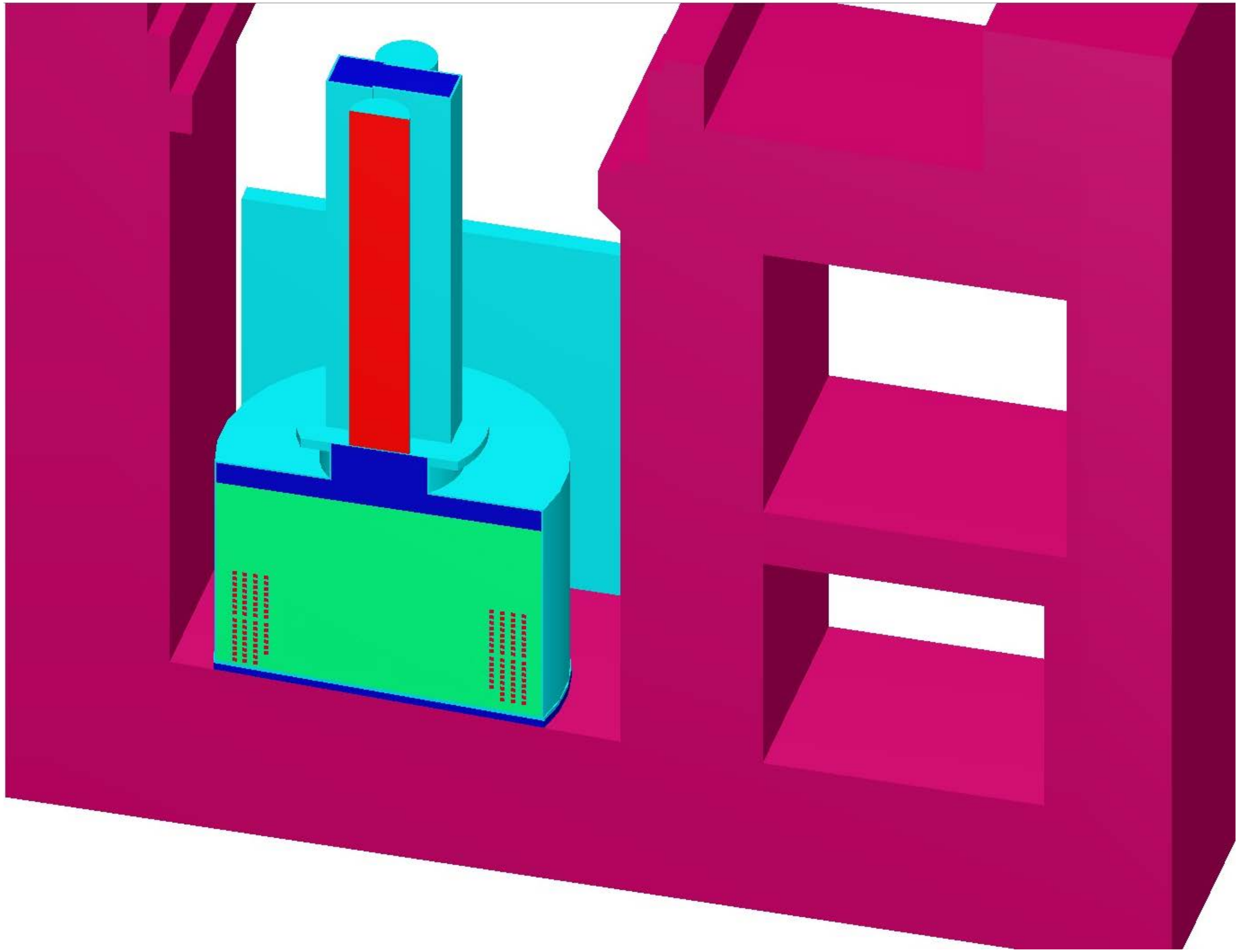


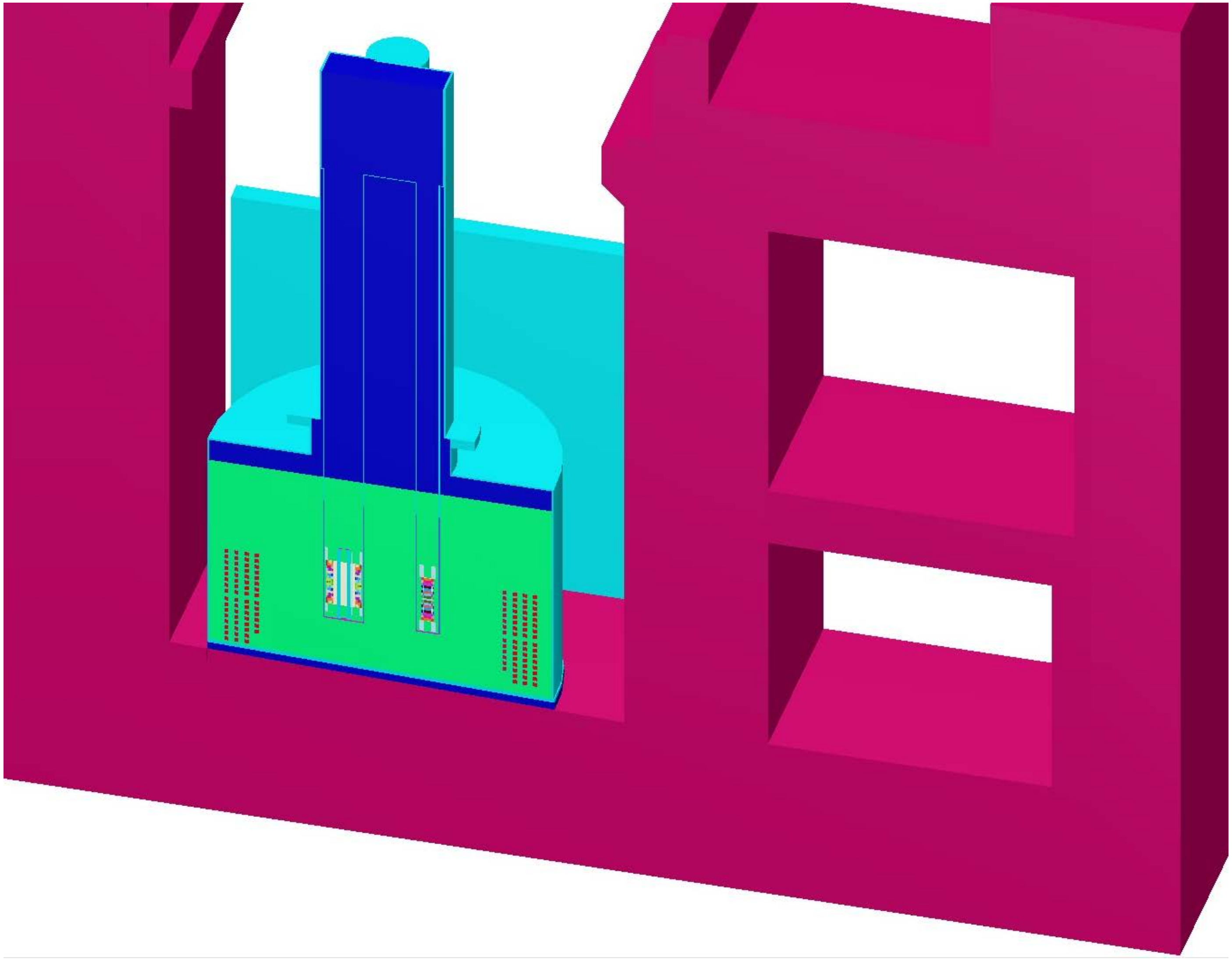


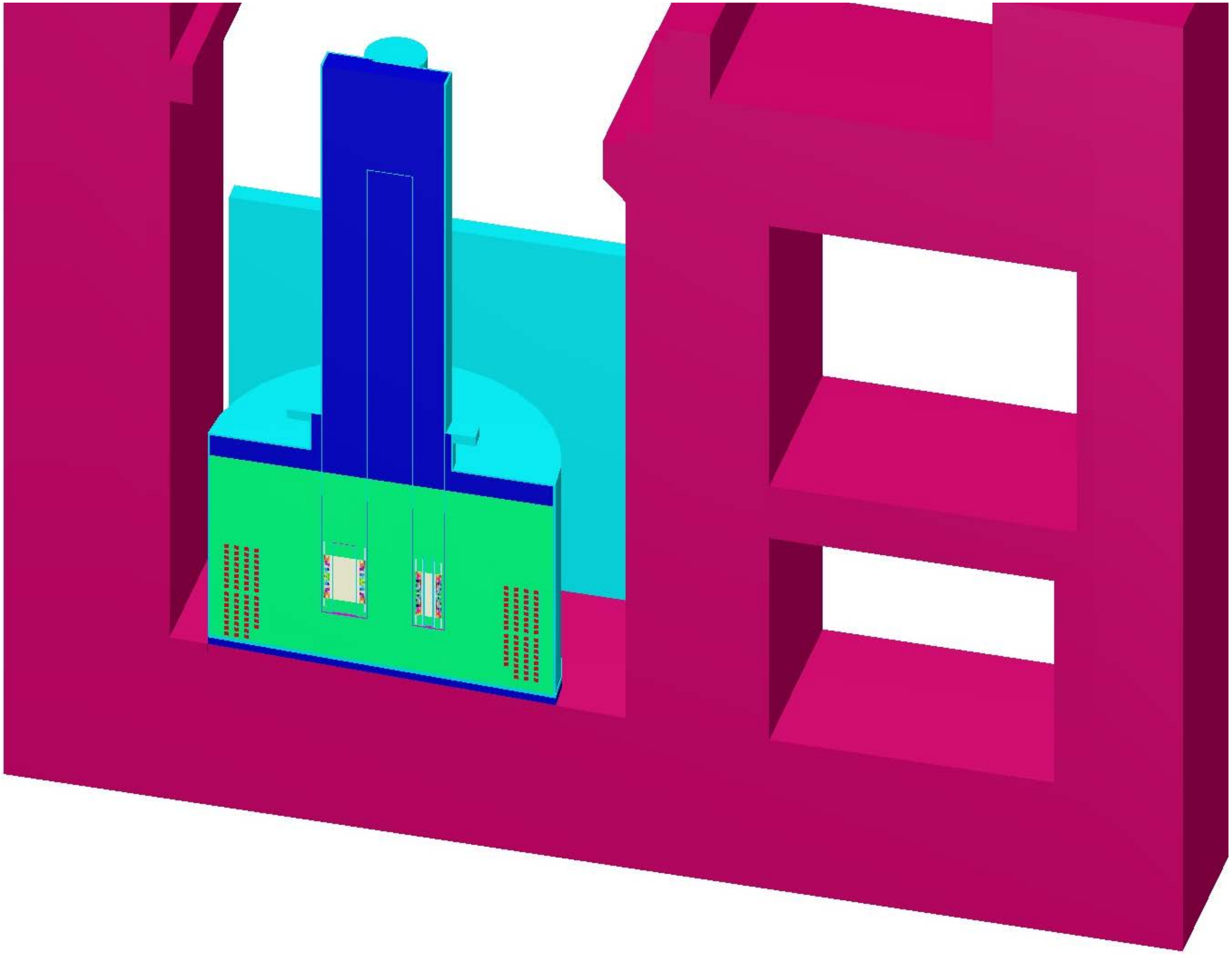


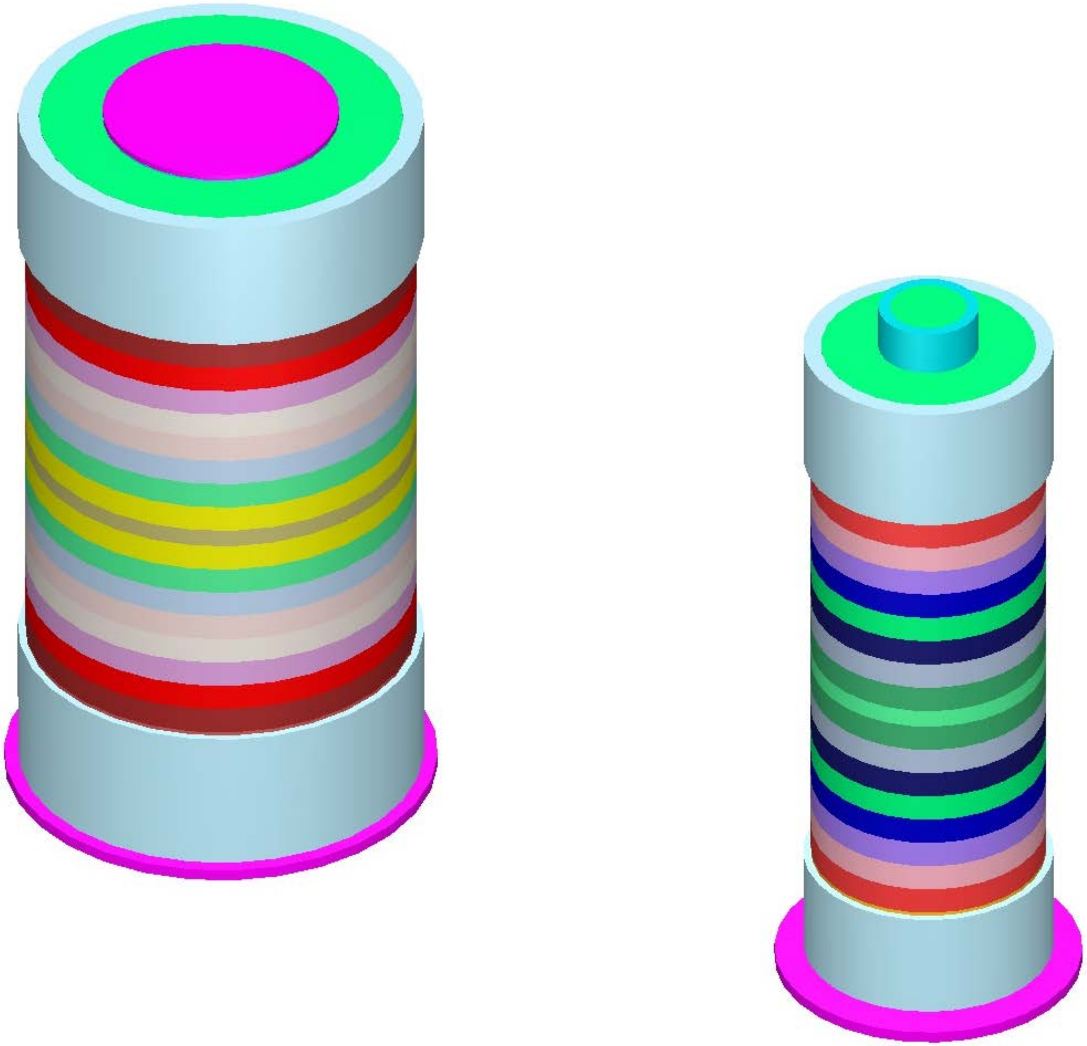


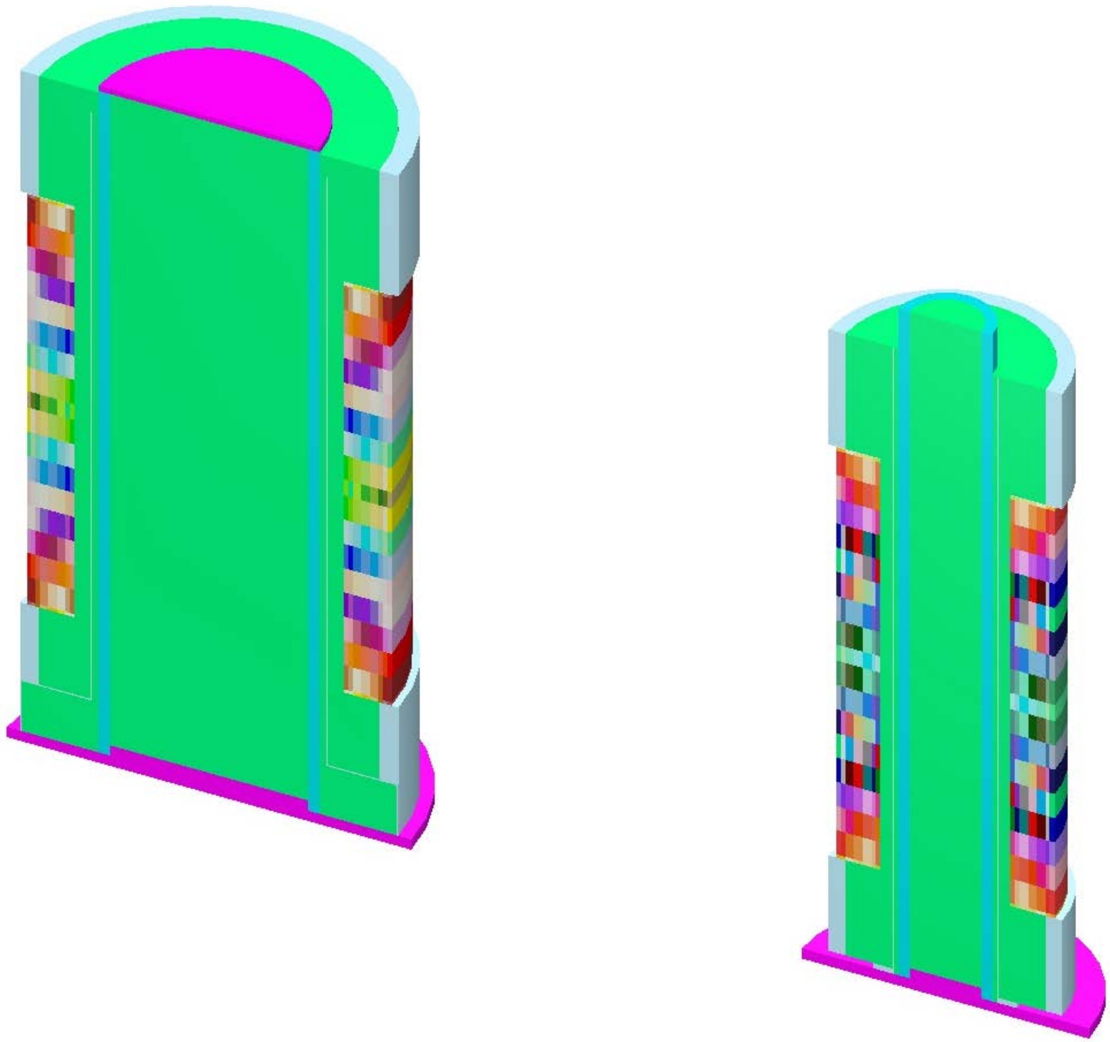


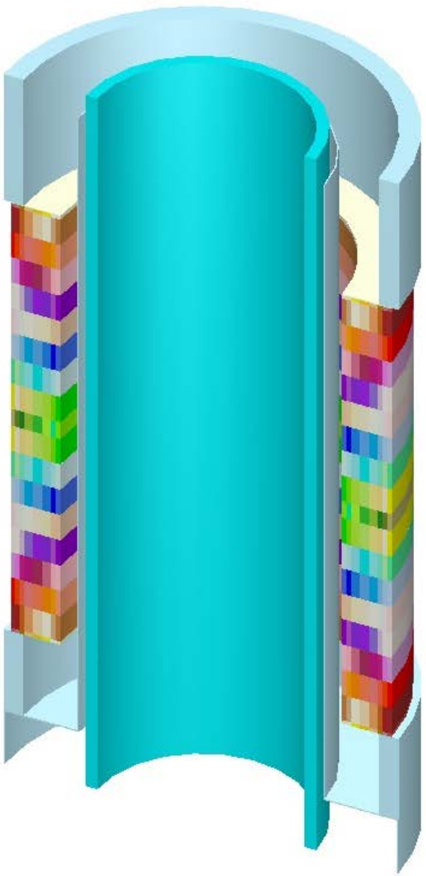


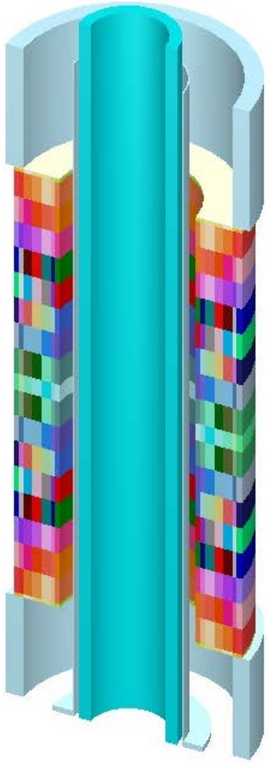


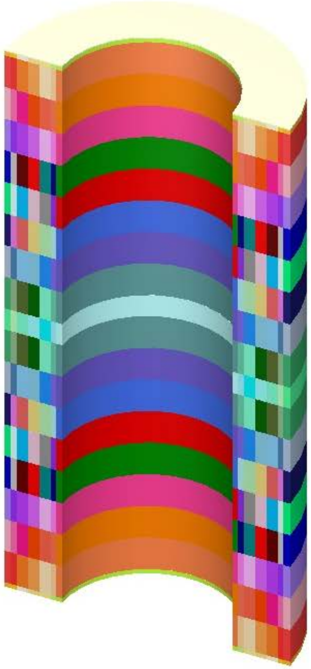


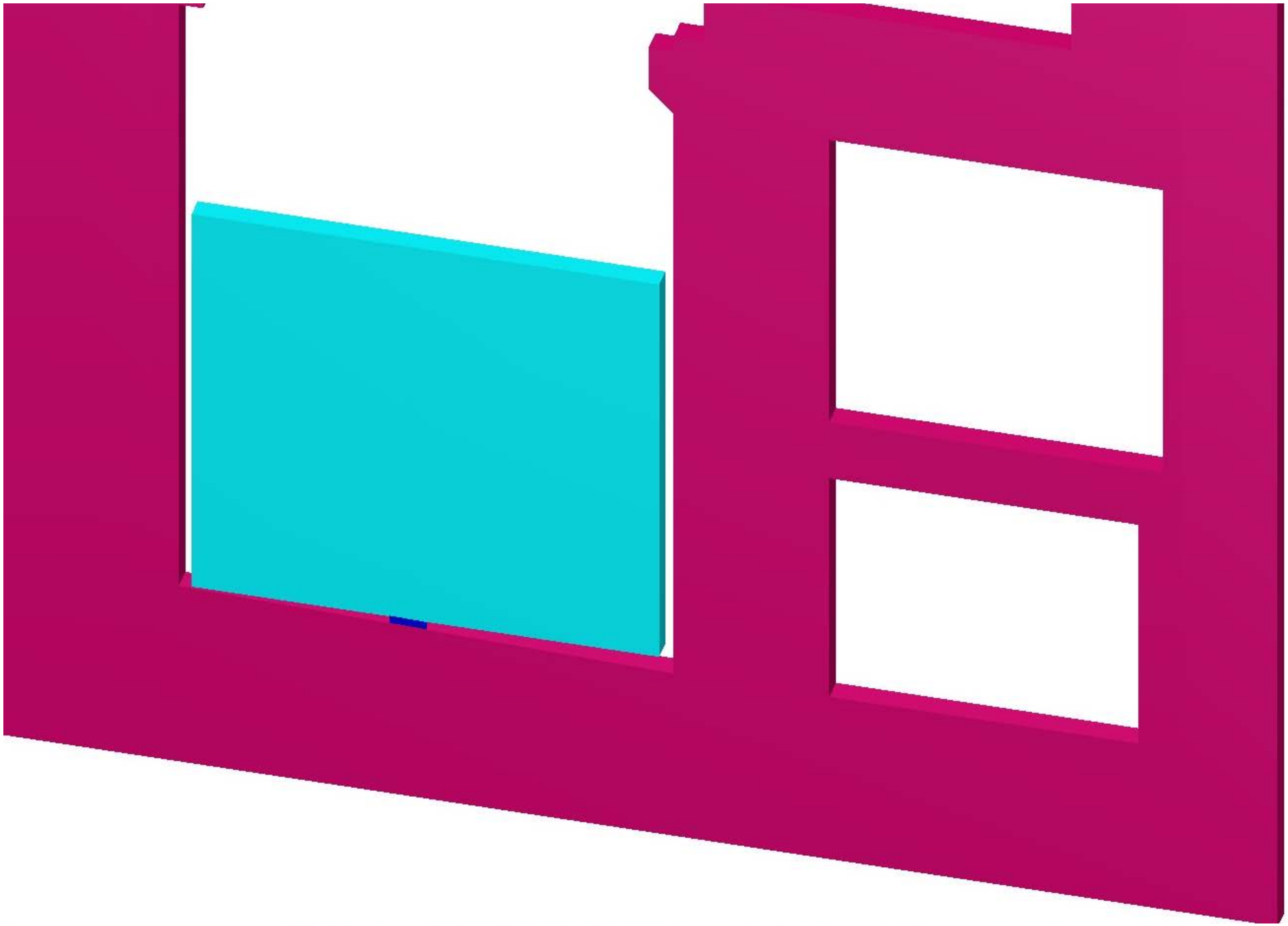












Results Part 2 – As Modeled

- 6.1D k-effective: 0.6628
- 6.2R/F k-effective: 0.0000 (No fissile assumed)
- Sump k-effective: 0.2673
- 6.3D k-effective: 0.4167
- 6.4D k-effective: 0.7587

- 6 Hot k-effective: 0.7592

- Communication: No
  - As expected

Questions

Additional Slides

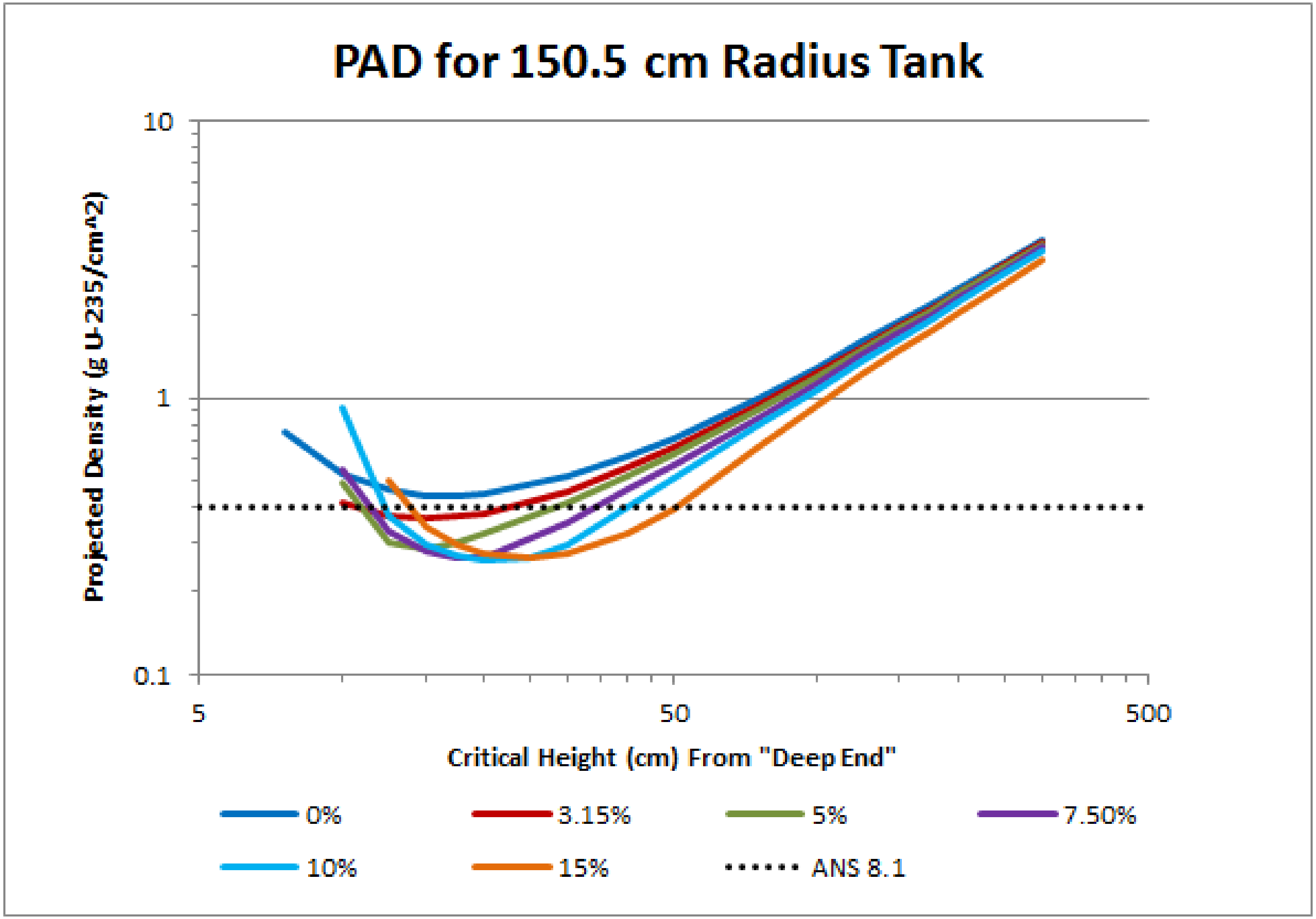
Results – Overall Behavior – Wedge Limited

- Height at which Solution Breaks Plane of Shallow End

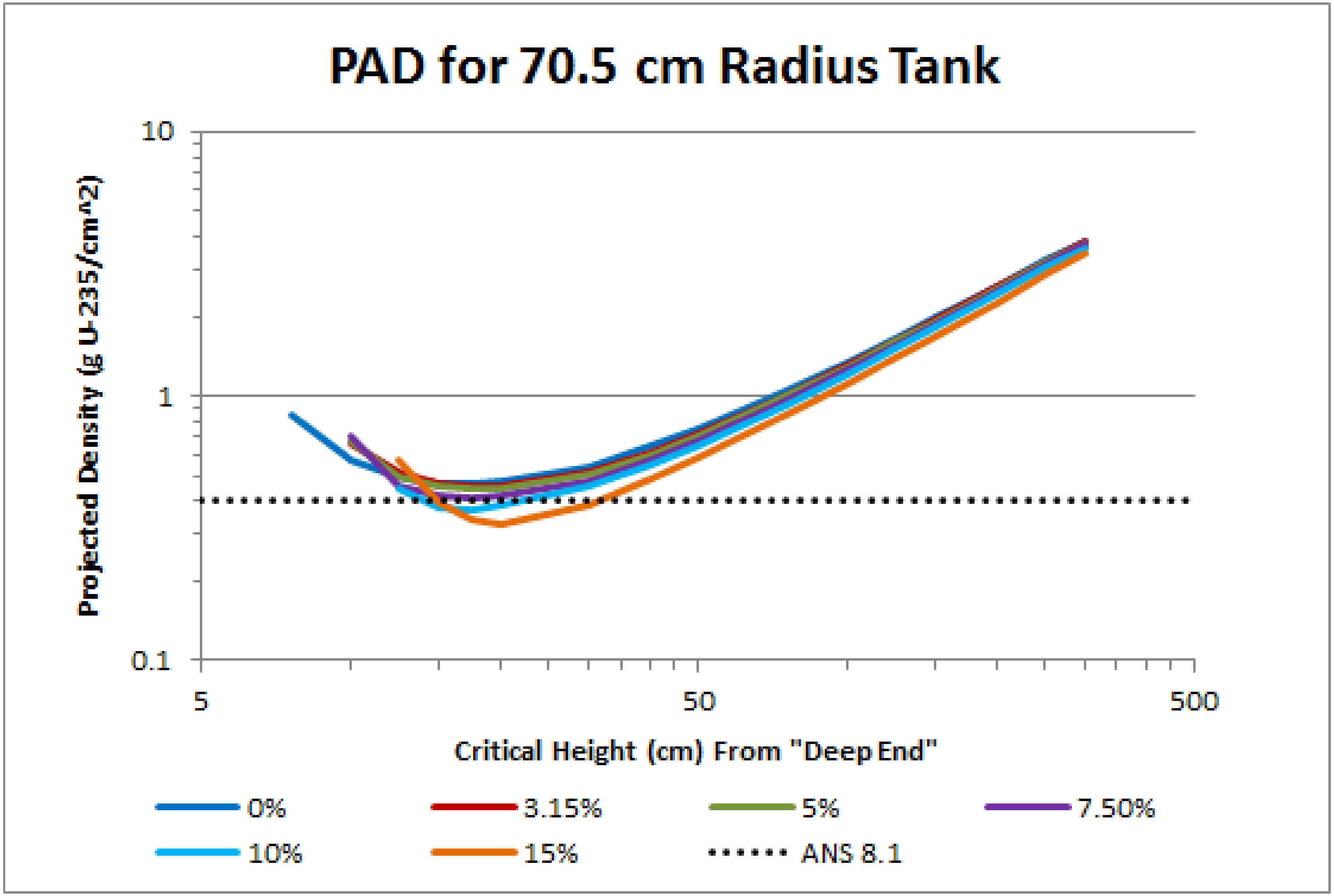
Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
3.15%	3.24	4.44	7.62	9.48
5%	5.14	7.05	12.10	15.05
7.5%	7.72	10.57	18.15	22.57
10%	10.29	14.10	24.19	30.10
15%	15.43	21.15	36.29	45.15

- Highlighted cases are where minimum PAD occurred in truncated wedge shape

Results - PAD

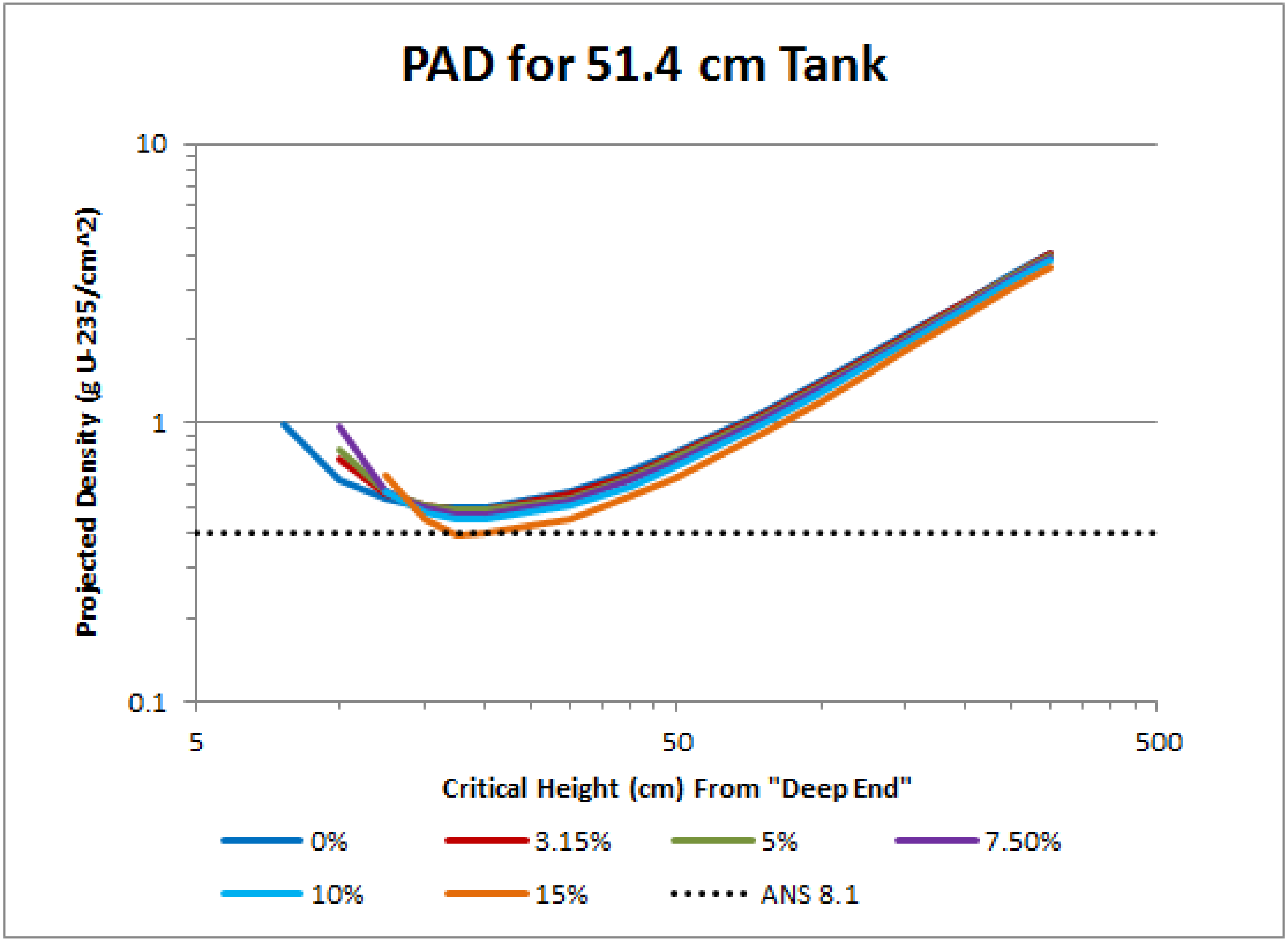

PAD for 150.5 cm Radius Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

Results - PAD

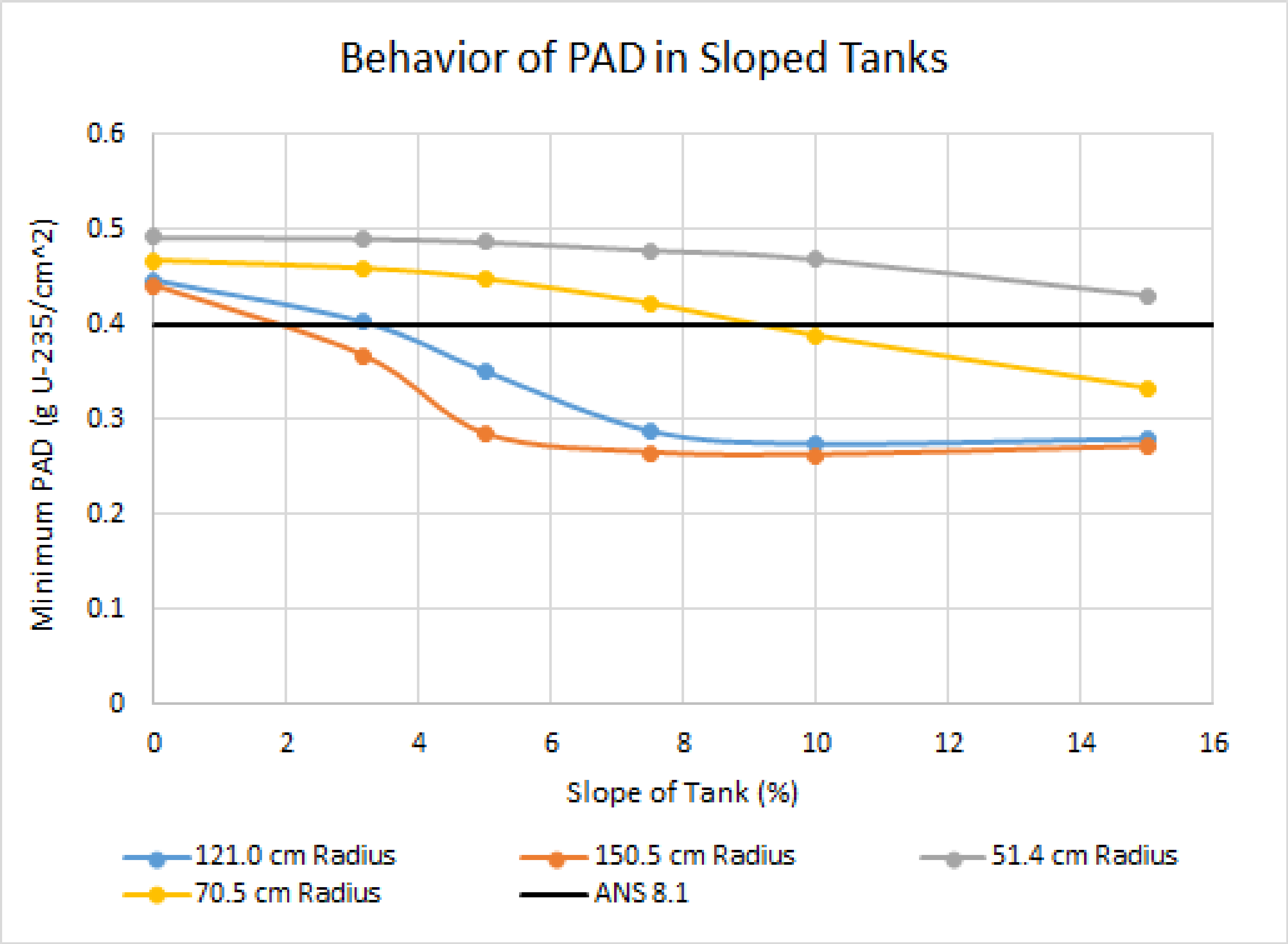


PAD for 70.5 cm Radius Tank
10
1
0.1
Projected Density (g U-235/cm^2)
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

Results - PAD


PAD for 51.4 cm Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

Results – Overall Behavior



• Fitted PAD

Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
0%	0.4879	0.4766	0.4540	0.4459
3.15%	0.4907	0.4549	0.3794	0.3482
5%	0.4882	0.4409	0.3440	0.3064
7.5%	0.4798	0.4205	0.3063	0.2683
10%	0.4657	0.3983	0.2800	0.2512
15%	0.4204	0.3488	0.2618	0.2801

- Height at which Solution Breaks Plane of Shallow End

Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
3.15%	3.24	4.44	7.62	9.48
5%	5.14	7.05	12.10	15.05
7.5%	7.72	10.57	18.15	22.57
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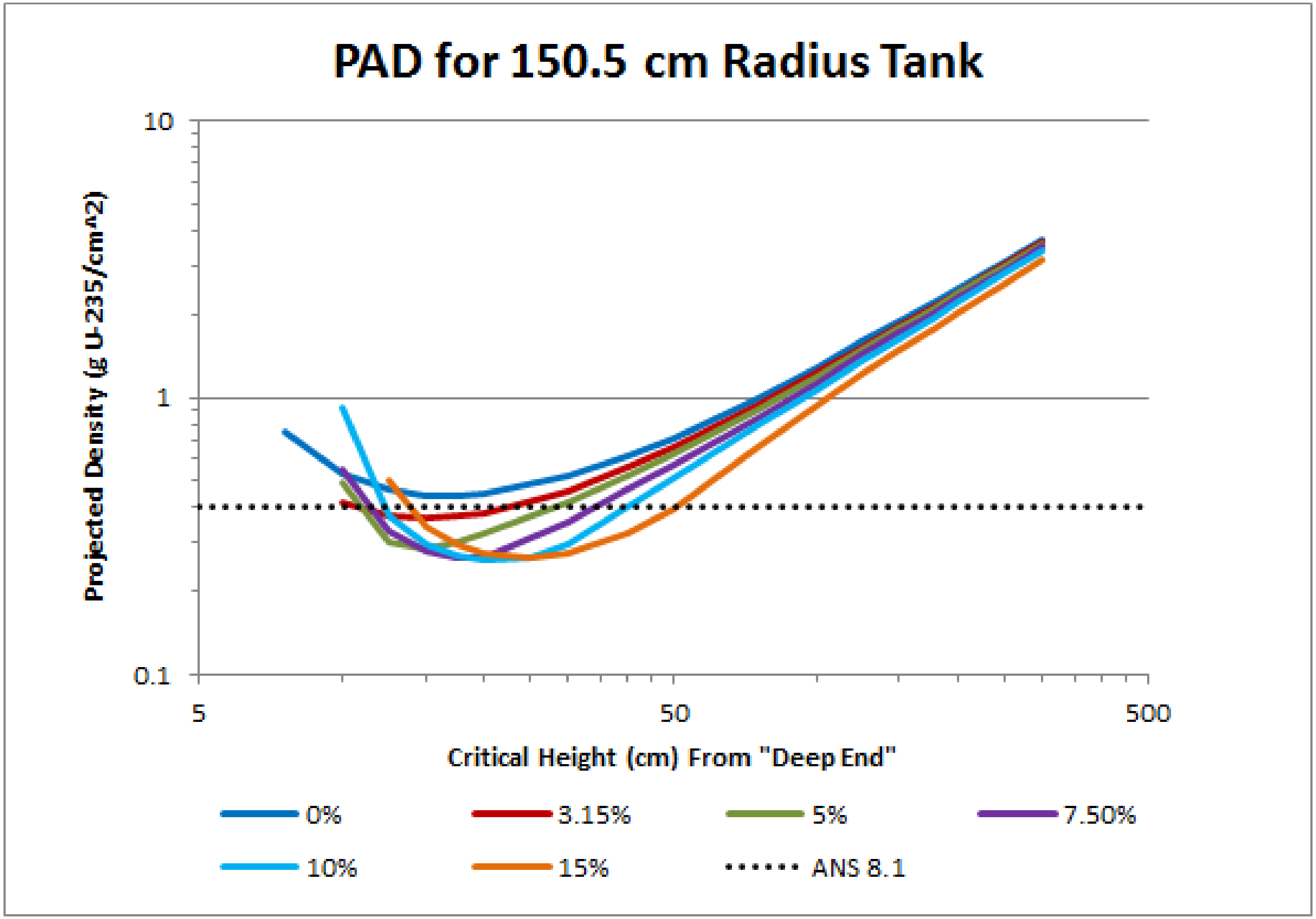
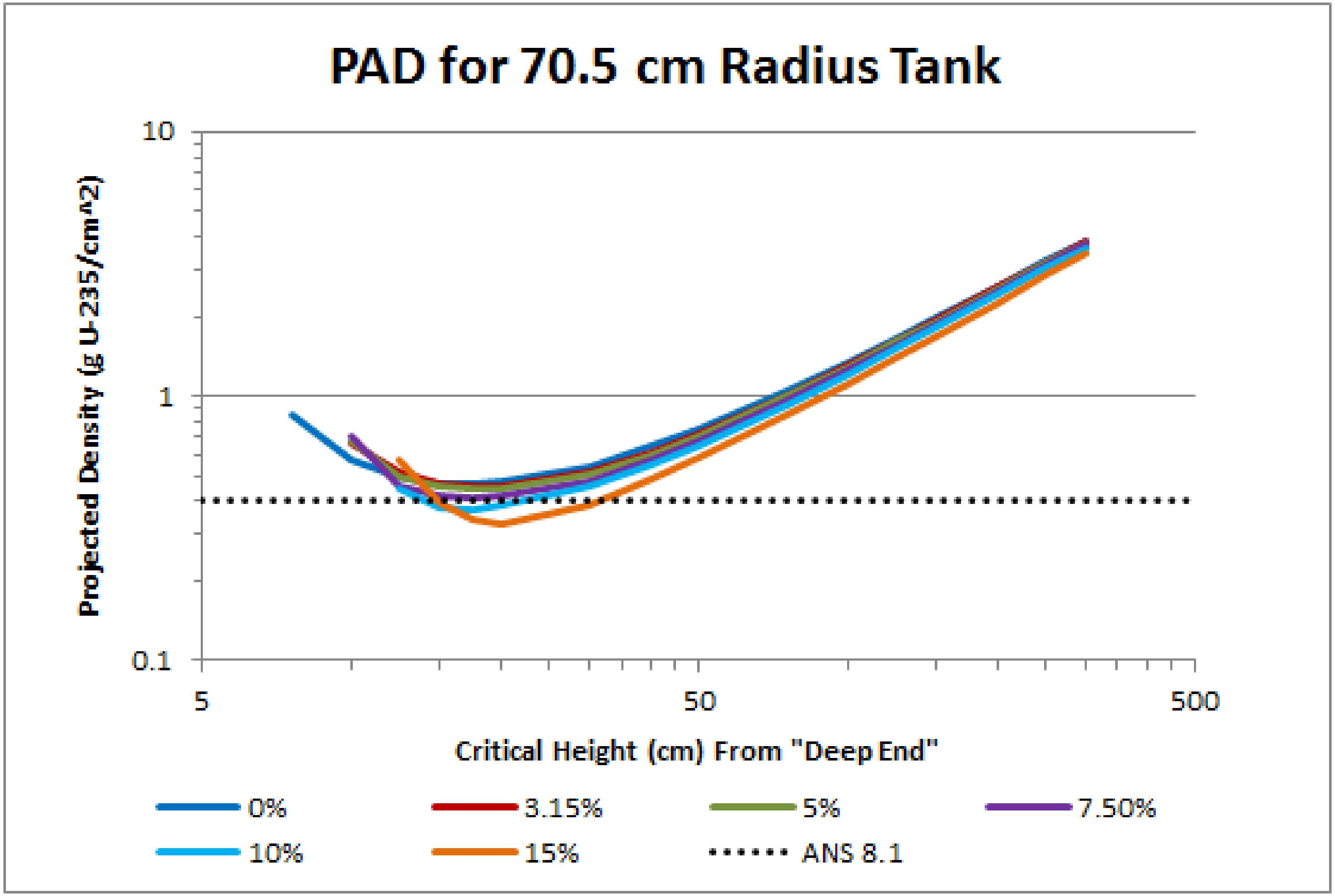
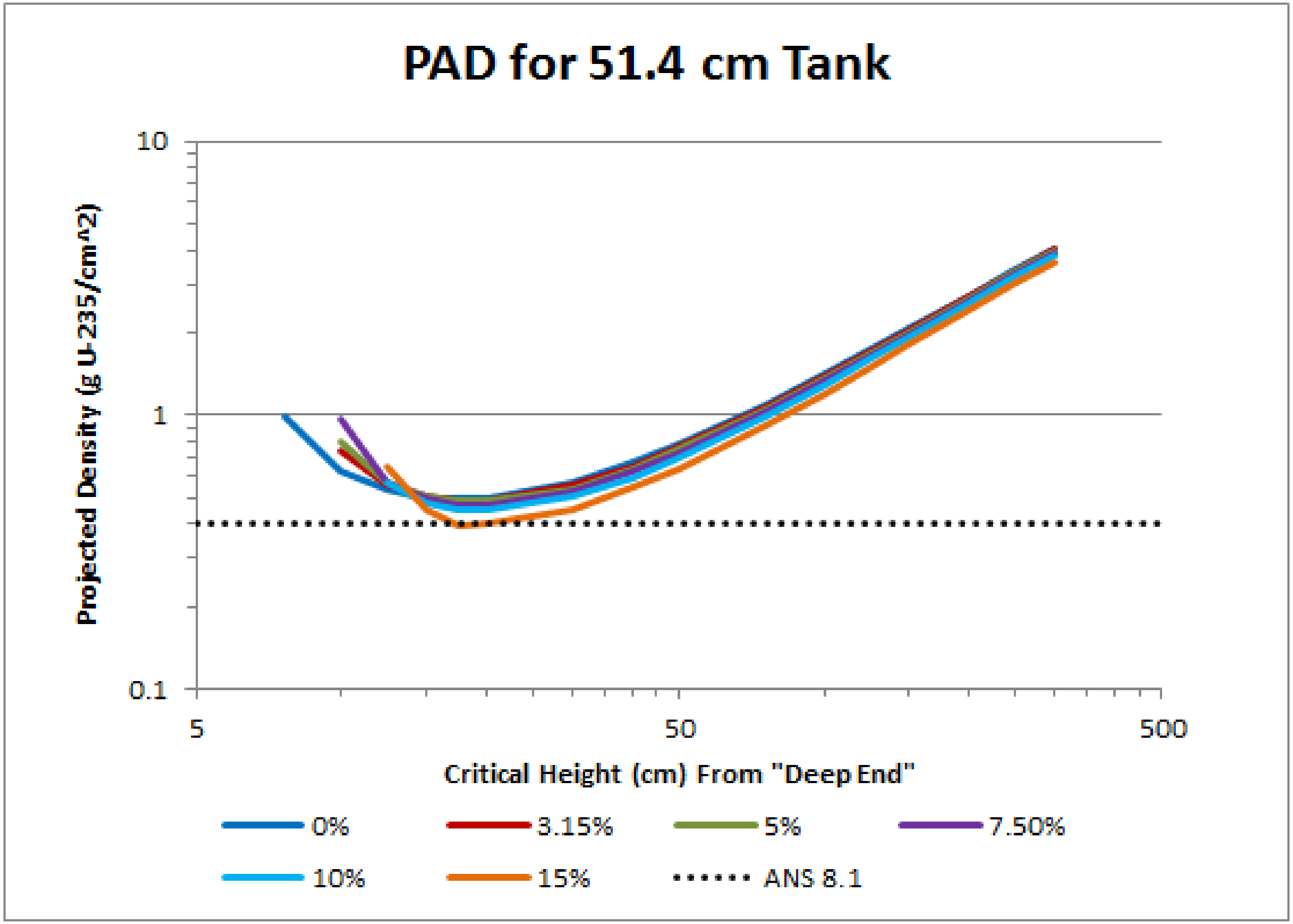
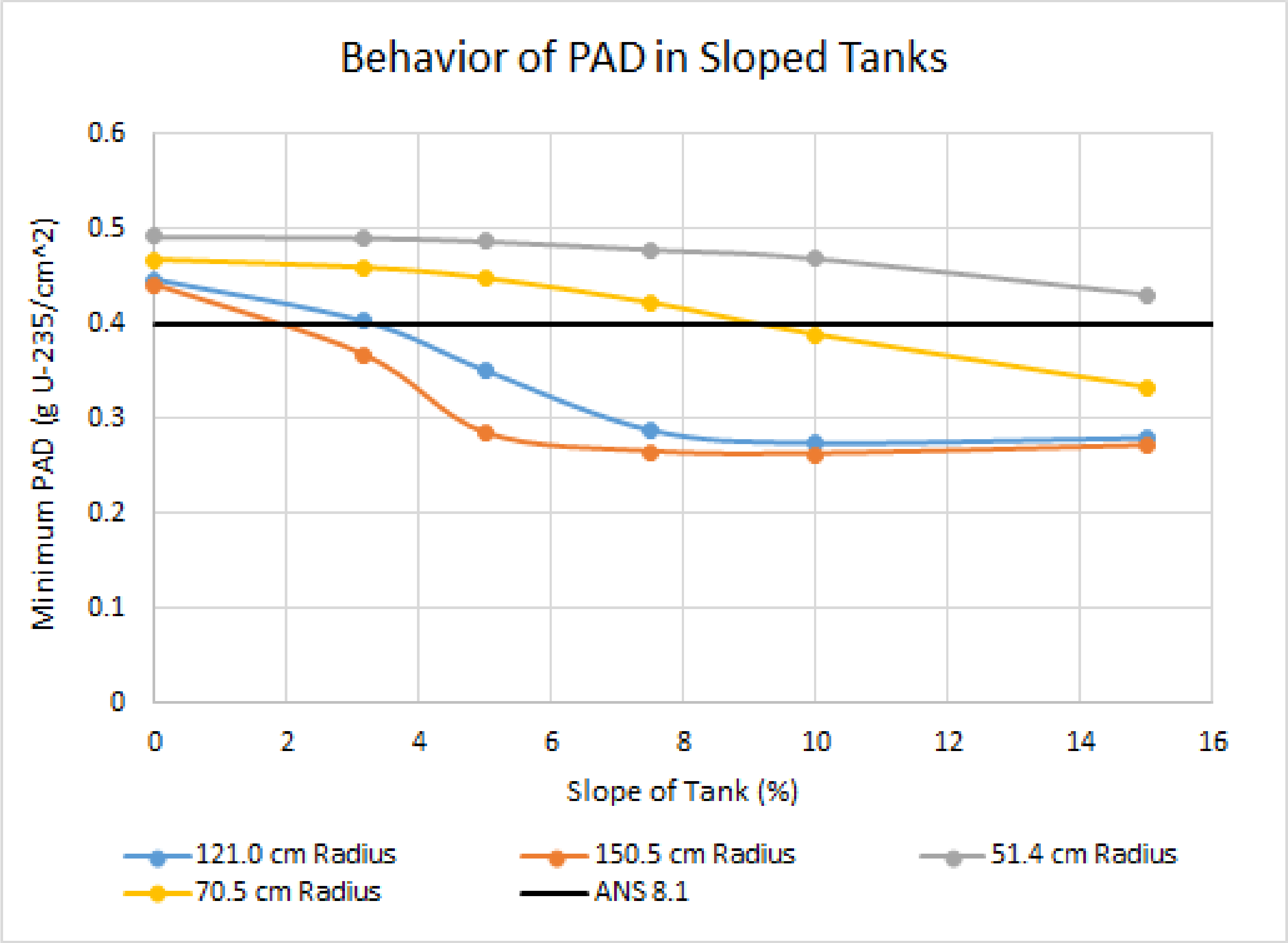
- Highlighted cases are where minimum PAD occurred in truncated wedge shape


PAD for 150.5 cm Radius Tank
10
1
0.1
Projected Density (g U-235/cm^2)
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1


PAD for 70.5 cm Radius Tank
10
1
0.1
Projected Density (g U-235/cm^2)
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1


PAD for 51.4 cm Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1


Behavior of PAD in Sloped Tanks
Minimum PAD (g U-235/cm^2)
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
Slope of Tank (%)
121.0 cm Radius
150.5 cm Radius
51.4 cm Radius
70.5 cm Radius
ANS 8.1

Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
0%	0.4879	0.4766	0.4540	0.4459
3.15%	0.4907	0.4549	0.3794	0.3482
5%	0.4882	0.4409	0.3440	0.3064
7.5%	0.4798	0.4205	0.3063	0.2683
10%	0.4657	0.3983	0.2800	0.2512
15%	0.4204	0.3488	0.2618	0.2801