Sloped Bottom Tanks and Areal Density – Part II: Functional Behavior of Projected Areal Density

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Motivation for Inquiry

- From Part I: investigation was made to establish a mass limit for H-Canyon product decanters based on areal density
  - Decanters have sloped bottoms
  - For those vessels areal density based mass limits were still usable
  - Improves efficiency of operation of those vessels
- 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!

Background

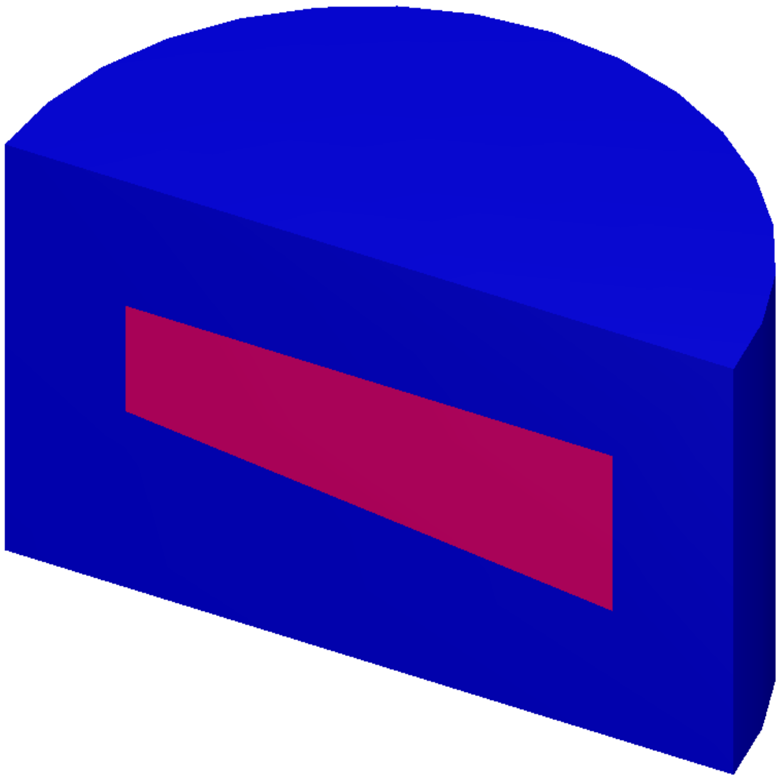
- In sloped bottom tanks, the bottom plan is not orthonormal to the remaining dimensions!
  - Flat is not always economic, convenient, available, or safe from a chemical or processing hazard aspect
- Is there a relationship between slope, area, and what may be called a *projected* areal density (PAD) 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.



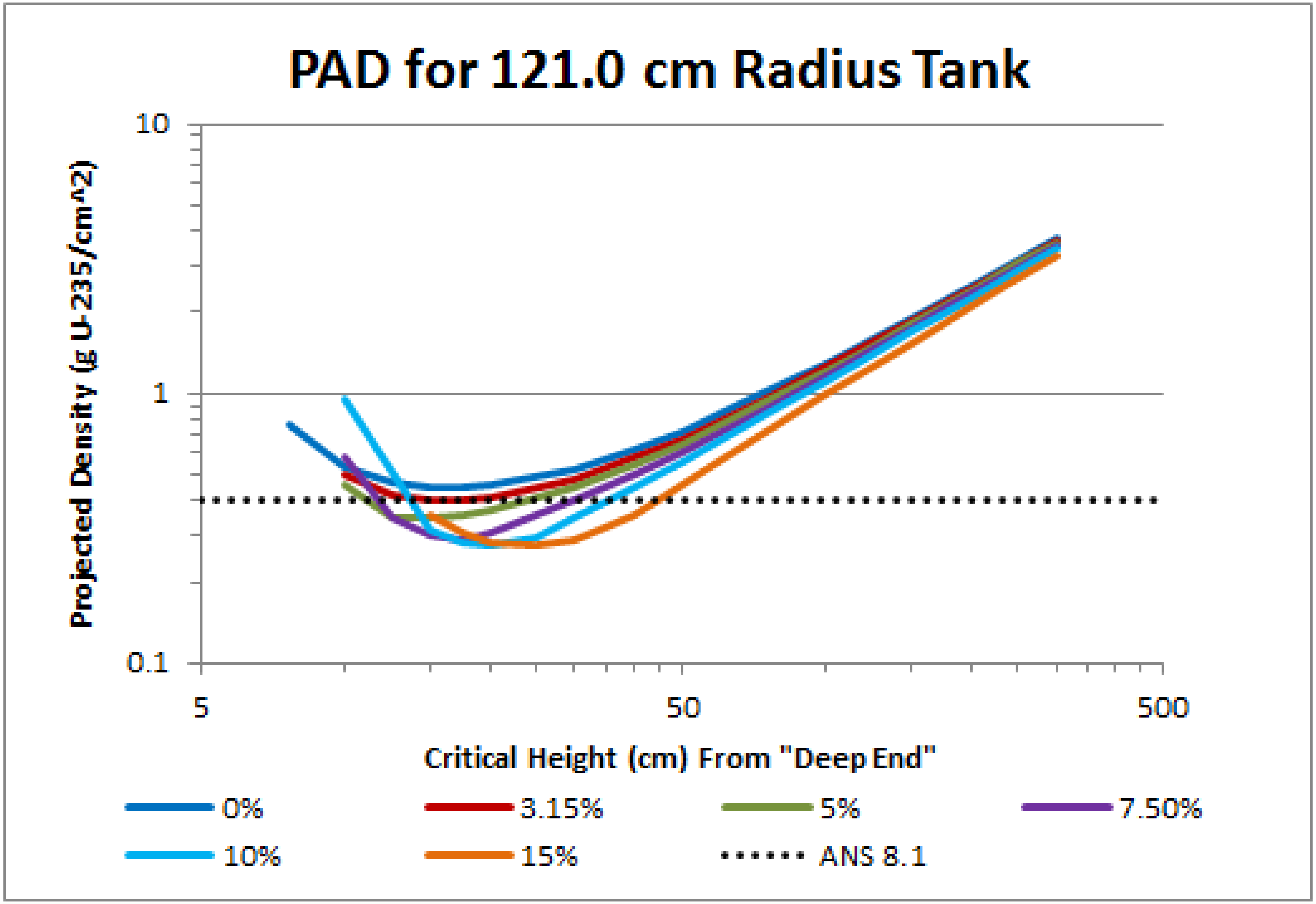
Analytical Approach

- PAD presented here is defined as projected onto the solution surface
  - Chosen because easily defined on design drawings and understood by Operations and Engineering
  - 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

Results - PAD

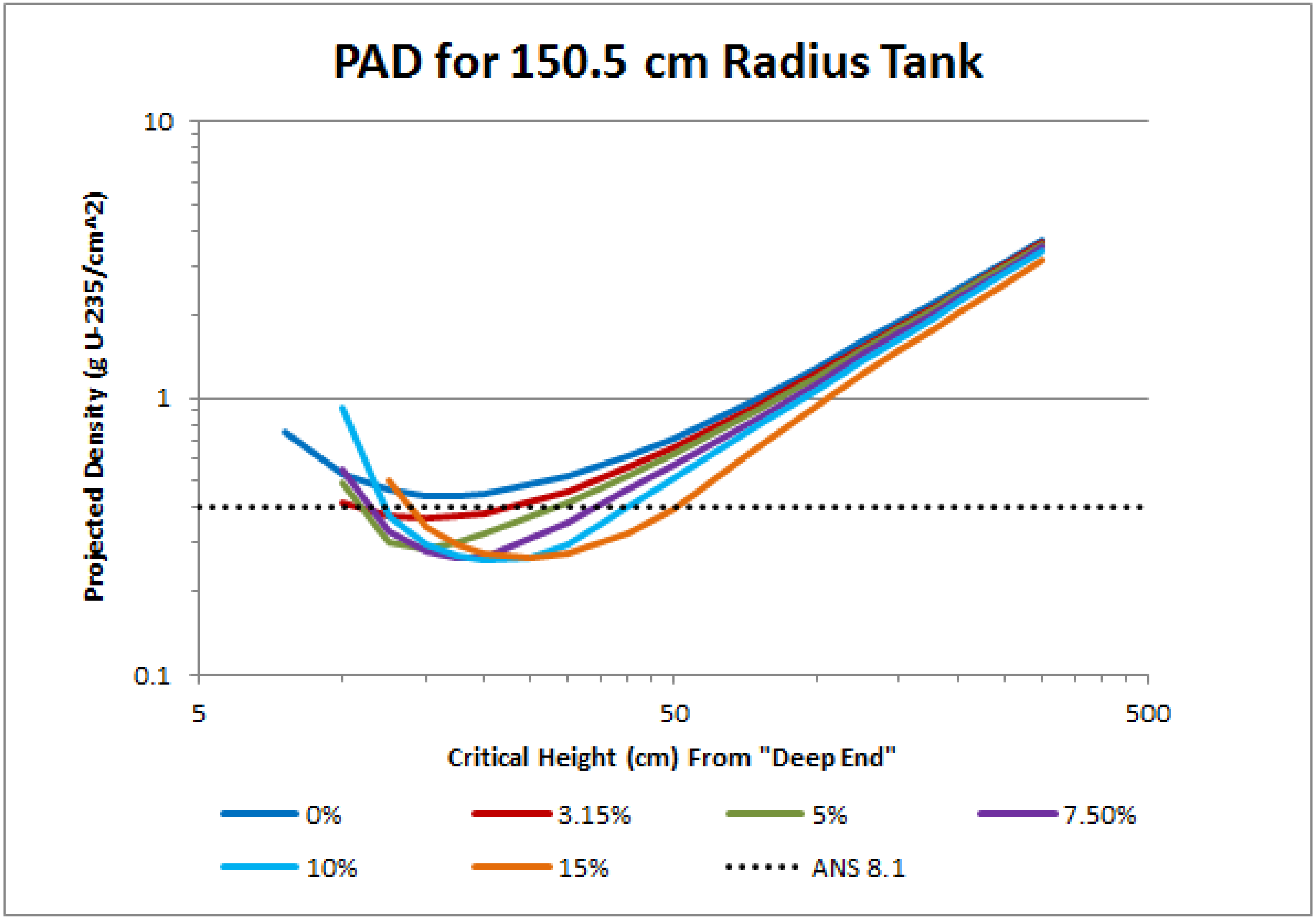
- For each radius and slope, determined the minimum PAD that would result in a critical configuration
  - As would be done with areal density on flat bottoms tanks
  - Critical heights are measured from the “deep end” of the solution, i.e. the point that would be tangent to the low end tank wall

Results - PAD



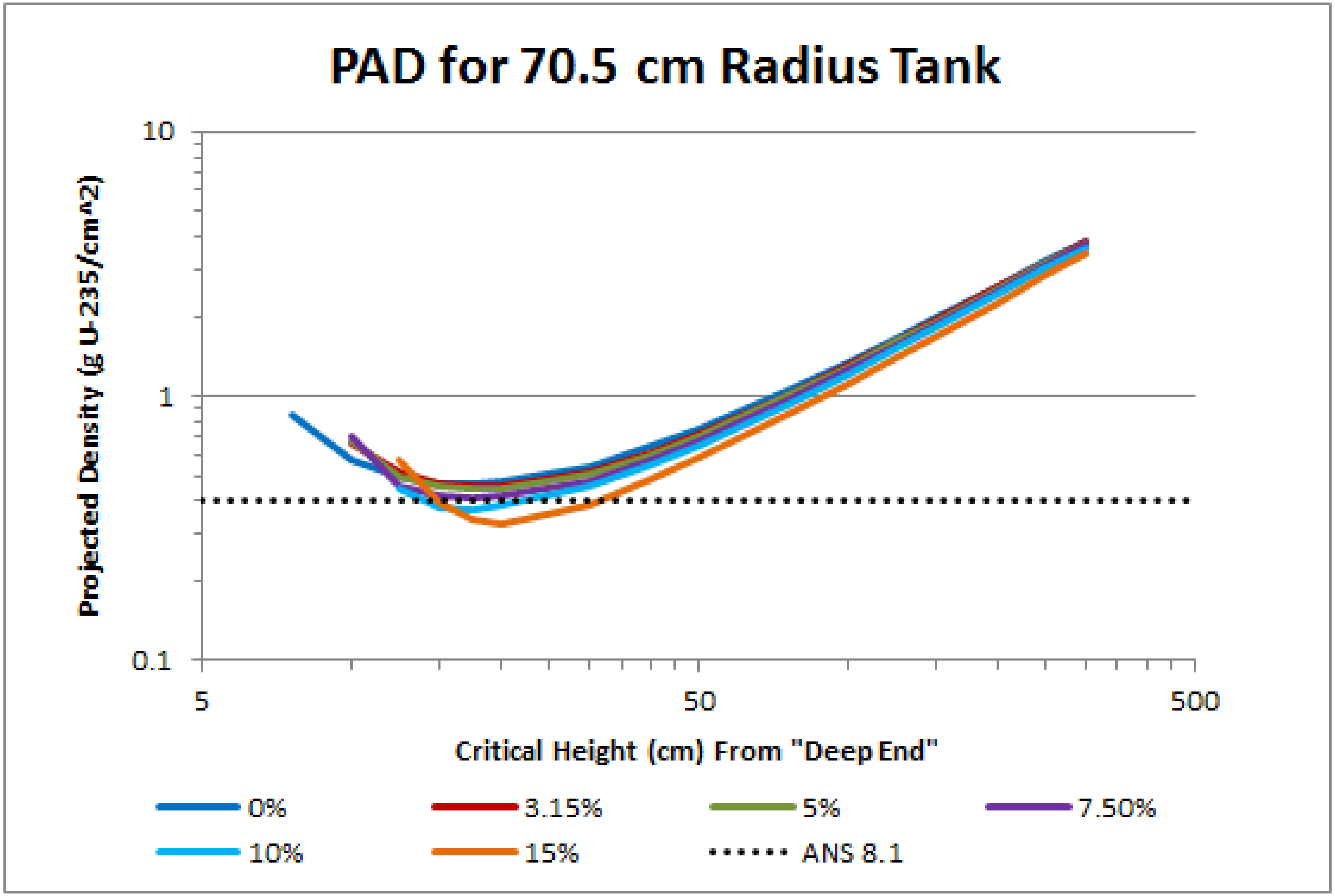
PAD for 121.0 cm Radius Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

Results - PAD



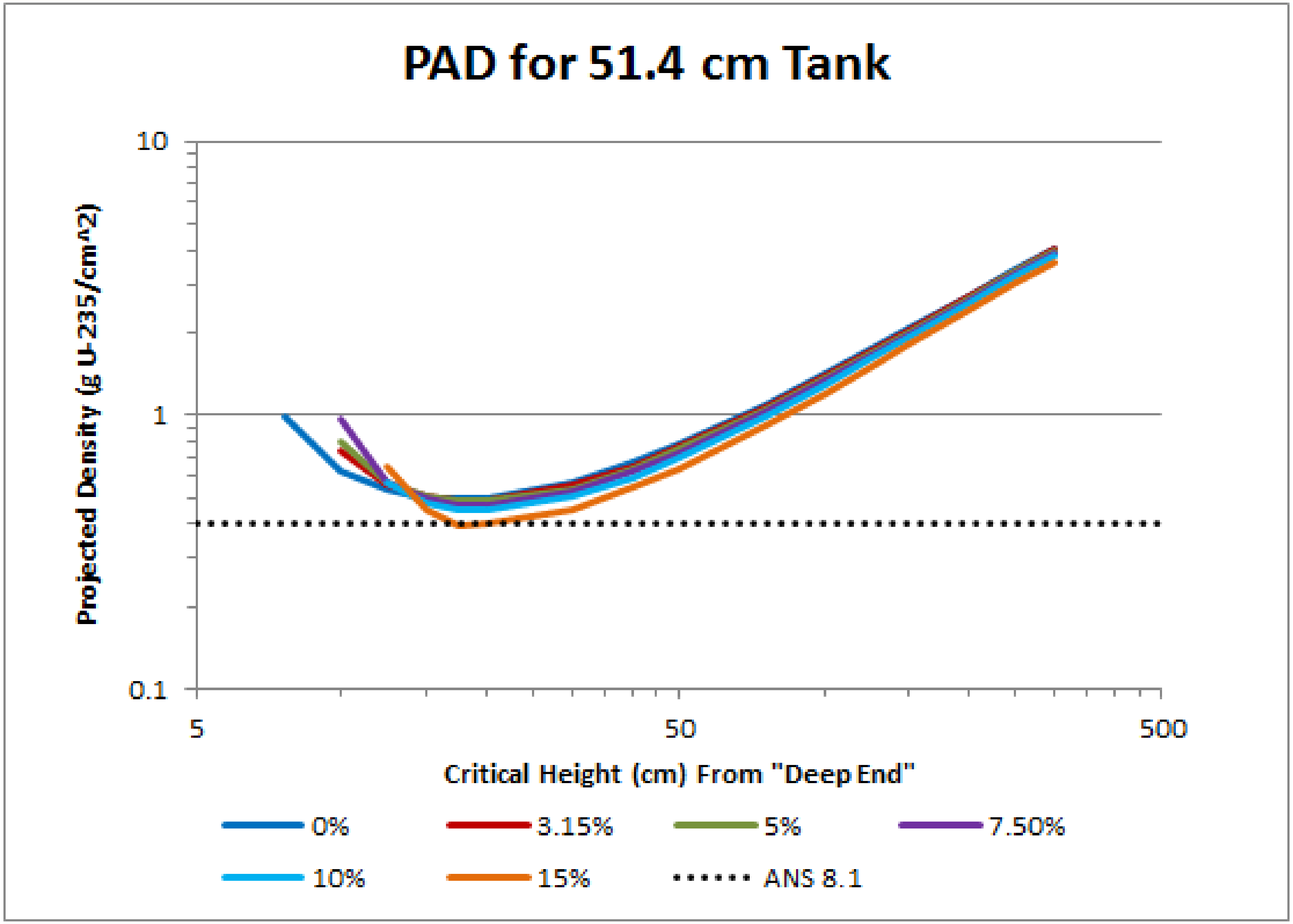
PAD for 150.5 cm Radius Tank
Projected Density (g U-235/cm^2)
10
1
0.1
5
50
500
Critical Height (cm) From "Deep End"
0%
3.15%
5%
7.50%
10%
15%
ANS 8.1

Results - PAD



PAD for 70.5 cm Radius Tank
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 51.4 cm 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

- 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: 3.58 kg to 31.40 kg depending on tank size
  - H/U-235: 575 to 1015, average 825
  - Concentration (g U-235/L): 25.5 to 44.0, average 31.6

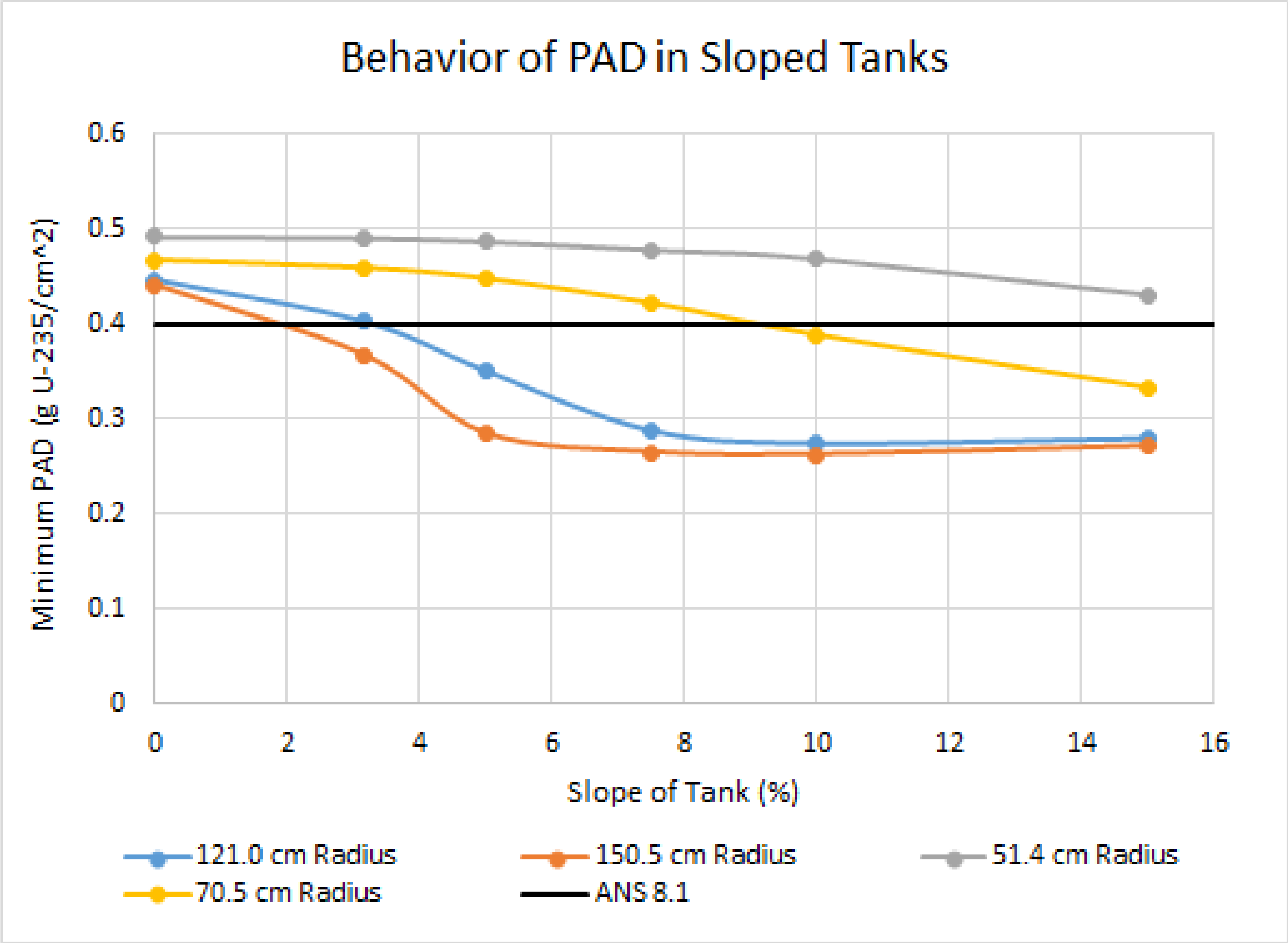
Results – Overall Behavior – Wedge Limited

- Height at which Solution Breaks Plane of Shallow End

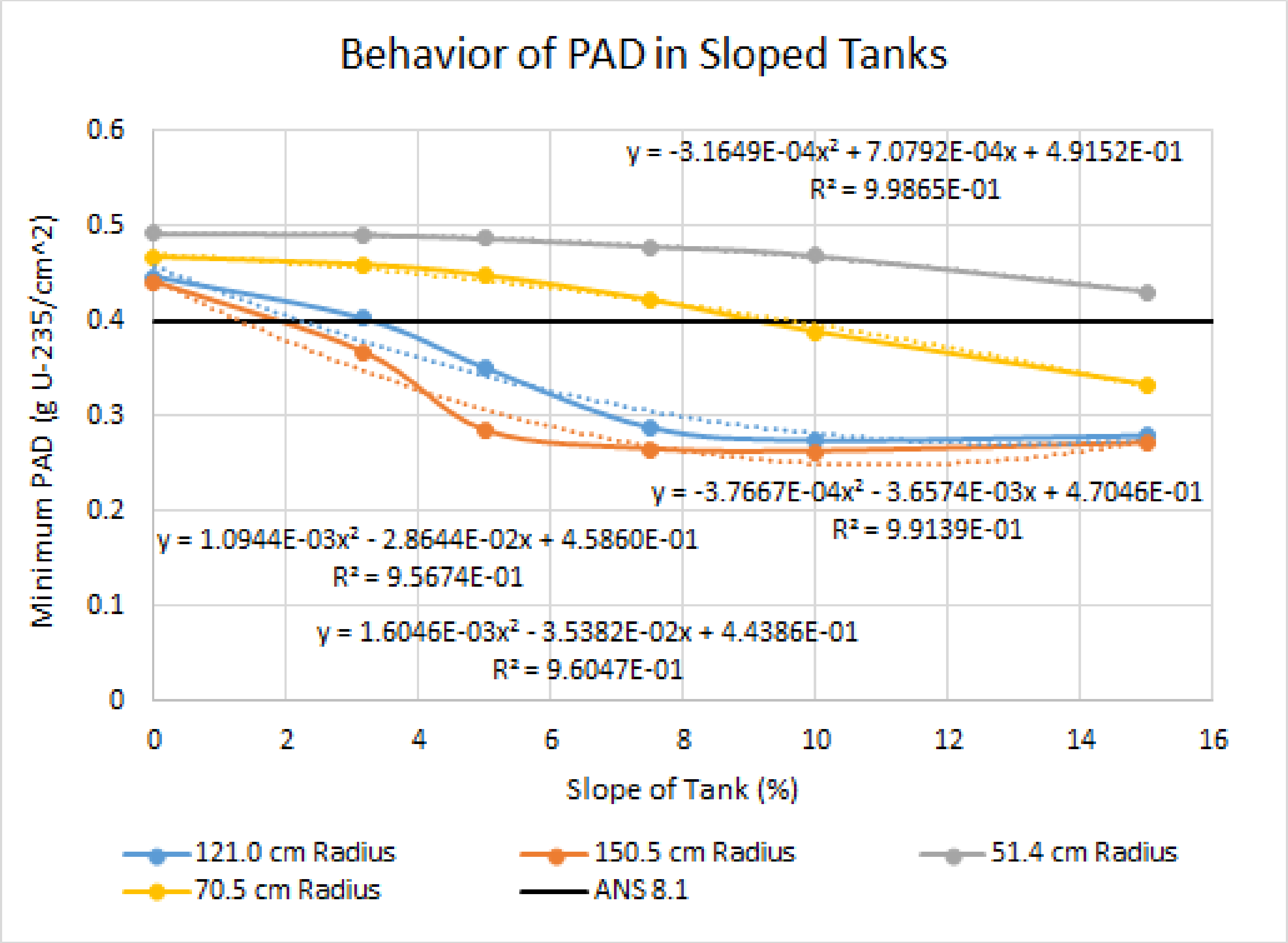
Slope	51.4 cm radius	70.5 cm radius	121.0 cm radius	150.5 cm radius
3.15%	3.24	4.44	7.62	9.48
5%	5.14	7.05	12.10	15.05
7.5%	7.72	10.57	18.15	22.57
10%	10.29	14.10	24.19	30.10
15%	15.43	21.15	36.29	45.15

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

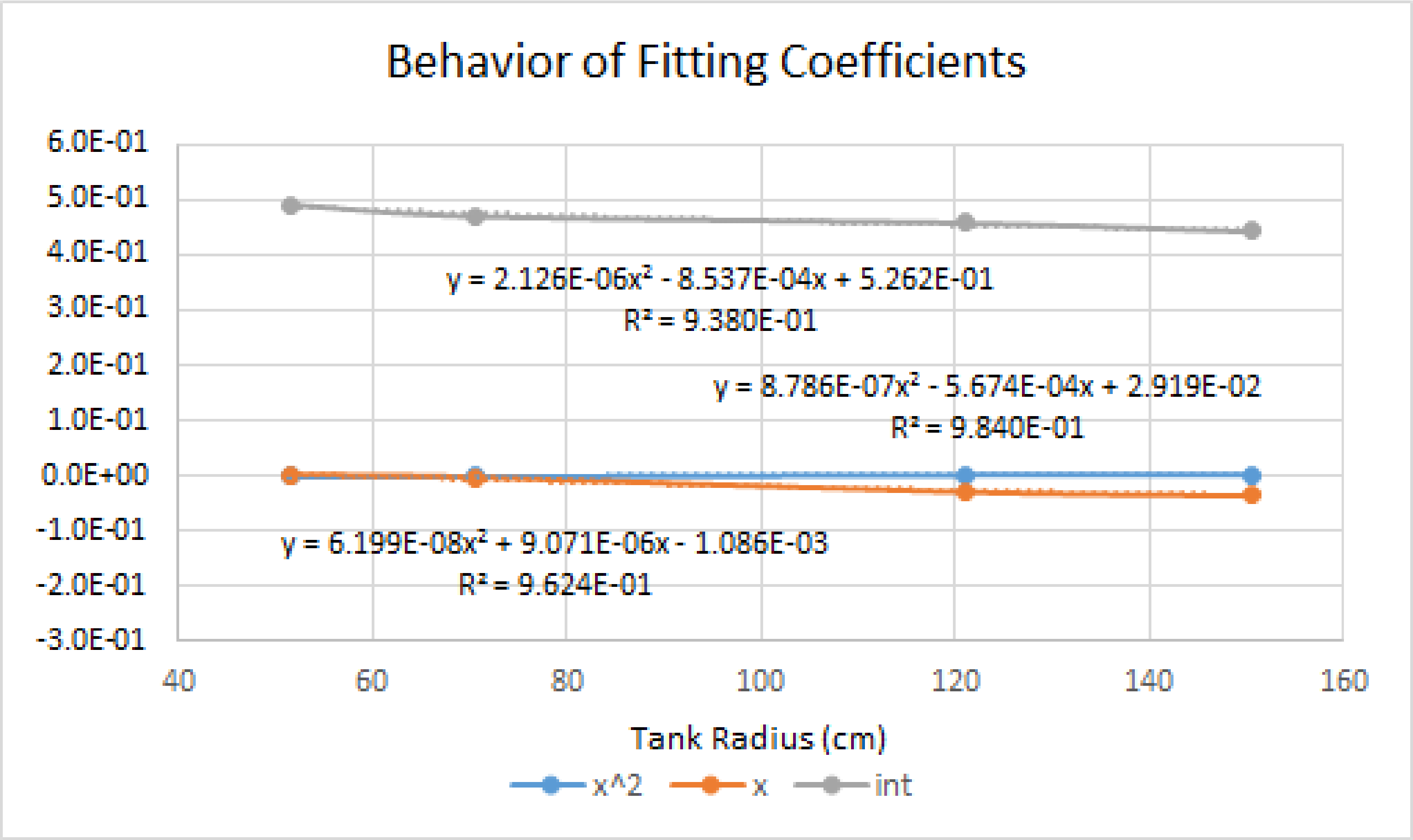
Results – Overall Behavior



Results – Overall Behavior Fitted



Results Coefficient Fitting



Results – Functional 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:

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

Conclusions & Future Work

- PAD relationship found to be approximately parabolic in radius and slope
- Could be used 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 selected the lowest PAD and apply that value
  - Provided radius and slope are bounded by the available data
- Prevent extensive computational analysis like that in Part I
- Future work
  - Vetting of approach and data confirmation
  - Does the behavior hold for non-circular tanks?

Questions

- Percent difference between calculated and fitted PAD

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