Sloped Bottom Tanks and Areal Density – Part I: Case Study in H-Canyon Decanters

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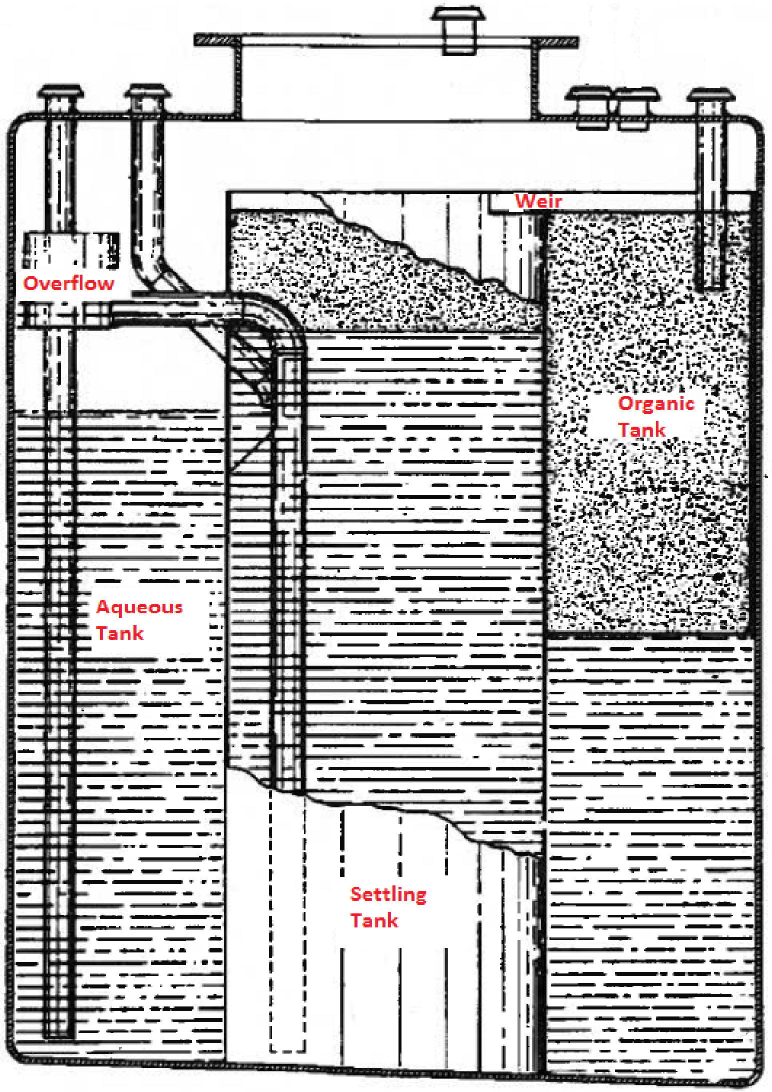
Introduction - Process

- HM-Process to separate and purify Highly Enriched Uranium for downblend to Low Enriched Uranium
  - 1st cycle separates
  - 2nd cycle purifies
- Solvent extraction carried out in mixer settler banks – counter current flow chemical contactor systems
- Product solution passed through decanters between cycles
  - Adds hold up time
  - Allows further separation of aqueous product from remaining trace organic solvent phase

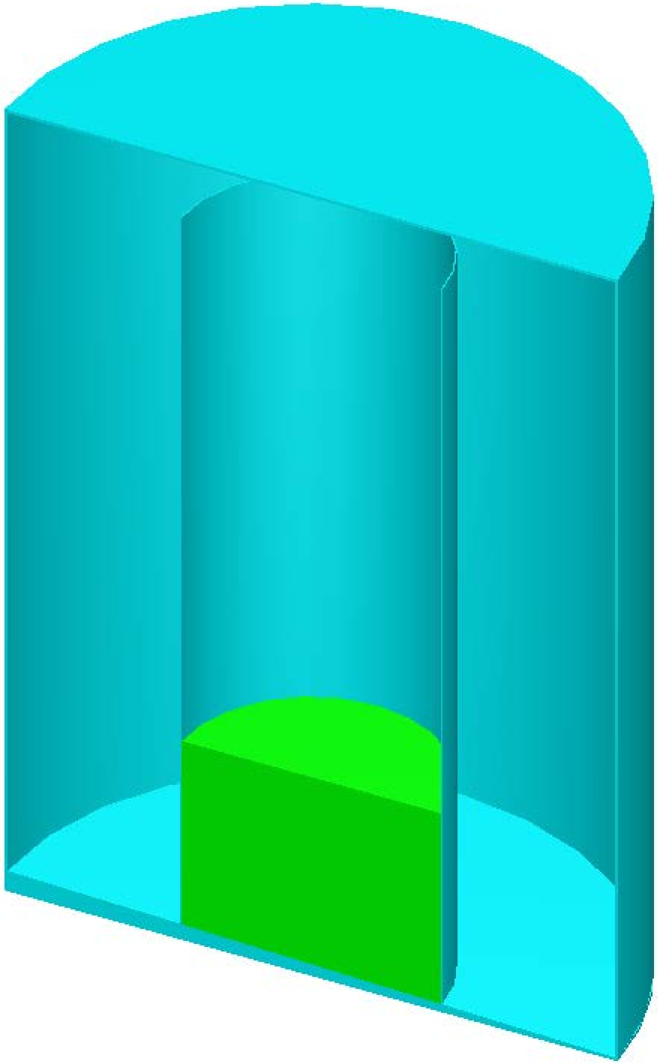
Decanters

- Product decanters come in 8'x11' and 10'x11' sizes, similar internal design
- Sloped bottom
  - Matches H-Canyon floor slope
  - 3.125% grade
  - Air pocket between bottom head and canyon floor ~3"
- 3 internal sections
  - Settling, organic, aqueous
  - Piping, heating/cooling coils



Decanters

- During processing, subject to 11.5 g U-235/L single parameter limit
- Once processing stops, subject to 700 g U-235 single parameter limit
  - Not permitted for interim storage
  - Volume of 13500 to 21000 L results in concentration as low as 0.03 g U-235/L
  - Requires multiple flushes into downstream tanks
  - Taxes system and operators
  - Creates dilute solution that must be re-concentrated



Methodology – Modeling & Assumptions

- Operations asked Criticality Safety for relief from the 700 g U-235 limit, perhaps using the areal density value already listed as a facility control
- Fixed U-235 masses based on areal density value of 0.40 g U-235/cm^2 and SETTLING CHAMBER cross sectional area.
  - For 8x11 tank: 3324.5 g U-235 (3.3 kg)
  - For 10x11 tank: 6243.1 g U-235 (6.2 kg)
  - Both much greater than 700 g
- Acid neutral, pure uranyl nitrate solution at 73 wt.% enrichment

Methodology – Modeling & Assumptions

- Fixed fissile mass, variable concentration → variable height
  - Concentration limited to near precipitation of 650 g U/L down to the point of overflow of the center chamber at ~1.3 g U/L
- Tank modeled as stainless steel cylinder with inner chamber
- Stainless steel wedge used to model sloped bottom
  - Left as solid steel, eliminating air pocket in model
  - Conservatively increases reflection into fissile solution

Methodology – Partially Filled Sloped Bottom

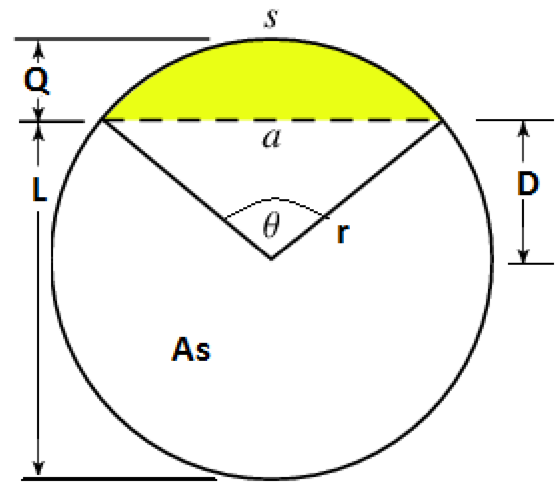
- Solution concentrates until its volume eventually becomes flush with, then drops below shallow end of bottom head
- Significance of sloped bottom tank and why we don't use areal density outright here!
  - Areal density is typically projected onto surface ORTHONORMAL to the other two dimensions. This bottom is not.
- Solution takes the shape of a truncated wedge:

- To model this, must have method to determine volume and convert back and forth with height and concentration

Methodology – Partially Filled Sloped Bottom

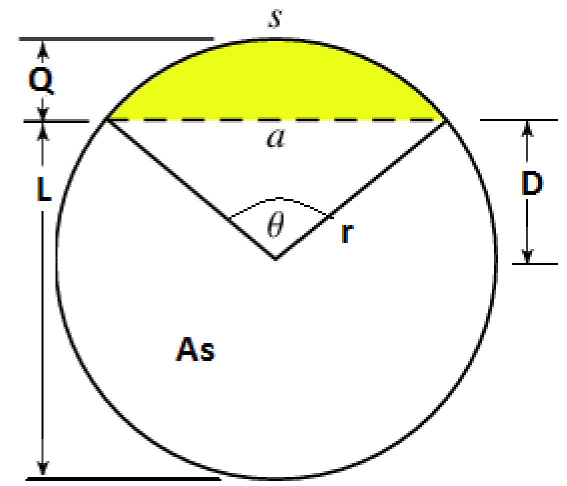
- Volume require numerical integration
  - Integrate area over height
- If deep end depth is *h* and fraction slope of the tank is *l*, then volume of the solution is:

$$V_S = \int_0^h \left\{ \frac{-r^2}{2} \left[\left(2\mathrm{acos}\left(1 - \frac{2r \quad - h'/l}{r} \right) \right) \right. \right.$$



- 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' $\theta = 2\operatorname{acos}\left(1 - \frac{2r - h'/l}{r}\right)$

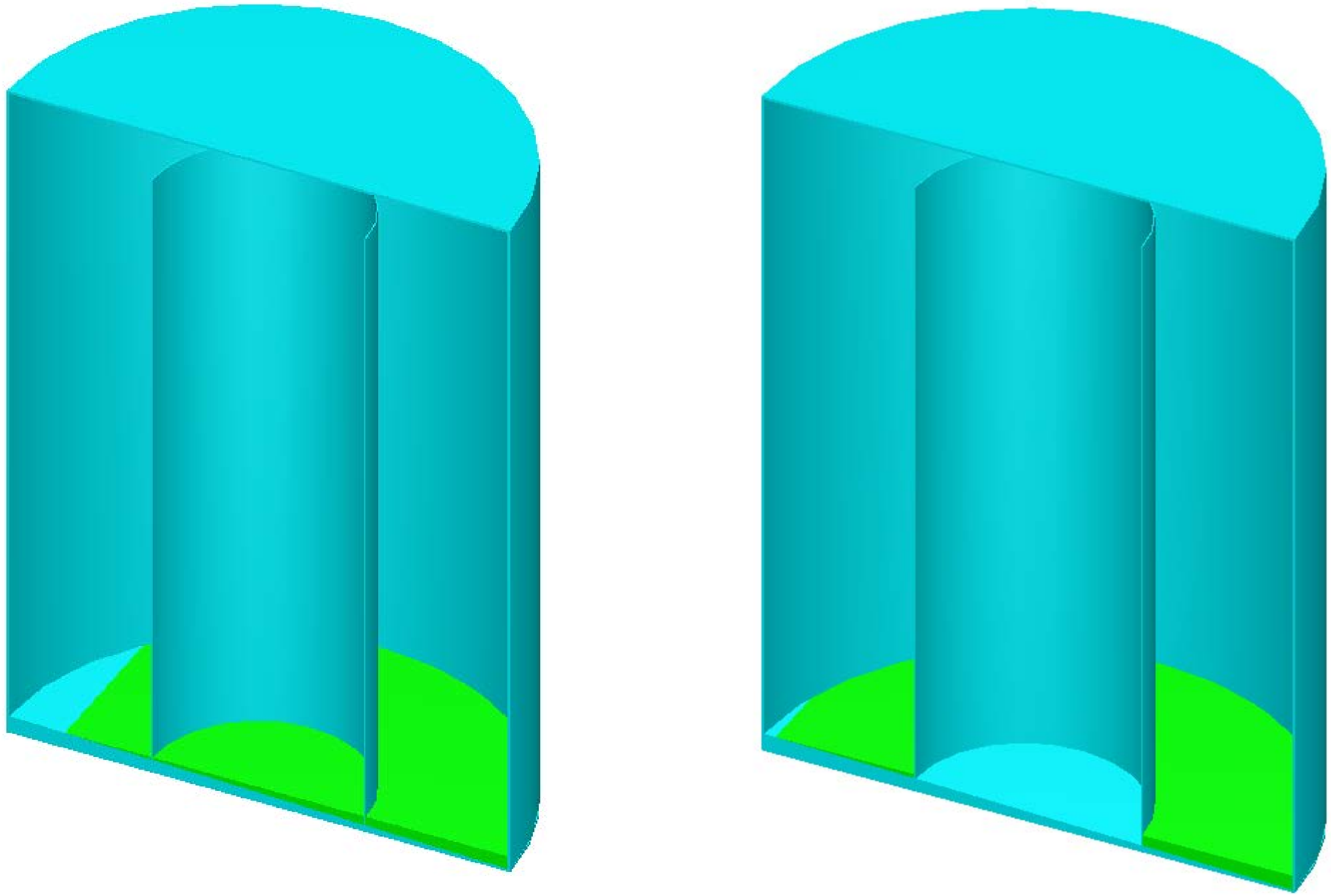
Mechanical Tolerance

- Dilution cases assumed nominal geometry of tank
- Peak cases between 9.2 and 70 g U-235/L were rerun
- Selection of mechanical tolerances examined for each concentration in each diameter decanter:
  - 1) replace all steel with water
  - 2) replace bottom head wedge of steel with wedge of void
  - 3) reduce inner diameter of settling chamber by 2.54 cm

Leaks

- A known small slow leak exists between the settling chamber and the aqueous chamber, at the bottom weld, in at least one decanter
- Given enough time, solution would equilibrate through the leak
- Analyze bounding cases with equilibrated solution and solution only in aqueous section

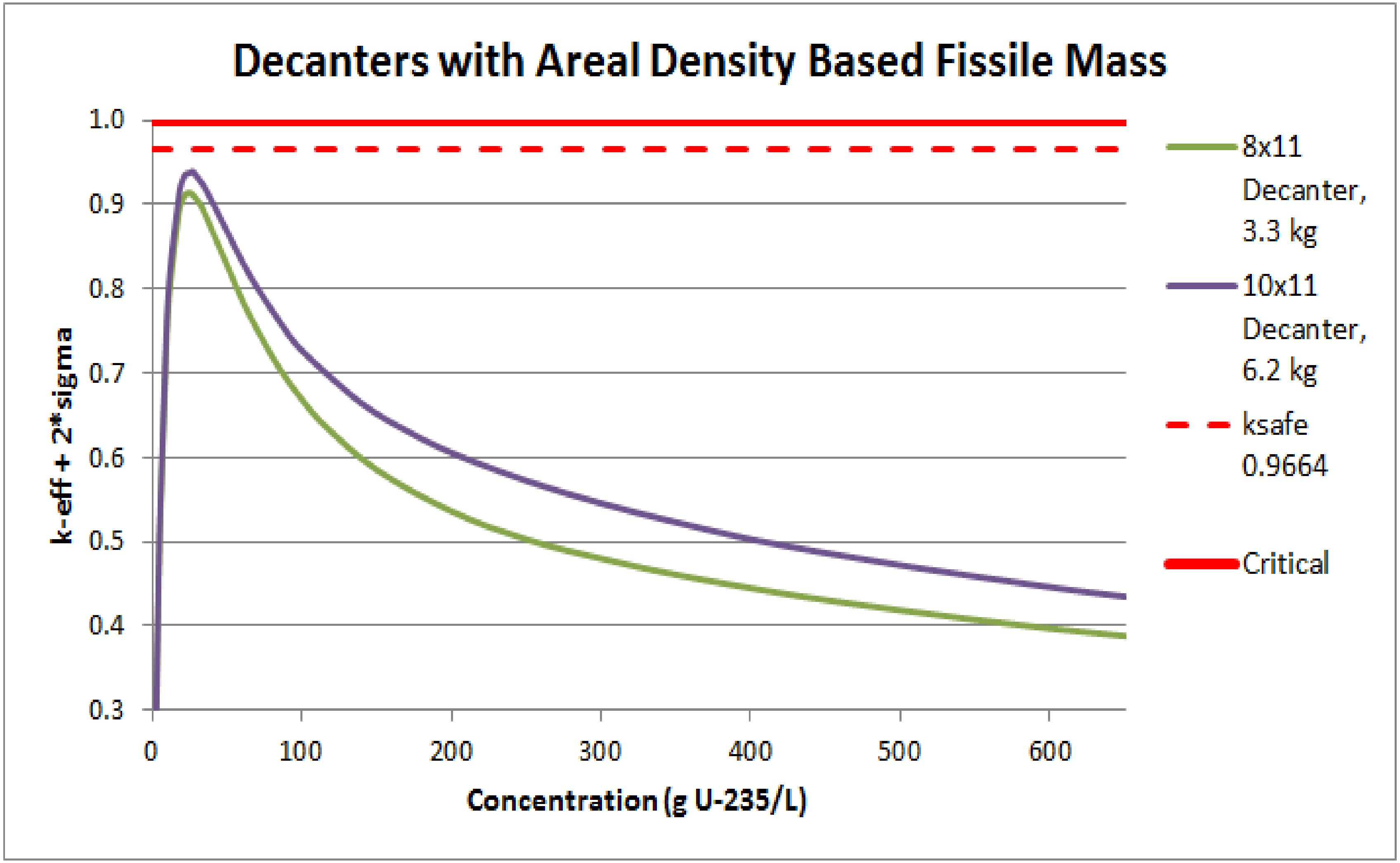
Leaks



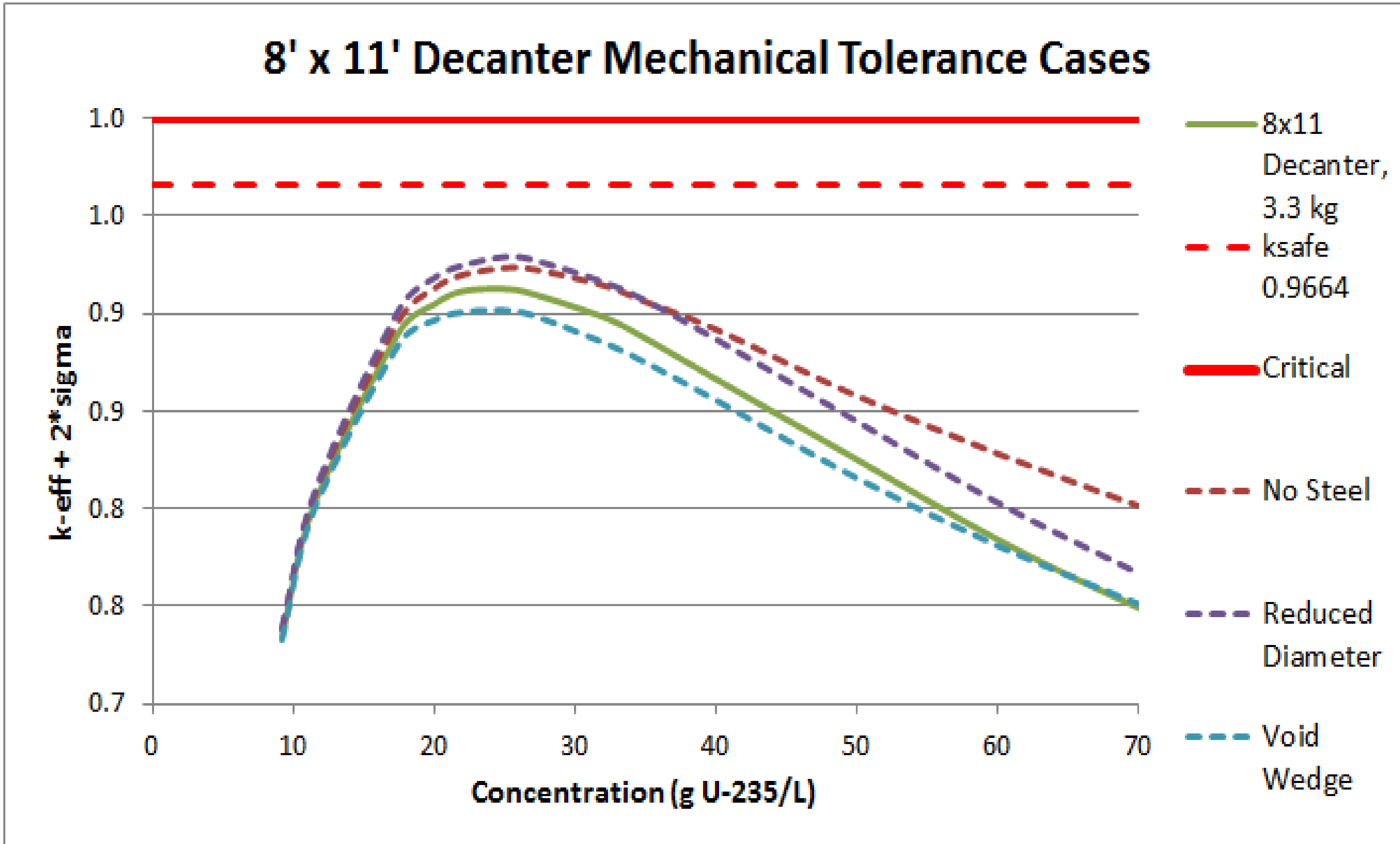
Computational Modeling & Limit

- All modeling is performed in the KENO-VI module of SCALE 6.1
- Validated internally for applications to HEU solution processing
- K-safe determined, with margin, to be 0.9664

Results – Concentration



Results – Mechanical Tolerances



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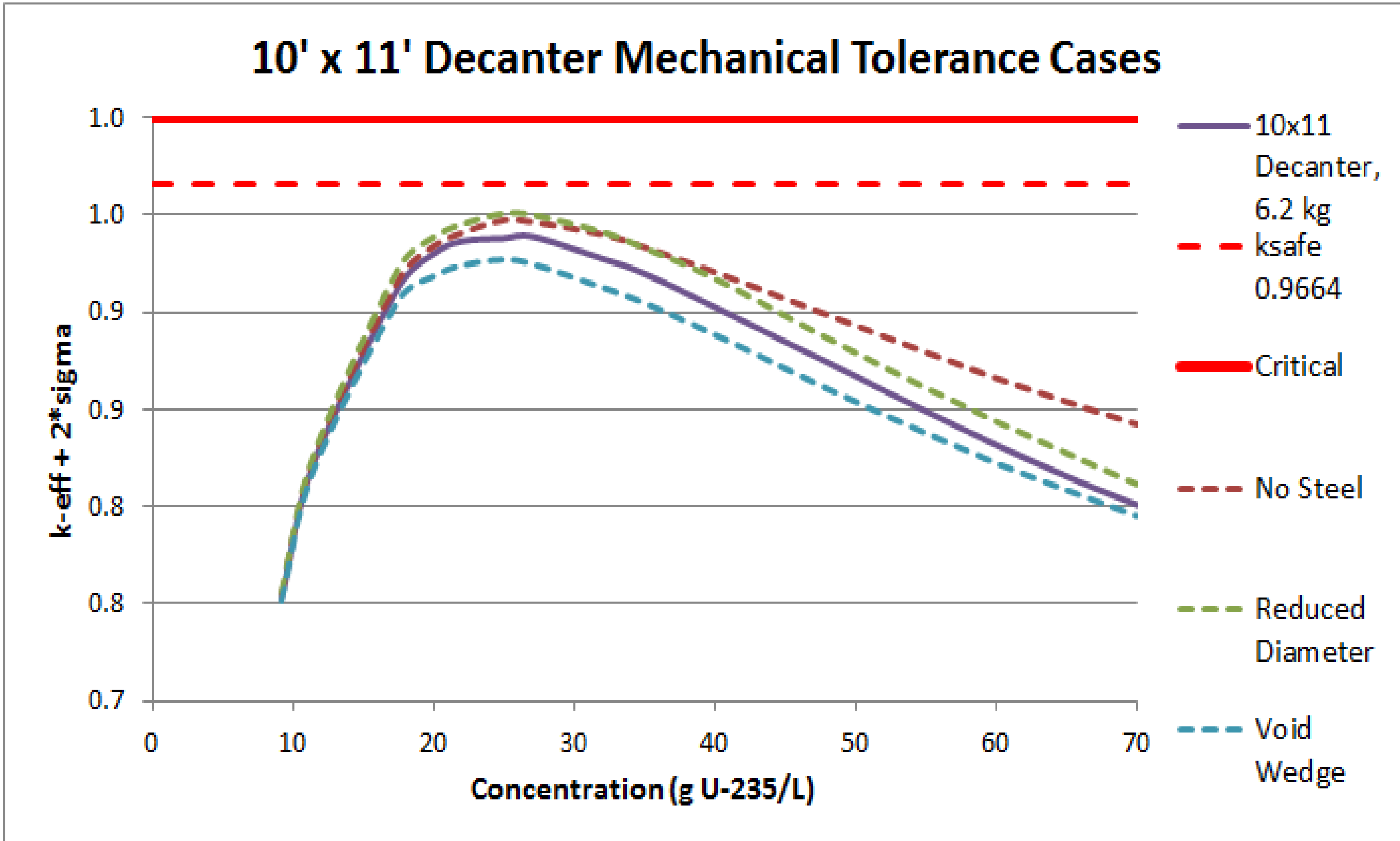

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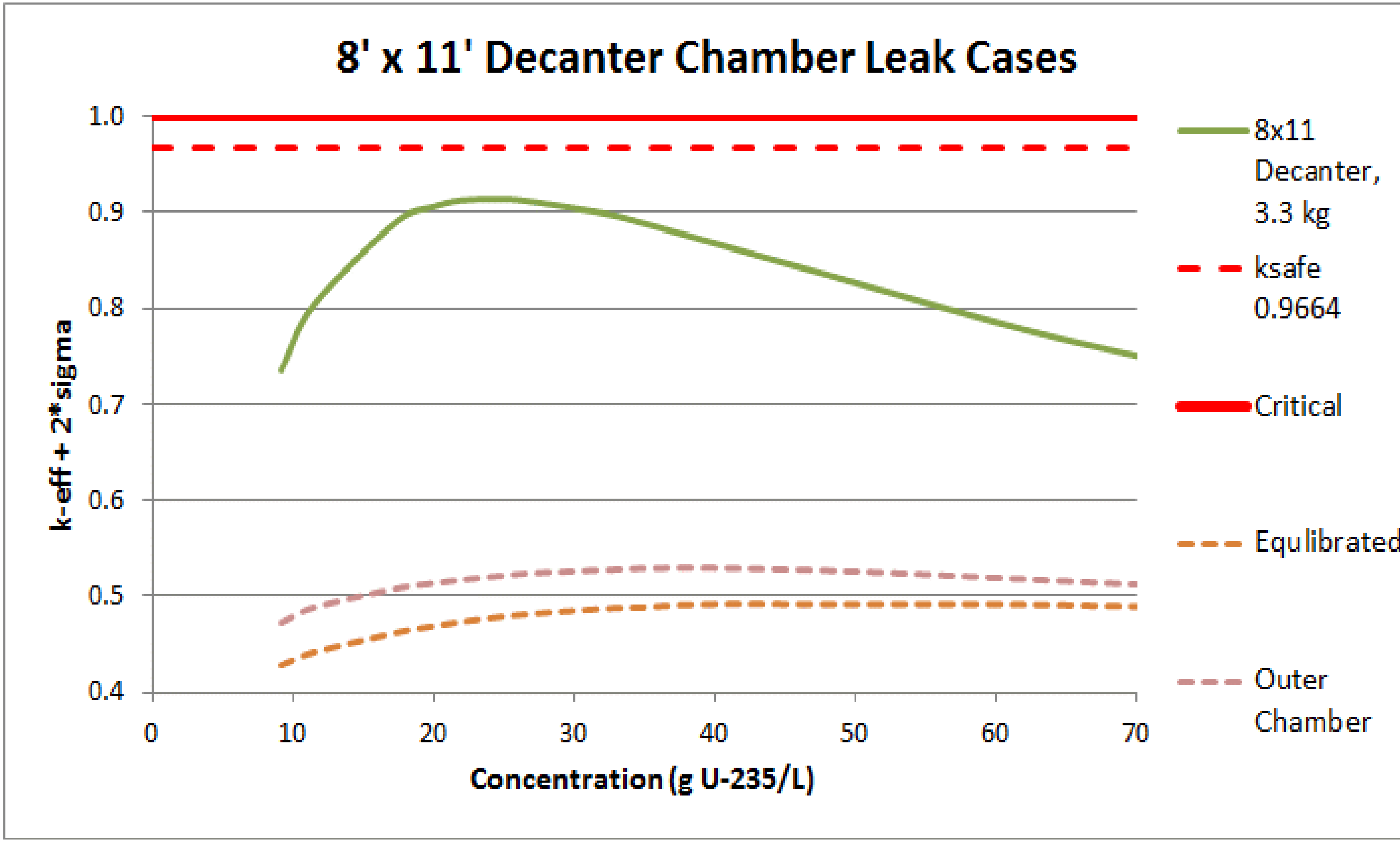

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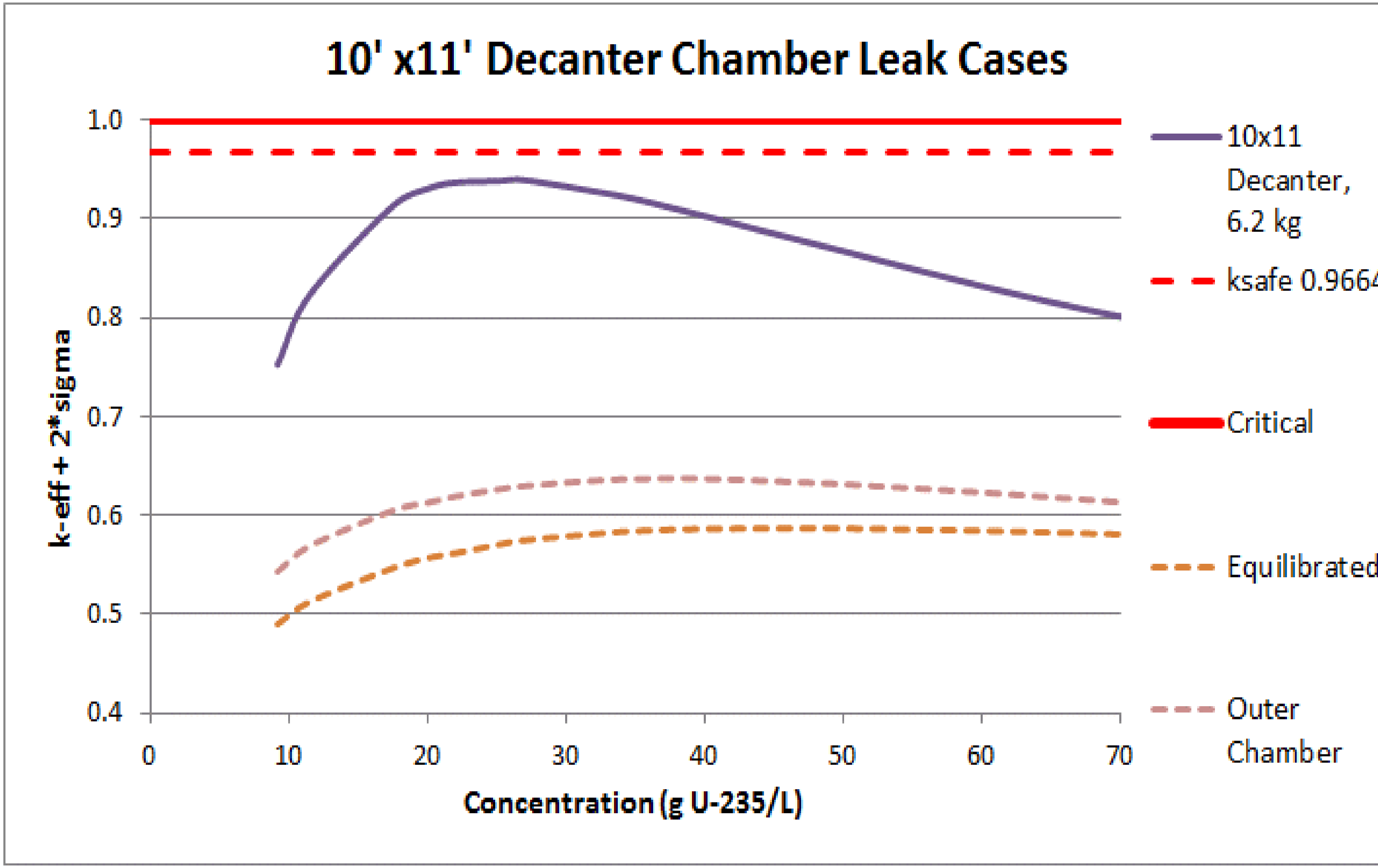


Conclusions

- Despite the slight slope of 3.125% the areal density based mass is usable as a limit
- All cases remained safely subcritical for 3324.5 g U-235 in the 8x11 decanter and 6243.1 g U-235 in t he 10x11 decanter
- Reduces operator burden, operational time, and process waste
- Impetus for further investigation…

Further Investigation

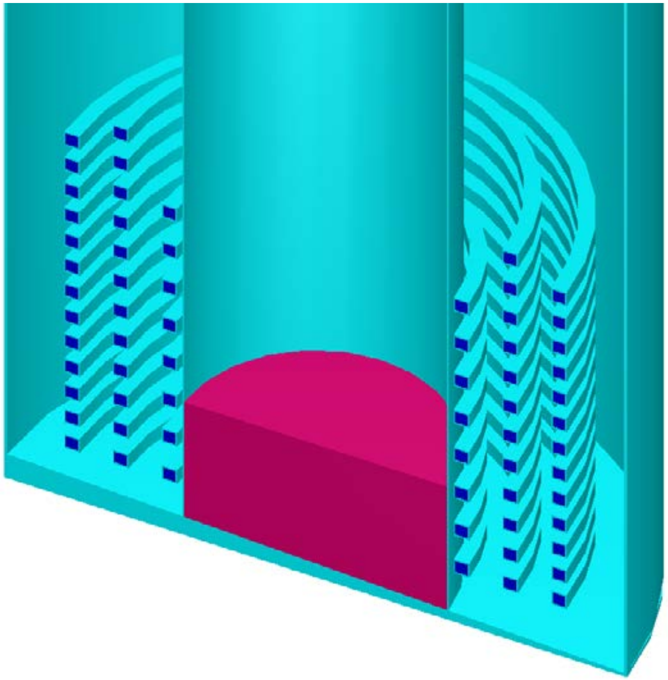
- Why does areal density work? Small mass? Slight slope?
- Does it work in other sloped cases?
- What does areal density mean in a system where the plane of projection is NOT orthonormal to the other dimensions?
- Is there a functional relationship between slope of the tank and the areal density projected onto that non-orthonormal surface?
- Further investigation was warranted and is presented in Part II

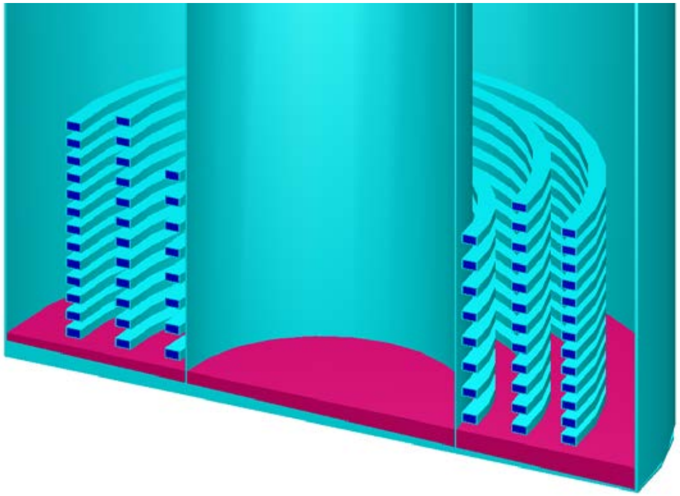
Acknowledgements

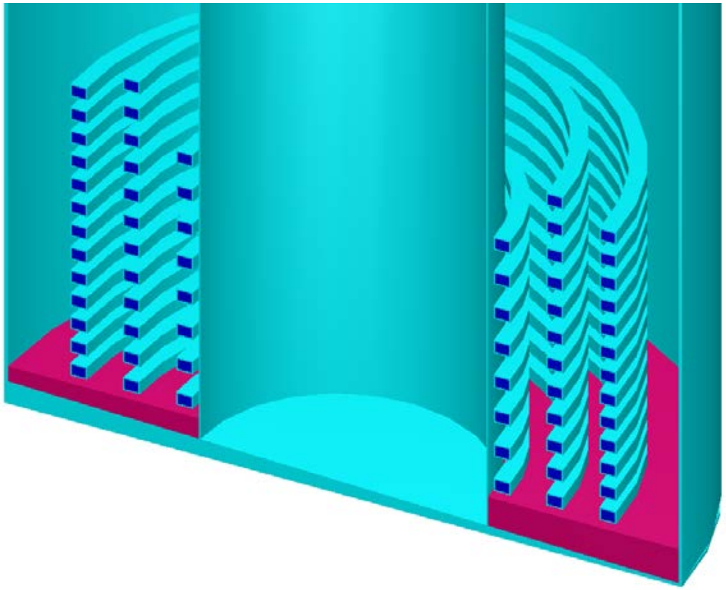
- This work was funded as part of DOE-EM operational budget for H-Canyon.
- Thanks to the men and women of facility engineering for prompting this study.

Additional Slides

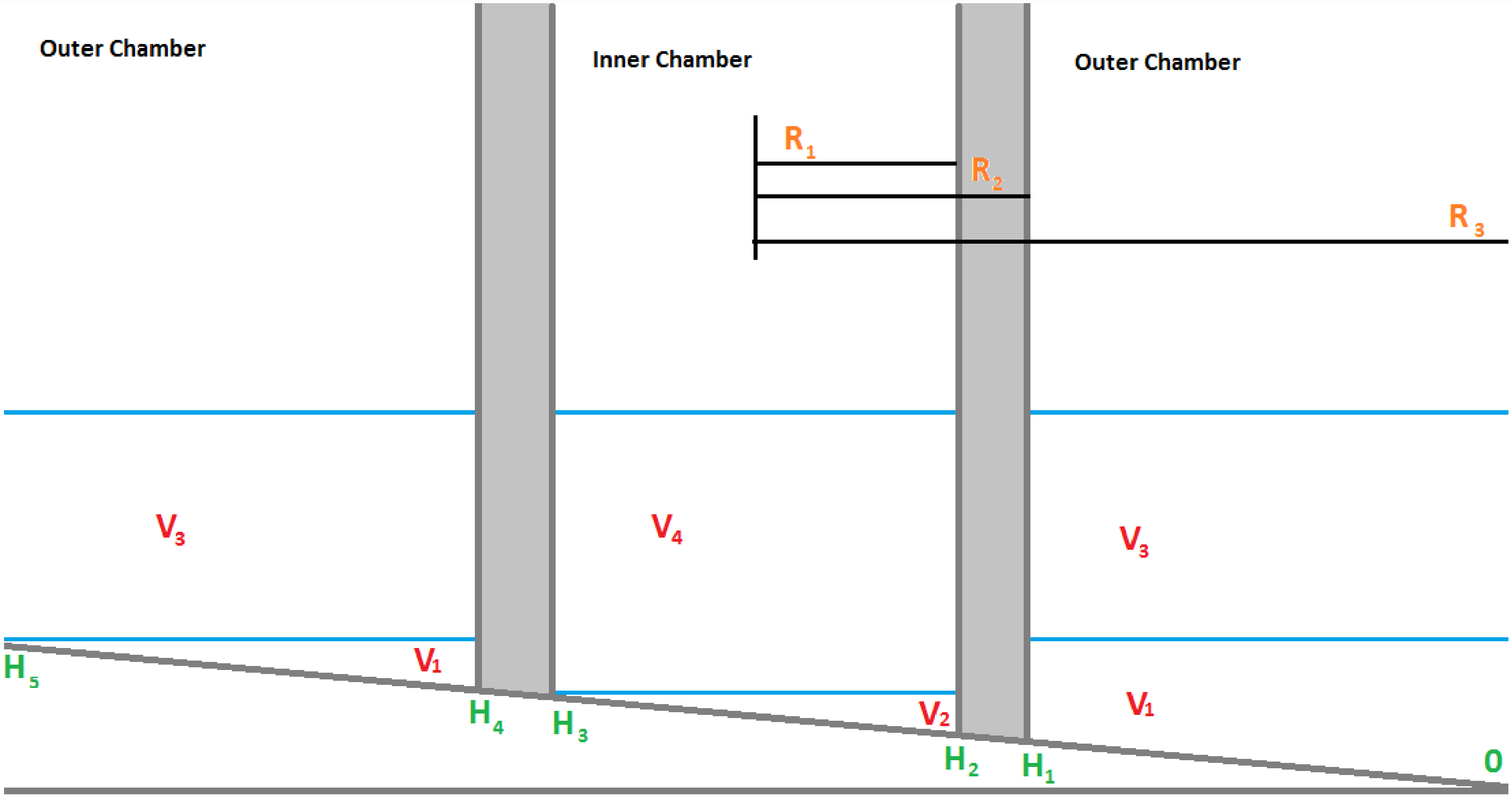
Cooling/Heating Coils







Analytical Breakdown of Tank Volumes



$$V(h) = V_1(h) + V_2(h) + V_3(h) + V_4(h) - V_{coils}(h)$$

$$V_{outer}(h) = V_1(h) + V_3(h) - V_{coils}(h)$$