NCSD Competition Solution Session

Presented by the NCSD Membership Committee

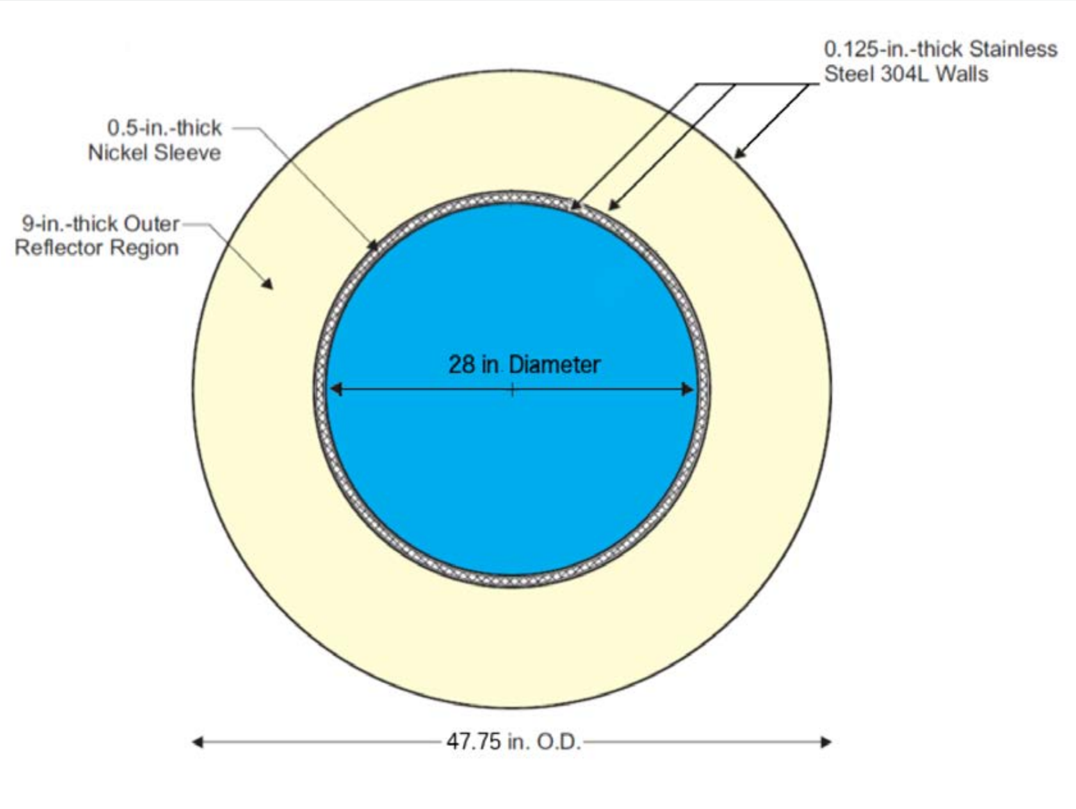
You are a criticality safety engineer at a nuclear waste treatment facility. Waste is treated, conditioned, and stored at this facility, and some processes produce fissile material in solution.

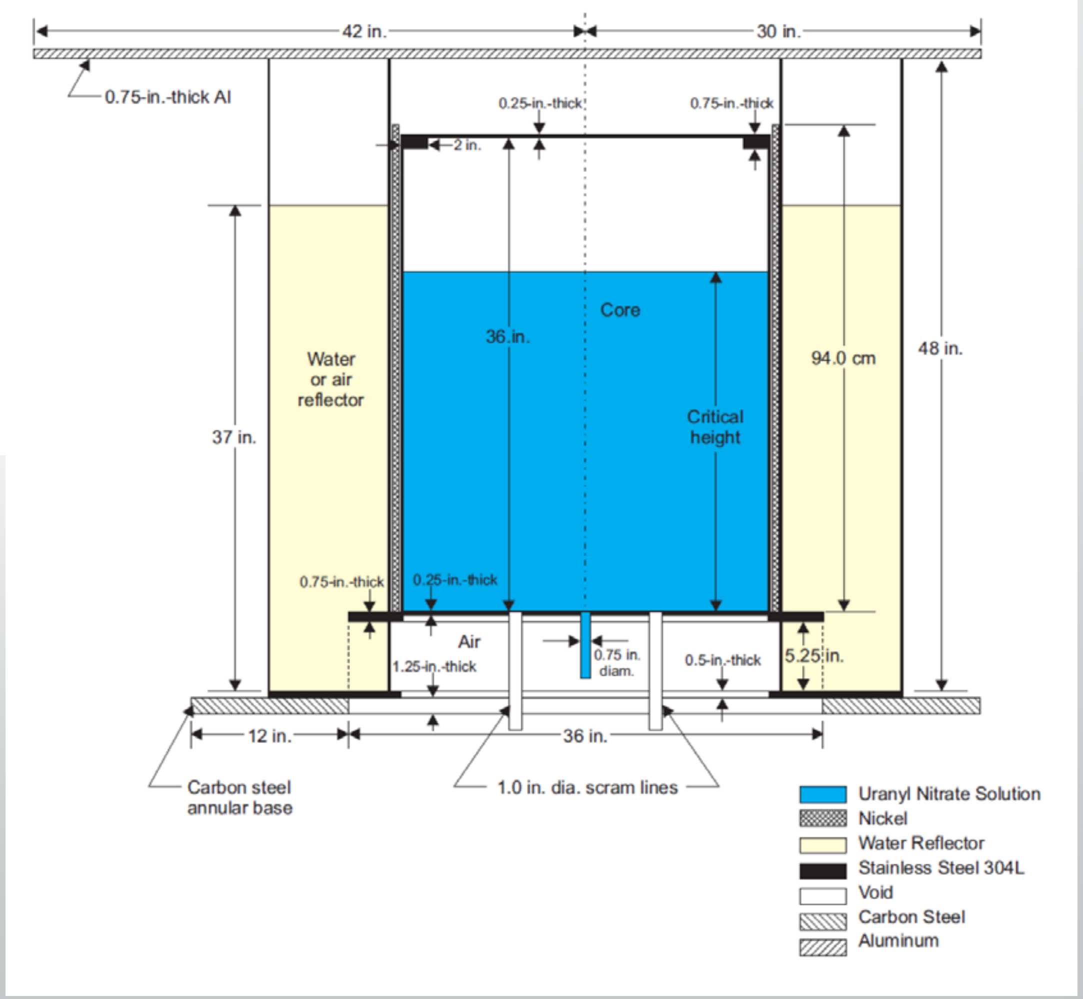
You have been asked to set appropriate limits on the volume of uranyl nitrate solution that can be stored in a process tank to ensure the system remains subcritical during normal operations.

Given the specifications below, describe the parameters of concern for safe storage and movement of the uranyl nitrate solution, and the limits (administrative, engineering, or other) you deem appropriate. State any assumption clearly. Your submission may be comprised of a written draft design document, a model, an engineering drawing, or other appropriate format of your choice but make it clear to the judges how you will ensure the system remains subcritical during storage, how solution is placed and removed from the tank, and how you will prevent inadvertent criticality during normal operations.

Specifications:

- The solution is highly enriched uranyl nitrate
  - $UO_2(NO_3)_2$
  - 93% U^{235}, 5.8% U^{238}, and .9% U^{234}, and the remainder U^{236}
- Facility management wants to process as much waste as possible, and so you are asked to store as much solution as safely possible, and allow it to move in and out of the tank as quickly as safely possible.
- The company operating this facility has specific requirements for the design of the tank. It has been manufactured at an appropriate quality level from an approved vendor. Assume at this point, redesigning the tank is not a financially reasonable option. However, inlet and outlet nozzles have not yet been designed. They are waiting for your instructions on positioning and diameter. They have provided you these drawings of their tank design:


0.125-in.-thick Stainless Steel 304L Walls
0.5-in.-thick Nickel Sleeve
9-in.-thick Outer Reflector Region
28 in. Diameter
47.75 in. O.D.


42 in.
30 in.
0.75-in.-thick Al
0.25-in.-thick
0.75-in.-thick
2 in.
Core
36 in.
Water or air reflector
Critical height
94.0 cm
48 in.
37 in.
0.75-in.-thick
0.25-in.-thick
Air
0.75 in. diam.
1.25-in.-thick
0.5-in.-thick
5.25 in.
12 in.
36 in.
Carbon steel annular base
1.0 in. dia. scram lines
Uranyl Nitrate Solution
Nickel
Water Reflector
Stainless Steel 304L
Void
Carbon Steel
Aluminum

How do I know if I win?

- The winner will be announced Tuesday at the NCSD Awards dinner; a dinner seat has been reserved for the winner and second place, who will both be notified in advance via email.
- Free spots at the awards dinner have also been reserved for the 3 fastest complete submissions. Be sure to stop by the NCSD committee meetings to get your early bird packets so you can finish the problem early!
- The solution to the problem will be presented Wednesday afternoon at the Membership Challenge Activity Debrief and Solution Discussion–Panel session. This session is open to any who are interested in learning the process required to solve the kind of sample problem highlighted in the calculation competition. An iPad 1st prize and Fitbit 2nd prize will also be awarded at this time.

Can I ask for help?

- Yes! You are encouraged to find NCSD members and ask for technical tips and assistance in your approach to the problem. You can identify knowledgeable division members by the radiation symbol sticker on their name badges:

What do I have to do to compete?

- Go to ncsd.ans.org to download the problem statement. Propose a solution and send it to the provided email. Your solution may include a basic physics calculation, a model, a statement of safety and reasonability, or some other justification to explain why it is a

Parameters to Consider:

- Mass: Mass of the fissile material
- Absorption: Loss of absorbers
- Geometry: Shape of the fissile material
- Interactions: Interactions between other fissile materials nearby
- Concentration: Concentration of the solution
- Moderation: A material that interacts with fissile material
- Enrichment: Percent of the fissile material
- Reflection: Material that can reflect materials
- Volume: Size of the container

State Assumptions to Eliminate Some Factors, and Focus on Factor to Control

- “only normal operation is considered, many of these parameters are assumed to be held constant or are of little concern”
  - Assume room temperature, meaning thermal expansion and contraction effects are ignored along with temperature changes to cross sections.
  - Due to the long half-life of uranium-235 (7.04 × 108 years) [3], it is assumed that neutron production by (α, n) reactions is negligible.
  - All materials are assumed to be standard compositions and densities
  - The problem statement prohibits redesign of the tank, so geometry is fixed
- Conclusion: the parameters that need to be investigated to determine criticality are solute concentration and volume of solution.
  - "The mere existence of a fissile material in quantities greater than a minimum critical mass inside of a container creates some finite risk that criticality will occur."
  - Changing the uranyl nitrate concentration of the solution results in a change in moderation of the system, with very low concentration solutions being over-moderated and very high concentration solutions being under-moderated. Improper mixing can result in solute gradients, leading to variations in moderation and possible criticality
  - in order to ensure that the tank remains subcritical during operation despite any kind of solute gradient, it is beneficial to operate at a total mass of uranium in solution below the minimum critical mass (MCM).
  - It follows that the sole parameter used in this case to determine probability of a critical incident is the mass of uranium in the system relative to the MCM of the system

Half Critical Mass

- The acceptable safety limit on mass as a means of criticality control as “an amount less than half that required to sustain a nuclear reaction under any credible conditions of geometry, moderation, and reflection." Therefore once the MCM is found for a system, it should be ensured that no more that 50% of this mass of uranium is in the system at any time.

Determine Critical Mass - Modeling

The model given for the tank is shown in Figure 2. The final MCNP input model is shown in Figure 3.

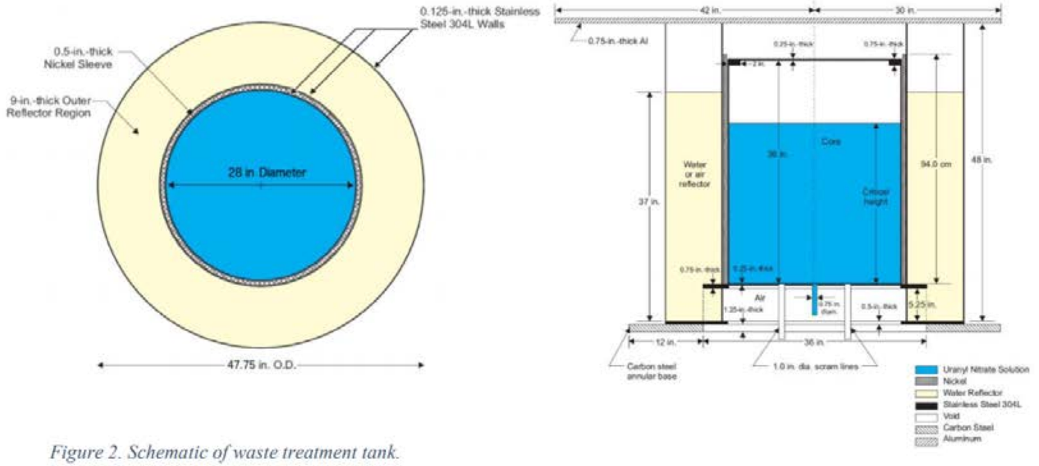


Figure 2. Schematic of waste treatment tank.

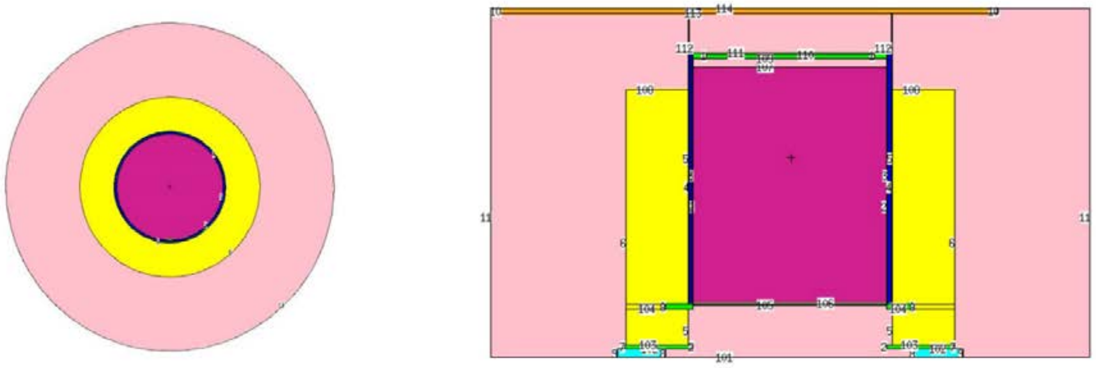
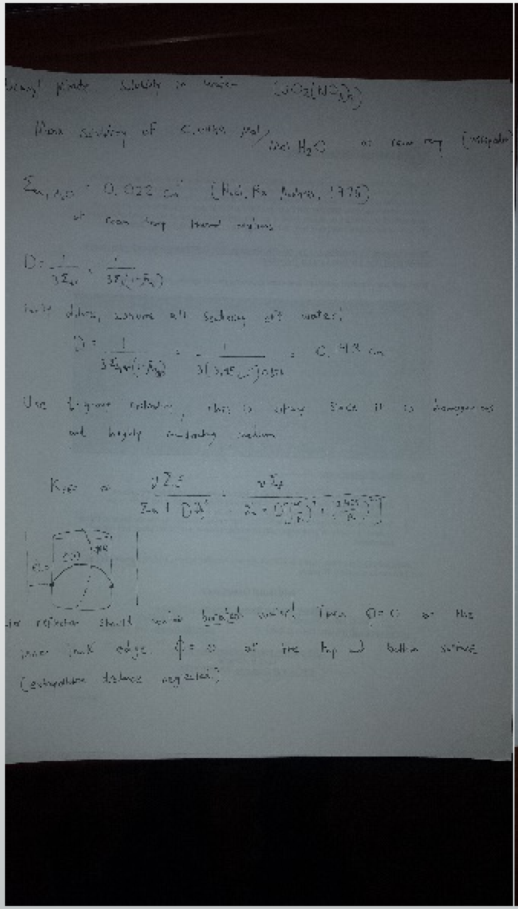
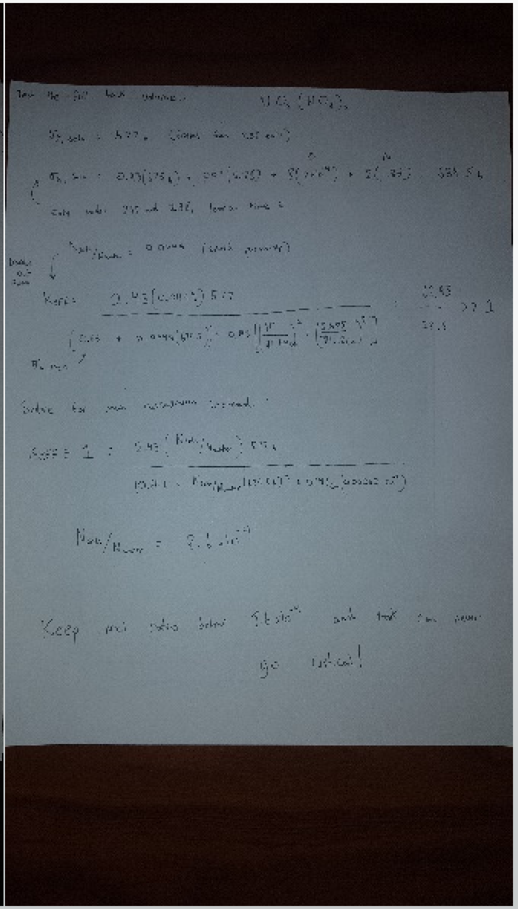


Figure 3. MCNP Model of the waste treatment tank.

Determine Critical Mass – Hand Calculations





Determine Critical Mass – Infer a Baseline from References

- LA10860
- LA12808

Develop Controls

S. Coleman's Approach

- Engineered controls
  - Inlet nozzle diameter and position
  - Outlet nozzle diameter and position
- Administrative controls
  - Concentration band (uranyl nitrate – nitric acid)

K. Vaughn's Approach:

- Using a handbook and interpolations from the table of water-moderated uranium systems, a value for a critical mass at 93% enrichment was 0.852 kg. Therefore the limit should be 0.426 kg of uranium in the tank.
- For the purposes of solution mixing, tank inlet and outlet pipe locations are not a major concern. However, strategic placement of tank inlet and outlets can be advantageous for accident conditions

Thanks to everyone who participated!

Also, huge thank you to John Miller and Deb Hill for officially supporting this effort in their role as NCSD Chair; to the problem development team and judging panel; and also to all the members who volunteered to be available to help take questions and encourage the participants to develop quality solution.

Please fill out and return the feed back forms and let us know how we can improve for next year!