TECHNIQUES FOR FIELDING KR-DOPED DEUTERIUM ICE AND ICE SHELLS IN ICF TARGETS

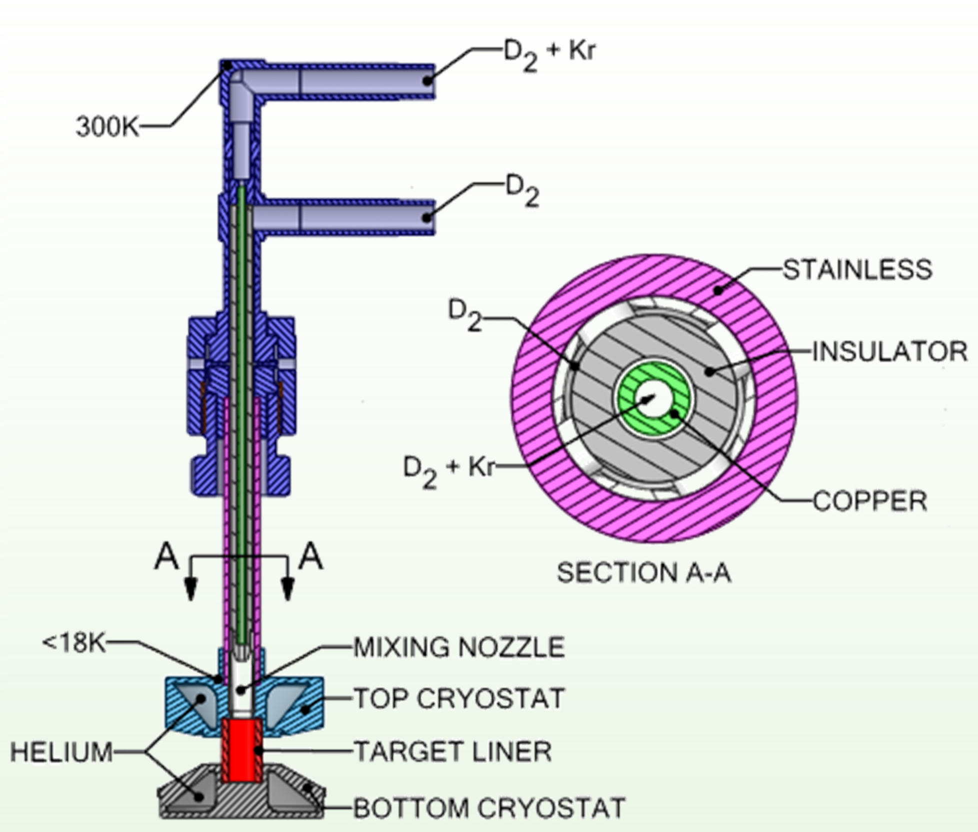
J. A. Crabtree, K. Chandler, R. Vesey, P. Lake, J. Hanson, and E. Muro
Sandia National Laboratories, Albuquerque, NM 87185, USA

ABSTRACT

Cryogenic ice fills offer higher fuel densities than can be achieved with gas or liquid fills in ICF targets. Fielding such targets with dopants, however, is difficult since the deuterium fusion fuel freezes and diffuses at different temperatures and rates than the high-Z dopant. Initial attempts indicated that effectively all of the Kr was stripped from the fuel prior to filling the target. Computational Fluid Dynamic analysis coupled with repeated attempts has enabled the development of techniques for successfully fielding Kr-doped D_2 ice and ice shell targets. By using two different techniques to form cryogenic fuel of doped deuterium, we obtained significant D-D neutron yields on three ICF campaigns, consisting of ten shots. This work marks the first time that a Kr-doped D_2 ice shell fuel has been fielded on Z as well as the first time Kr-doped ice has been fielded in ICF.

DESIGN

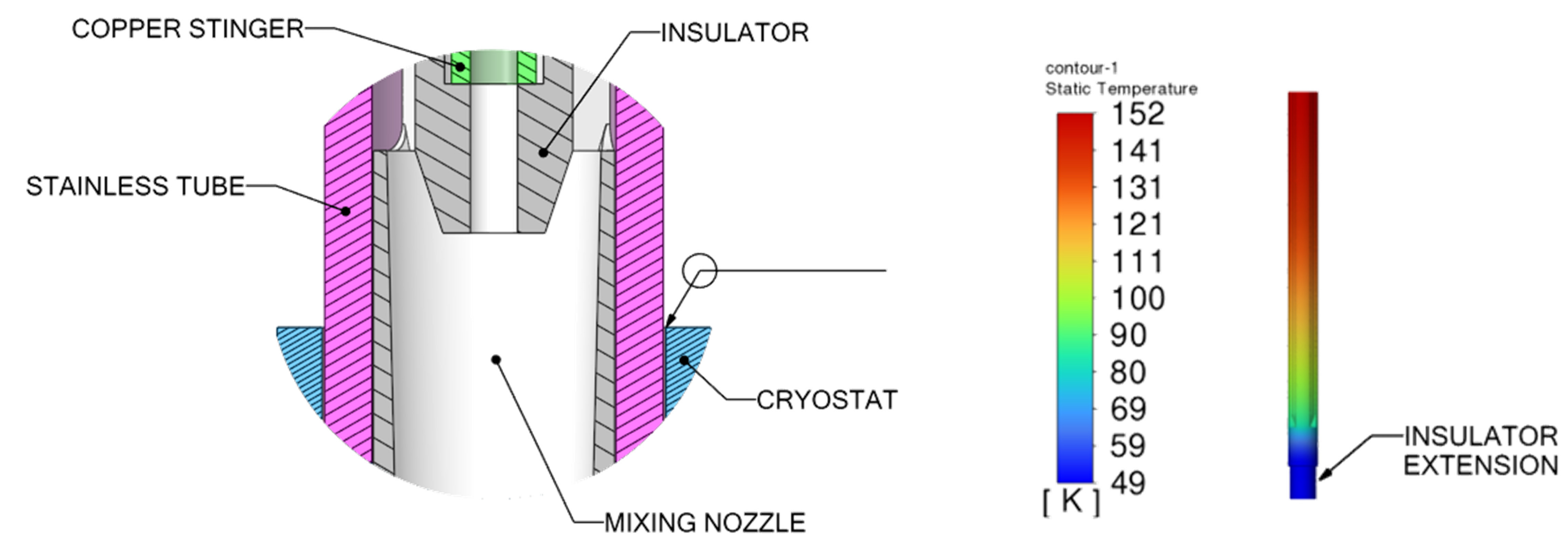
- The obvious challenge to producing Kr-doped D_2 ice is the significant difference in the freezing point of the two gases.
  - Kr = 116K
  - D_2 = 18.7K
- To avoid separation and/or settling of the two gases, desublimation is used to fill the target.
  - The fill pressure is kept below the triple point of D_2 (2.49 psia)
- Initial attempts involved injecting a pre-mixed (D_2 + Kr) feed utilizing a warm gas tube as close to the target cell as possible.
  - Effectively ALL of the Kr was stripped from the incoming stream during the fill process.
- To mitigate this, a dual gas feed assembly was designed.



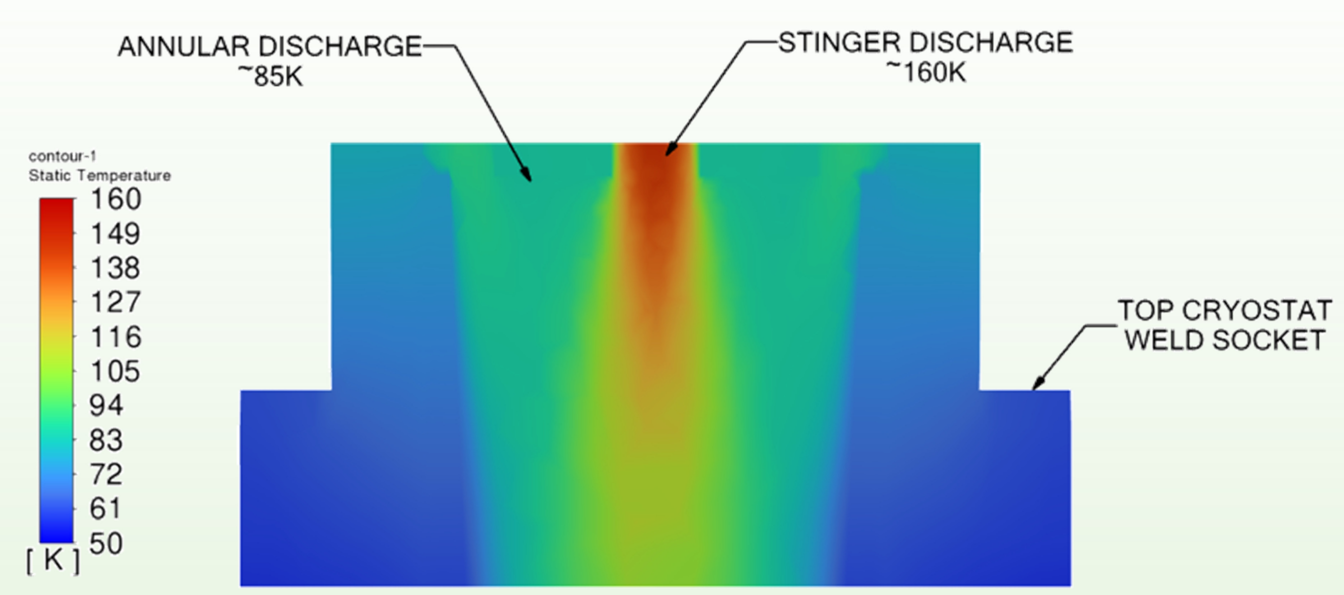
- Doped flow (D_2 + Kr) is introduced through a centrally located copper "stinger" that is thermally anchored to the warm gas feed assembly.
- Dilution flow (D_2) is routed through the annulus and is cooled by the stainless tube welded to the top cryostat.
- The warm doped flow exits the stinger and is mixed with the colder dilution flow in the mixing nozzle prior to entering the target.

CFD ANALYSIS

- To validate the concept, CFD analysis was performed on various iterations of the design:
  - Length and wall thickness of stainless tube
  - Insertion depth of the copper stinger
    - Too deep and close would erode ice fill or shell
  - Insulator dimensions to achieve desired dopant fraction
  - Insulator is also extended beyond the mixing nozzle to the top of the liner to avoid any ice buildup along the walls above the target.
    - Ice buildup in this area would lead to errors in determining shell thickness from expected pressure drop.
      - Per CFD analysis, the minimum insulator temperature is ~49K

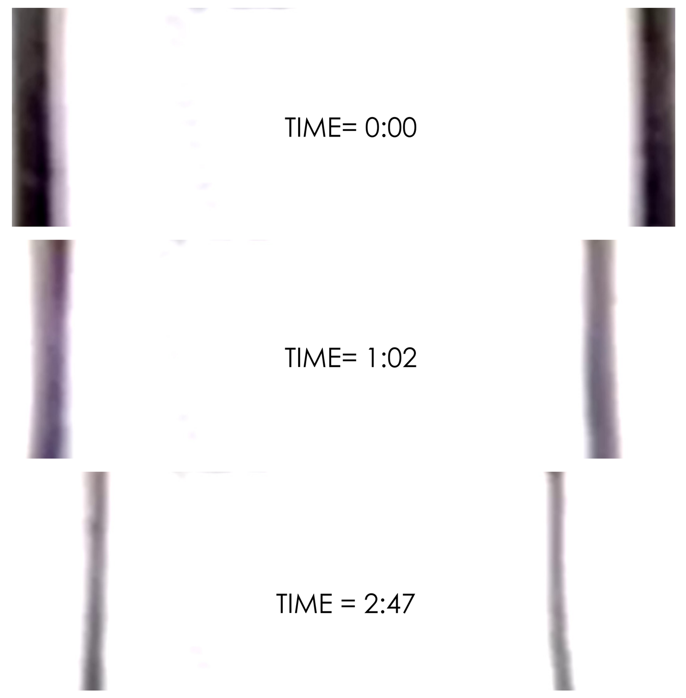


- By thermally anchoring the copper stinger to the warm gas feed assembly, the Kr doped D_2 stream is kept warm enough for the Kr to remain in the gaseous phase.
  - Stinger discharge temperature is estimated at ~160K
- The dilution flow of pure D_2 is routed through the annulus which is insulated from the warm stinger and cooled by the stainless tube welded to the cryostat.
  - Annular discharge temperature is estimated at ~85K
- In theory, before the Kr can plate out on the cold walls, it will freeze out in the annular D_2 dilution stream and be carried into the target as a solid with the cold D_2 gas prior to being deposited in the target via desublimation.



TECHNIQUES & TESTING

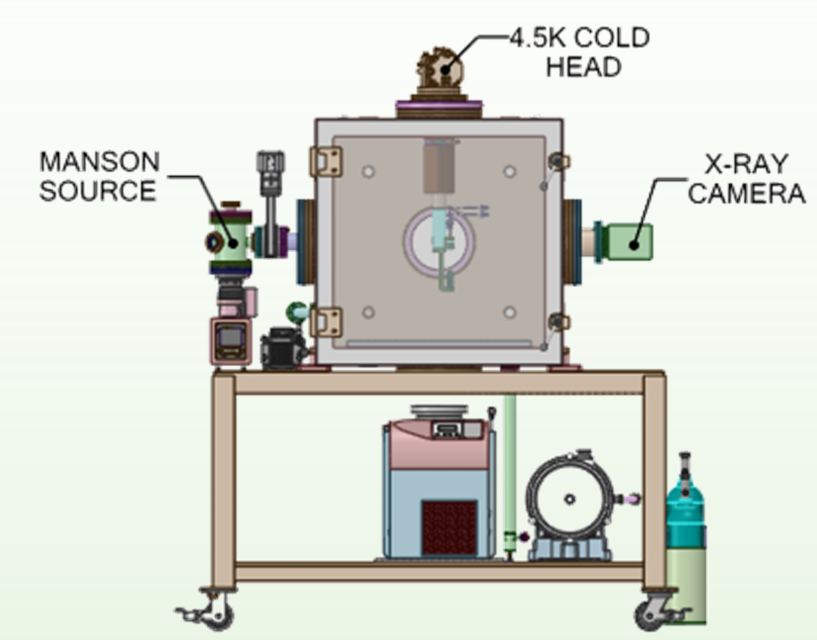
- Currently all ice fills are performed using desublimation where the target is filled to ~2.4 psia via two separate plenums immediately prior to cooling down the target.
- Depending upon whether we are doing a solid fill or a shell, the technique is slightly different.
  - For solid fill, once the cryostats are stabilized at ~25K, the bottom cryostat is bottomed out and the top is stepped down until the target is completely filled as determined by the observed pressure drop.



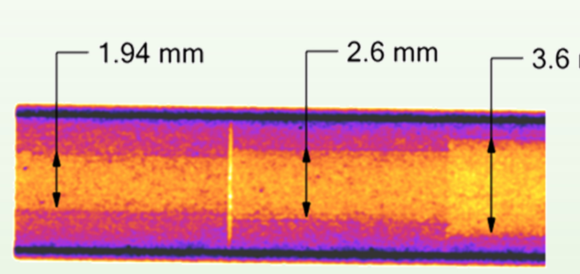
- For shells, the process is a bit more complicated in that the top and bottom cryostats are stepped down together to achieve a uniform ice shell thickness.
- Once the desired shell thickness is obtained, the temperature must be precisely controlled to maintain the target pressure at the vapor pressure of the ice so as to ensure the shell does not continue to grow or erode.
- In lab testing with a sapphire target liner, It took ~3 minutes to form an 0.8 mm thick ice shell.

FUTURE DIAGNOSTIC CAPABILITY

- As seen above, we can visually confirm the ice configuration using a sapphire target liner but actually target liners are typically made of Be.
- In order to better characterize the ice configuration in a more prototypic configuration, we have been developing an advanced target metrology lab.
- A Manson source coupled with an x-ray camera will be used to obtain radiographs at various time intervals during an active ice fill with Kr-doped D_2.



- To confirm that suitable radiographs could be taken using the Manson source, three tubes of varying wall thicknesses were machined of 5 mg/cc Br-doped foam and loaded into a typical Be liner.



Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2024-10190D