Sandia National Laboratories

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Development of an Enriched Lithium Deuteride (^{6}LiD) 14-MeV Neutron Spectrum Modifier for The Annular Core Research Reactor Facility

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Reactor Facility Development (Org. 01391)

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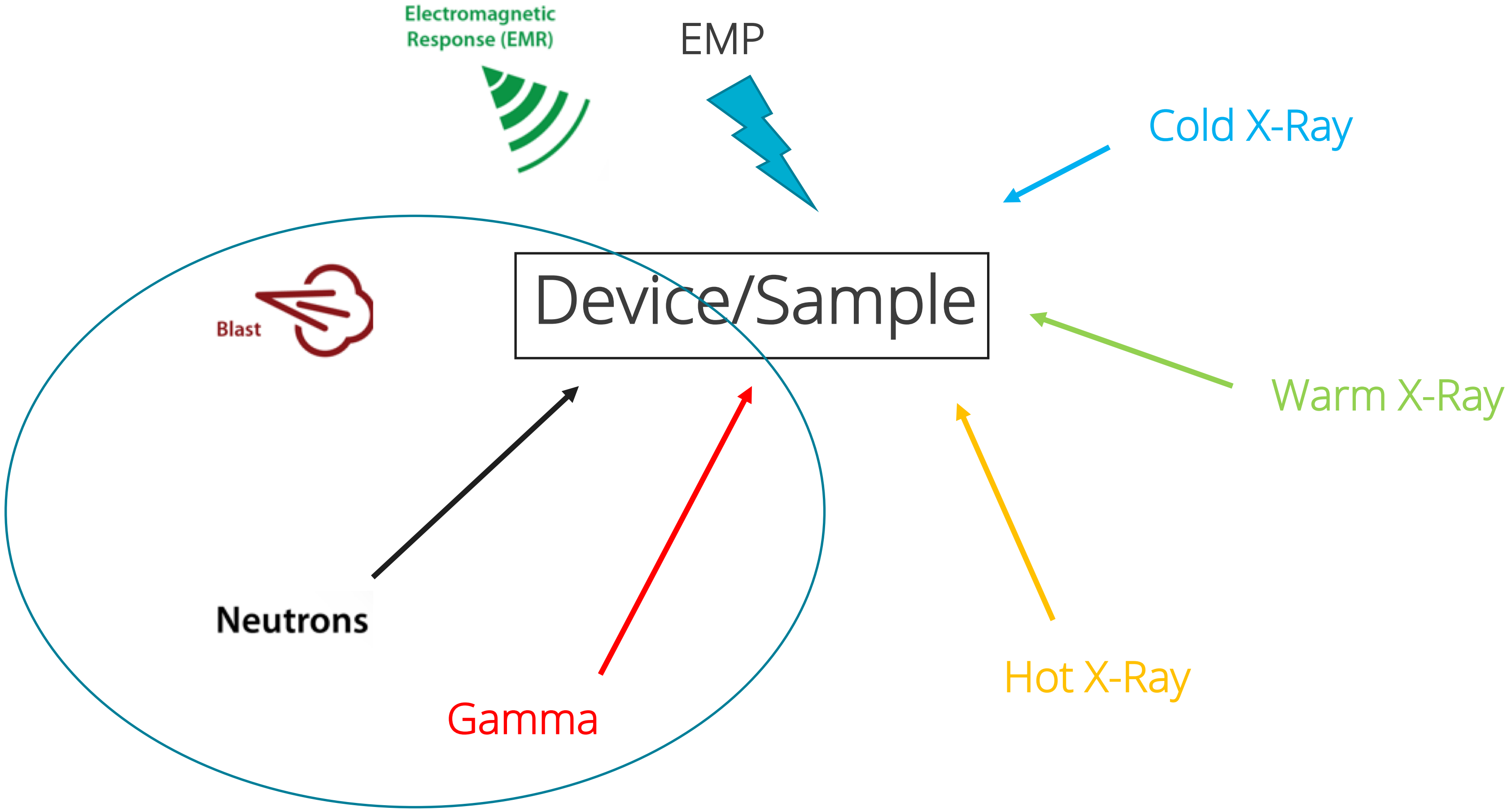
Combined Radiation Environments Testing



Electromagnetic Response (EMR)

EMP

Cold X-Ray

Device/Sample

Blast

Warm X-Ray

Hot X-Ray

Neutrons

Gamma

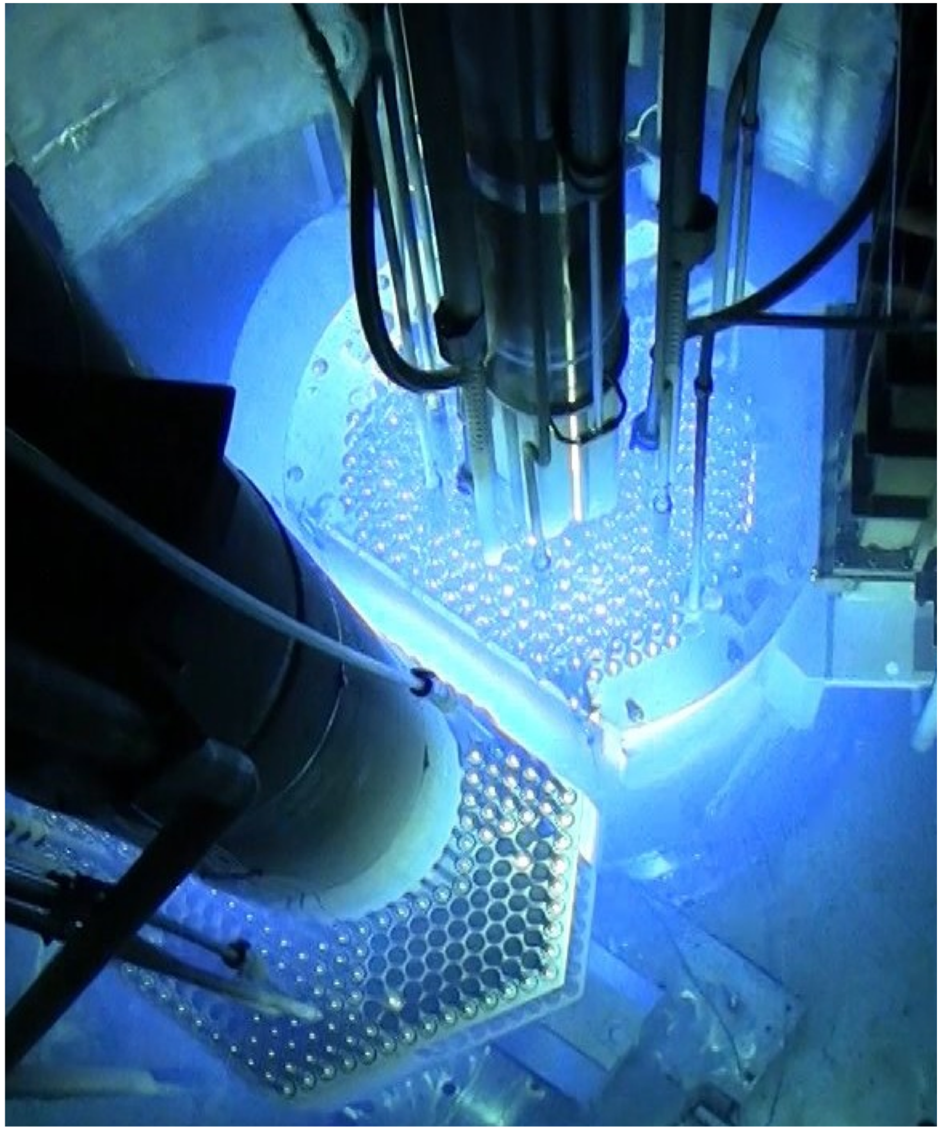
Current Facilities Used by Sandia for 14-MeV Testing

- National Ignition Facility (NIF) – Livermore, CA
  - 300 ps burn width
  - 1.5E+16 neutron fluence in 4π
  - Can field 4 1” inch tall, 4” wide components
  - 1 shot per day, ~3 days per year for certain experimenters at Sandia
- OMEGA – Rochester, NY
  - 100 ps burn width, more isotropic than NIF
  - 1.8E+14 neutron fluence in 4π
  - Usually fields 1.5” diameter circuit boards
  - 10-14 shots per day, ~3 days per year for certain experimenters at Sandia
- ASP (AWE) – London, UK
  - Steady-state deuteron accelerator (tritium target)
  - 1.5E+10 n/cm^2-s at 1 cm
  - 6 hrs. per day, 9 days every 2 weeks
- SNL Ion Beam Laboratory (IBL) – Albuquerque, NM
  - 5E+08 to 1E+09 n/cm^2-s, ~1E+13 n/cm^2 fluence over one week
  - 50 – 100x less powerful than ASP, but can operate 24/7 until the target is depleted (~1 week)

Challenges:
- Throughput vs. fluence, or lack of both

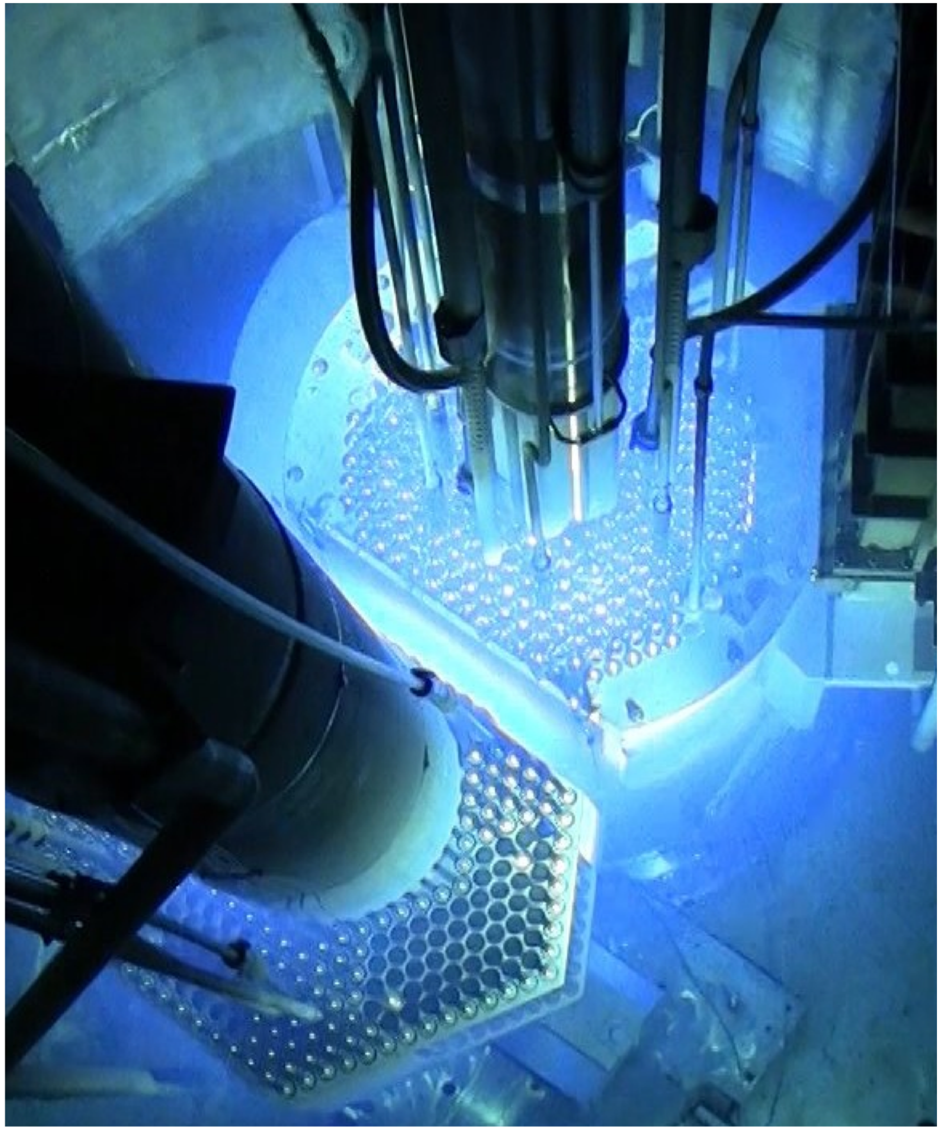
Benefits of a Reactor-Based Source

- Steady-state Operation:
  - Allows for experimenters to look for single event or combined effects in active devices
  - Can achieve high fluences
  - Device can anneal over time of irradiation
  - More isotropic fluence on device
- Threshold for most experiments is ~1E+12 n/cm^2
- Goal for most is ~1E+13 n/cm^2
- Why not use an accelerator?
  - Generally low flux
  - Anisotropic
  - Lack of combined effects



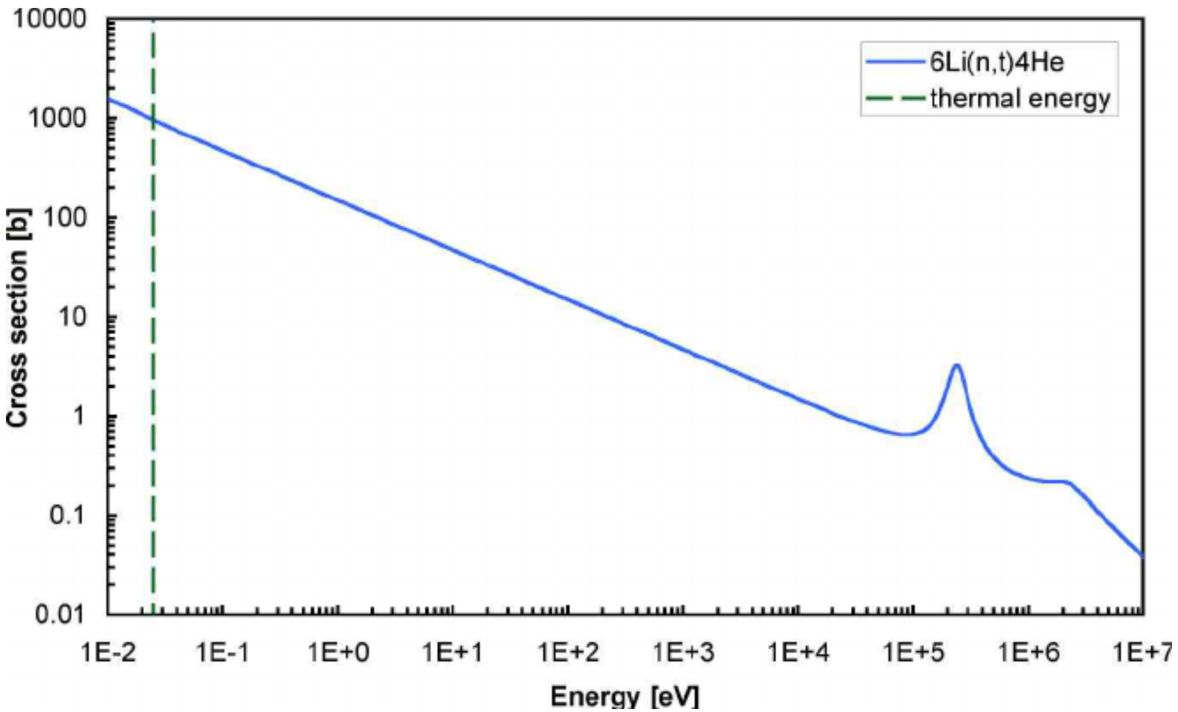
Current Neutron Irradiation Capabilities at ACRRF

- ACRR: BeO-UO_2 (ceramic in TRIGA cladding)
- FREC-II: UZrH (ACPR’s gapped TRIGA fuel)
- In both cases, the neutron energy upper limit is (mostly) governed by fission spectrum
- What is the limit for ^{235}U? ~8 MeV? With what probability of emission?
- Some systems we care about may be subjected to energies from 14-MeV (D-T fusion) neutron energies down to thermal
- Easy to slow a neutron down to a (more or less) specific energy, difficult to gain significant energy



^{6}LiD as a 14-MeV Neutron Source

- Creation of tritium atom from absorption of thermal neutron:
  - $^{6}\mathrm{Li} + n \rightarrow \mathrm{T} + {}^{4}\mathrm{He}$
  - ~938 barns
- Transport of tritium into lattice deuterium atom, resulting in fusion:
  - $\mathrm{D} + \mathrm{T} \rightarrow {}^{4}\mathrm{He} + n$
  - $^{6}\mathrm{Li} + \mathrm{T} \rightarrow {}^{8}\mathrm{Be} + n$
  - Result: ~14.1 MeV neutron
- Conversion efficiency typically below 1E-03 $n_{14\text{-MeV}}/n_{\text{thermal}}$

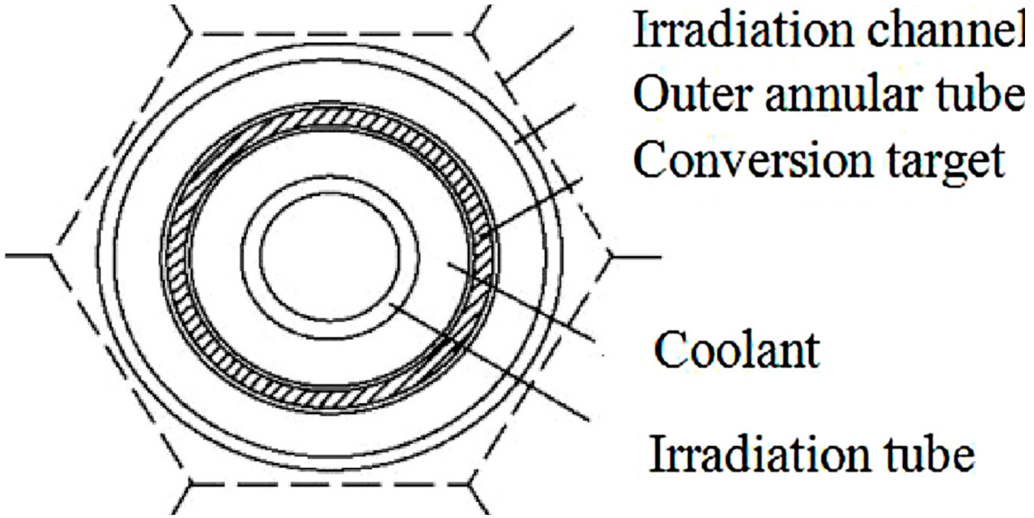


- But wait… I thought we needed a “small fission bomb…” to do this…

My intent was to make an MCNP joke about 10 lost thermal neutrons but they are difficult to find in certain applications.

Examples of Reactor-Based Converters

- 2017 – High Flux Engineering Test Reactor – China (125 MW)
  - Flux conversion ratio: 2.71E-4
  - Converter material: enriched LiD 88.5%



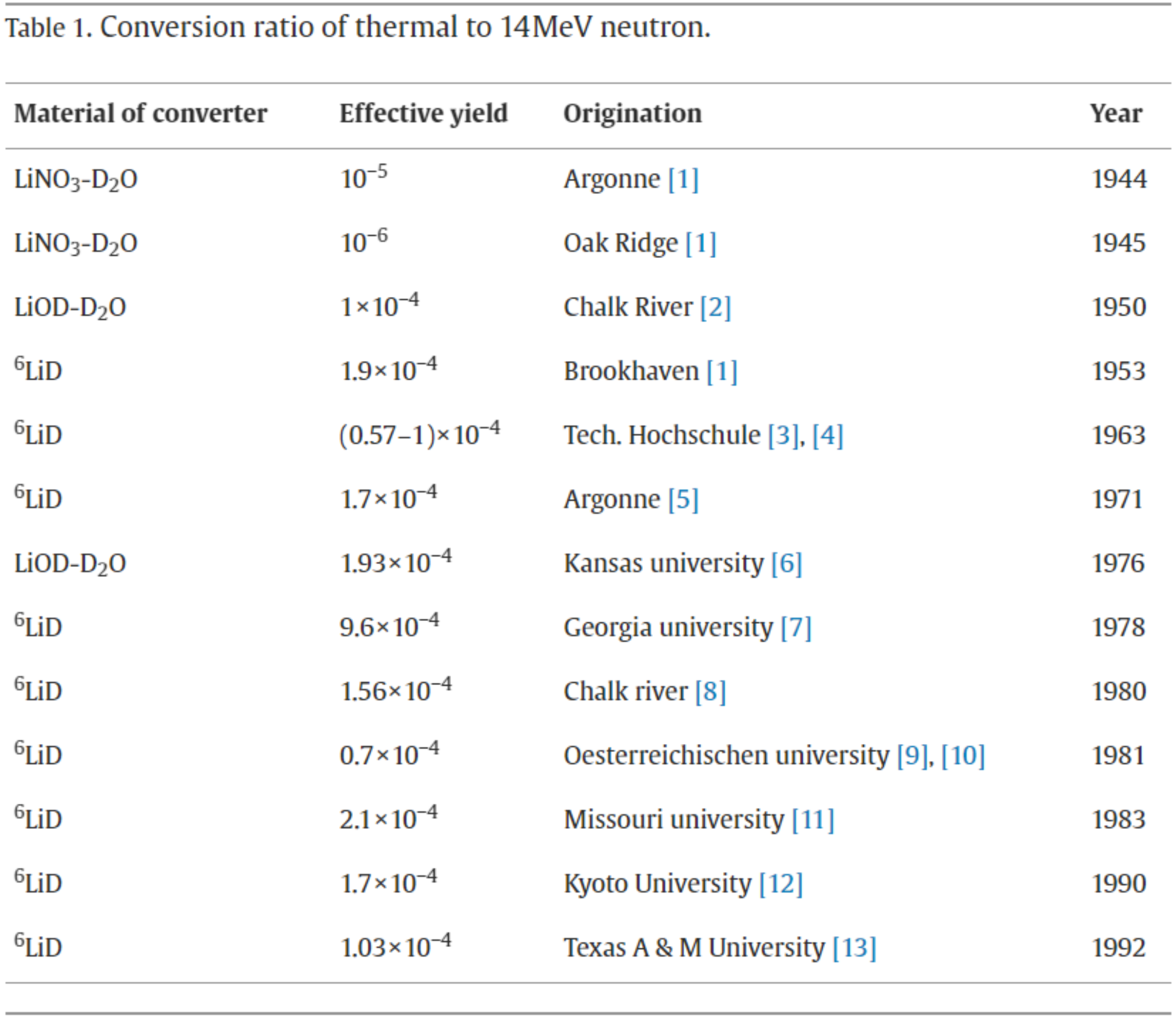


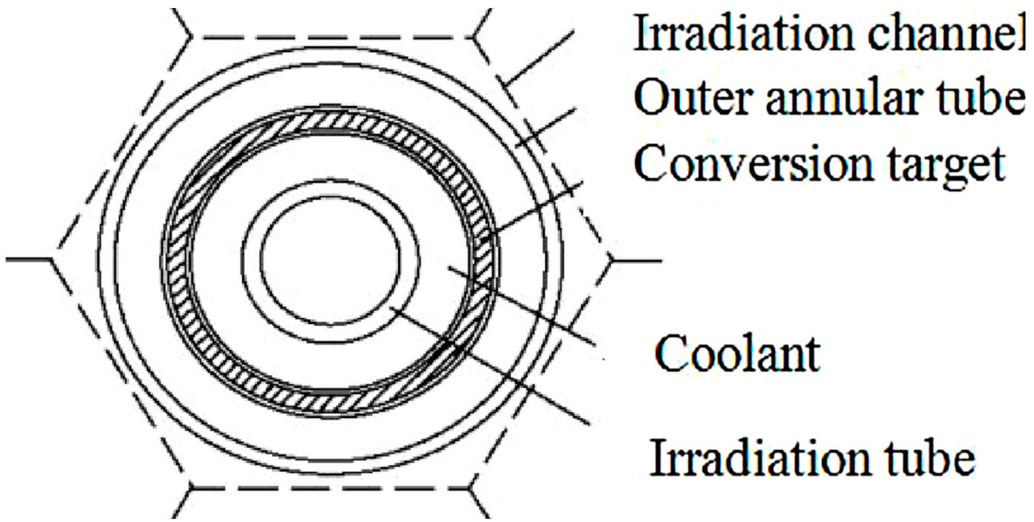
Table 1. Conversion ratio of thermal to 14MeV neutron.

Material of converter	Effective yield	Origination	Year
$LiNO_3$-D_2O	10^{-5}	Argonne [1]	1944
$LiNO_3$-D_2O	10^{-6}	Oak Ridge [1]	1945
LiOD-D_2O	1×10^{-4}	Chalk River [2]	1950
^{6}LiD	1.9×10^{-4}	Brookhaven [1]	1953
^{6}LiD	$(0.57–1)\times10^{-4}$	Tech. Hochschule [3], [4]	1963
^{6}LiD	1.7×10^{-4}	Argonne [5]	1971
LiOD-D_2O	1.93×10^{-4}	Kansas university [6]	1976
^{6}LiD	9.6×10^{-4}	Georgia university [7]	1978
^{6}LiD	1.56×10^{-4}	Chalk river [8]	1980
^{6}LiD	0.7×10^{-4}	Oesterreichischen university [9], [10]	1981
^{6}LiD	2.1×10^{-4}	Missouri university [11]	1983
^{6}LiD	1.7×10^{-4}	Kyoto University [12]	1990
^{6}LiD	1.03×10^{-4}	Texas A & M University [13]	1992

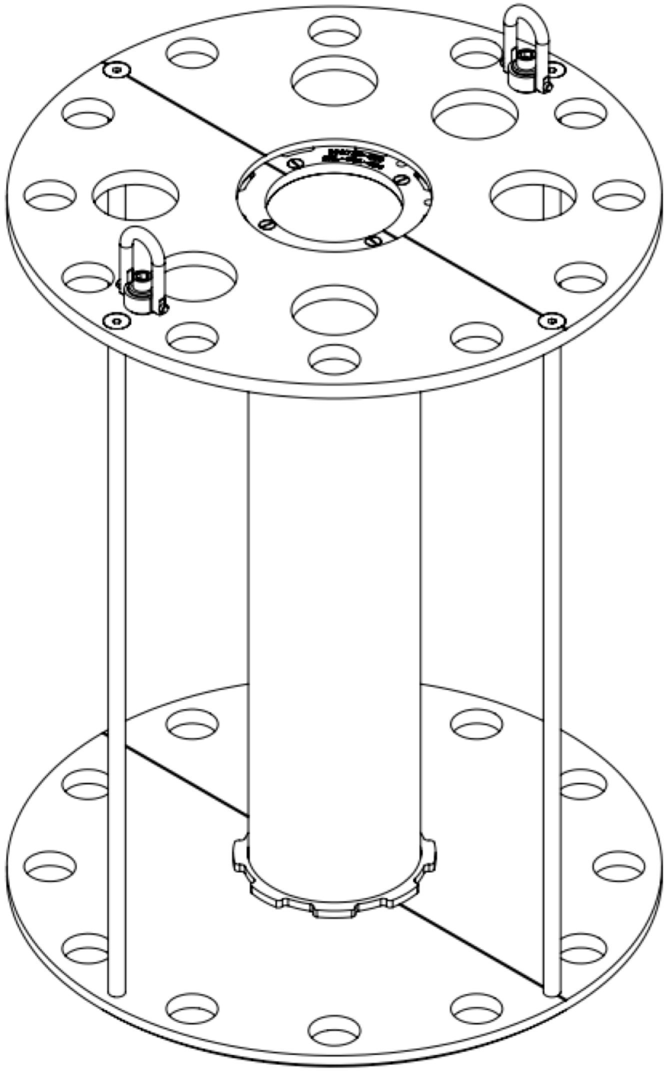
Design of a ^{6}LiD Spectrum Modifier for FREC-II

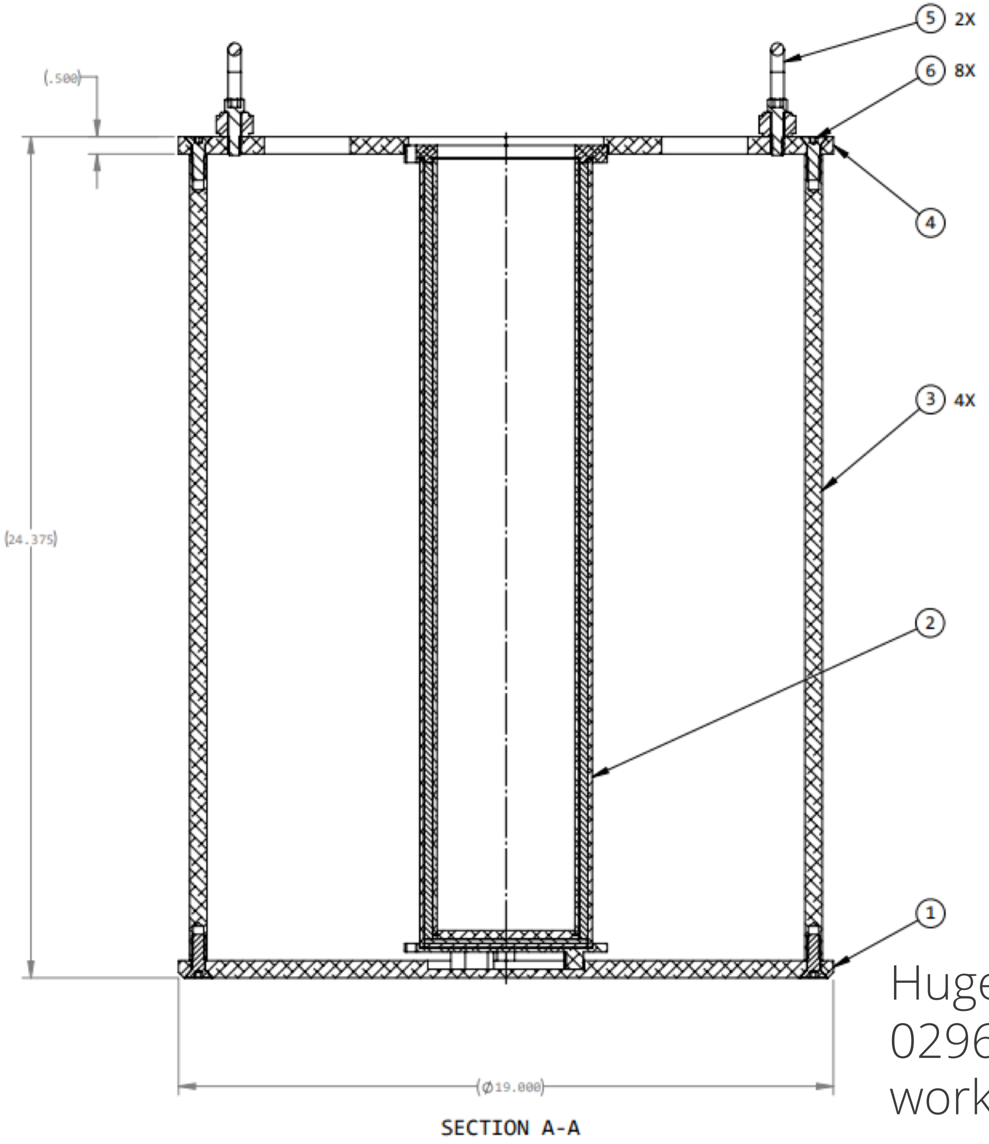
Requirements:

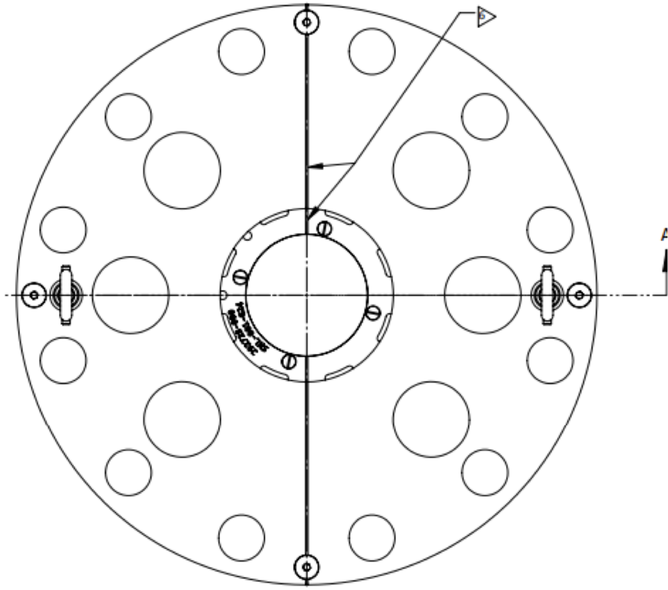
- Achieve conversion ratio equal to or greater than HFETR
- Perform pulse and steady-state operations
- Fit in either ACRR (~9") or FREC-II (~21") central cavities
- Accommodate samples ~6" in diameter
- Air-cooled
- Easily removed/installed
- Achieve fluence of 1E+13 n/cm2
- Retain tritium
- Constructed of low activation hazard materials
- Enable the isolation of 14-MeV effects



Design of a ^{6}LiD Spectrum Modifier for FREC-II







Huge thanks to Augie Chapa at 02962 for mechanical design and working with ML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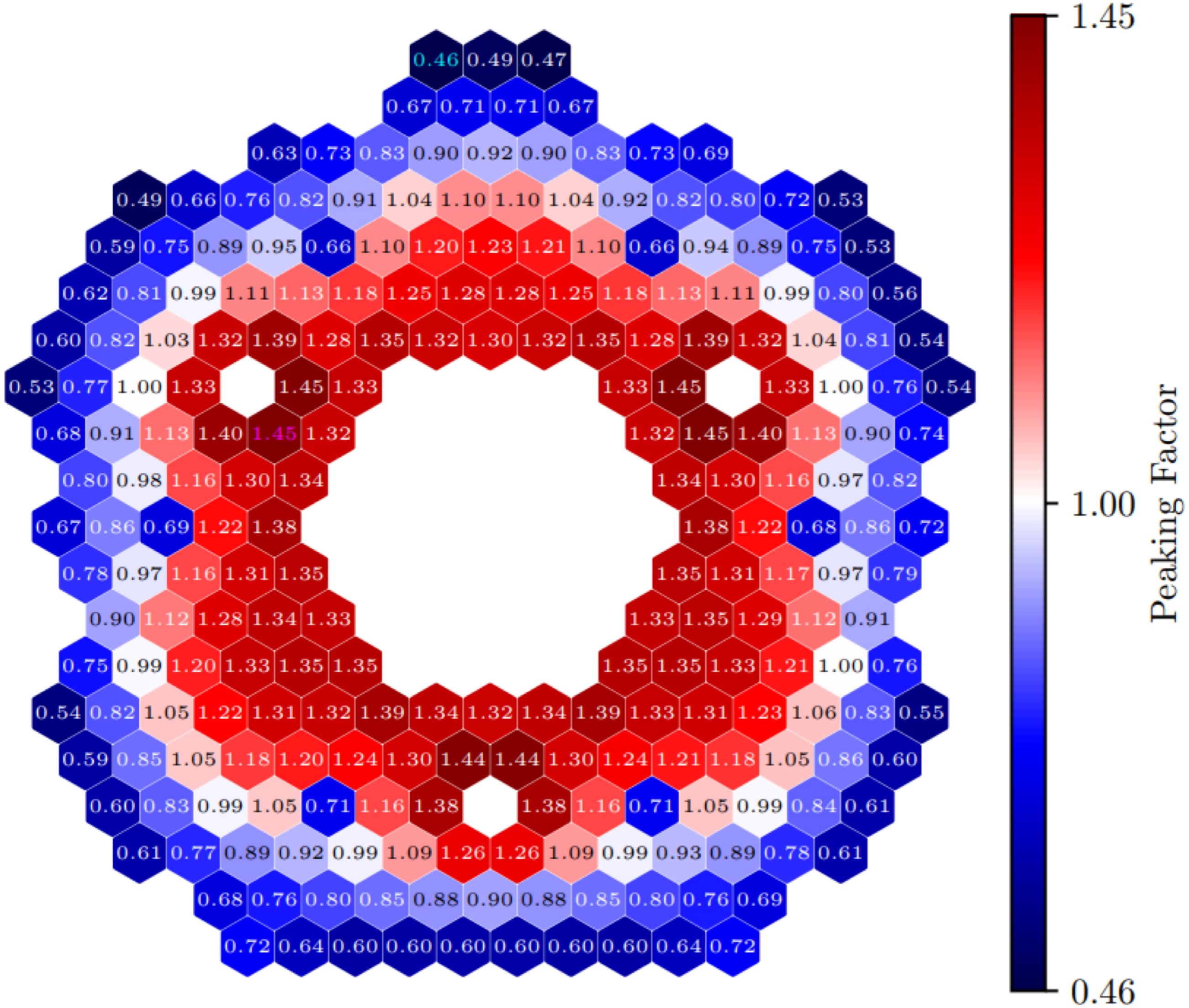
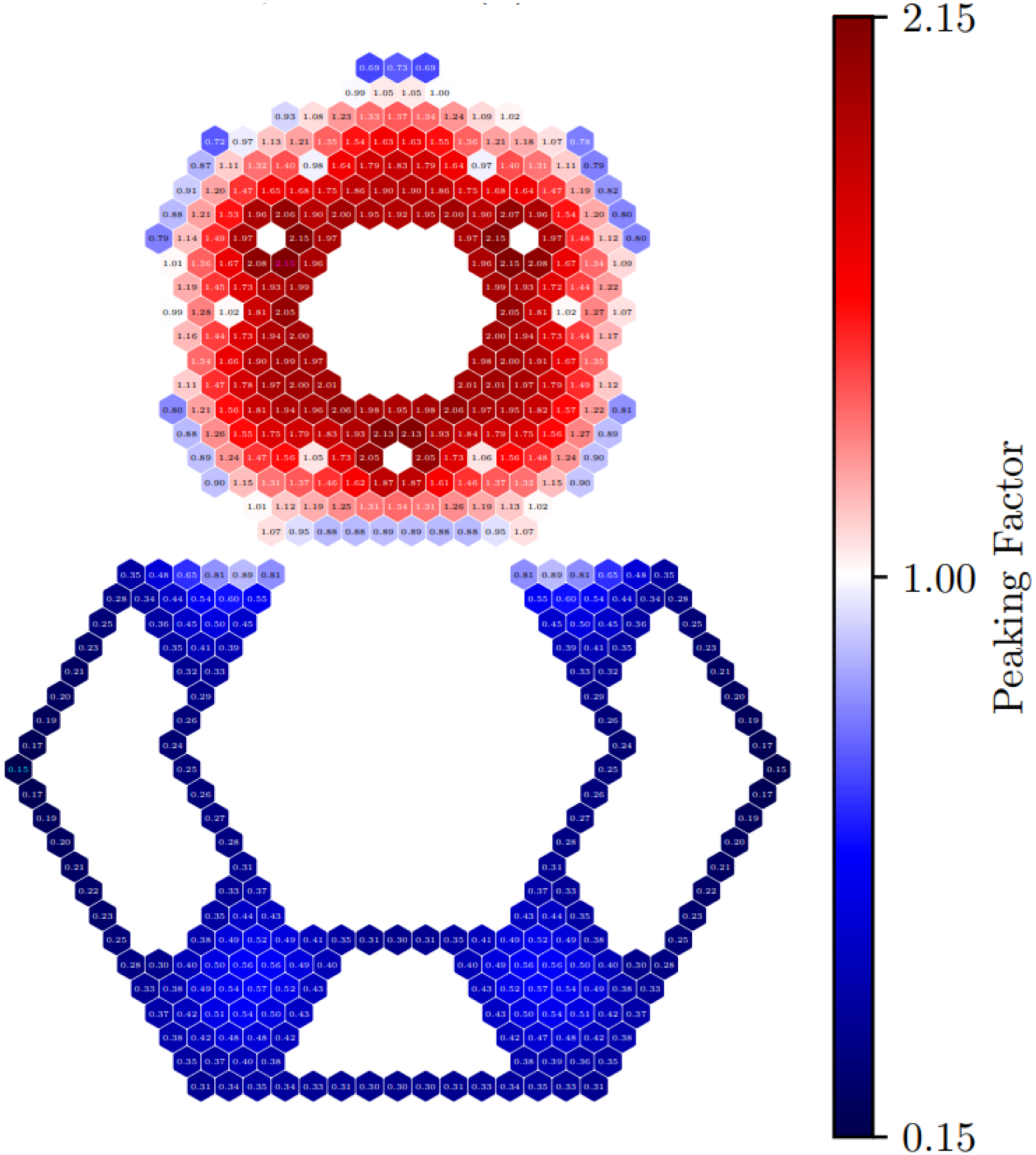
Steady-State Predicted Performance

- ^{6}LiD bucket located in 21” FREC-II cavity (-$0.50)
- Why FREC-II? Close to -$4.25 limit and radial PPF of 1.72 in ACRR
- ACRR core max power peaking factor of 1.45 (must be ≤1.52)
- Total number of fuel elements ≥ 1.46 is 6 (must be 20 or less)
- Product of the highest FREC Core Radial PPF and the FREC-to-ACRR coupling factor (based on average power) is ≤ 0.784



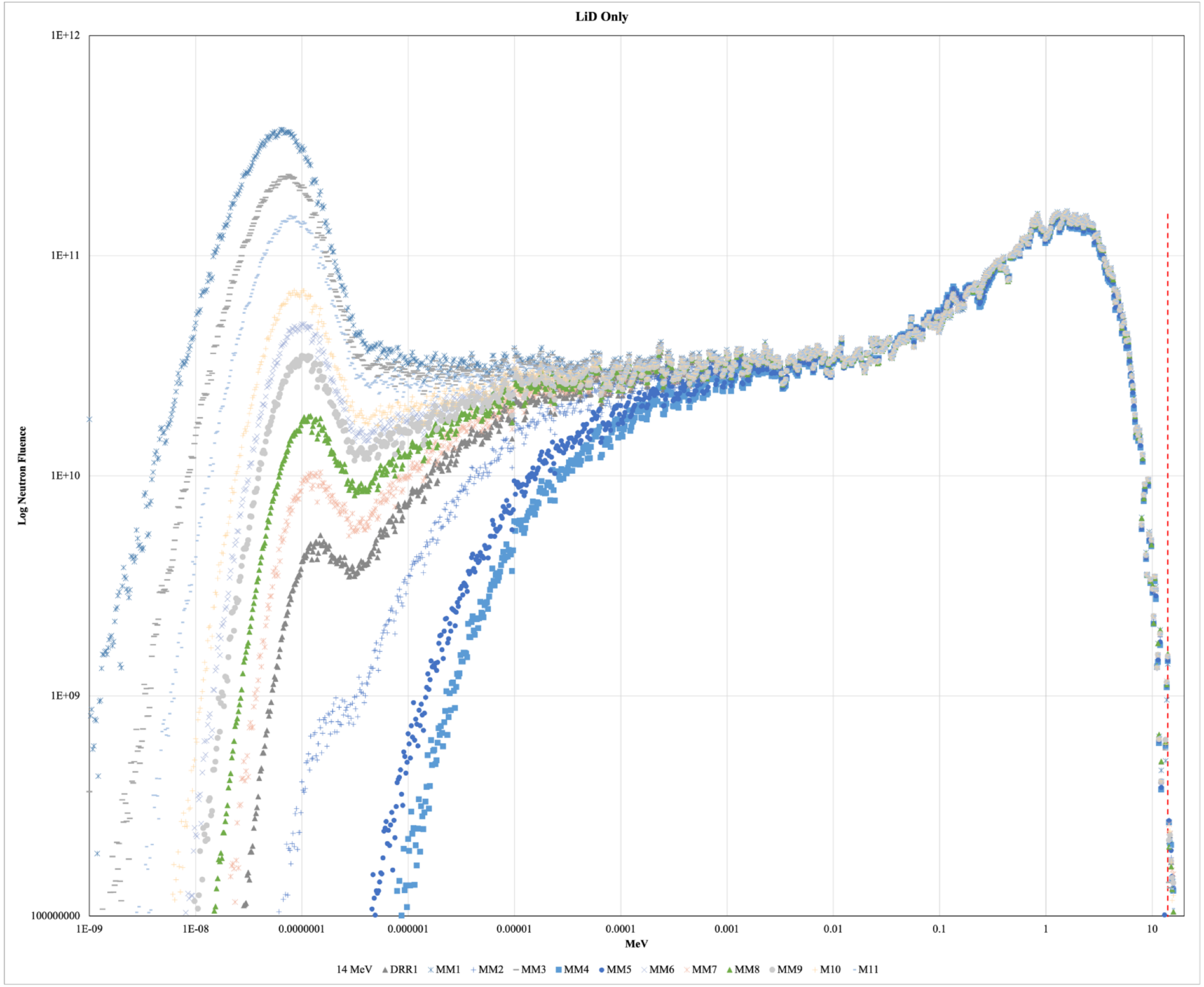
Pulse Safety

- $4.99 pulse
- Max radial power peaking factor of 2.15 in ACRR core
- 0.89 in FREC-II
- Currently no intent to use in pulsing operations, but is possible



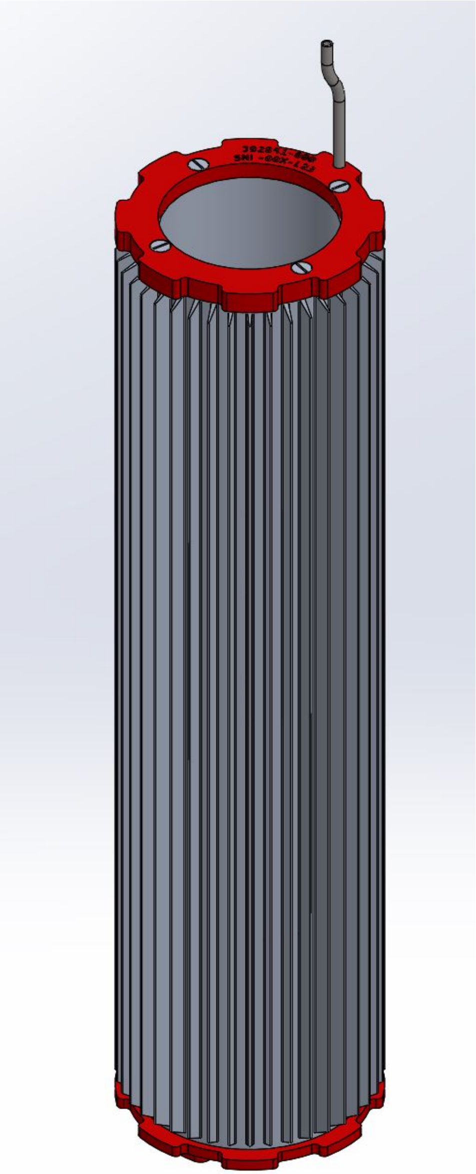
Predicted Steady-State Neutronic Performance

- MCNP model with 26-group cavity spectrum source histogram
- Mode D,n but no T reaction tally. Estimate fusion neutron production from ^{6}Li absorption rate
- Thermal to 14-MeV conversion ratio of about 1E-03 for a thickness of 0.5 cm
- 14-MeV flux of about 1E+09 n/cm^2-s

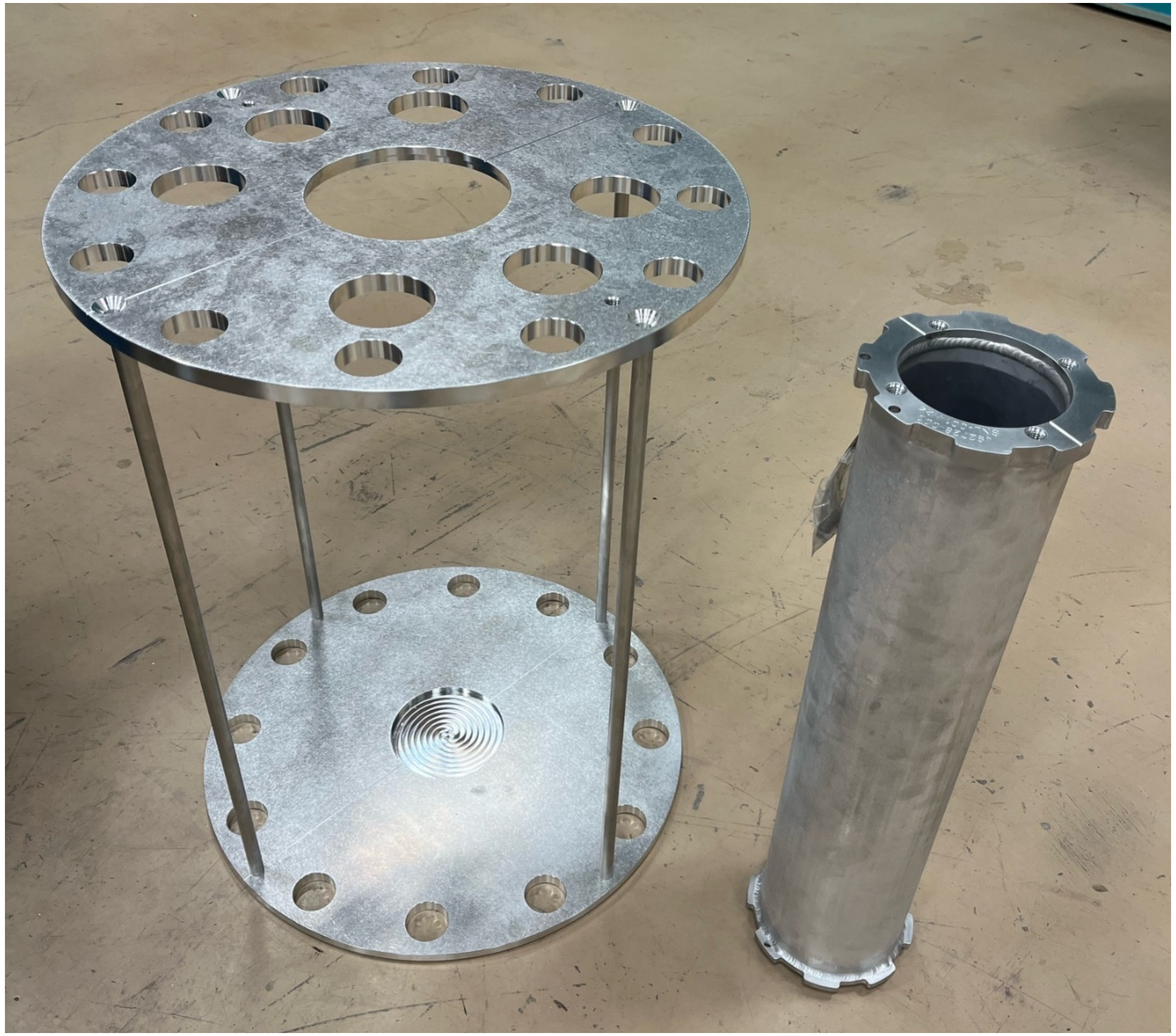


Thermal Performance/Considerations

- Initial concept used cooling fins to dissipate heat
- Found to have negligible impact in natural convection regime
- Fins removed for ease of manufacturing
- Thermocouple access holes in upper flange
- Need to keep temperature below 150 °C to prevent formation of LiAlH corrosion product (degrades integrity of vessel)



Acquiring ^{6}LiD from Y-12 National Security Complex



Safety Considerations

- Moisture is very bad… Particularly when LiH is powdered
    - LiH reacts with moisture to form a corrosion layer, releasing hydrogen gas.
    - Corrosion layer is composed of a thin Li_2O buffer layer
    - Followed by a layer of LiOH
    - Followed by another layer of $LiOH \cdot H_2O$ on top of the LiOH layer if RH > 15%
    - <u>**Long story short: takes the oxygen from water and releases hydrogen gas that ignites**</u>
- Vessel must remained sealed to retain hydrogen gasses and nitrogen fill gas
- Coke ash is most effective at fire suppression (main constituent SiO_2)
    - Robs the LiH of moisture
    - Not effective if vessel is breached and dropped in the pool (unlikely)
- <u>**Drop test resulted in minor 1/8" dent**</u>

Remaining Work

- Ship from Y-12 back to Sandia
  - NRC 741 form
  - Sandia authorization to ship
  - Ship
  - Receipt inspection
- Weld fill port screws (laser or electron beam)
- Lithium hydride fire burn rate calculations
- Perform burnup and hydrogen pressure calculations
- Take experiment plan back to committee
- Initial characterization
- Detailed radiation metrology and characterization

Acknowledgements and Thanks

- Dave Clovis (Concept, research & proposal)
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