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Molten Salt Reactor PROGRAM

Beryllium Carbide as a Neutron Moderator

Anne Campbell
Oak Ridge National Laboratory

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Grand Question

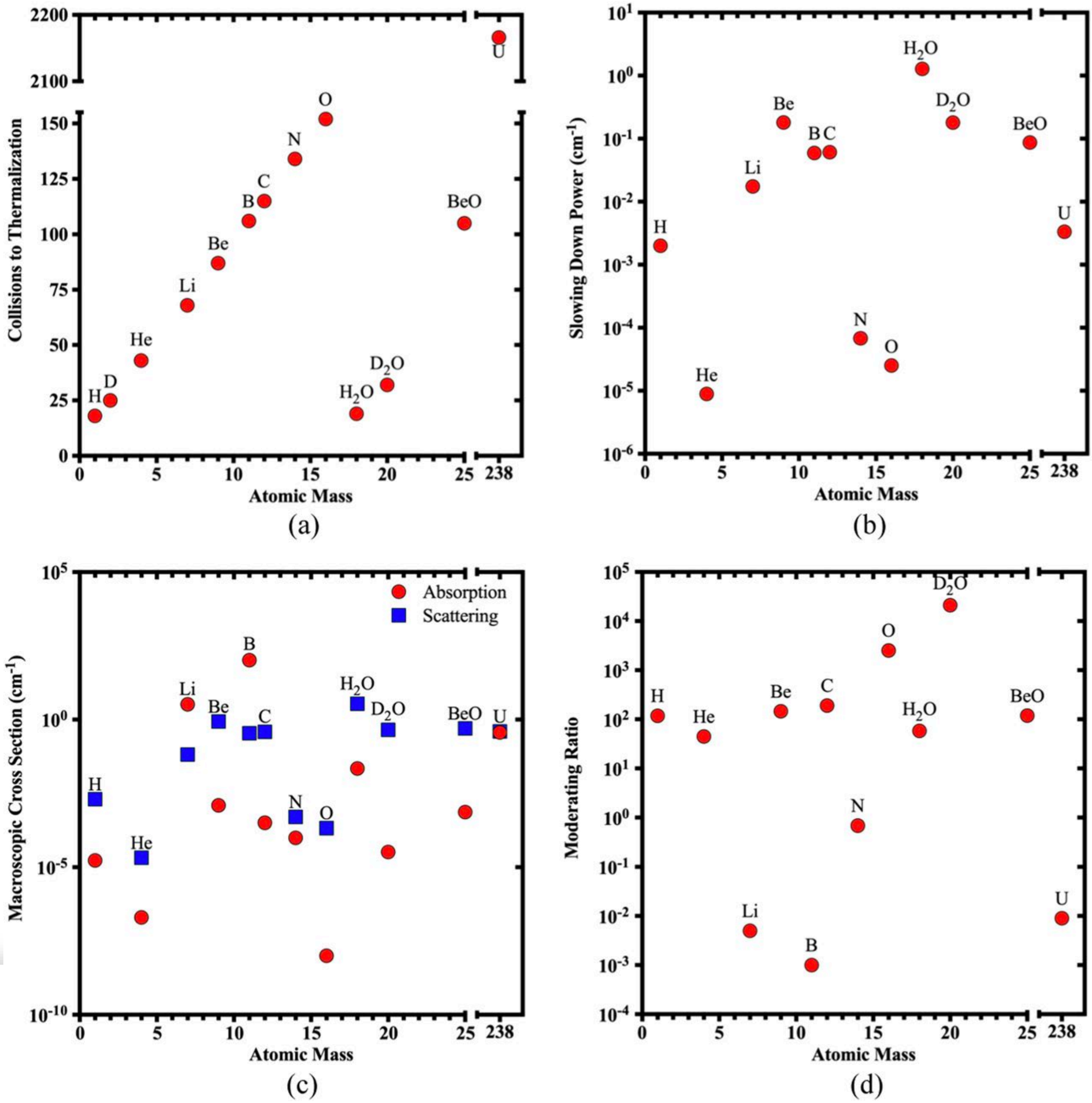
Can beryllium carbide be used in future reactors as a replacement moderator for graphite?

Long-term (10+ years) to answer this question, but can perform preliminary screening

Why Beryllium Carbide?

Campbell & Burchell Timothy D. (2020). Radiation Effects in Graphite. Comprehensive Nuclear Materials 2nd edition, vol. 3, pp. 398–436

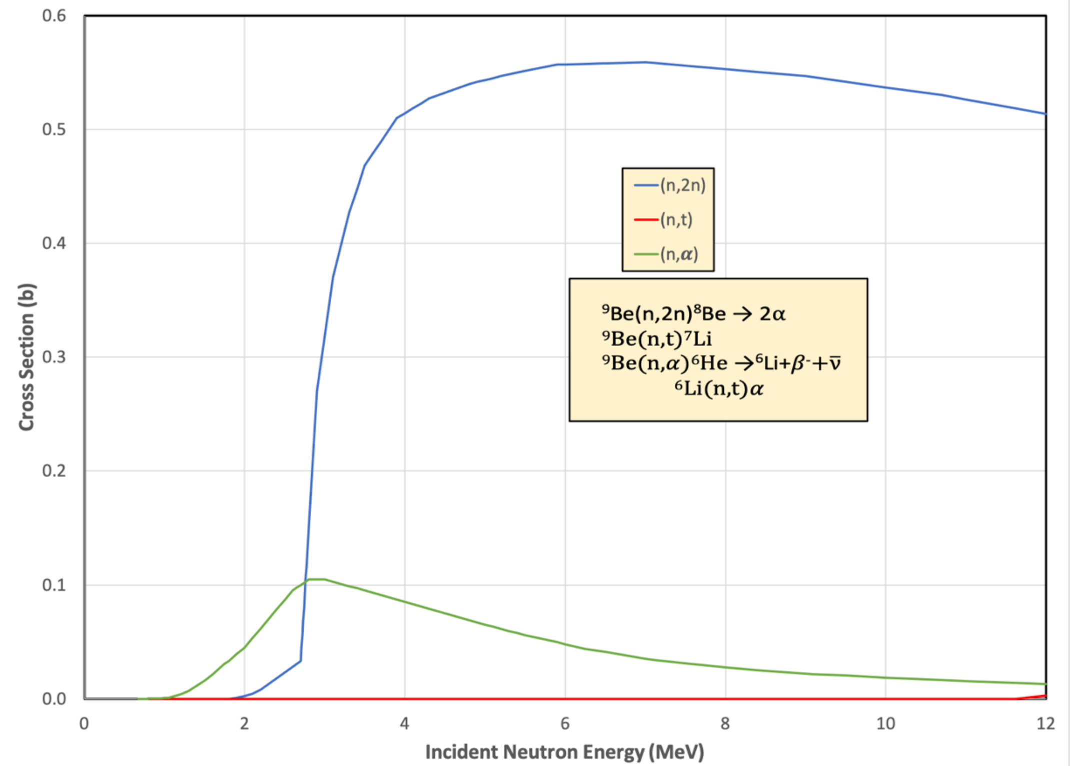
- **High moderating efficiency and low absorption cross section**
- **Be slowing down power ~2.5x > than carbon**
- **Chemically compatible with coolant salts**
- **Antifluorite crystal structure – the same crystalline configuration (with anions and cations reversed) as exceptionally radiation damage resistant fluorite type crystals (e.g., UO_2**
  - The anti-fluorite crystal (Li_2O) has also been shown to have high radiation damage tolerance [1,2]



[1] Moriyama et al., *Journal of Nuclear Materials*, **258-263**, (1998) 587-594.
[2] Noda, et al., *Journal of Nuclear Materials*, **123**, (1984) 908-912

Technical Challenges with Beryllium Carbide

- **Long history of graphite as neutron moderators (CP-1, X-10 ~80 years) research and knowledge – only limited low dose studies in Be_2C [1-3]**
- **Be_2C is brittle, vulnerable to thermal stress cracking**
  - Can we mitigate brittle nature via fiber reinforcement?
- **Be_2C it toxic, moisture sensitive, chemically reacts with U**
  - Would need a protective layer (NbC)
- **Be_2C is a methanide (when exposed to H it decomposes into methane)**
  - Can this be utilized for tritium management strategy?
  - Methane is easily trapped and doesn't diffuse through metal alloys
- **Be does have gas generating reactions with neutrons (He and ^3H)**
  - May be beneficial for fusion systems for ^3H production



Be gas generating reactions (data from ENDF/B-VIII.0)

[1] Maya et al., GA-A-17842; (1985)
[2] Marion & Muenzer, SAND--78-0227C, CONF-780622, (1978)
[3] Feldman & Silverman, NAA-SR-114, (1951)

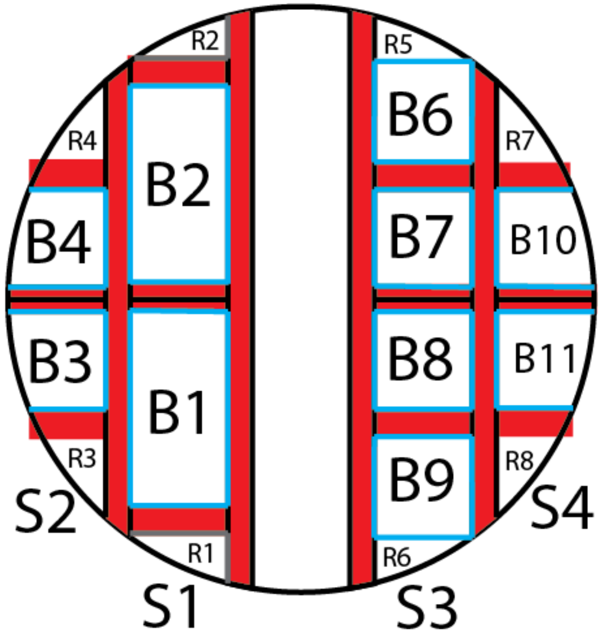
What are the first steps?

- Need solid Be_2C samples – concern is production and processing is export controlled technology
- Understand high temperature stability of Be_2C
- Preliminary understanding of irradiation effects in Be_2C
- Degradation behavior when exposed to hydrogen
- Understand thermal properties

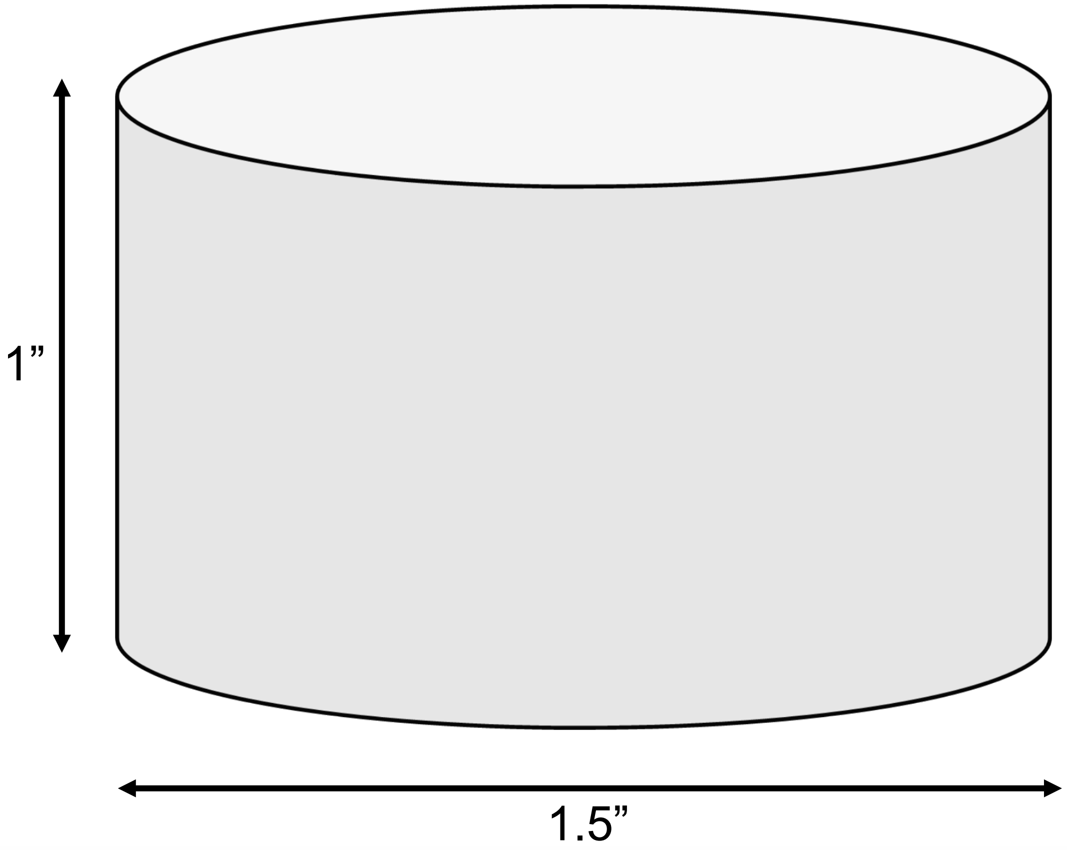
Obtaining Material

- **Materion Brush Inc. in Elmore, OH already has technology to produce solid pieces of Be_2C**
  - Processing and other information is export controlled technology and proprietary
- **At start of this effort, Materion already had a puck 1.5" diameter and 1" thick produced. Agreed to machine and sell the pieces to ORNL**
- **Sectioning plan developed to create pieces that will be used in this effort**
  - Material is in the process of cutting pieces, feedback about the technical challenges will be of importance going forward
- **Materion is in process of cutting pieces. Will discuss any difficulties with cutting**

As-Produced Be_2C (1.5” diameter, 1” tall)

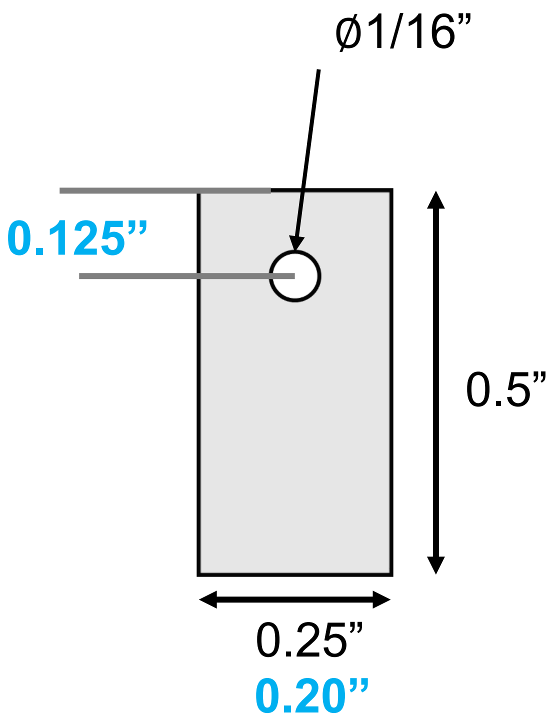


Top View sectioning plan
To scale
Red area is cutting allowance



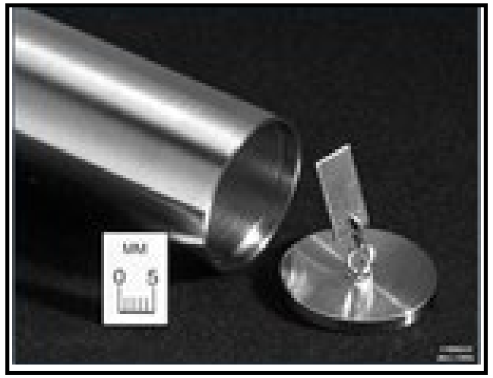
Shapes and sizes of specimens

- 1.5" × 0.2" × 0.2" bars parallel to puck diameter – thermal expansion or flexural strength testing
- 1" × 0.2" × 0.2" bars parallel to puck thickness – thermal expansion flexural testing
- 0.5" × 0.25" × 1/8" thick coupons (right) – thermal stability testing / XRD
- 0.1" × 0.1" × 0.25" semi-square rods for hydrogen degradation testing

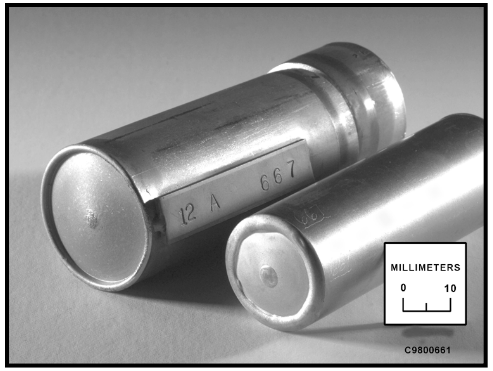


High Temperature Stability

- **Thermal stability of Be_2C unknown – can be potential no-go concern**
- **Measure X-ray diffraction (XRD) pattern of samples (wrap in Kapton film to contain material)**
- **Seal Be_2C samples in the sample Molybdenum capsules used for static salt exposures – use inert gas instead of salt**
  - Perform high temperature exposures (650°C-800°C) for times ranging from 1-10 days
- **Open capsules, wrap coupons in Kapton film and remeasure XRD spectra**
  - Determine if any significant change in phases present and their concentration



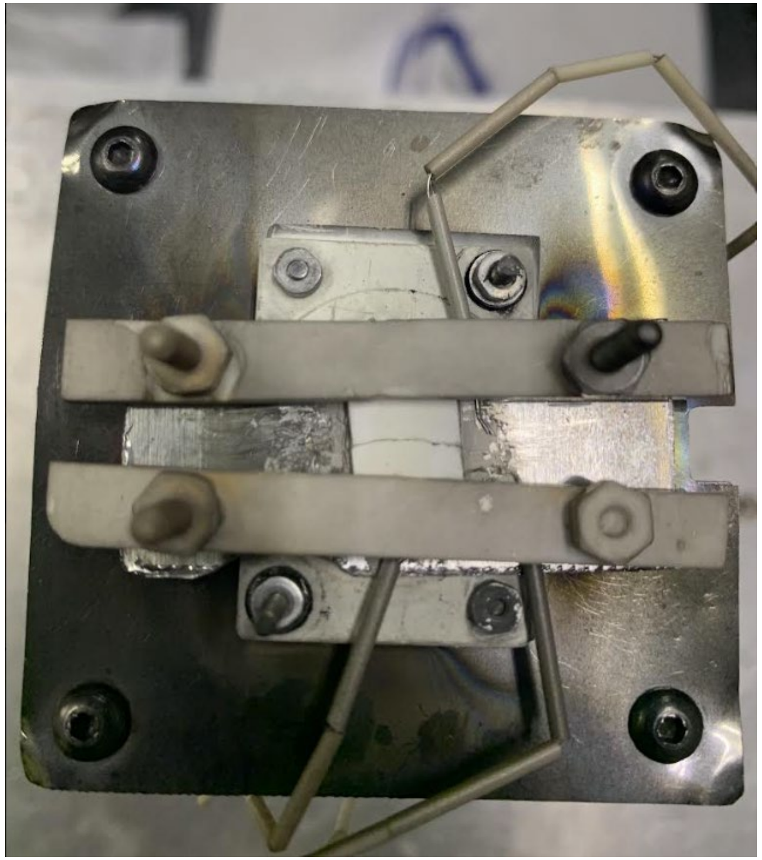
Sample mounted on Mo capsule lid (courtesy J. Keiser)



Inner and outer capsules (courtesy J. Keiser)

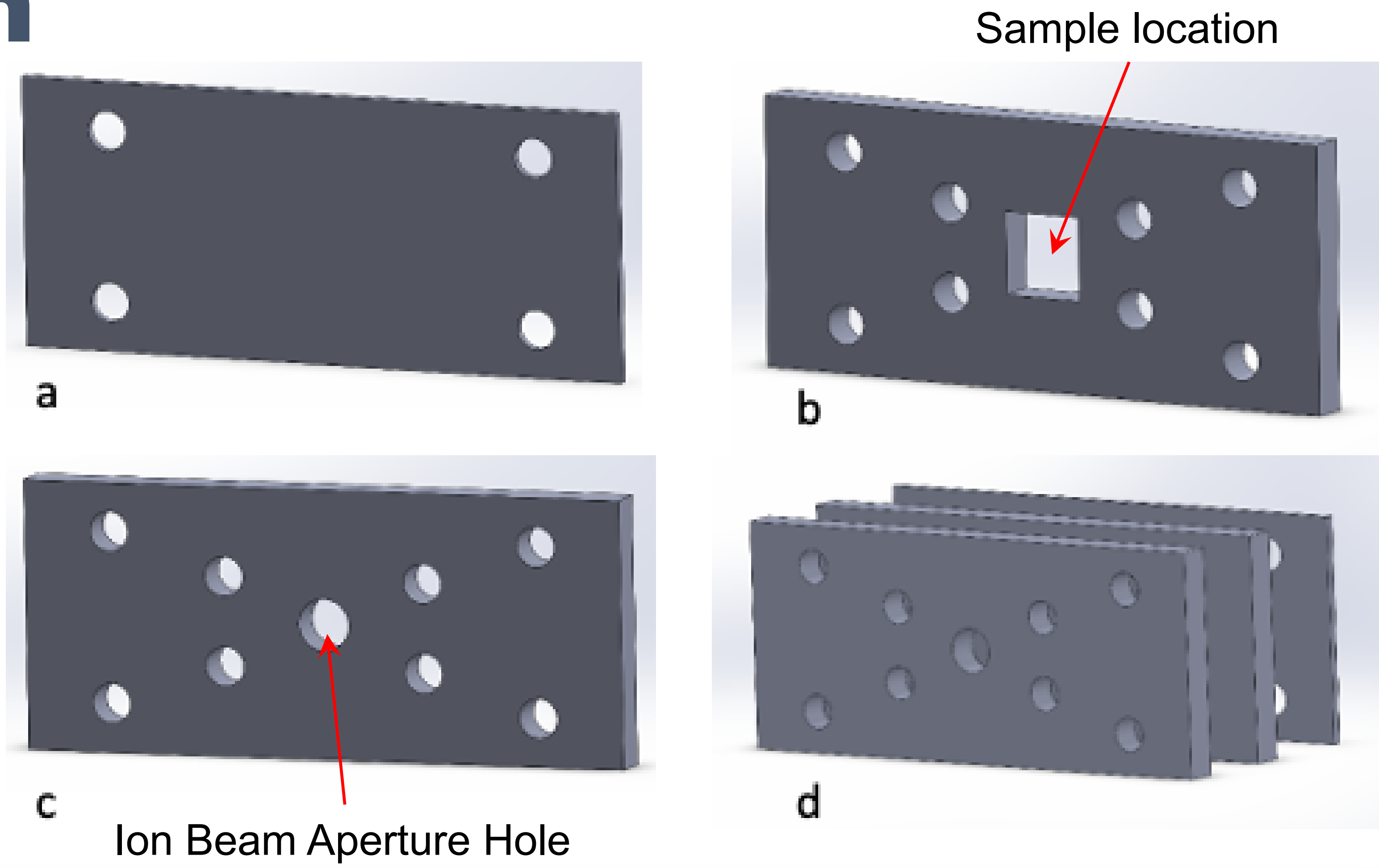
Irradiation Stability

- **Neutron irradiation takes multiple years (3+) and can be cost prohibitive for initial study**
  - Performing preliminary studies via ion irradiation – University of Michigan MIBL
- **UofM using Li_2O as surrogate until Be_2C obtained**
  - Original irradiation of Li_2O with oxygen ions to 50 dpa saw specimen crack on the stage (right picture)
- **Had good temperature control of sample at 700°C for 70 hours (50 dpa) and 4.5 hours (5 dpa)**



Additional Work Controls for Be_2C Ion Irradiation

- Gold sputter coater – act as containment of Be_2C during ion irradiation
- New 3-piece sample holder (right)
- Next 50 dpa irradiation planed with Li_2O to confirm sputter coat and new holder behave as expected



Fundamental Understanding of Irradiation Effects

- **Ab initio to develop density functional theory (DFT) for atomistic evaluation of radiation defects in Be2C**
- **Molecular dynamic models will be used to model full collision cascades**
  - Will require evaluation of the different interatomic potentials that have been developed to determine their suitability for irradiation interaction modeling
- **Future efforts will steer towards Kinetic Monte Carlo, cluster dynamics, discrete dislocation dynamics, and crystal plasticity**
  - Understand how larger features in Be_2C affects the response to irradiation damage and larger defect behaviors
- **Key long-term modeling efforts will have to focus on the behavior of the gasses produced from neutron capture and transmutation**

Degradation in hydrogen environment

- **Be_2C degrades to methane in the presence of hydrogen**
  - Can this be used for ^3H mitigation?
- **Small pieces of Be2C will be exposed to molten salts in a skimmer with fixed concentrations of hydrogen gas**
  - Quantify the rate of decomposition of Be2C into methane
- **This will be a critical knowledge for future use in MSRs where hydrogen and tritium will be produced both by neutron capture in the solid Be and Be containing salts**

Thermal Properties

- **Materion has performed limited thermal properties measurements on the bulk Be_2C piece**
  - Data has not yet been shared with ORNL (may fall under an NDA)
- **Plan is to measure preliminary thermal properties at INL**
  - 1.5”x0.2”x0.2” bars parallel to puck diameter
  - 1”x0.2”x0.2” bars parallel to puck thickness
  - Use these two directions to quantify any anisotropy due to processing

Beyond FY23

- **From these preliminary results evaluate if a neutron irradiation campaign is viable – begin planning**
- **Work with Materion to develop advanced processing methods to tailor material properties**
- **Any future work will require setup of capabilities for handling and testing solid Be_2C both pre- and post-irradiation**
  - Glove boxes, testing equipment (mass/dimensions, elastic properties, strength, CTE, thermal diffusivity, etc.)

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Thank you

campbellaa@ornl.gov

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