INL/MIS-25-83859-Revision-0

Update on R&D progress by DOE

March 2025

William E Windes

Changing the World's Energy Future

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Update on R&D progress by DOE

GIF VHTR Materials PMB Meeting
Baden, Switzerland
March 17-19, 2025

William Windes
Idaho National Laboratory
Idaho Falls, ID, USA

Yanli Wang
Oak Ridge National Laboratory
Oak Ridge, TN, USA

High Temperature Materials

Graphite and Composite Program

Baseline: unirradiated material properties

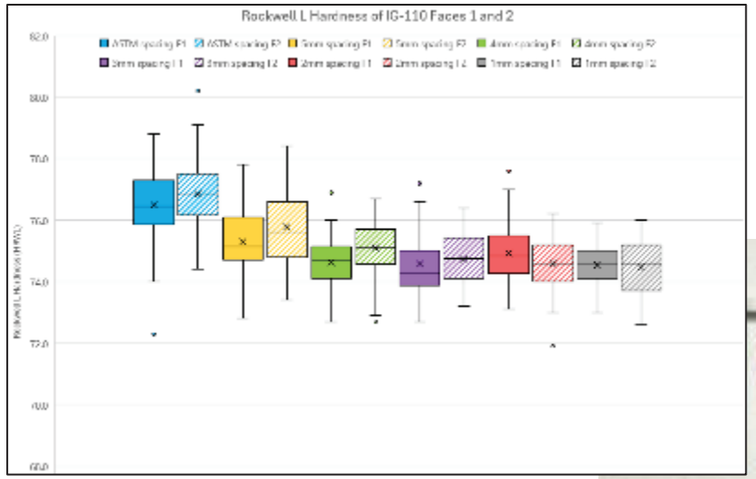
- Five major graphite grades, multiple Billets; 30,000+ data points, NQA-1 conforming
- Unirradiated material properties
  - ***Adding ET-10 grade (Kairos Power)***
- Data used to qualify major sections of ASME
  - ***HHA-3000 (Design)***
  - ***Irradiation code rules (2027+)***
- New Unirradiated data being added
  - ***Oxidation rate data***
  - ***Split disc (tensile) measurements***
- Available on NDMAS
  - https://ndmas.inl.gov/SitePages/NDMAS_Pages_Home.aspx
  - Lead by: courtney.otani@inl.gov

Graphite	Lab	Billet #	Percent Complete					
			Machining	Mass and Density	Elastic Testing	Mechanical Testing	Thermal Testing	Split Disc
PCEA	ORNL	XPC01S8- 11	100%	100%	100%	100%	100%	
PCEA	INL	XPC02S8-7	100%	100%	100%	100%	100%	50%
PCEA	INL	XPC01S8-9	100%	100%	100%	100%	100%	
PCEA	INL	XPC02S8-5	100%	100%	100%	100%	100%	100%
PCEA	INL	XPC01D3- 35	66%					
PCEA	INL	XPC01D3- 36	100%	100%	100%	100%	100%	50%
NBG-18	INL	635-4	100%	100%	100%	100%	100%	50%
NBG-18	INL	635-14	100%	100%	100%	100%	100%	
NBG-18	ORNL	635-6	100%	100%	100%	100%	100%	
2114	INL	A20568	100%	100%	100%	100%	100%	50%
2114	NL	A20570	100%	100%	100%	100%	100%	
2114	ORNL	116310	100%	100%	100%	100%	100%	
NBG-17	INL	830-3	100%	100%	100%	100%	100%	
NBG-17	INL	V104	100%	100%	100%	100%	100%	50%
IG-110	INL	089052-7	100%	100%	100%	100%	100%	
IG-110	INL	10X69	100%	100%	100%	100%	100%	50%

ASTM Test Development

Degraded graphite Testing:

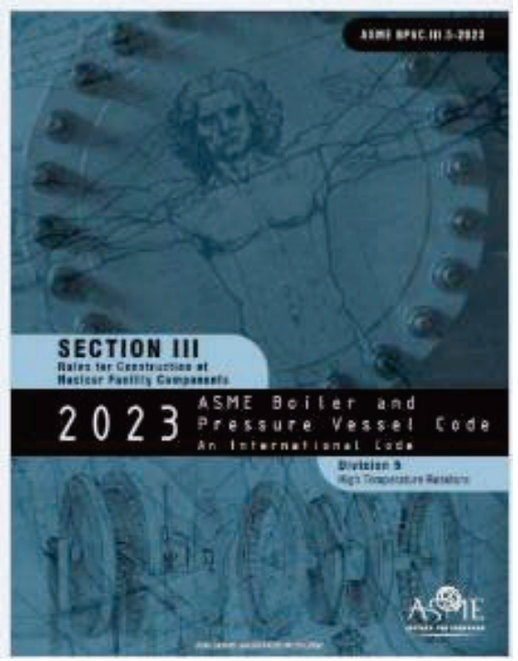
- Emphasis on HT mechanical testing:
  - *Graphite **and** matrix material*
- Oxidation effects
  - *Mechanical and physical properties after Oxidation*
- Molten salt testing
  - *Mechanical and physical testing*
  - *In-situ or "regular"*
- Hardness testing – C748
  - *Not suitable for matrix material*
  - *Corrections being made in 2024*
- Improved Split-disc strength
  - Irradiation strength
  - HT testing



Tomography of NBG-18 sample exposed to molten FLiNaK, 3 bar, 750°C, 336 hours

Design and construction rules (ASME-based)

- **BPVC 2025 is complete**
  - Significant progress in graphite Design rules in 2025 version
- **New emphasis for BPVC 2027**
  - Continue Design work
    - *Establish V_m changes*
    - *Documentation*
  - Ceramic composite code rules (experiment validation)
  - Irradiation Behavior (before turnaround dose)
  - Material Qualification Methodology (Graphite)
  - Graphite component failure – Definition and code rule actions
    - ***Section XI (RIM) is priority***



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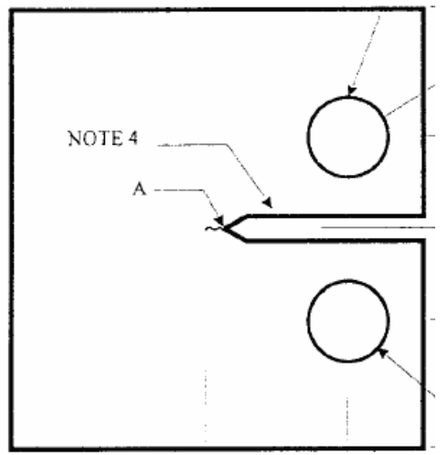
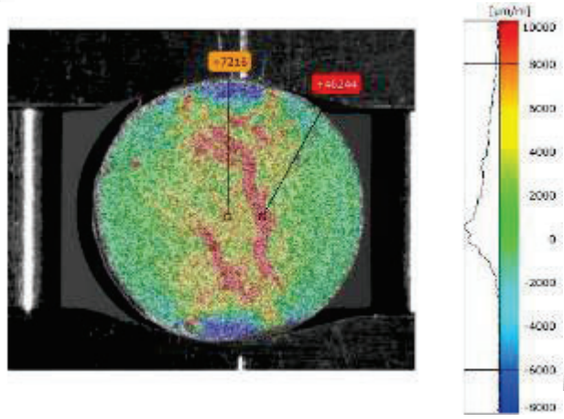
New Fuel Matrix Mechanical Studies

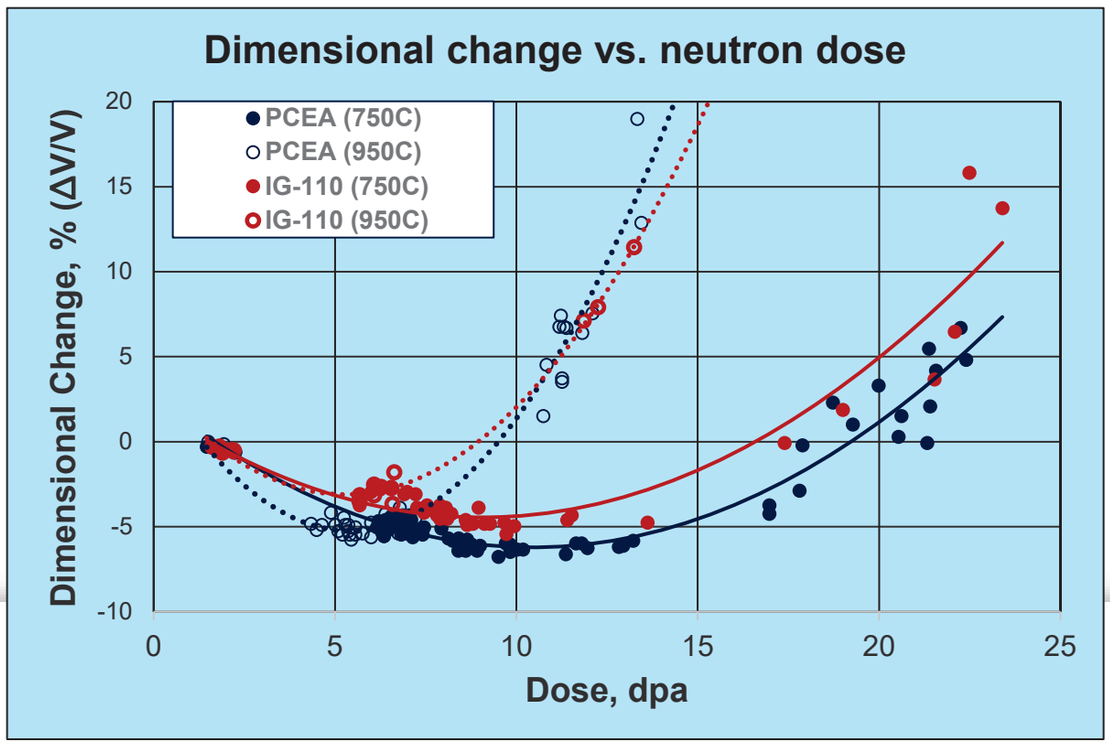
- **Fabrication of fuel matrix specimens:**
  - Making large fuel matrix samples for mechanical testing
  - With and w/o particle “fuel”
- **Strength and crack propagation testing**
  - Mechanical testing
    - Tensile, compressive, bend strength
    - High temperature changes
  - Fracture
    - CT, Split disc,
    - *DIC, XCT, and fractography*
  - Hardness measurements
    - Comparison with graphite
  - Collaborating with commercial vendors
    - Pebbles from commercial vendors

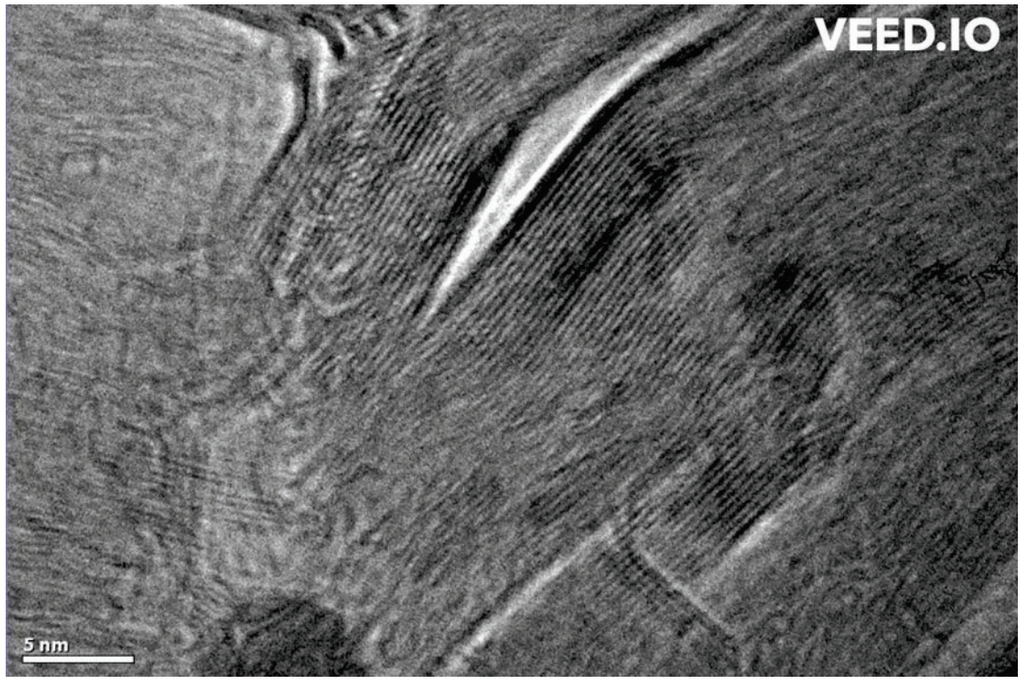




Irradiation Damage Studies

- **Semi-empirical models with existing data**
  - All data (excluding some GIF Handbook)
  - Need to determine common traits
    - ***Most likely before Turnaround dose***
    - ***Within the temperature range of 300C – 800C***



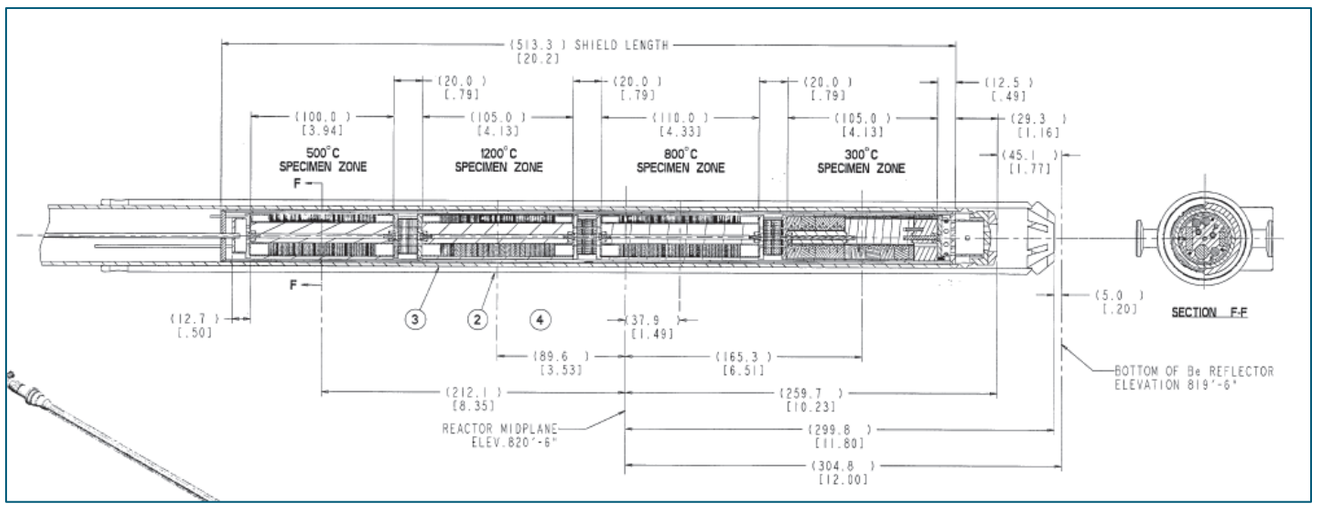


Fundamental irradiation defects study

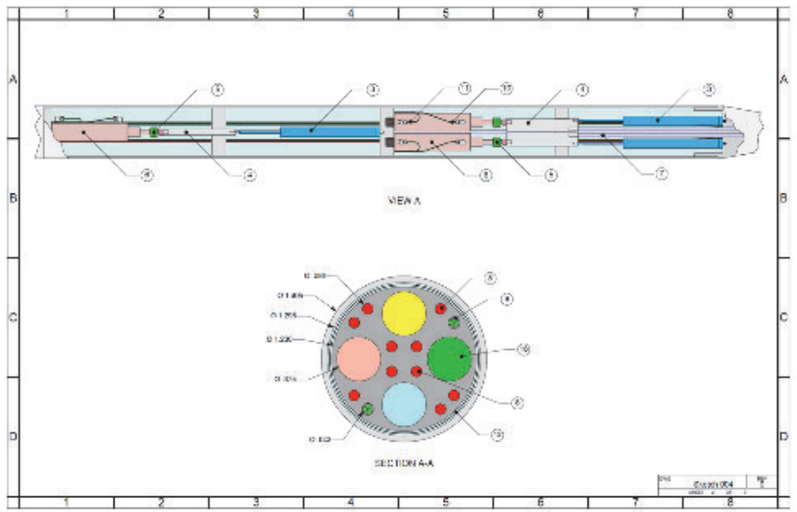
- We must understand (fundamentally) what is happening in graphite under neutron irradiation
- We have the tools now to characterize these defects
- Needed for long term life-time predictions

Vender Irradiation Capsules (VIC)

ORNL (HFIR)



INL (ATR)



- **DOE recognizes a need for graphite irradiation experiments**
  - Preparing “generic” capsule designs at INL (ATR) and ORNL (HFIR)
  - Design specific irradiation conditions can be accommodated in refined design
    - *Temperature, mechanical load (creep), dose, etc.*
- **New VIC meeting – 17-19 June 2025 (Hybrid meeting)**

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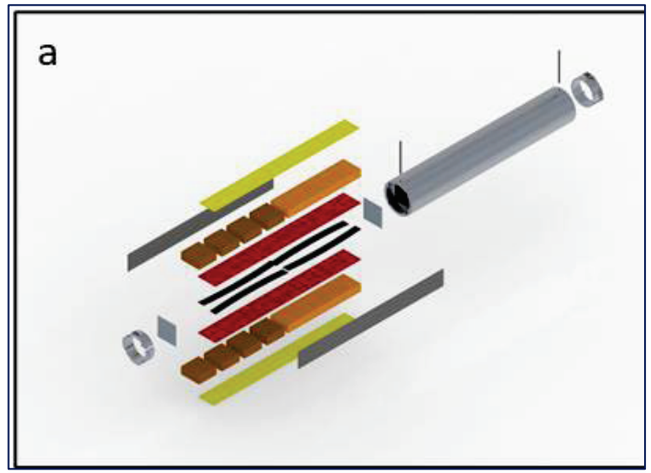
Graphite Supply Chain Worries

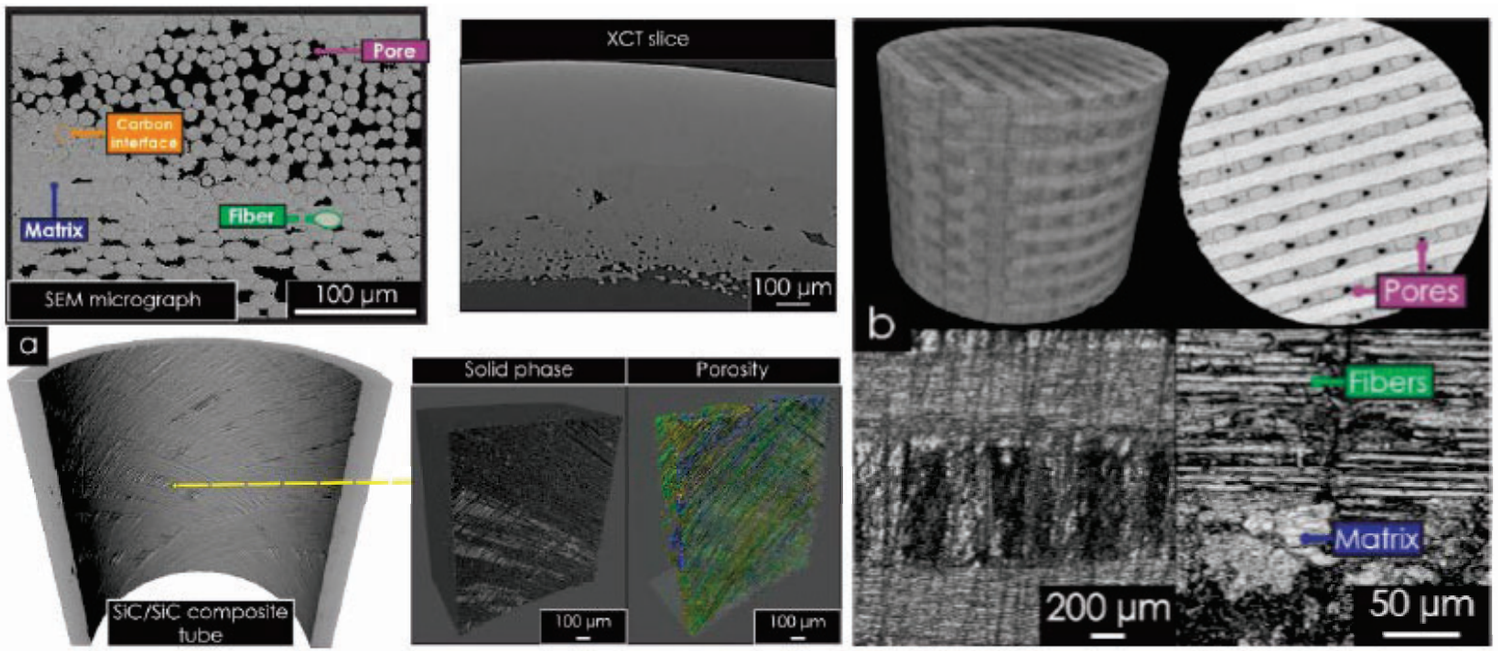
- **Issue: Can graphite producers provide enough nuclear graphite for the anticipated High Temperature Reactor designs throughout the world.**
  - *Material supply questions as well as geopolitical*
- **Answer: There will never be a problem getting enough nuclear graphite**
  - Even building several large reactor designs per year (10,000 tons/yr) there will be enough graphite
- **Nuclear graphite is actually semi-conductor grade graphite (Specialty Graphite)**
- **Semi-conductor annual production (60K-75K+) guarantees there will be enough graphite for future nuclear uses even at most optimistic reactor build projections.**
  - Domestic supplier issues are purely commercial (and/or politically) driven – not supply.
- **(Natural) Flake graphite for fuel compacts/pebbles: no issues**
  - *Flake graphite is used for electric battery (Li ion) manufacture. Only a miniscule amount needed for annual TRISO fuel production compared to battery material requirements.*
- **Raw materials: Only potentially significant risk. *Nuclear Industry may need to address this issue* with new raw material sources**

Ceramic Composite activities

J.W. Geringer, et.al., ORNL/TM-2024/3737, "Experimental Test Plan for Material Property Evaluation of Various Ceramic Matrix Composite Structures in Support of ASME Section III-5", February 2025

- **New DOE activity in ceramic composite**
  - Experimental studies to validate ASME code rules for ceramic composites
- **Focus**
  - Understanding manufacturing changes which affect the design methodology
    - ***1D, 2D, 3D, 4D, etc. = how does this change the failure prediction methodology***
  - Environmental effects
    - ***Temperature, Irradiation & Oxidation effects***





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