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Graphite-Molten Salt Interactions

Dr. Nidia Gallego

Oak Ridge National Laboratory, USA

24 May 2023

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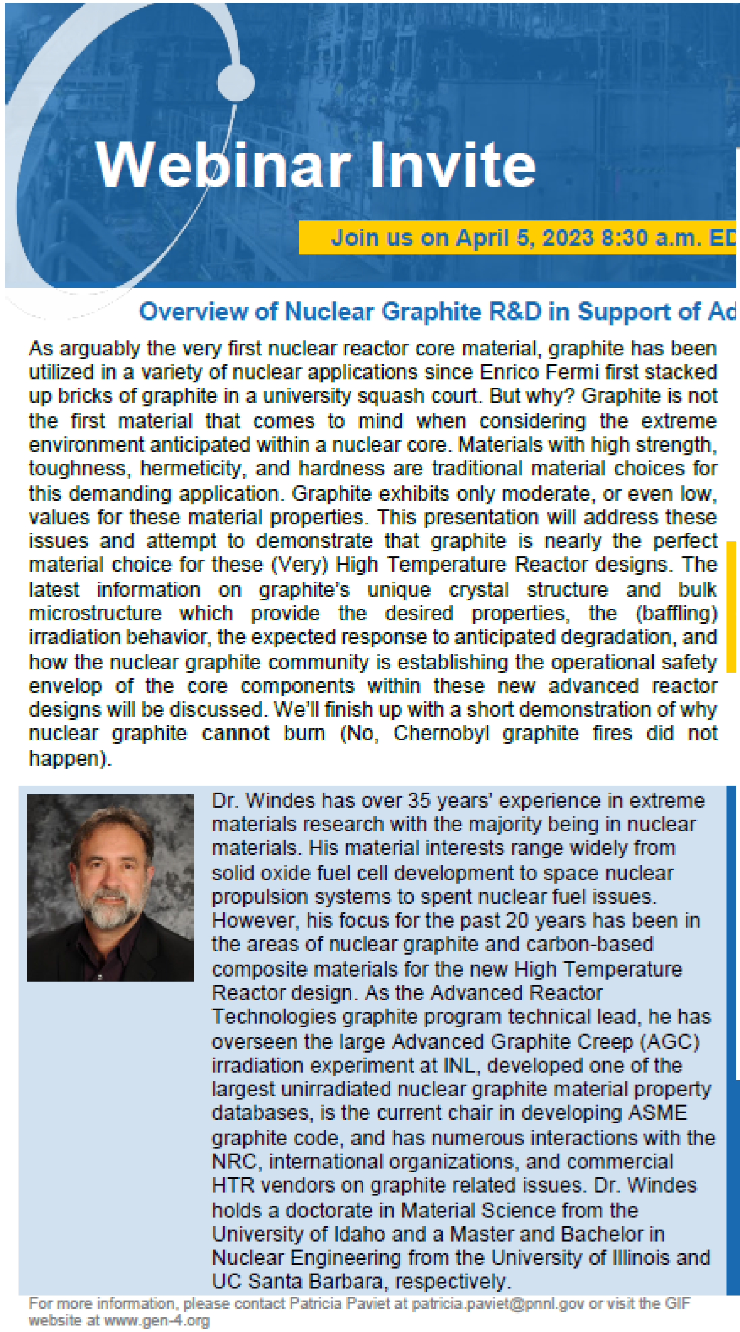
Meet the Presenter

Dr. Nidia Gallego, Distinguished Research Scientist in the Physical Sciences Directorate at Oak Ridge National Laboratory (ORNL). She earned her MSc and PhD in Materials Science and Engineering from Clemson University (Clemson, SC) and joined ORNL in December 2000. Her research interests include, among others, physical and chemical properties of carbon materials, effects of neutron irradiation on graphite and carbon materials for use on space power systems. Currently, Nidia is the ORNL Technical Lead for the graphite activities for both the GCR and MSR campaigns funded by the US DOE Advanced Reactor Technologies (ART) Program, and the Task Lead for Production of Carbon-Bonded Carbon Fiber (CBCF) components as part of the Radioisotope Power Systems Program funded by NASA.

Email: gallegonc@ornl.gov



Webinar Invite

Join us on April 5, 2023 8:30 a.m. ED

Overview of Nuclear Graphite R&D in Support of Ad

As arguably the very first nuclear reactor core material, graphite has been utilized in a variety of nuclear applications since Enrico Fermi first stacked up bricks of graphite in a university squash court. But why? Graphite is not the first material that comes to mind when considering the extreme environment anticipated within a nuclear core. Materials with high strength, toughness, hermeticity, and hardness are traditional material choices for this demanding application. Graphite exhibits only moderate, or even low, values for these material properties. This presentation will address these issues and attempt to demonstrate that graphite is nearly the perfect material choice for these (Very) High Temperature Reactor designs. The latest information on graphite's unique crystal structure and bulk microstructure which provide the desired properties, the (baffling) irradiation behavior, the expected response to anticipated degradation, and how the nuclear graphite community is establishing the operational safety envelop of the core components within these new advanced reactor designs will be discussed. We'll finish up with a short demonstration of why nuclear graphite **cannot** burn (No, Chernobyl graphite fires did not happen).

Dr. Windes has over 35 years' experience in extreme materials research with the majority being in nuclear materials. His material interests range widely from solid oxide fuel cell development to space nuclear propulsion systems to spent nuclear fuel issues. However, his focus for the past 20 years has been in the areas of nuclear graphite and carbon-based composite materials for the new High Temperature Reactor design. As the Advanced Reactor Technologies graphite program technical lead, he has overseen the large Advanced Graphite Creep (AGC) irradiation experiment at INL, developed one of the largest unirradiated nuclear graphite material property databases, is the current chair in developing ASME graphite code, and has numerous interactions with the NRC, international organizations, and commercial HTR vendors on graphite related issues. Dr. Windes holds a doctorate in Material Science from the University of Idaho and a Master and Bachelor in Nuclear Engineering from the University of Illinois and UC Santa Barbara, respectively.

Hiroki Hayafune, JAEA, Japan; Patrick Alexander, Terrapower, USA; Ron Omberg, PNNL, USA

26 July 2023, Off-gas Xenon Detection and Management in Support of MSRs, Dr. Hunter Andrews, ORNL, USA; Dr. Praveen Thallapally, PNNL, USA

For more information, please contact Patricia Paviet at patricia.paviet@pnnl.gov or visit the GIF website at www.gen-4.org

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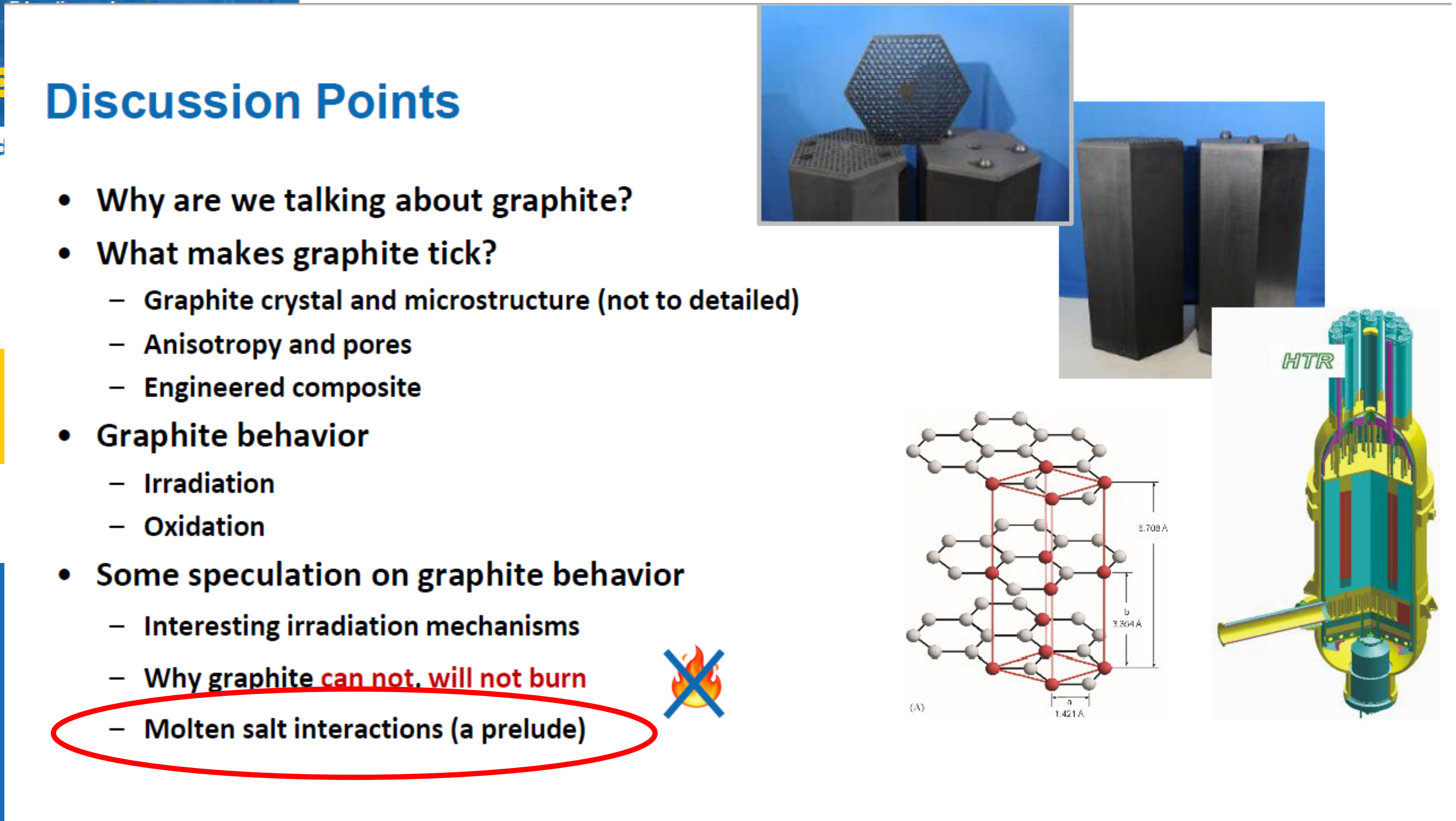


Discussion Points

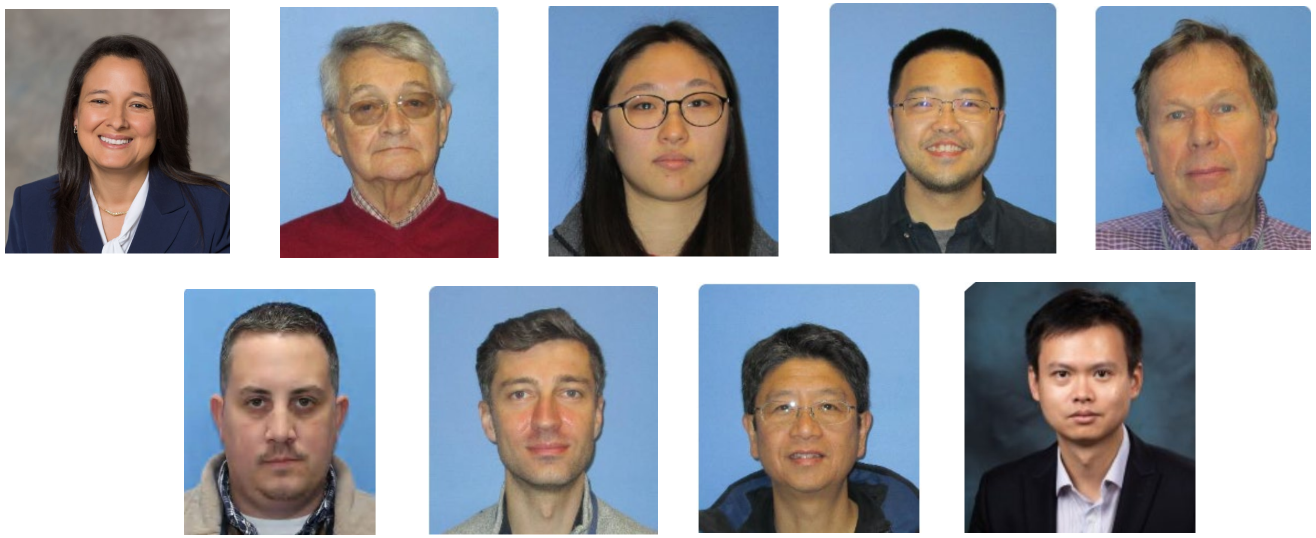
- Why are we talking about graphite?
- What makes graphite tick?
  - Graphite crystal and microstructure (not to detailed)
  - Anisotropy and pores
  - Engineered composite
- Graphite behavior
  - Irradiation
  - Oxidation
- Some speculation on graphite behavior
  - Interesting irradiation mechanisms
  - Why graphite can not, will not burn
  - Molten salt interactions (a prelude)

A recording of the presentation and the slide deck is available from the GIF website (https://www.gen-4.org/gif/jcms/c_82831/webinars).

Team Effort – ORNL Contributors

Nidia Gallego
Cristian Contescu
Jisue Moon
Yuxuan Zhang
Jim Keiser
Adam Willoughby
Dino Sulejmanovic
Jun Qu
Xin He

Many others around ORNL and other collaborators at INL and other organizations



Financial Support from US DOE-NE Advanced Reactor Technology Program

This research used resources at the High Flux Isotope Reactor, a US DOE Office of Science User Facility operated by the ORNL

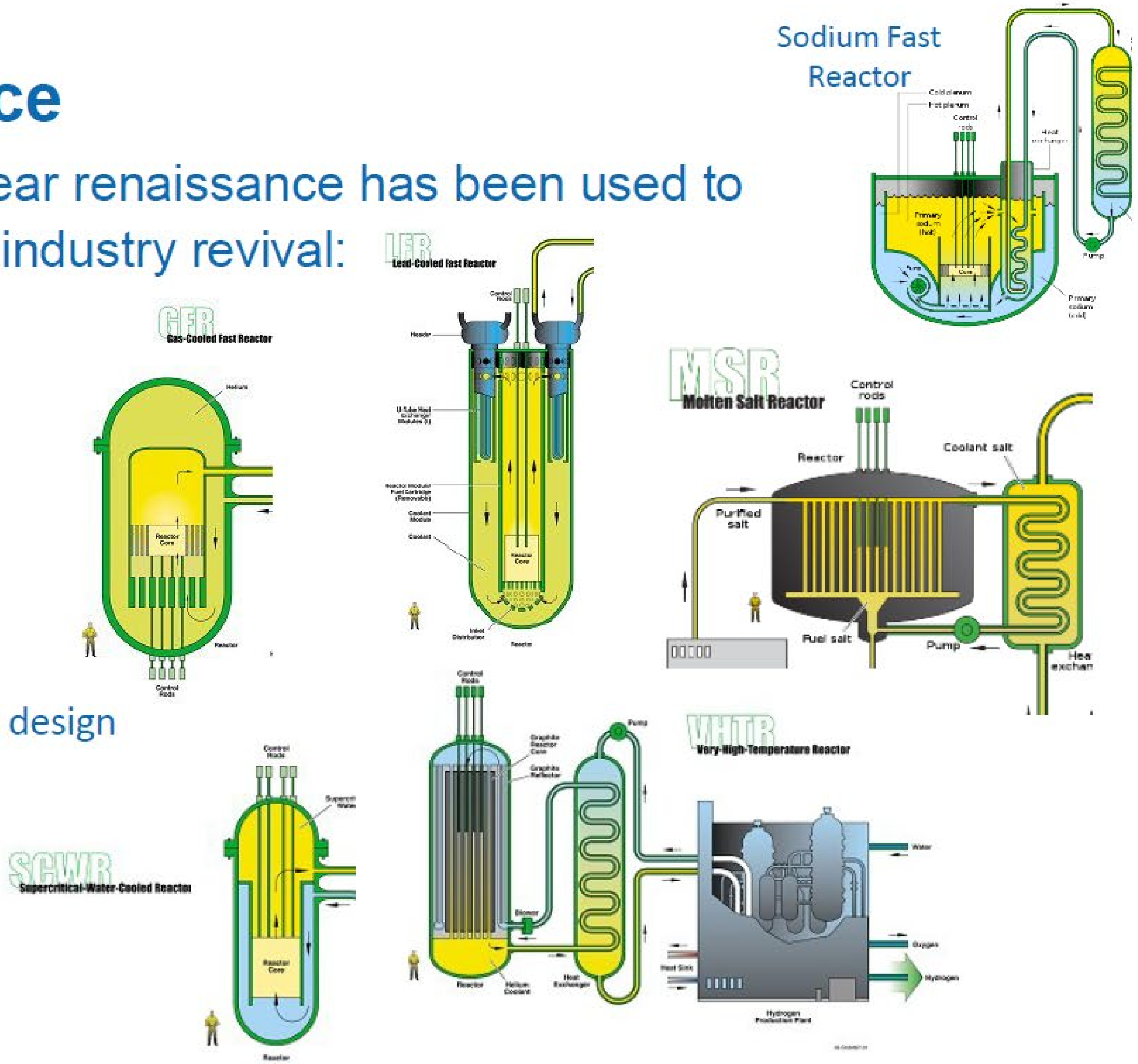
The Nuclear Renaissance

(Since about 2001) the term nuclear renaissance has been used to refer to a possible nuclear power industry revival:

- Rising fossil fuel prices
- Limiting greenhouse gas emission

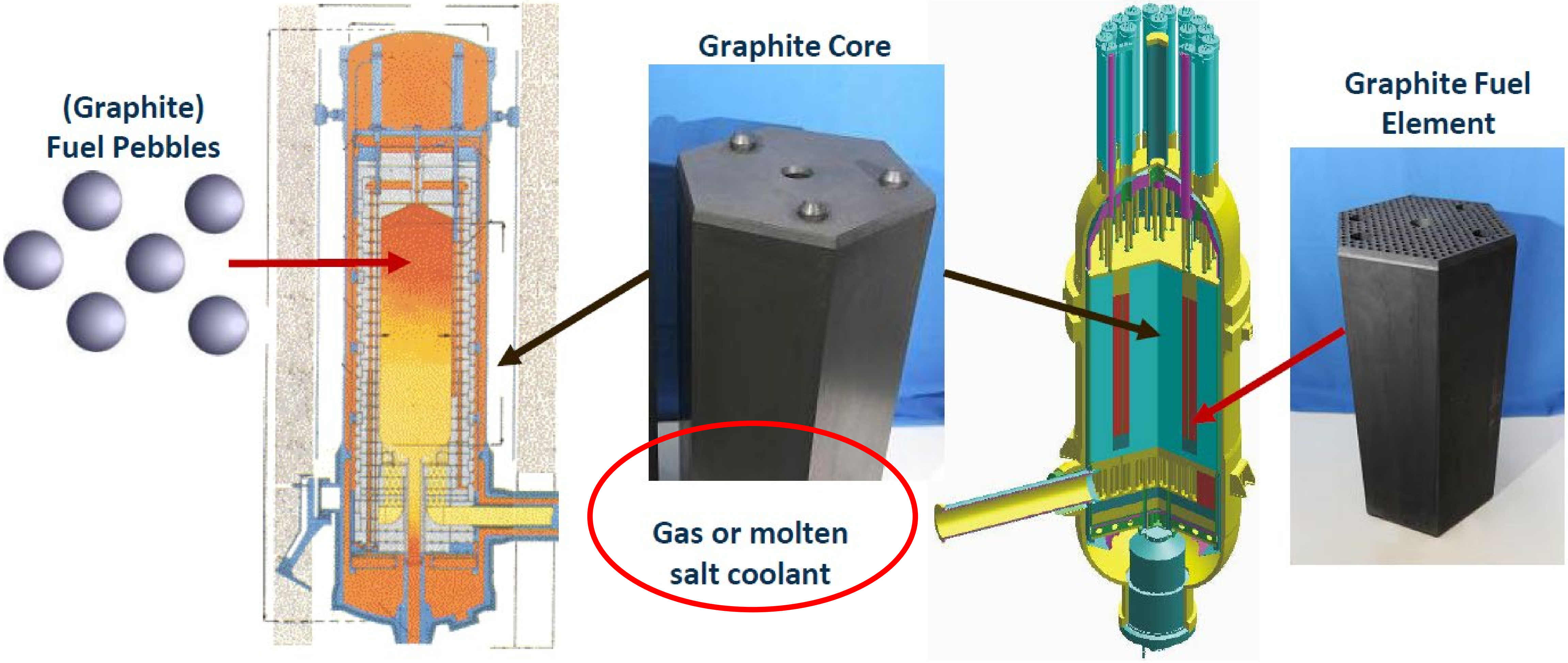
Generation IV reactor designs

- Inherently & Passively safe
  - Natural shutdown and cooling from design
- New designs = new uses
  - Process heat
  - Small modular designs
  - Variety of coolants and fuels



From Windes' Seminar

(Very) High Temperature Reactor (HTR)



(Graphite) Fuel Pebbles

Graphite Core

Graphite Fuel Element

Gas or molten salt coolant

Pebble Bed

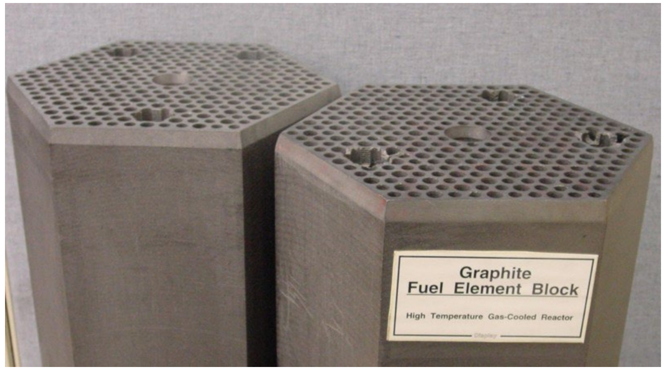
Prismatic

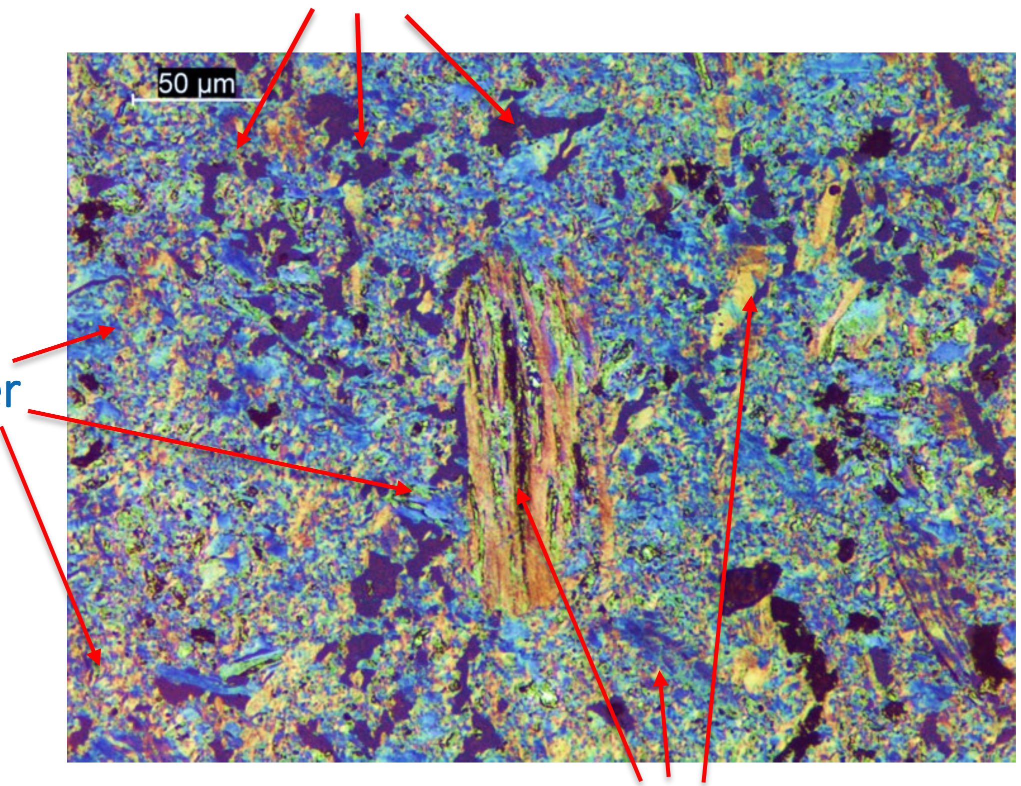
From Windes' Seminar

Outline

- Review of Nuclear Graphite and its Microstructure
- Graphite salt intrusion studies
  - Effect of temperature, pressure and time
  - Neutron imaging studies to understand salt penetration depth and distribution
  - Contact angle measurements for the development of predictive models
- Graphite wear behavior in molten salt
  - Wear behavior of graphite pin on stainless steel flat
  - Effect of temperature, sliding speed and environment.
- Summary and On-going Activities

Understanding Manufactured Graphite

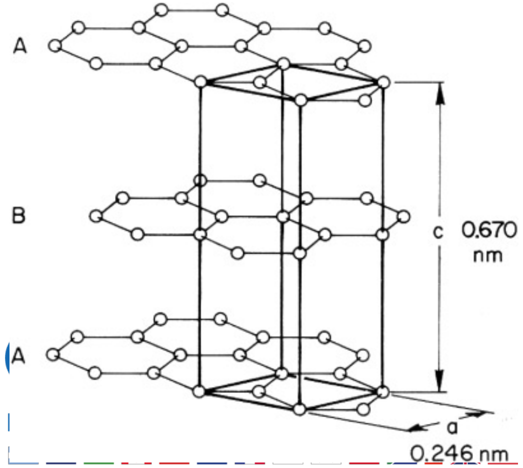


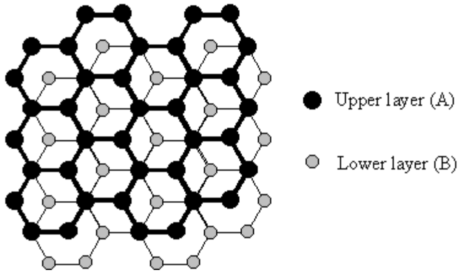


Pores

Pitch binder

Filler particles



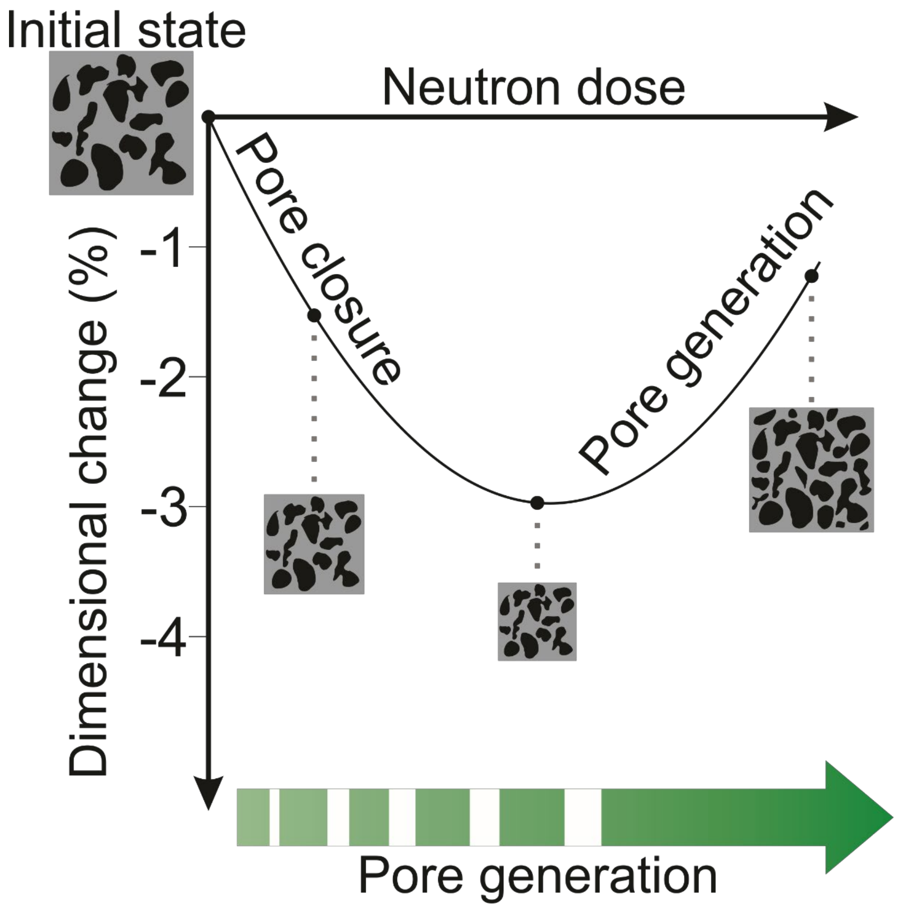


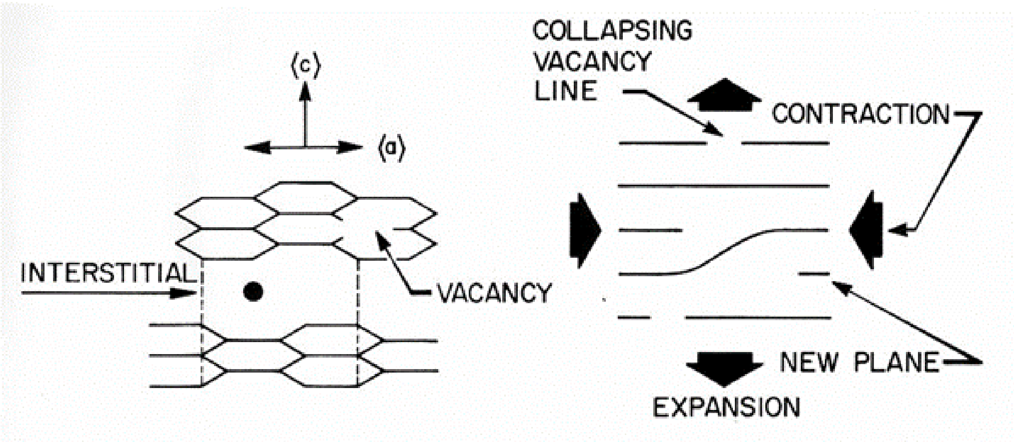
Manufactured Graphite has about **20 % porosity**

Why is porosity important in Graphite?

Microstructure and Porosity Defines the Properties and Irradiation Behavior of Graphite

- Graphite contains pores at multiple length scales
- Neutron irradiation affects the size of the porosity in graphite
- The irradiation effects on graphite contribute to the generation of new porosity
- Porosity (edge / basal sites) determines Reactivity
- Oxidation Rates Correlates with Edge Sites (Porosity)





What does Porosity in Graphite Mean to MSRs?

- Salt intrusion into pores?
- Effect of that salt intrusion on graphite properties? (mechanical, thermal)
- Chemical Interaction between salt and graphite?
- Edge sites for tritium retention?

One carbon 6 C 12.0107 Carbon … many graphites!

Porosity in graphite comes in different shapes, sizes and connectivity

One carbon, many graphite grades

Graphite classification according to ASTM D8075

				Country of origin	Irradiation data	Forming process	Availability
AGC-Campaign	**H-451**	Medium	1.71	SGL USA	Low dose	Extruded	🟥
	NBG-17	Medium-fine	1.86	SGL (Germany/ France)	Low dose	Vibro-molded	🟩
	NBG-18	Medium	1.87	SGL (Germany/ France)	Low dose	Vibro-molded	🟩
	PCEA	Medium-fine	1.79	GrafTech (USA)	Low dose	Extruded	🟨
	IG-110	Fine < 100	1.76	Toyo (Japan)	Low dose	Iso-molded	🟩
	IG-430 (dropped)	Fine < 100	1.80	Toyo (Japan)	Low dose	Iso-molded	🟨
	2114 (added)	Superfine < 50		Mersen (France-USA)	Low dose		🟩
MSRE	**CGB**	Medium	1.86	Union Carbide (USA)		Extruded	🟥
OTHER fine grain graphites	**POCO-ZXF-5Q**	Microfine < 2	1.78	USA	Low dose	Iso-pressing	🟩
	POCO-AXF-50	Ultrafine < 10	1.78	USA	Low dose	Iso-pressing	🟩
	POCO-TM	Ultrafine < 10	1.82	USA	Few data	Iso-pressing	🟩
	G347A	Ultrafine < 10	1.85	Tokai (Japan)	High dose	Iso-pressing	🟩
	IGS743NH	Superfine < 50	1.80	Nippon (Japan)	Low dose	Iso-molded	🟩
	ETU-10	Superfine < 50	1.74	Ibiden (Japan)			🟩

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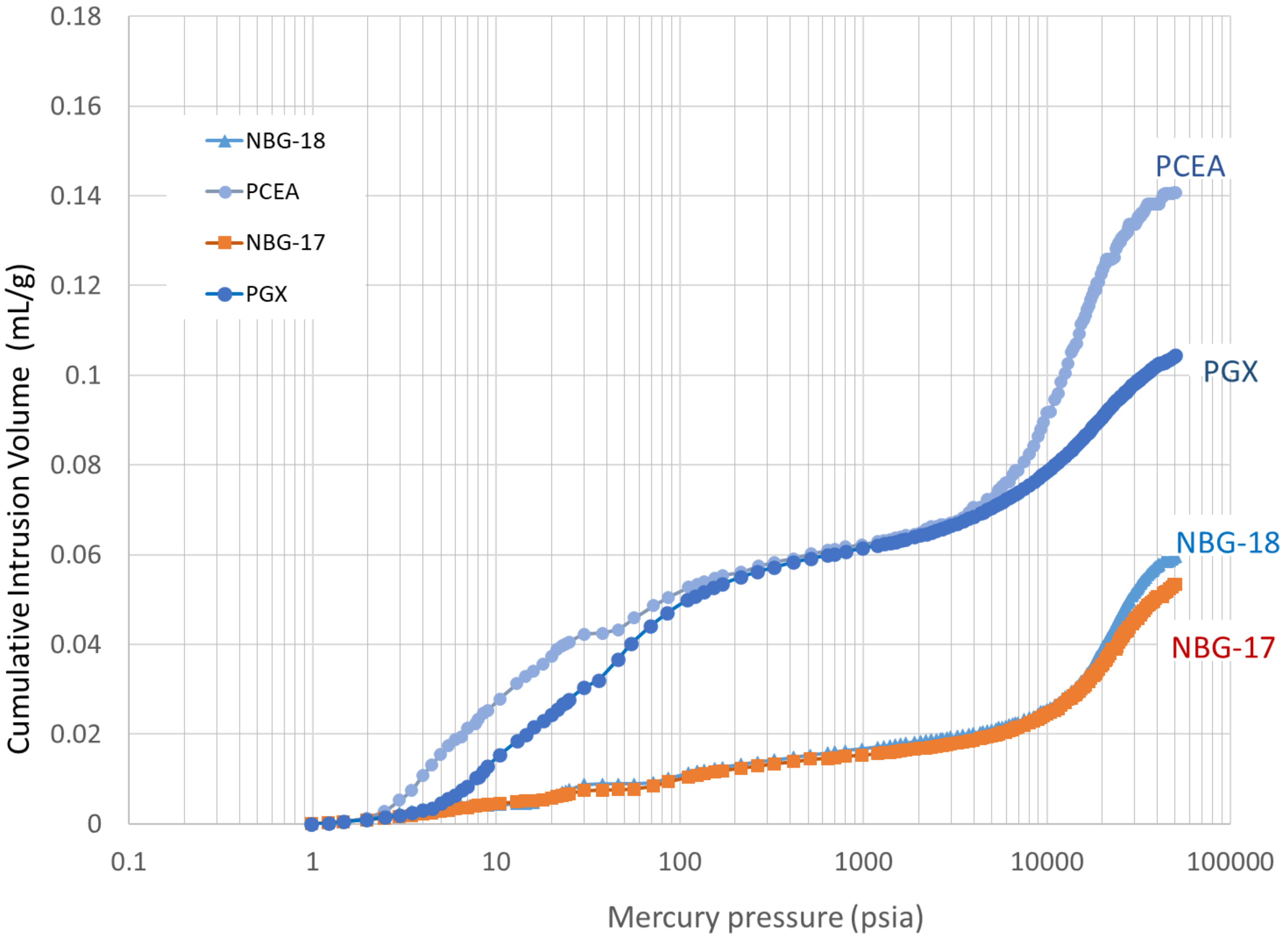
Mercury intrusion showed a wide range of porosity distributions in nuclear graphite

- Fine grade graphites showed a sharp uptake after a given threshold pressure
- Medium and large grain graphites showed a continuing uptake over the whole pressure range



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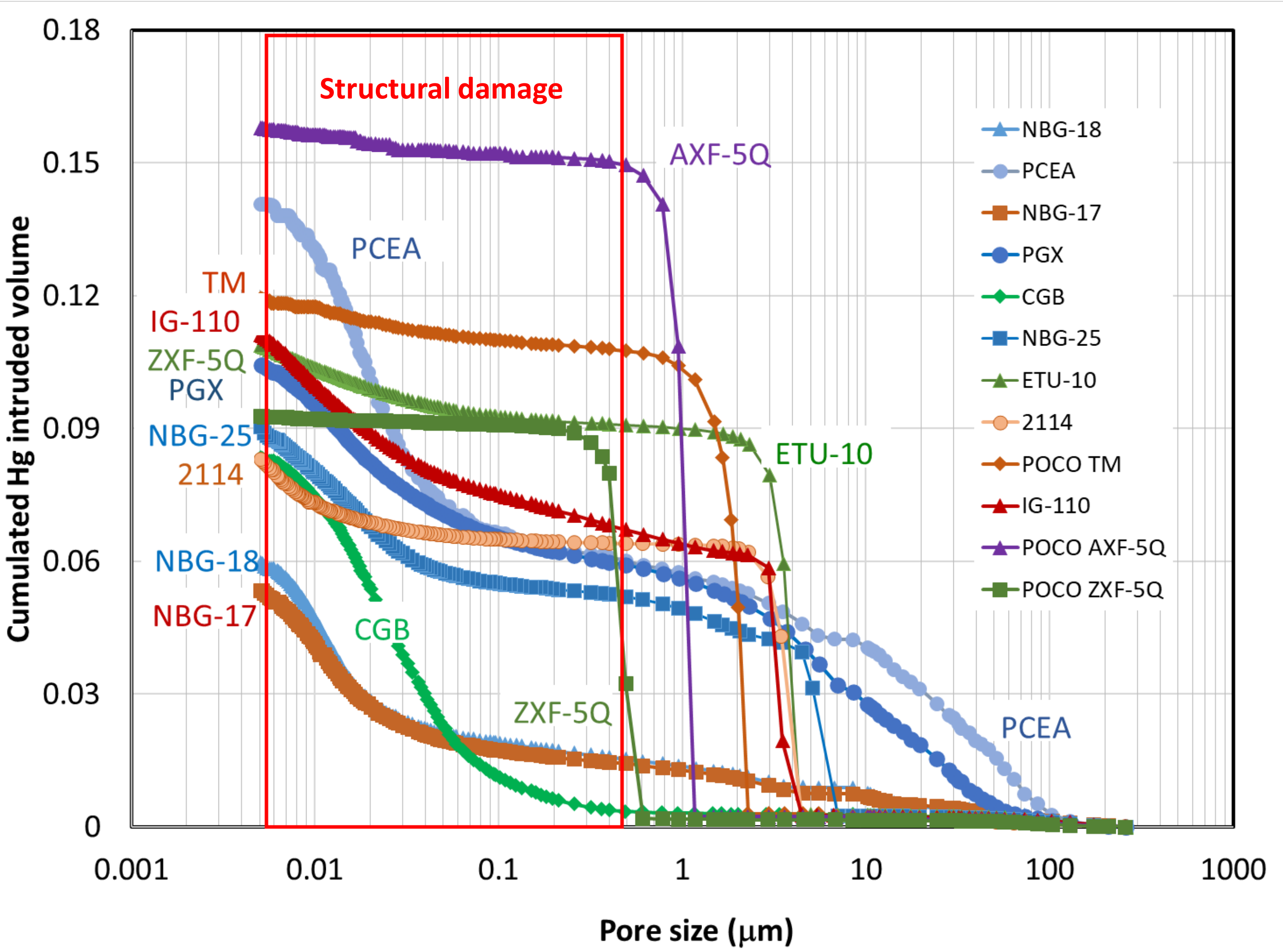
Pore size distribution from mercury intrusion porosimetry

Washburn eq.

$$D_P = -\frac{4\,\sigma\cos\theta}{P}$$



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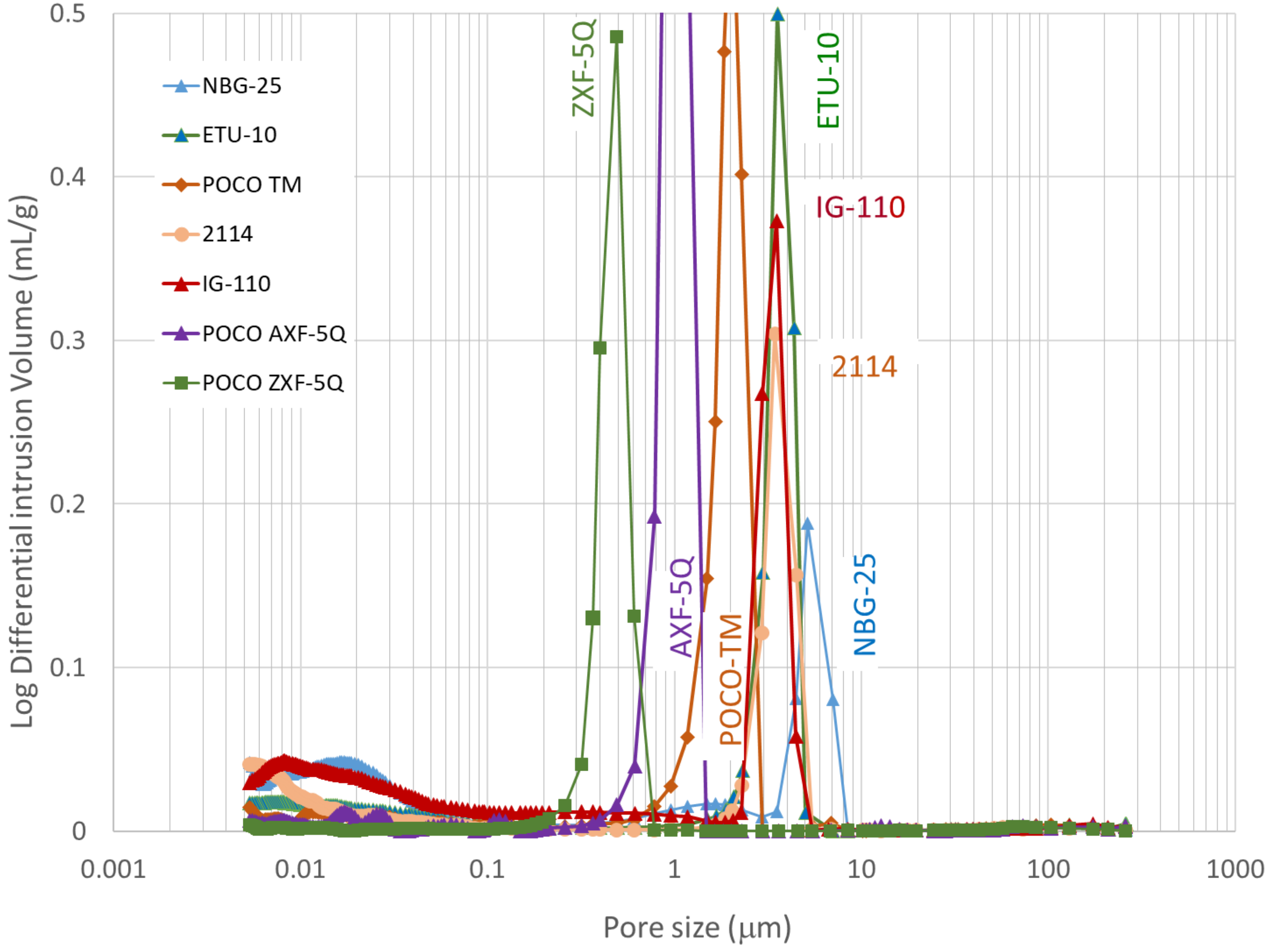
Pore size distribution from mercury intrusion porosimetry

Graphite grades	Grain size [µm]	Pore diameter [µm]
CGB	?	< 0.2
ZXF-5Q	1	0.5
AXF-5Q	5	0.9
TM	10	2
IG-110	10	3.9
2114	13	3.5
ETU-10	15	3.6
NBG-25	60	5.1
PGX	460	5.6 & 30
NBG-17	800	3 & 12 & 51
PCEA	800	64
NBG-18	1600	12



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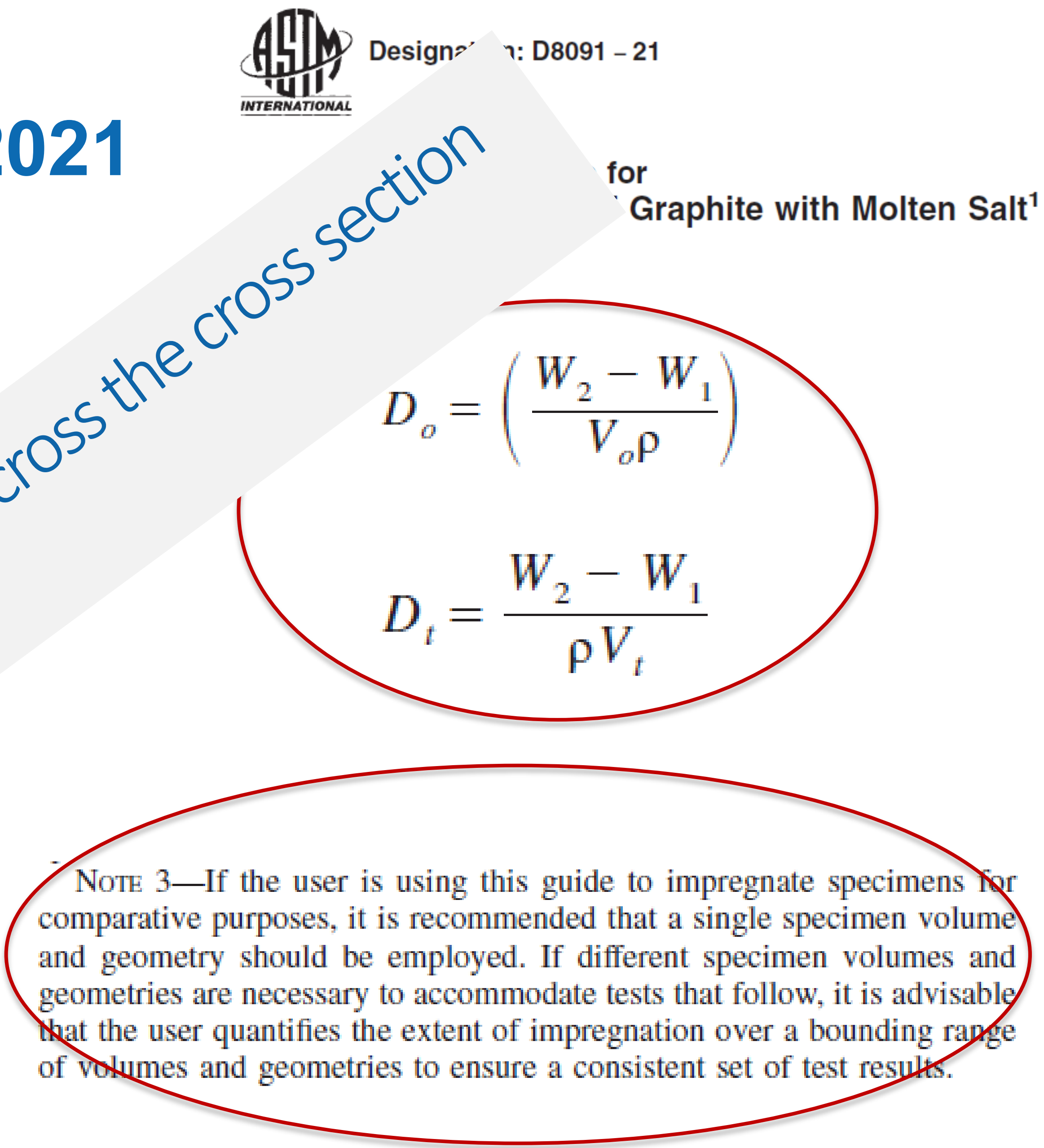
How to measure salt intrusion?

ASTM D8091-16 and revised in 2021

- Guideline for apparatus and procedure for producing graphite specimens impregnated with molten salts
- Introduces two quantification parameters f intrusion:
  - Fraction of *open pore* volume intrud
  - Fraction of *total pore* volume int
- Guide does not specify sa or size
- Guide does not s conditions

How about salt distribution across the cross section of the sample?



Designa n: D8091 – 21

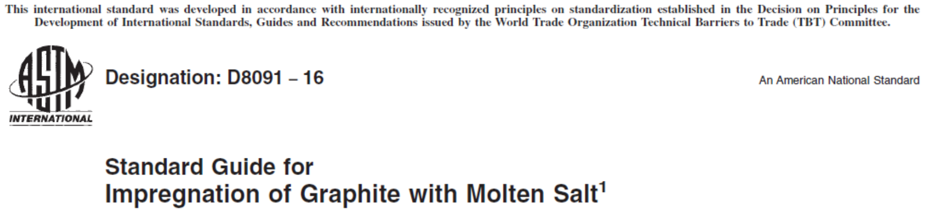
for Graphite with Molten Salt[1]

$$D_o = \left(\frac{W_2 - W_1}{V_o \rho}\right)$$

$$D_t = \frac{W_2 - W_1}{\rho V_t}$$

NOTE 3—If the user is using this guide to impregnate specimens for comparative purposes, it is recommended that a single specimen volume and geometry should be employed. If different specimen volumes and geometries are necessary to accommodate tests that follow, it is advisable that the user quantifies the extent of impregnation over a bounding range of volumes and geometries to ensure a consistent set of test results.

ORNL’s Salt Intrusion System

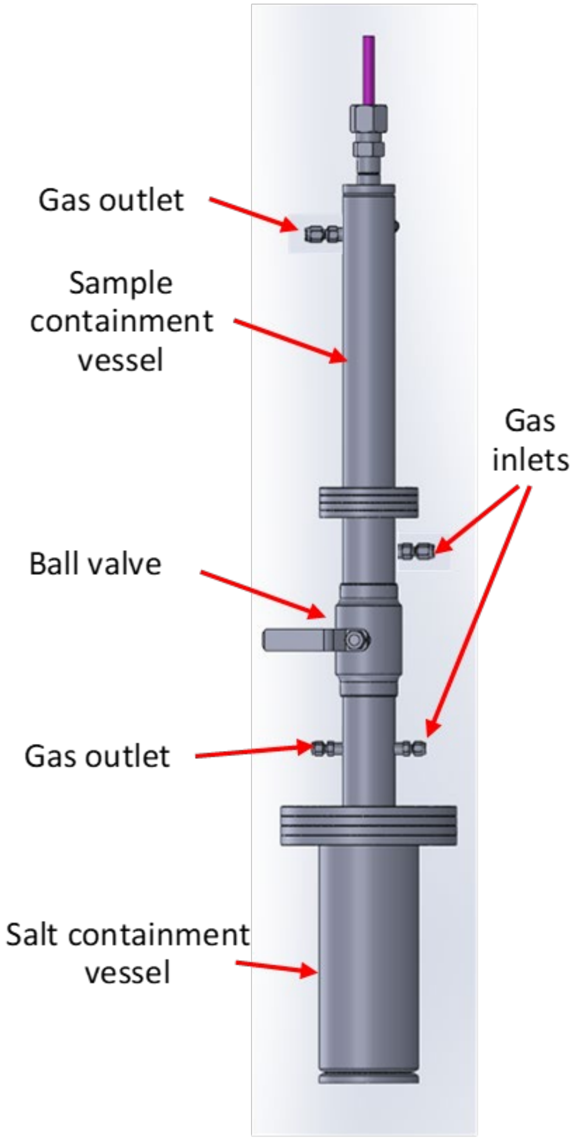


This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

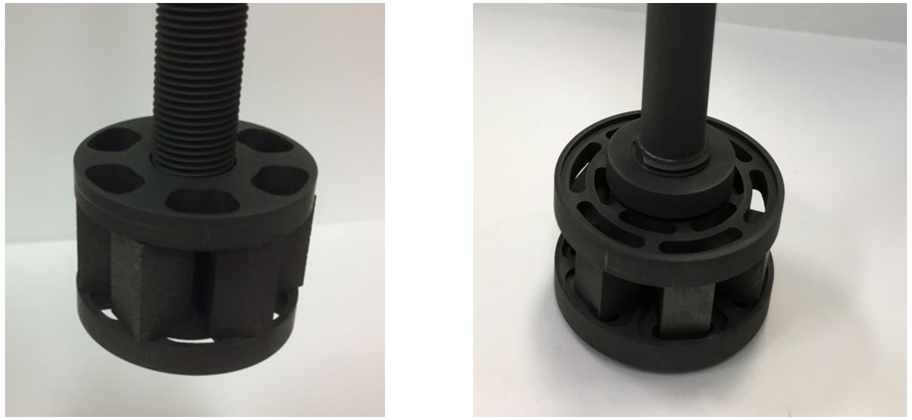
Designation: D8091 – 16

An American National Standard

Standard Guide for
Impregnation of Graphite with Molten Salt[1]



- Designed and built high pressure salt intrusion testing system (approved for FLiNaK)
- The system is designed for operation at temperatures up to 750°C and pressures up to 10 bar
- It includes an all-graphite holder that can accommodate up to six samples
- Includes in-situ vacuum of samples prior to salt intrusion, and cooling under gas pressure after removing from salt

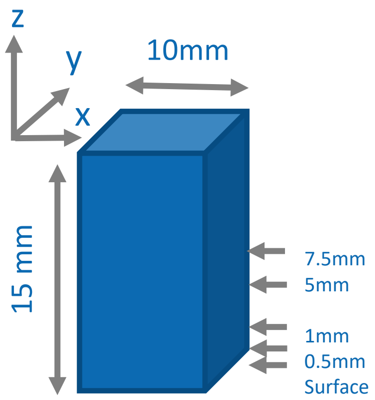


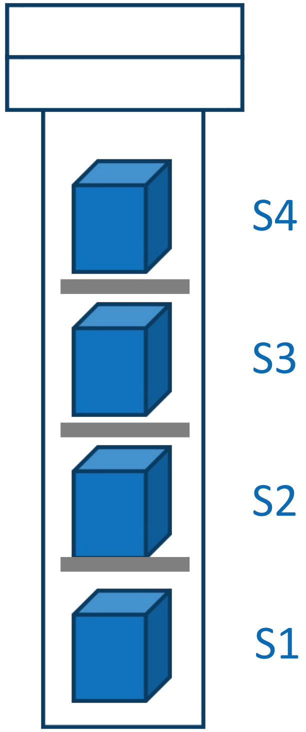
Neutron imaging enables the visualization of salt within the graphite

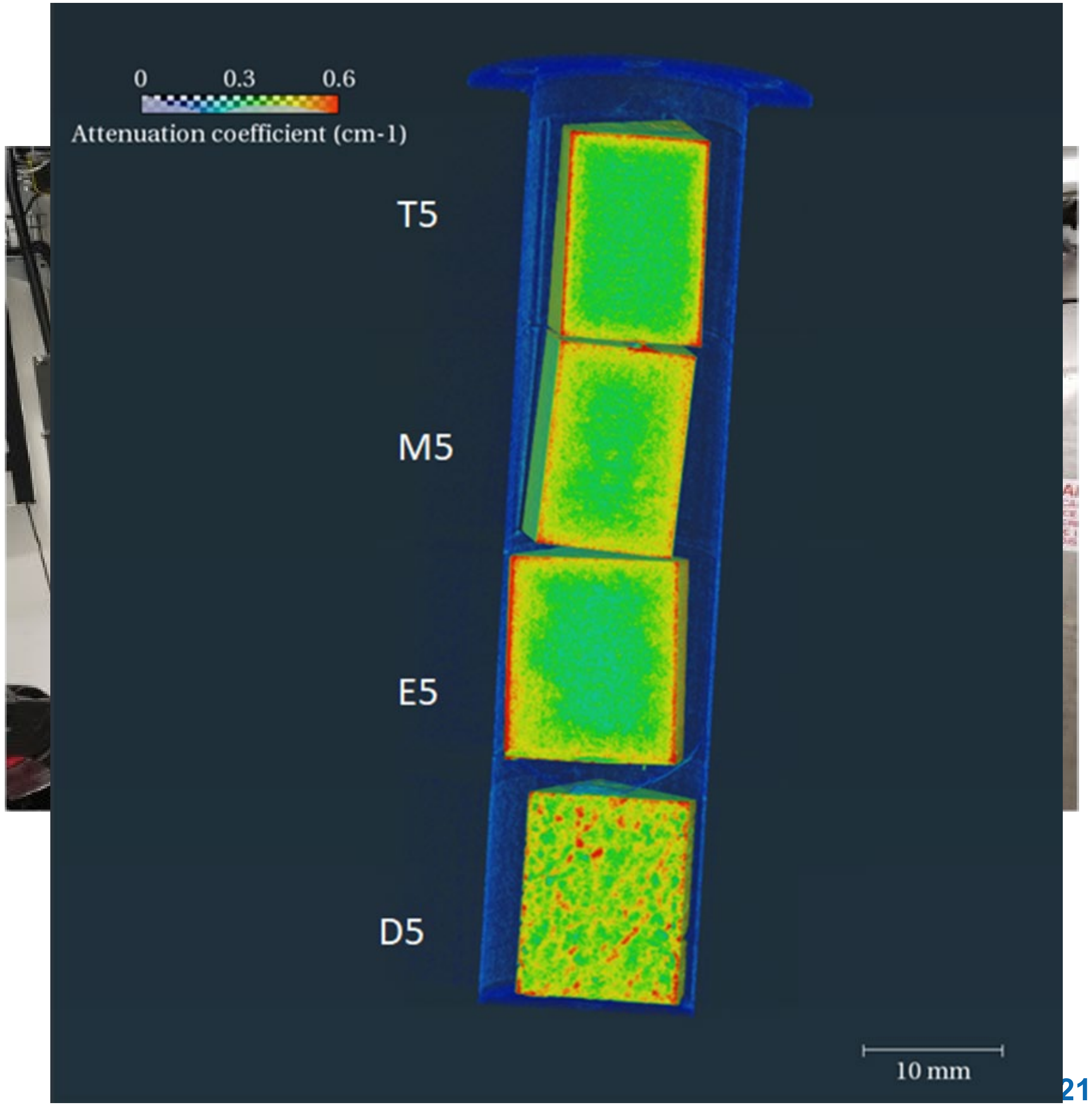
- Proof of principle experiment at Neutron Imaging Beamline CG-1D (ORNL’s HFIR)
- Image resolution ~ 75 µm

FLiNaK impregnated graphite samples

- **P: 5 bar**
- **T: 750C**
- **t: 12 hours**





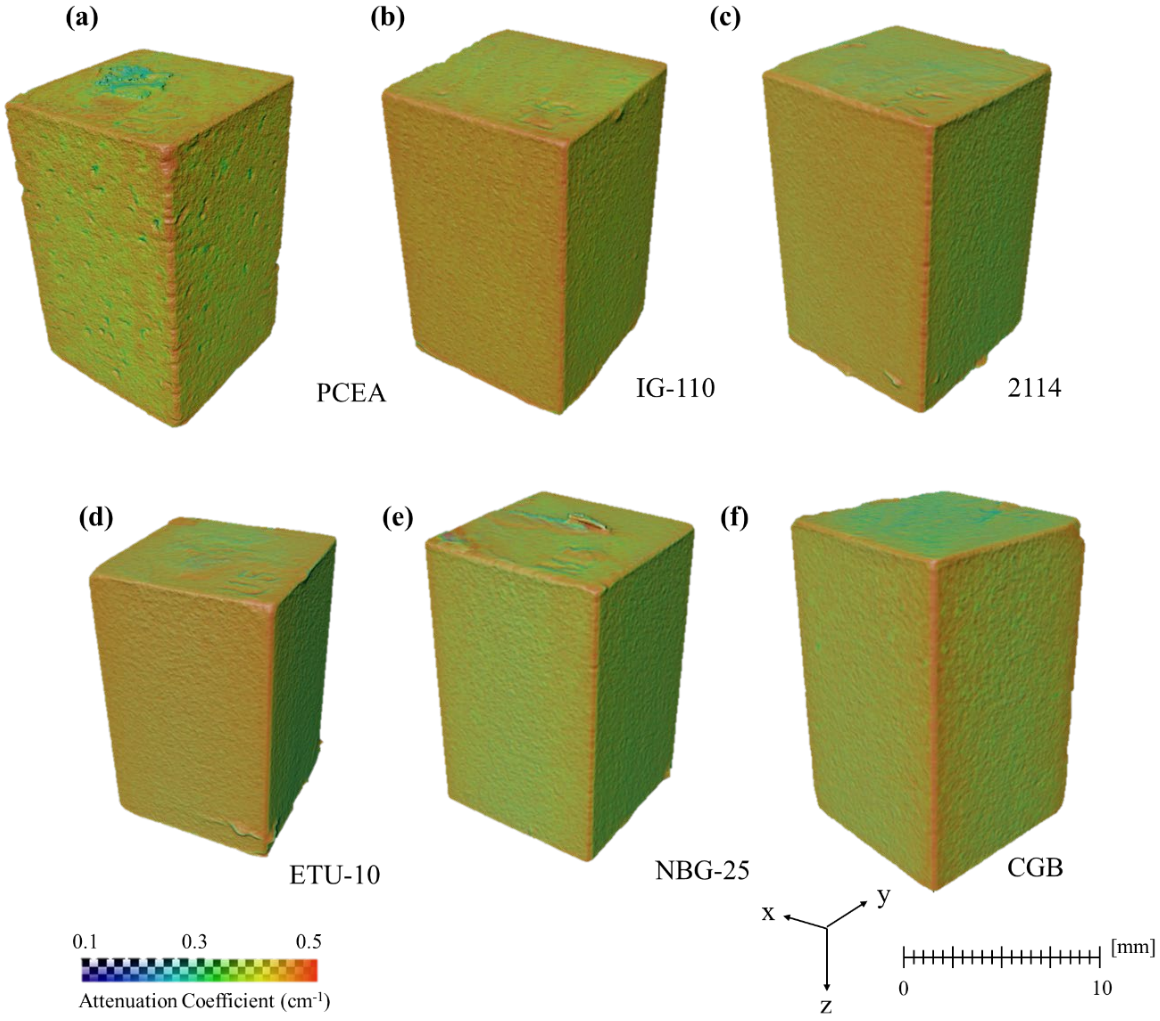


3D reconstructed images of the graphite samples after FLiNaK intrusion

FLiNaK impregnated graphite samples

- **P: 5 bar**
- **T: 750C**
- **t: 12 hours**

Moon, Gallego, et al. . Submitted for publication



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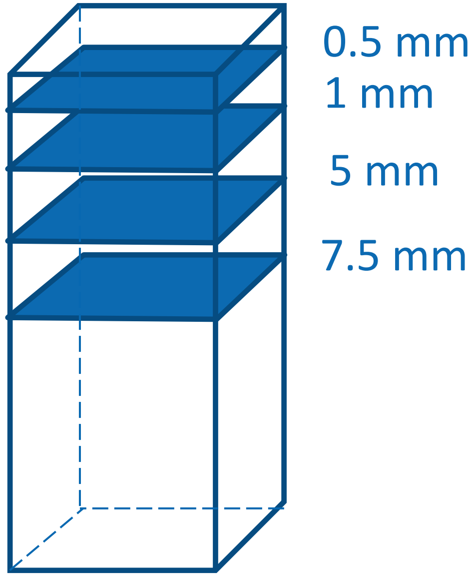
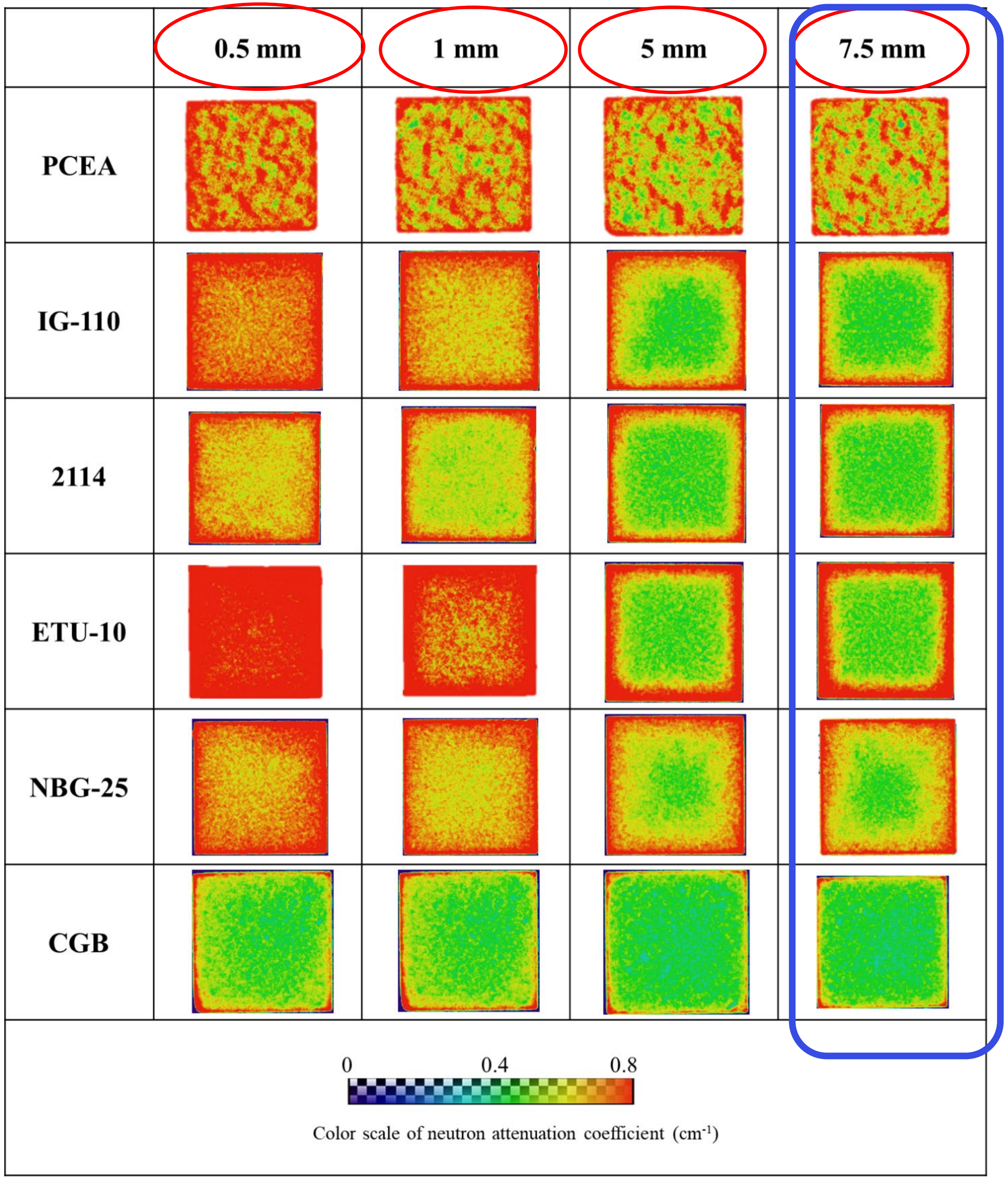
Neutron attenuation coefficient maps

- Neutron imaging planes at various locations allows the understanding of the salt distribution within the graphite sample.

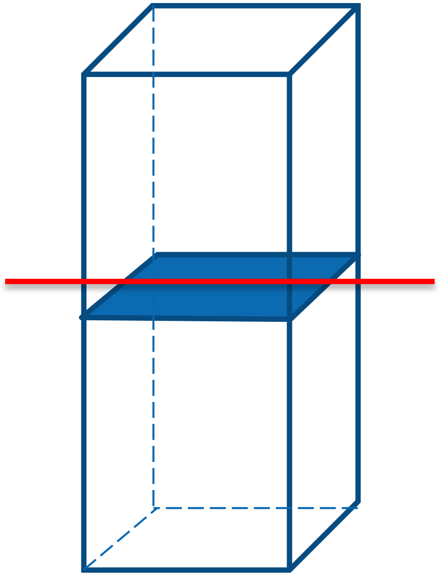


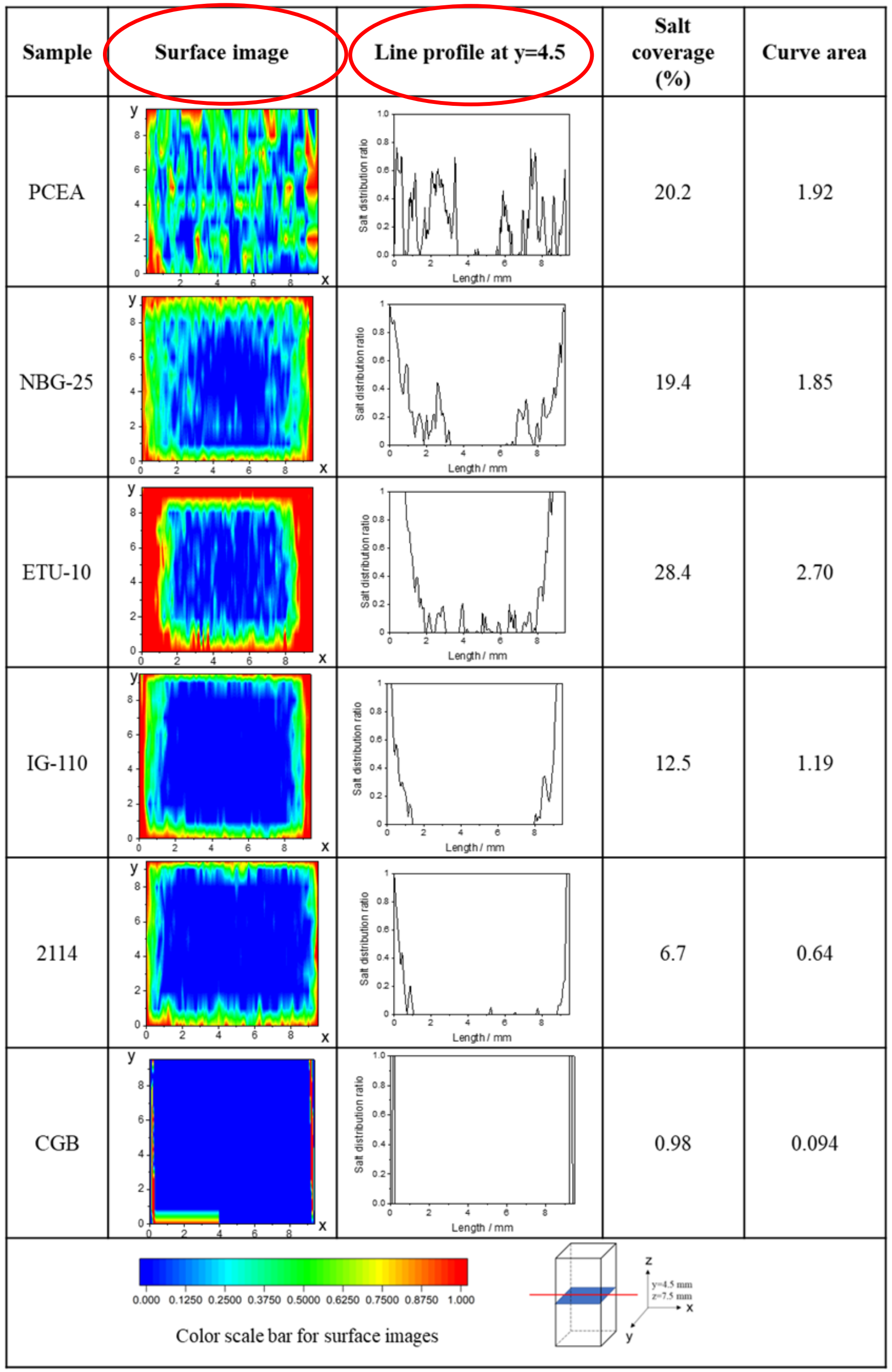


Color scale of neutron attenuation coefficient (cm^{-1})

Coverage maps

- Attenuation coefficient maps can be converted to coverage maps utilizing sample properties before and after intrusion.





Sample	Surface image	Line profile at y=4.5	Salt coverage (%)	Curve area
PCEA			20.2	1.92
NBG-25			19.4	1.85
ETU-10			28.4	2.70
IG-110			12.5	1.19
2114			6.7	0.64
CGB			0.98	0.094

Color scale bar for surface images

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A neutron tomography study to visualize fluoride salt (FLiNaK) intrusion in nuclear-grade graphite

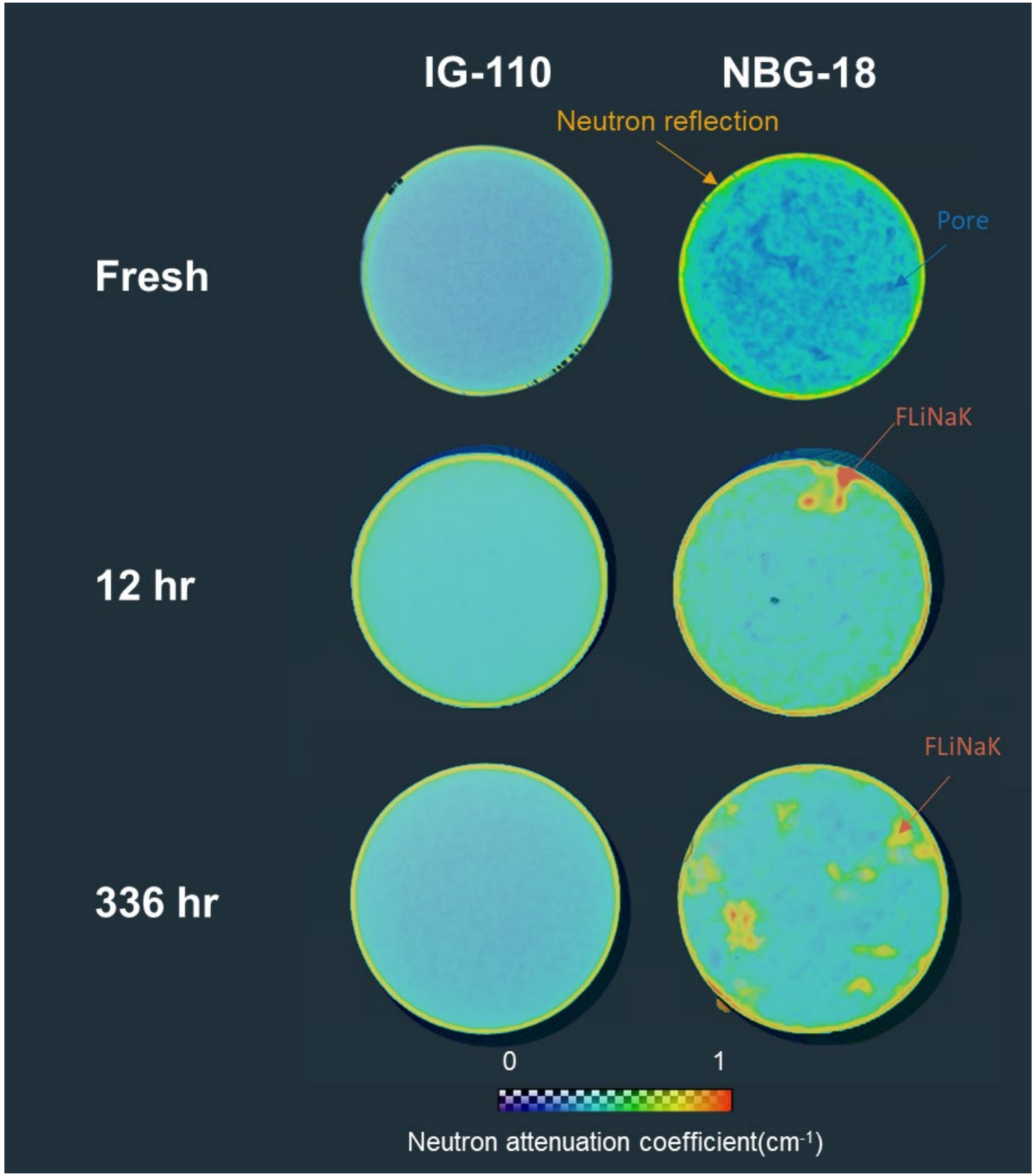
Under review

Jisue Moon[1*], Nidia C. Gallego[2*], Cristian I. Contescu[2], James R. Keiser[3], Dino Sulejmanovic[3], Yuxuan Zhang[4] and Erik Stringfellow[4]

How about time?

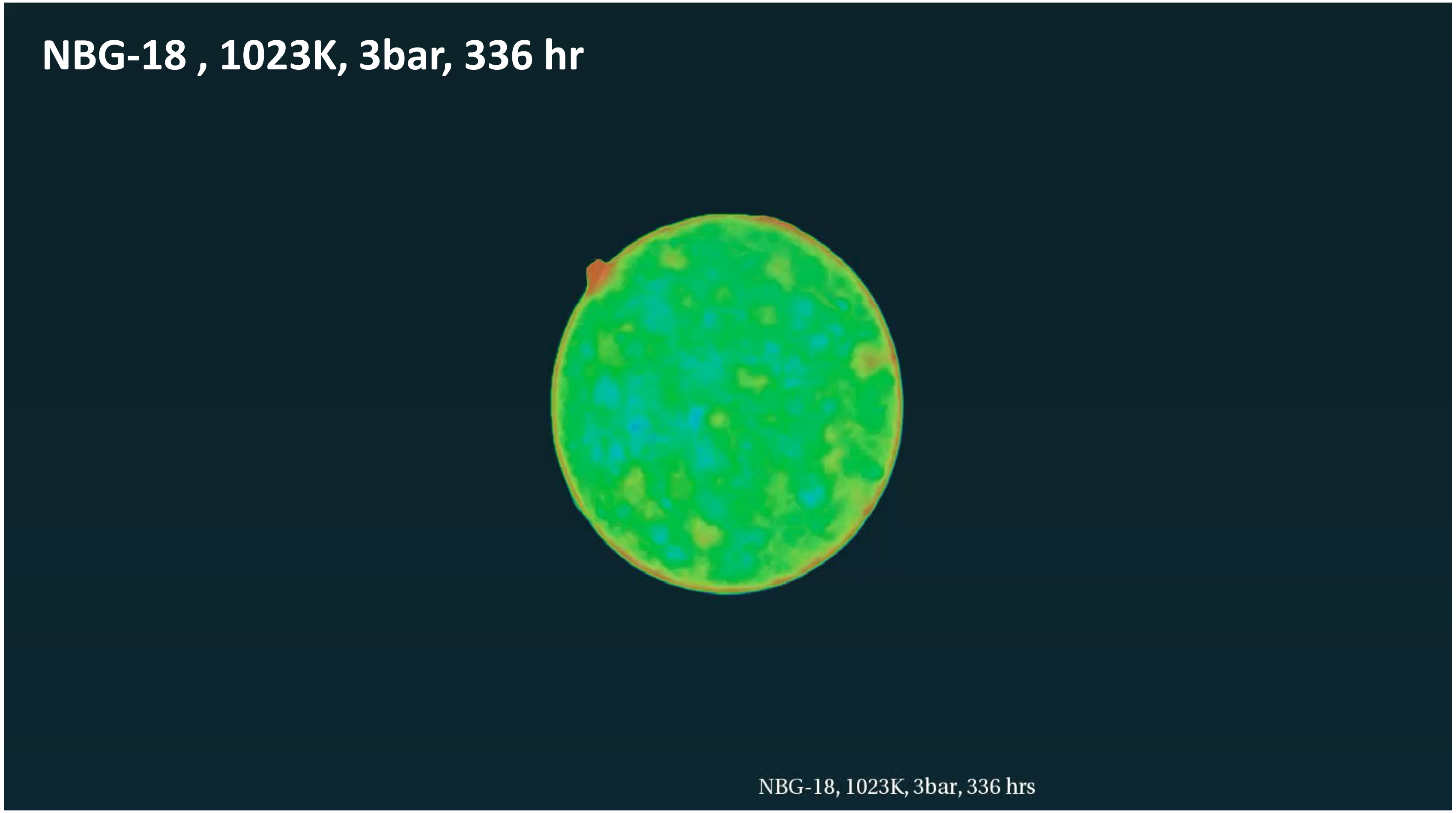
Neutron tomography analysis with different infiltration time

- Graphite sample: cylinders of 10 mm (diameter) X 20 mm (height)
- Infiltration time: 12 hr vs. 336 hr (2 week)
- For fine graphite, there is no evidence of infiltration (both imaging and weight change)
- For coarse graphite, pores near the surface were filled with FLiNaK and the degree of the infiltration increased with time.
- FLiNaK impregnation conditions
  - **P: 3 bar**
  - **T: 750C**
  - **t: 12 hours or 336 hours (2 weeks)**



Preliminary Results

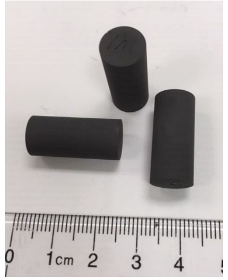
- Intrusion Conditions:
- P: 3 bar ;
- T: 750ºC;
- 336 hrs


NBG-18 , 1023K, 3bar, 336 hr

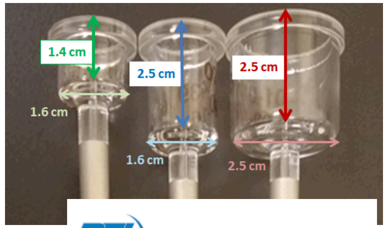
NBG-18, 1023K, 3bar, 336 hrs

Can we predict salt intrusion?

The Washburn equation may be used to study how salt might penetrate into graphite

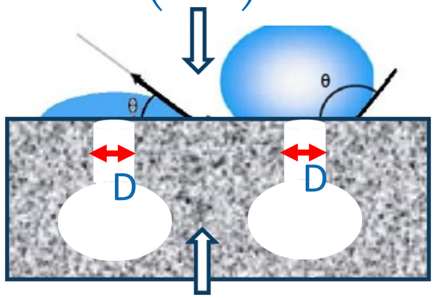


Penetrometer cells

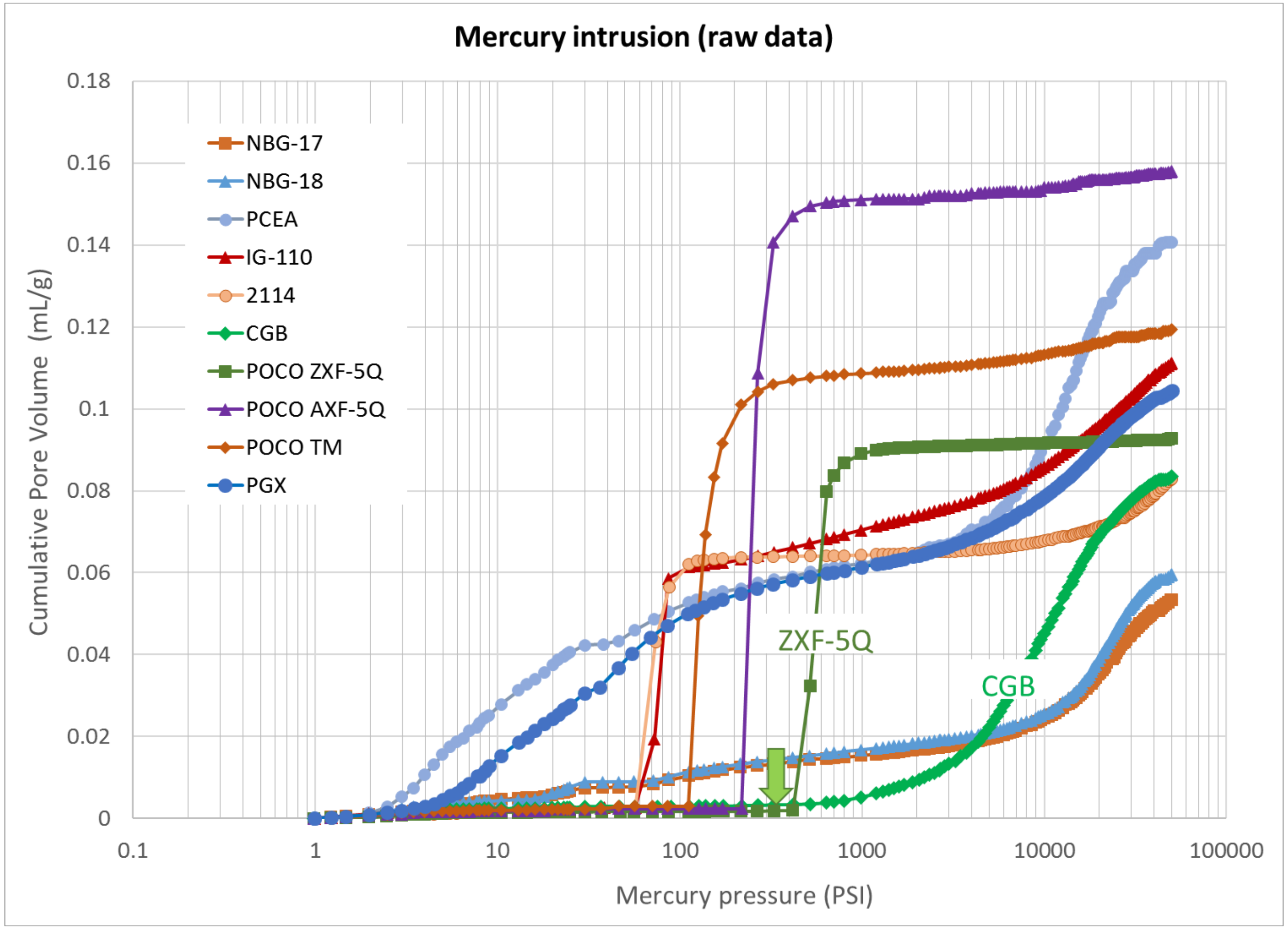


PTL Particle Technology Labs

$$\left(\frac{\pi D^2}{4}\right) * P$$



$$-\sigma * \cos(\theta)$$


Mercury intrusion (raw data)

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The Washburn equation

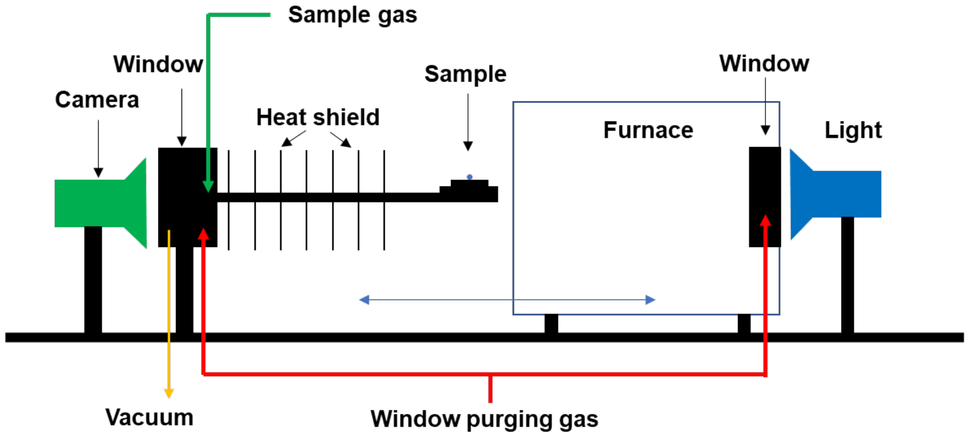
$$P = \frac{4\gamma}{d}\cos\theta\ .$$

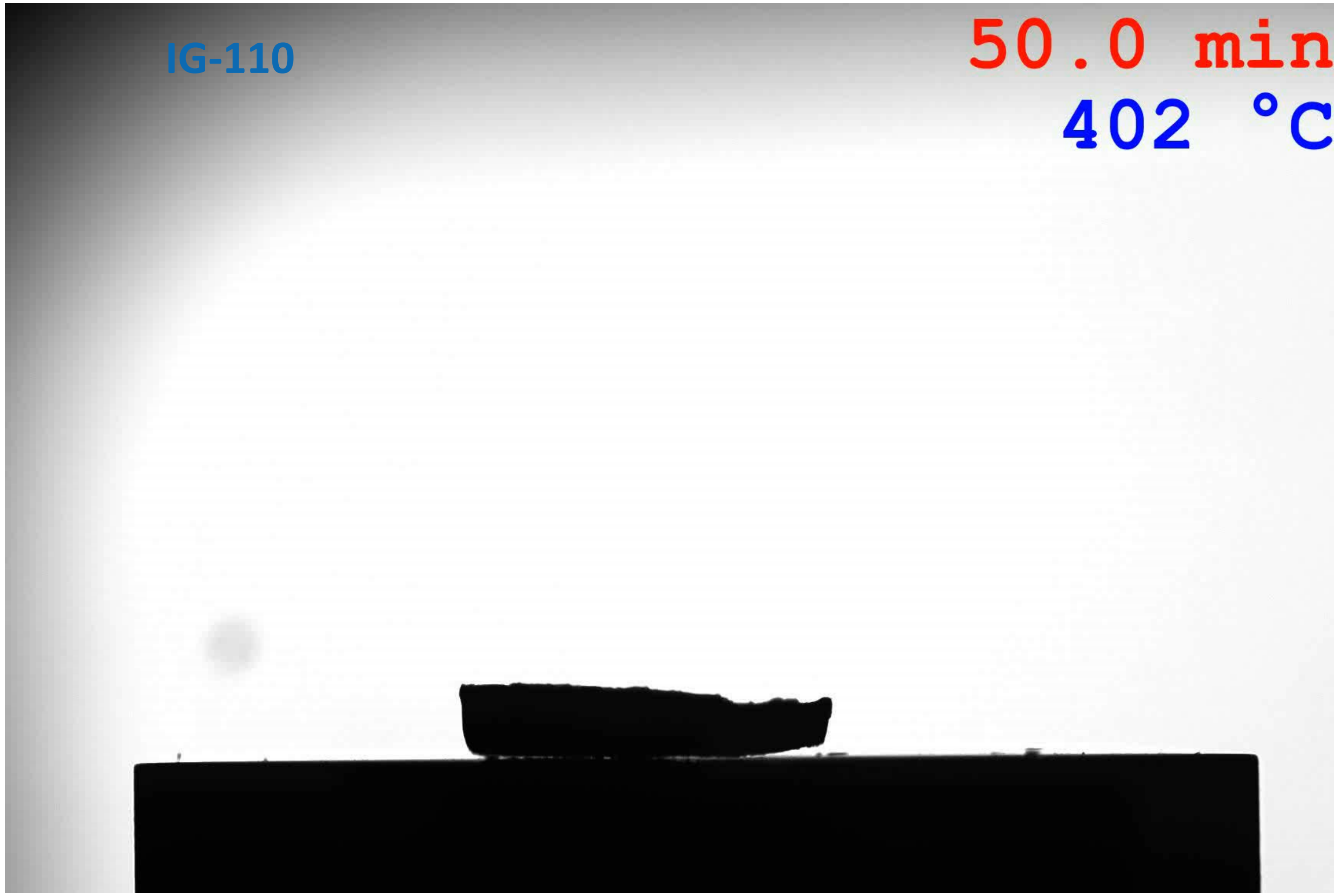
- Pressure differential (*P*) required to push a fluid into a capillary tube (assumed right cylinders) of diameter (*d*)

Fluid properties:

- Surface tension (γ) and
- Wetting angle (θ) at the solid-liquid interface

High temperature contact angle measurement





Contact angle measurement condition

- Salt : 3mm diameter salt(~8 mg)
- Graphite dimension: 10mm diameter with 2mm thickness

Salt properties

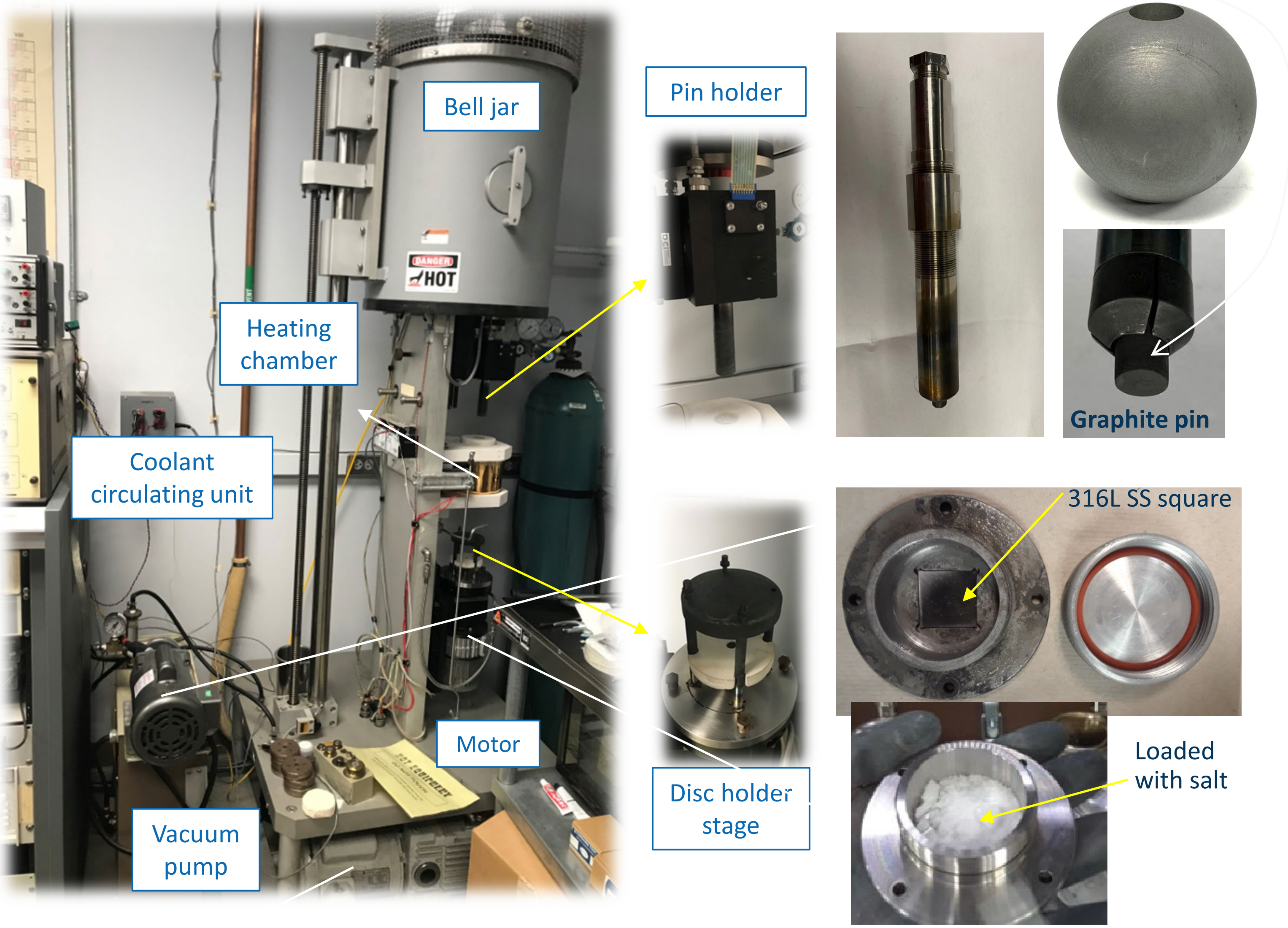
- FLiNaK Melting point 454 °C

Understanding wear properties of graphite in a molten salt

Feasibility Study of Graphite Wear Testing in Molten FLiNaK Salt

Experimental:

- Graphite pin sliding against 316L SS surface
- Salt: FLiNaK
- **Temperature: 550 & 650 ºC** (up to 1000 ºC)
- Gas environment: Ar
- Normal load: 20 N (up to 100 N)
- Rotating speed: 120 rpm (up to 1000 rpm)
- **Sliding speed: 1, 10 & 100 mm**/s
- Sliding distance: 1000 m (~2 hrs 30 mins)



Bell jar

Heating chamber

Coolant circulating unit

Motor

Vacuum pump

Pin holder

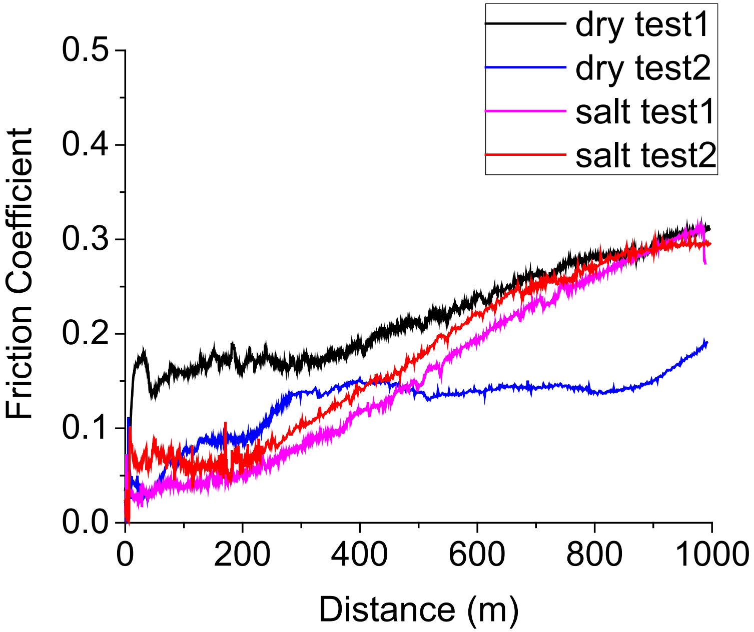
Graphite pin

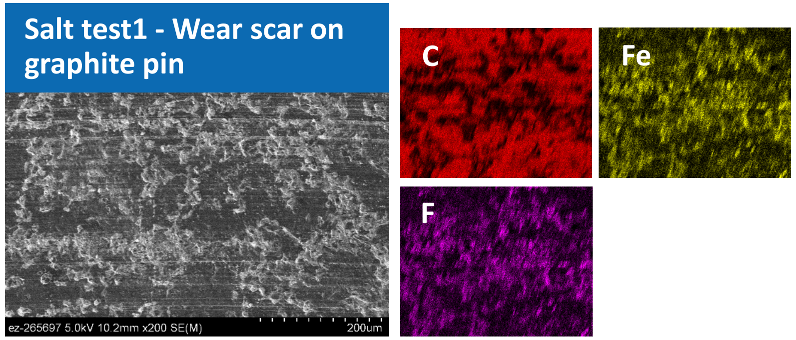
Disc holder stage

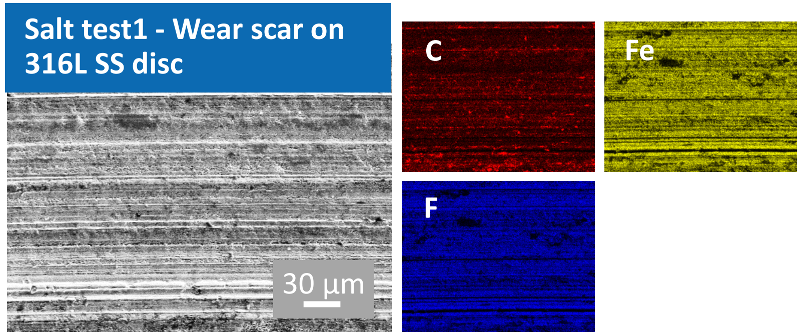
316L SS square

Loaded with salt

Initial friction and wear results of graphite pin sliding against 316L SS (Argon vs. molten FLiNaK salt)




Salt test1 - Wear scar on graphite pin


Salt test1 - Wear scar on 316L SS disc

Wear Volume (mm^3)	Dry testing (Argon)		Testing in FLiNaK Salt	
	Test1*	Test2	test1	Test2
Graphite pin	0.32	0.14	0.29	0.53
316L SS disc	*(0.02)*	*(0.01)*	0.11	0.07

"( )" represents volume increase or deposit (instead of wear loss)

**Dry test1 might have something wrong based on the surface morphology post test…*

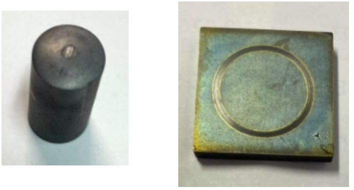
Observations:

- Molten FLiNaK appears to significantly increased wear losses of both the graphite pin and stainless steel disc.
- Mutual material transfer occurred between the graphite pin and 316L SS disc.
- Salt-reacted compounds were found on the graphite wear scar, possibly as a result of salt intrusion into graphite pores.
- Salt-reacted compounds were also found on the 316L SS worn surface, possibly as a result of tribocorrosion.

Test Matrix for graphite pebble pin sliding against 316H stainless steel (SS) disc in molten FLiNaK salt

Ar gas, 20 N	Sliding speed (mm/s) – constant test duration (10,000 sec)		
Temperature (°C)	**1**	**10**	**100**
650	(#3) No salt (Dry)		
	(#4) Molten salt flooded	(#6) Molten salt flooded	(#8) Molten salt flooded
	(#9) Molten salt starved		(#7) Molten salt starved
550	(#5) Molten salt flooded		

#3



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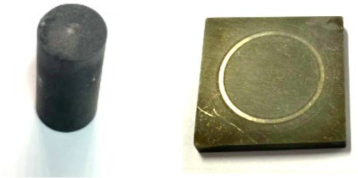

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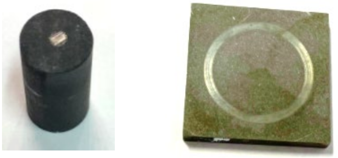

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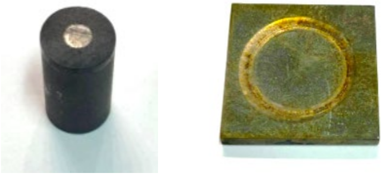

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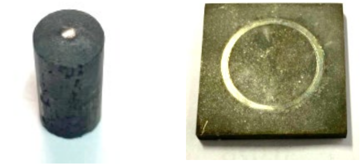
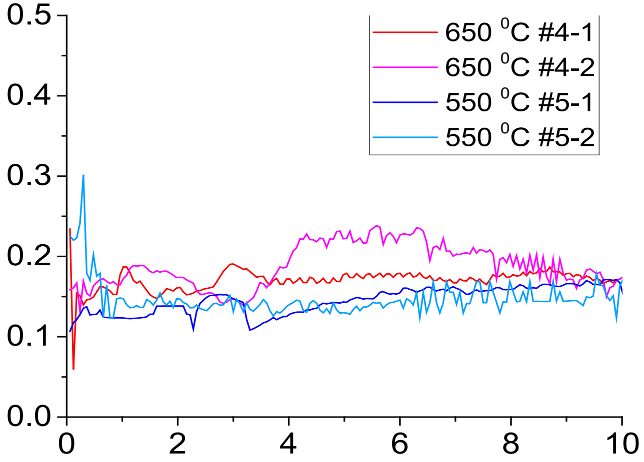
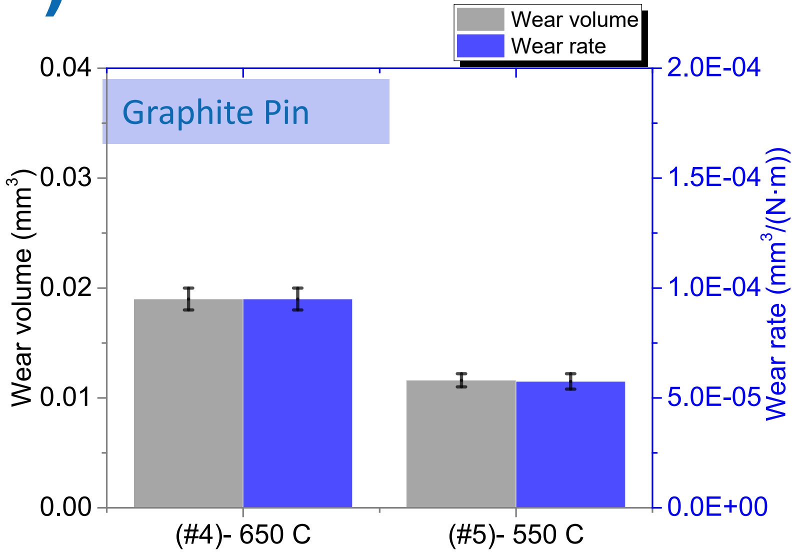


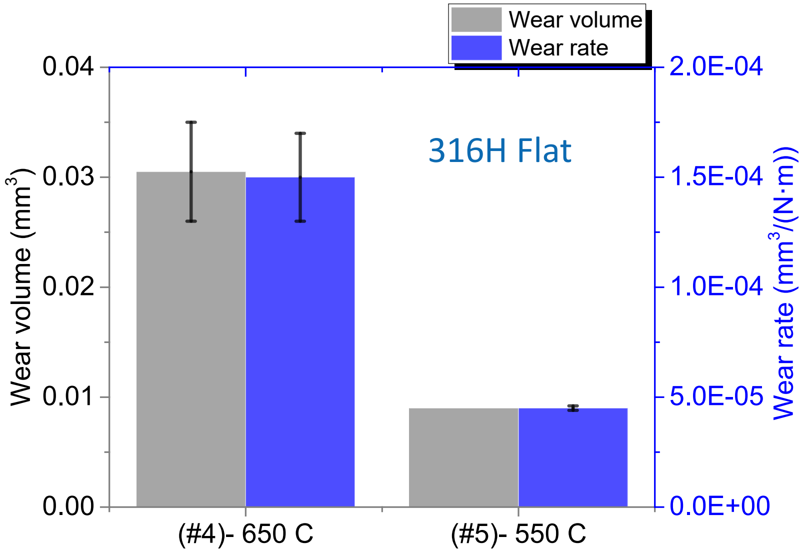
Effect of Temperature (@Speed = 1 mm/s)

Increased wear losses for both the graphite and 316H SS at a higher temperature with more pronounced change for SS:

- **Viscosity** of the molten salt is lower at a higher temperature, leading to poorer lubrication and thus more solid-solid contact;
- The salt **corrosion rate** on the 316H SS would increase at a higher temperature. On the other hand, the graphite pin is expected to have little corrosion because graphite is chemically inert in the molten salt;
- **316H SS is softened** (more prone to wear) but **graphite becomes stronger** (less prone to wear) at a higher temperature.

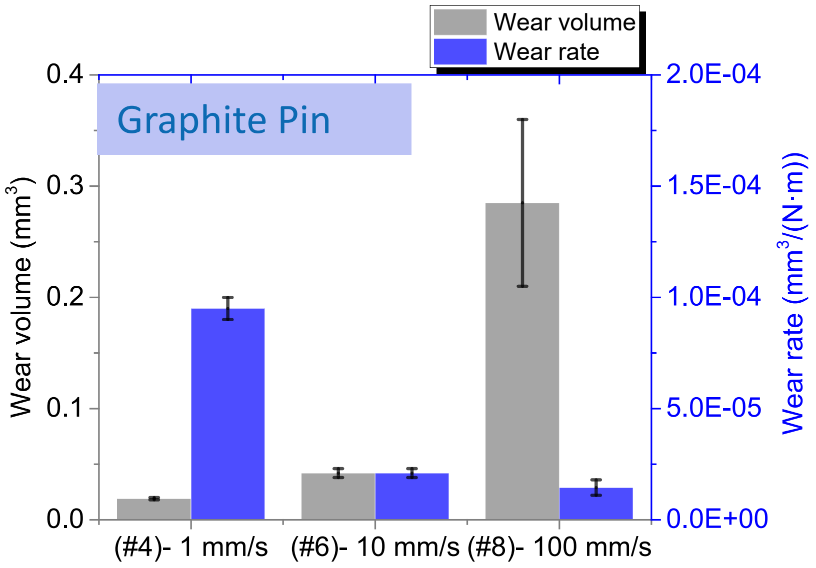


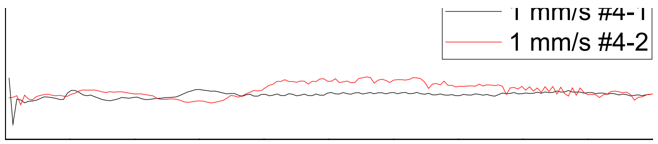


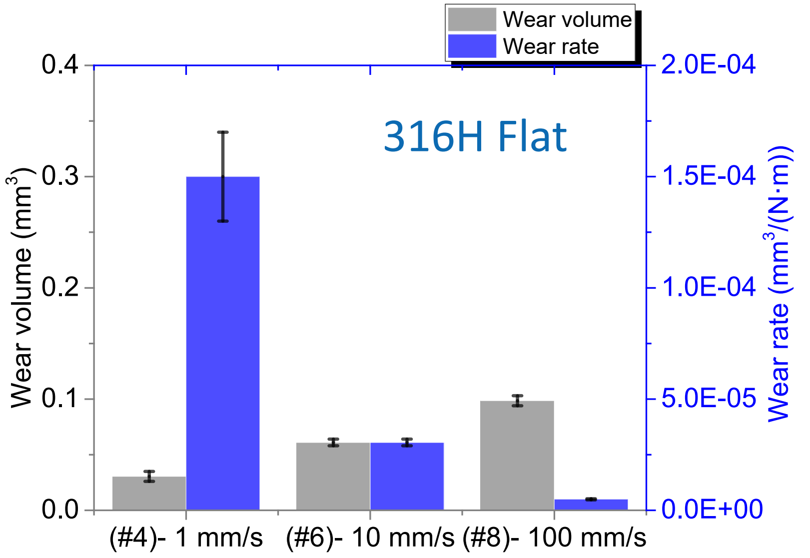


Effect of Sliding Speed

- **A higher speed generated a higher wear volume but a lower wear rate.**
  - A higher speed experienced a longer sliding distance but had a thicker lubricant film at the interface;
  - Running-in generally has a higher wear rate than steady-state because of reducing contact pressure as a result of enlarging contact area (wear scar).
- **Graphite pin wear was smaller at 1 mm/s, became similar at 10 mm/s, and larger at 100 mm/s in comparison with the SS flat wear.**
  - While both the graphite and SS experienced the vibration-induced impact, the brittle graphite is more prone to microfracture and consequently more wear loss when vibration becomes more intense at a higher sliding speed.



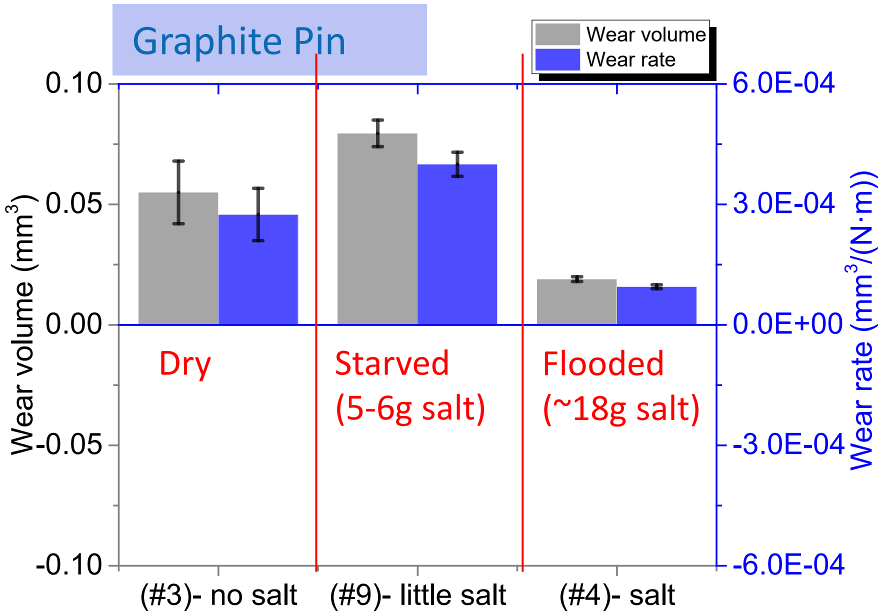


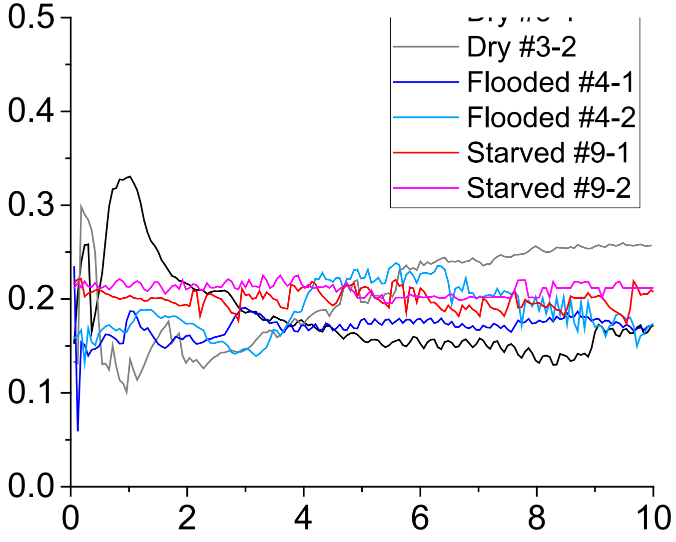


(@T = 650 °C)

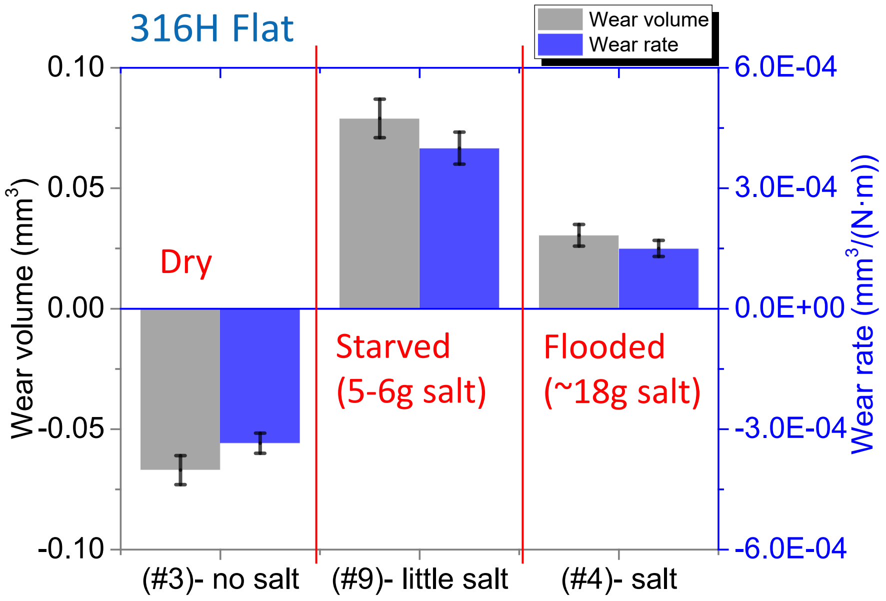
Effect of Salt Presence and Quantity

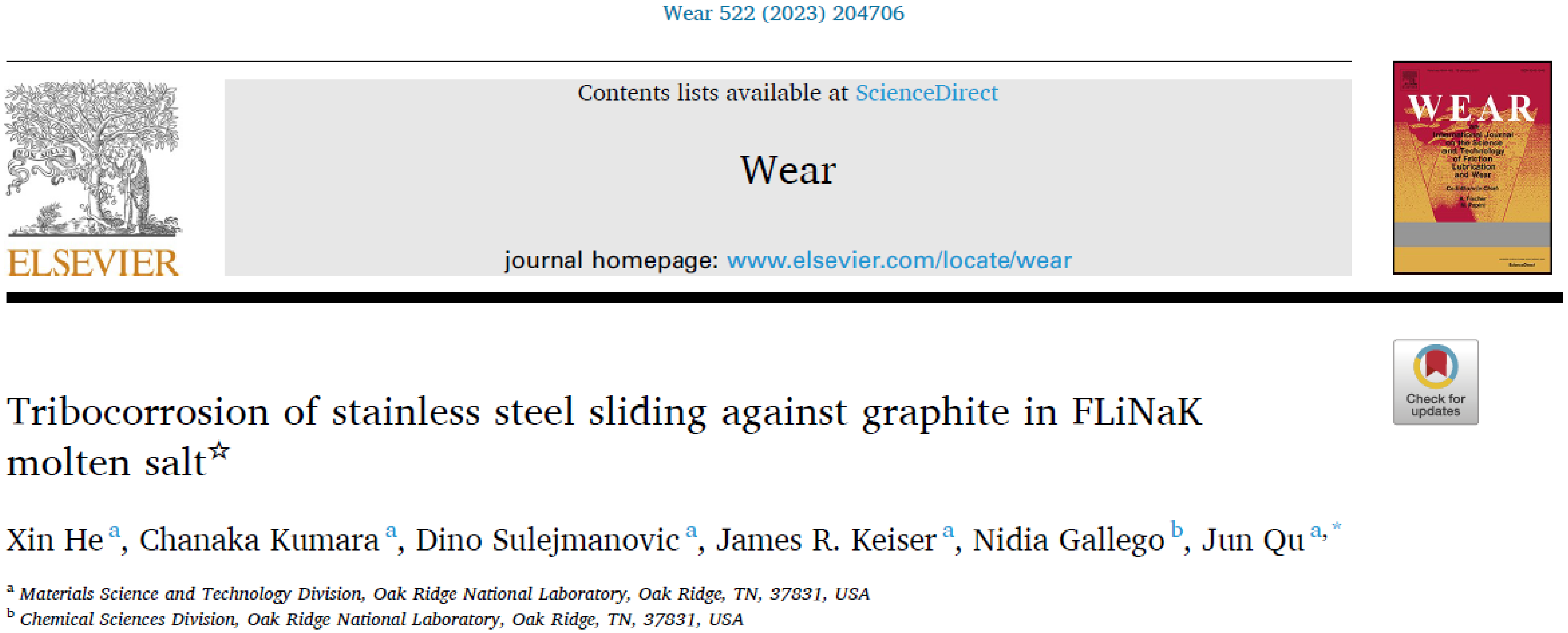
- **In dry sliding, graphite pin had wear loss but SS flat had deposition.**
    - Volume loss on the graphite pin was similar to volume gain on the SS flat.
- **Molten salt flooded lubrication reduced the graphite wear while made the SS have material removal rather than deposition.**
    - Flooded molten salt lubricated the contact interface to reduce material transfer or adhesive wear.
- **Molten salt starved lubrication generated much more wear on both graphite and SS than either dry or flooded lubrication.**
    - Limited molten salt prevented formation of a self-lubricating graphite transfer film but was unable to provide a stable protective lubricant film at the contact interface.





(@Speed = 1 mm/s & T = 650 ^{o}C)





Wear 522 (2023) 204706

Contents lists available at ScienceDirect

Wear

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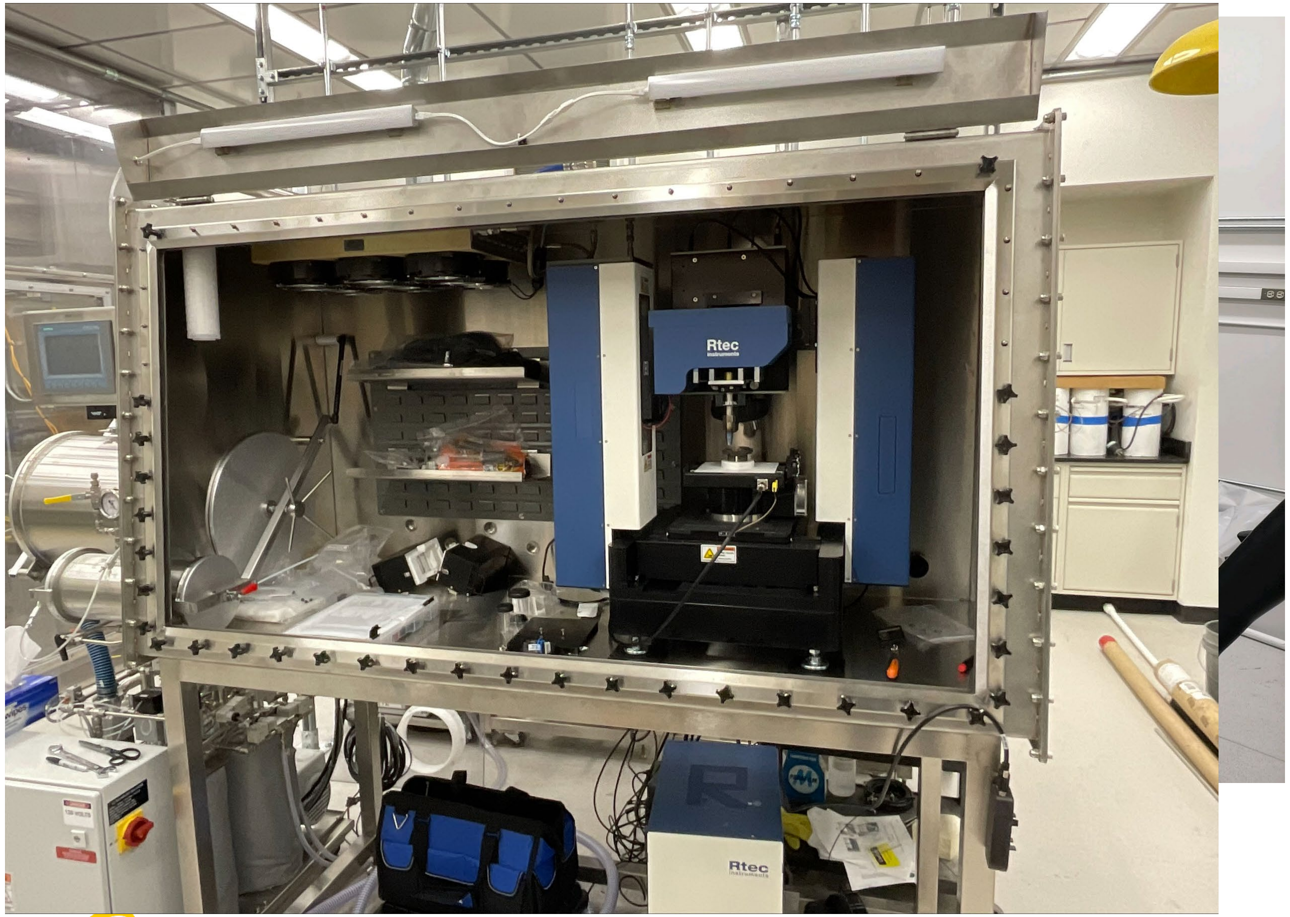
Tribocorrosion of stainless steel sliding against graphite in FLiNaK molten salt[☆]

Xin He[a], Chanaka Kumara[a], Dino Sulejmanovic[a], James R. Keiser[a], Nidia Gallego[b], Jun Qu[a,*]

[a] Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA
[b] Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831, USA

New glovebox and tribometer will enable measurements under more controlled environment



- A customized four-glove glovebox (LC Technology Solutions Inc., of Salisbury, MA) was procured and installed (05/31/2022) by the Graphite –GCR campaign

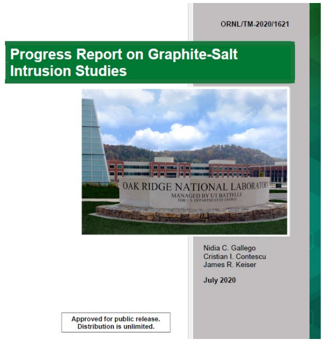
- New tribometer (RTEC Instruments Inc., from San Jose, CA)(Graphite –GCR campaign): Installed in glovebox; tests are being conducted to exercise capabilities and understand system prior to closing the glovebox

- Tests will be conducted in inert environments and with molten salts.

Summary

- Salt intrusion happens but it is highly dependent on temperature, pressure, time and graphite grade
- Salt distribution and penetration depth is highly dependent on pore structure
- On-going work to further analyze the data collected on effect of intrusion time, and additional neutron imaging time has been approved
- Continue the evaluation of contact angle measurements and the effect of other variables (graphite grade, surface finish, pre-treatment, moisture content, salt impurities…)
- Initial scoping studies of the wear behavior of graphite in molten salts were completed and published.
- New facilities have been installed and will allow us to continue our studies under more control environments.

Publications


ORNL/TM-2020/1621

Progress Report on Graphite-Salt Intrusion Studies

Nidia C. Gallego
Cristian I. Contescu
James R. Keiser

July 2020

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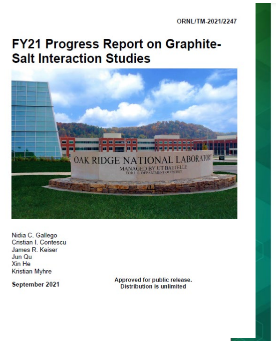
ORNL/TM-2021/2247

FY21 Progress Report on Graphite-Salt Interaction Studies

Nidia C. Gallego
Cristian I. Contescu
James R. Keiser
Jun Qu
Xin He
Kristian Myhre

September 2021

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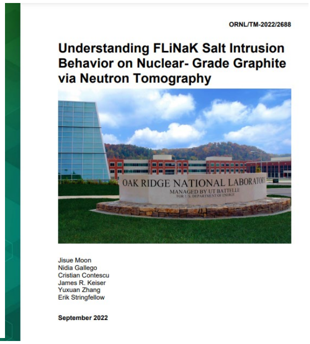
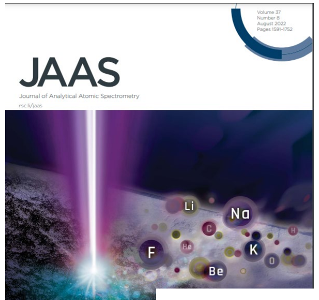

ORNL/TM-2022/2688

Understanding FLiNaK Salt Intrusion Behavior on Nuclear- Grade Graphite via Neutron Tomography

Jisue Moon
Nidia Gallego
Cristian Contescu
James R. Keiser
Yuxuan Zhang
Erik Stringfellow

September 2022


Volume 37
Number 8
August 2022
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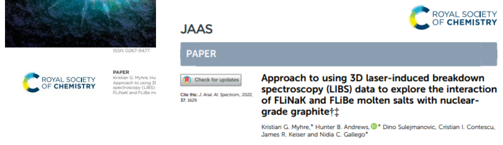
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PAPER

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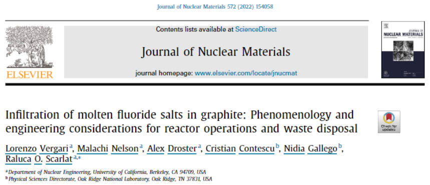
Approach to using 3D laser-induced breakdown spectroscopy (LIBS) data to explore the interaction of FLiNaK and FLiBe molten salts with nuclear-grade graphite†‡

Kristian G. Myhre,* Hunter B. Andrews,* Dino Sulejmanovic, Cristian I. Contescu, James R. Keiser and Nidia C. Gallego*


Journal of Nuclear Materials 572 (2022) 154058

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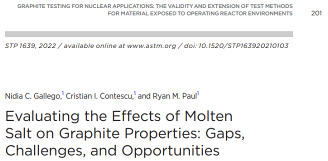
Infiltration of molten fluoride salts in graphite: Phenomenology and engineering considerations for reactor operations and waste disposal

Lorenzo Vergari[a], Malachi Nelson[a], Alex Droster[a], Cristian Contescu[b], Nidia Gallego[b], Raluca O. Scarlat[a,*]

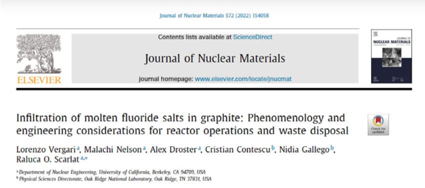
[a] Department of Nuclear Engineering, University of California, Berkeley, CA 94709, USA
[b] Physical Sciences Directorate, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA


GRAPHITE TESTING FOR NUCLEAR APPLICATIONS: THE VALIDITY AND EXTENSION OF TEST METHODS FOR MATERIAL EXPOSED TO OPERATING REACTOR ENVIRONMENTS 201

STP 1639, 2022 / available online at www.astm.org / doi: 10.1520/STP163920210103

Nidia C. Gallego,[1] Cristian I. Contescu,[1] and Ryan M. Paul[1]

Evaluating the Effects of Molten Salt on Graphite Properties: Gaps, Challenges, and Opportunities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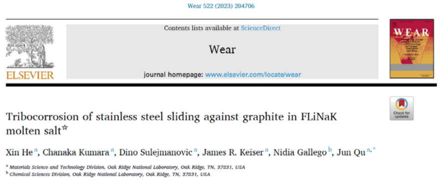
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- Gallego NC, Contescu CI, Keiser JR, “Progress Report on Graphite-Salt Intrusion Studies” ORNL/TM-2020/1621 (August 2020)
- Gallego NC, Contescu C, Keiser J, Qu J, He X, Myhre K., “FY21 Progress Report on Graphite-Salt Interaction Studies” ORNL/TM-2021/2247 (October 2021)
- Moon J, Gallego NC, Contescu C, Keiser JR, Zhang Y, Stringfellow E, “Understanding FLiNaK salt intrusion behavior on nuclear grade graphite via neutron tomography” ORNL/TM-2022-2688 (September 2022)
- Vergari L, Gallego N, Scarlat S, et al., Infiltration of molten fluoride salts in graphite: phenomenology and engineering considerations for reactor operations and waste disposal. J Nuclear Materials, 154058. (2022)
- Myhre K, Andrews H, Gallego NC, et al., Approach to using Three-Dimensional Laser Induced Breakdown Spectroscopy Data to Explore the Interaction of Molten FLiNaK with Nuclear Grade Graphite (JAAS 37 (8), 2022, 1629-1641)
- Gallego NC, Contescu CI, Paul R, “Evaluating the Effects of Molten Salt on Graphite Properties: Gaps, Challenges, and Opportunities” In Graphite Testing for Nuclear Applications: The Validity and Extension of Test Methods for Material Exposed to Operating Reactor Environments, ASTM 2023
- He X., Qu J, et al., Tribocorrosion of stainless steel sliding against graphite in FLiNaK molten salt (Wear 522 (1) 2023, 204706)
- Workshop Report – being finalized
- Moon J, Gallego NC et al., A neutron tomography study to visualize fluoride salt (FLiNaK) intrusion in nuclear-grade graphite (submitted for publication, under review).

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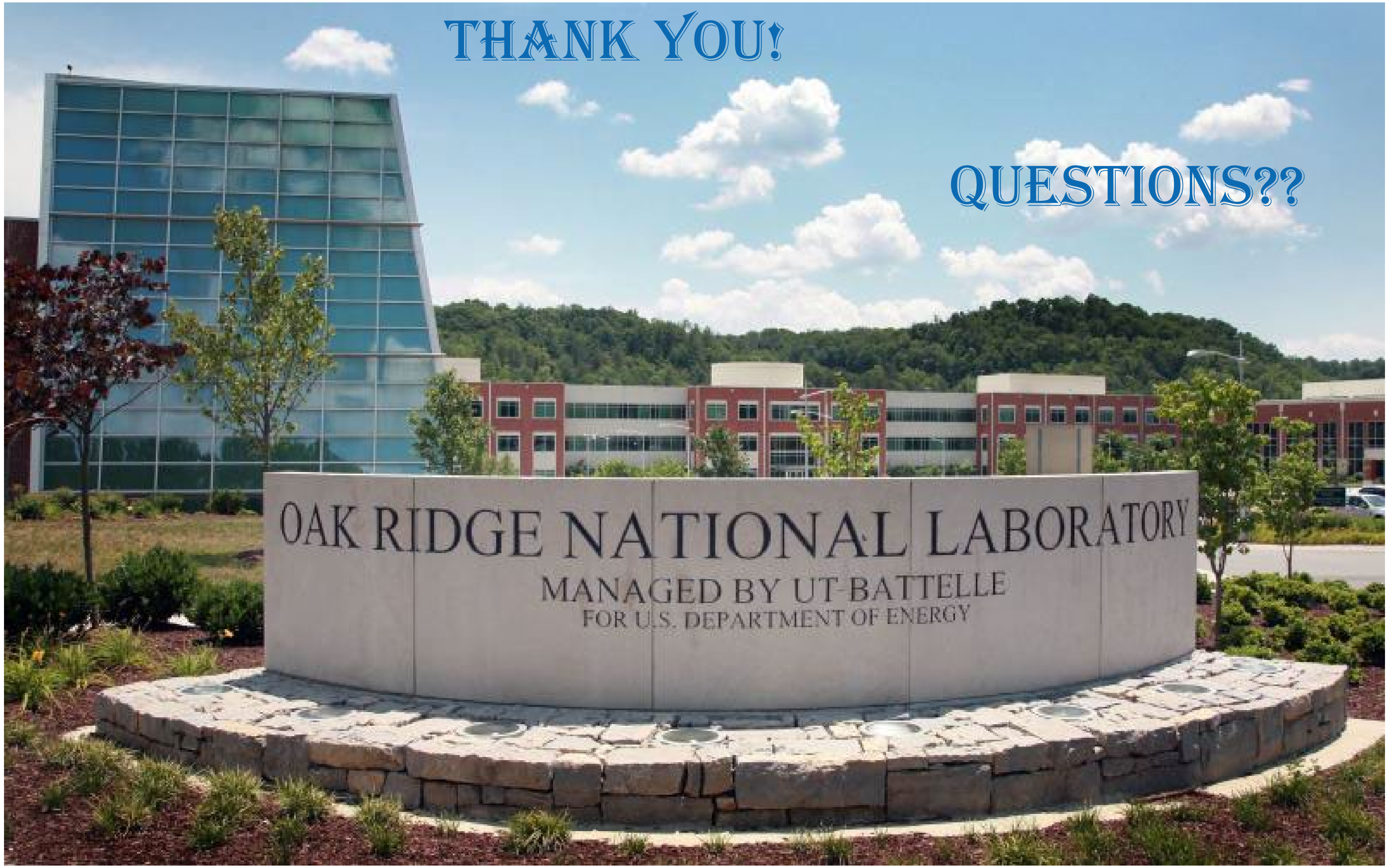

Upcoming Webinars

Date	Title	Presenter
21 June 2023	Panel Session: International Knowledge Management and Preservation of SFR	Joel Guidez, CEA (retired), France; Hiroki Hayafune, JAEA, Japan; Ron Omberg, PNNL, USA; Cal Doucette, ARC Energy, Canada; and Patrick Alexander, Terra Power, USA
26 July 2023	Off-Gas Xenon Detection and Management in Support of MSRs	Dr. Hunter Andrews, ORNL Dr. Praveen Thallapally, PNNL, USA
31 August 2023	Corrosion and Cracking of SCWR Materials	Prof. Lefu Zhang, Shanghai Jiao Tong University, China