Pyrolytic Graphite – An Enabling Material for Radioisotope Power Systems

ORNL Radioisotope Power Systems
Special Component Manufacturing and Testing Program

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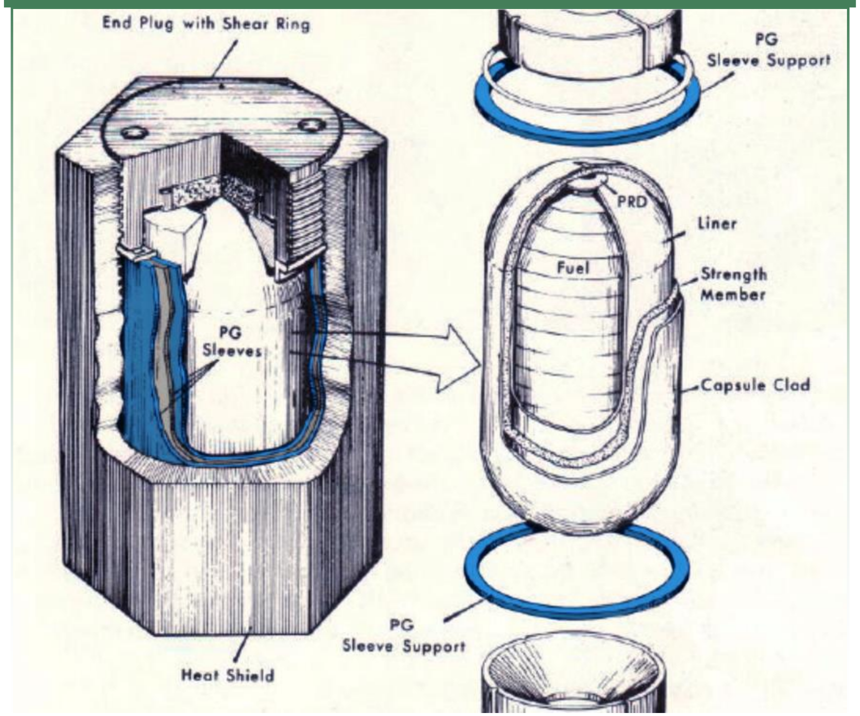
Pyrolytic Graphite (PG) has served an enabling role as an insulator in current and legacy radioisotope power systems in support of the intact reentry design philosophy. ORNL has assessed vendors for LWRHU insulator production.

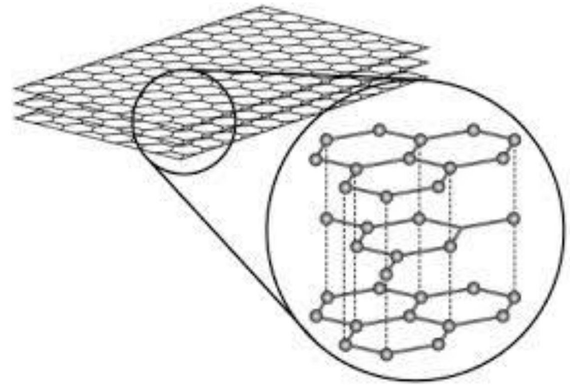
Pioneer RTG



Light Weight Radioisotope Heater Unit

Ref: MRC – Mound Laboratory

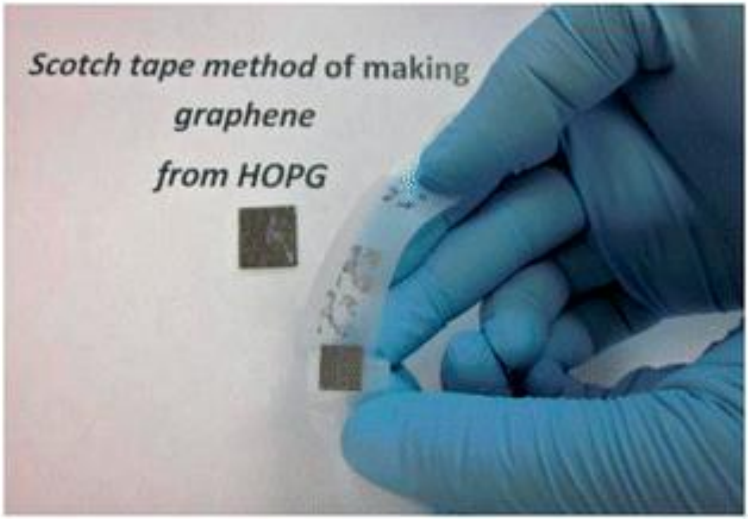
Graphite is one of the allotropic forms of Carbon



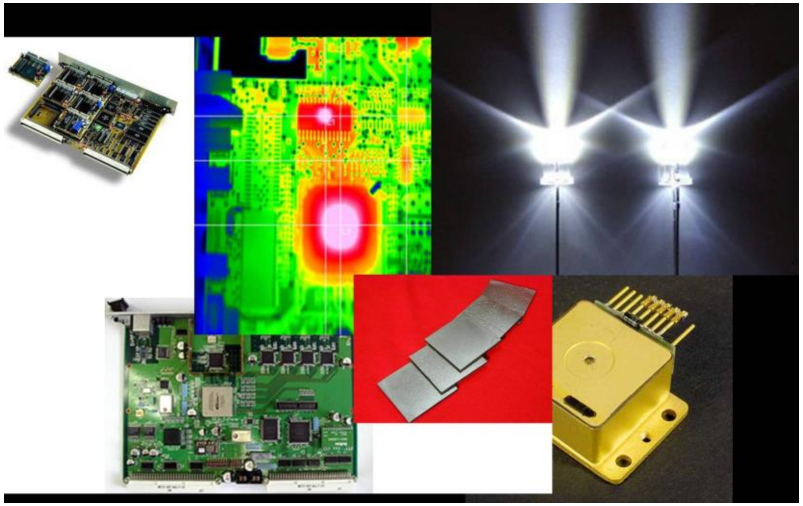
- **Pyrolytic Graphite is formed by high temperature decomposition of hydrocarbon gasses onto substrates (usually polycrystalline graphite). PG deposits as basal plane additions within individual grains that become aligned with the deposition surface and each other.**
- **Consequently, polycrystalline PG components embody the anisotropic properties of PG on a macroscopic scale.**

Pyrolytic graphite employed for thermal protection of radioisotope heat sources…

is not Highly Oriented Pyrolytic Graphite (HOPG) used for exotic physics experiments and as a source of graphene

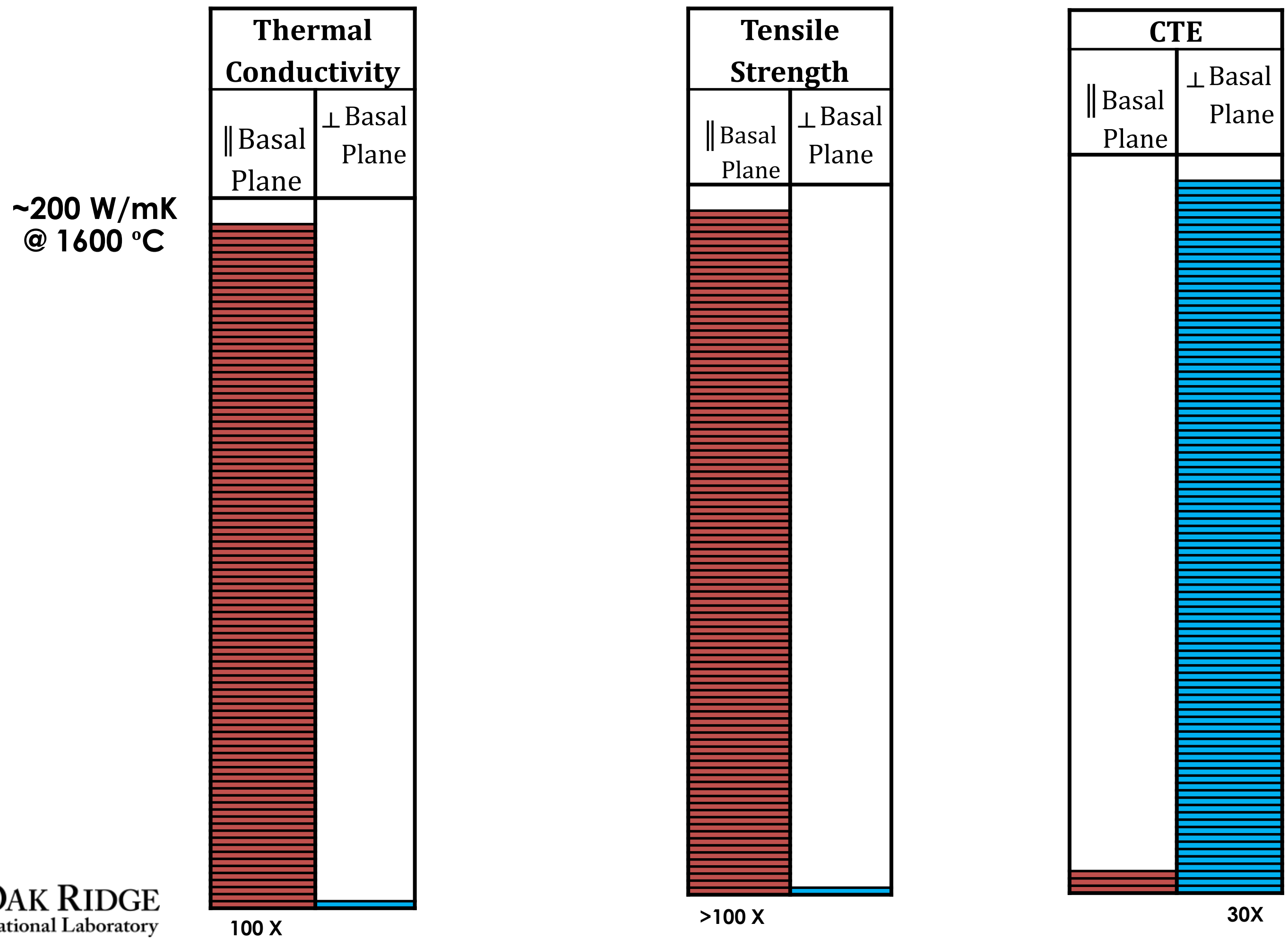


Pyrolytic Graphite of interest is a commercially produced thermal management material employed for a variety of applications, particularly the electronics industry.

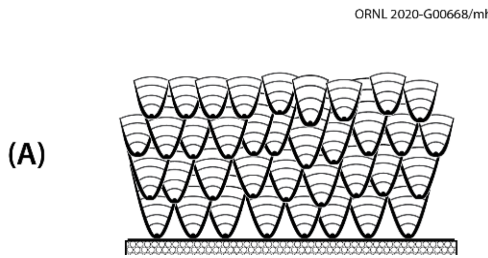


Ref: MiNTEQ International

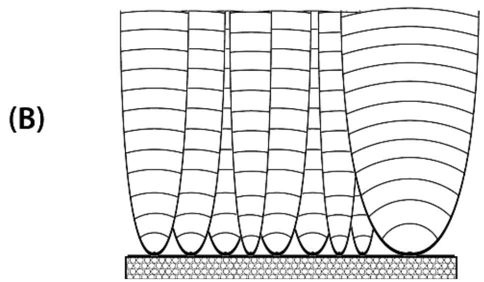
The anisotropic properties of PG are defined by crystal structure with very strong covalent bonds in the basal plane of the hexagonal unit cell and very weak Van der Waals bonding between.



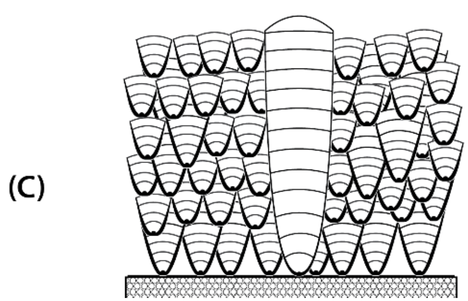
The microstructure of PG nucleates on a substrate at High Temperature (> 1000 °C) and grows as conically shaped grains.



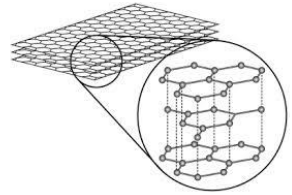
Continuous Nucleation

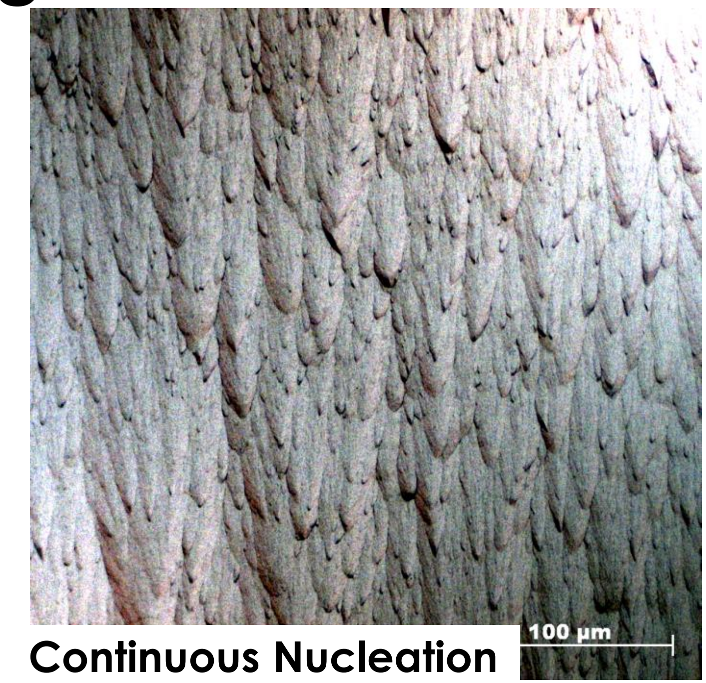


Surface Nucleation



Mixed Nucleation

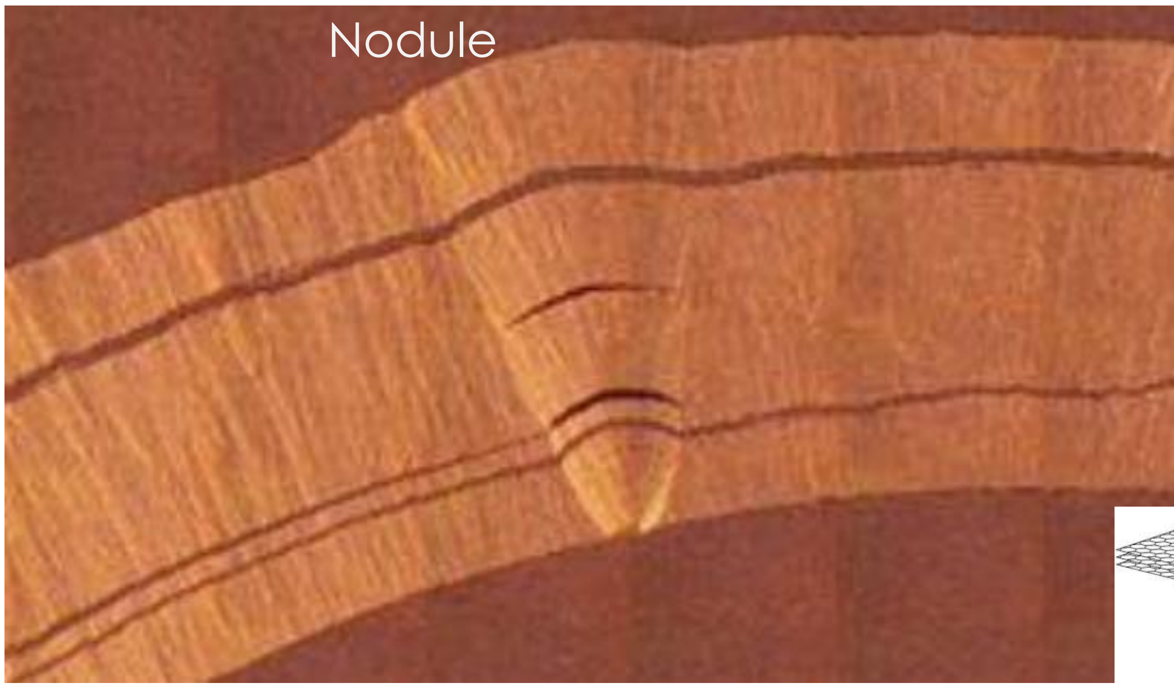


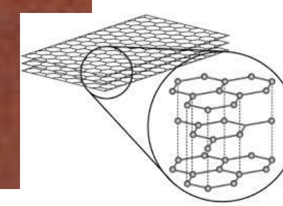


Continuous Nucleation

Mixed Nucleation

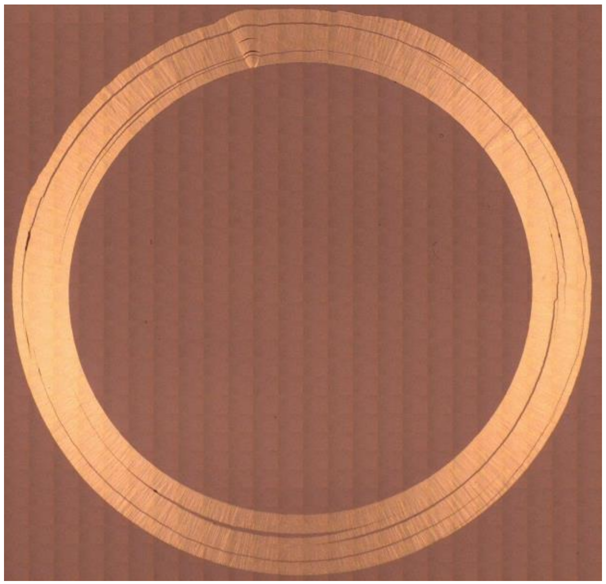
Impingement of conical grains result in local and long-range compressive stress within a component. Large Conical Grains also result in Surface Nodules



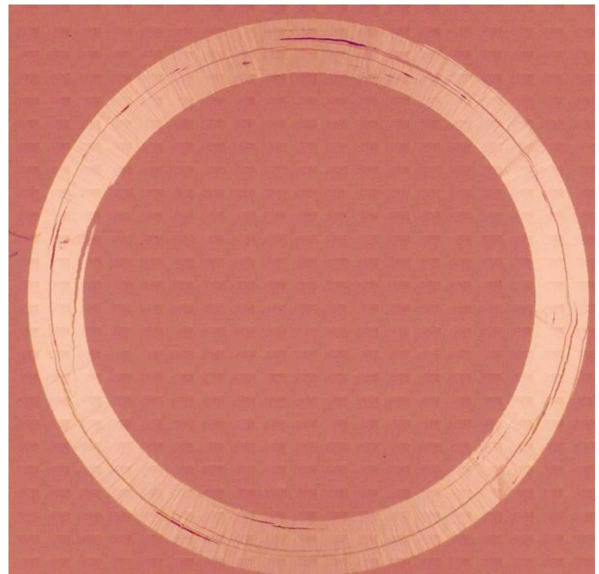


Fabricating cylindrical PG components is challenging due to high anisotropy in CTE and strength. The axial and circumferential directions are coincident with the PG basal planes having very low CTE, hence limited contraction from the deposition temp. The material between has a 30X higher CTE and low strength in the radial direction.

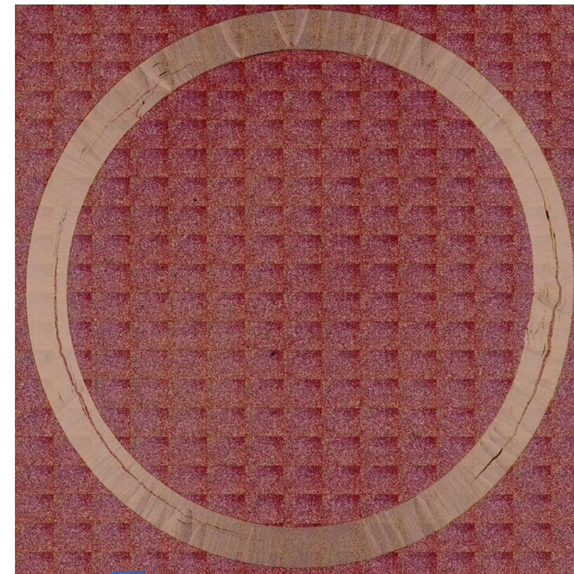
LWRHU PG Insulators below:



Outer Insulator

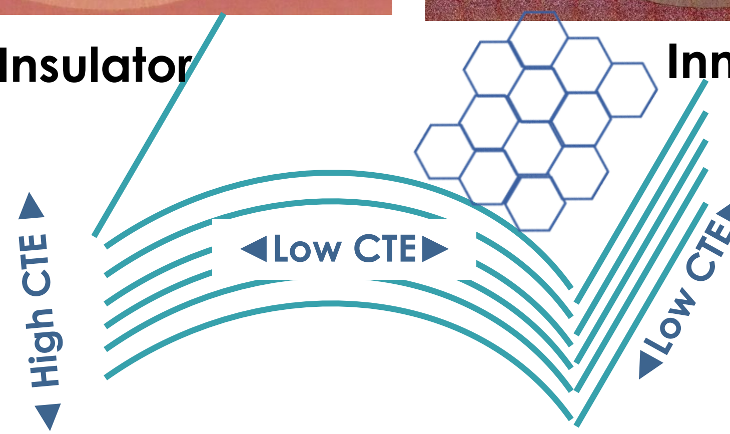


Middle Insulator

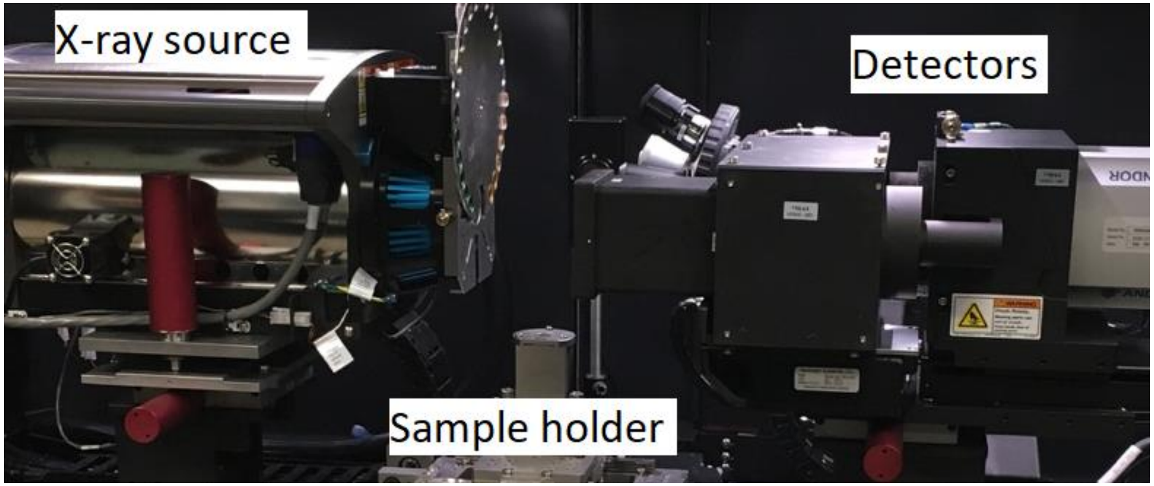


Inner Insulator

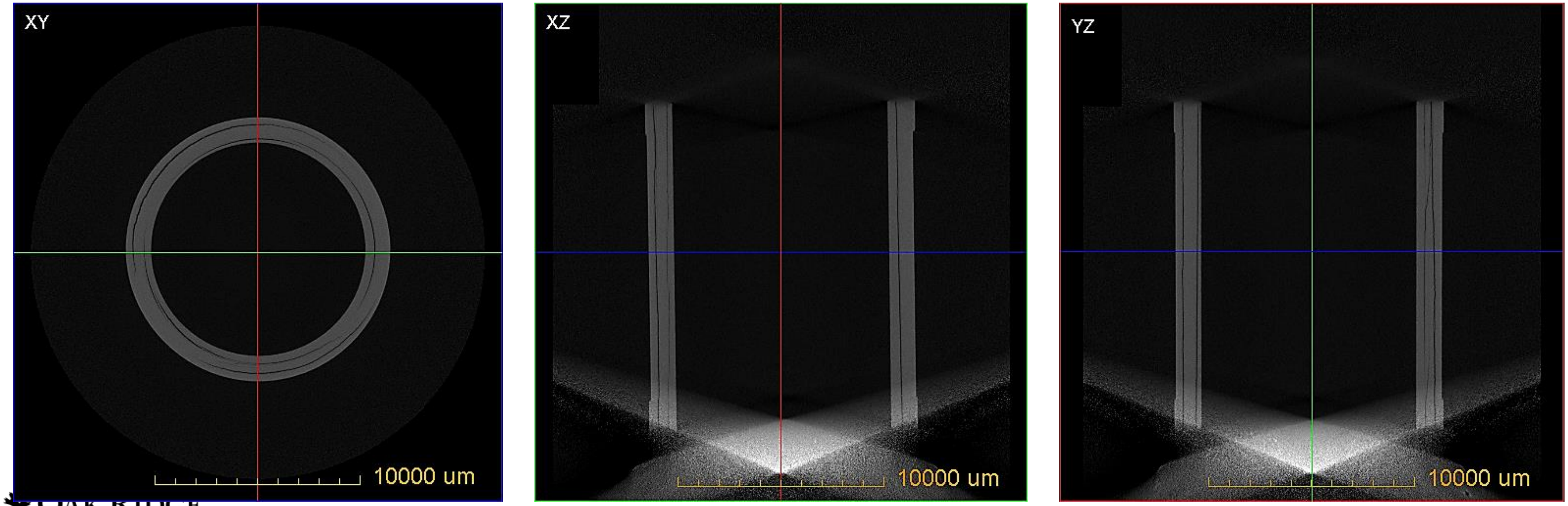
Insulator Cap



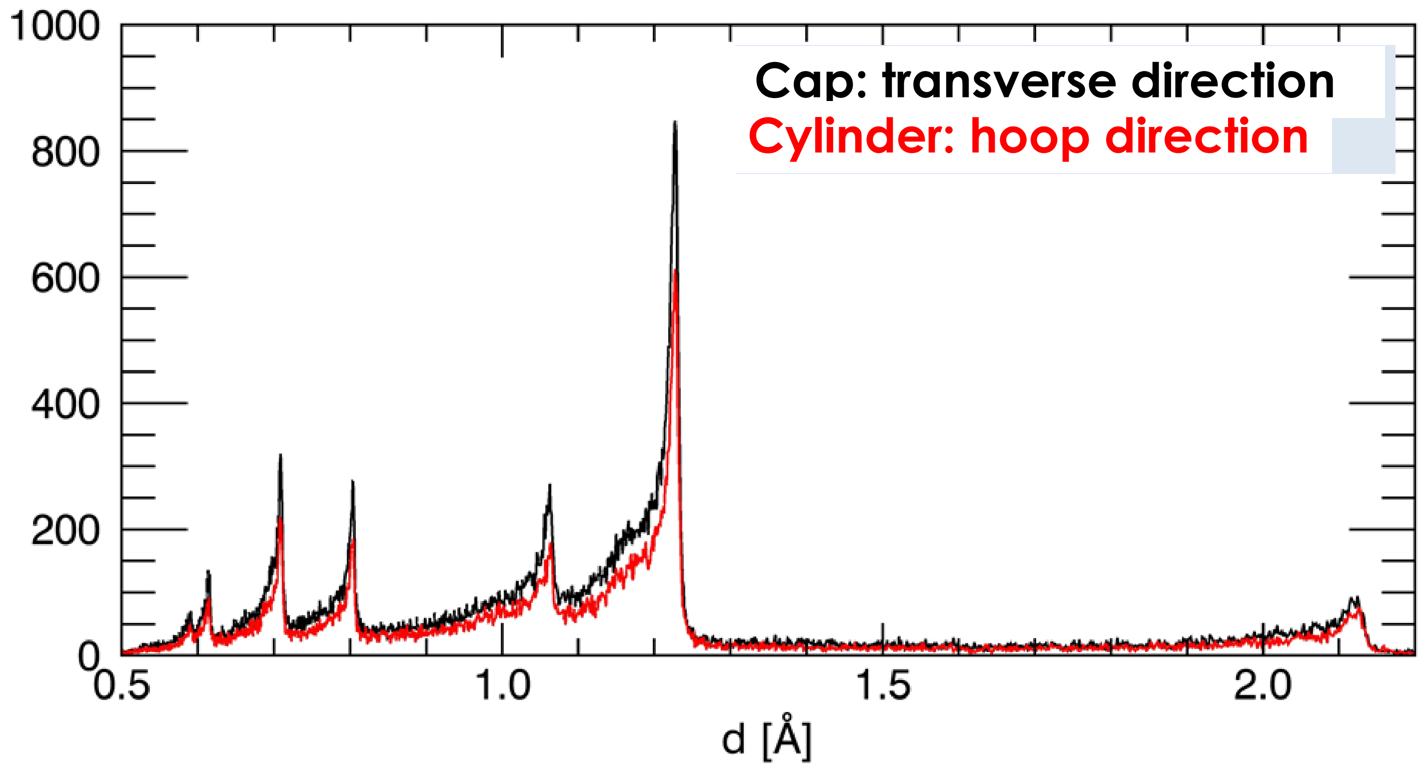
X-ray Tomography reveals the 3-D character of interplanar separations.



Credit: Dr. Thomas Watkins



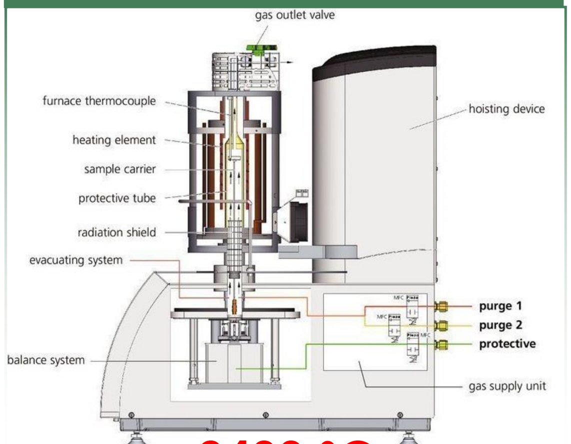
SNS Neutron Diffraction results show significant internal compressive stress in the basal plane directions of the LWRHU insulator cylinders and caps. Note left side "tail" on peaks indicate lattice compression = microstructural impingement



Credit: Dr. Alexandru Dan Stoica

ORNL has Extensive High Temperature Thermal Analysis Capability for Characterizing Materials Such as Pyrolytic Graphite

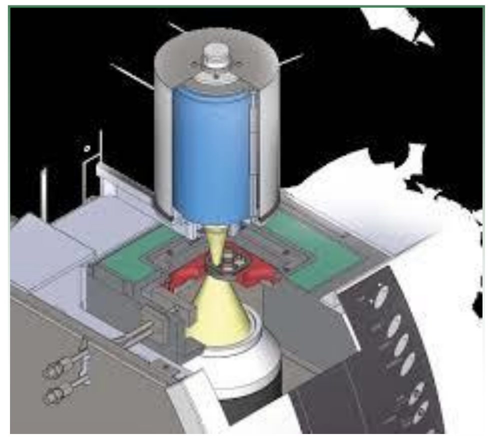
Simultaneous Thermal Analysis: DTA/TG/DSC



2400 °C

DSC: 1600 °C

Flash Thermal Diffusivity



Hyper Flash 1200 °C

TA Flashline 2500 °C

Dual-pushrod Dilatometry

SiC furnace: 1600 °C

Graphite Furnace: 2400 °C

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Lessons Learned

Pyrolytic Graphite exhibits unique anisotropic properties that make it an ideal insulator for many RPS thermal protection applications.

Pyrolytic Graphite is uniquely imperfect in ways that should be considered in design, production and application.

Acknowledgement

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