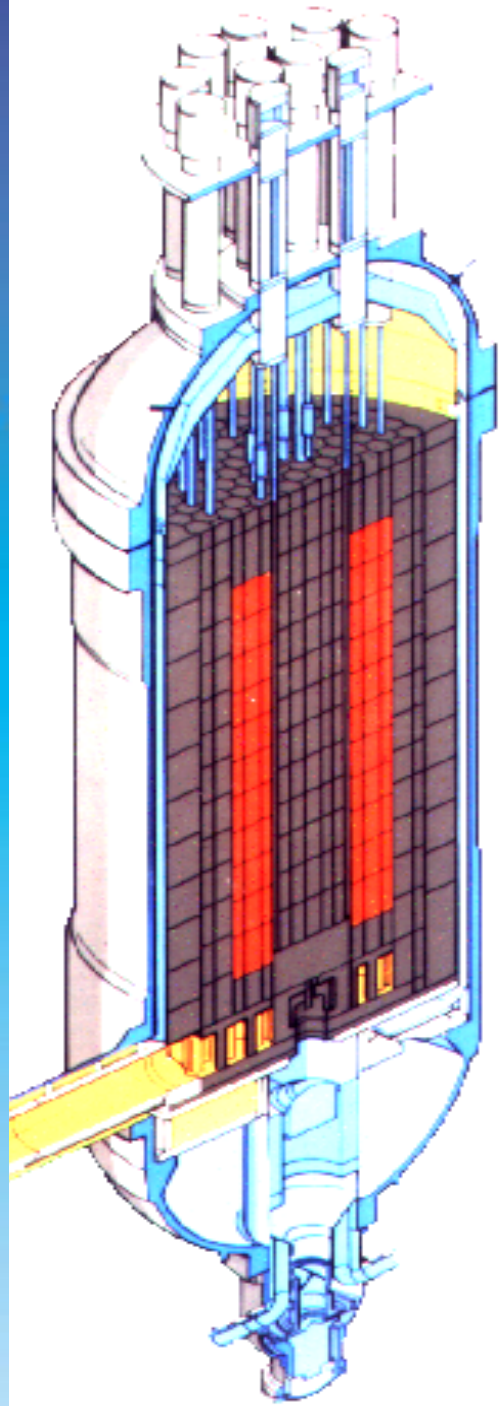
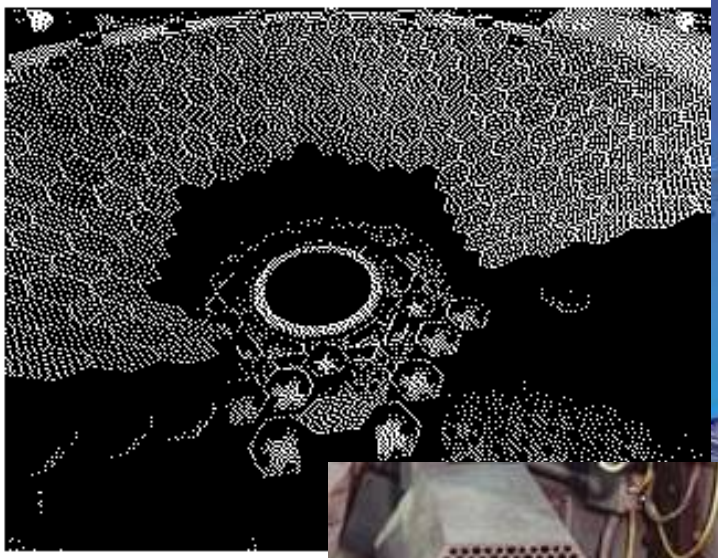
NGNP Graphite Program

NRC Graphite Workshop

Will Windes, NGNP graphite technical lead

Rockville, MD, 16-18 March, 2009

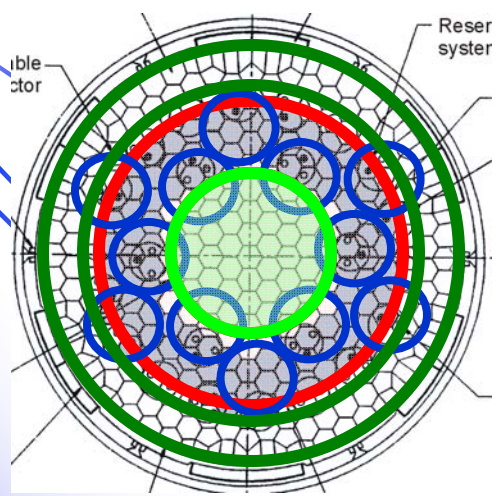


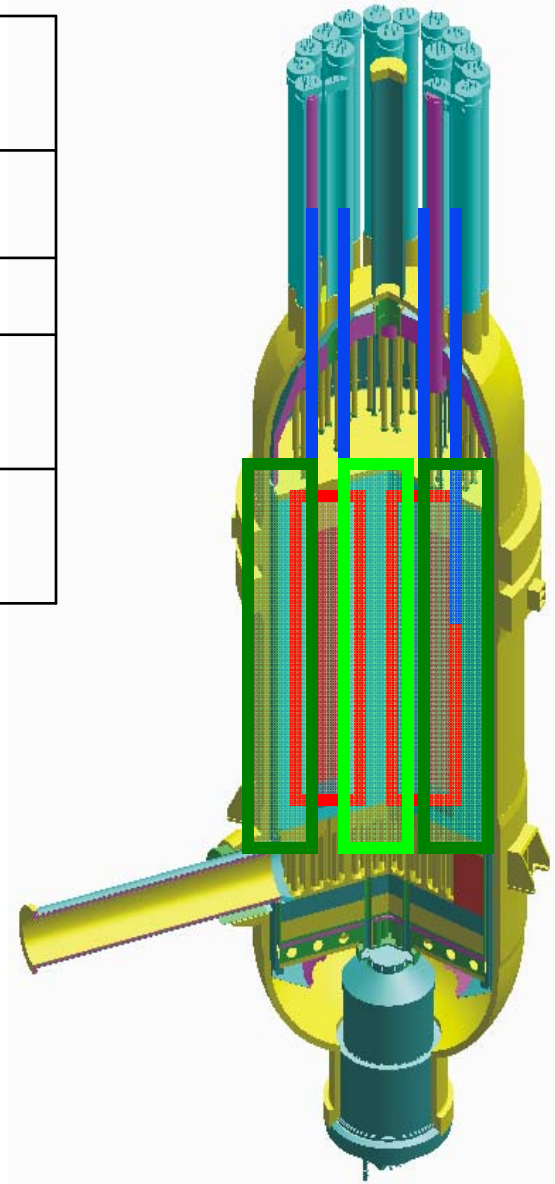


Electricity
to Grid

NGNP core components

Component	Normal Operation	Off-Normal	dpa
Graphite fuel block	~1200 ºC	~1400 ºC	~ 0.8/yr
Control rods	~1000 °C	~1200 ºC	~ 0.5/yr
Reflector blocks – inner	~900 ºC	~1200 ºC	~ 0.5/yr
Reflector blocks - outer	~800 °C	~1100 °C	~ 0.2/yr



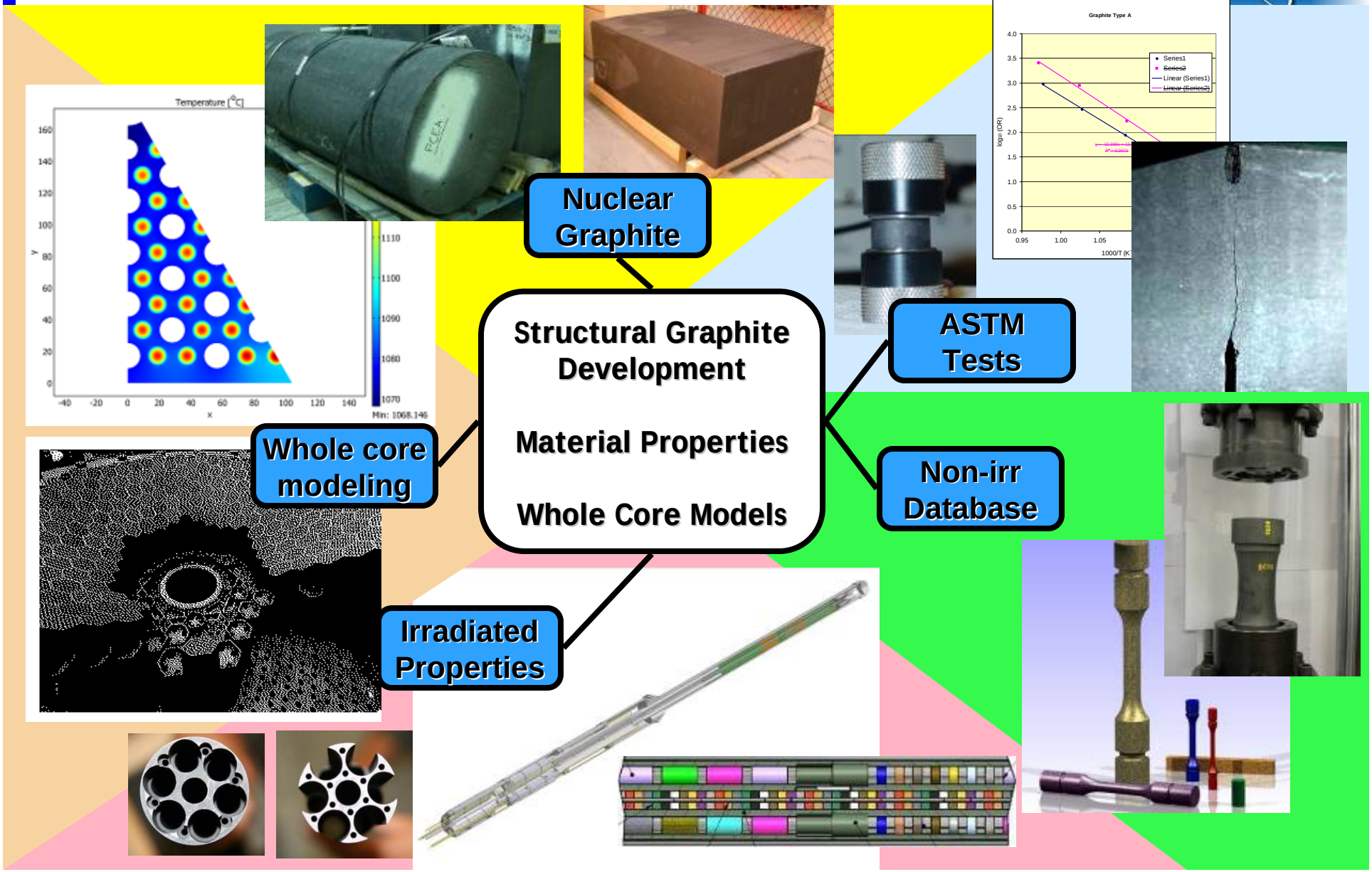


NGNP assumptions

- Either a prismatic core or pebble bed core
  - Graphite – (compressive applications)
  - Ceramic composites – (tensile applications)
- No decision of specific graphite type
- 750 C (to start with) - 900-950 C (eventually)
- 400-600 MW_t
- He inert gas coolant (limited impurities)

- Funding Partnership with private sector
- Vendors = Westinghouse (PB), GA, & AREVA

Research Map

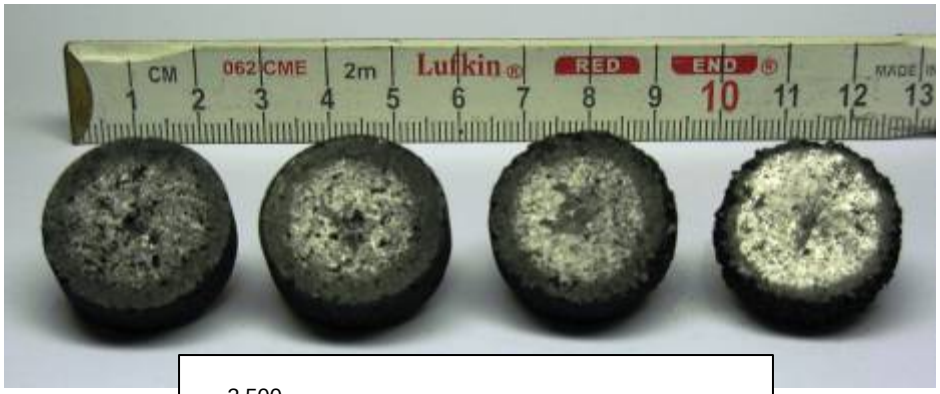


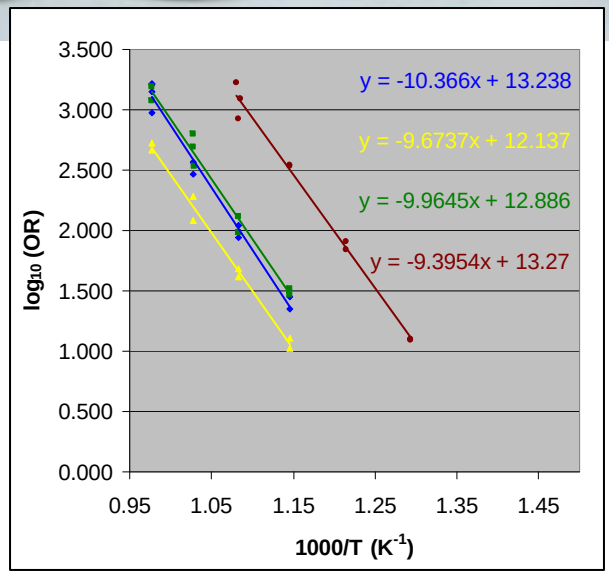
ASTM Standards

- All licensing data generated using ASTM standards
  - Except when none currently exist
- New standards being developed
  - **Air oxidation** = Nearly complete
  - **Fracture toughness** = Working data from RR
  - **XRD techniques** = Evaluating
  - **NDE techniques** = Evaluating/screening studies
  - **Shear tests** = Evaluating
- Evaluation of existing standards
  - DYM, small sample, sonic measurements, thermal

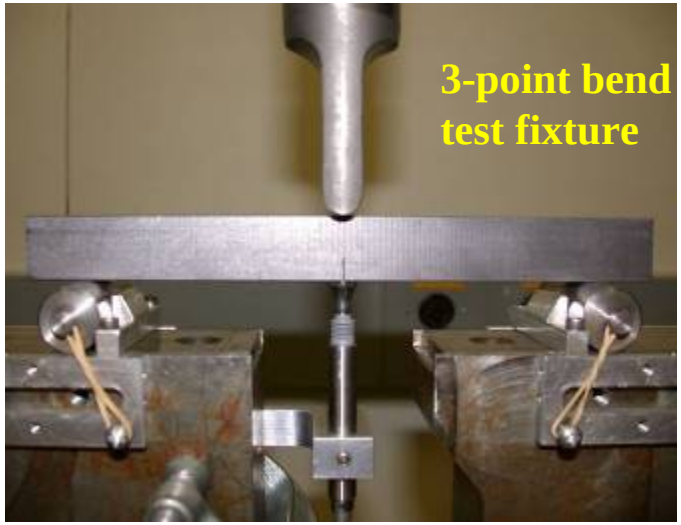
ASTM: Development

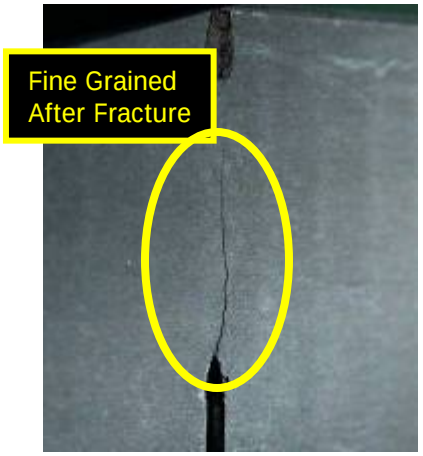
Graphite Oxidation



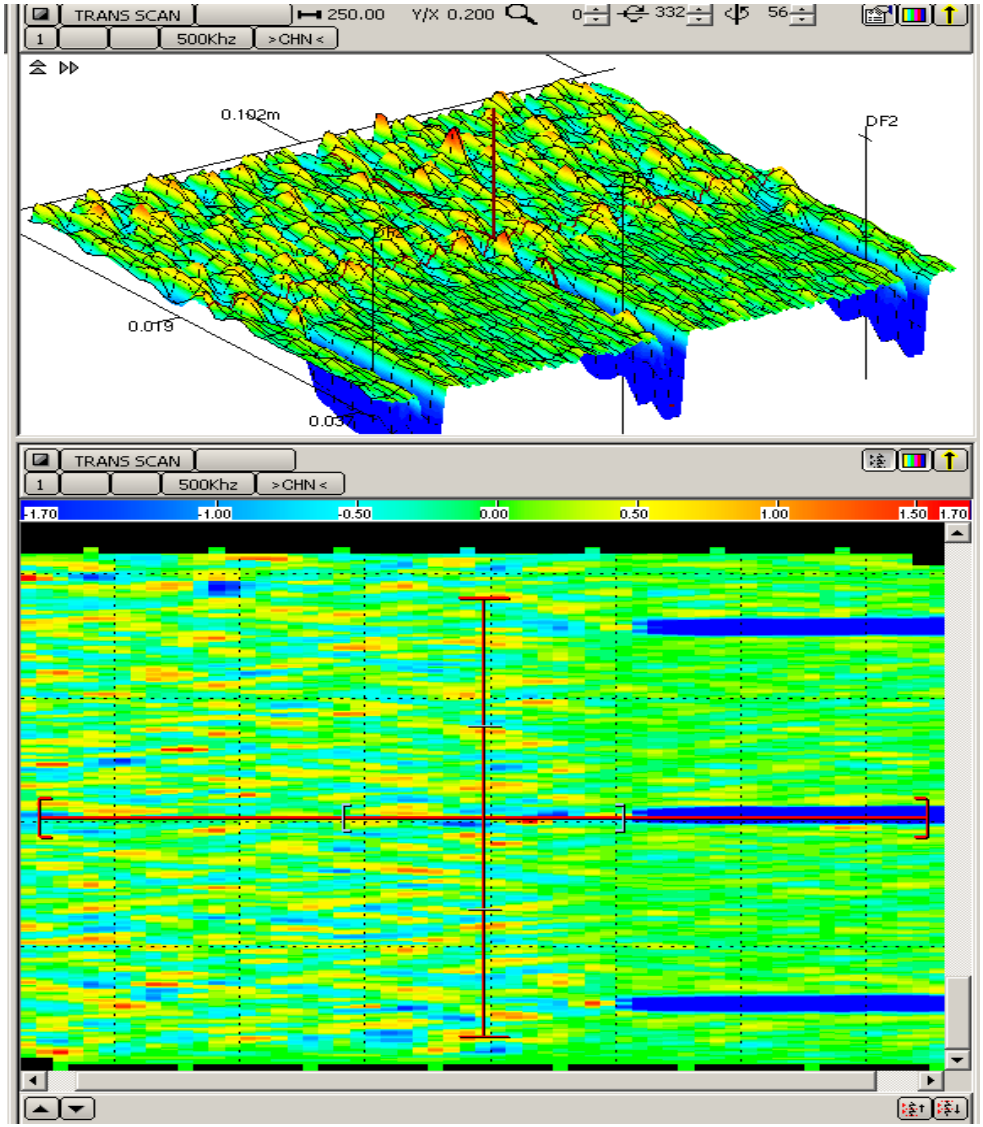


Fracture toughness





ASTM: Development



- NDE Techniques for large graphite components
  - Flaw type determination
  - Penetration depth
  - Spacial resolution
- Needed to identify disparate flaws
  - Different than “normal” distribution flaws
  - Similar to what metals have for validation

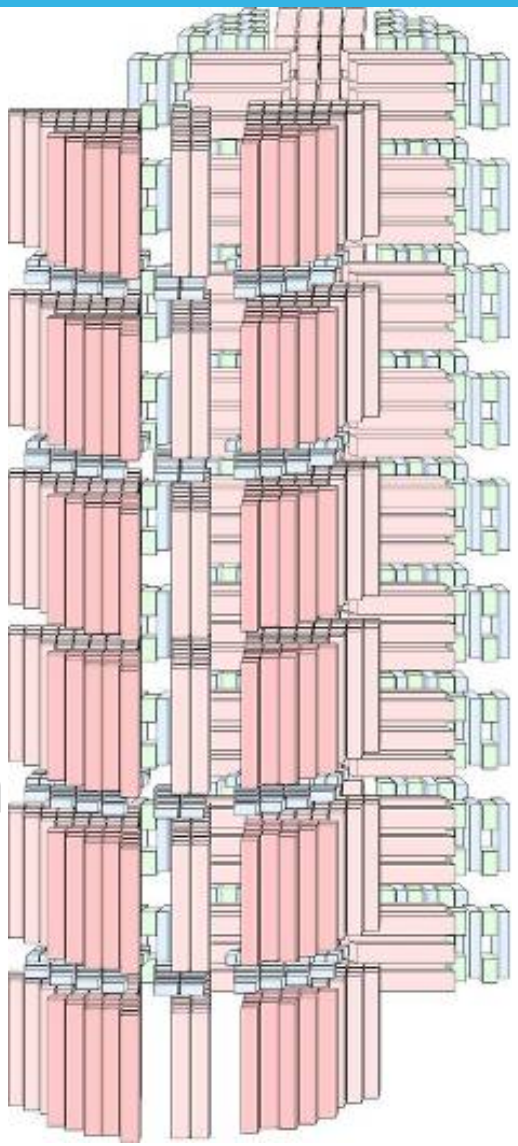
ASTM: Evaluations

- Current standards may not be appropriate
  - Thermal diffusivity – “short” samples needed (4-6 mm)
    - But grain size = 2-3mm reducing averaging effect
    - Sample size : Grain size ??
  - 3-point bend – “long” and “wide” samples needed
    - Irradiation samples are difficult
    - Where does the dimensional ratio fall apart ??
  - Sonic measurements – “large” samples needed for accurate time of flight
    - Again, small samples are difficult
    - Signal data interpretation (i.e. start & stop)
    - Coupling issues, specifically for irradiation samples

Baseline characterization

- **Baseline material properties**

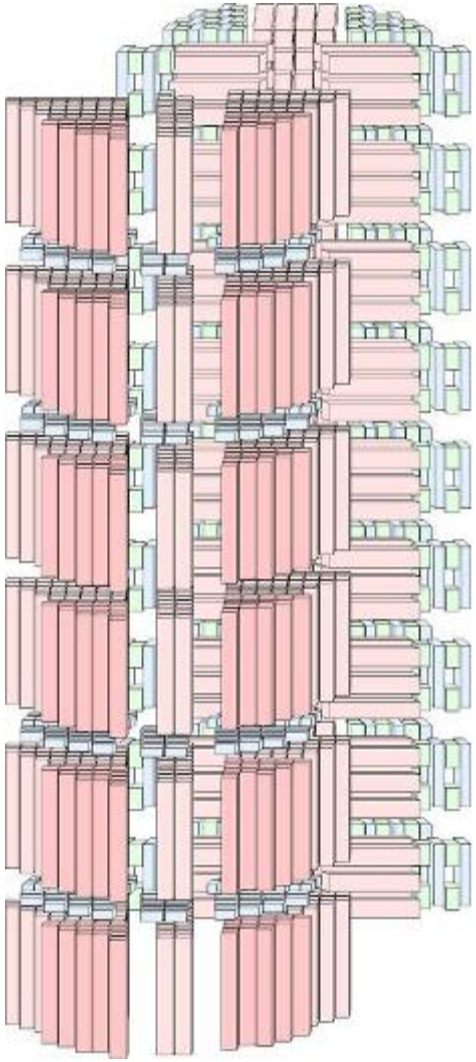
- **Variations in:**
  - **Intra-billet**
  - **Inter-billet**
  - **Lot-to-lot**

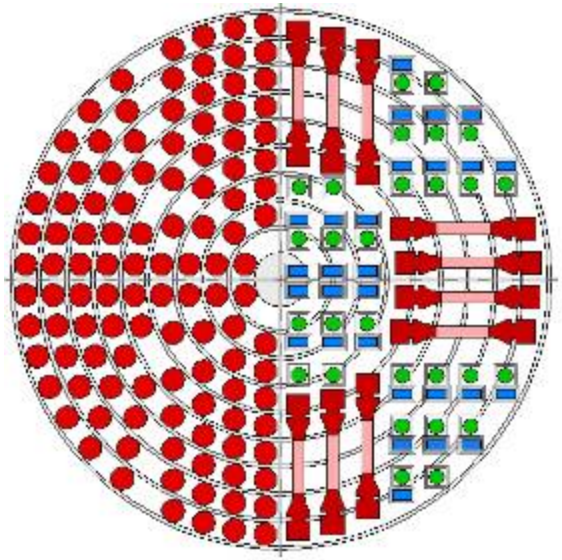


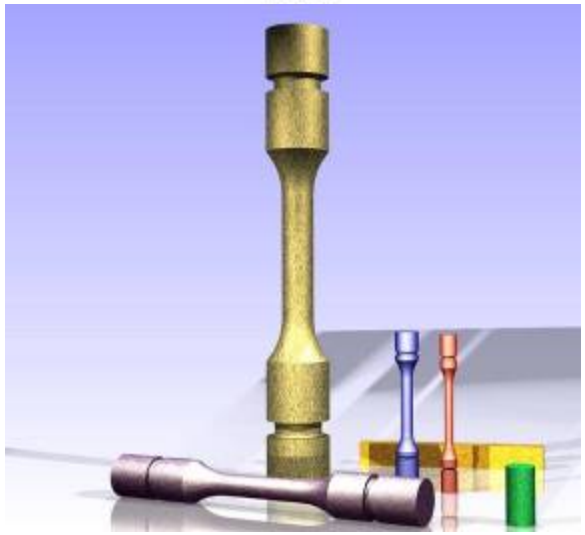
- **Irradiation results superimposed on top of baseline values**
  - Irr. results are **not** true property values

Baseline characterization

- **Statistically representative sampling matrix**
- **Finest spacial resolution – min. sample size**
- **Physical, thermal, and mechanical property measurements**







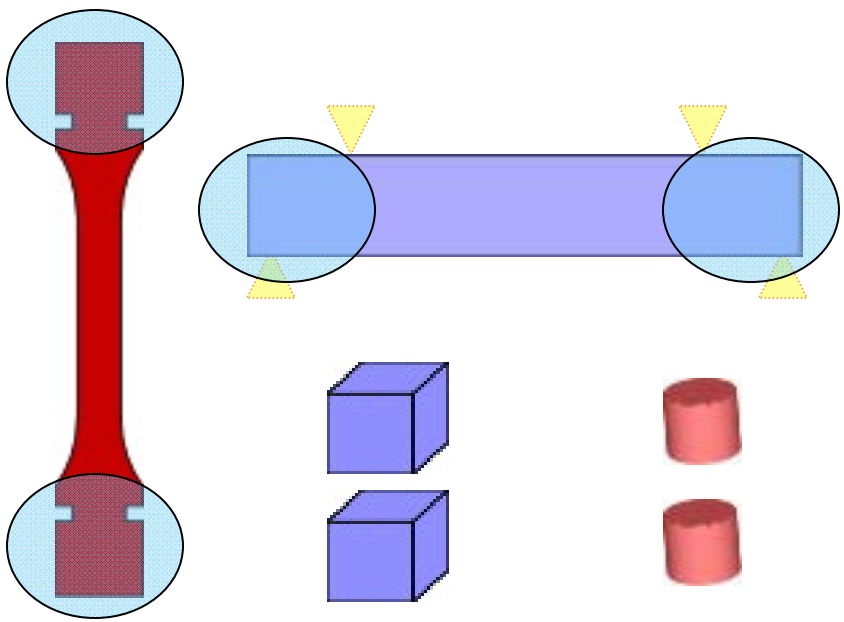
Baseline characterization

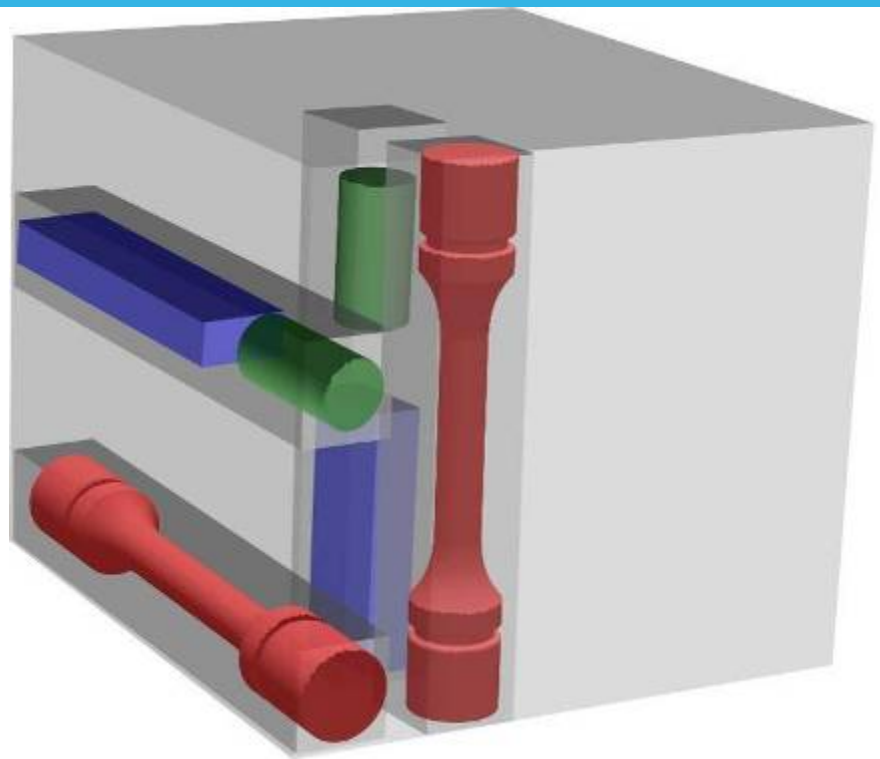
- Baseline material properties to be measured
  - Detailed pre-irradiation dimensional characterization (for creep experiments)
  - Mass, (bulk density)
  - Chemical analysis
  - Fundamental frequency (Young's modulus)
  - Sonic velocities (Shear and Young's modulus,
  - Poisson's ratio
  - Electrical Resistivity
  - Coefficient of thermal expansion (25-800 ^{o}C)
  - Thermal conductivity (25-1000 ^{o}C)
  - Mechanical Strength
    - Compressive, tensile, flextural (bending)
  - *Fracture toughness, shear strength, oxidation ?*

- **PCEA**
- **NBG-18**
- NBG-17
- IG-110
- IG-430
- Others

Baseline characterization

- Full-size mechanical samples
  - No grain size verses sample size issues
- NDE before destructive

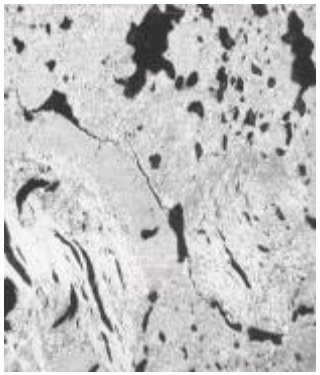


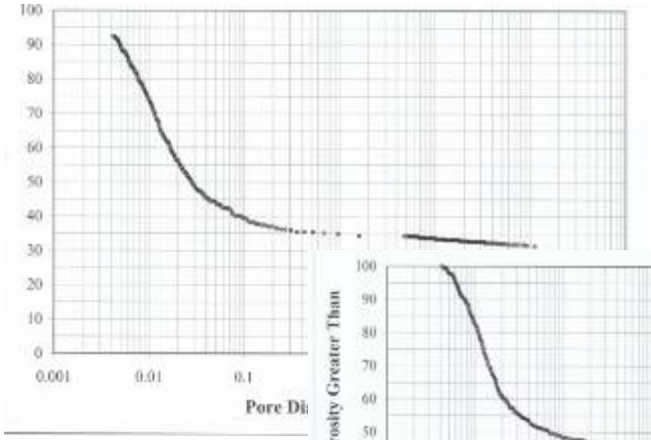


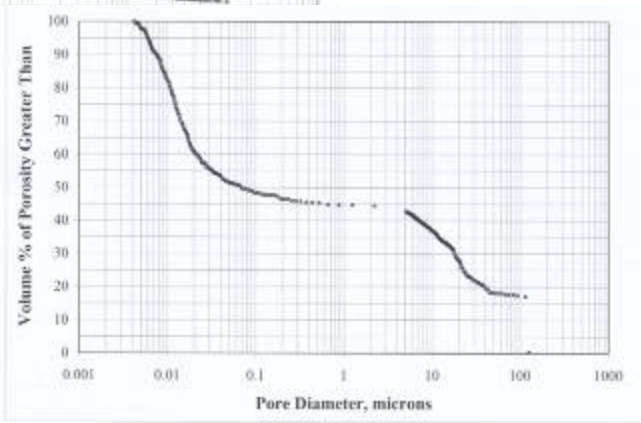
- Thermal analysis after mechanical
  - Small samples OK
  - “Same” location in billet

Other “baseline” properties

- **Multi-axial mechanical testing**
  - **Stresses are complex – need complex tests**
  - **Data used to model whole core behavior**
- **Microstructure analysis**
  - **Pore size and distribution**





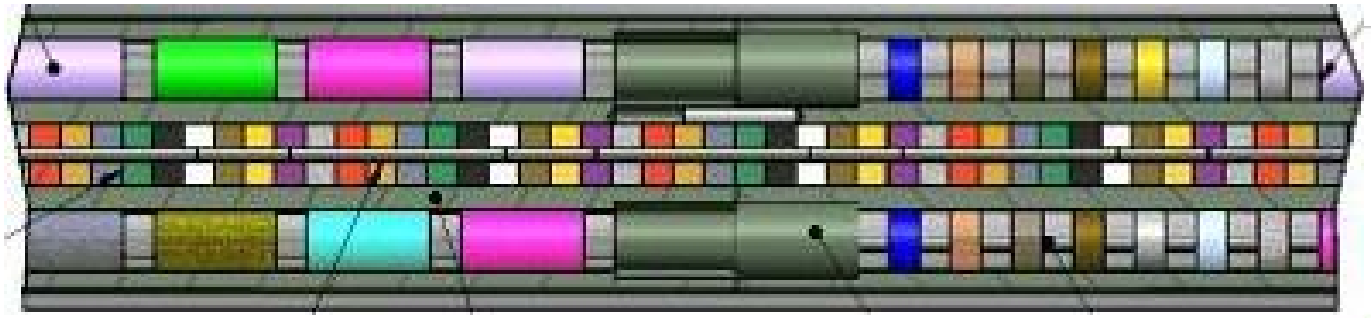


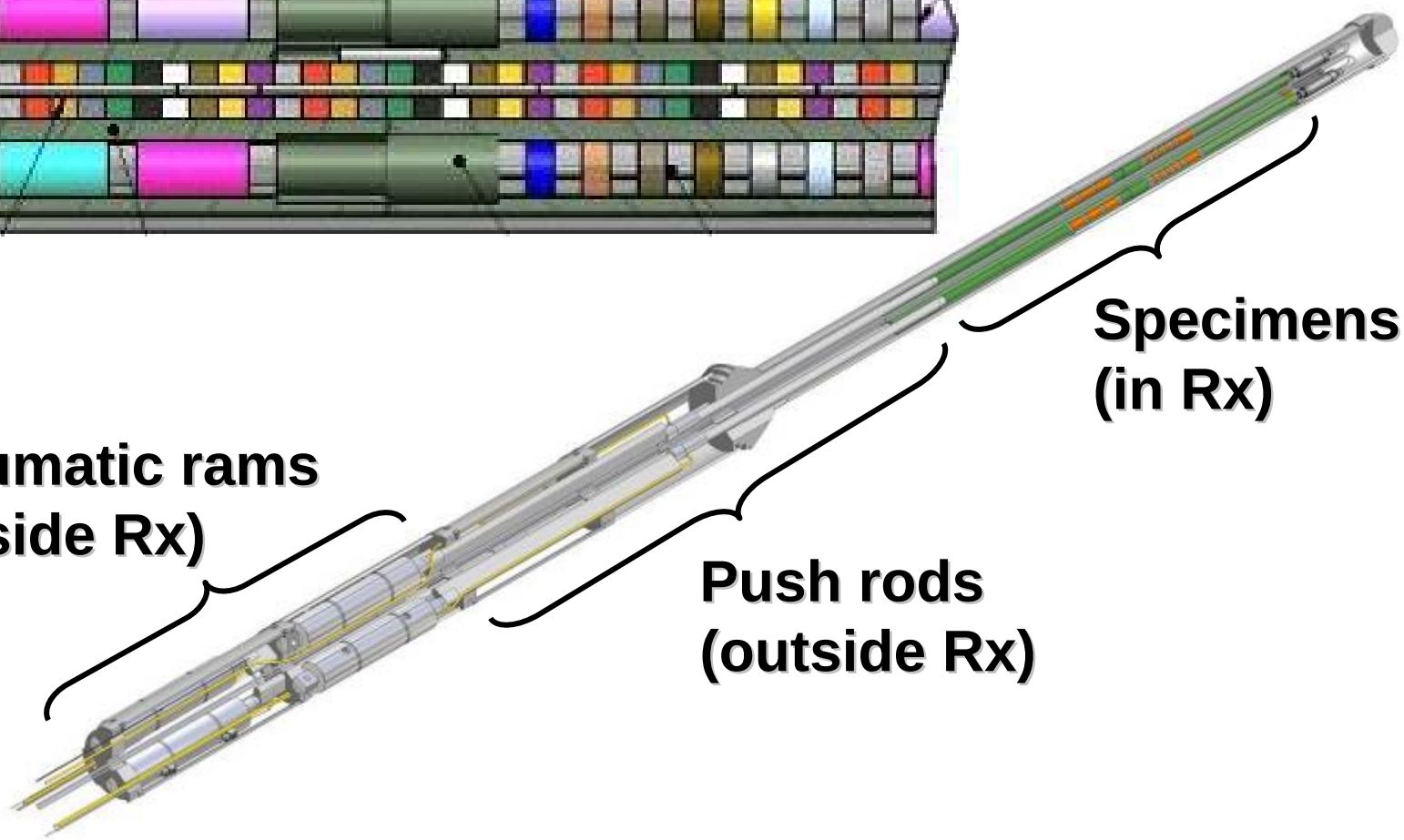
Microstructural modeling

- **Needed to figure out what’s really going on in microstructure during irradiation? (basal plane pinning. Or is it?)**

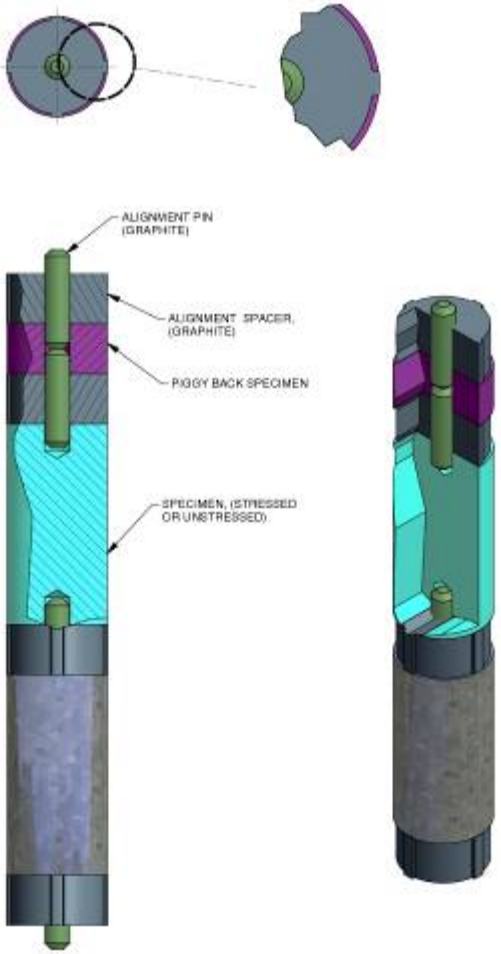
Irradiation activities

ATR Graphite Creep (AGC) experiments



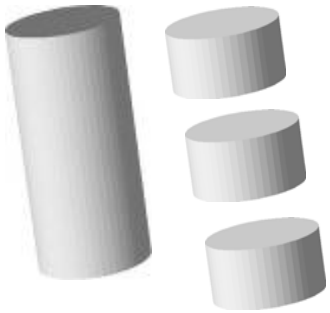


AGC Samples



AGC sample loading scheme

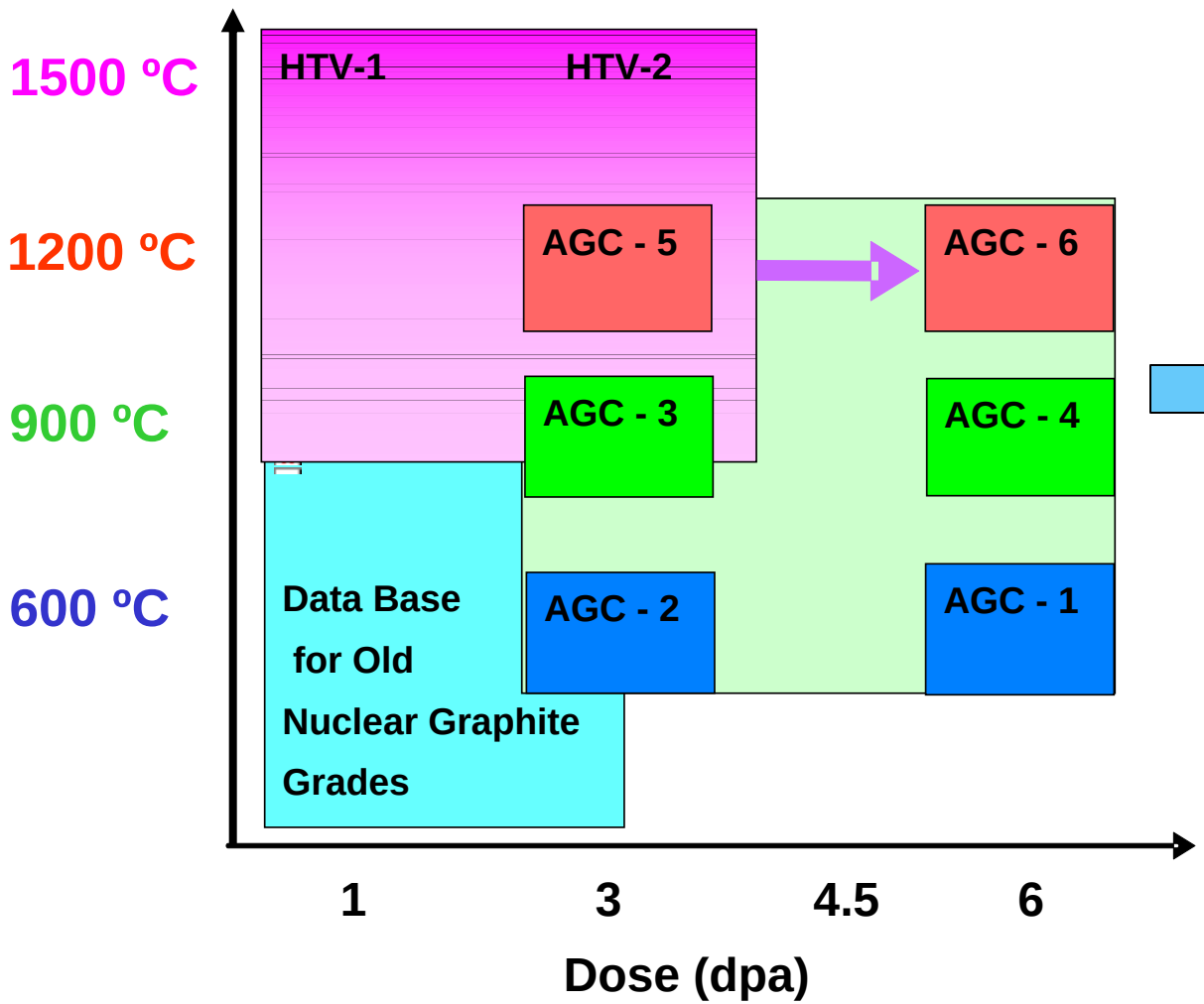
- Creep samples
  - Ø12 mm x 25 mm (1/2”x1”)
- Piggyback samples
  - Ø12 mm x 6 mm (1/2”x1/4”)
- Six major (creep) grades
  - H-451, IG-110, PCEA, NBG-18, NBG-17, and IG-430
- Ten piggyback grades
  - NBG-25, PCIB, PPEA, NBG-10, BAN, HLM, PGX, S2020, HOPG, and A3 matrix



AGC Experiments

- Total of six irradiation capsules operating at 600, 900, and 1200 C.
- Fluence range 0.5-7 dpa (covers both PB and prismatic)
- 90 creep specimen pairs (stressed and unstressed) and over 300 piggyback specimens
- Compressive loads applied to creep grades
  - 2, 2.5 and 3 Ksi compressive
  - No applied load to piggyback specimens
- Material properties ***after*** irradiation creep
- Provides change to baseline graphite properties

AGC Experiments

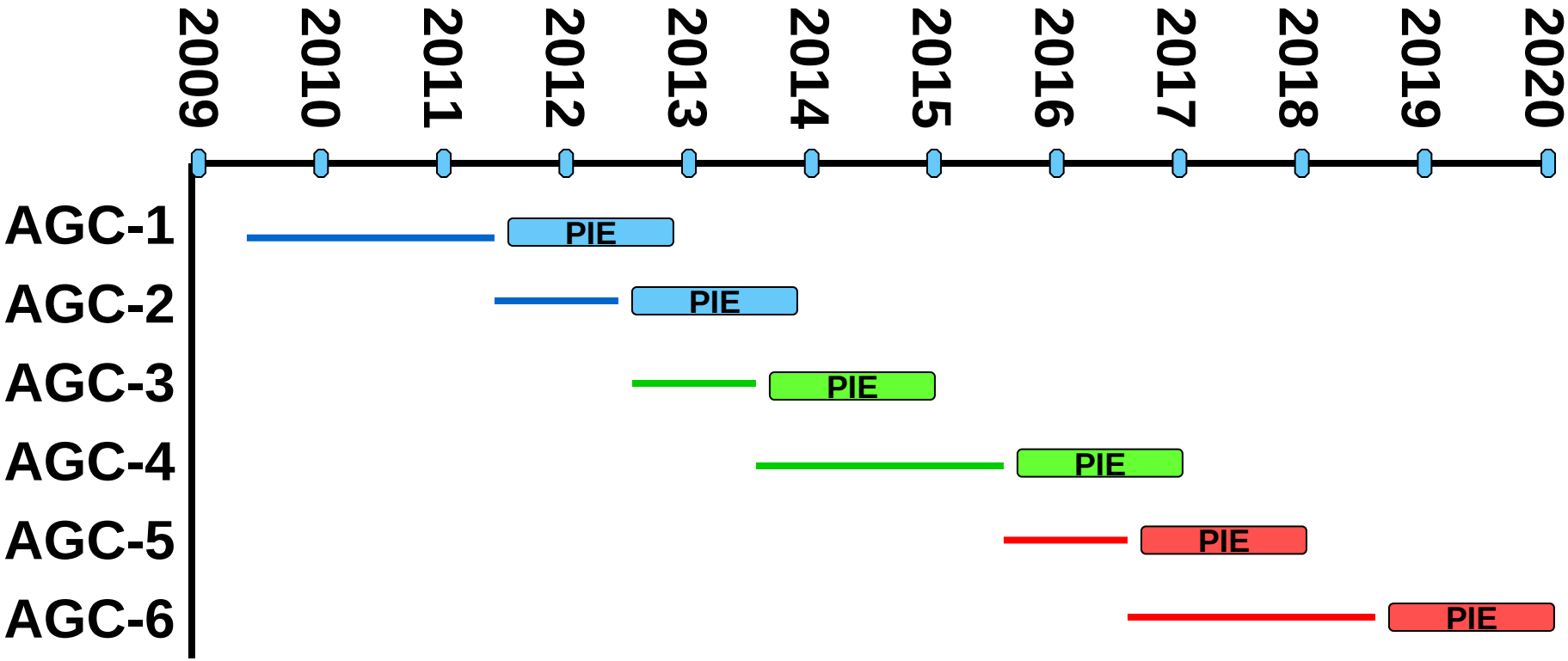


Graphite material property database

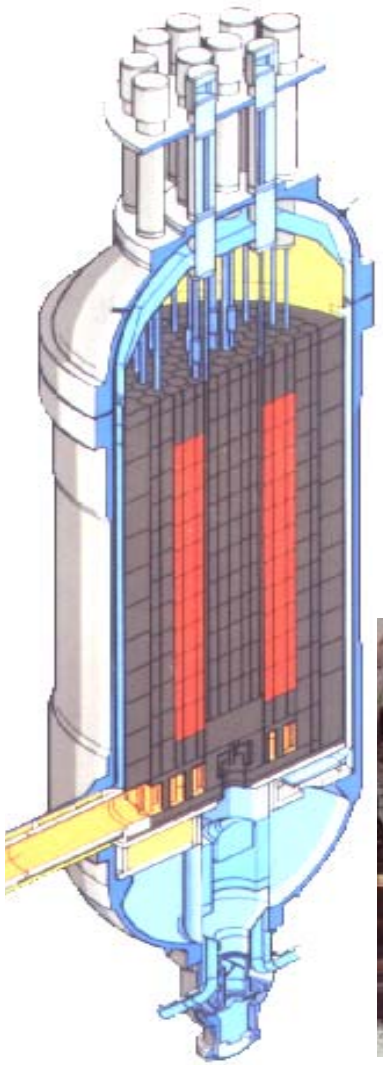
- Irradiation creep
- Thermal changes
- Mechanical changes
- Physical changes

High Dose Tensile Irradiation Creep Studies are still under discussion

AGC Schedule

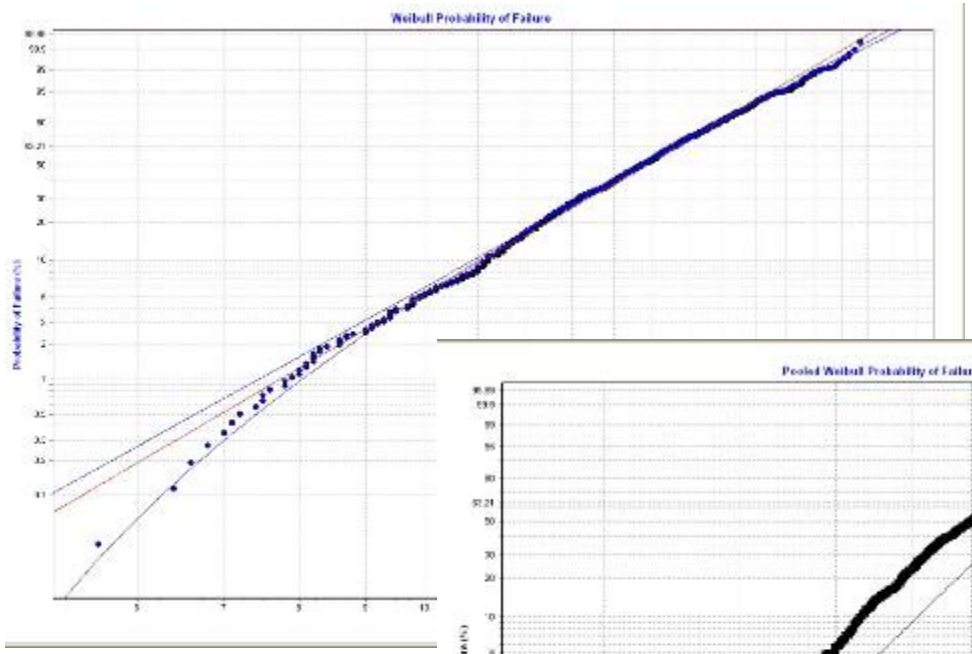


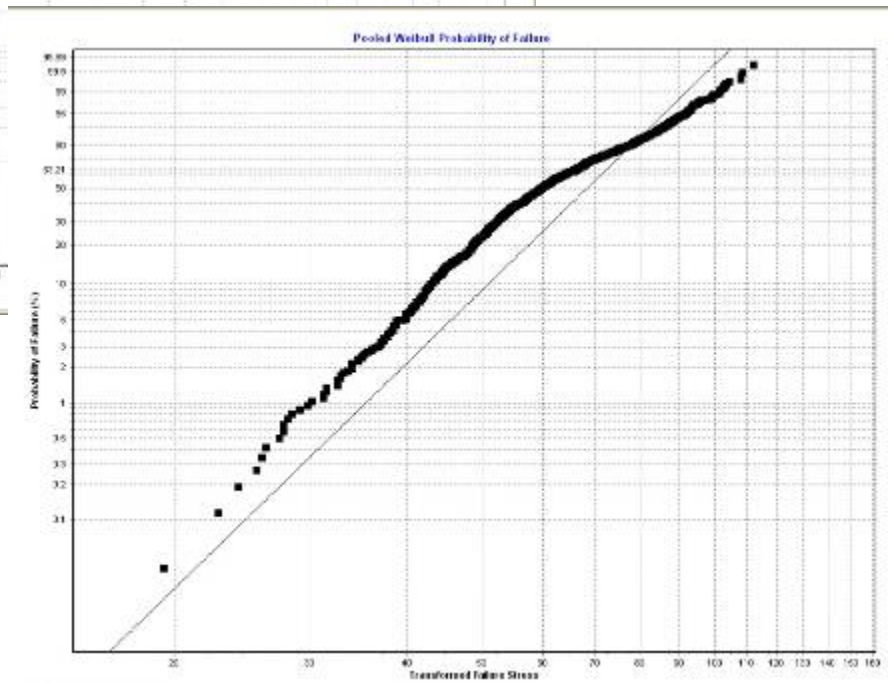
Whole core modeling



- Ground work needed before modeling begins
  - Investigate previous work and relationships
  - Gather past data and results
- Start to build relationship between reactor conditions and graphite behavior
- Employ probablistic rather than deterministic approaches

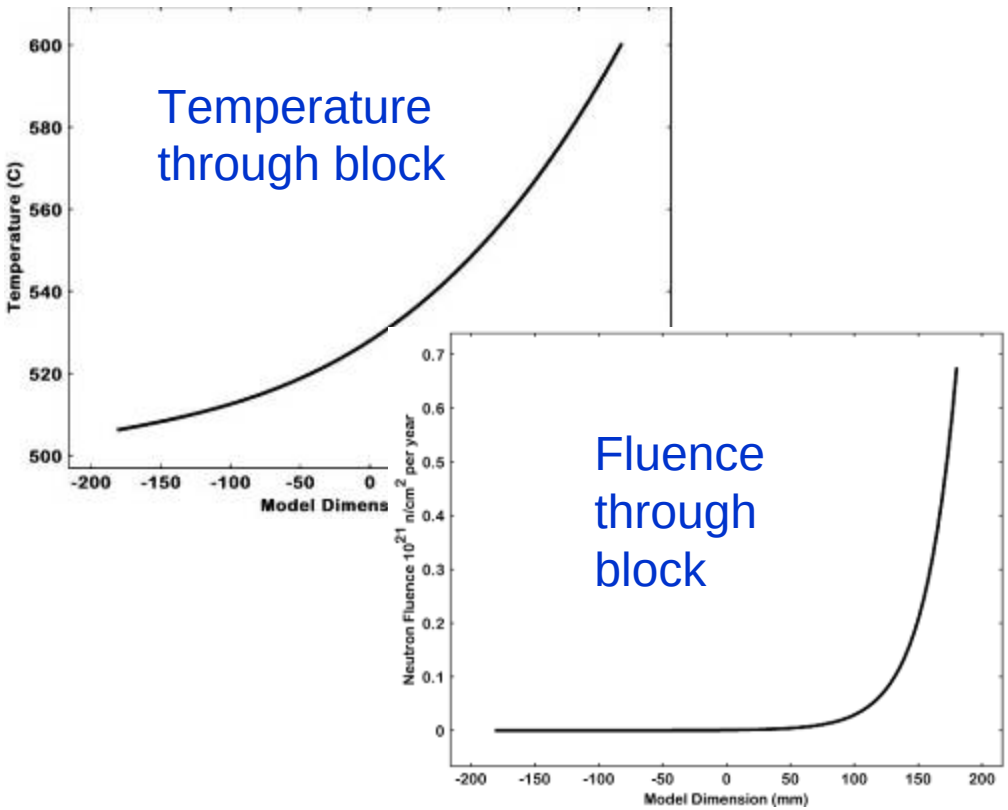
Modeling: Ground work



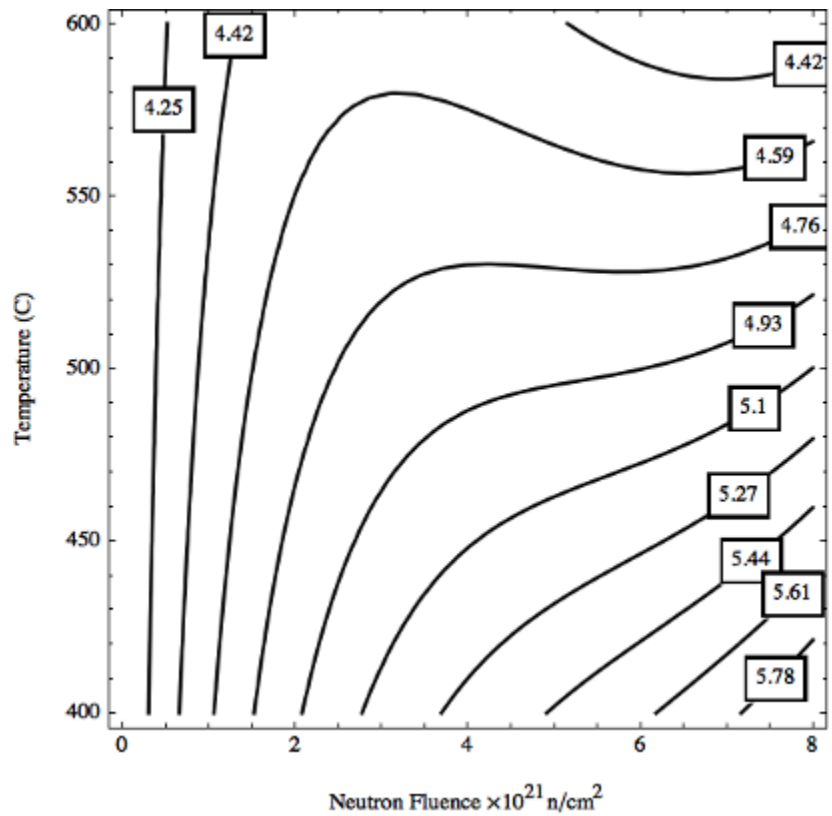


- Gleaning useful data from previous work (Price *et al.*)
- Now need to start to build relationship between current Rx conditions and new graphite types

Modeling: Assumptions and initial data

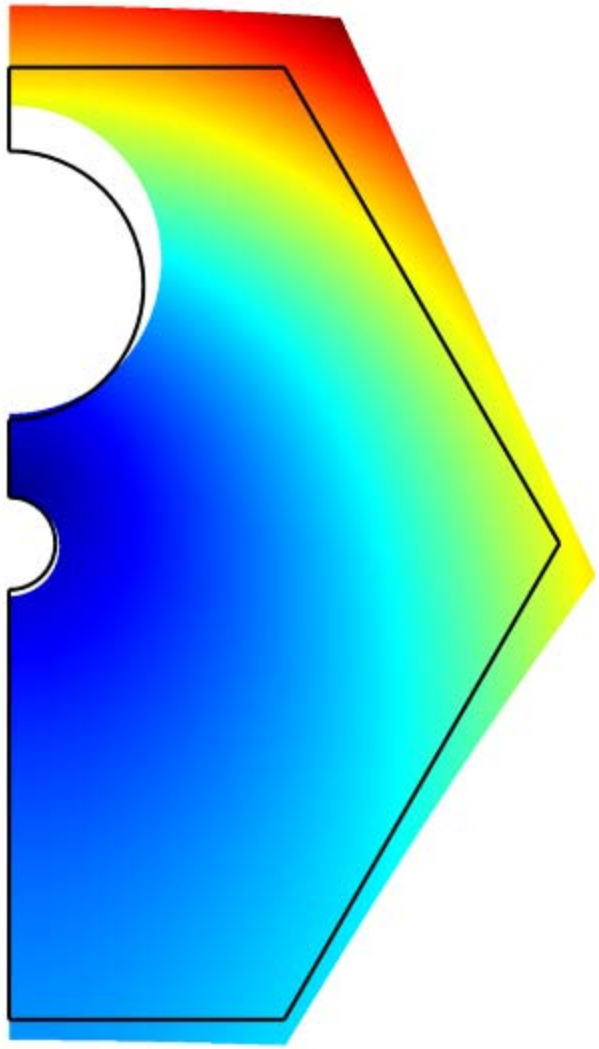


Thermal expansion due to dose and temperature in H451



- Current and past information combined to determine graphite behavior

Modeling: Initial models



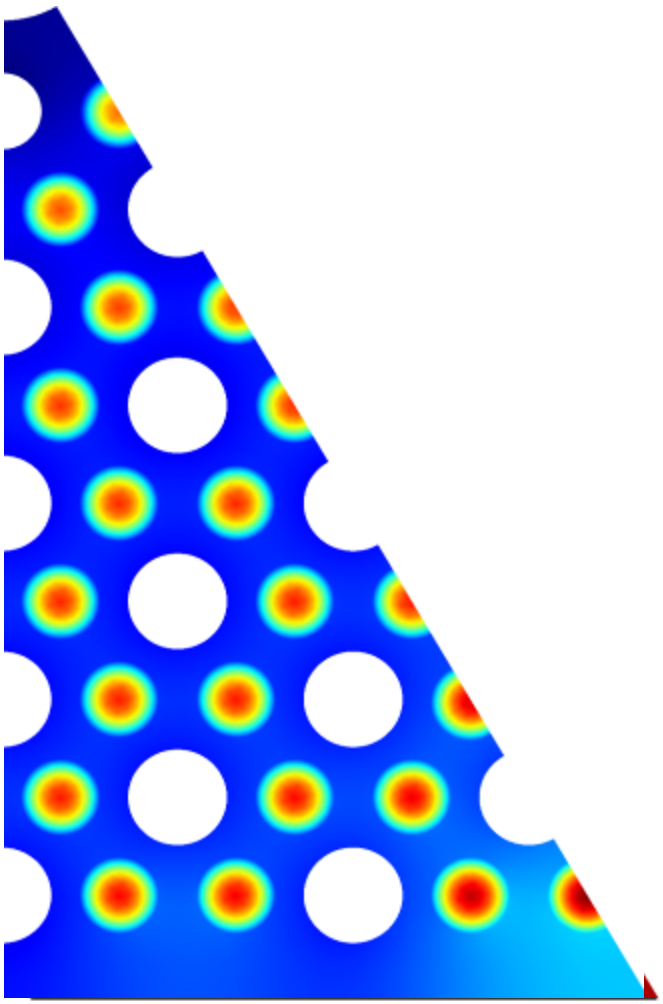
Initial models based upon NGNP conditions

- Temperature, flux, load, dose, dimensions, etc.

- Initial behavior modeled
  - Thermal displacements

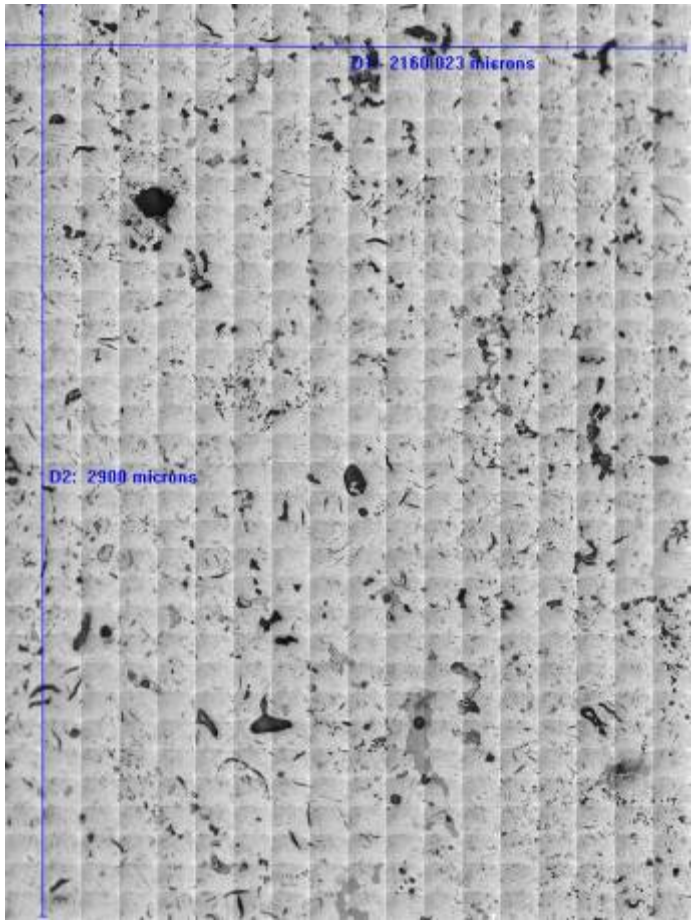
Modeling: Initial models

- Initial models based upon NGNP conditions
  - Temperature, flux, load, dose, dimensions, etc.
- Initial behavior modeled
  - Temperature gradients
  - Fuel & graphite temperature



Basic Research

- Minimal direct role from NGNP
- Long range research objectives
  - NEUP and university projects
  - IAEA
- Areas of interest
  - Irradiation creep
  - Strength/fracture
  - Microstructure evolution
  - Ceramic composites



- Considered critical to understanding the data generated from the rest of the program

ASME support

- ASME simply provides an accepted process for approving any data generated for the materials
- Code case = How to use a material in a specific application
- Looks at the whole picture
  - Baseline data, irradiation data, component modeling results, whole core modeling, and compares to the expected operating conditions

- **NRC is interested in having a code case for graphite**
  - Makes it easier to approve of graphite types
  - Makes it easier to use graphite over time with common understanding of behavior
  - But a code case is not mandatory, just harder

In summary

- All licensing data is taken by ASTM Standards
- Baseline material properties are the **real** values for graphite
  - Statistically valid, no weak pockets/areas
- AGC (irradiation) results are the changes to the material properties
  - Measured values are not the true material properties
- Whole core model is the final repository for the data
  - Data results and graphite behavior are interpreted using the model
- Research activities (NEUP/University) needed to understand results
- ASME simply provides an accepted process for approving any data generated for the materials

Thank You

- Questions ?