

July 14, 2020 – Session 3

**Will Windes**

DOE ART Graphite R&D Technical Lead

# AGC Status

AGC-4, HDG-1, ASME data

# Graphite Irradiation (AGC Experiment)

## Behavior models

- Predicts irradiated material properties and potential degradation issues
- Irradiation behavior for continued safe operation

## Licensing & Code

- Establishes an ASME approved code (for 1<sup>st</sup> time)
- Develops property values for initial components and irradiation induced changes

## Graphite R&D Program

Defines the safe working envelope for nuclear graphite and protection of fuel

## Virgin Properties

- (Statistically) Establishes as-received material properties
- Baseline data used to determine irradiation material properties

## Mechanisms and Analysis

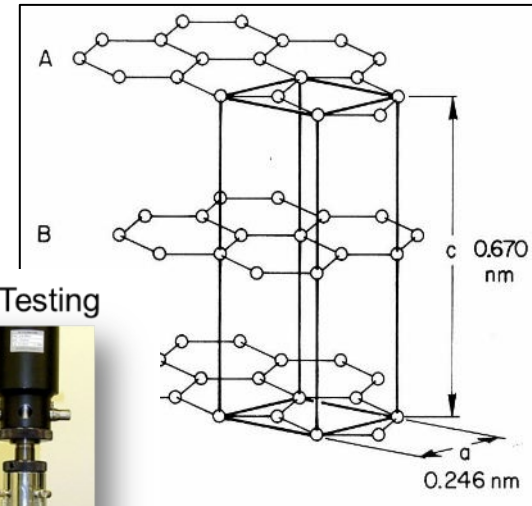
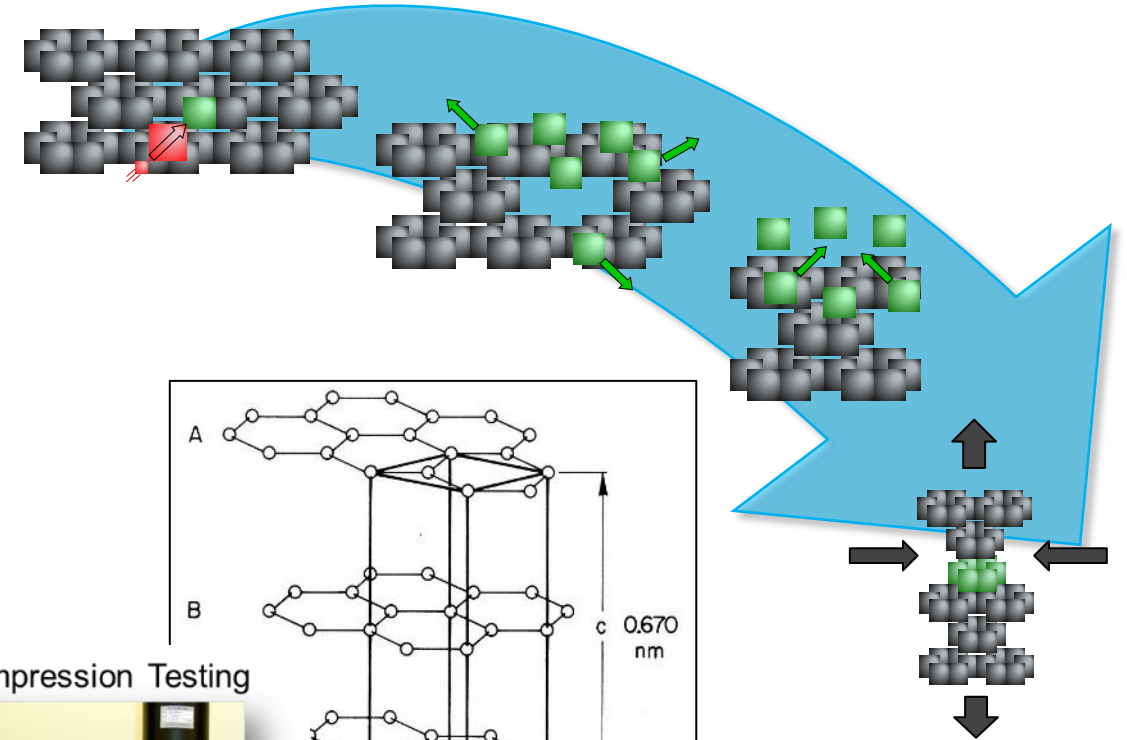
- Data analysis and interpretation
- Understanding the damage mechanisms is key to interpreting data

## Irradiation

- Determines irradiation changes to material properties
- Irradiation behavior for continued safe operation

# Topics of discussion

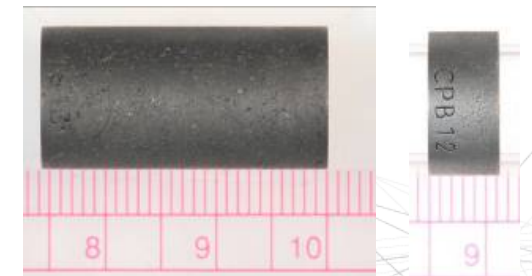
- Advanced Graphite Creep (AGC) Experiment
  - What is the AGC Experiment?
  - A timeline of what we have done so far
- Past
  - AGC-1, AGC-2, AGC-3, and HDG-1 irradiation
- Present
  - HDG-1 Irradiations
  - AGC-4 Disassembly
- Future
  - AGC-4 PIE
  - HDG Irradiations
- ASME Data
- Conclusions



Compression Testing



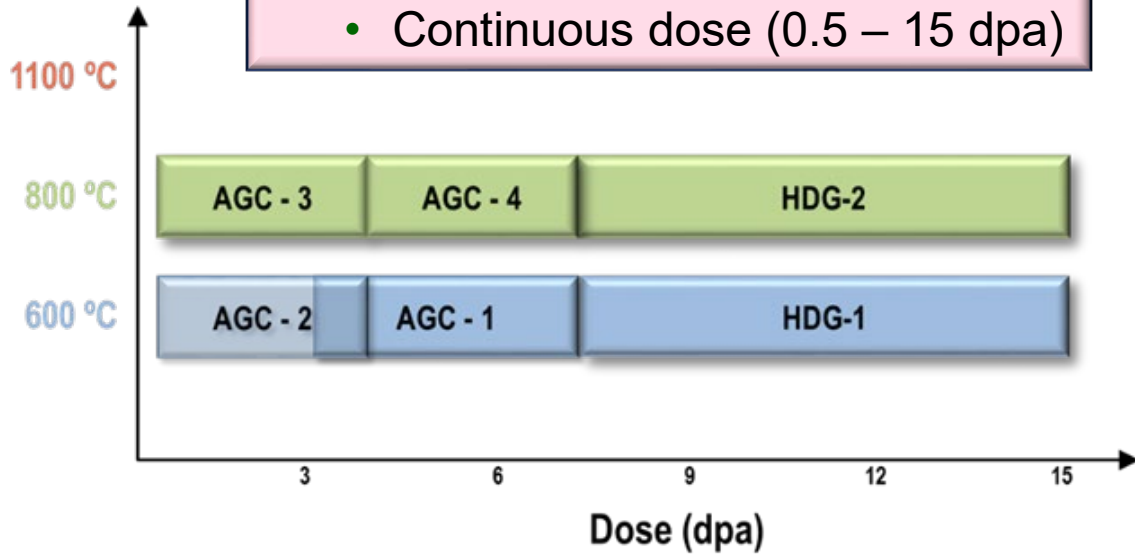
ASTM C695-91



# What is the AGC Experiment?

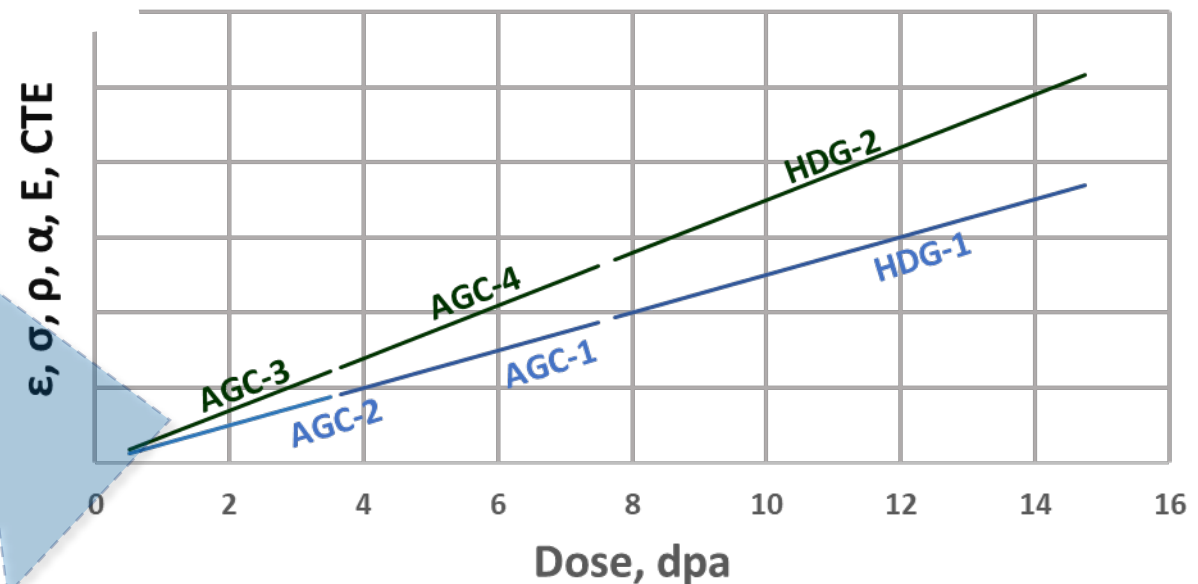
## Three pairs of test capsules

- ~500 samples / capsule
- 2 Irradiation temperatures
- 3 Stress levels
- Continuous dose (0.5 – 15 dpa)

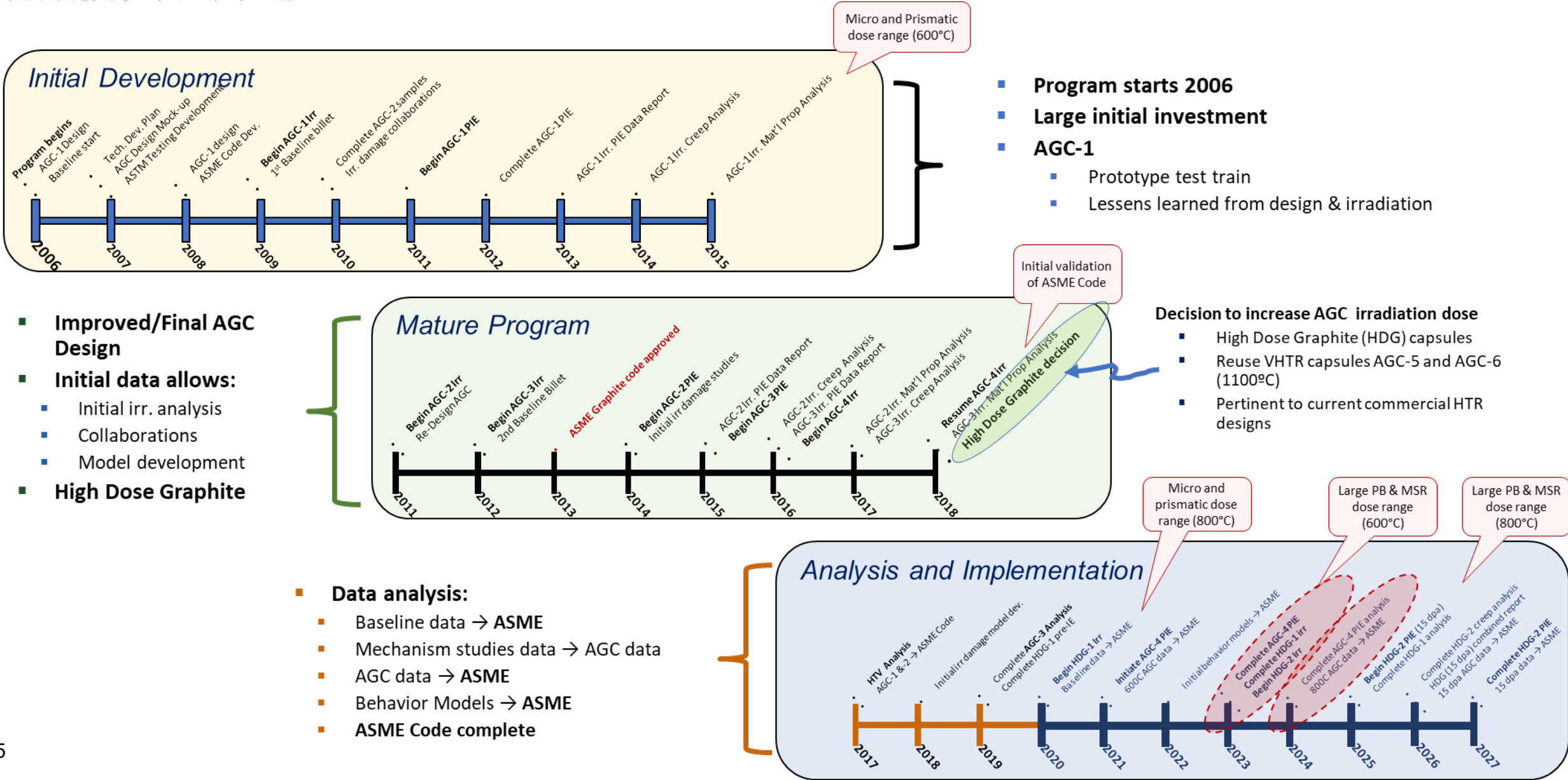


## By comparing between test series

- Property change by dose
- Property change by temperature
- Property change by stress
- Temperature dependent creep rate for each grade
- Irradiation induced changes before and after turnaround dose



# The AGC Experiment (AGC & HDG Capsules)



- Program starts 2006
- Large initial investment
- AGC-1
  - Prototype test train
  - Lessons learned from design & irradiation

- Improved/Final AGC Design
- Initial data allows:
  - Initial irr. analysis
  - Collaborations
  - Model development
- High Dose Graphite

- Decision to increase AGC irradiation dose
- High Dose Graphite (HDG) capsules
  - Reuse VHTR capsules AGC-5 and AGC-6 (1100°C)
  - Pertinent to current commercial HTR designs

- Data analysis:
  - Baseline data → ASME
  - Mechanism studies data → AGC data
  - AGC data → ASME
  - Behavior Models → ASME
  - ASME Code complete

# Past Accomplishments

## Completed initial 600°C & 800°C irradiation

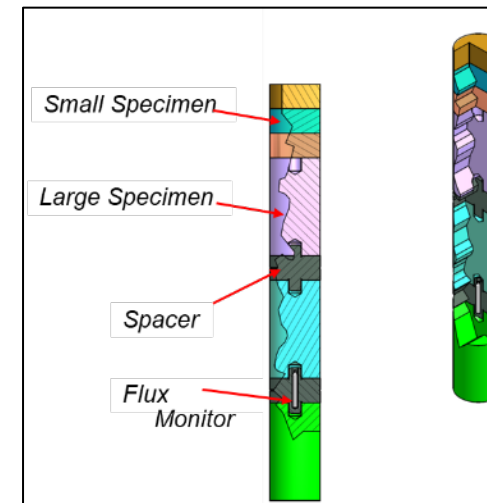
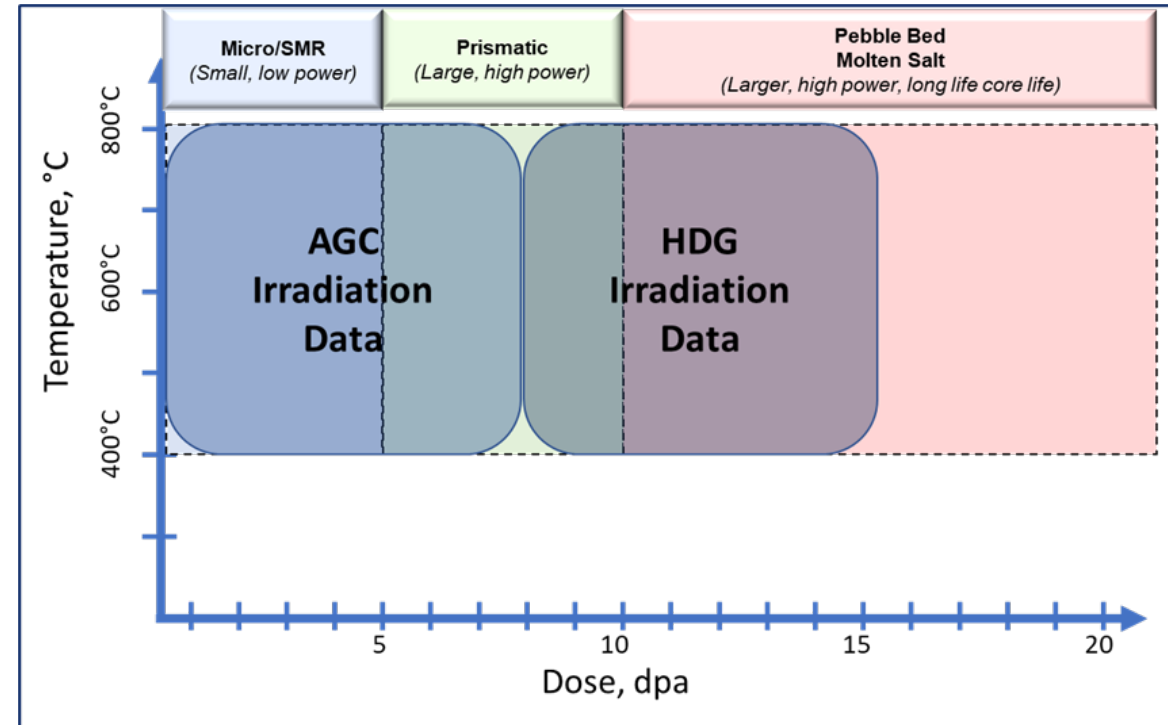
- AGC-1 and AGC-2 (600°C, 0 - 7 dpa)
- AGC-3 and AGC-4 (800°C, 0 - 8 dpa)

## Completed initial PIE

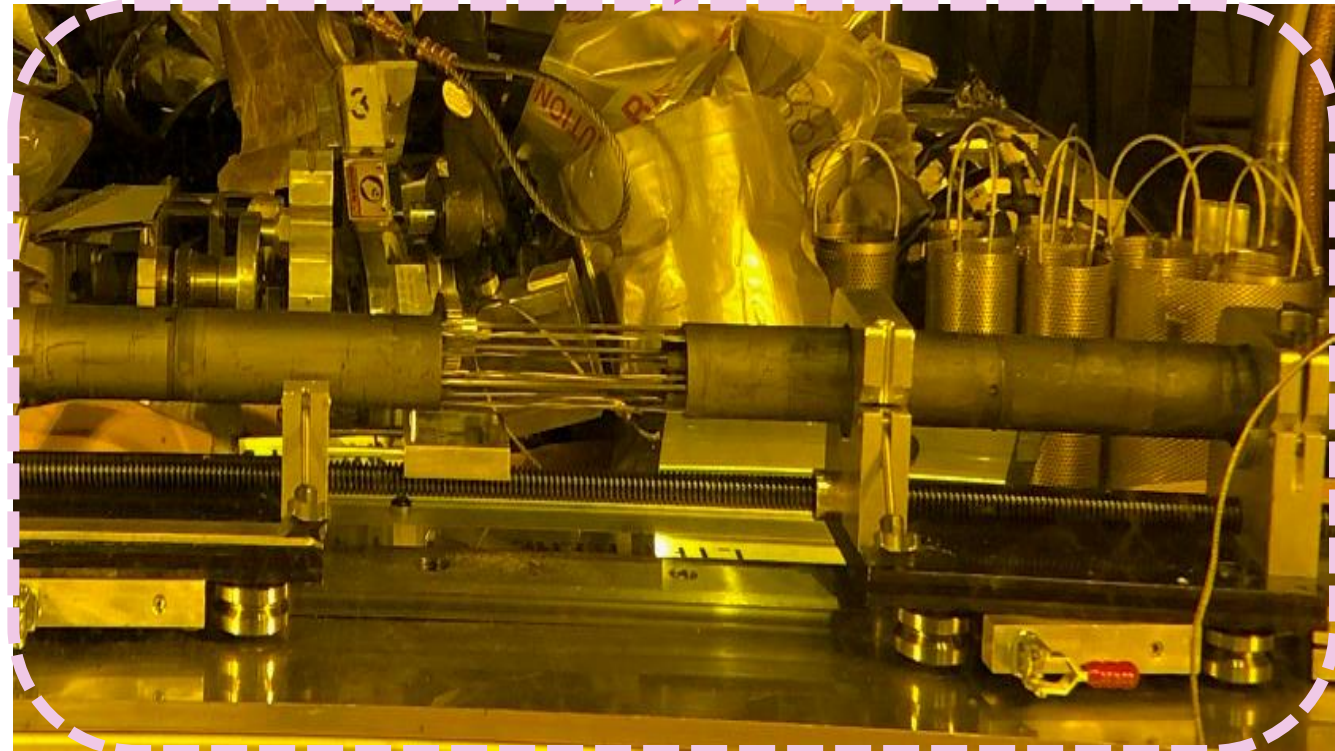
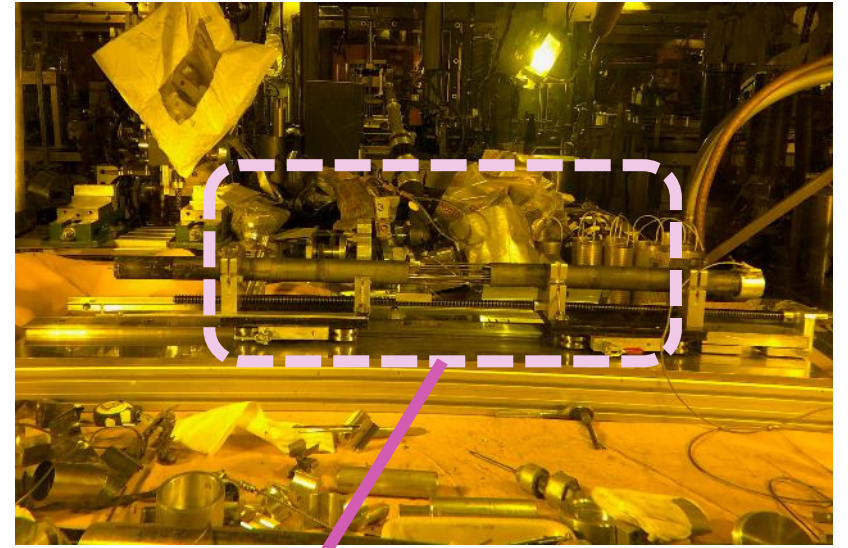
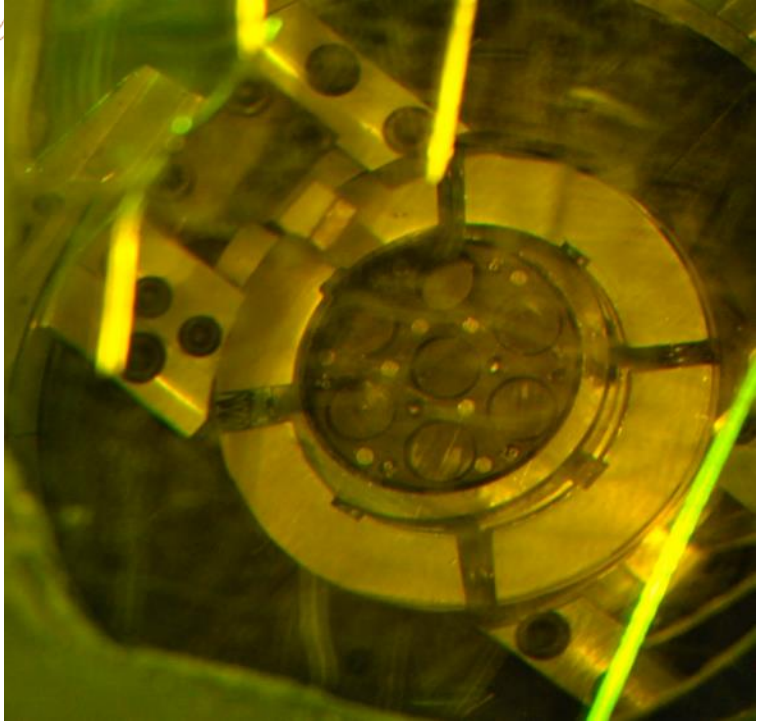
- AGC-1 and AGC-2 (600°C, 7 dpa)
- AGC-3 (800°C, 8 dpa)
- **AGC-4 in 2021/2022**

## Re-irradiate select samples

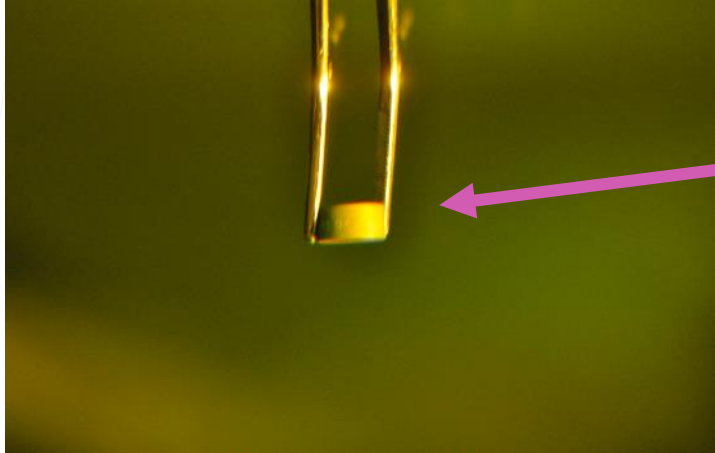
- HDG-1 has 2 of 11 irradiation cycles
  - Currently out for ATR CIC (Core Internals Changeout)
  - AGC-2 samples → HDG-1
- HDG-2 capsule design and sample order complete
  - AGC-3 & AGC-4 samples → HDG-2



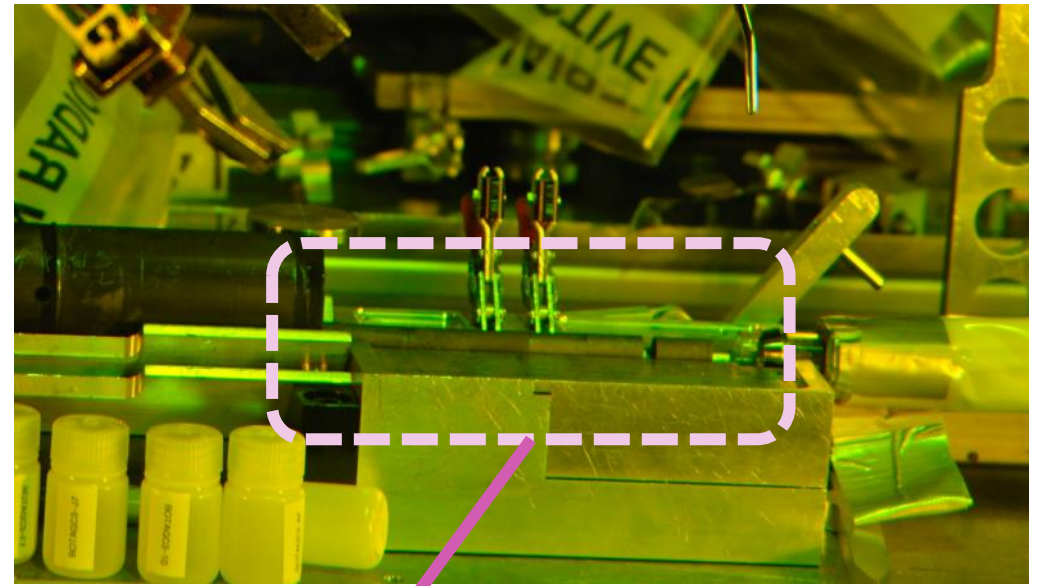
# Present Status – AGC-4 Disassembly



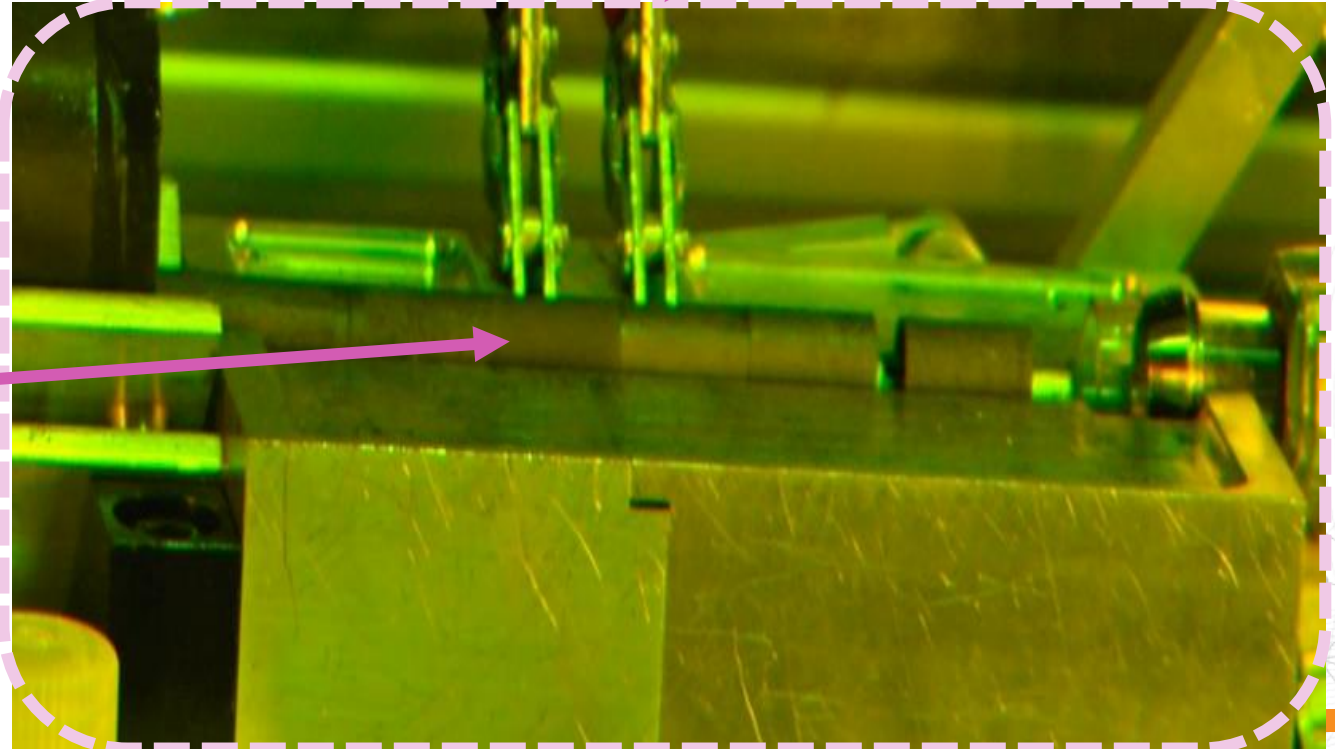
# Present Status – AGC-4 Disassembly



**Piggyback sample**

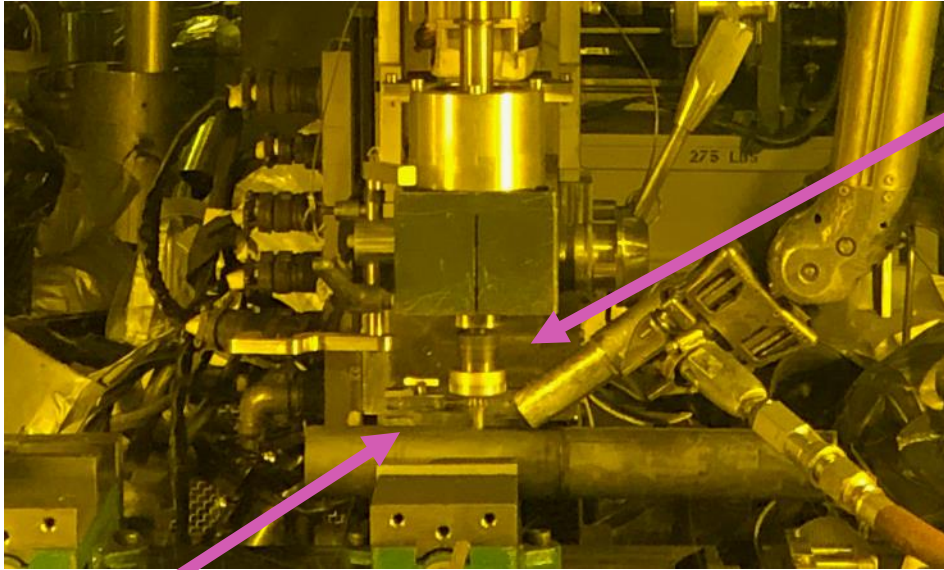


**Creep samples**  
Being loaded in  
transfer tubes





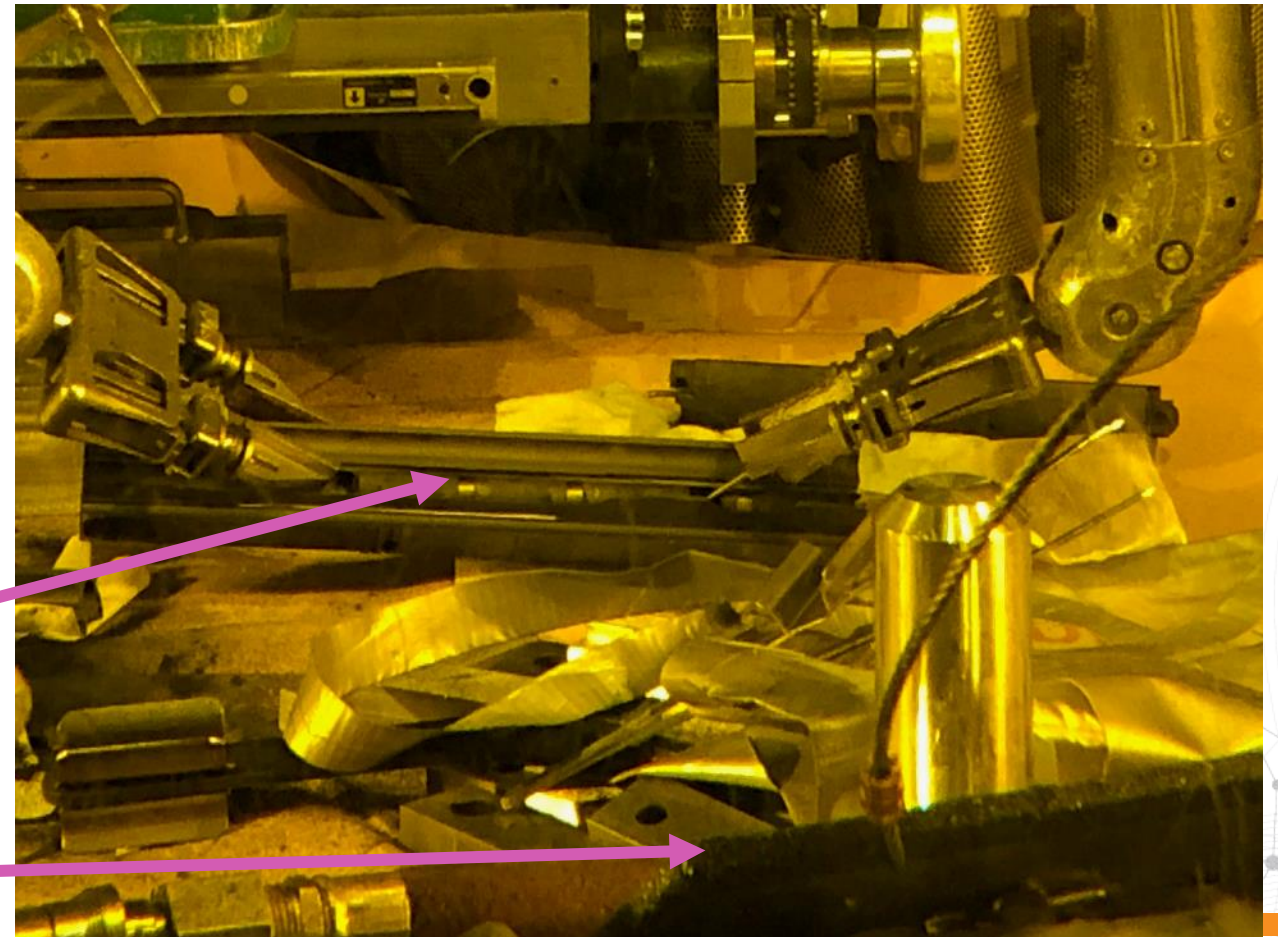
# Present Status – AGC-4 Disassembly



**Milling machine**  
Milling graphite body open

**Graphite Body**

**Extracting piggyback samples**  
From machined Graphite Body



**Broken half of graphite body**

# Present & Future Status – AGC-4

## Nearly all AGC-4 samples recovered

- Approximately 4-5 samples were clearly crushed
- A final count during PIE

## High activity levels detected

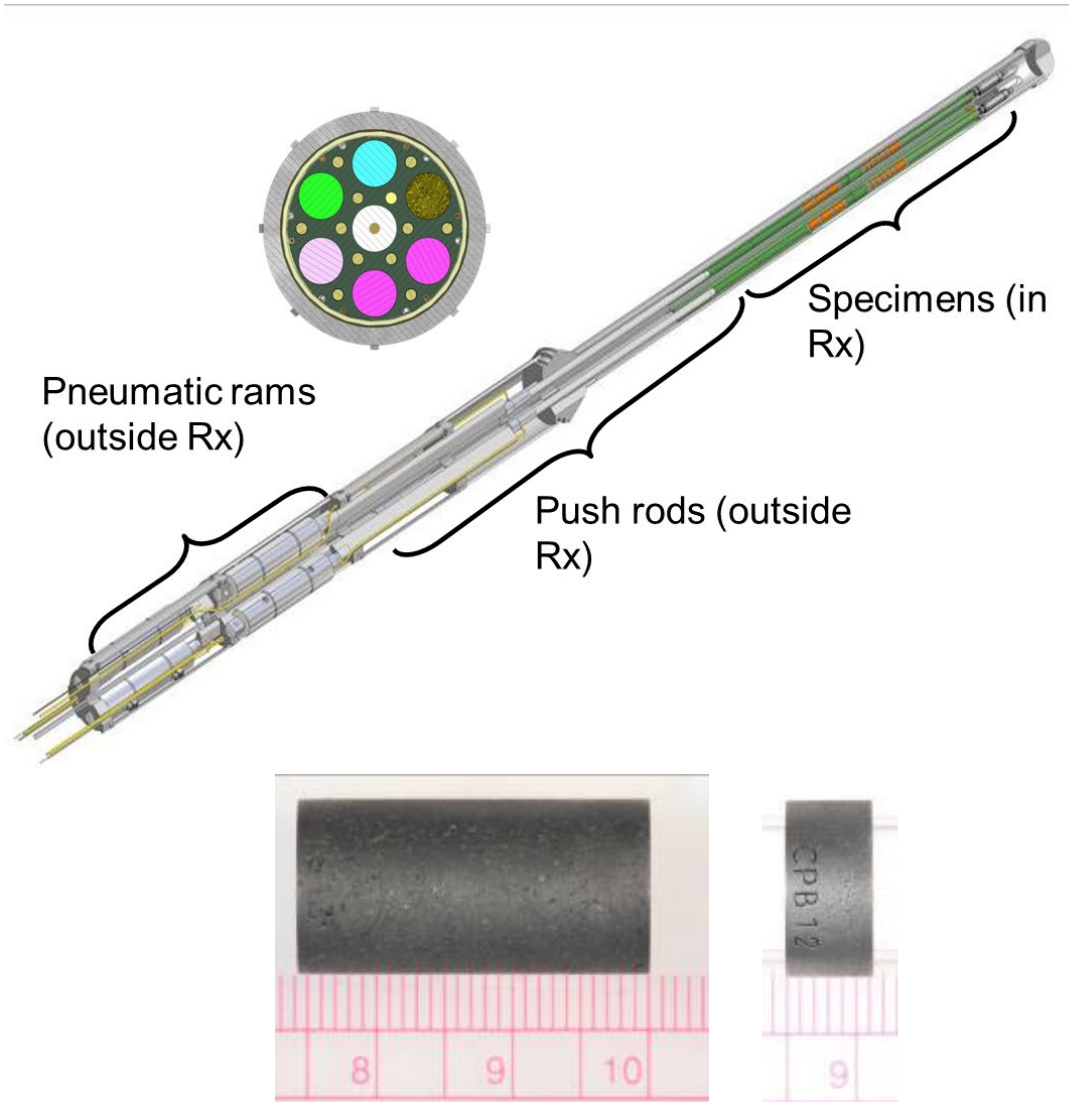
- Initial activity levels of samples are very high
- Samples being transferred to Analytical Lab
- We should have analysis completed end of month

## PIE options based on activity levels

- If activity levels are low enough → Carbon Lab
  - Modestly shielded glovebox
  - So, sample activities must be pretty low
- If activity levels are too high → PIE on the desert
  - Want to avoid this if at all possible



# Present & Future – High Dose Graphite capsules



## HDG-1 irradiation

- Currently out of reactor during ATR CIC
- Should be re-inserted 4<sup>th</sup> quarter of 2021
- 2 of 11 irradiation cycles have occurred
  - *Temperature is slightly higher than anticipated (+/- 100C, rather than +/- 50C)*

## HDG-2 irradiation

- Capsule design is unchanged
- Initial loading order has been established
  - Samples from AGC-3 and AGC-4 (800C) will be used for HDG-2
  - AGC-4 sample activity may affect loading order
- HDG-2 will undergo irradiation immediately after HDG-1 is complete
  - Anticipated mid-2023 timeframe

**Note: Final AGC Experiment irradiation schedule is unaffected by AGC-4 delays**

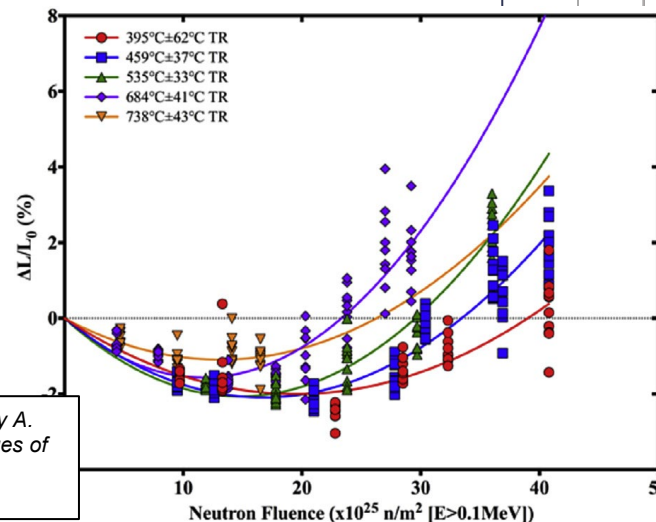
# ASME : Irradiation data

Main function of AGC was to provide “case study” data

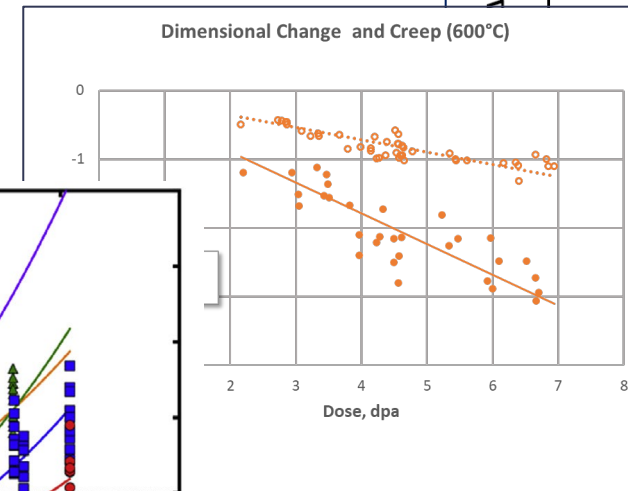
- Irradiation data for a specific grade
  - Case study to be built for each grade
- There are problems with this approach
  - Many Rx designers are using other grades
  - No ASTM standard for nuclear grade graphite

Generic response using all data

- AGC data will be used along with other data
  - Creep data will be very important
- General design rules for all grades
- Data to be contained within referenceable white papers in BPVC appendixes



From: Anne A. Campbell, Yutai Katoh, Mary A. Snead, Kentaro Takizawa, "Property changes of G347A graphite due to neutron irradiation", Carbon 109 (2016) 860-873



From: William E. Windes David T. Rohrbaugh W. David Swank, "AGC-3 Irradiation Creep Strain Data Analysis", INL/EXT-19-54725, July 2019

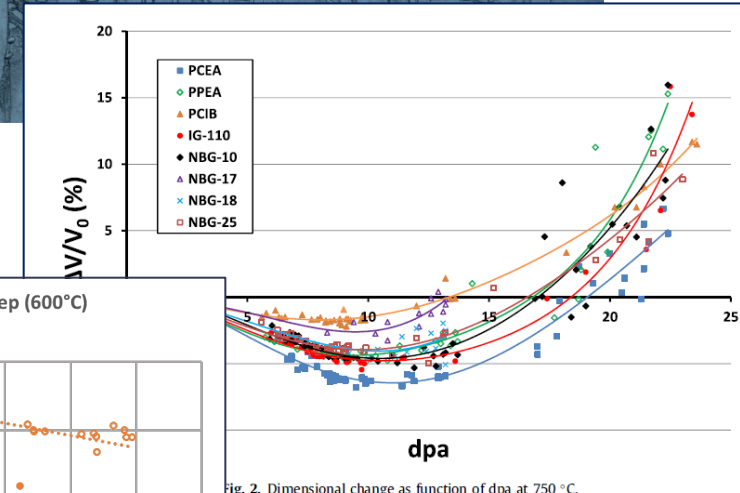


Fig. 2. Dimensional change as function of dpa at 750 °C.

M.C.R. Heijna, S. de Groot, J.A. Vreeling, "Comparison of irradiation behaviour of HTR graphite grades", Journal of Nuclear Materials 492 (2017) 148e156

# Conclusions on FY21 Graphite Status

## AGC Experiment Status:

- **AGC-1 & AGC-2** : 600°C (0.5 to 7 dpa)
  - Initial irradiation, PIE, and analysis is complete
- **AGC-3** : 800°C (0.5 to 3.5 dpa)
  - Initial irradiation, PIE, and analysis is complete
- **AGC-4** : 800°C (3 to 8.5 dpa)
  - Irradiation complete (February 2020)
  - **Undergoing disassembly now**
  - PIE (2021 – 2022)
  - Analysis and data to Handbook (2022)
- **HDG-1** : 600°C (7 to 15 dpa)
  - Currently in reactor (August 2020): 2 1/2 year cycle to max. 15 dpa
  - **Re-irradiation of AGC-2 specimens**
    - Added super-fine grain sized grades => Of interest for MSR applications
- **HDG-2** : 800°C (7 to 15 dpa)
  - Irradiation begins 2023
  - Re-irradiation of AGC-3 & -4 specimens to max. 15 dpa

|              | Pre-Irr testing      | Design Capsule | Assemble & Insert | Irradiate | PIE | Analysis |
|--------------|----------------------|----------------|-------------------|-----------|-----|----------|
| <b>AGC-1</b> | [Progress bar: 100%] |                |                   |           |     |          |
| <b>AGC-2</b> | [Progress bar: 100%] |                |                   |           |     |          |
| <b>AGC-3</b> | [Progress bar: 100%] |                |                   |           |     |          |
| <b>AGC-4</b> | [Progress bar: ~85%] |                |                   |           |     |          |
| <b>HDG-1</b> | [Progress bar: ~60%] |                |                   |           |     |          |
| <b>HDG-2</b> | [Progress bar: ~10%] |                |                   |           |     |          |

Dave Rohrbaugh, Will Windes, and W. David Swank, "HDG-1 Graphite Pre-Irradiation Data Package Report", August 2020