



# AGC Experiment Status

July 2024

*Changing the World's Energy Future*

William E Windes



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# **AGC Experiment Status**

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**July 2024**

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U.S. Department of Energy  
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**GAS-COOLED REACTOR**

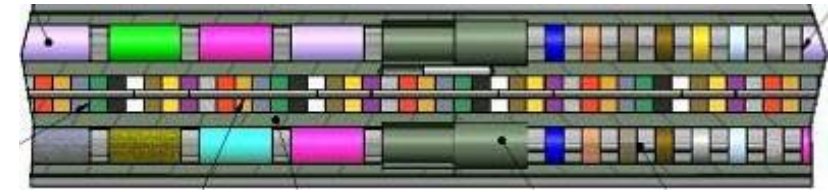
ADVANCED REACTOR TECHNOLOGIES PROGRAM

17 July 2024

# AGC Experiment Status

**Will Windes**

DOE ART Graphite Technical Lead - INL



DOE ART GCR Review Meeting

*Hybrid Meeting at INL*

July 16–18, 2024

# History and status of the AGC-4

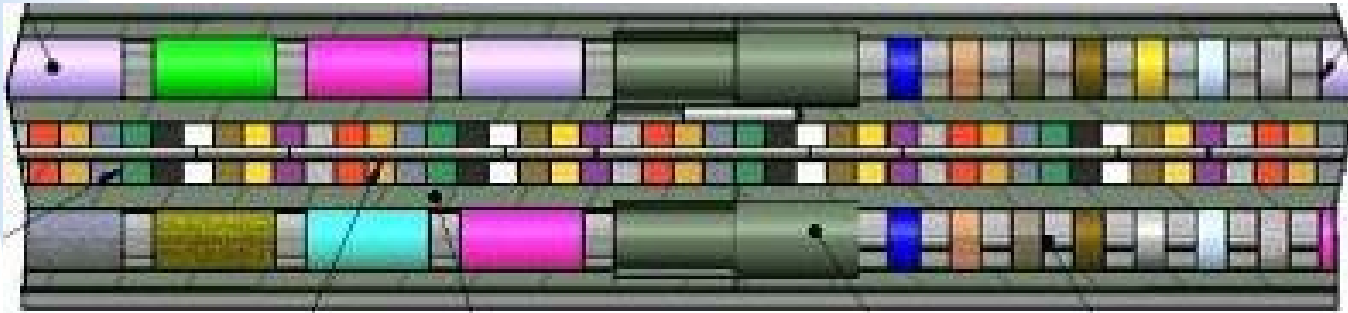
- A review of the AGC experiment
  - What is it and why is it important?
  - Capsule and specimen layout
  - Experimental test matrix (old and new)
  - Status of the experiment irradiation schedule
- The AGC-4 capsule and specimens
  - Irradiation and disassembly history
  - Status of the PIE measurements so far
  - What/when will be complete



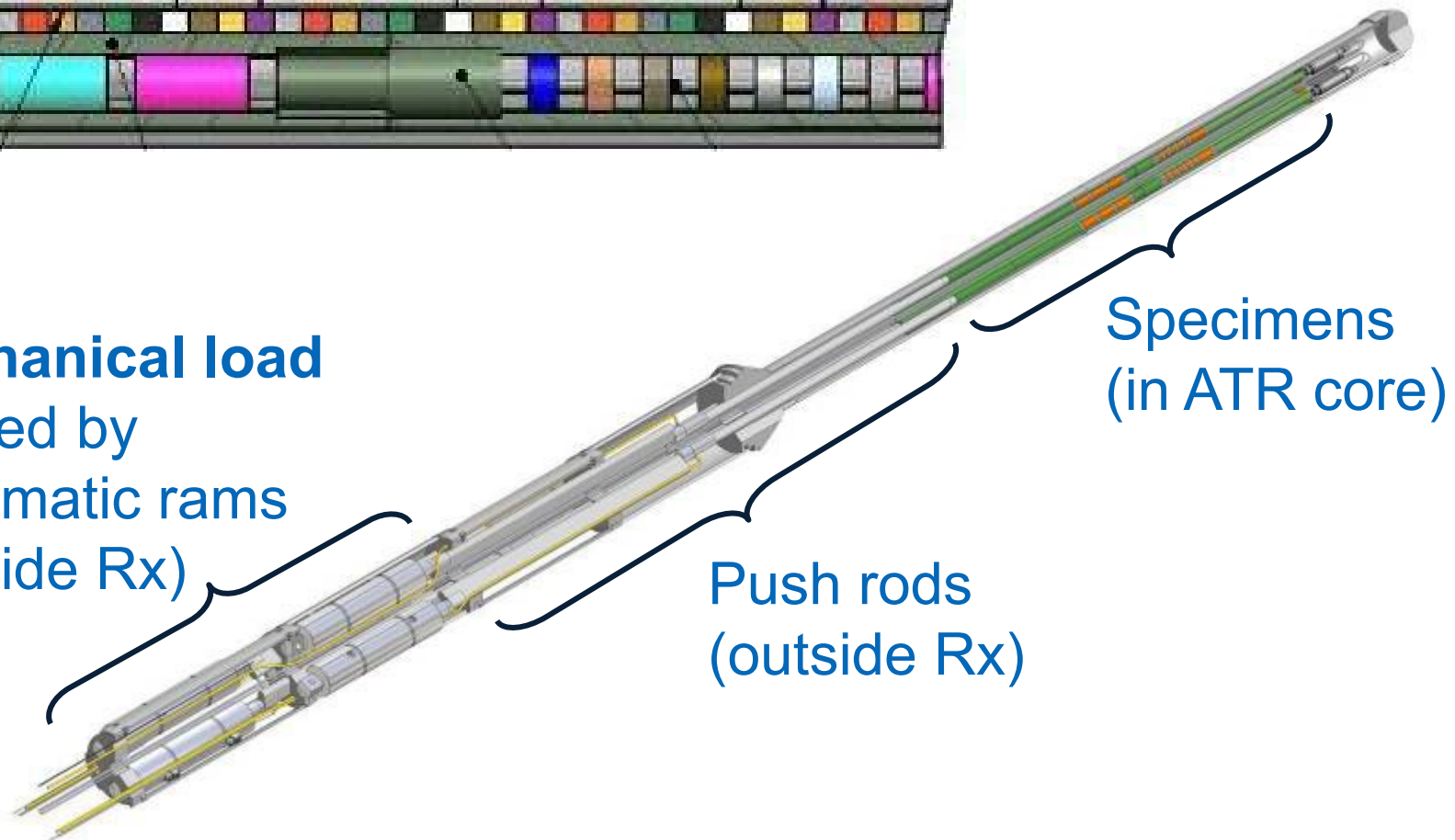
# What is the AGC Experiment?

## Advanced Graphite **Creep** (AGC)

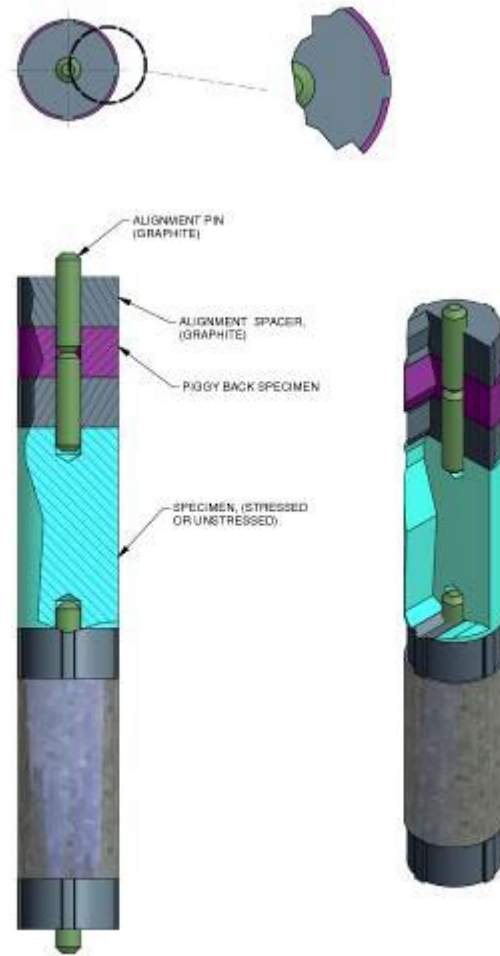
- Largest irradiation creep experiment in world.
  - 2000+ specimens
  - 10,000s of data points



**Mechanical load**  
applied by  
pneumatic rams  
(outside Rx)

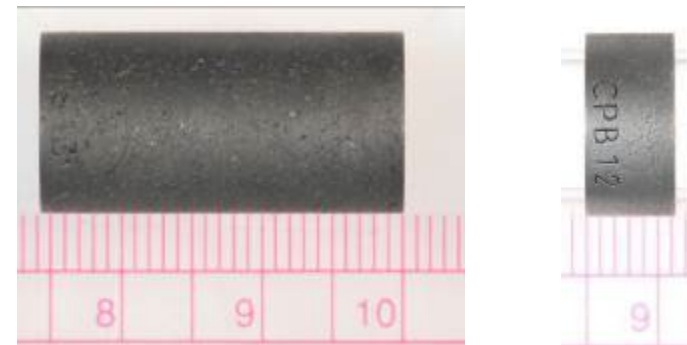


# AGC graphite grades and samples

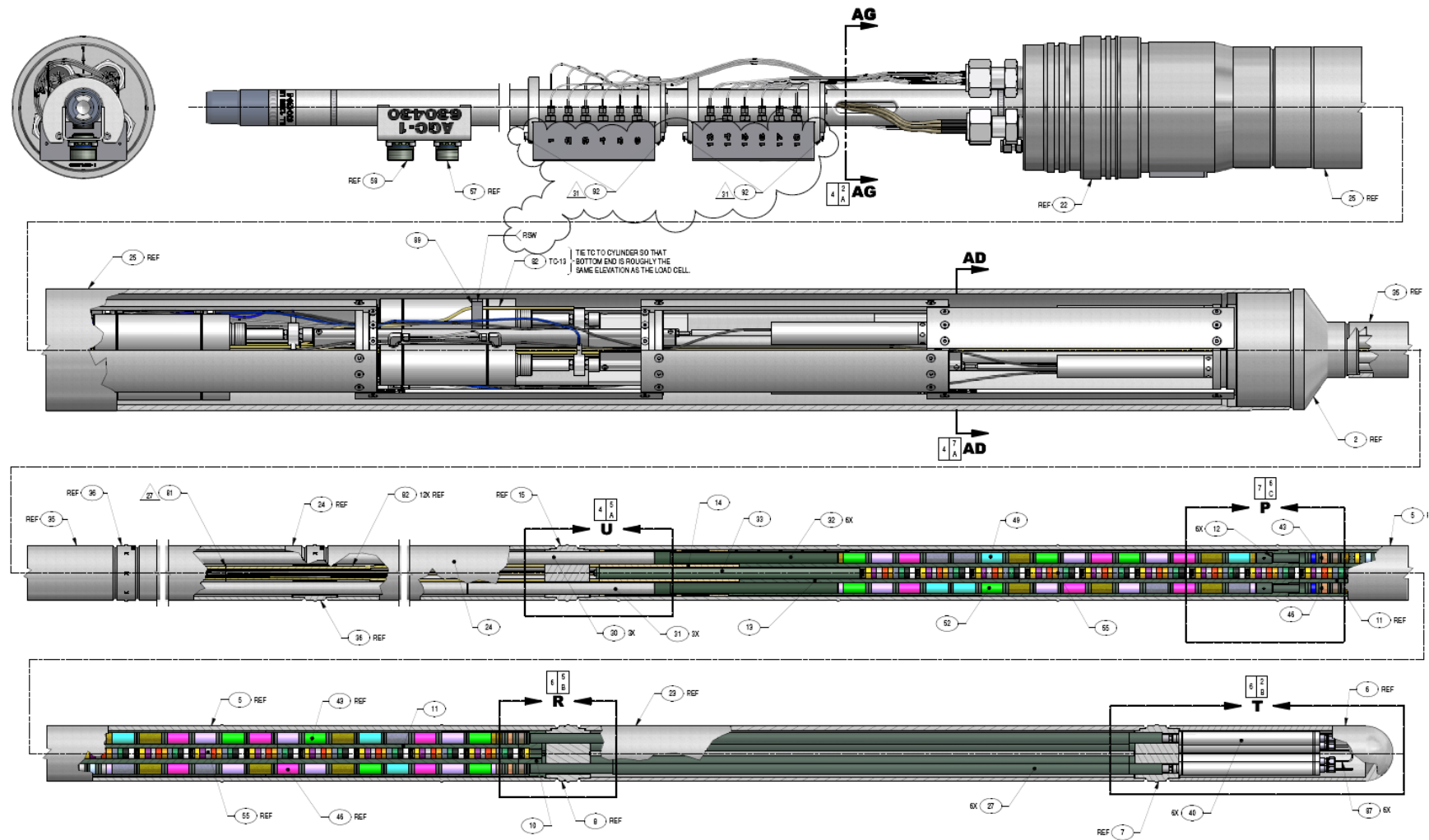


AGC sample loading scheme

- Creep samples
  - $\text{Ø}12 \text{ mm} \times 25 \text{ mm}$  ( $1/2'' \times 1''$ )
- Piggyback “button” samples
  - $\text{Ø}12 \text{ mm} \times 6 \text{ mm}$  ( $1/2'' \times 1/4''$ )
- Six-seven major (creep) grades
  - H-451, IG-110, PCEA, NBG-18, NBG-17, 2114, and IG-430
- Ten piggyback grades
  - NBG-25, PCIB, PPEA, NBG-10, BAN, HLM, PGX, S2020, HOPG, and A3 matrix



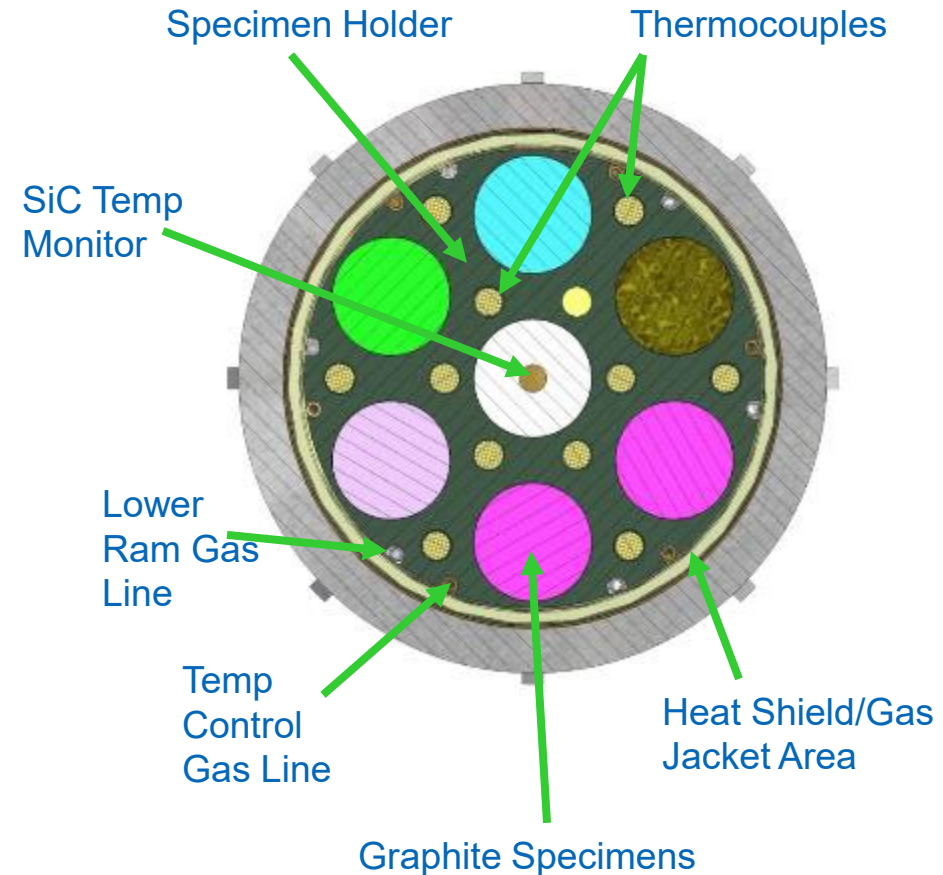
# AGC-1 Test Train





# AGC-1 Test Train Design Features

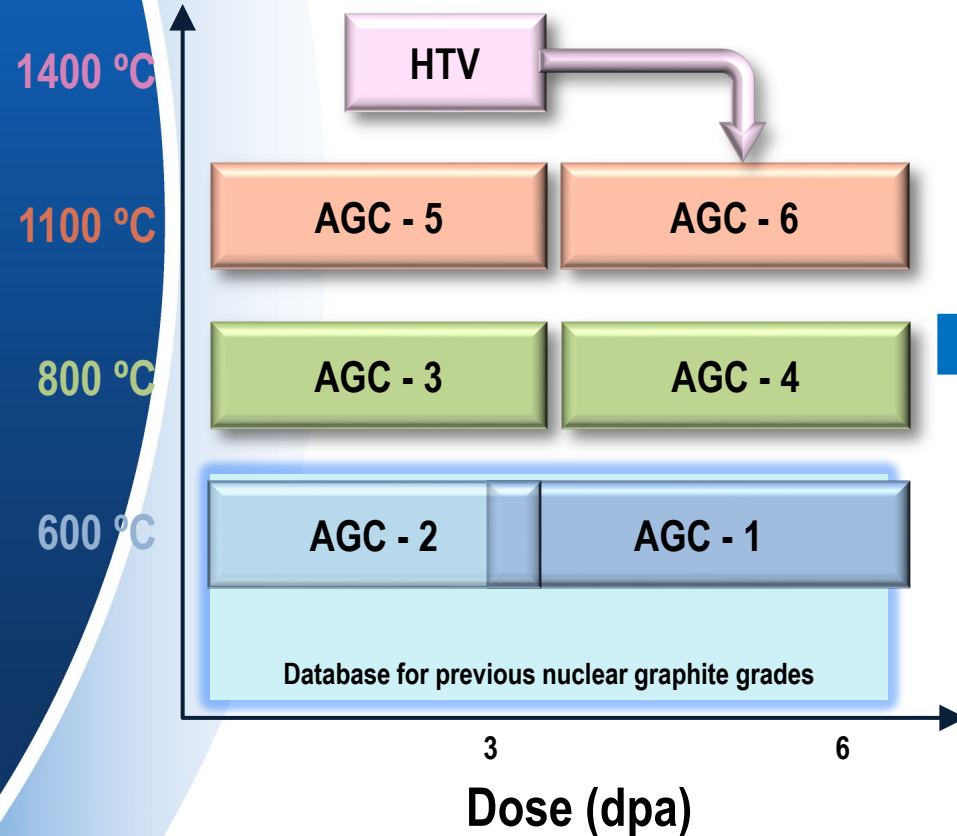
- Six specimen stacks around capsule perimeter with compressive load on upper half of stack
- Seventh specimen stack in center without compressive load
- Graphite specimen holder to contain graphite specimen stacks and thermocouples (TCs)
- 12 TC locations with positions located through core height
- Flux wires in spacers between graphite specimens in peripheral stacks
- Heat shield between graphite and capsule boundary to limit radiation heat transfer to capsule boundary



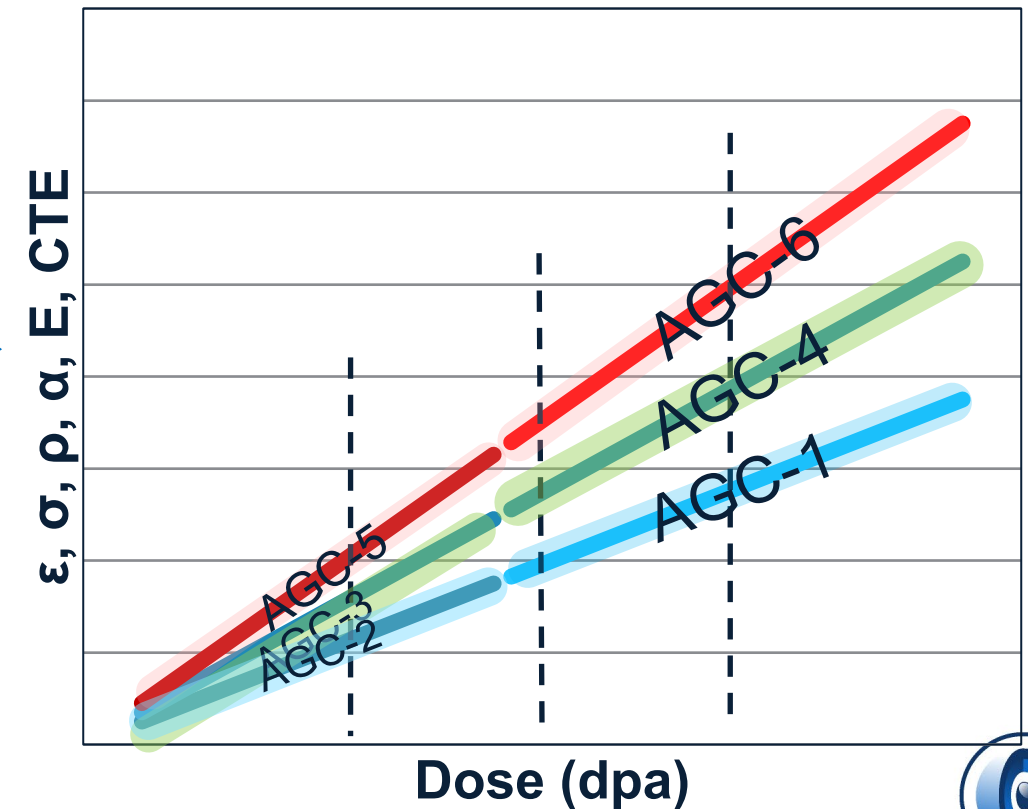
AGC Capsule Cross Section

# Original purpose and scope of AGC experiment

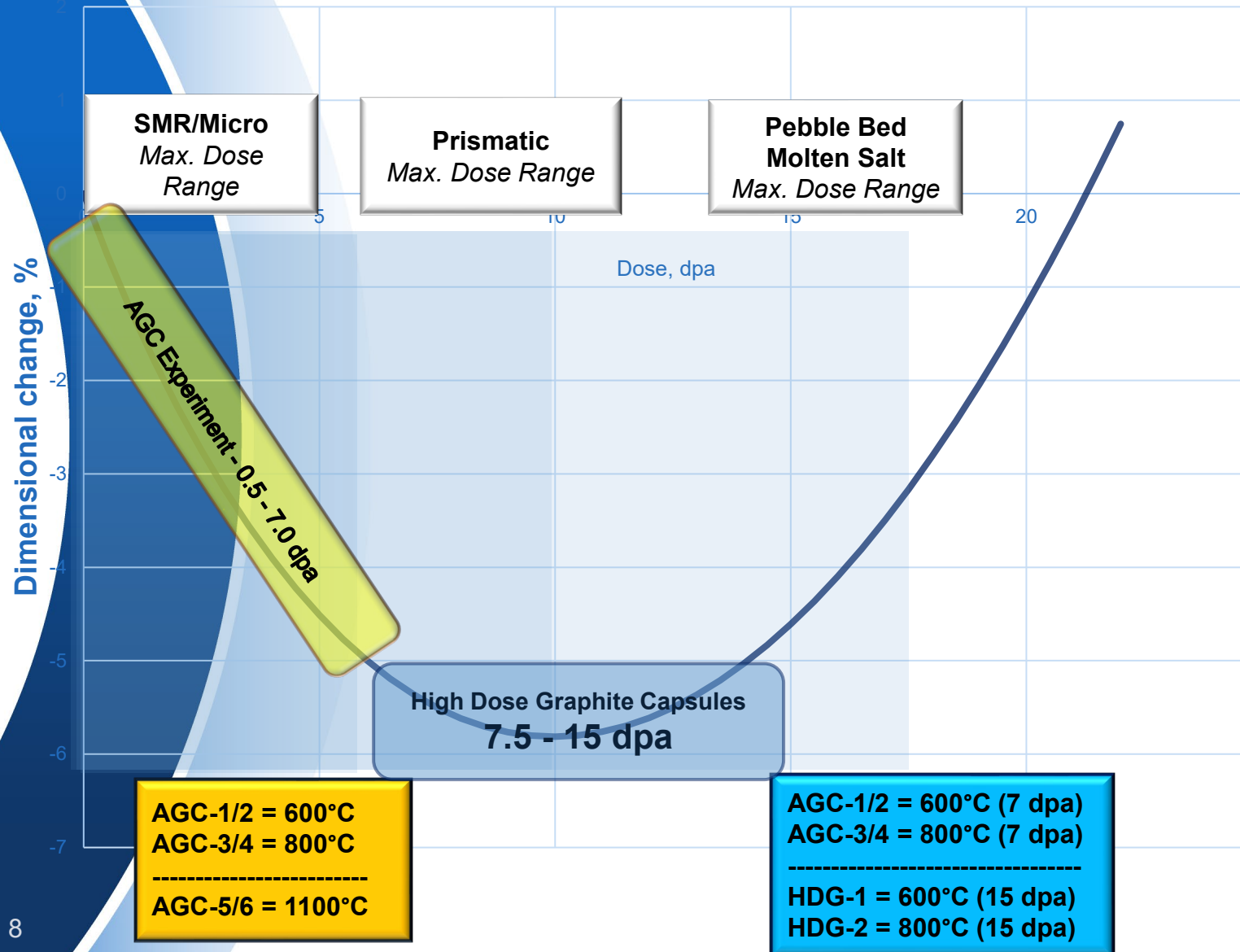
- Three pairs of test capsules
  - 3 Temperatures
  - 3 Stress levels
  - Continuous dose (0.5 – 7 dpa)



- By comparing between test series
  - Property change by dose
  - Property change by temperature
  - Property change by stress



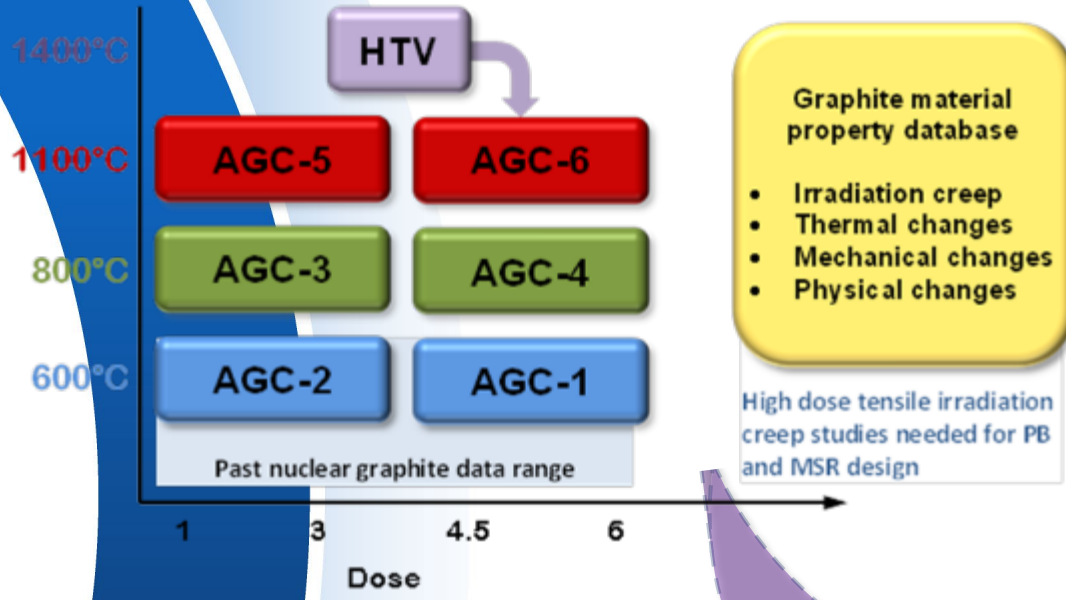
# Redirection of AGC irradiation program – High Dose Capsules



## Re-irradiation of existing AGC samples

- Reuse previous irradiated specimens
  - Already have up to 7 dpa dose
    - Saves time and money
    - Timely release of data to vendors
  - Irradiations past Turnaround
    - Significant changes to irr. Behavior
    - Very little data past Turnaround
    - Even less **creep** data past Turnaround
  - AGC-2 (600°C samples) in 1<sup>st</sup> capsule
  - AGC-3 & 4 (800°C samples) in 2<sup>nd</sup> capsule
- Repurpose AGC-5 & AGC-6 capsules
  - No new capsule
  - No change to design
    - Already irr. to 600°C & 800°C
  - Replaces AGC-5 & AGC-6 irradiation
  - **Minor changes to assembly of capsule**
- No changes to PIE
  - Testing in INL's CCL w/o additional changes
  - Sample rad levels should be similar

# New AGC Irradiation Schedule (2018)

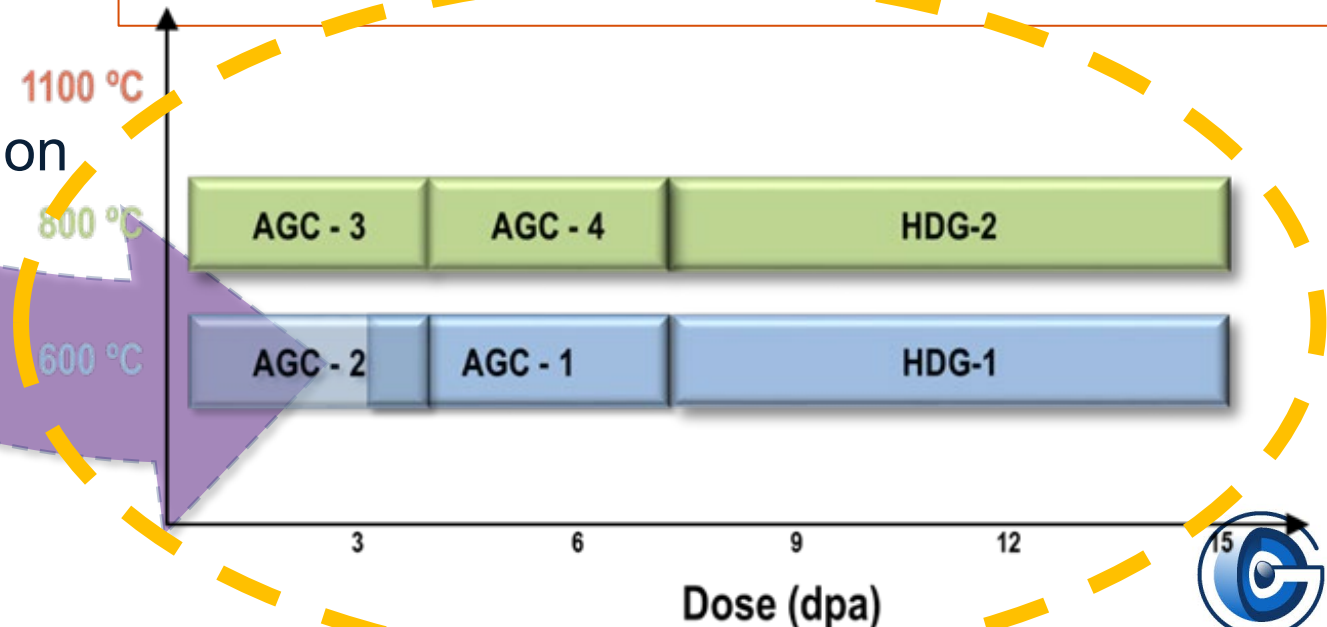


## ■ New AGC direction

- Higher Dose (15 dpa)
  - High Dose Graphite (HDG Capsules)
- Lower Temperatures (600 – 800°C)
- Re-irradiating previous specimens

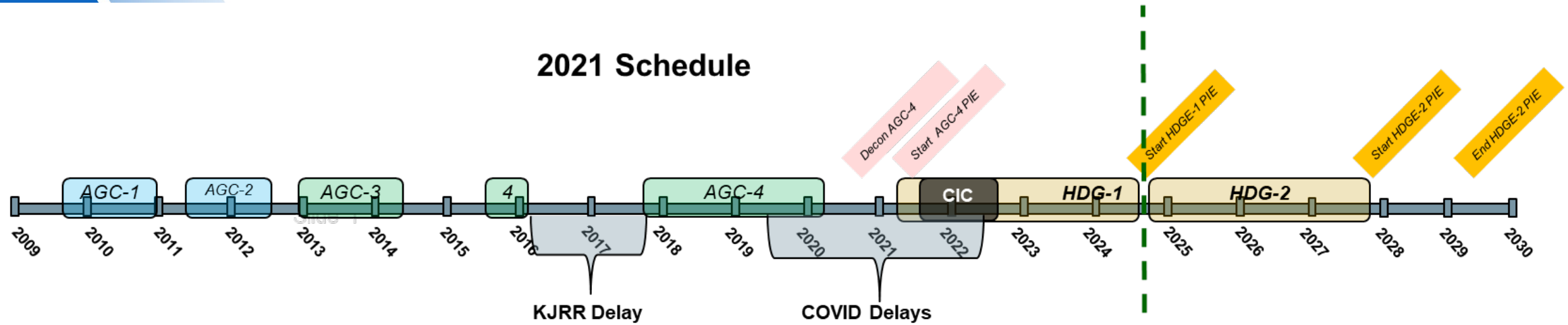
**Note: While we gain higher dose levels we lose temperature dependence.**

- Complete initial 600°C and 800°C irradiation
  - AGC-1 and AGC-2 (600°C irradiation)
  - AGC-3 and AGC-4 (800°C irradiation)
- Re-irradiate select samples
  - AGC-1 / AGC-2 → HDG-1
  - AGC-3 / AGC-4 → HDG-2

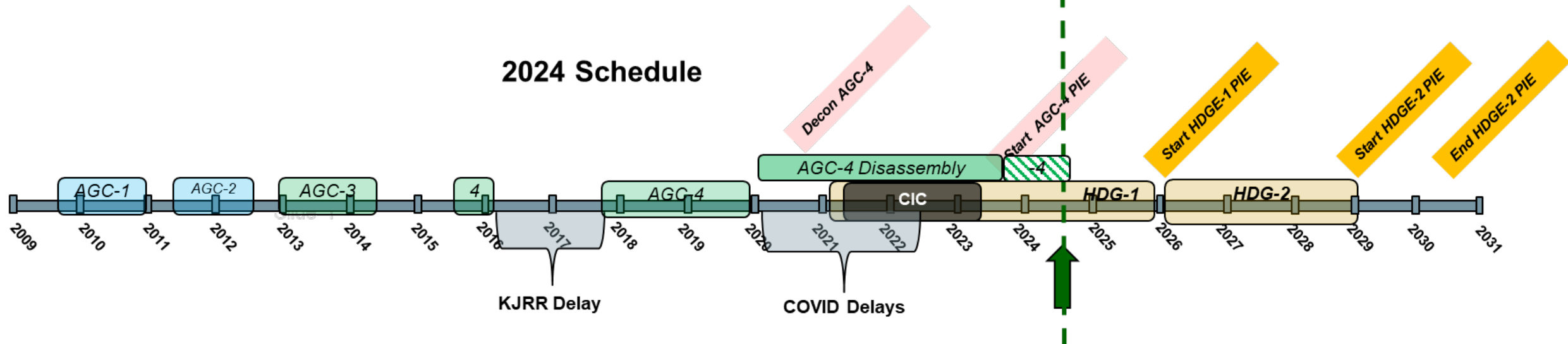


# AGC schedule update

## 2021 Schedule

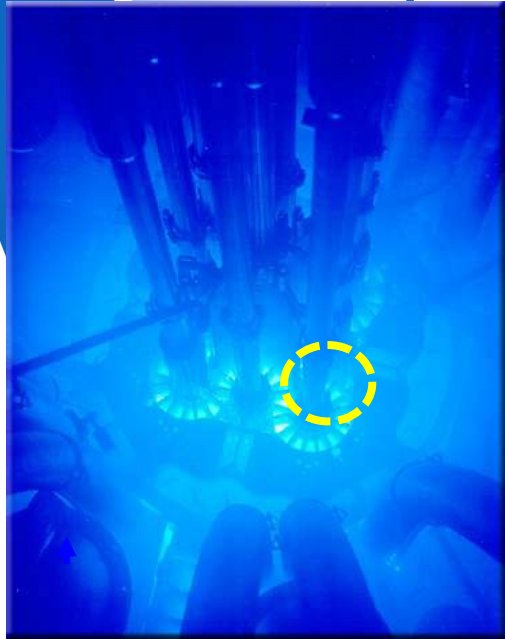


## 2024 Schedule

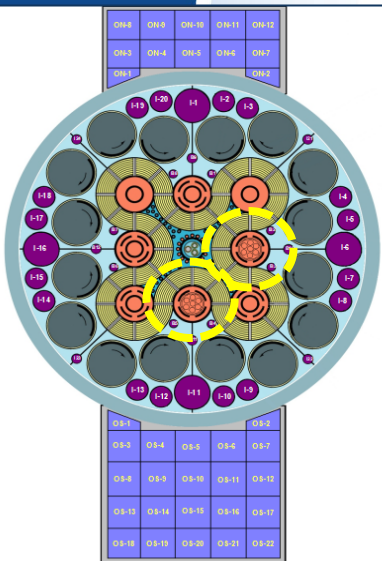




# (A brief) AGC-4 Irradiation and disassembly history (1)

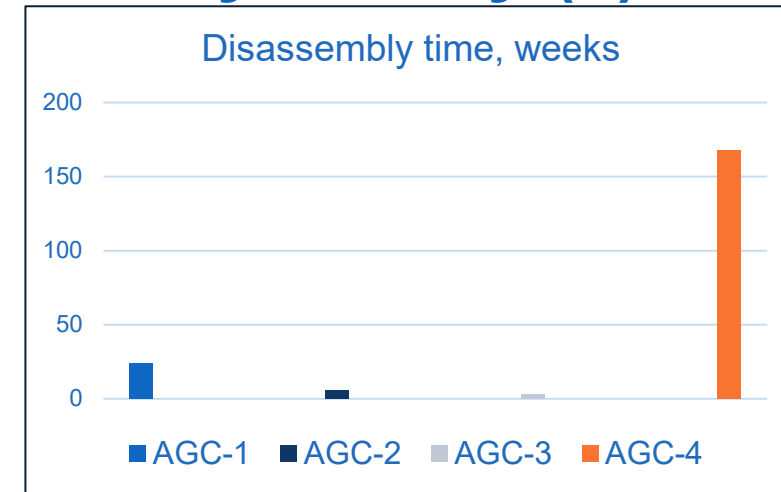


- Things were going well ... too well
  - That change on 2<sup>nd</sup> irradiation cycle
  - Fuel experiment in adjacent flux trap increased center energy
- Temperature excursions in center region far exceeded our limits
  - As much as 1000°C - 1100+ °C for a day or so
  - Adjustment of gas mixture/flow and compromise with other regions got center temperatures down to 900+ °C.
  - Removed AGC-4 for remainder of fuel experiment but damage was done
  - We limped along with temperature ranges ~120°C rather than ~20°C
  - AGC-4 irradiation ended January 2020...



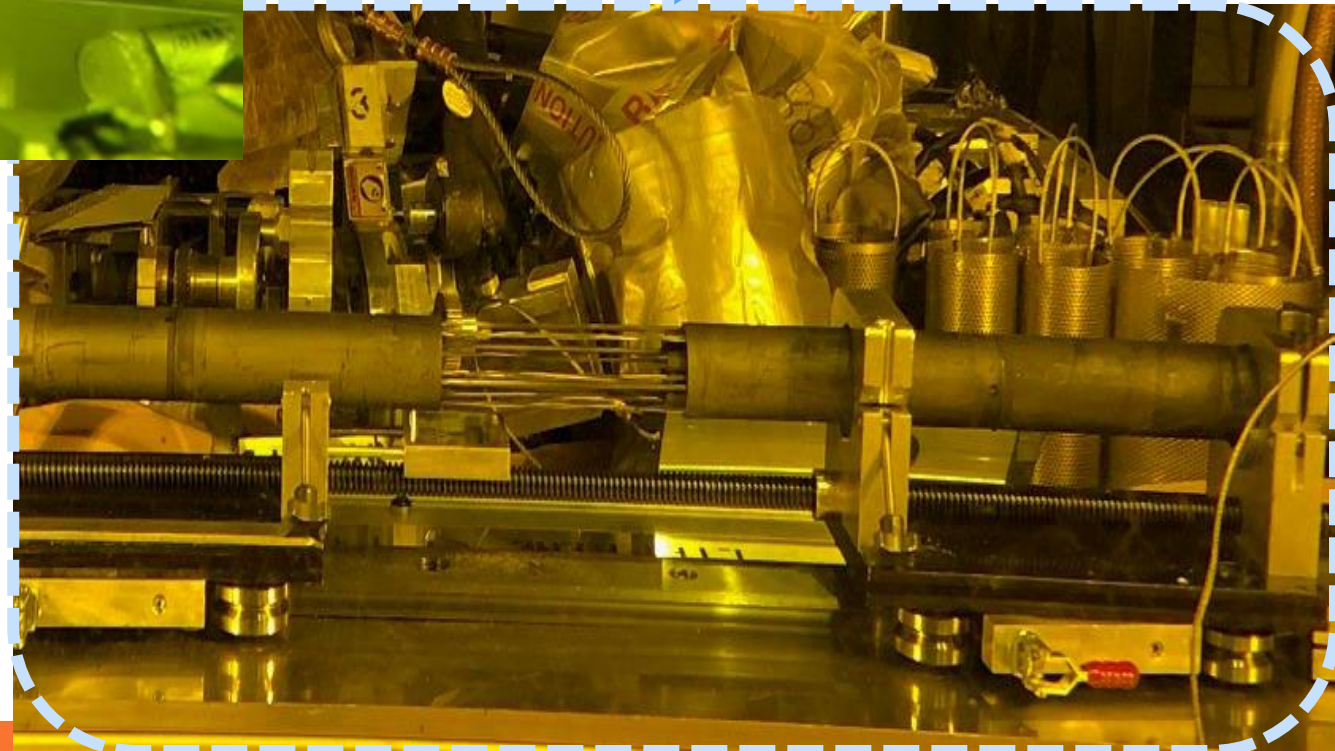
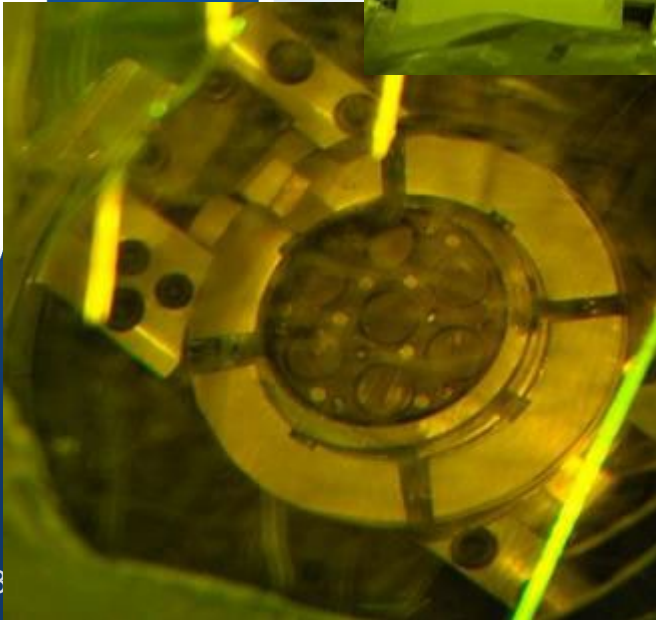
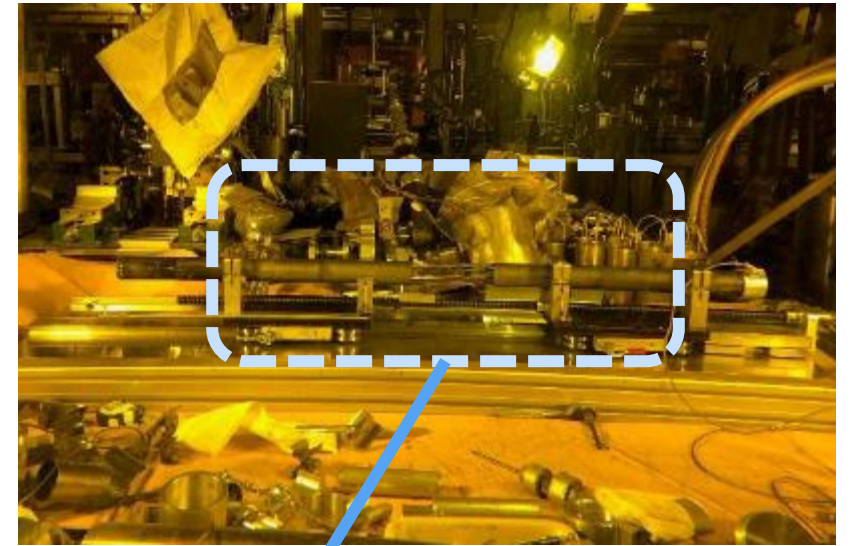
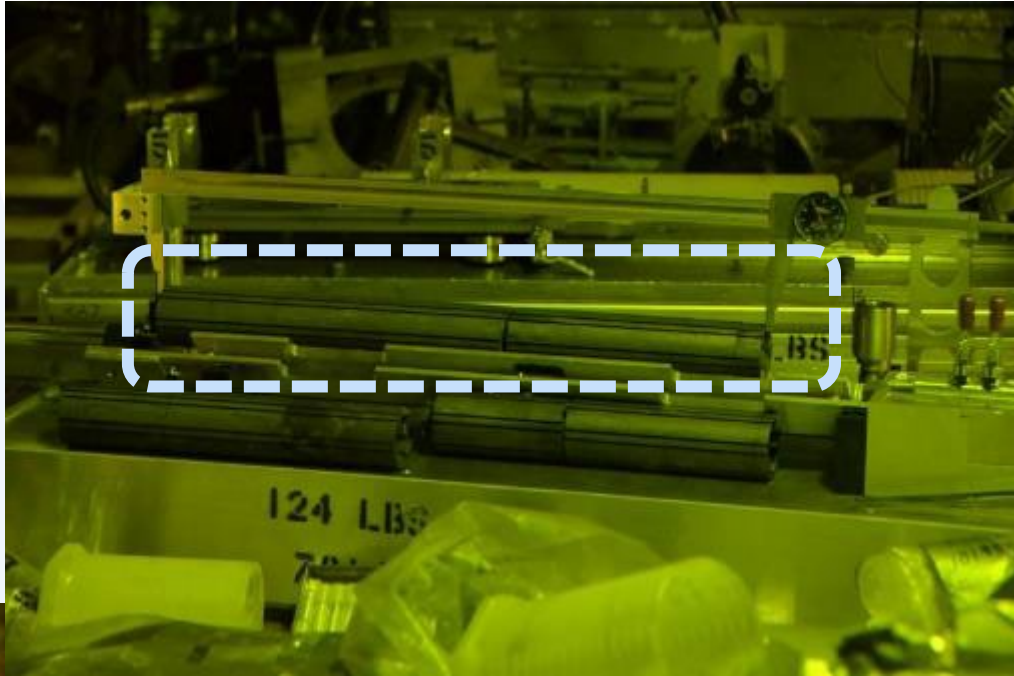
## (A brief) AGC-4 Irradiation and disassembly history (2)

- COVID-19 did not do AGC-4 any favors
  - Everything came to a screeching halt (same as everywhere)
- The high temperature excursions in center region appeared create additional physical and radiological problems:
  - Could not “push out” the central button “piggyback” specimens.
  - Eventually had to machine them out
  - Some specimens were very radiologically active
    - *1R, 2R, 10R, even 12R vs a normal 2-5 mR*
  - Created a logistical nightmare with additional infrastructure to handle it all.



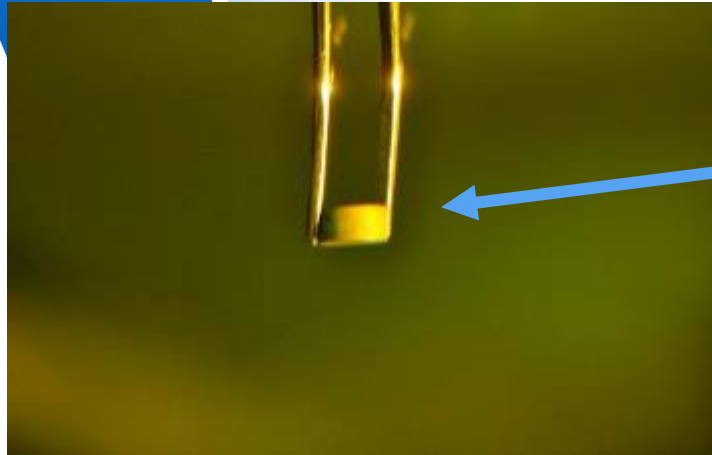


## AGC-4 Disassembly (in pictures)

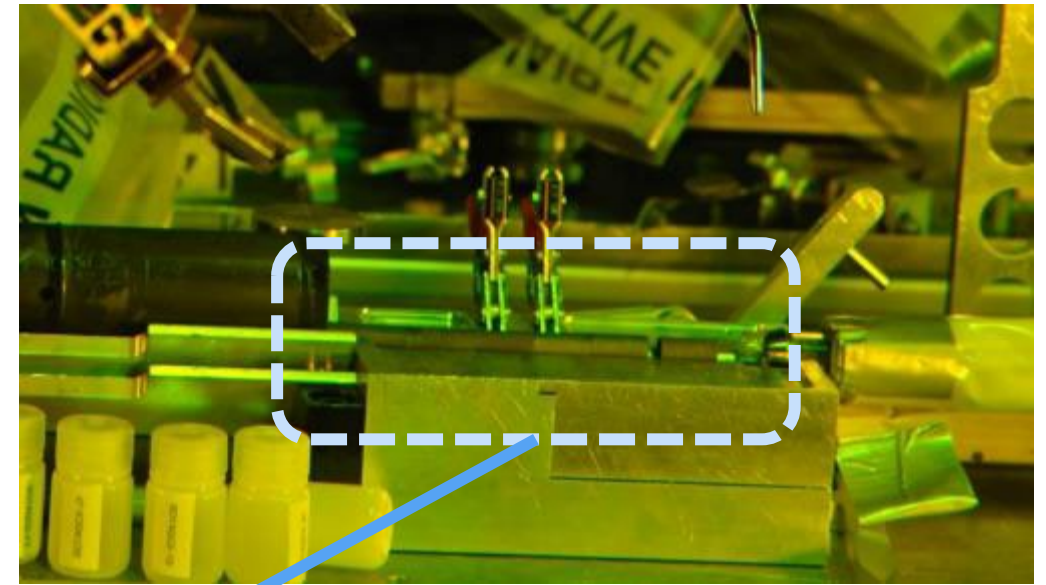




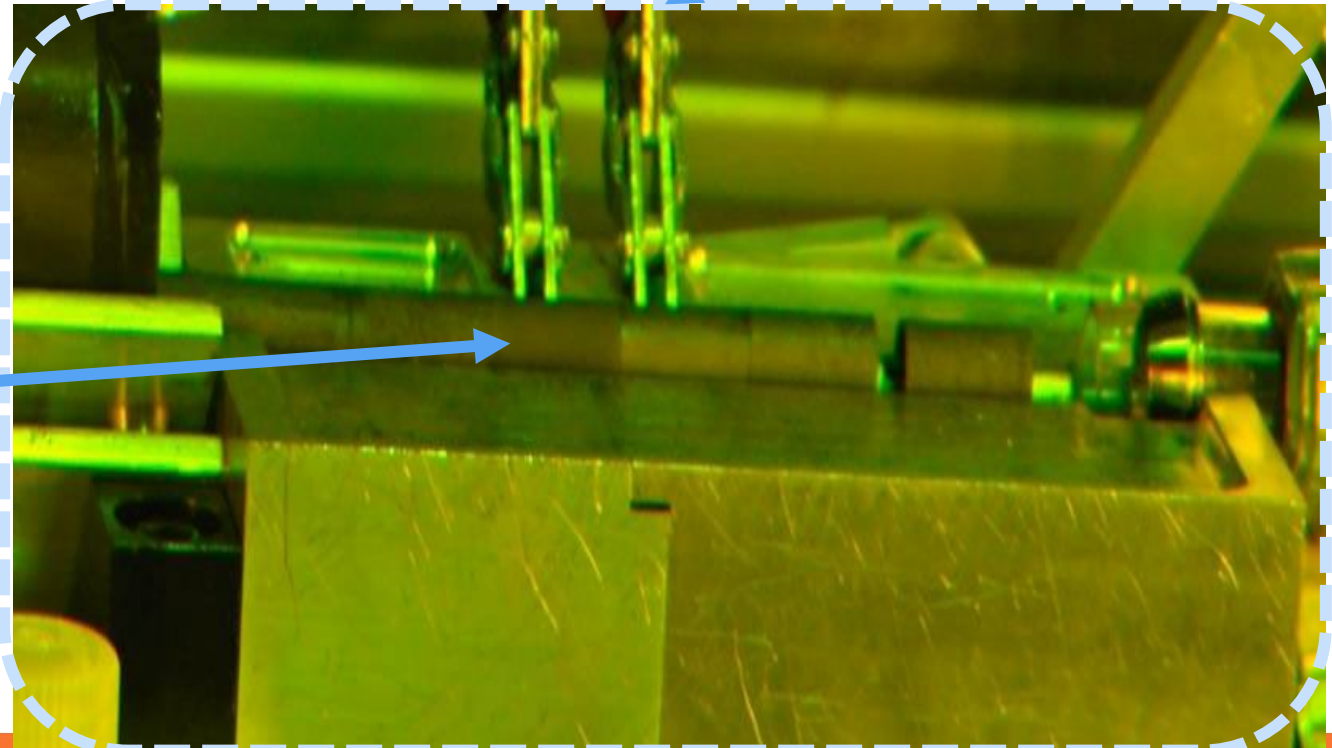
# AGC-4 Disassembly (in pictures)



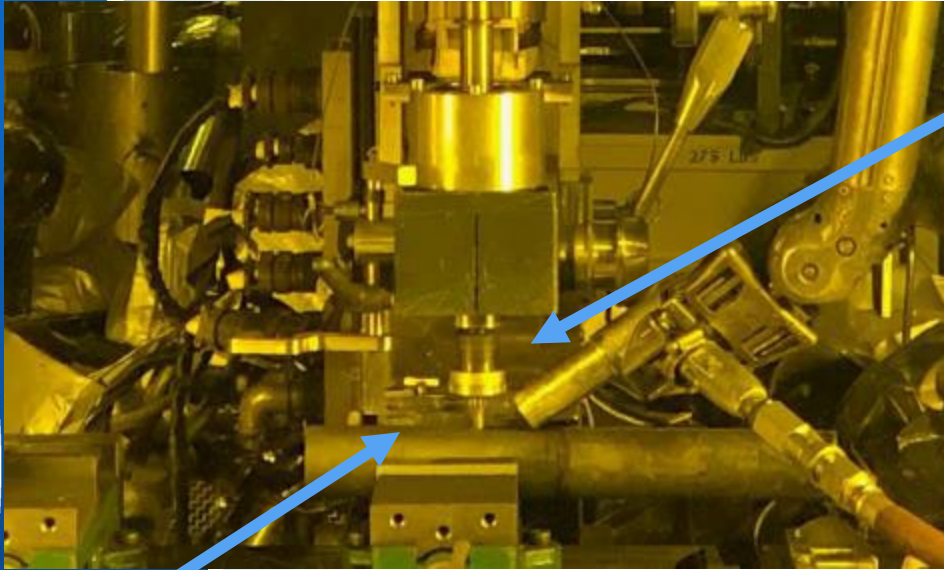
**Piggyback sample**



**Creep samples**  
Being loaded in  
transfer tubes



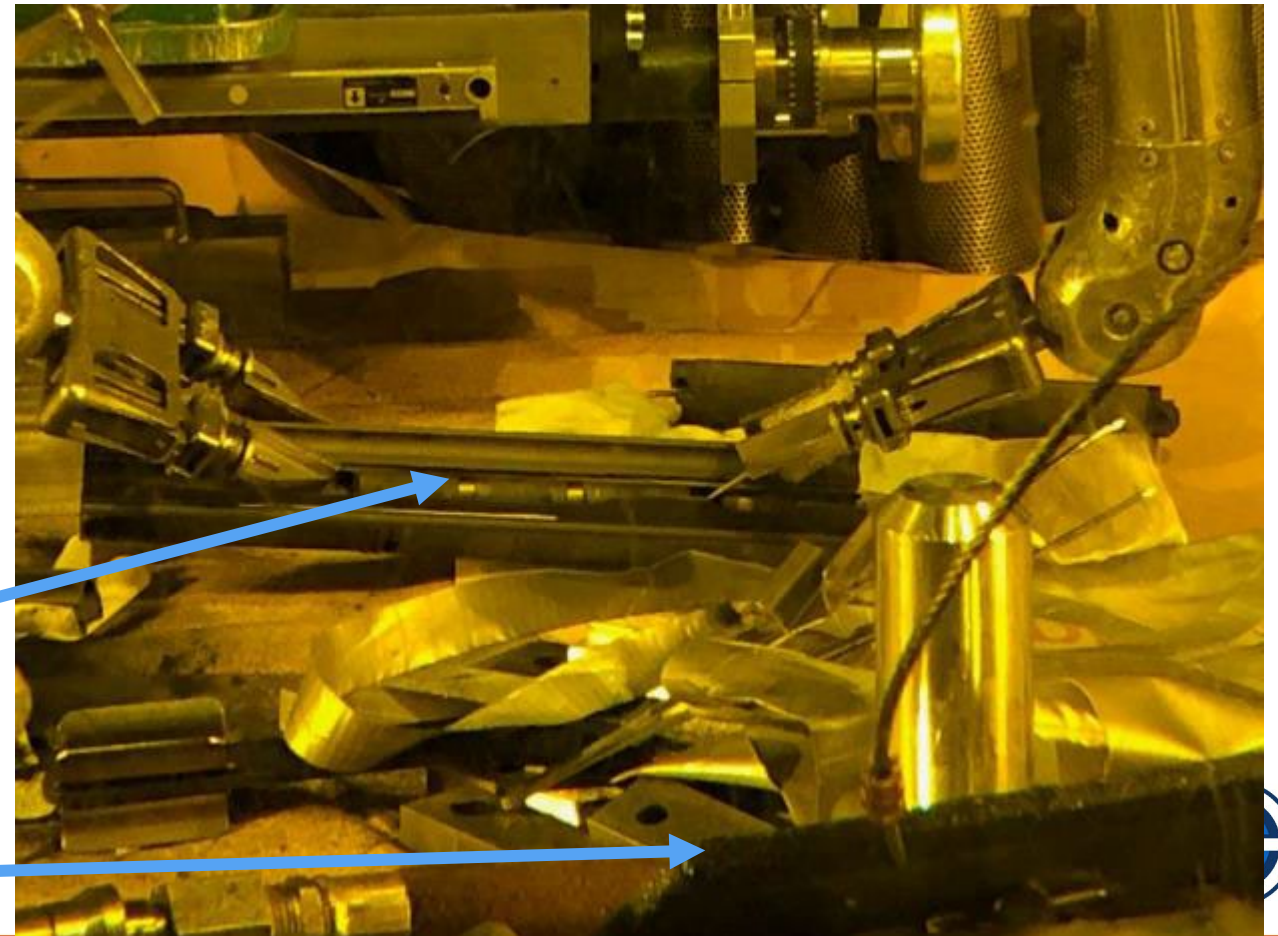
# AGC-4 Disassembly (in pictures)



**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

## More AGC-4 samples recovered than expected

- I expected a complete loss or maybe 50% recovery
- Disassembly took nearly 3 years, scattered over 3 facilities and 5 different locations

## High activity levels detected

- Initial activity levels of samples were very high in HFEF
- Samples waited to be transferred to Analytical Lab
  - *In shielded drum, then hot cell, then special glovebox, then hood, and others ...*
- Radiation measurements took quite a while
- In meantime, we performed oxidation and element analysis
  - *Turns out the problem is primarily Nickel.*
  - *Not sure where it came from. TCs? Gas zone partitions?*
  - *Frankly, we don't care since we're never operating a capsule in those conditions again*

## Shipping/PIE options based on activity levels

- If activity levels are low enough → Carbon Lab
  - *Modestly shielded glovebox only*
  - *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*
  - *Only some property measurements possible*



# Shipment and initial PIE

## High activities require additional steps

- Only a few specimens had high rad levels
- Special decon glovebox set-up
- Decontamination of all specimens
  - *Activity levels measured for individual specimens*
  - *However, nickel contamination could not be wiped clean*

## AGC-4 Shipment activity levels

- 0-100mR on contact = IRC Carbon Lab
- 100mR – 1 R on contact = MFC (AL/IMCL)
- Specimens >1R = Disposal or oxidation to determine contamination

Philip L. Winston, INL/EXT-21-63591 R1, "AGC-4 Disassembly Report", August 2023



Typical lead lined shipping drum assembly (~5000 lbs) and new small quantity shipping drums (~50 lbs)

# Initial PIE strategy

## PIE based on activity/location

- 0-100mR on contact = IRC Carbon Lab
  - *Most of the available AGC-4 specimens have been shipped to IRC Carbon Lab*
  - *All specimen previously shipped in FY23 have had physical material property measurements completed by May 2024.*
    - *Thermal testing takes longer and is ongoing*
    - *Mechanical testing occurs last (and reluctantly)*
  - *Last (17) “warm” samples in drum and ready to ship (end of July?)*
- 100mR – 1 R on contact = MFC (AL/IMCL)
  - *Once last Carbon Lab specimens are shipped decision on PIE activities at MFC*
  - *Possible to send specimens to IMCL for physical and thermal measurement*
  - *However, there is the “rate of diminishing return” to consider*
- Specimens >1R = Disposal or oxidation to determine contamination





# AGC-4 specimens recovered

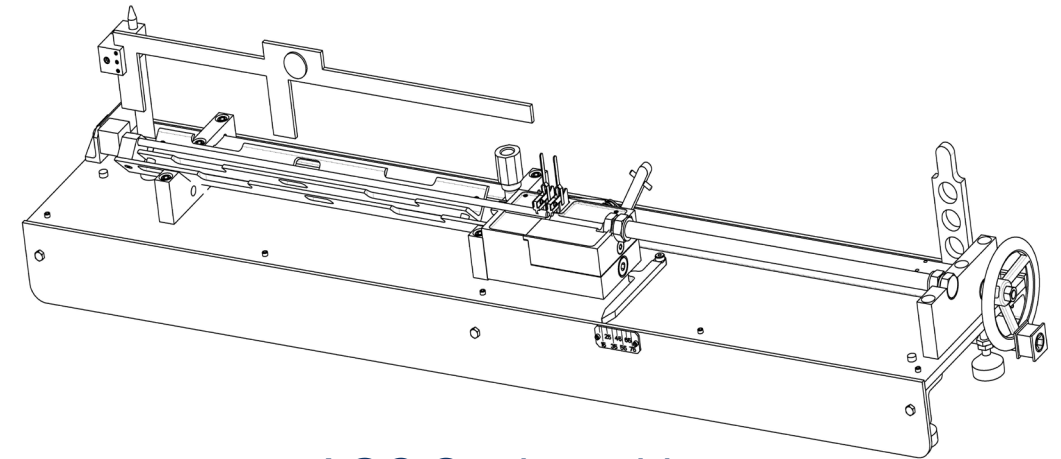
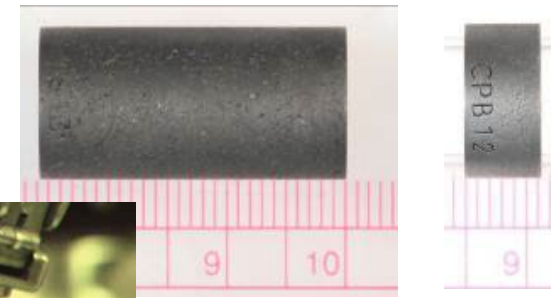
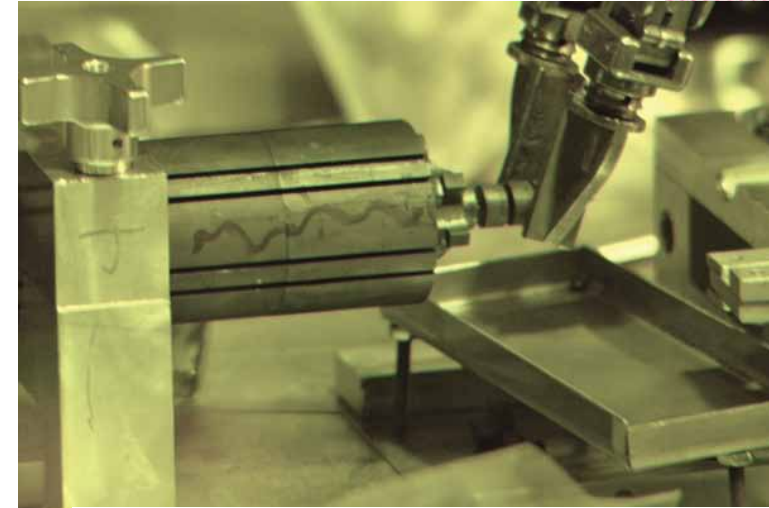
## Where we think AGC-4 specimens are

- 277 specimens at IRC Carbon Lab
  - Currently undergoing PIE
- 75 “warm” specimens (<100mR) shipping
  - 58 “warm” specimens at Carbon Lab
  - 17 “warm” specimens being shipped
- 88 specimens either lost or “too hot”
  - *Lost = crushed, machined, or rolled off sorting table during disassembly*

## In summary

- 80% of AGC-4 specimens fully recovered
- 20% of AGC-4 not recoverable
  - *And we should be able to get measurements from some of the “too hot” specimens*

**While not perfect, I am very happy with 80%**

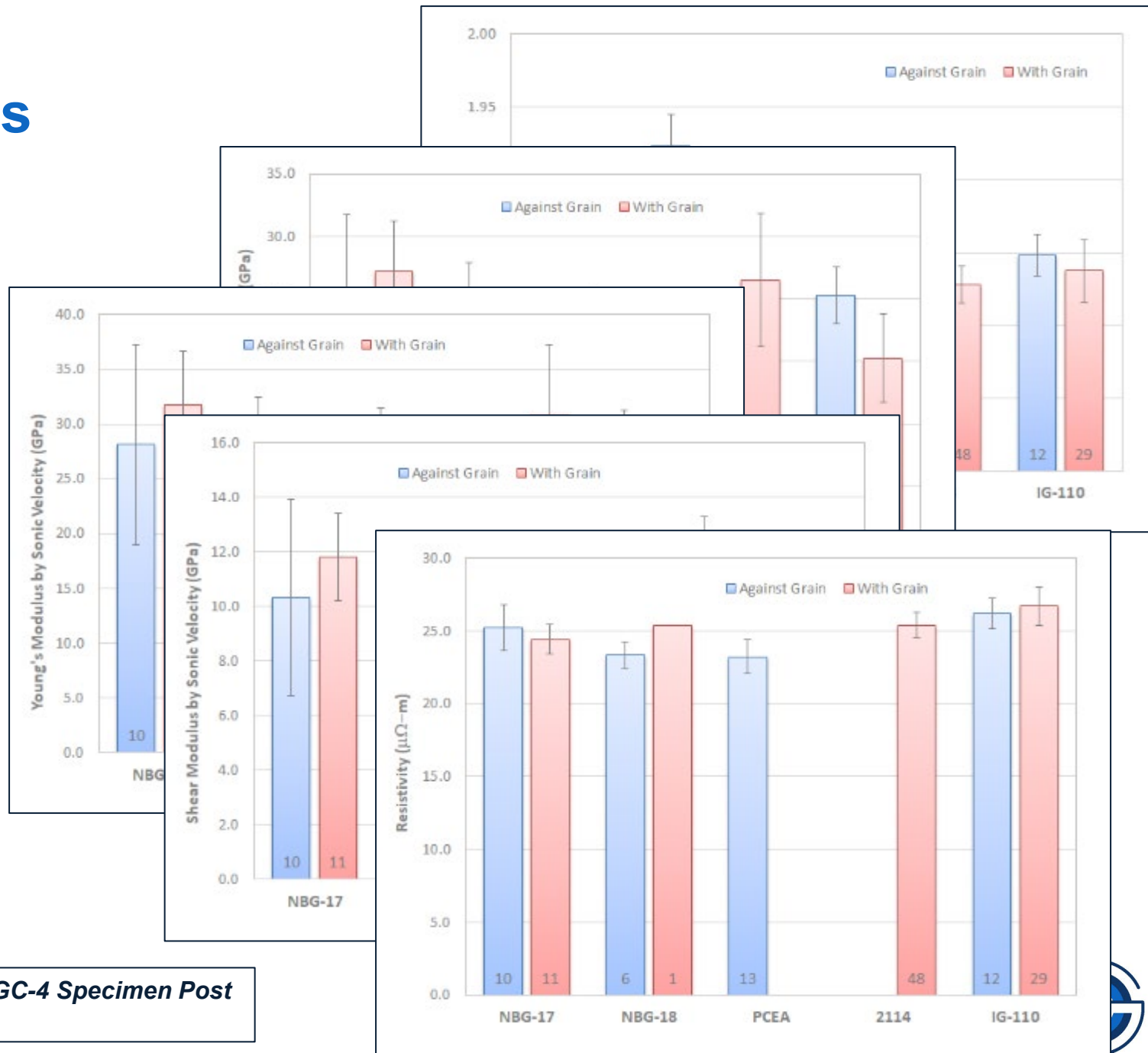


AGC Sorting table



# Initial PIE results

- Physical property measurements completed
  - Initial results appear to be more or less typical, based on AGC-1 thru AGC-3 data*
  - Analysis of data next year*
- Thermal property measurements ongoing
  - Thermal property (diffusivity & CTE) take ~ 1 day/specimen*
  - Estimate completion early next spring.*
- AGC-4 Data report FY25
  - Analysis report may take a bit longer due to weird irradiation problems*
- Mechanical testing – FY25 or beyond



Austin C. Matthews, et al., INL/RPT-24-78112 "AGC-4 Specimen Post Irradiation Examination Data Interim Report,"

# 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)
  - Specimen decontamination complete
  - **80% of AGC-4 specimens shipped to Carbon Lab**
  - Initiated PIE (Testing 2023 – 2024)
- **HDG-1** : 600°C (7 to 15 dpa)
  - Back in ATR – ready for irr: 5 more cycles to 15 dpa
    - **ATR currently operational**
  - Re-irradiation of AGC-2 specimens + super-fine grain size
- **HDG-2** : 800°C (7 to 15 dpa)
  - Initial design begins 2024
  - Re-irradiation of AGC-3 & -4 specimens to max. 15 dpa

	Pre-Irr testing	Design Capsule	Assemble & Insert	Irradiate	PIE	Analysis
AGC-1	<div></div>					
AGC-2	<div></div>					
AGC-3	<div></div>					
AGC-4	<div></div>					
HDG-1	<div></div>					
HDG-2	<div></div>					

- **Philip L. Winston, INL/EXT-21-63591 R1, "AGC-4 Disassembly Report", August 2023**
- **Austin C. Matthews, et al., INL/RPT-24-78112 "AGC-4 Specimen Post Irradiation Examination Data Interim Report,"**





## Questions?

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