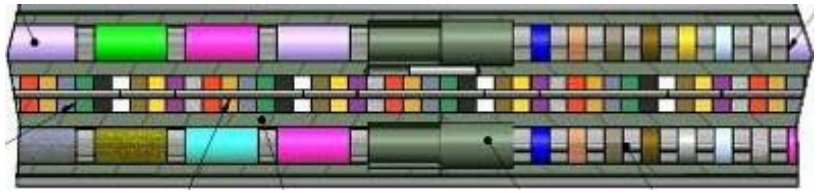
GAS-COOLED REACTOR
ADVANCED REACTOR TECHNOLOGIES PROGRAM



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

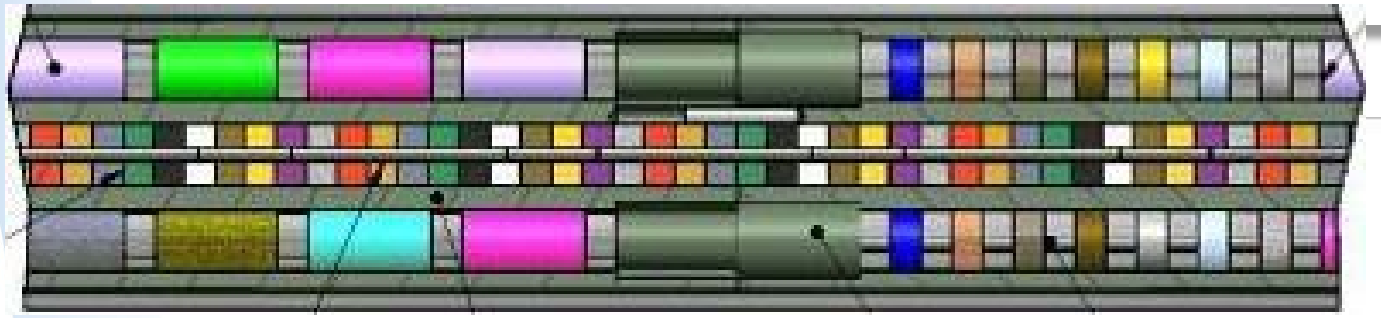
History and status of the AGC-4

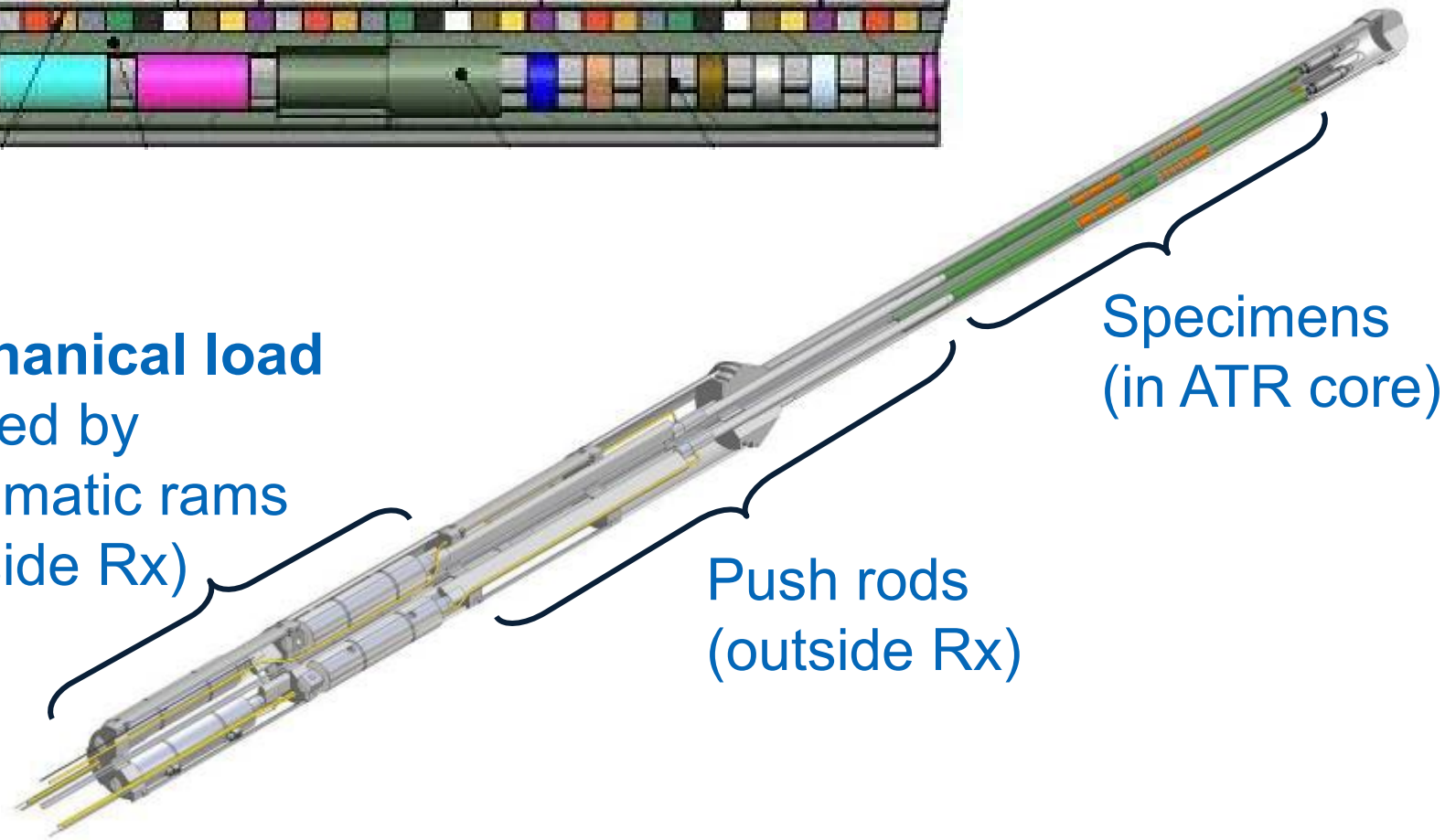
- A review of the AGC experiment
  - What is it and why is it important?
  - Capsule and specimen layout
  - Experimental test matrix (old and new)
  - Status of the experiment irradiation schedule
- The AGC-4 capsule and specimens
  - Irradiation and disassembly history
  - Status of the PIE measurements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

What is the AGC Experiment?

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

Advanced Graphite **Creep** (AGC)



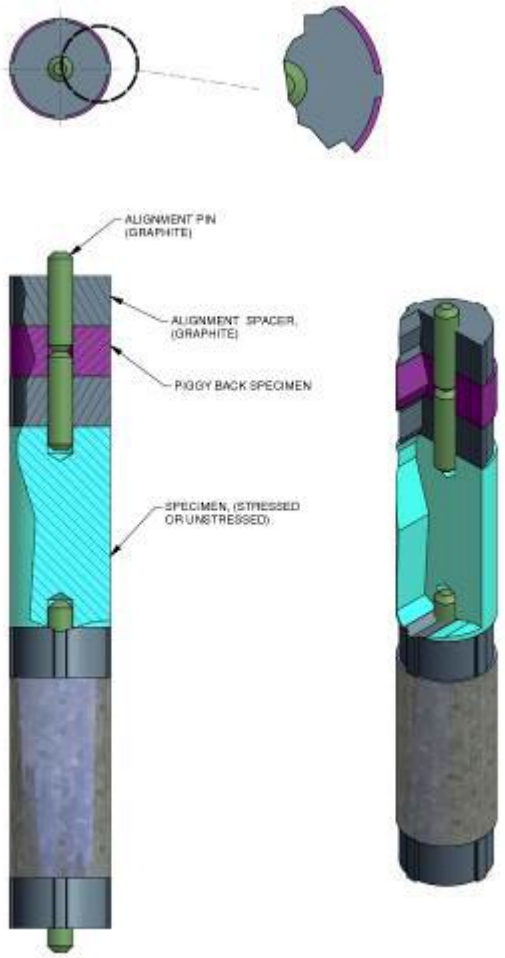


Mechanical load applied by pneumatic rams (outside Rx)

Specimens (in ATR core)

Push rods (outside Rx)

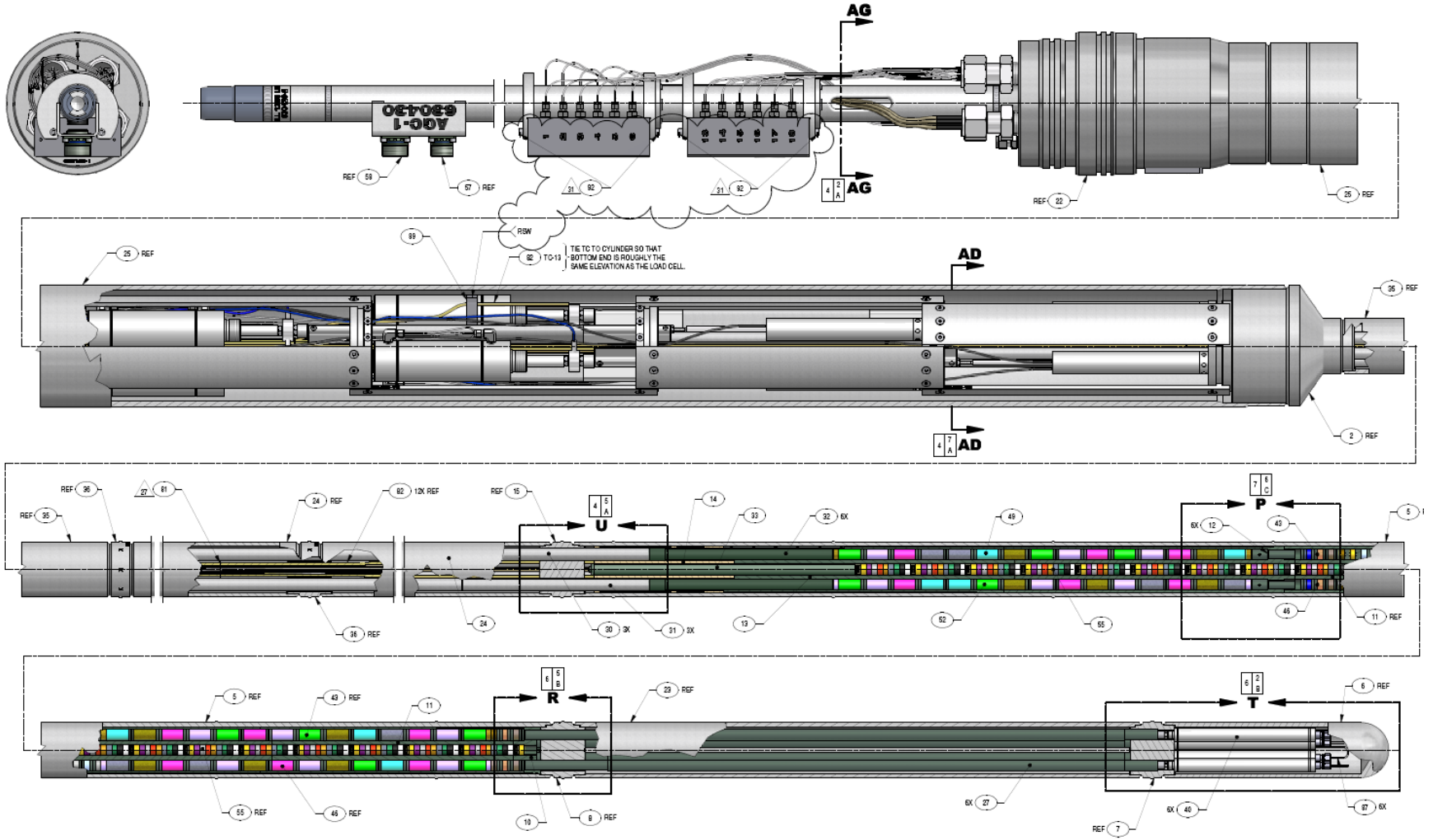
AGC graphite grades and samples



AGC sample loading scheme

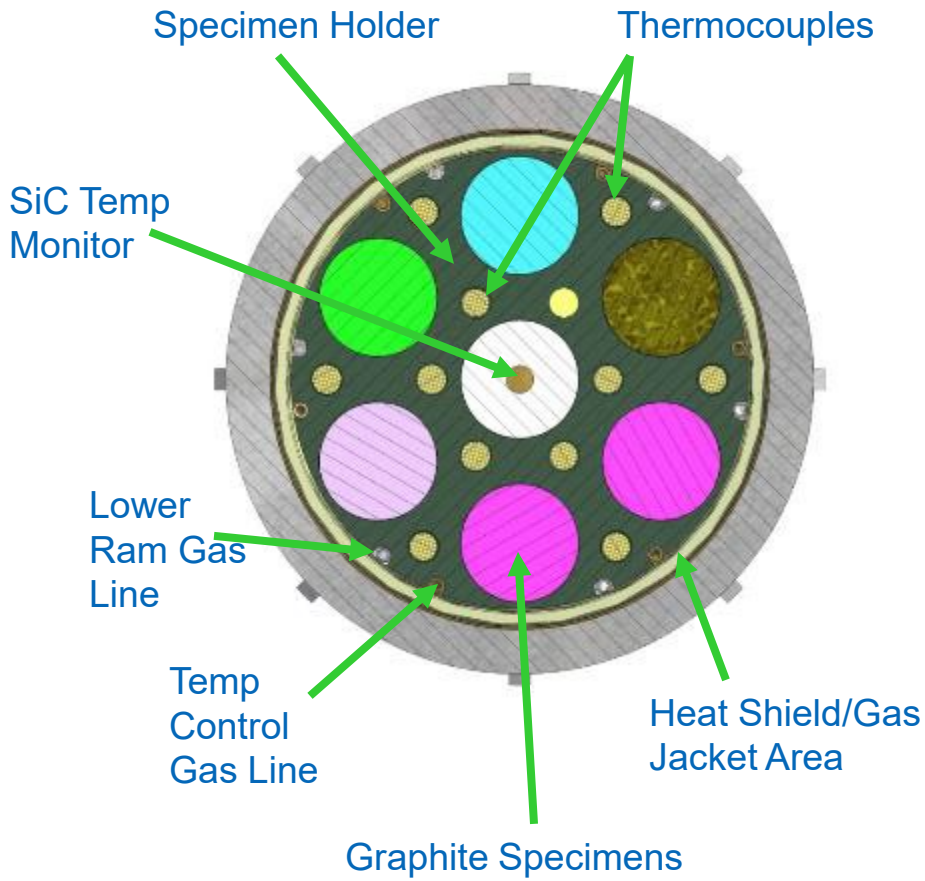
- Creep samples
  - Ø12 mm × 25 mm (1/2” × 1”)
- Piggyback “button” samples
  - Ø12 mm × 6 mm (1/2” × 1/4”)
- Six-seven major (creep) grades
  - H-451, IG-110, PCEA, NBG-18, NBG-17, 2114, and IG-430
- Ten piggyback grades
  - NBG-25, PCIB, PPEA, NBG-10, BAN, HLM, PGX, S2020, HOPG, and A3 matrix

AGC-1 Test Train



AGC-1 Test Train Design Features

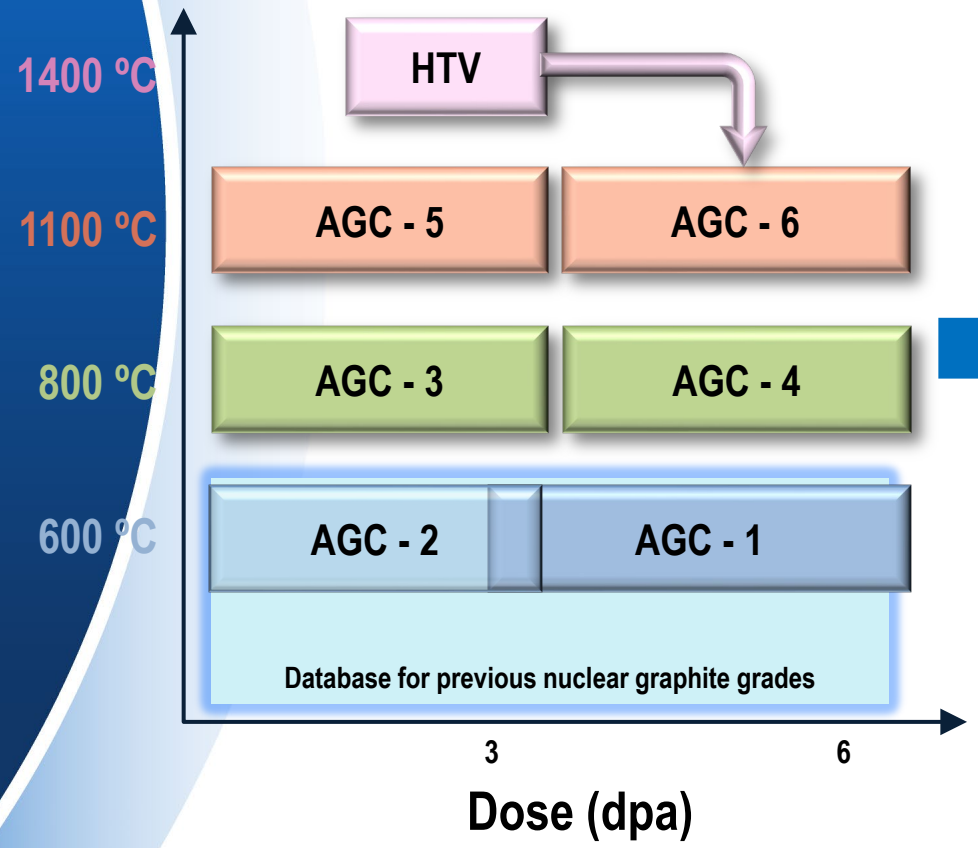
- Six specimen stacks around capsule perimeter with compressive load on upper half of stack
- Seventh specimen stack in center without compressive load
- Graphite specimen holder to contain graphite specimen stacks and thermocouples (TCs)
- 12 TC locations with positions located through core height
- 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



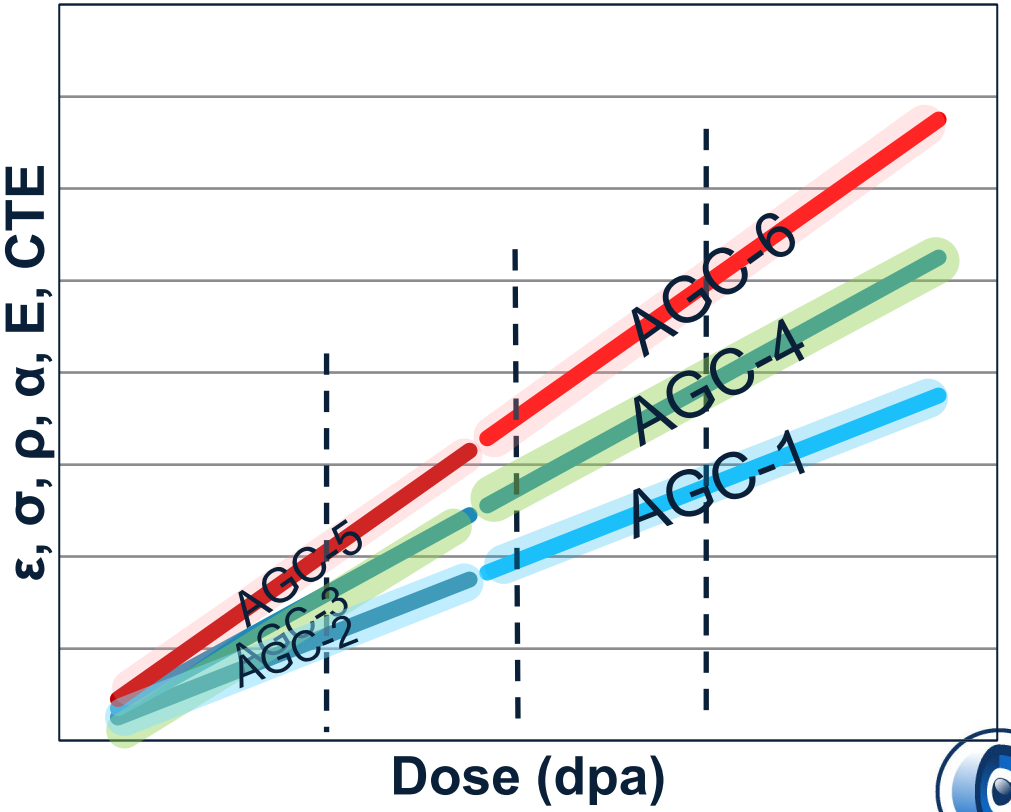
AGC Capsule Cross Section

Original purpose and scope of AGC experiment

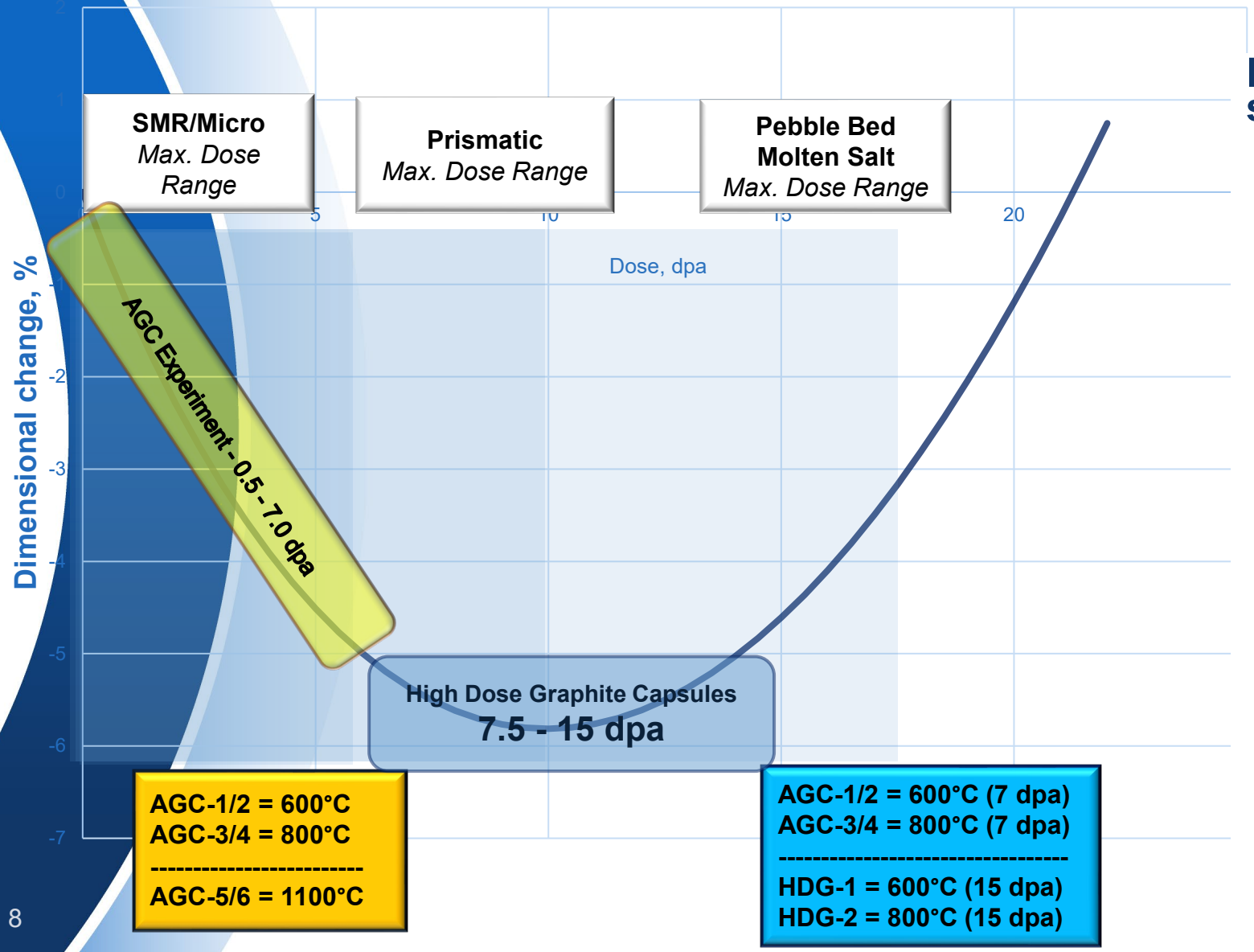
- Three pairs of test capsules
  - 3 Temperatures
  - 3 Stress levels
  - Continuous dose (0.5 – 7 dpa)



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



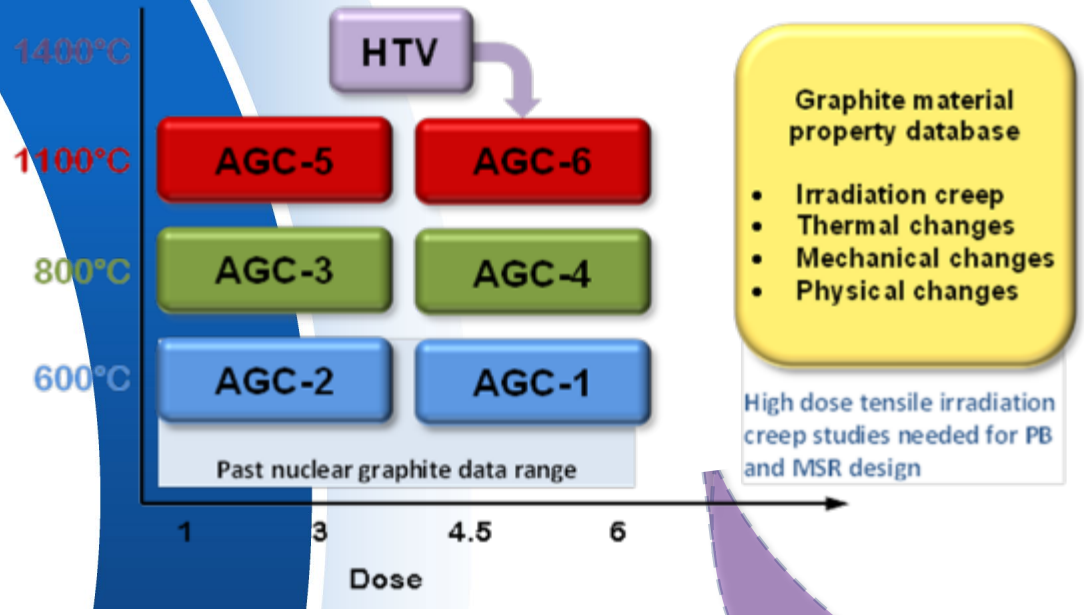
Redirection of AGC irradiation program – High Dose Capsules



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 1st capsule
  - AGC-3 & 4 (800°C samples) in 2nd 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)



Graphite material property database

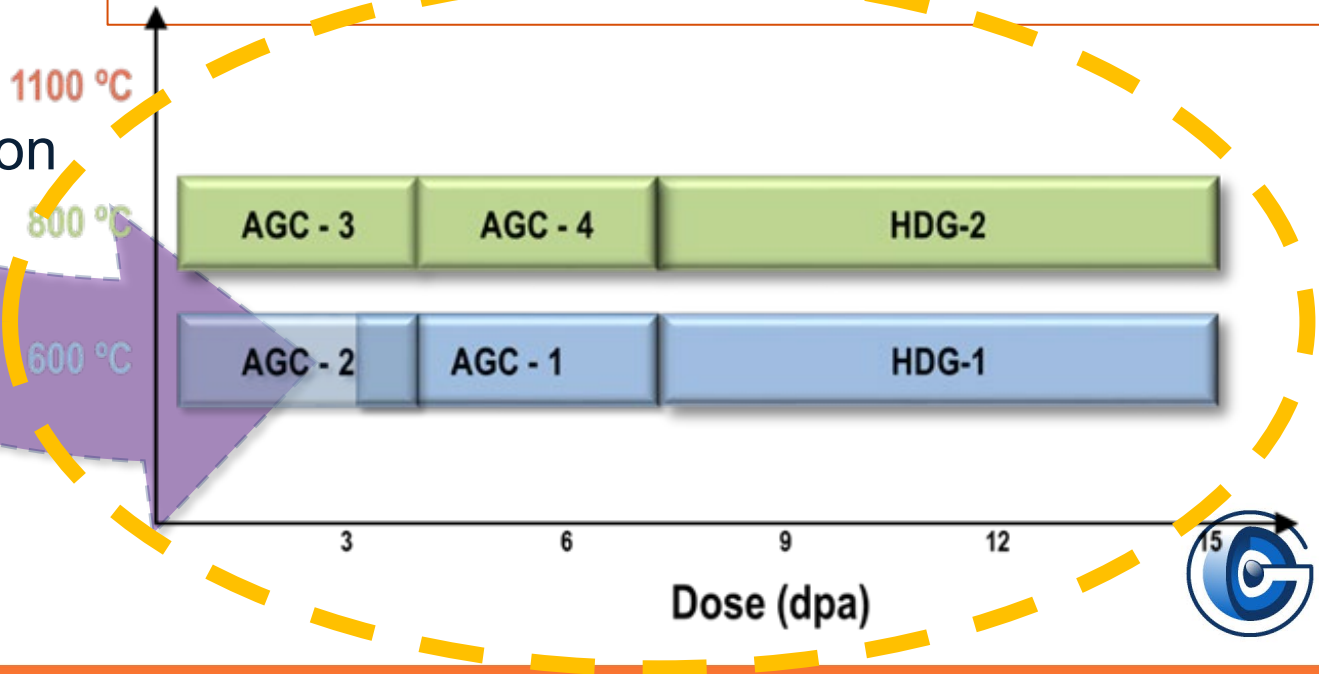
- Irradiation creep
- Thermal changes
- Mechanical changes
- Physical changes

High dose tensile irradiation creep studies needed for PB and MSR design

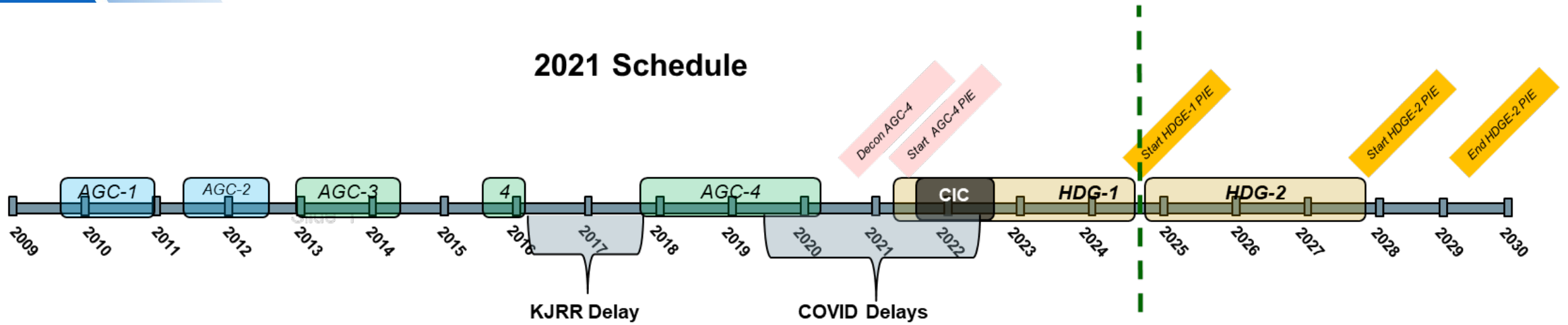
- New AGC direction
  - *Higher Dose (15 dpa)*
    - *High Dose Graphite (HDG Capsules)*
  - *Lower Temperatures (600 – 800°C)*
  - *Re-irradiating previous specimens*

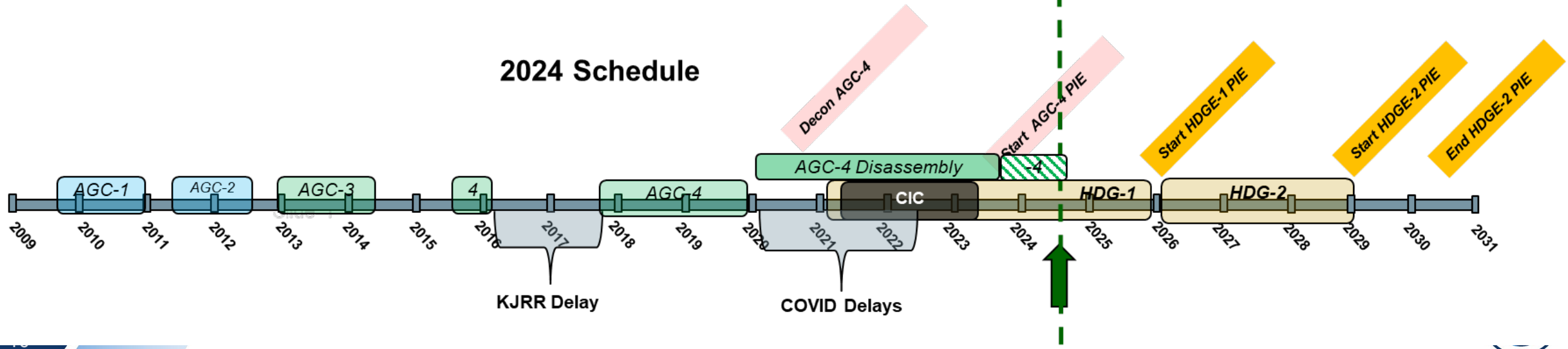
Note: While we gain higher dose levels we lose temperature dependence.

- 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

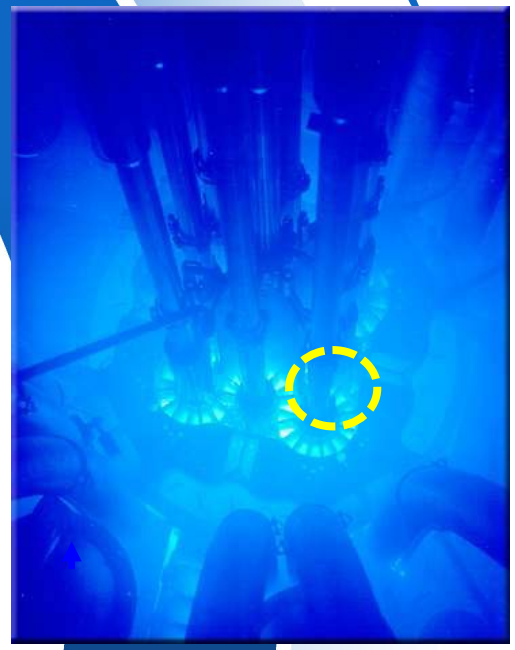


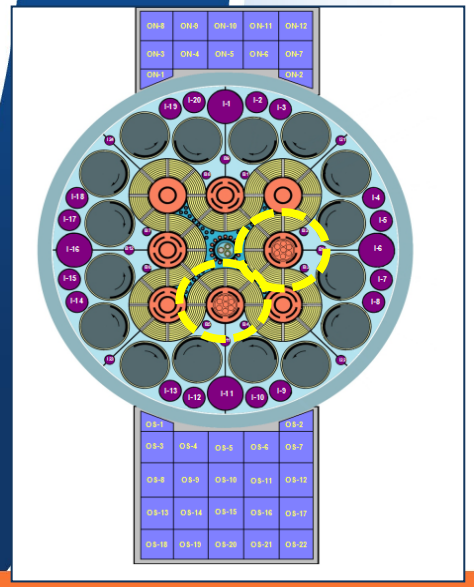
AGC schedule update





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

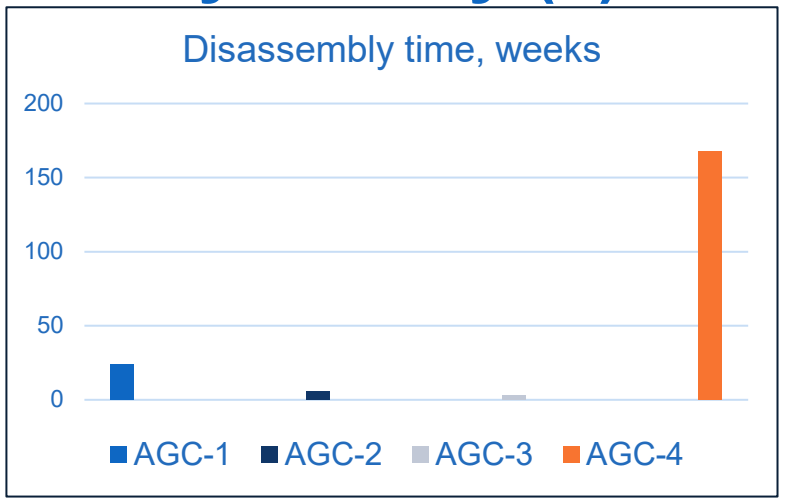




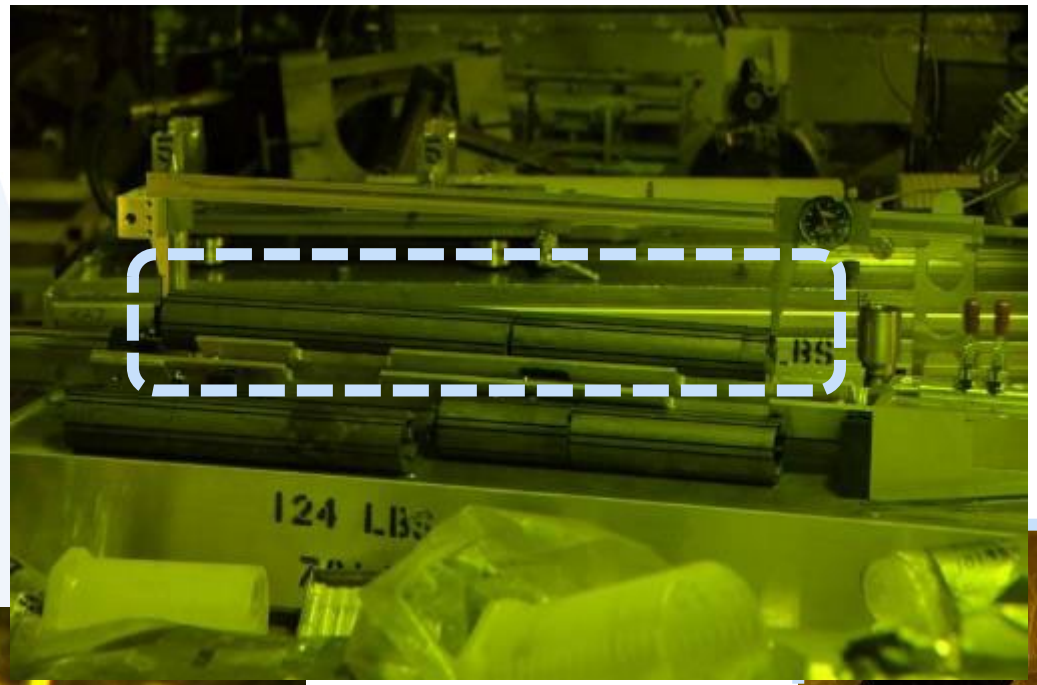
- Things were going well … too well
  - That change on 2nd irradiation cycle
  - Fuel experiment in adjacent flux trap increased center energy
- Temperature excursions in center region far exceeded our limits
  - As much as 1000°C - 1100+ °C for a day or so
  - Adjustment of gas mixture/flow and compromise 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…

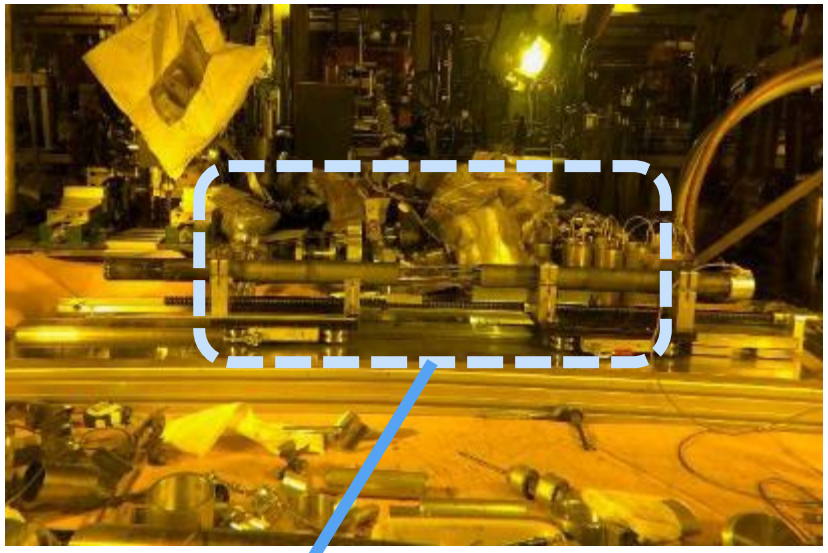
(A brief) AGC-4 Irradiation and disassembly history (2)

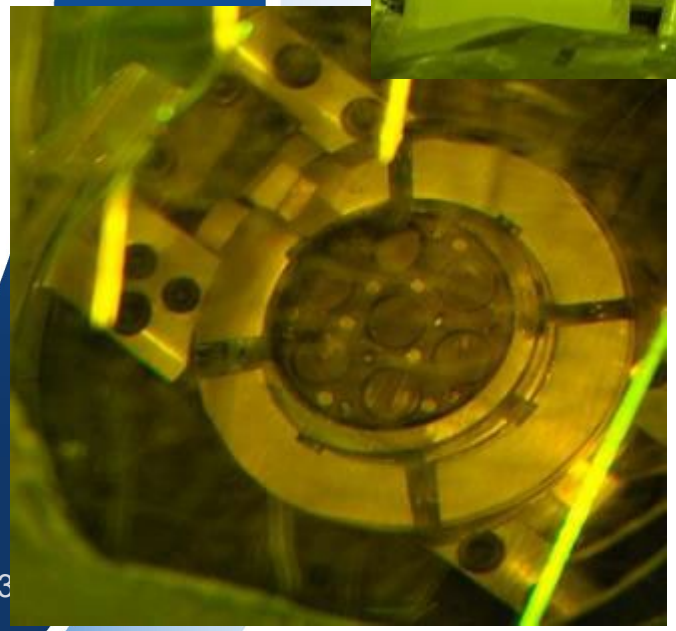
- COVID-19 did not do AGC-4 any favors
  - Everything came to a screeching halt (same as everywhere)
- The high temperature excursions in center region appeared create additional physical and radiological problems:
  - Could not “push out” the central button “piggyback” specimens.
  - Eventually had 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.

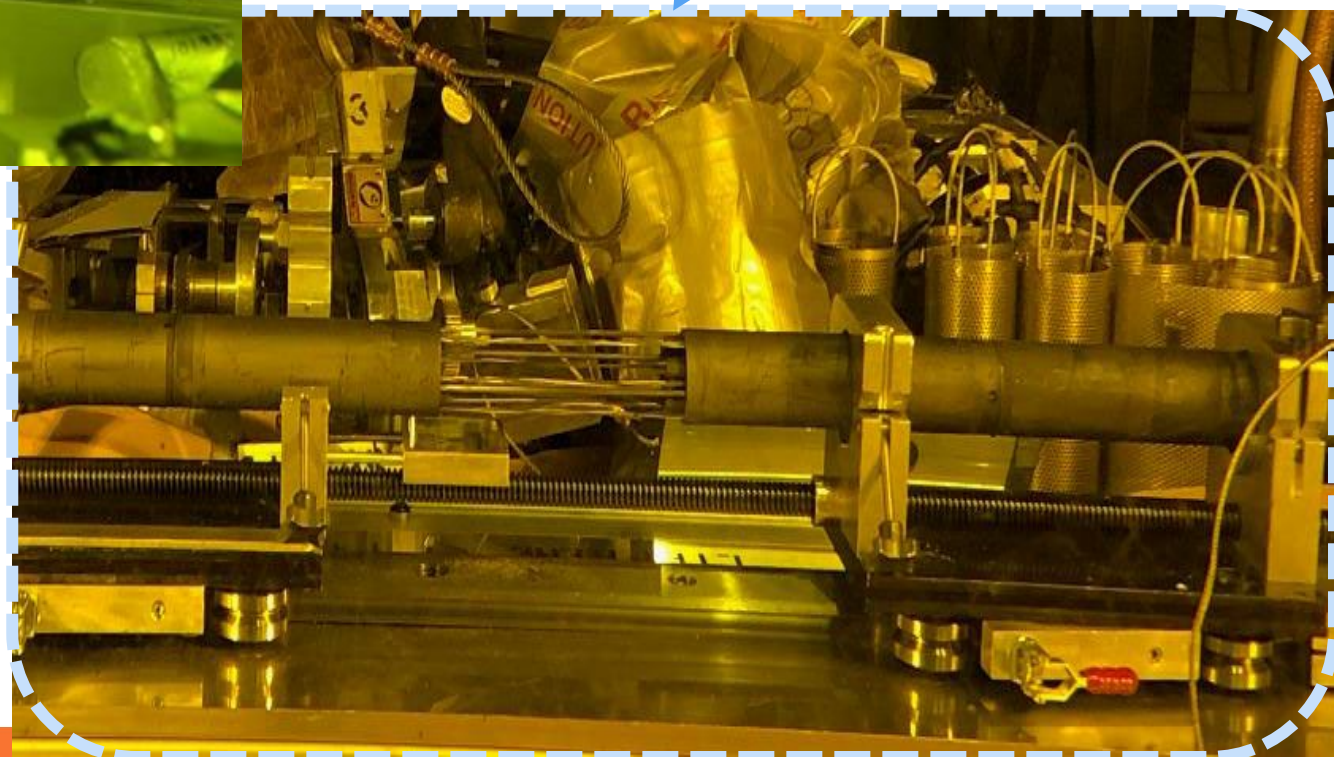


AGC-4 Disassembly (in pictures)

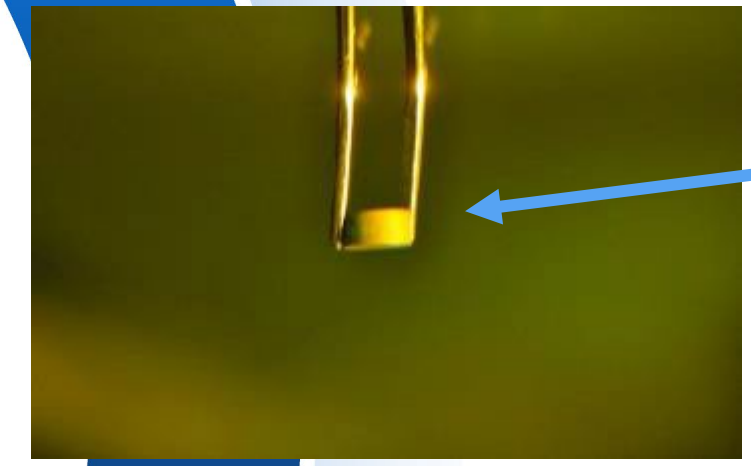




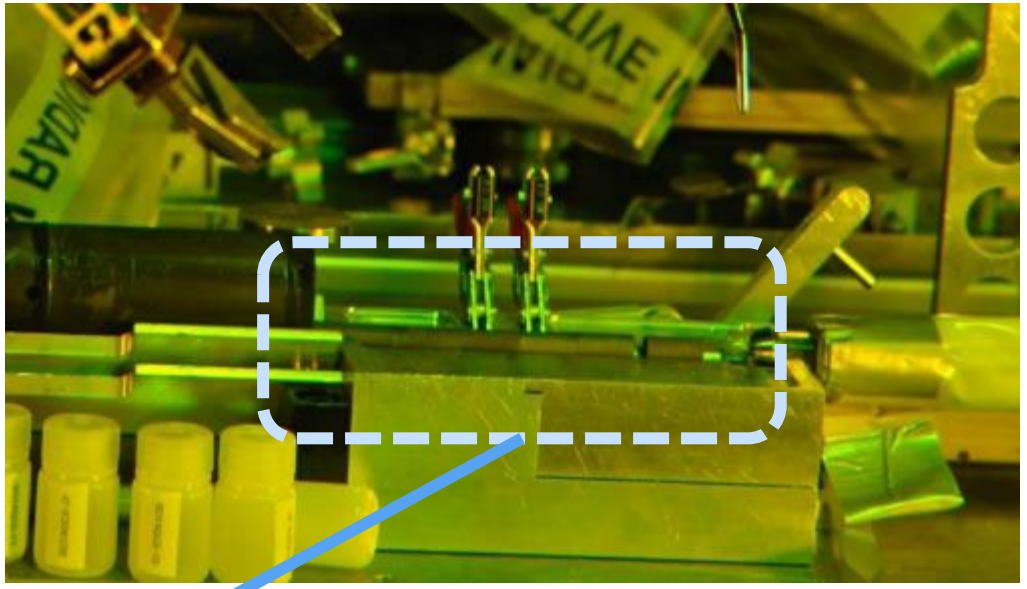


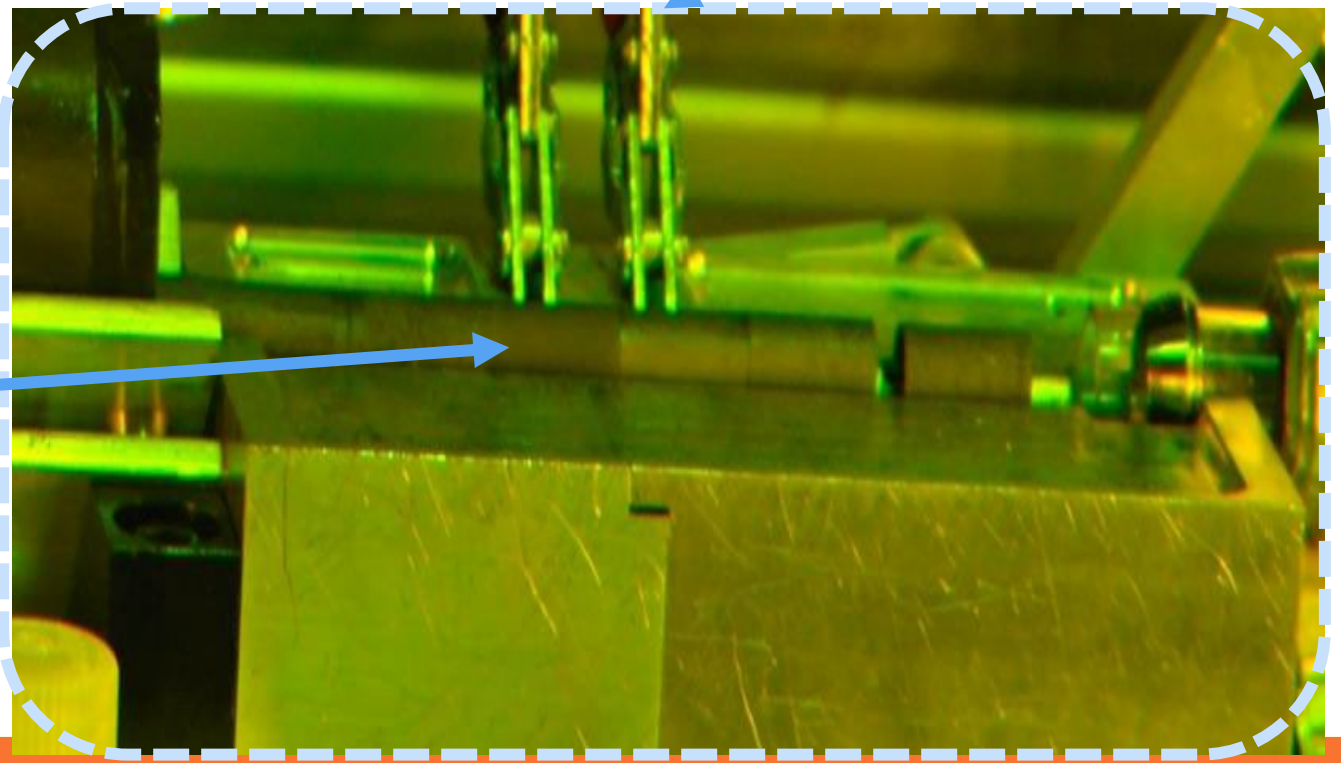


AGC-4 Disassembly (in pictures)



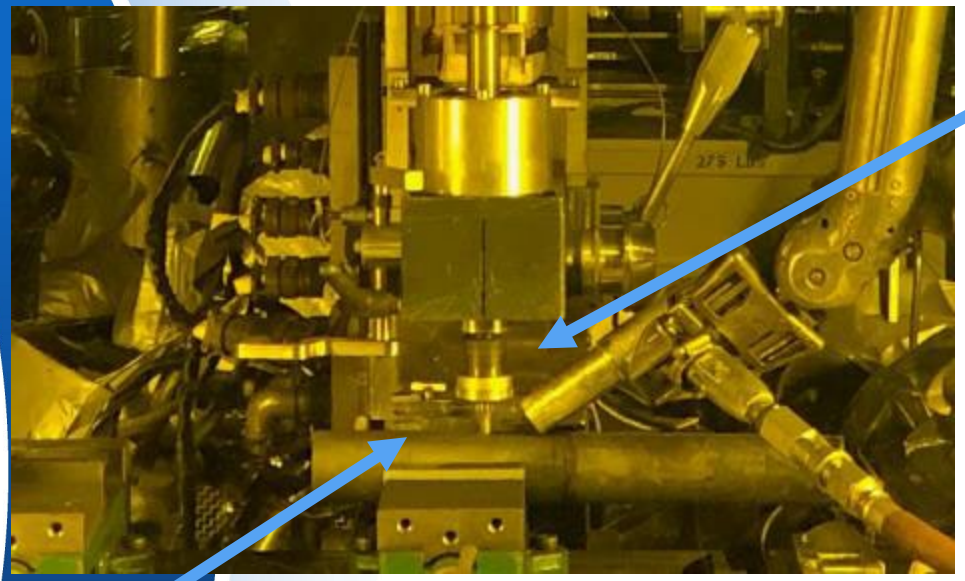
Piggyback sample





Creep samples
Being loaded in transfer tubes

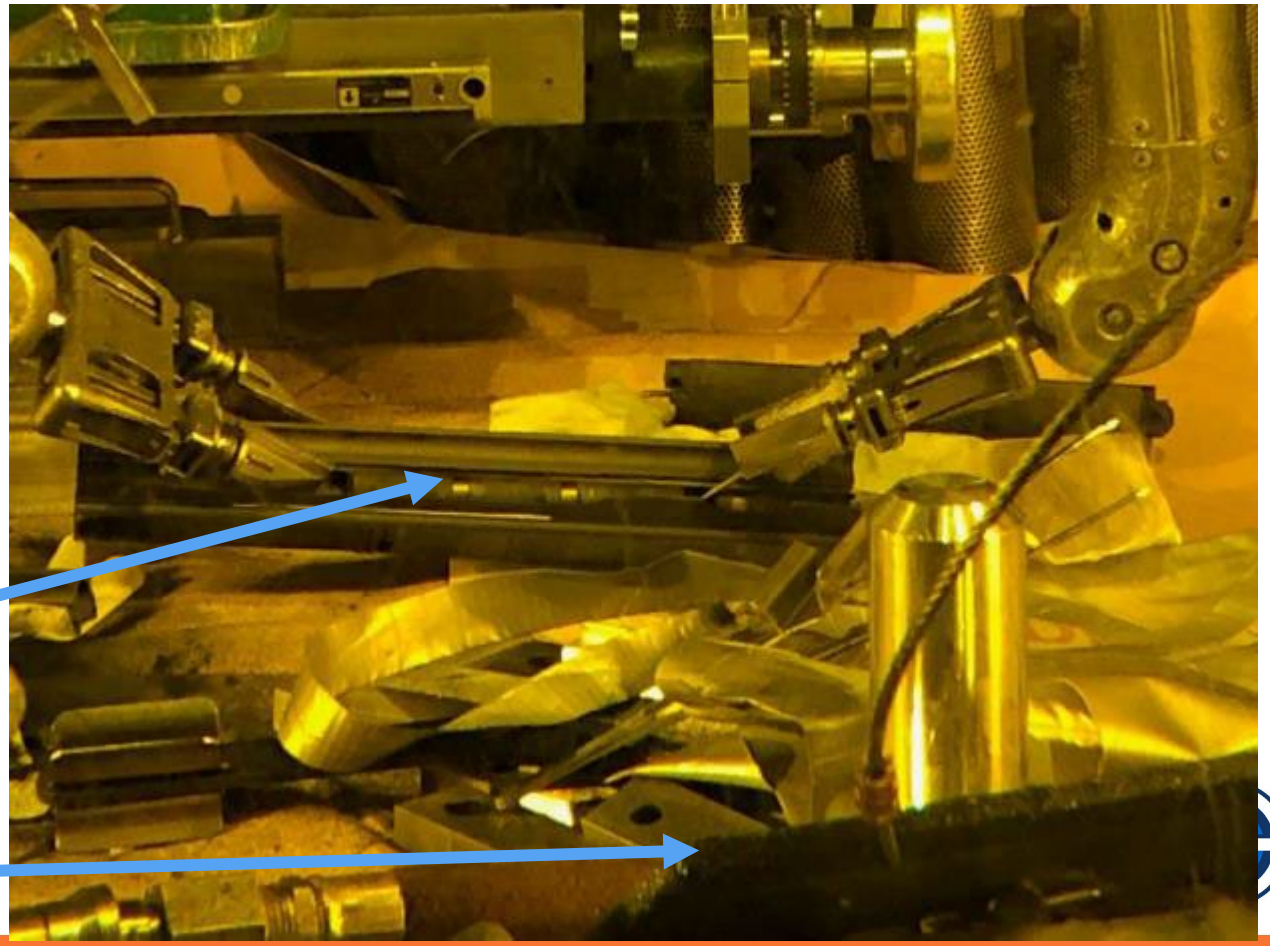
AGC-4 Disassembly (in pictures)



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 <u>some</u> 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

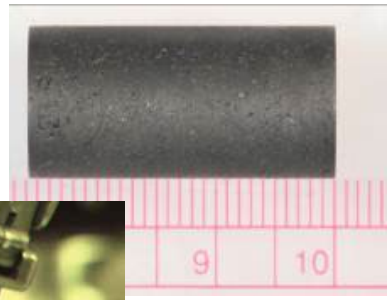
Typical lead lined shipping drum assembly (~5000 lbs) and new small quantity shipping drums (~50 lbs)

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



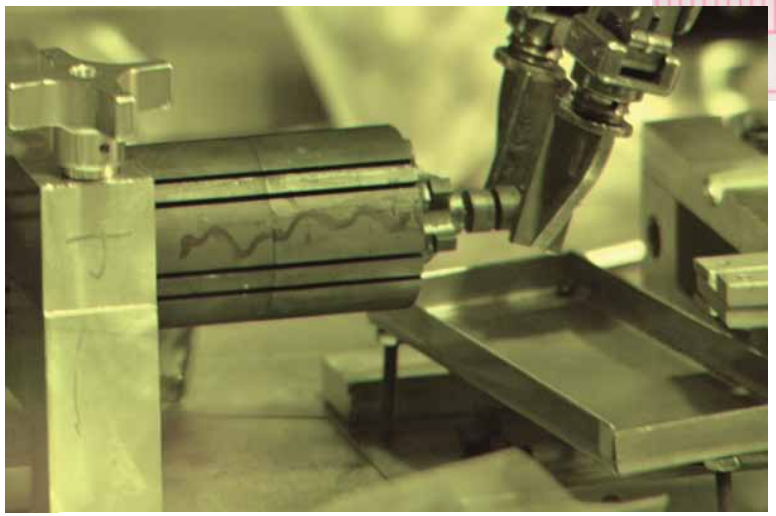
Where we think AGC-4 specimens are

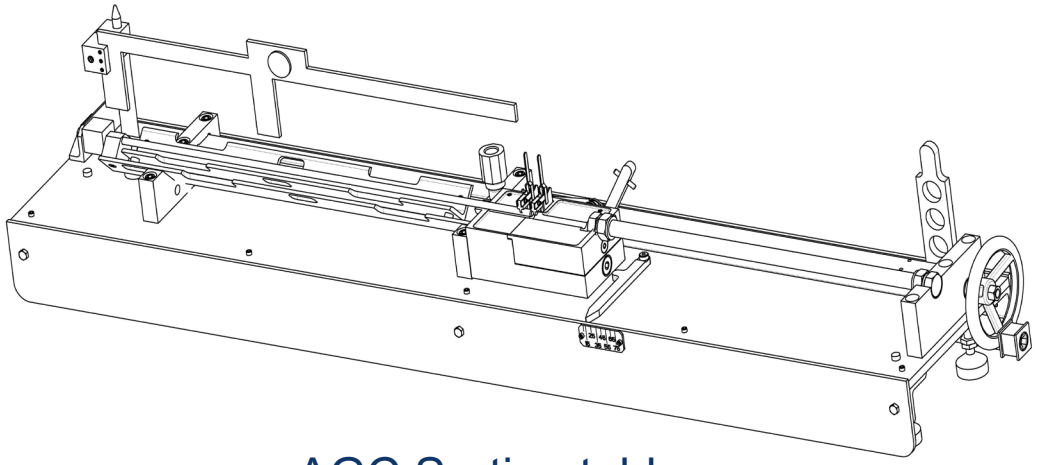
- 277 specimens at IRC Carbon Lab
  - Currently undergoing PIE
- 75 “warm” specimens (<100mR) shipping
  - *58 “warm” specimens at Carbon Lab*
  - *17 “warm’ specimens being shipped*
- *88 specimens either lost or “too hot”*
  - *Lost = crushed, machined, or rolled off sorting table during disassembly*

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%

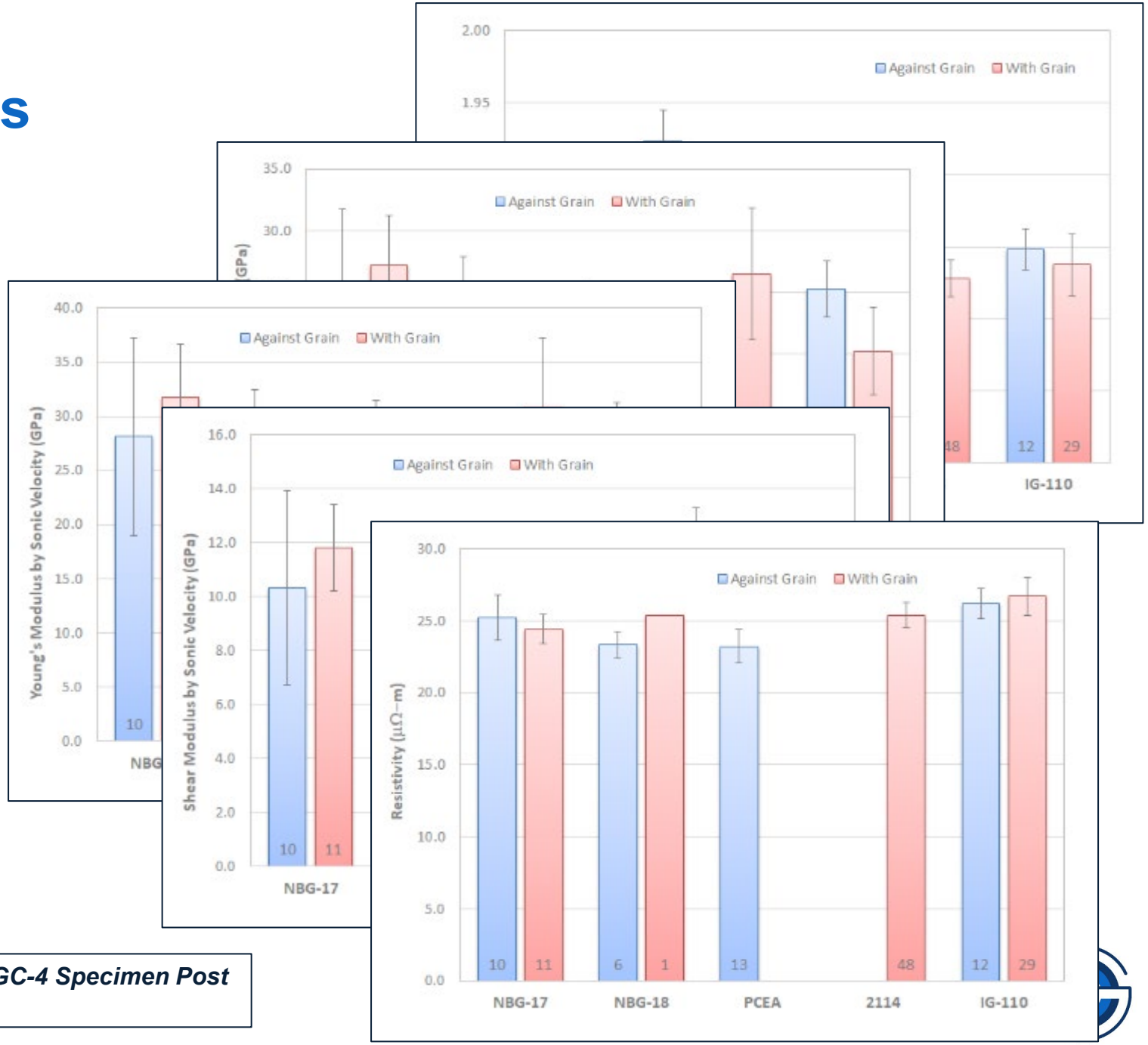




AGC Sorting table

Initial PIE results

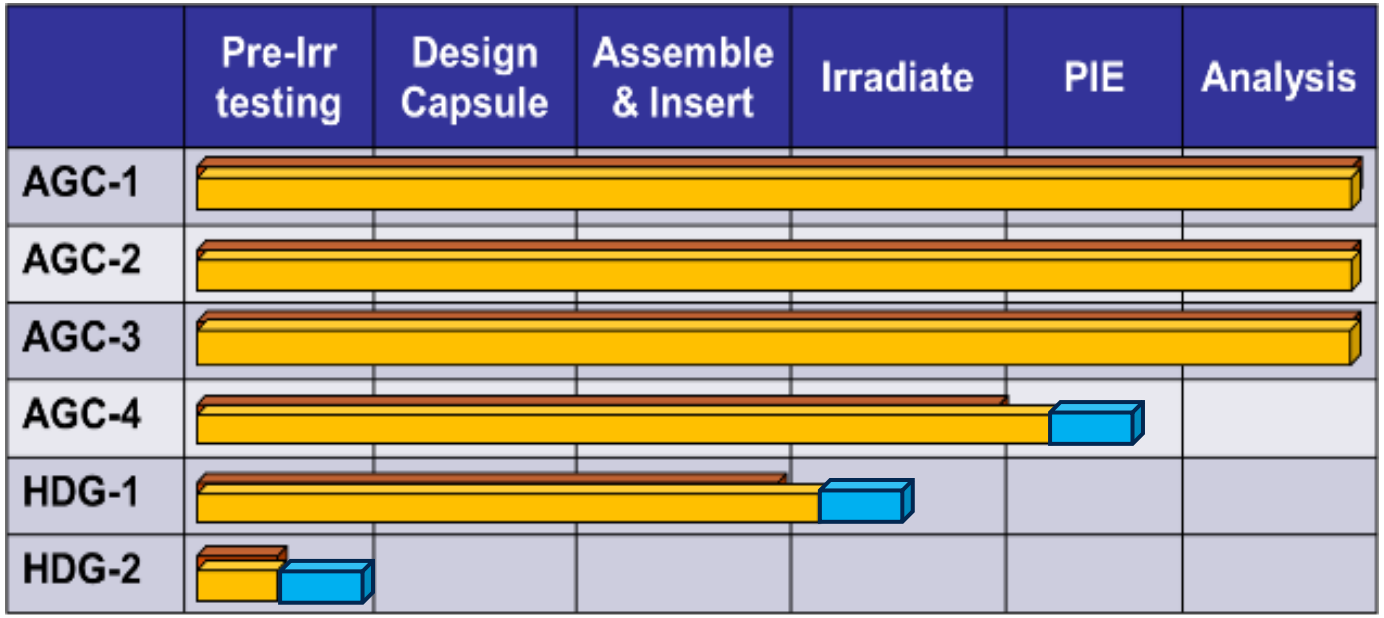
- Physical property measurements completed
  - *Initial results appear to be more or less typical, based on AGC-1 thru AGC-3 data*
  - *Analysis of data next year*
- Thermal property measurements ongoing
  - *Thermal property (diffusivity & CTE) take ~ 1 day/specimen*
  - *Estimate completion early next 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



- ***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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