INL/MIS-21-63273-Revision-0

AGR-5/6/7 Irradiation Results and Reporting

July 2021

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Idaho National Laboratory

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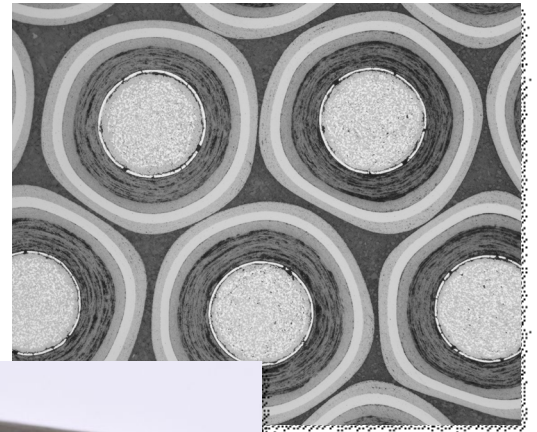
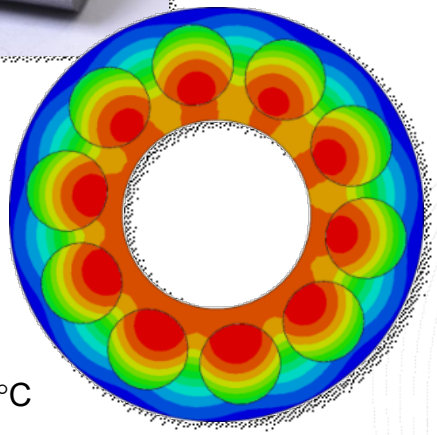
AGR-5/6/7 Irradiation Results and Reporting

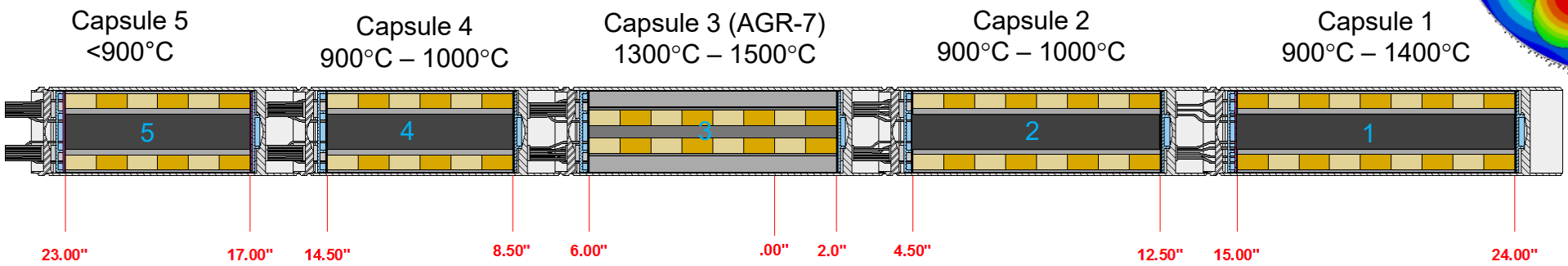
Advanced Reactor Technologies

AGR-5/6/7 Irradiation

- Final fuel qualification irradiation (AGR-5/6) and performance margin test (AGR-7)
- 425 µm diameter UCO kernels with 15.5% ^{235}U enrichment
- Target time-average peak fuel temperatures ~1500°C
- Target peak burnup 18% FIMA
- 194 fuel compacts (~570,000 particles) in five capsules
- Irradiation started Feb 2018 in ATR Northeast Flux Trap







AGR-5/6/7 test train axial cross section

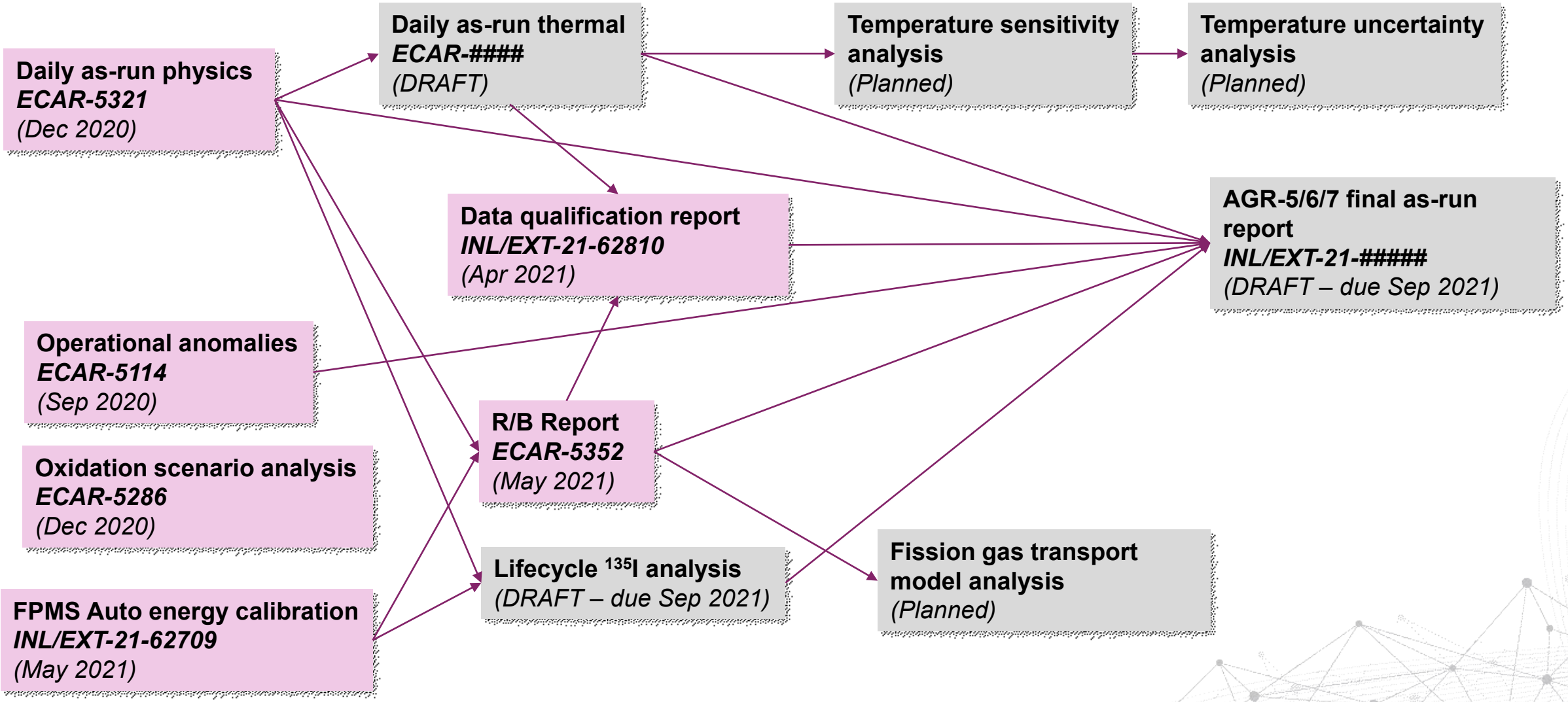
AGR-5/6/7 Status

- Large increase in fission gas from Capsule 1 observed in October 2019 (~235 EFPD, peak burnup ~8% FIMA)
- Experiment terminated early (July 2020) after 361 EFPD and peak burnup 15.3% FIMA
  - Primarily to ensure timely shipment to MFC and avoid conflicts with ATR Core Internals Changeout (CIC)
- Expedited shipment from ATR to MFC was not realized in late 2020; experiment shipped to MFC in March/April 2021 (two sections)
- Conflicts at HFEF with ART-AGC work and other DOE programs, as well as facility maintenance outages, have delayed the start of destructive capsule examination
- Capsule 1 PIE remains the top priority

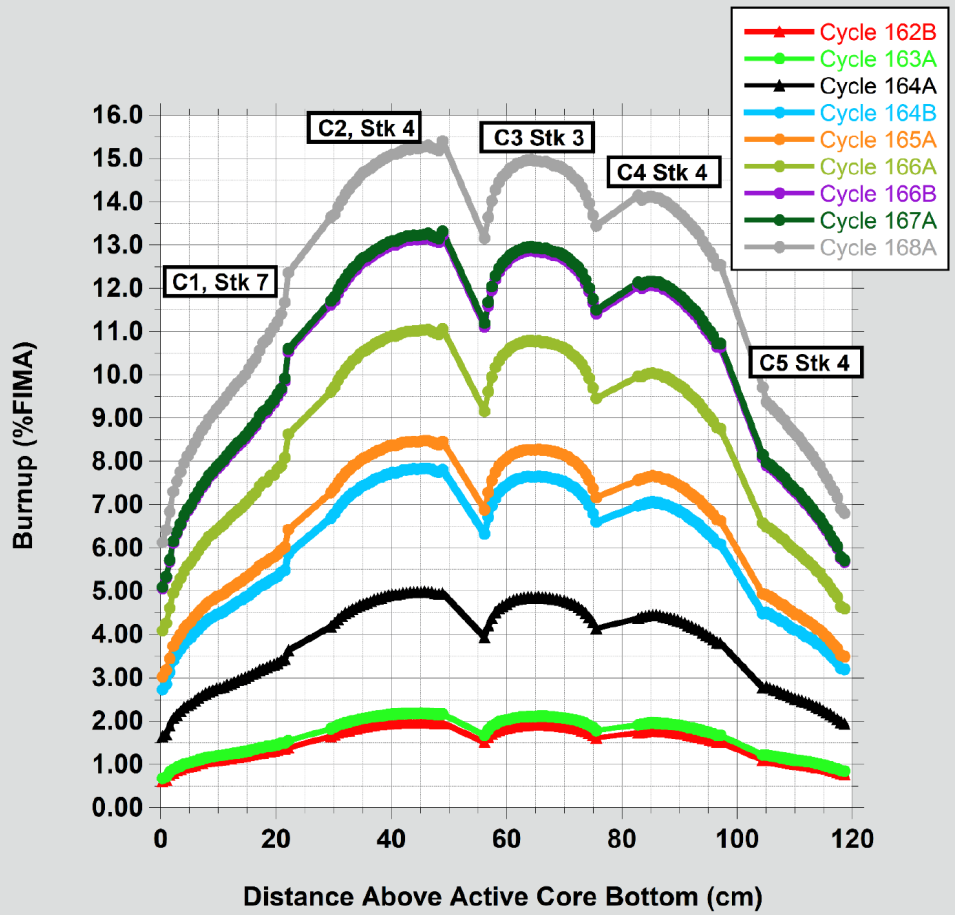
AGR-5/6/7 Operational Issues

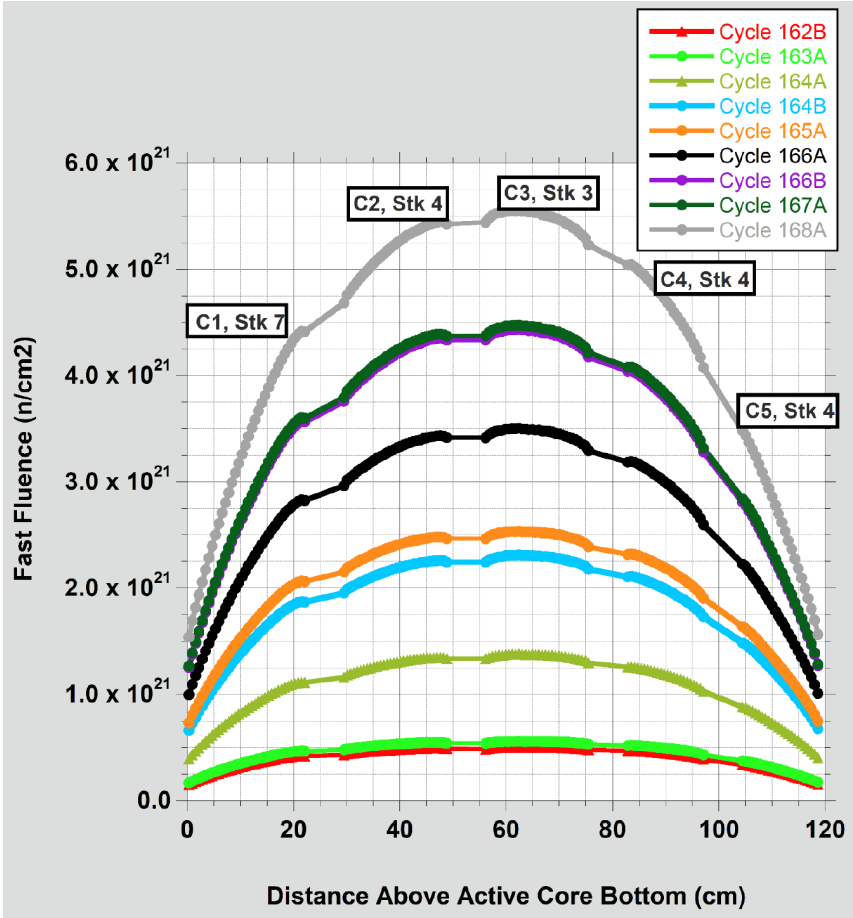
- Gas line integrity in Capsule 1 was compromised starting with the 4th cycle (Cycle 164B)
  - M. Nelson, “AGR-5/6/7 Gas System – Analysis of Various Anomalies Encountered During Irradiation,” ECAR-5114, September 2020
  - J. Palmer, “AGR-5/6/7 Irradiation Summary as of the End of Cycle 167A,” Presentation at 2020 ART-GCR Annual Program Review, July 2020
- These issues persisted and worsened throughout the irradiation and including occlusion (abnormally low flow) and breaks (gas flow leaking into and out of gas lines)
- Fission gas leaking from Capsule 1 to the leadout entered other capsules and complicated fission gas R/B analysis for Capsules 2 – 5
- Challenged ability to maintain fuel temperatures in Capsule 1

AGR-5/6/7 Reporting



AGR-5/6/7 Burnup and Fast Fluence

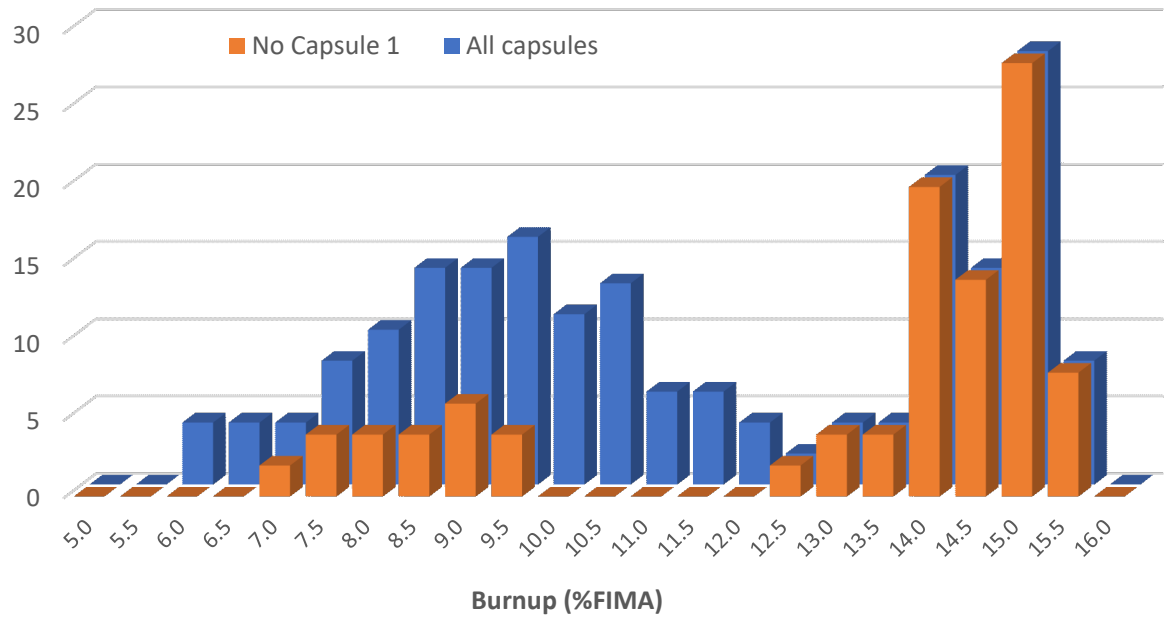




- Burnup (%FIMA)
  - Min: 5.7
  - Max: 15.3
  - Target: Max >18
- Fast fluence (n/cm^2)
  - Min: 1.6×10^{21}
  - Max: 5.6×10^{21}
  - Target: Max >5×10^{21}

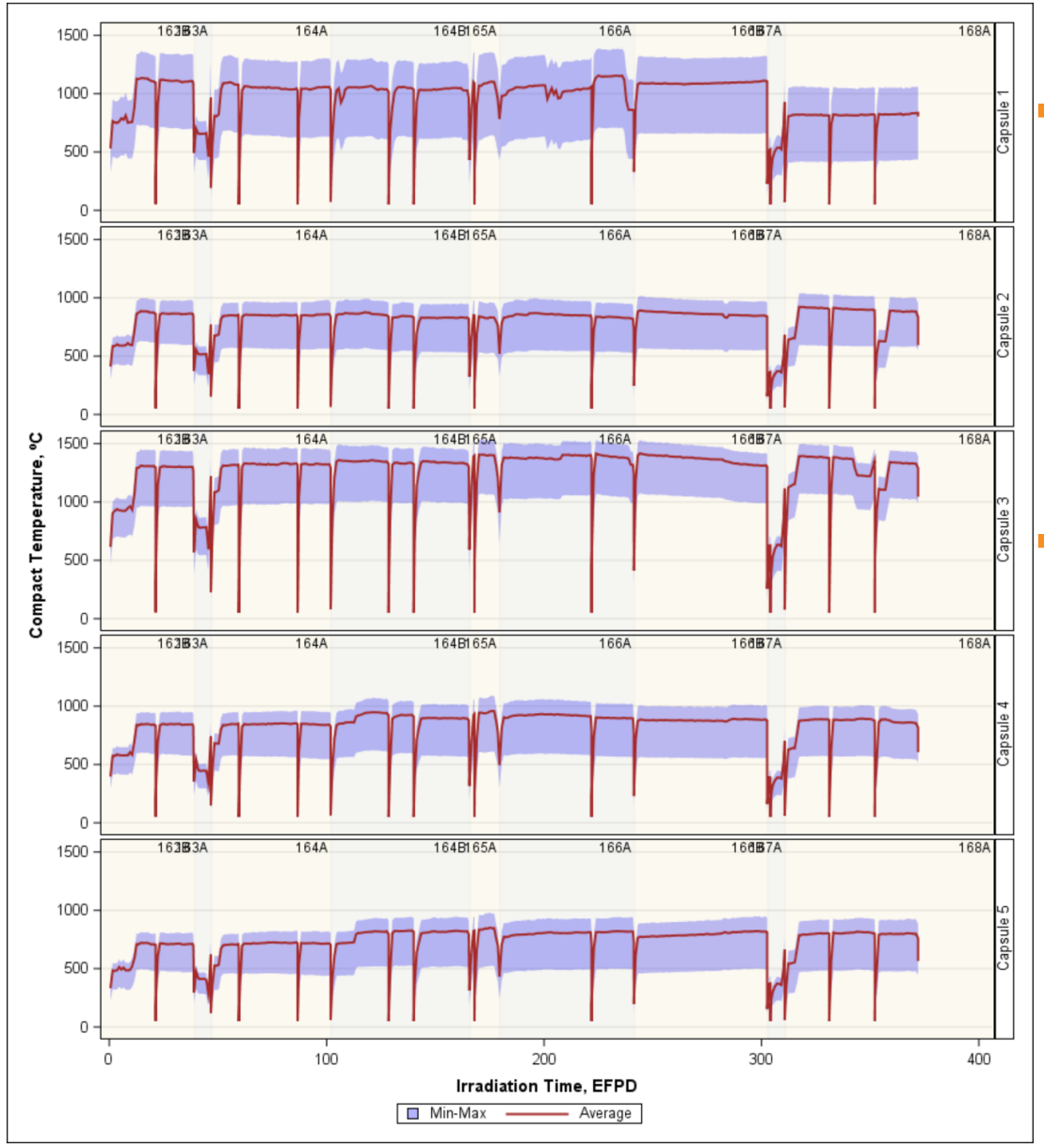
J. Sterbentz, "JMOCUP Physics Depletion Calculations for the As-Run AGR-5/6/7 TRISO Particle Experiment in ATR Northeast Flux Trap," ECAR-5321, December 2020

Burnup Distribution



- Limited compacts with intermediate burnup (11.5 – 13.5 %FIMA)
- Only Capsules 1 and 5 had burnup <12 %FIMA

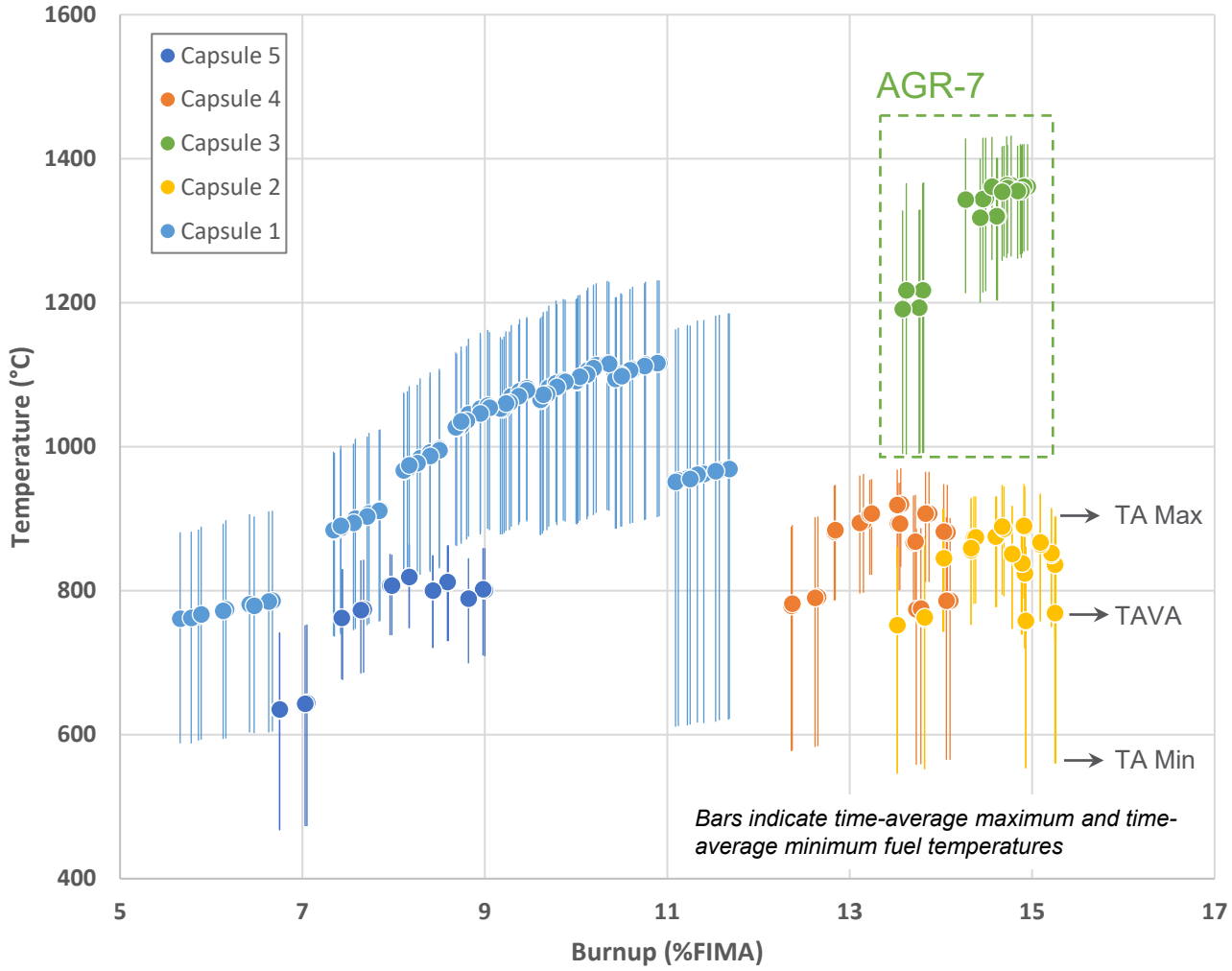
AGR-5/6/7 Fuel Temperatures



- Thermal model assumes 100% He in Cycle 168A which gives lowest fuel temperatures
- Low bias in predicted TC temperatures indicates possibility of higher fuel temperatures

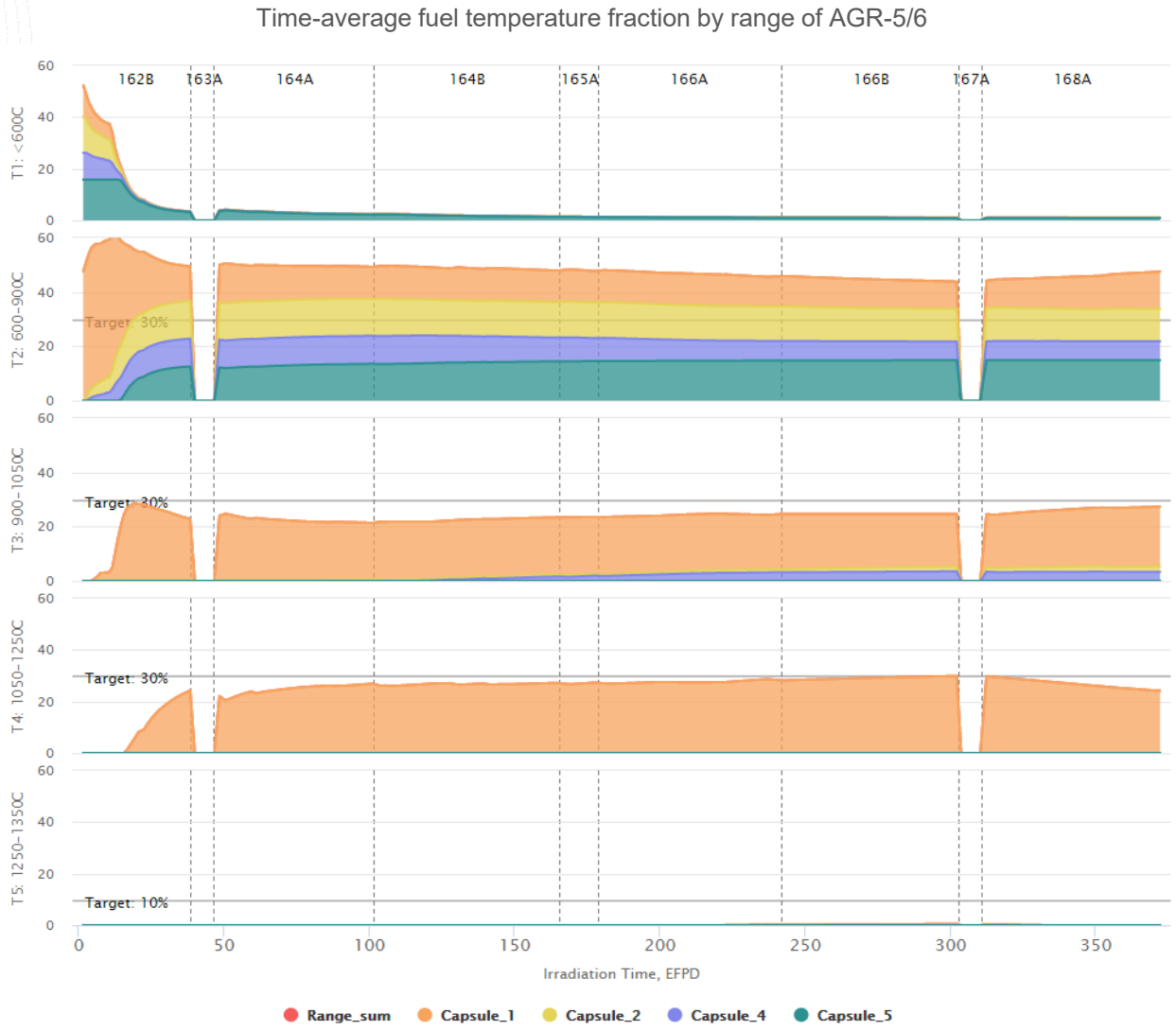
(J. Palmer et al., "Summary of Thermocouple Performance in the Advanced Gas Reactor Experiment AGR-5/6/7 During Irradiation in the Advanced Test Reactor," ANNIMA2021-04-196, June 2021)

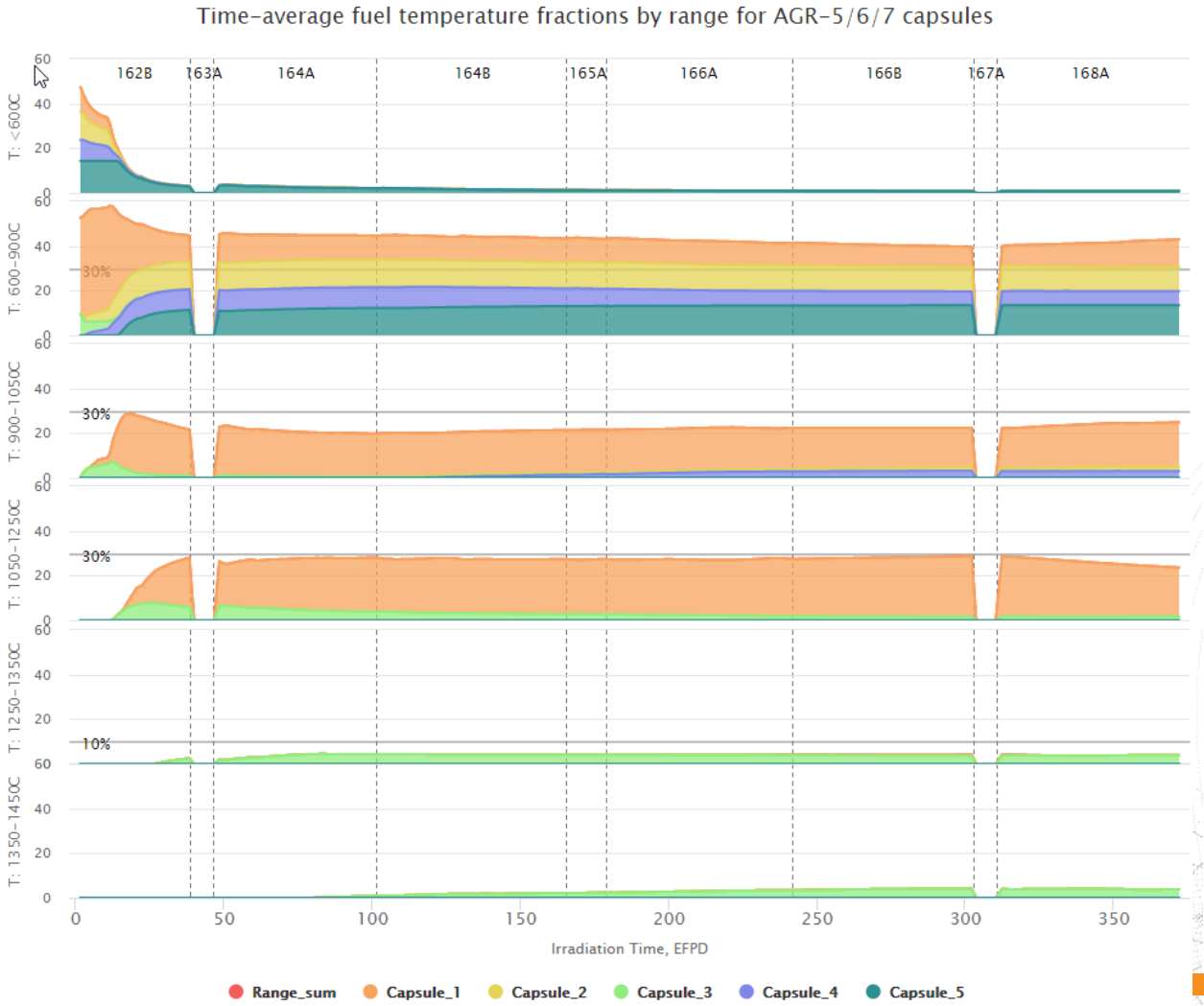
Time Averaged Fuel Temperatures



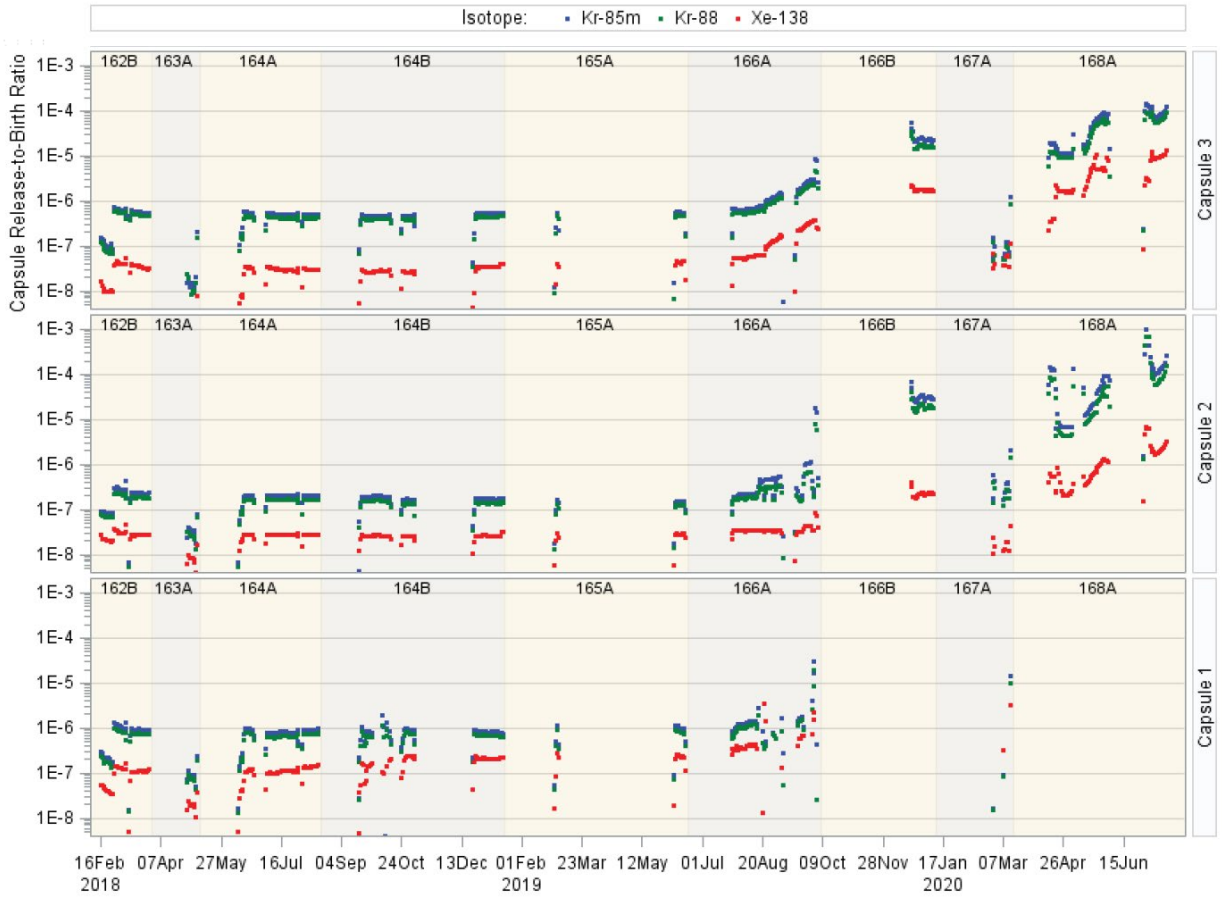
- Fuel temperature time averaging removes low-power PALM cycles (163A and 167A)
- Capsule 1 was relied upon for most of the upper temperature range for AGR-5/6
- Peak time-average temperature: 1432°C
  - Target: 1500 ±50°C
  - AGR-2: 1360°C

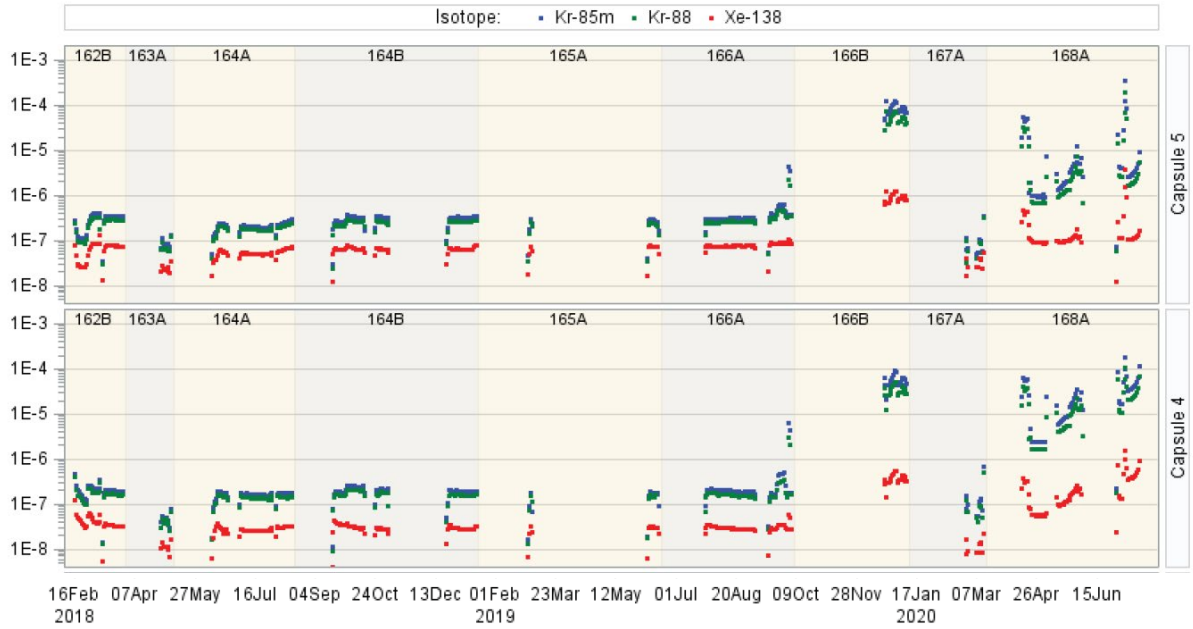
AGR-5/6/7 Temperature Distributions





Fission Gas Release-to-Birth Ratios





- Kr-85m R/B in early cycles was stable at ~10^{-7} to 10^{-6}
- Values unreliable from Cycle 166A onward due to leakage from Capsule 1

D. Scates, "Release-to-Birth Ratios for AGR-5/6/7 Operating Cycles 162B–168A," ECAR-5352

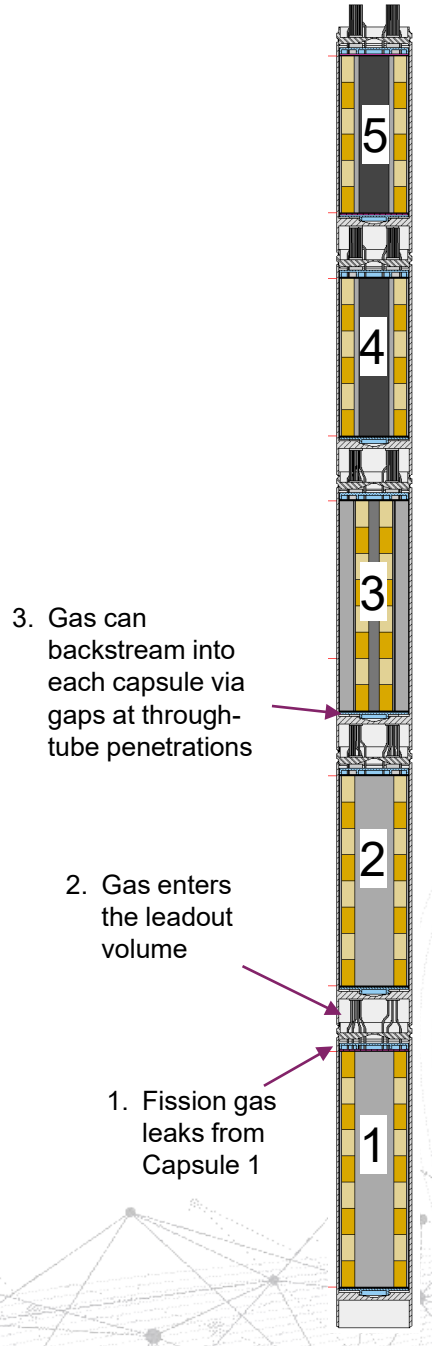
Quantifying In-Pile Particle Failure

Approach

- Utilize combined fission gas data streams to analyze for particle failures
  - Gross gamma spectra (peaks related to particle failure)
  - Isotopic gamma spectra peaks
  - R/B data (compare measured R/B with predicted values)

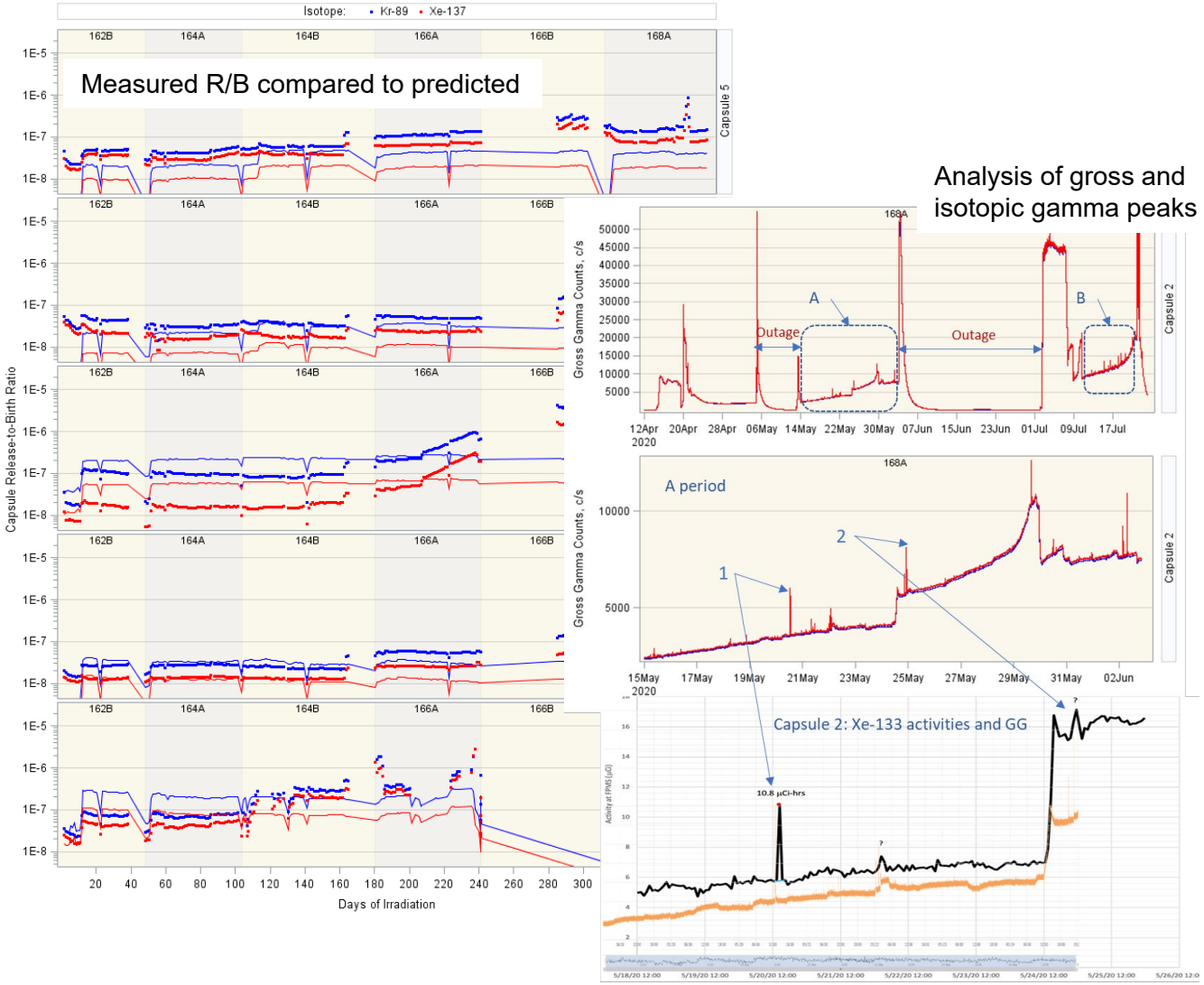
Challenges

- Capsule 1: No gas flow after Cycle 166A (no direct fission gas measurement)
- Capsules 2 – 5: In-leakage of gas from Capsule 1 impacts R/B analysis
- Uncertainty in starting number of exposed kernels
- Uncertainty in temperature of as-fabricated exposed kernel defects and in-pile failures, which impacts fission gas release
- Peaks in gamma spectra often appear to be unrelated to particle failure events



B. Pham et al., "AGR 5/6/7 Irradiation Test Final As-Run Report," INL/EXT-21-##### (DRAFT)

Particle Failure Analysis



Preliminary estimate of in-pile particle failures

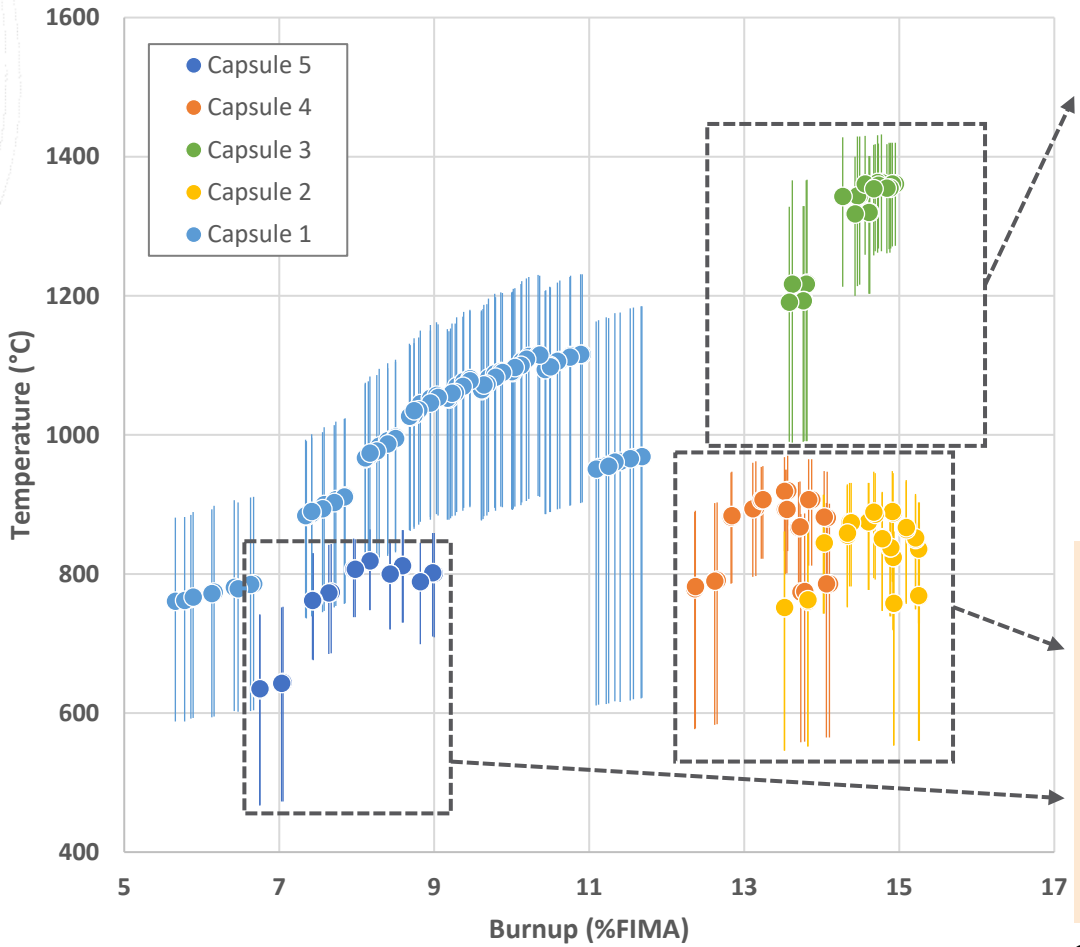
Capsule	# Failures
1	180 – 440 near the end of Cycle 166A; unknown thereafter
2	1 – 4 in Cycle 168A
3	≤15 in Cycle 168A
4	0
5	0

B. Pham et al., "AGR 5/6/7 Irradiation Test Final As-Run Report," INL/EXT-21-##### (DRAFT)

Considerations for Postirradiation Examination

- Implications for Capsule 1 fuel use
  - Most/all compacts are likely highly contaminated with fission products (Cs, Sr, Eu) from failed particles
    - This capsule not useful for evaluating fission product release from intact fuel (capsule mass balance, DLBL, safety testing)
  - Particle gamma counting still useful
  - Particle microanalysis still useful
  - Safety tests to determine particle failure – need compacts with zero failures (still probably unsuitable for assessing fission product release from intact fuel)
- Can we screen specific compacts for particle failure and use the “good ones”?
  - Short-duration heating in FACS to assess presence of particle failures (pass/fail)
- Compromised compacts
  - Testing in AMIX to assess impact of oxidation on failed fuel

In-Pile Particle Failure Statistics



- 24 fuel compacts
- 54,000 particles
- Likely several particle failures

Current estimated particle failure fraction (upper limit @ 95% confidence): ~5 – 40 $\times 10^{-5}$

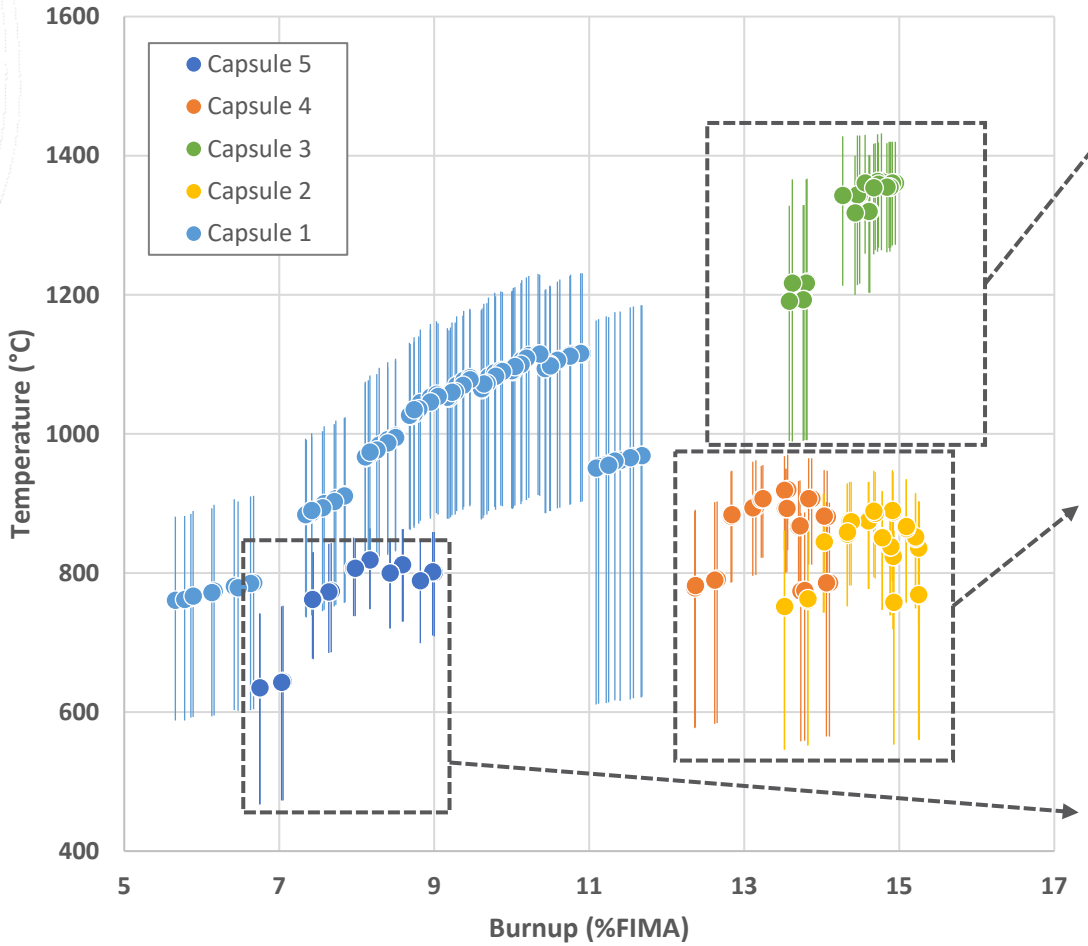
- 80 fuel compacts
- 207,000 particles
- Highest TAVA temperature = 919°C
- Estimated 1 – 4 particle failures in Capsule 2

Current estimated particle failure fraction (upper limit @ 95% confidence): ~2 – 4 $\times 10^{-5}$

- Original experiment specification called for ~500,000 particles irradiated under normal operating conditions (*SPC-1749*)
- If Capsule 1 fuel is eliminated from consideration due to the operational issues, there are still sufficient particle statistics, but irradiation temperatures are much too low
- Obtaining failure statistics over a representative temperature range will require screening out Capsule 1 compacts with external causes for particle failure

J.T. Maki, "AGR 5/6/7 Irradiation Test Specification," SPC-1749, 2015

Post-Irradiation Safety Testing Statistics



- 24 fuel compacts
- 54,000 particles
- Likely several particle failures

- 56 fuel compacts
- 125,000 particles
- Possible small number of failures (Capsule 2)

- 24 fuel compacts
- 81,000 particles
- Ample low-temperature, low-burnup compacts for testing

- Original experiment specification called for ~50,000 particles for 1600°C safety testing and ~20,000 particles for testing at 1700 – 1800°C (*SPC-1749*)
- Capsule 2 – 5 particle numbers are sufficient, but temperature distribution is problematic
- May require salvaging useable compacts from Capsule 1

J.T. Maki, "AGR 5/6/7 Irradiation Test Specification," SPC-1749, 2015

Summary

- AGR-5/6/7 irradiation is complete and PIE is underway
- Reporting is still in progress
- Time-average temperatures: 467 – 1432°C
- Burnup: 5.7 – 15.3% FIMA
- Preliminary estimate of particle failure indicate zero failures in Capsules 4 and 5, 1 – 4 in Capsule 2, and as many as 15 in Capsule 3
- Cause of Capsule 1 particle failures is not yet known

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