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Summary of Thermocouple Performance in the Advanced Gas Reactor Experiment AGR-5/6/7 During Irradiation in the Advanced Test Reactor

June 2021

Changing the World's Energy Future

Joe Palmer, Richard S Skifton, Grant L Hawkes, Cam Binh T Pham, Timothy L. Checketts, Michele Scervini

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Summary of Thermocouple Performance in the Advanced Gas Reactor Experiment AGR-5/6/7 During Irradiation in the Advanced Test Reactor

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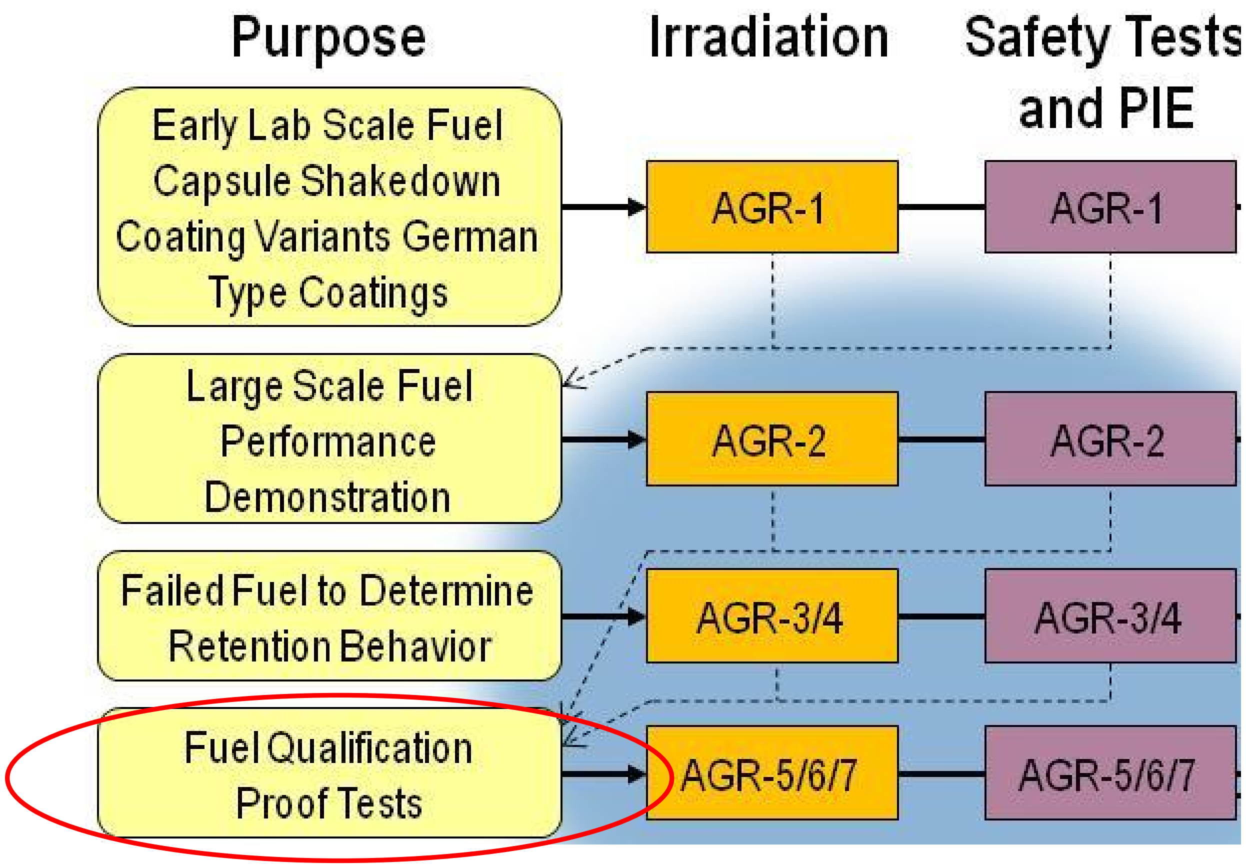
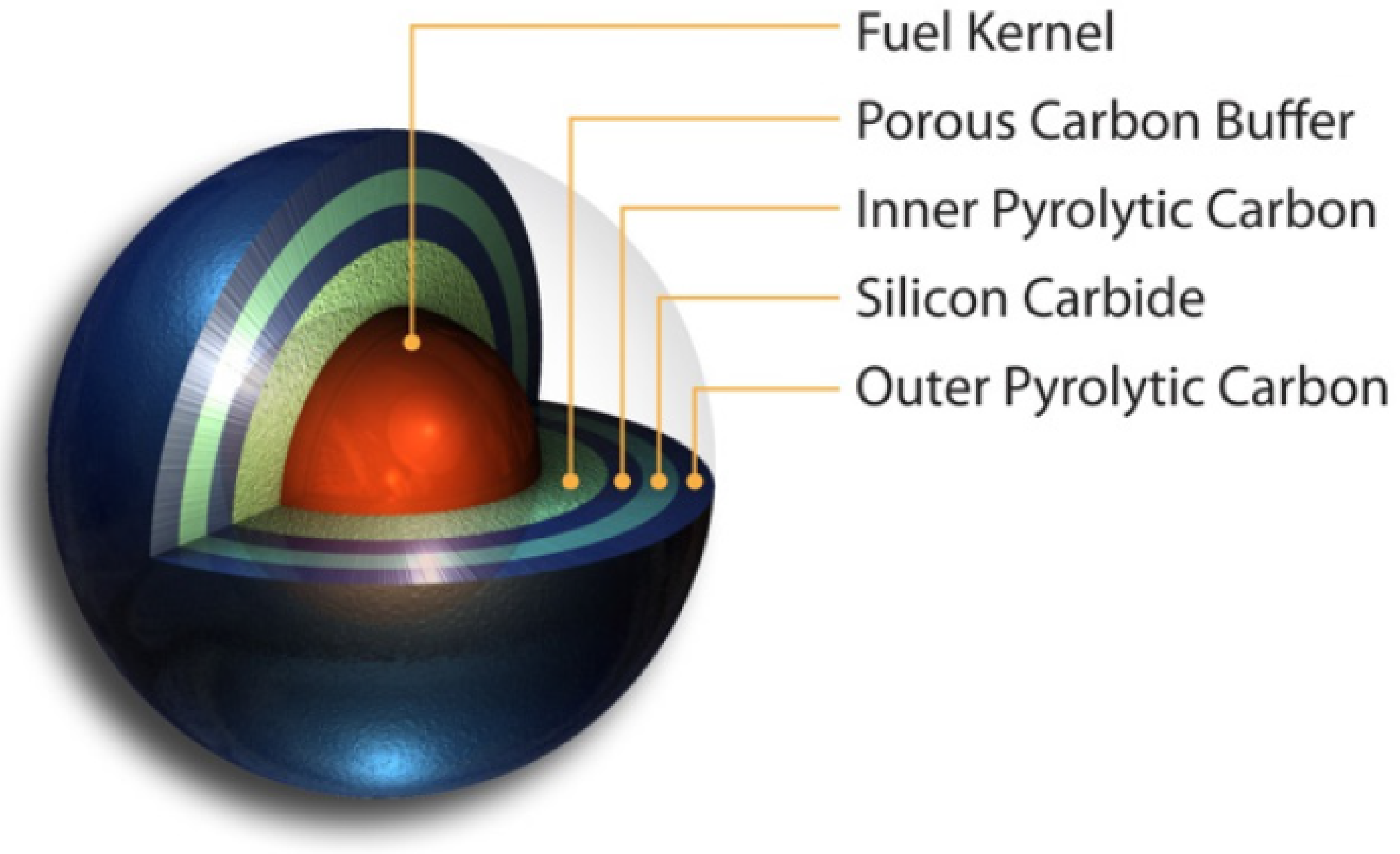


- AGR-5/6/7 mission and details
  - Fuel qualification (AGR-5/6) and margin test (AGR-7)
  - Originally envisioned as three separate tests
  - Covers wide range of temperatures and fuel burnup

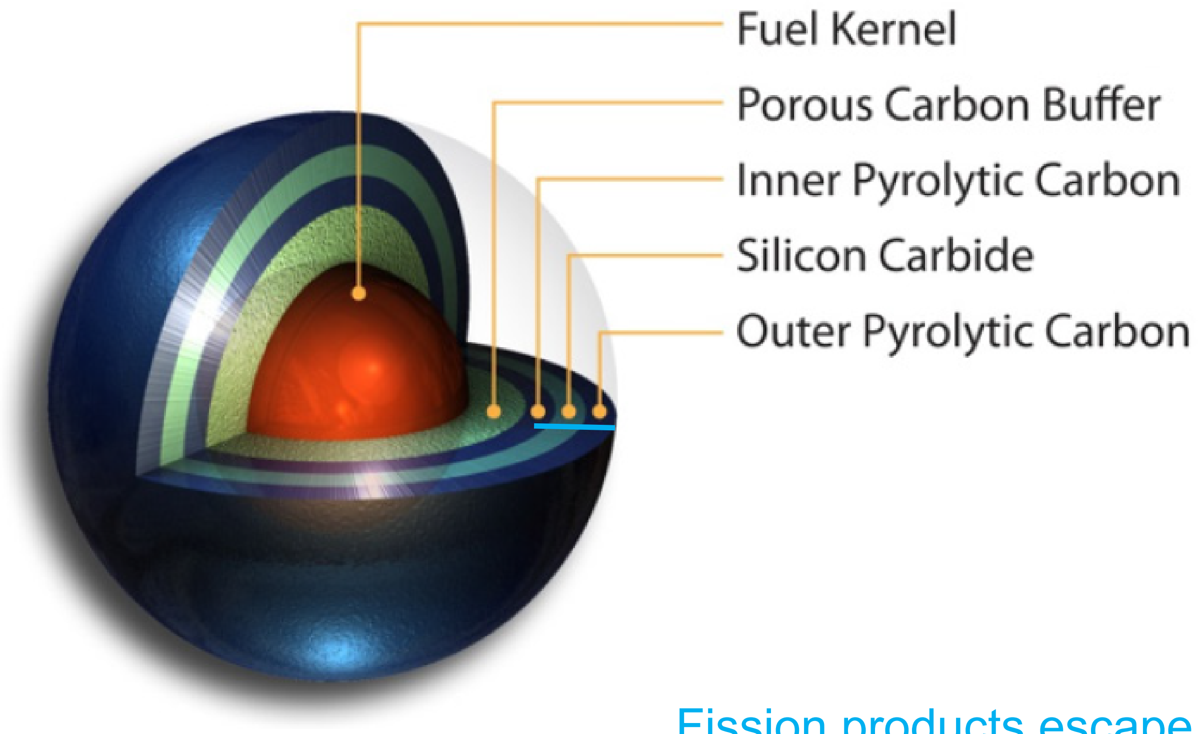
Fuel Particle



Fuel Compact

Particles are combined with matrix and resin material and pressed into compacts

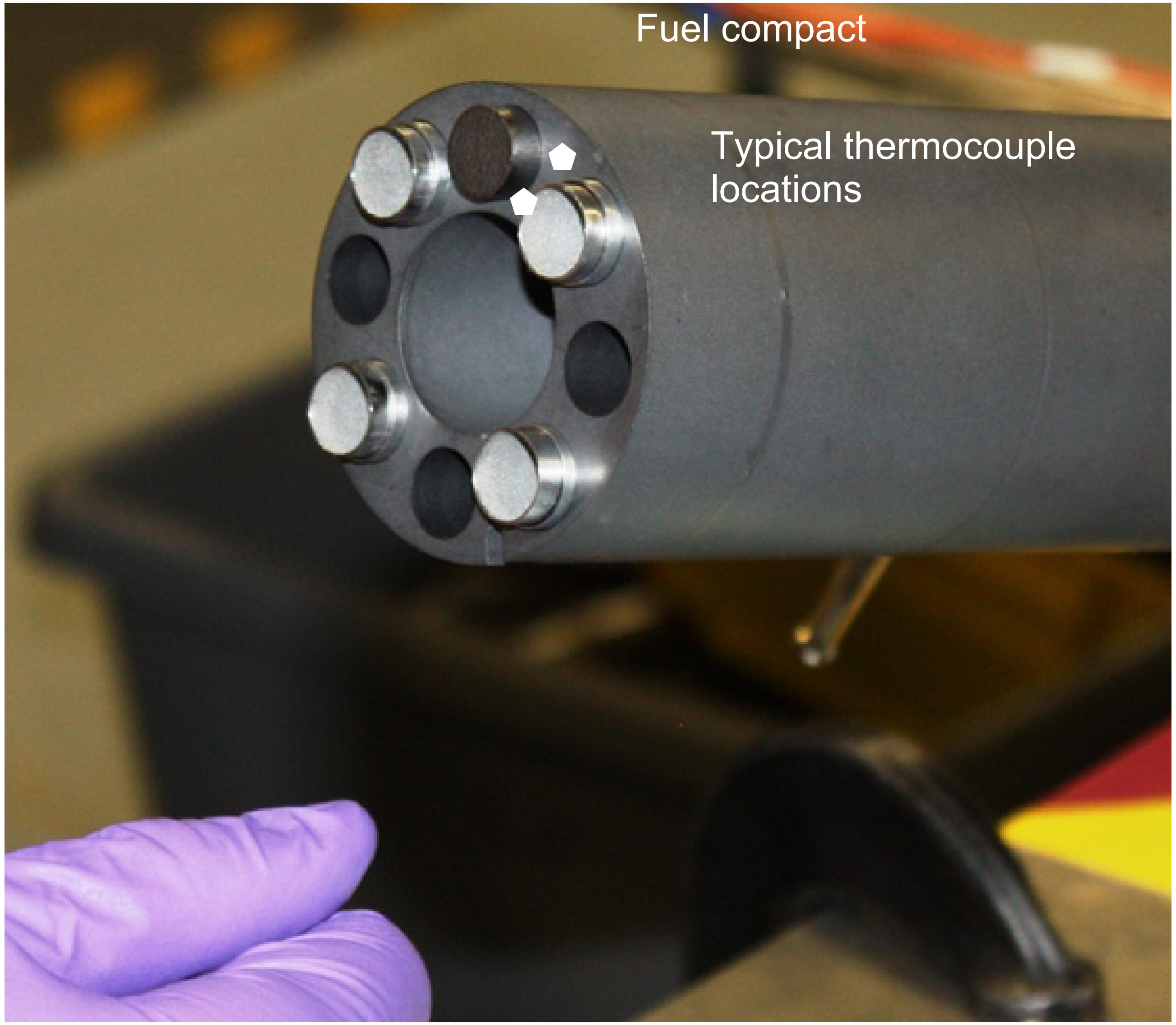
Purpose of AGR-5/6/7 Experiment



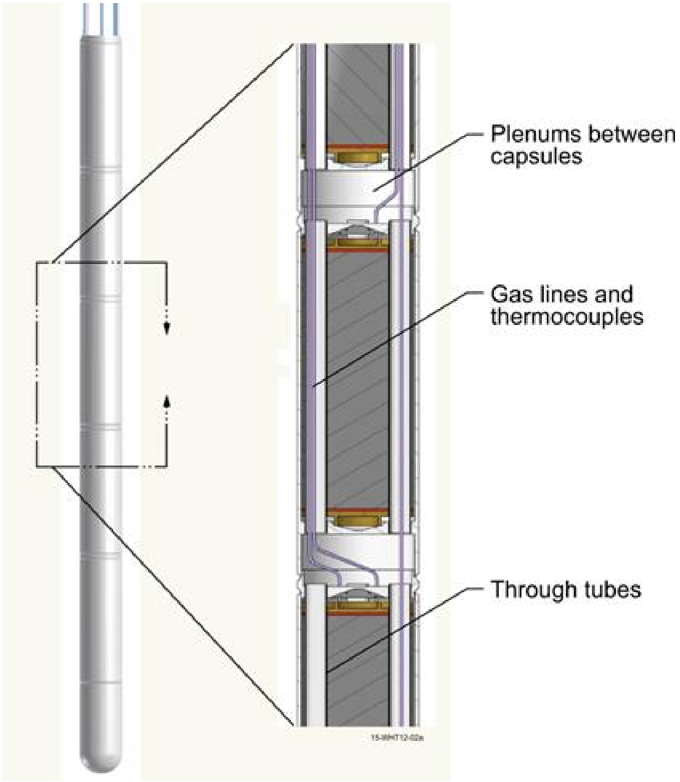
Fission products escape when one or more of these barriers fails

The purpose of the AGR-5/6/7 experiment is to demonstrate fission products are retained when irradiated at reactor operating temperatures and above

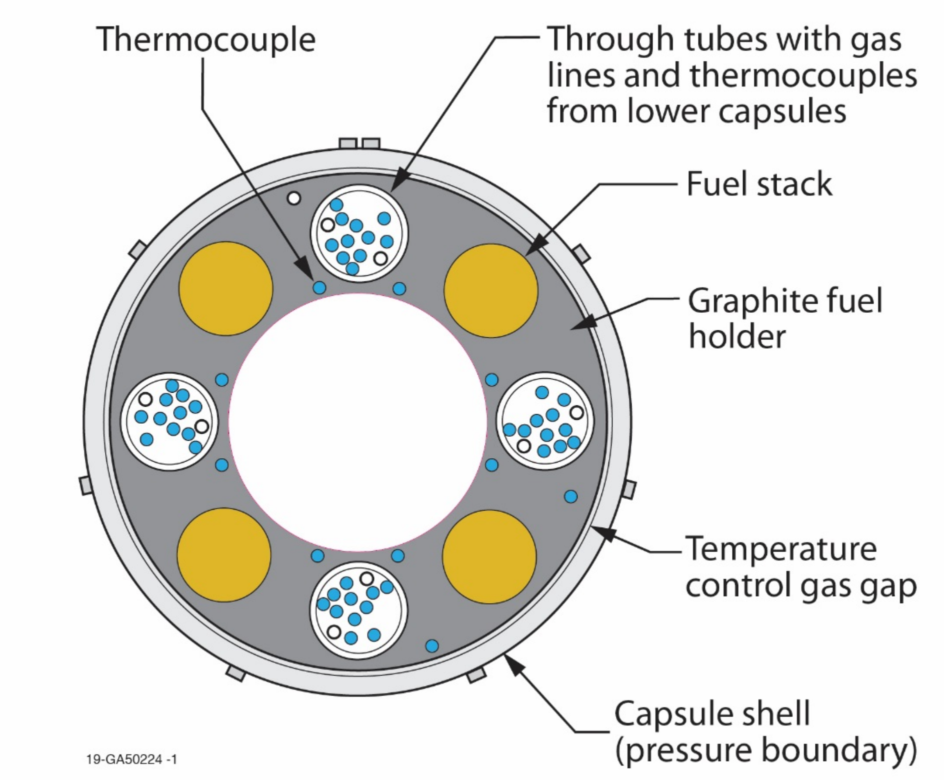
Fuel Compact Inserted in Graphite Holder



AGR-5/6/7 Test Train Design

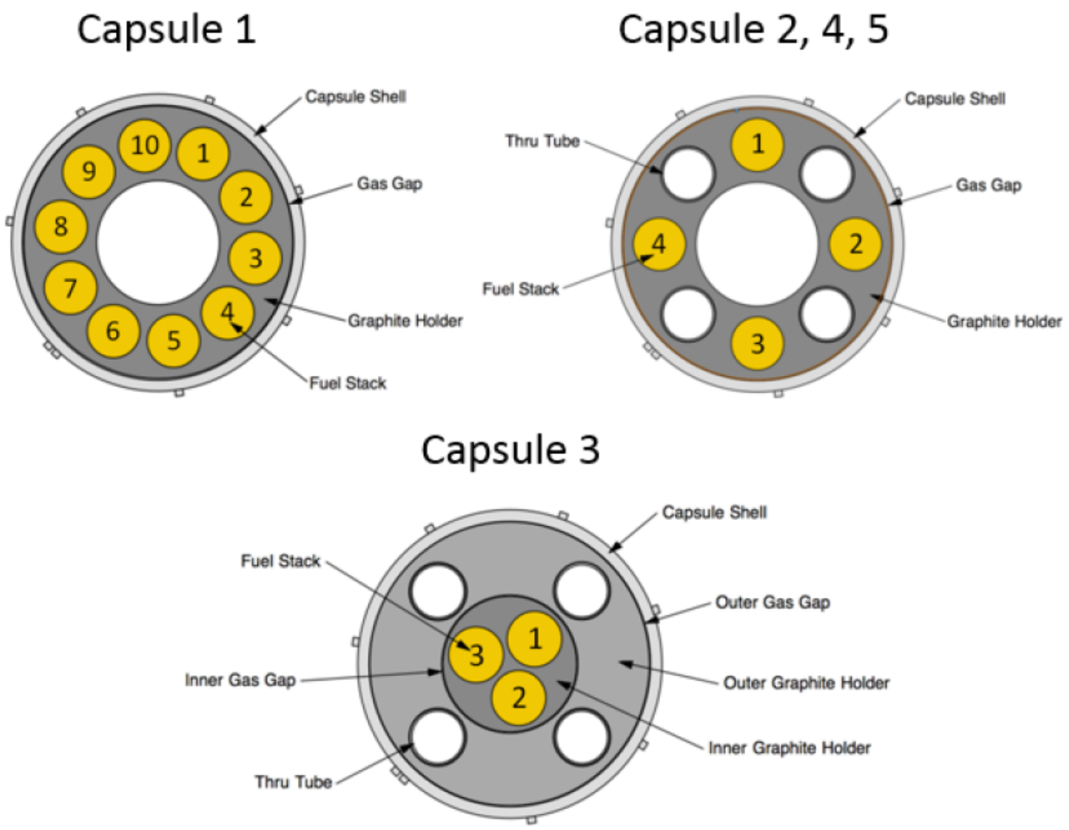


Elevation view of AGR-5/6/7 experiment



Cross-section view of AGR-5/6/7 experiment

Three Different Capsule Cross Sections



It is Difficult to Measure Very High Temperatures in a Reactor Environment

Why?

- Standard base metal thermocouples (Type K and Type N) drift at high temperatures due to metallurgical changes (above 600°C for Type K and above 1050°C for Type N)
- High temperature refractory thermocouples such as Types C, S, B, and R have high cross section alloying elements and are subject to rapid decalibration (drift) because their alloying elements transmute into other elements with different electromotive properties

Measuring High Temperatures in the AGR-5/6/7 Experiment

- The projected temperature measurement range for AGR-5/6/7 thermocouples encompasses a range from 700°C to 1450°C. Therefore, for the temperatures above 1050°C, advanced thermocouple types were needed.
- For 1000°C – 1250°C, AGR-5/6/7 used special Type N thermocouples developed by Cambridge University (called CAMB-N).
- For 1100°C – 1450°C, AGR-5/6/7 used Mo/Nb based thermocouples (called HTIR-TC) developed at INL.

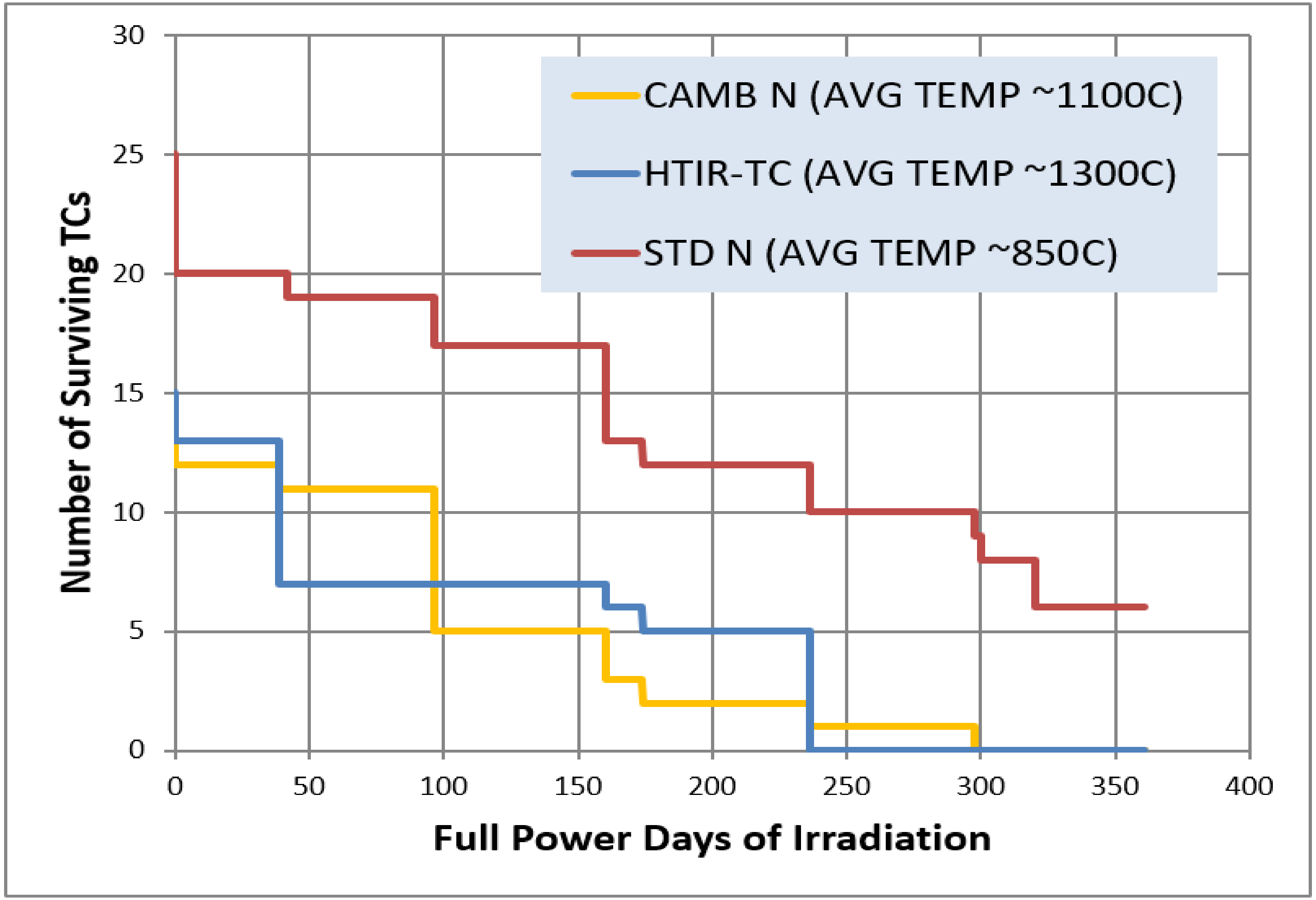
Irradiation Testing Results

In-Pile Testing Results – Neutron Fluence By Capsule

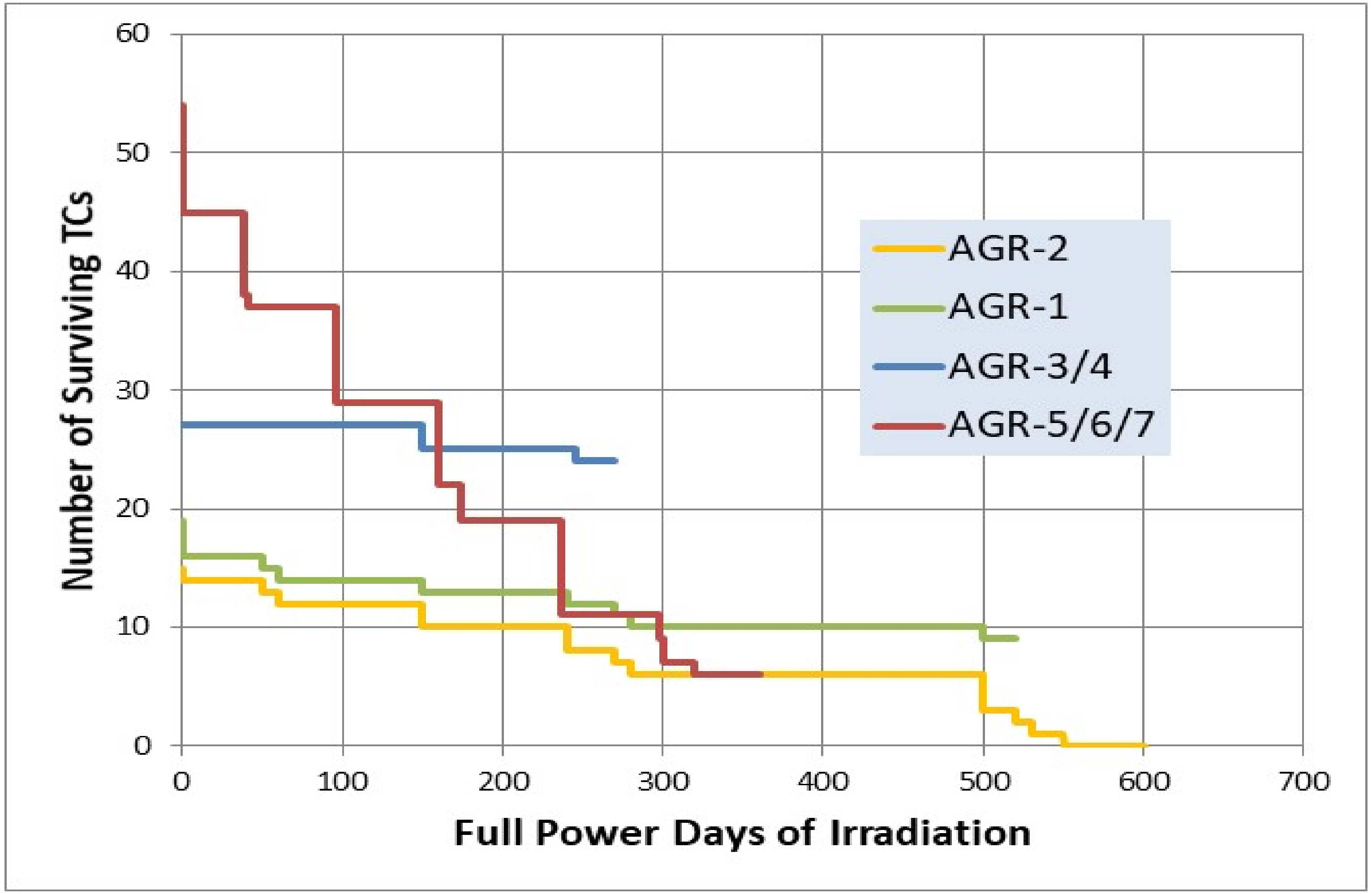
TABLE I
AGR-5/6/7 NEUTRON FLUENCE BY CAPSULE

Capsule ID	Thermal Fluence (n/cm^2 <0.5eV)	Fast Fluence (n/cm^2 >0.18 MeV)
Cap 5	2.2 E+21	2.4 E+21
Cap 4	3.9 E+21	4.5 E+21
Cap 3	4.9 E+21	5.4 E+21
Cap 2	4.8 E+21	5.2 E+21
Cap 1	3.4 E+21	3.8 E+21

In-Pile Testing Results – Failure Rate by Thermocouple Type



In-Pile Testing Results – Failure Rate Compared to Previous AGR Tests



In-Pile Testing Results – MTBF By TC Type

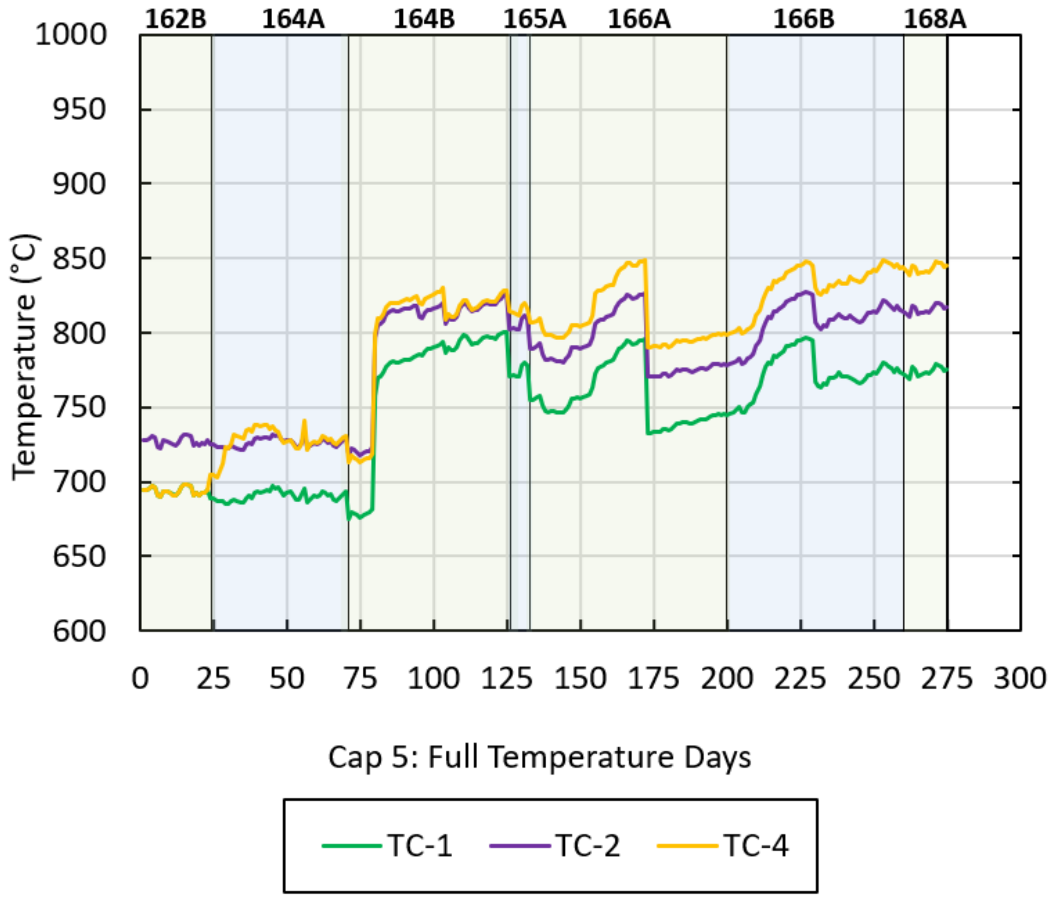
AGR-5/6/7 TC FAILURE SUMMARY

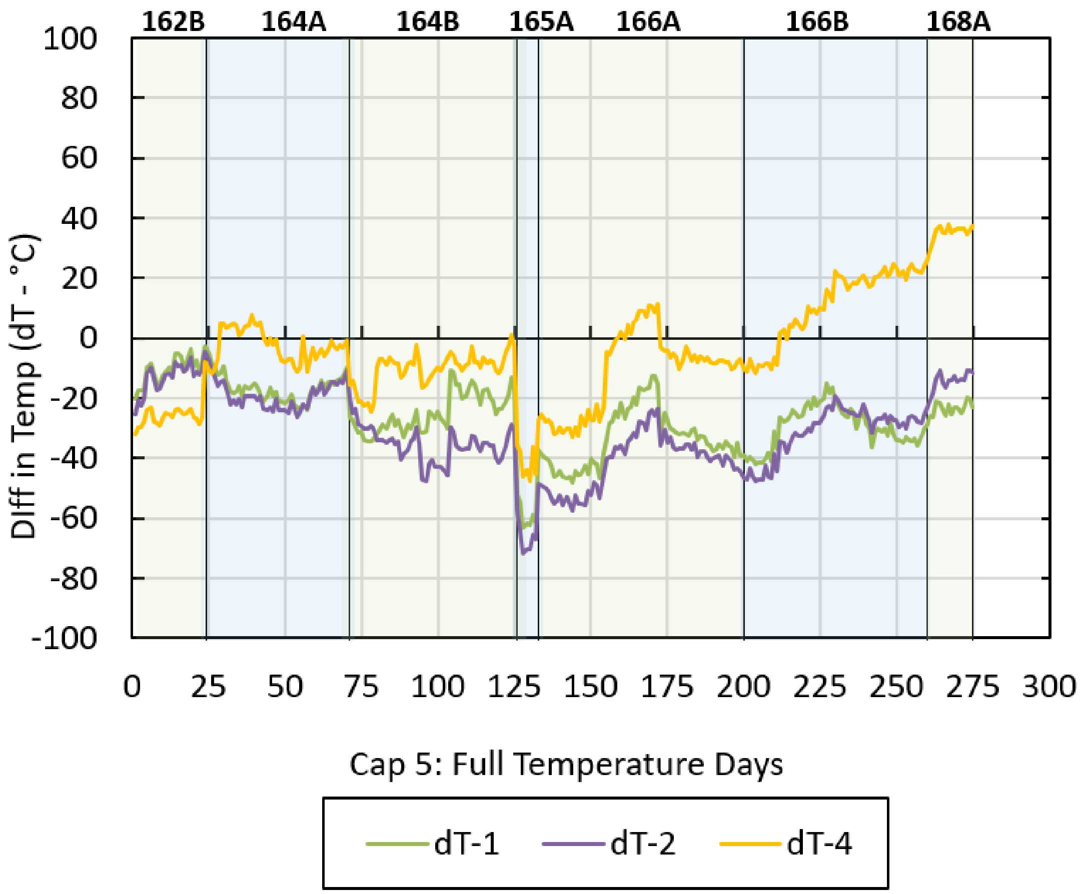
	HTIR-TC @1300°C	Type N CAMB @1100°C	Type N @850°C
MTBF (Days)	90	89	232
Survival Fraction >100 Days	6/13	3/13	17/19
Survival Fraction >200 Days	0/13	1/13	11/19
Survival Fraction >300 Days	0/13	0/13	9/19

Thermocouple Drift

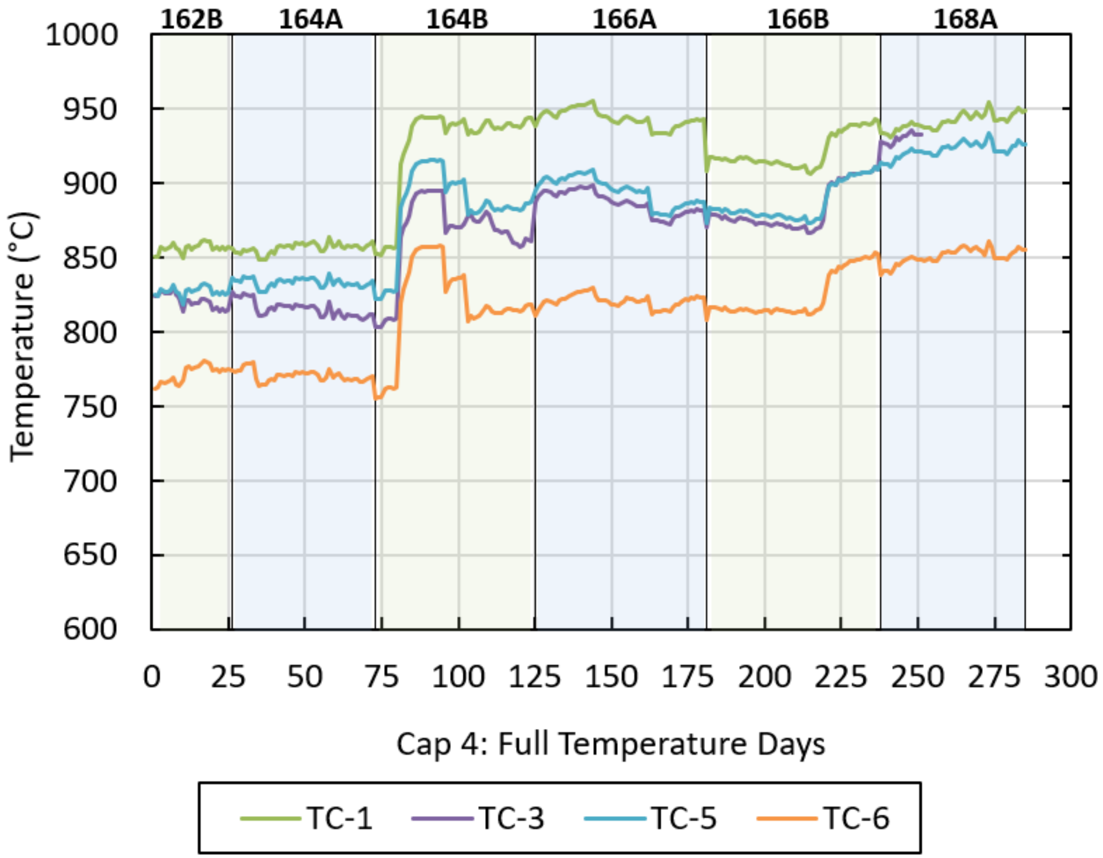
- No real evidence of thermocouple drift in the cooler capsules: 2, 4 and 5

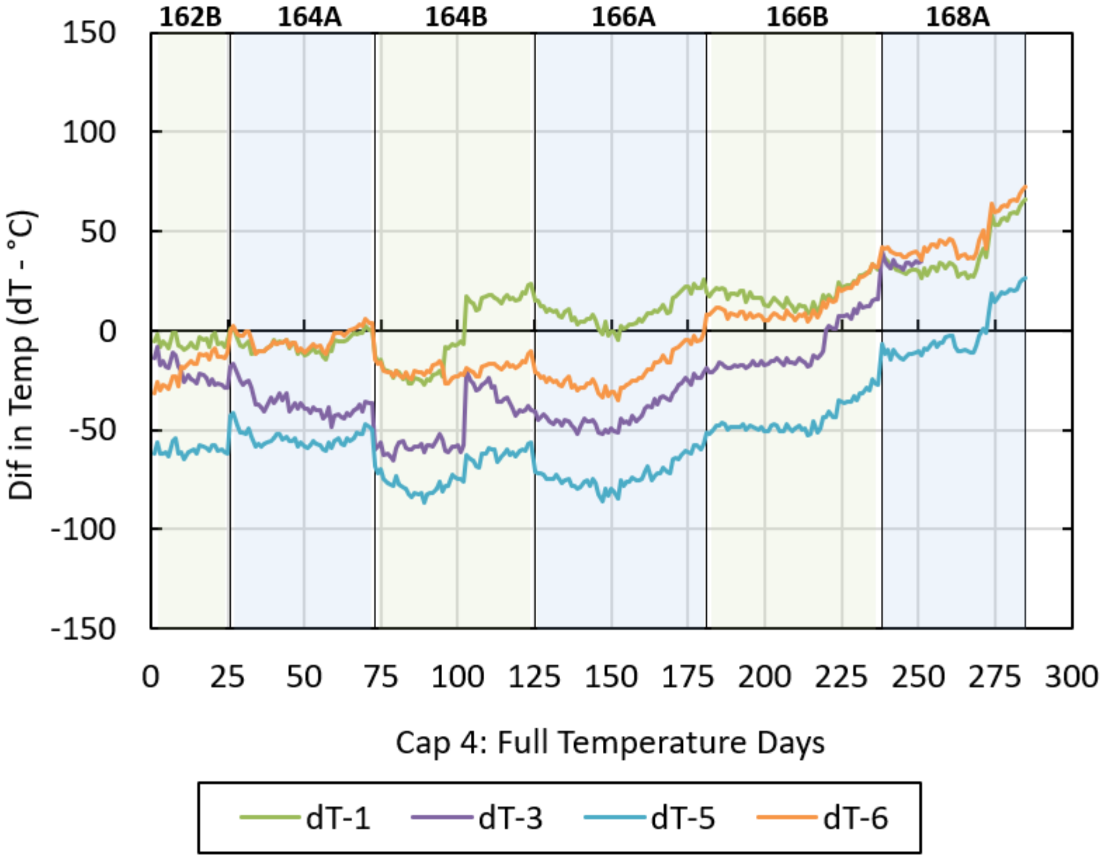
Capsule 5 Temperature Trends and Measured vs Thermal Model



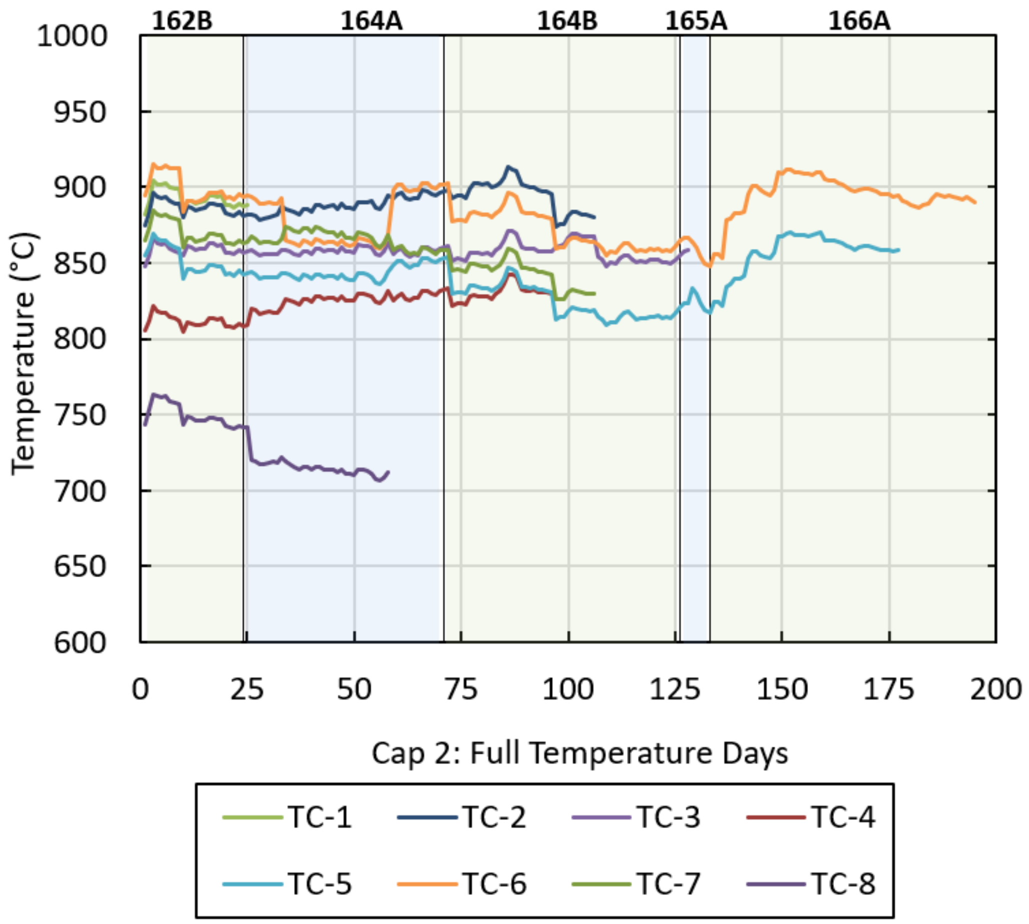


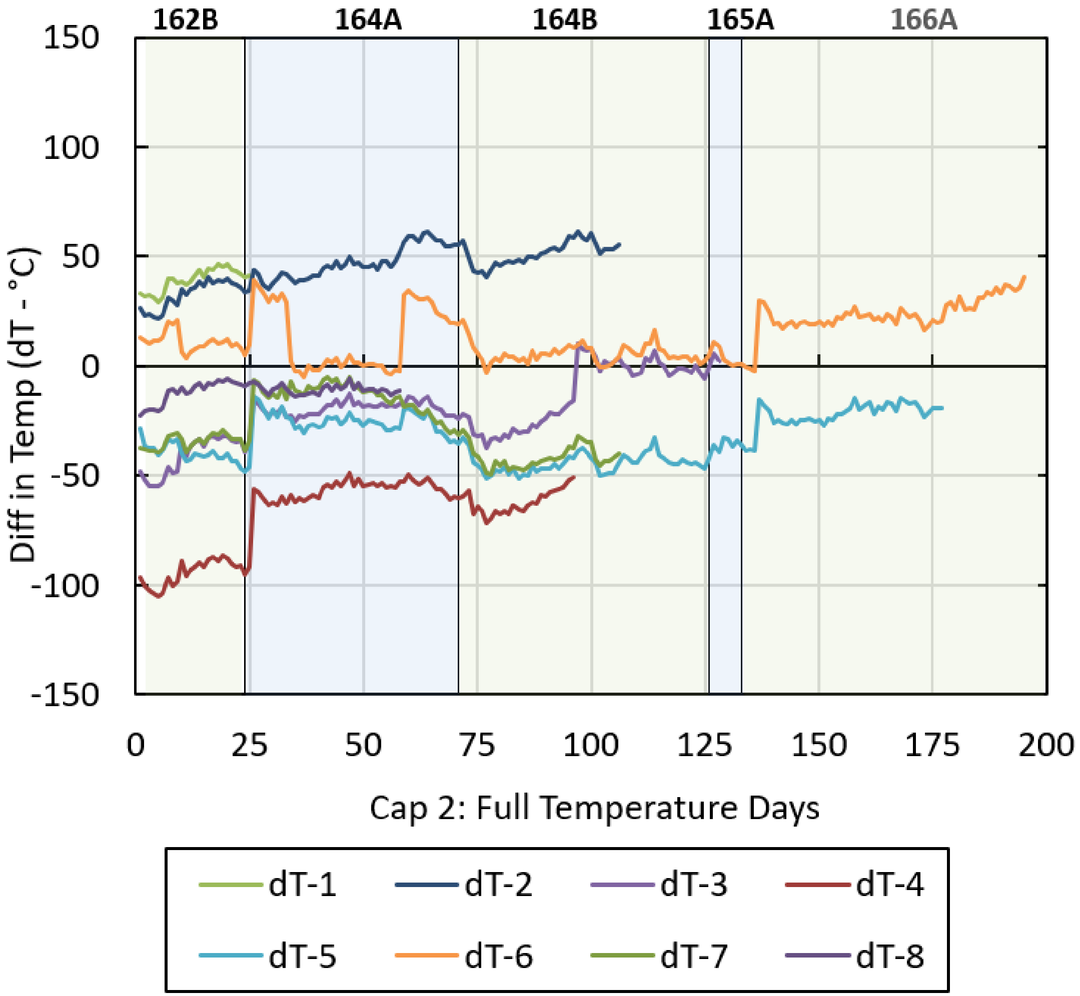
Capsule 4 Temperature Trends and Measured vs Thermal Model





Capsule 2 Temperature Trends and Measured vs Thermal Model



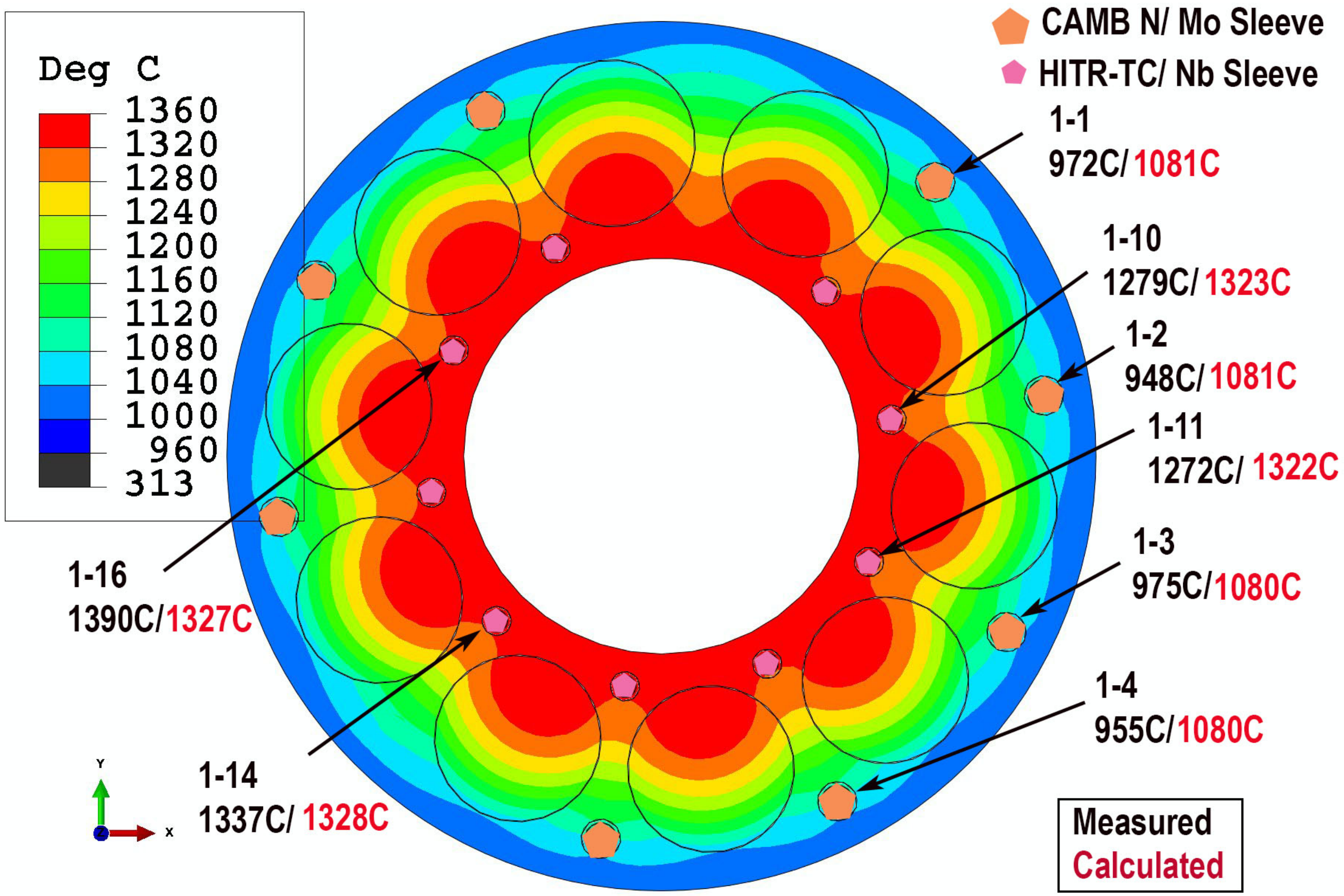


The analysis of Capsules' 1 and 3 thermocouple drift performance is complicated compared to 2, 4, and 5

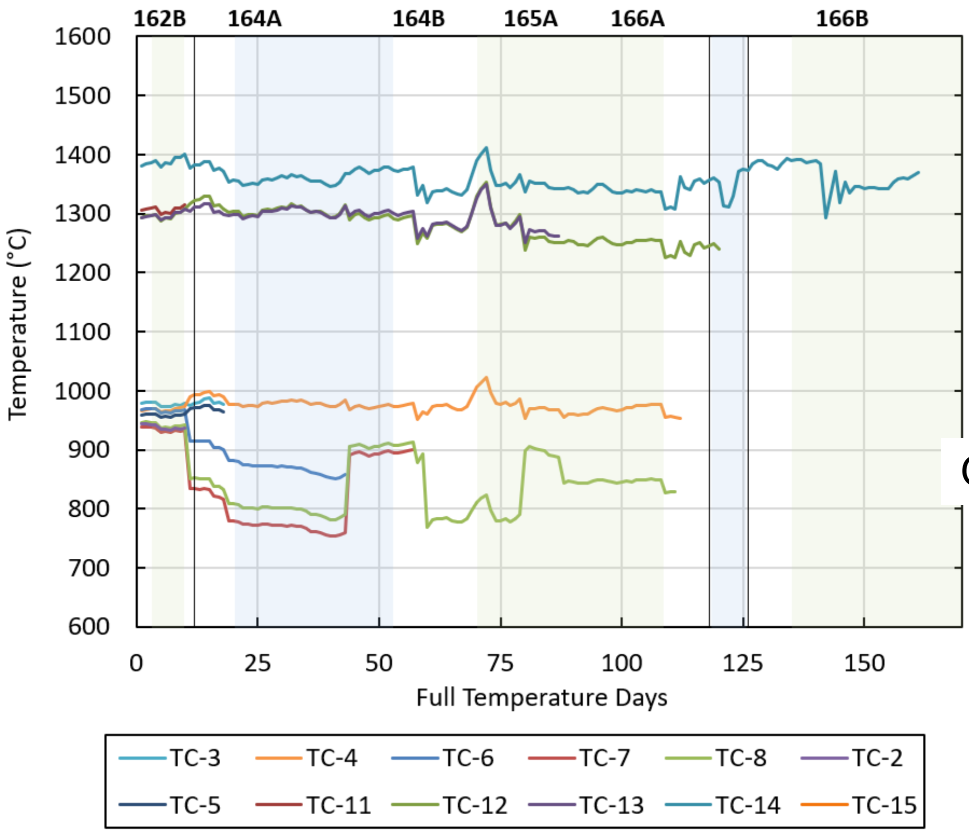
- Large number of thermocouples installed
- Several types of thermocouples
- Spread over a wide temperature range

Capsule 1 Thermocouples Measured vs Calculated at Startup

The thermal model was "tuned" to the thermocouple measurements at the beginning of irradiation when the TCs were fresh and fully trusted. The model was not adjusted subsequently to match TC measurements.



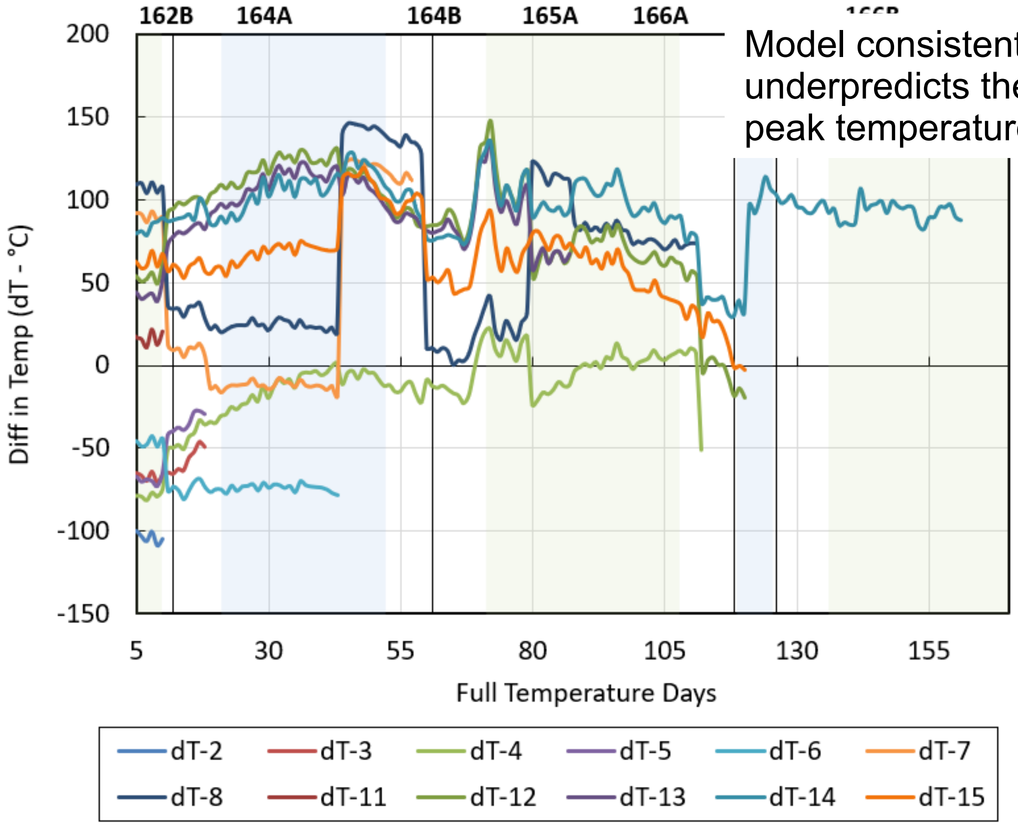
Capsule 1 Temperature Trends and Measured vs Thermal Model



Inside fuel ring

Outside fuel ring

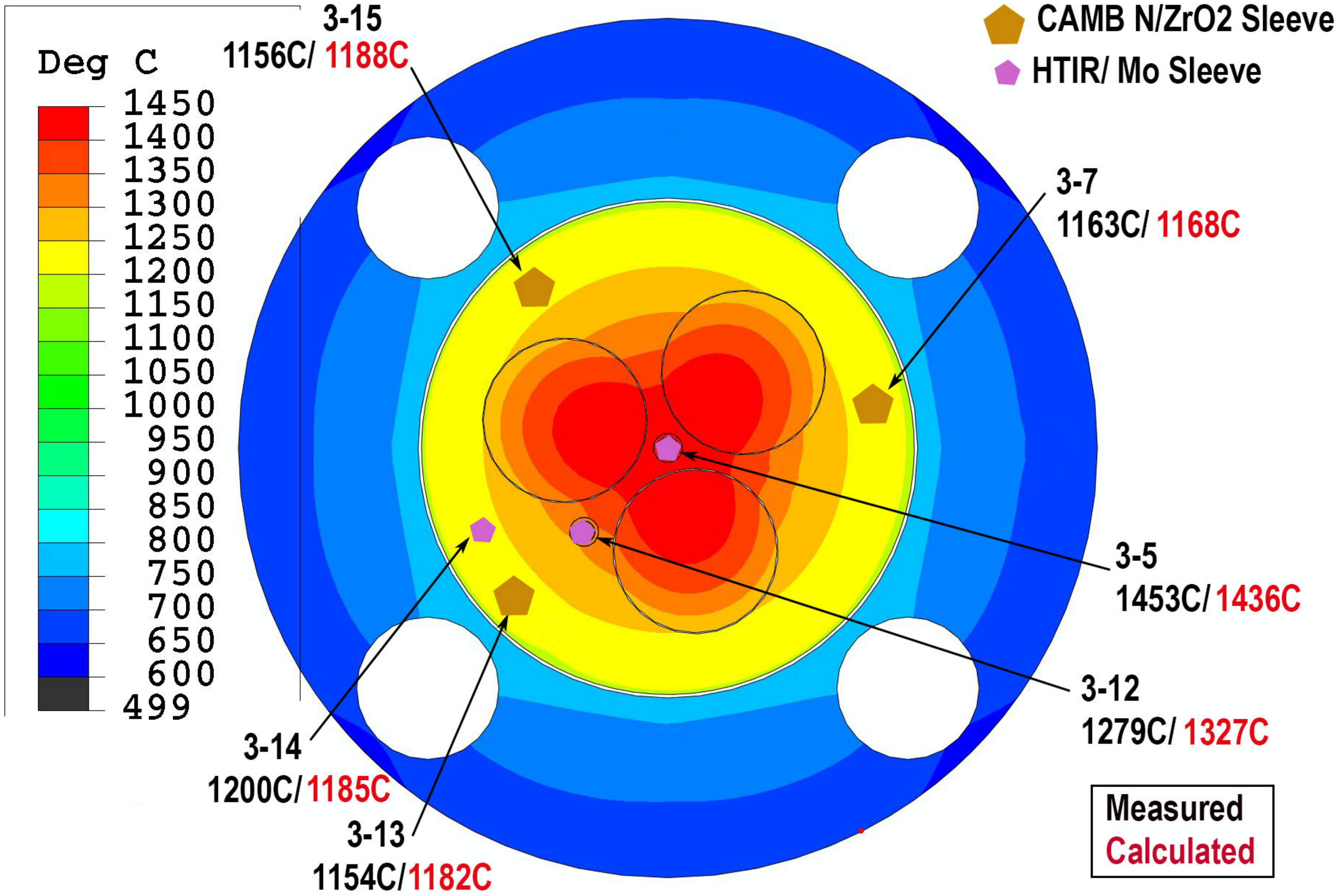
No obvious signs of thermocouple drift in Capsule 1



Model consistently underpredicts these peak temperatures

Thermal model tends to over predict the temperatures of the (cooler) TCs outside the fuel ring and underpredict the (hotter) TCs inside the fuel ring – indicating perhaps an overestimation of graphite conductivity

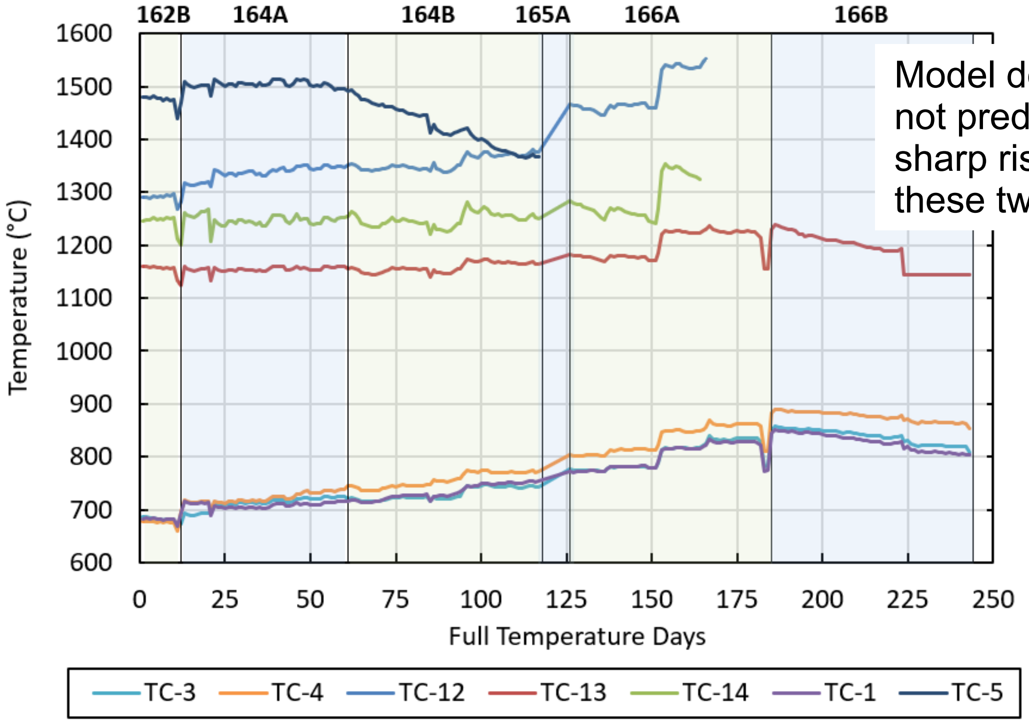
Capsule 3 Thermocouples Measured vs Calculated at Startup



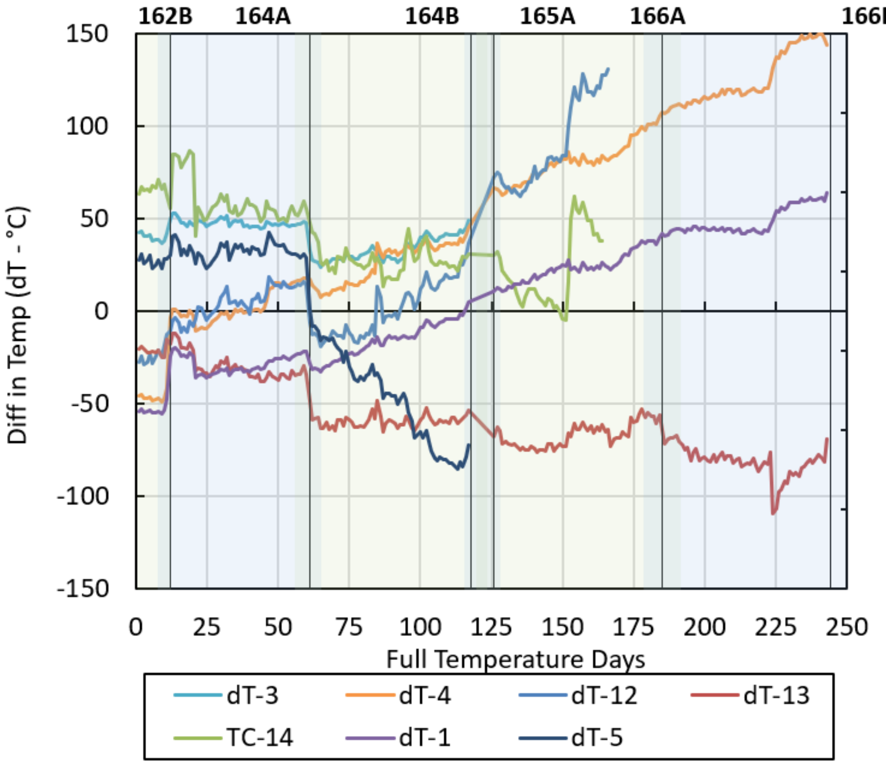
Thermal model tends to under predict the temperature difference between these two TCs – indicating perhaps an overestimation of graphite conductivity

Capsule 3 Temperature Trends and Measured vs Thermal Model

Clear evidence of drift in TC-3-5



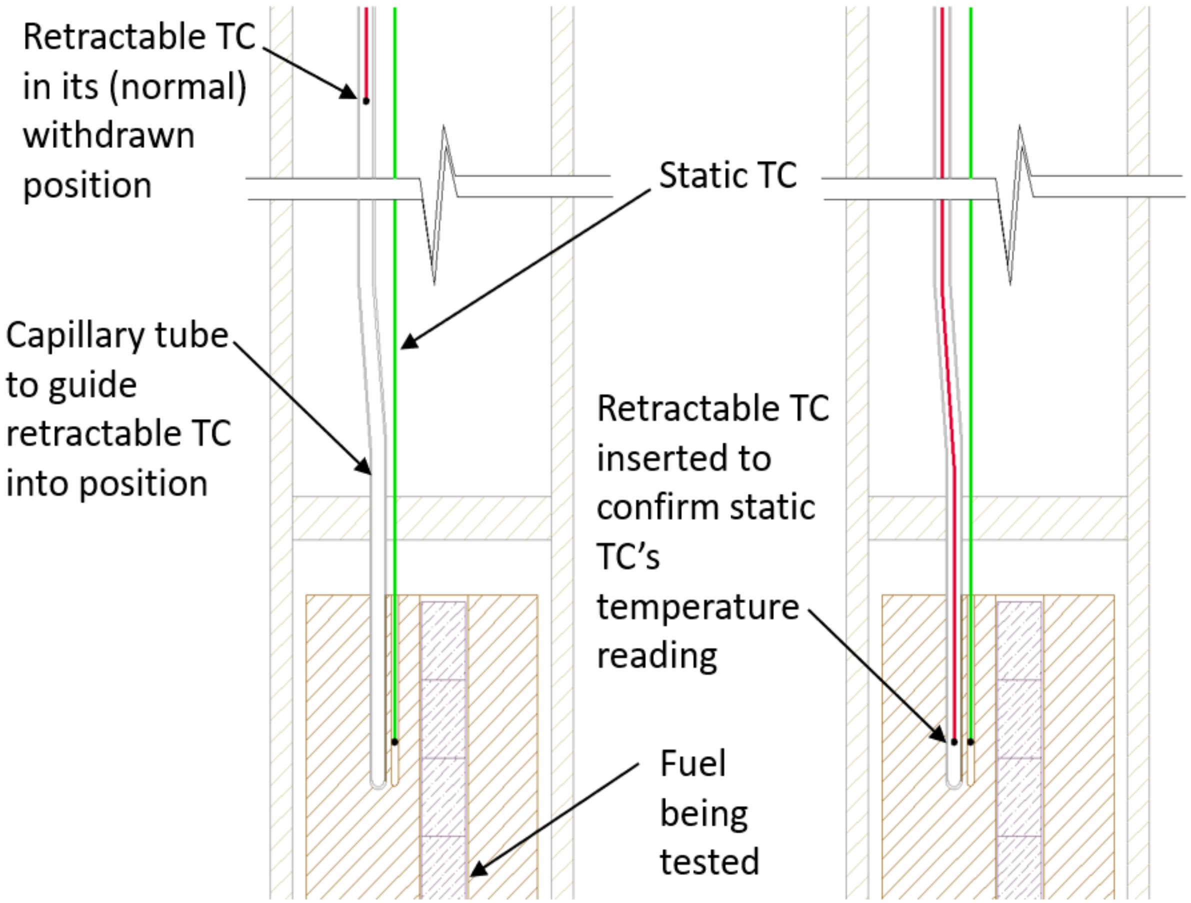
Model does not predict the sharp rise in these two TCs



These rising DTs may indicate underprediction by the model

Near the end of irradiation, a number of particle failures were observed in Capsule 3. This could have been due in part to peak particle temperatures greater than predicted by the thermal model.

Thermocouple drift and model drift seem to be inherent in such high temperature and complex experiments. Can anything be done to remedy?



Retractable TC to confirm temperature measurements

Conclusions

- Because of the high operating temperature of the AGR-5/6/7 experiment, a large number of thermocouples were incorporated into the test. However, as with previous AGR tests, all thermocouples failed in the lower capsules prior to the end of the test period.
- An analysis of the temperature trends for TCs in Capsules 2, 4, 5 indicates little evidence of drift and good overall agreement with the thermal model.
- The temperature data for Capsules 1 and 3 provide reasonable suspicion that the thermal model underpredicts the peak fuel temperatures.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Questions?

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