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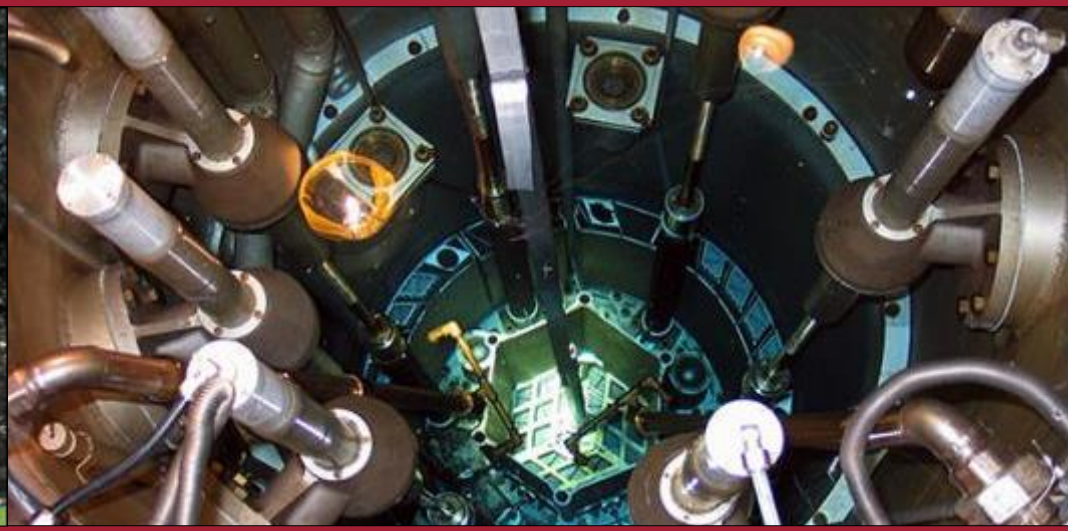

Experience with Tritium Evolution During Irradiation of MSRE Flibe in the MITR

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10/27/15

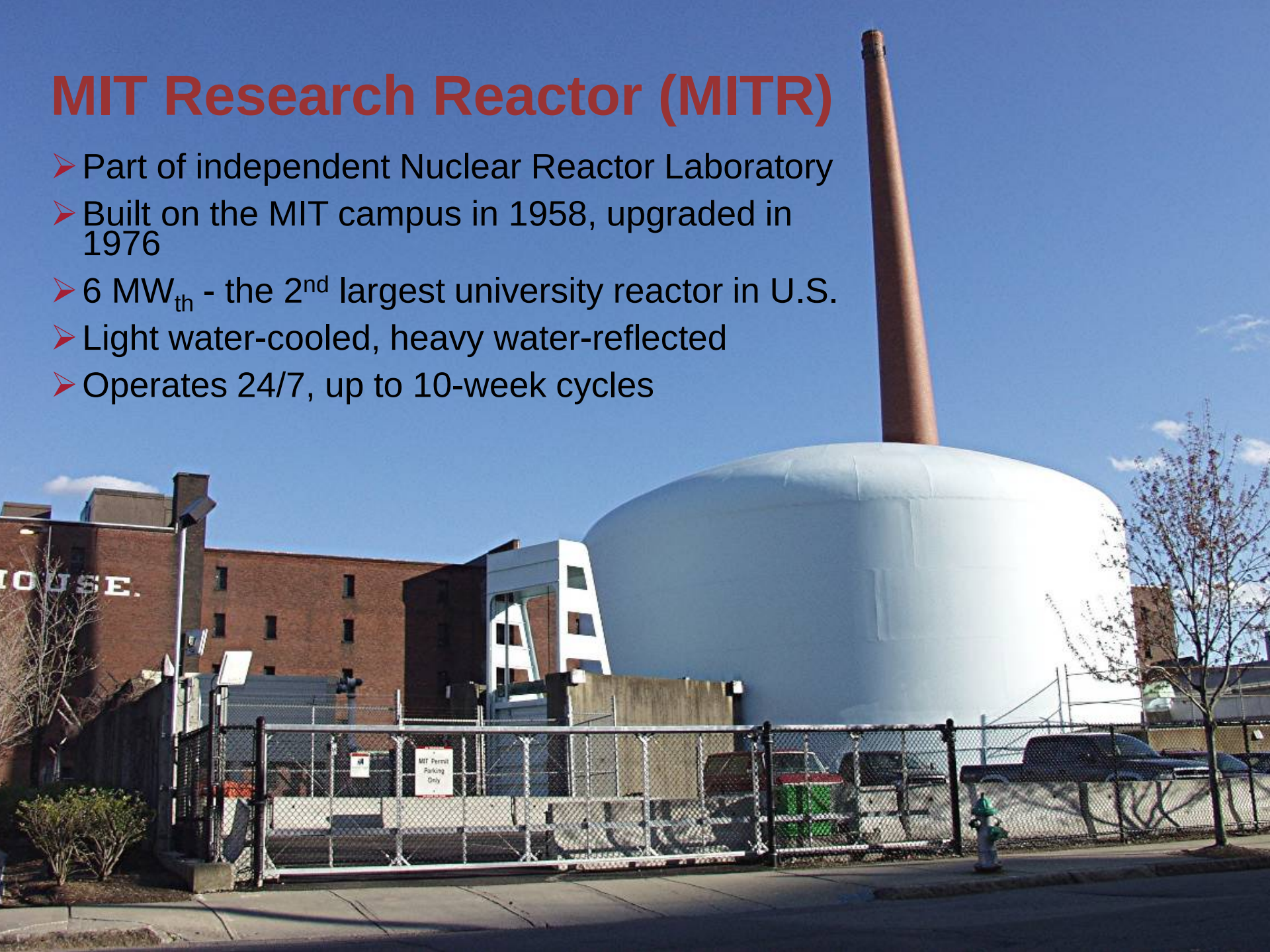
Outline

- MITR Introduction
- Tritium Experiments in the MITR
  - Goals
  - Limitations
- Tritium and Other Gas Release Measurements
  - FS-1
  - FS-2
- PIE Progress

- Please interrupt

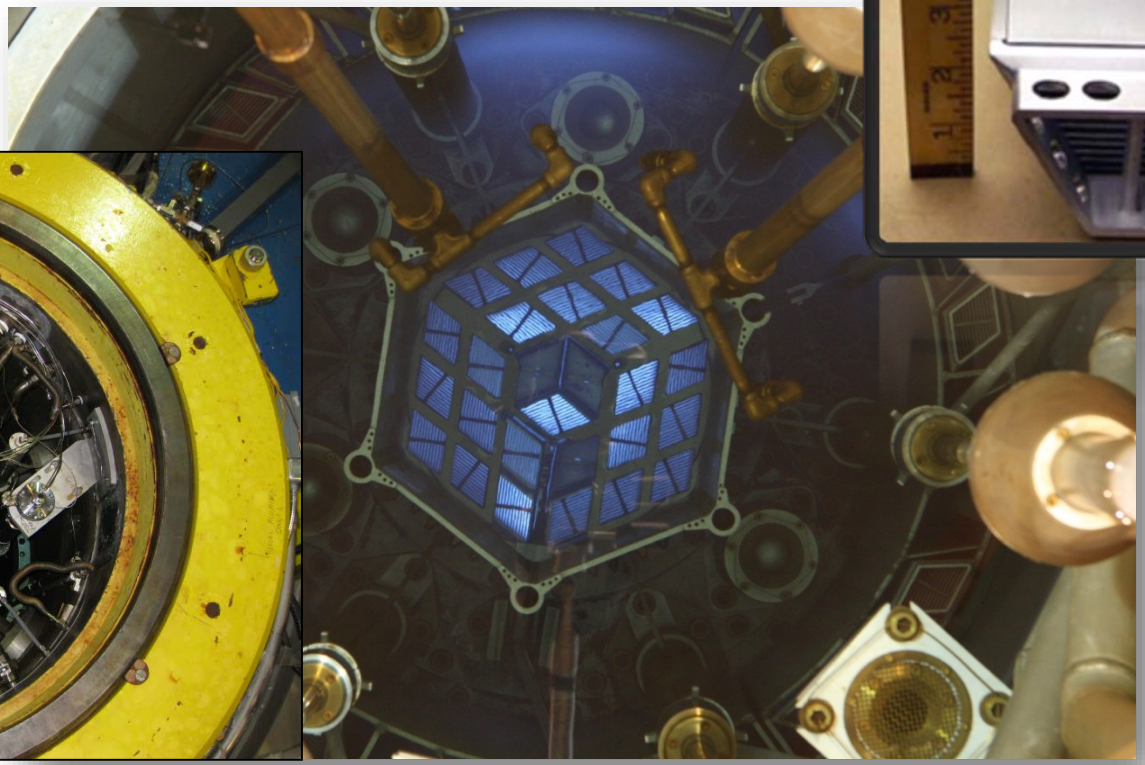
MIT Research Reactor (MITR)

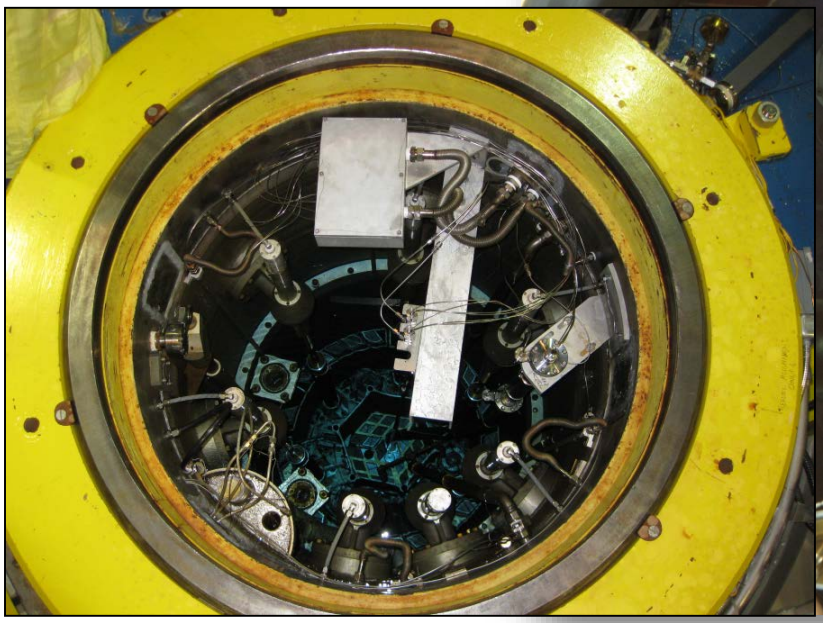
- Part of independent Nuclear Reactor Laboratory
- Built on the MIT campus in 1958, upgraded in 1976
- 6 MW_{th} - the 2nd largest university reactor in U.S.
- Light water-cooled, heavy water-reflected
- Operates 24/7, up to 10-week cycles



MITR Core

- 24 HEU rhomboidal elements with UAl_x plate-type fuel
- 50°C outlet, atmospheric pressure
- 3 dedicated in-core experimental positions





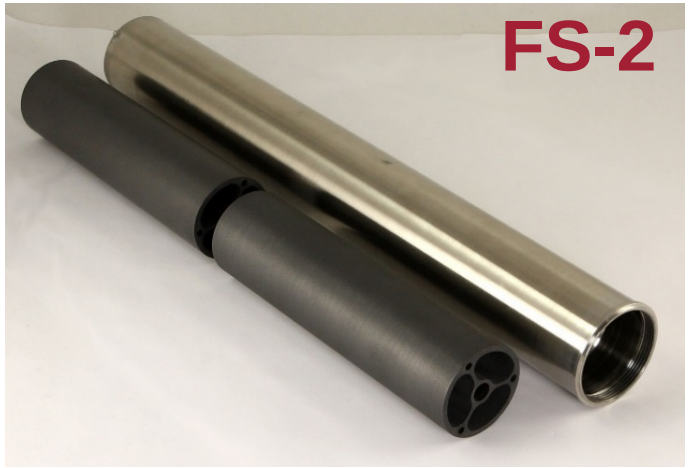
FHR IRP Irradiation Goals

- To test the interactions between the flibe and potential FHR fuel and structural materials
- To compare material test results with parallel test at University of Wisconsin (no irradiation)
- **To measure tritium production and partitioning among components**
- To evaluate the experimental components and methods for future FHR-related tests—the starting point that ultimately leads to larger experiments in HFIR and ATR

Initial Flibe Irradiations

- First in-core irradiation of MSRE flibe in 60 years
- Primary goal to identify potential safety and design issues for future experiments
- 1000 hours
- 700°C

- Study effect of different fluoride redox potentials on salt corrosion and tritium release
- Tritium and salt interaction with fuel compact graphite
- Cracking performance of TRISO particles
- 300 hours



Irradiation Design Progress

- Test conditions:
  - 700°C
  - Double encapsulation (Ni, Ti)
  - He cover gas, He/Ne control gas
  - 5.5MW reactor power

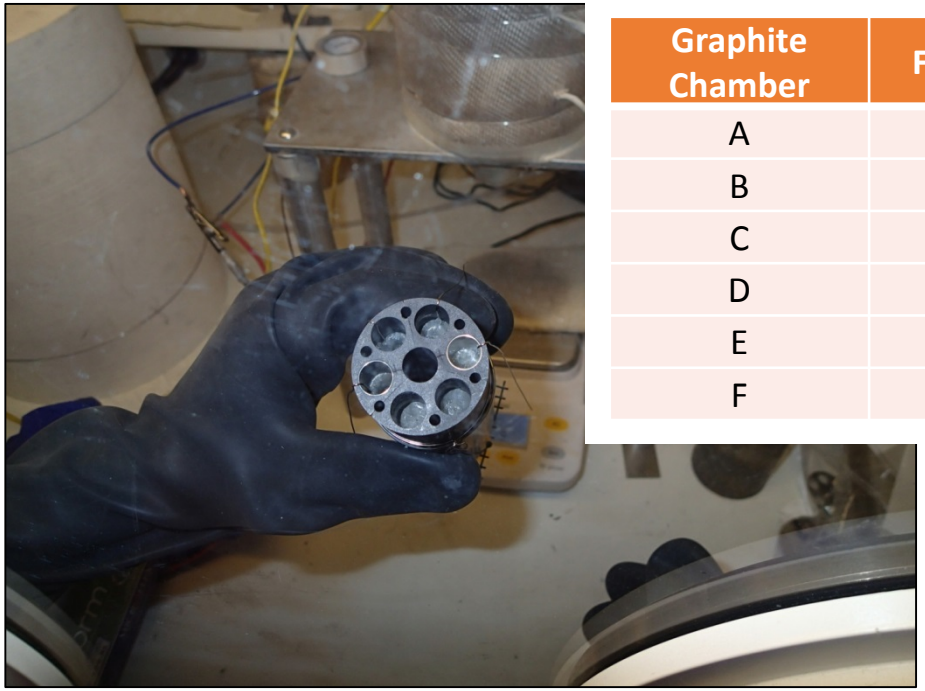
- FS-2 modifications:
  - Independent irradiation facility
  - 2.7x more salt volume
  - Two fluoride potentials
  - New C/C, graphite, and TRISO particles
  - Improved gas flow and exhaust

FS-1 Loading

Chamber	Container Material Combinations
A	Two Hastelloy-N samples
B	Two 316 Stainless Steel samples
C	Three types of SiC samples: R&H CVD SiC SiC/SiC Tyranno-SA3 CVI SiC composites SiC/SiC Hi-Nicalon type-S CVI SiC composite
D	300 surrogate TRISO particles
E	Two Hastelloy-N samples in nickel-lined hole
F	Two 316 Stainless Steel samples in 316SS-lined hole

FS-1 Capsule Assembly

Graphite sample holder filled with samples and flibe



Flibe Loading

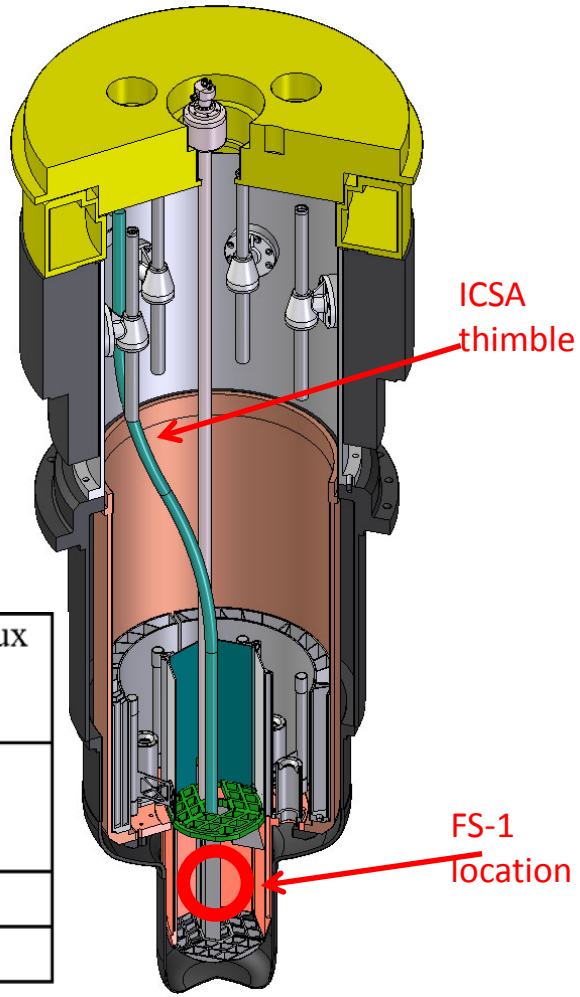
Graphite Chamber	Flibe Mass (g)
A	21.3
B	21.2
C	21.2
D	21.2
E	18.2
F	18.1

Capsule sealed with TCs and gas sampling lines

Samples in FS-1 are all identical to UW corrosion tests

FS-1 Capsule Irradiation

- The FS-1 capsule runs inside the MITR In-Core Sample Assembly (ICSA) thimble
  - The ICSA is an instrumented inert gas irradiation facility in a central core position
- Separate gas flow in capsule and thimble
- Thermocouples in graphite for temperature measurement

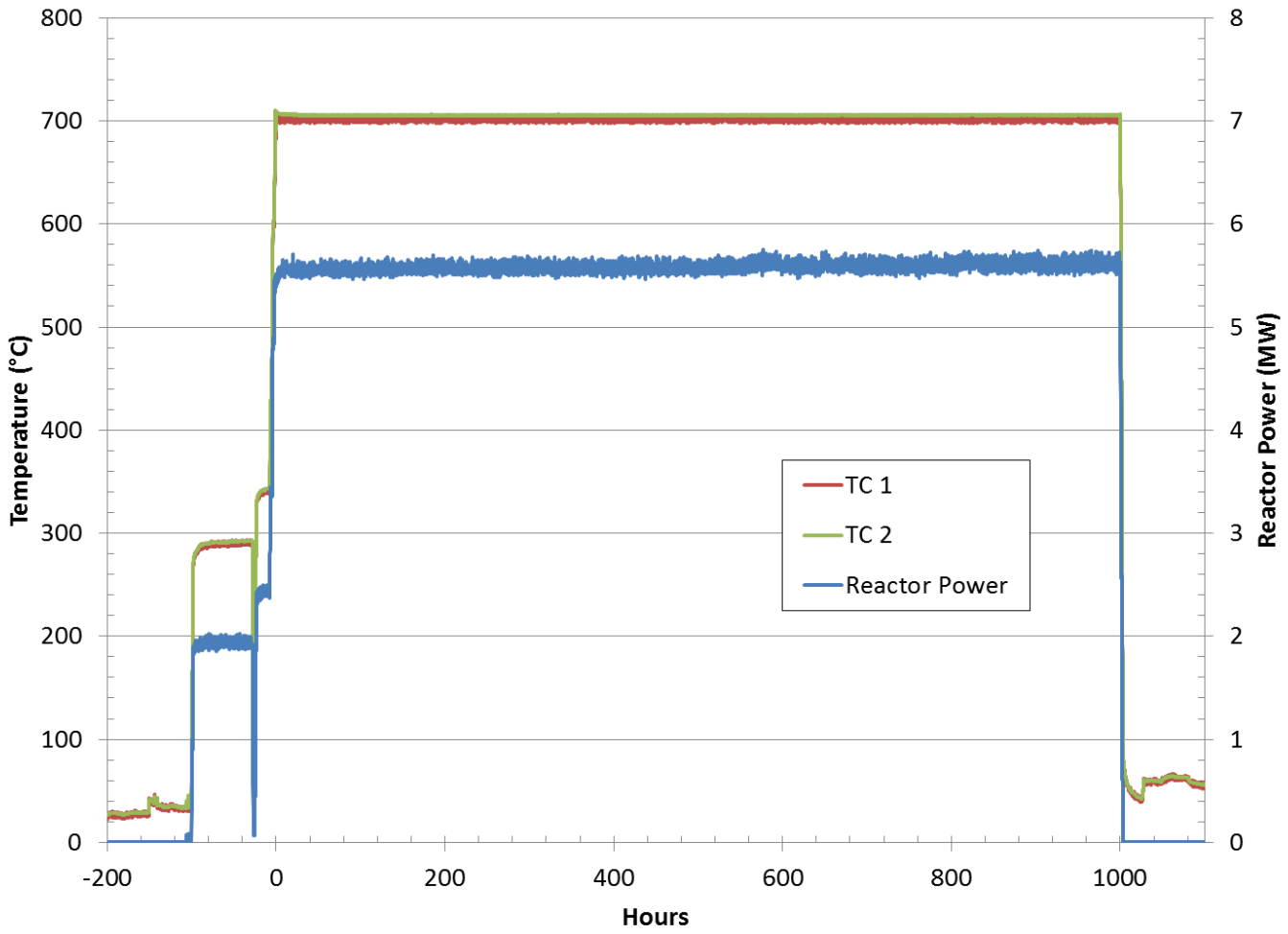


	Fast flux (n/cm^2-sec) (E > 0.1 MeV)	Total neutron flux (n/cm^2-sec)	Fast flux/Total flux ratio, %
FS-1 Flibe compartments (5.5 MW)	1.06×10^{14}	1.38×10^{14}	76.8
2009 PB-AHTR*	6.95×10^{13}	4.04×10^{14}	17.2
2011 AHTR*	6.18×10^{13}	3.64×10^{14}	17.0

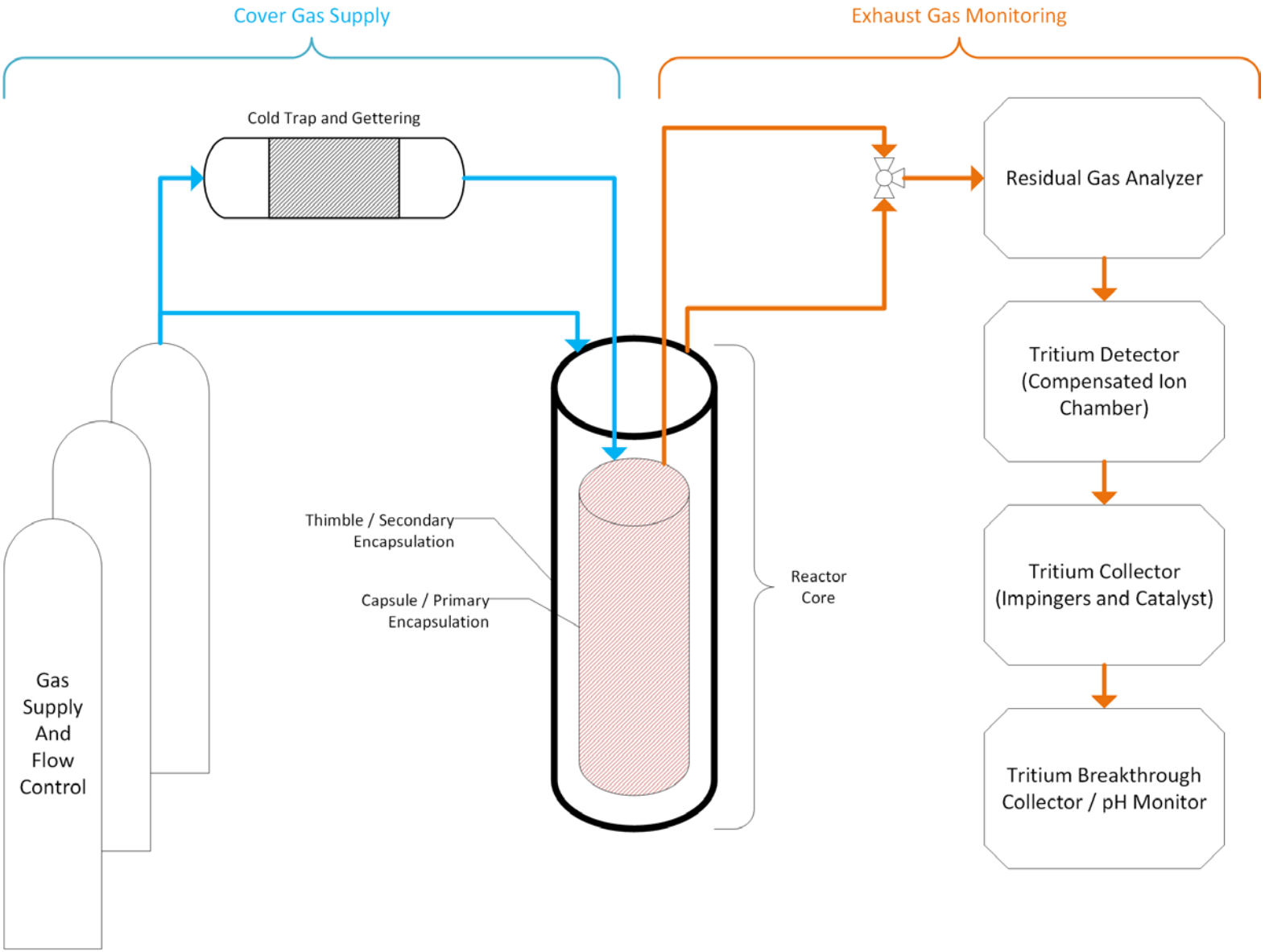
* FHR Materials, Fuels and Components White Paper, UCBTH-12-003, July 2013.

FS-1 Irradiation History

- Slow, stepped startup with fine control through melting
- Experimented operated at 700±3°C for 1000 hours



ICSA Irradiation Facility



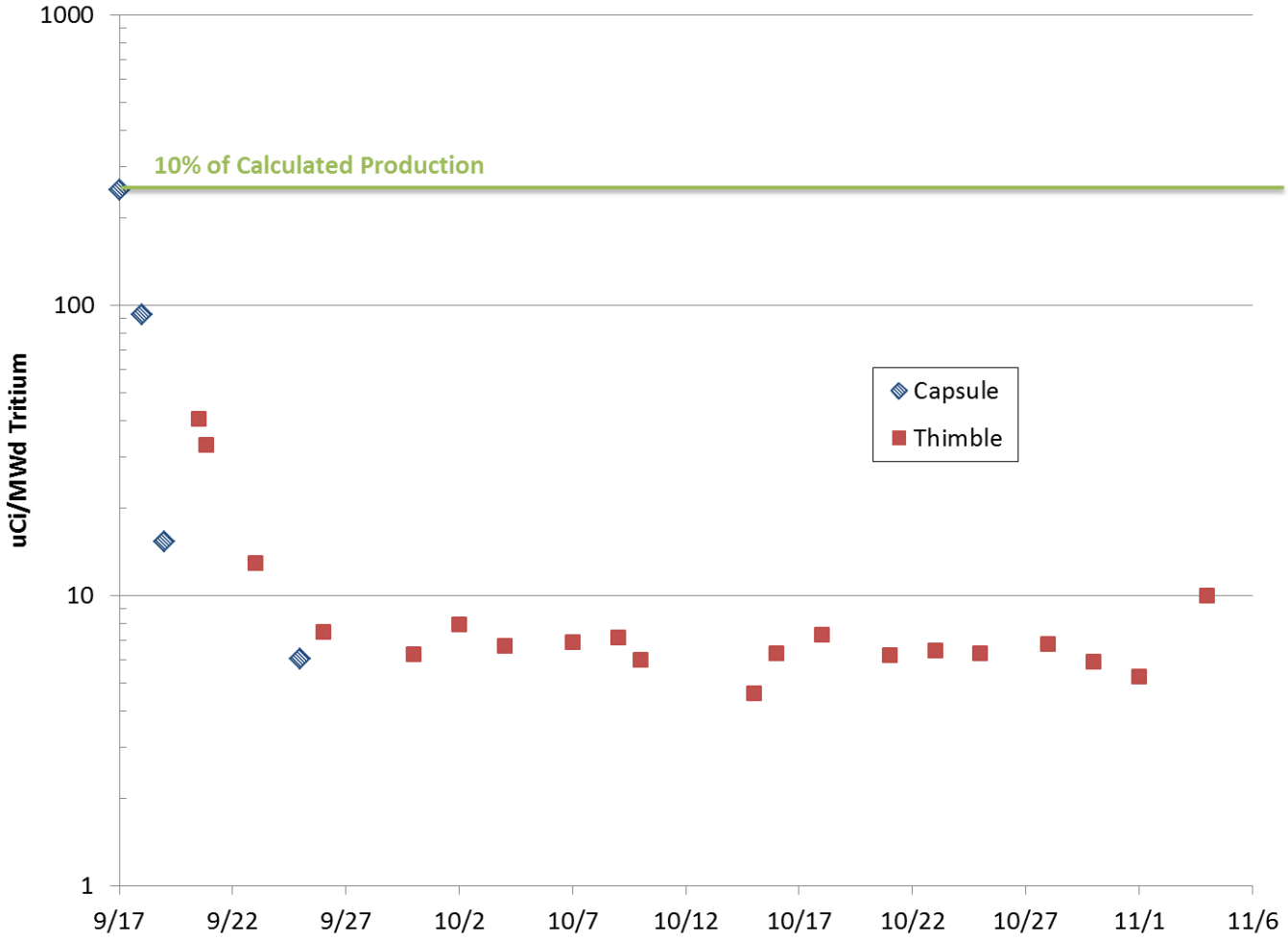
Tritium Measurements

- First irradiations attempted combination of real-time and integrated measurements
  - Dual compensated ion chambers used to measure real-time tritium activity
  - Six-pass water bubbler system with catalytic furnace to capture tritium in water for later liquid scintillation counting (LSC)
- This system should allow separate collection of soluble (TF, HTO, T_2O) and non-soluble (HT, T_2) species
- Bubbling with LSC has been is highly repeatable with good capture efficiency, and allows differentiation of H-3, C-14 activity

- Released activity below range of ion chamber sensitivity/background rejection

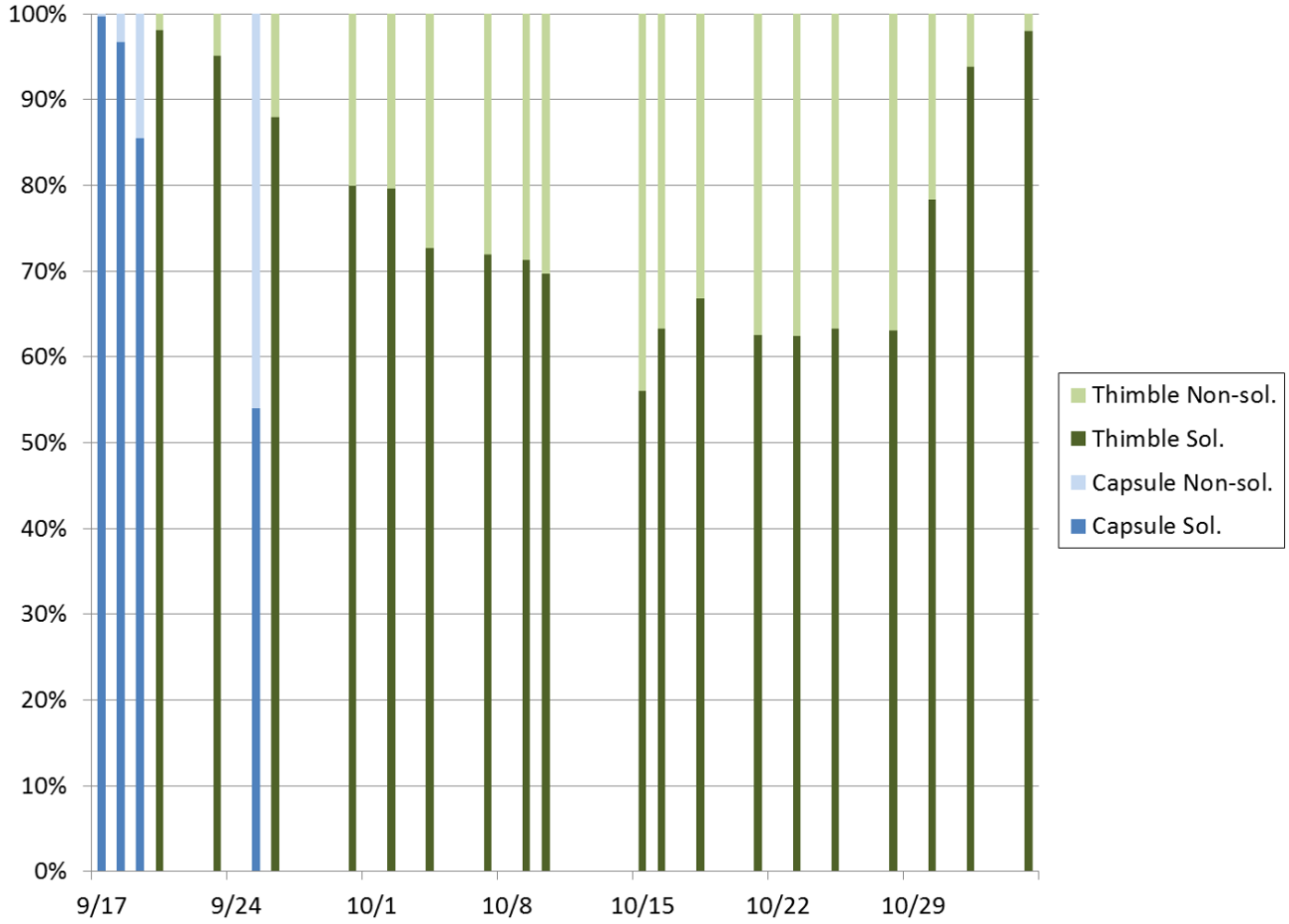
FS-1 Initial Findings – Tritium Activity

- Tritium counts integrated over 24-48 hour intervals
- Tritium collected during startup was ~10% of predicted production
- Subsequently, collected less than 1% of production
- Capsule and thimble tritium levels similar



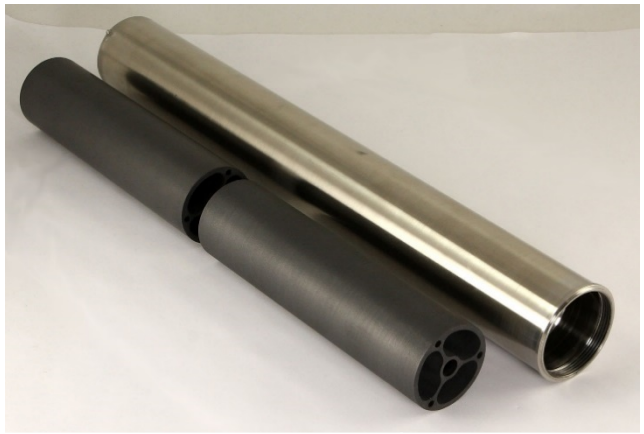
FS-1 Initial Findings - Solubility

- Tritium collected in initial impingers expected to be only water-soluble form,
  - Post-catalyzing furnace the previously non-soluble species will be captured
- Only non-soluble species (T_2) should be released through diffusion
- Additional tests are required to identify species to explain apparent contradiction



FS-2 Loading

- Added C/C and matrix graphite, removed Hastelloy
- Redox potentials straddle the historical MSRE potential (-665 to -707 kJ/mol F_2)

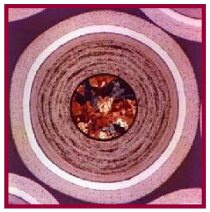


Graphite Holder	Compart-ment	Material	Flibe F_2 Potential (kJ/mol)
Upper	A	Graphites	-632
	B	SiC/SiC, TRISO	-632
	C	SiC/SiC, TRISO	-711
Lower	A	C/C	-632
	B	SS316	-632
	C	SS316	-711

FS-2 Loading

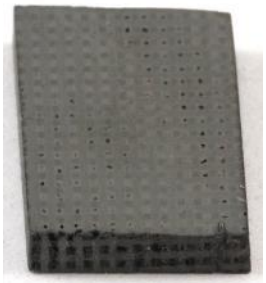
ARB-B1-Z009

IG-110U



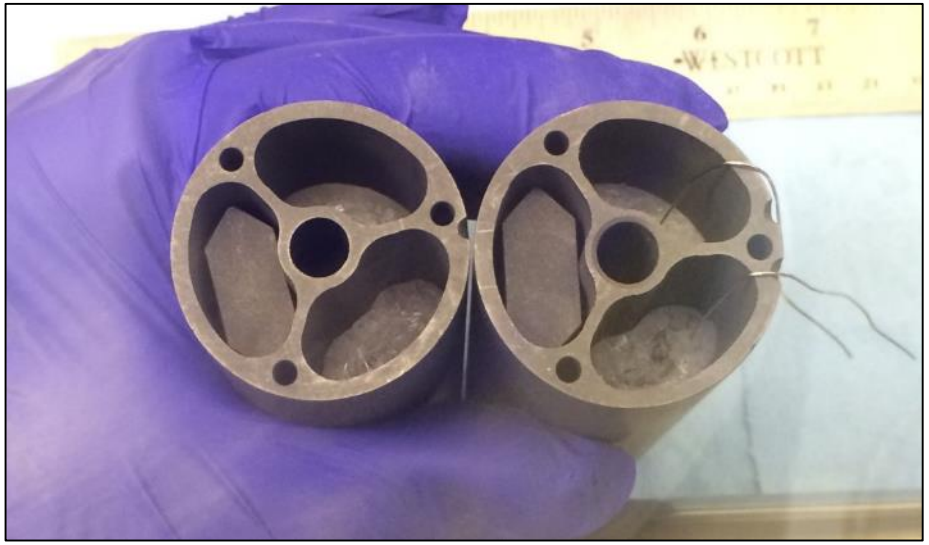
B&W TRISO
G73F-NF-93044

SS316

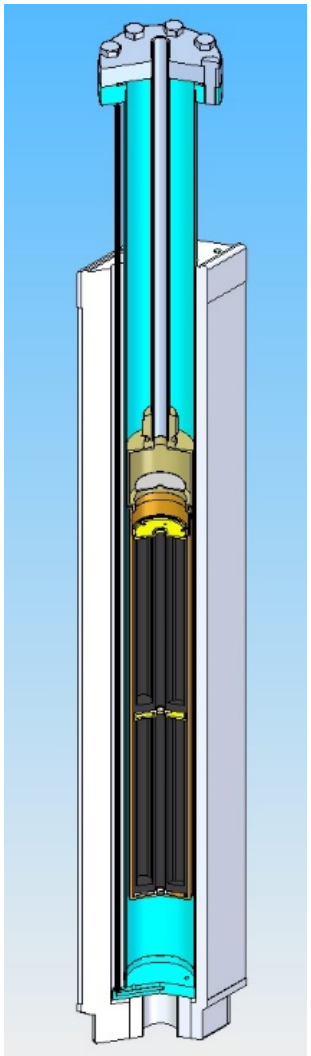


C/C

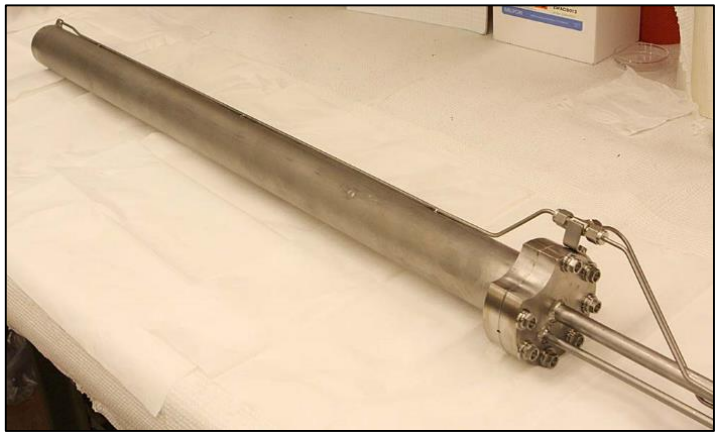
SiC/SiC

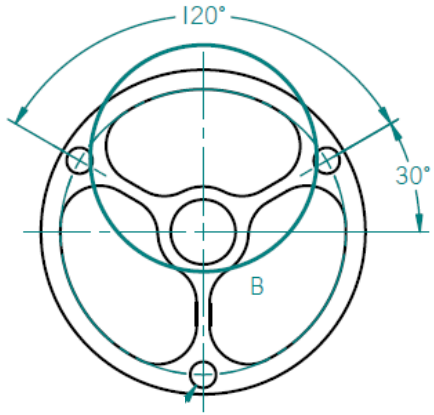


FS-2 In-Core Facility Design

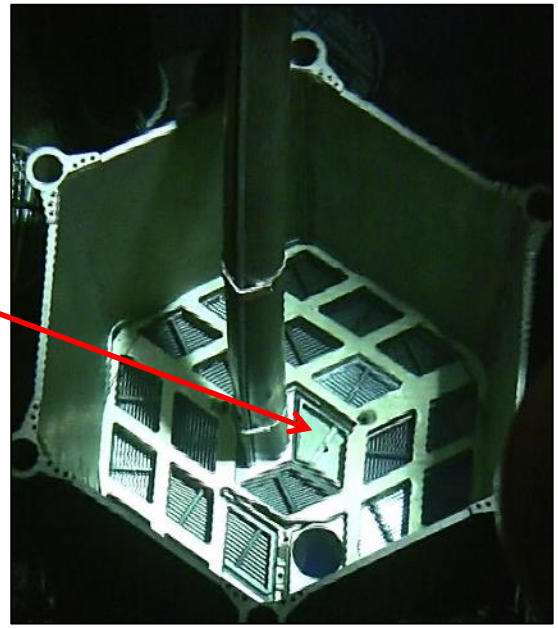


Legend:
White – Aluminum dummy element
Blue – Titanium thimble
Orange – Nickel capsule
Yellow – Internal nickel parts
Gray – Graphite sample/flibe holder



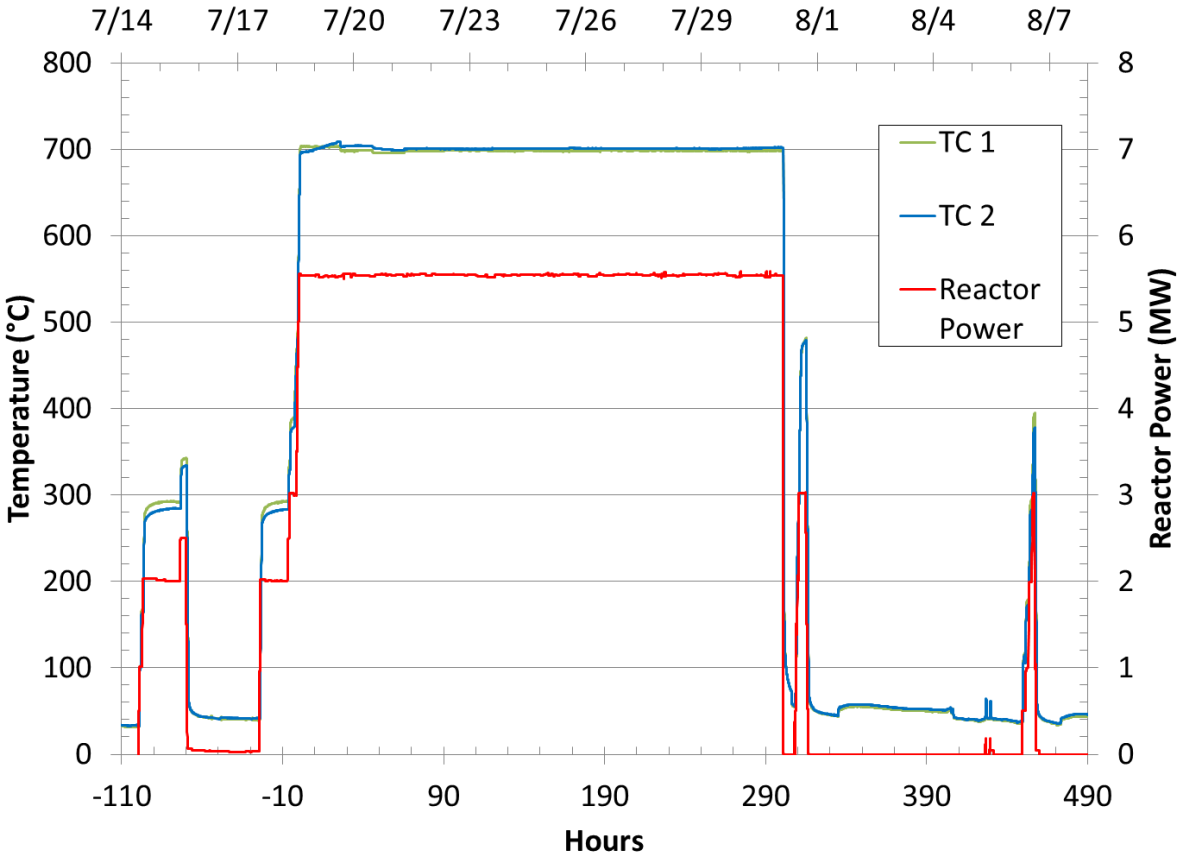


Graphite cross-section



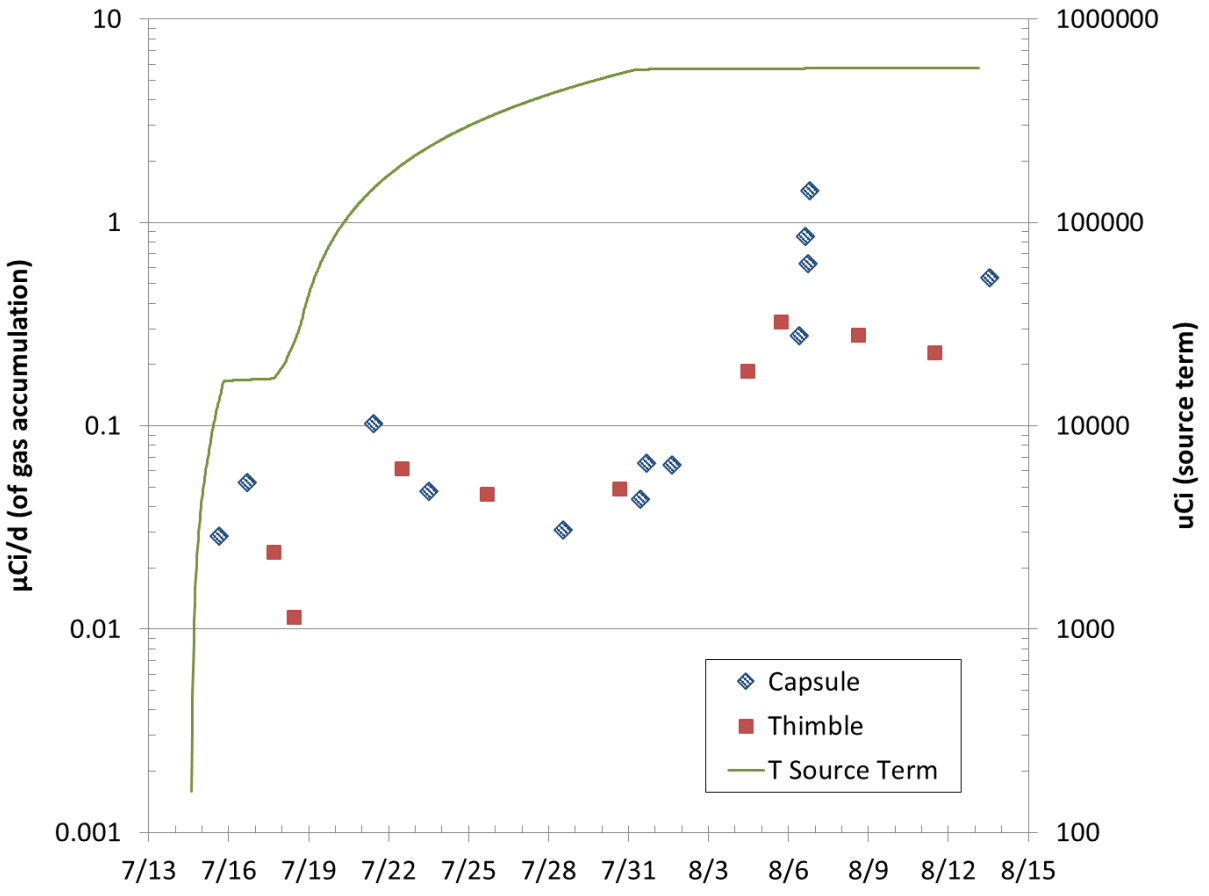
FS-2 Irradiation History

- First startup did not reach the flibe melting point
  - Reduction in power to 50kW for maintenance (~50°C)
- Eventual startup to 700°C was uneventful
- Unrelated reactor SCRAM at 300hrs, restart attempt
- After several days of troubleshooting, performed short test to 3MW, then removed experiment



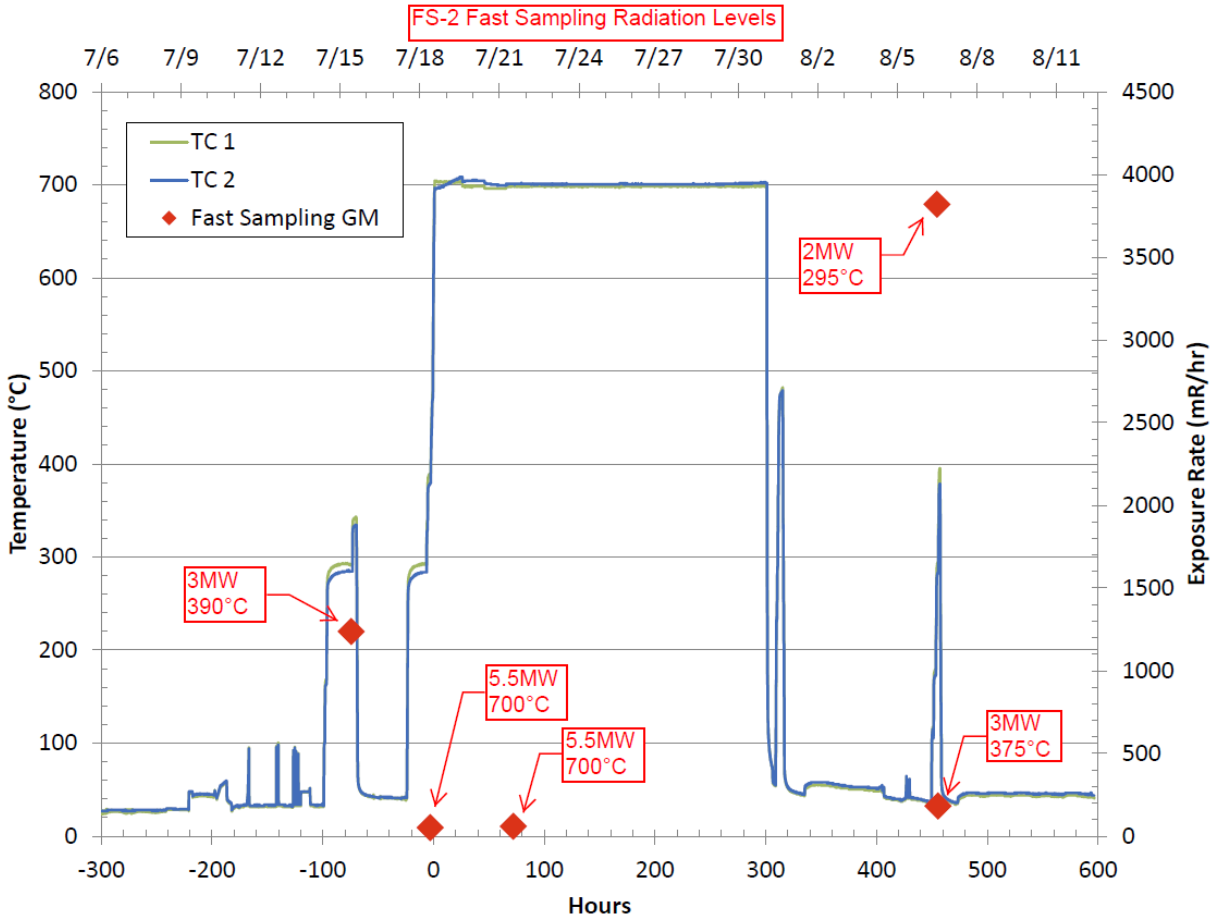
Tritium Release vs. Source Term

- Capsule and thimble gas tritium levels similar
  - Easy diffusion through capsule
- Majority of tritium is immediately soluble in water
  - Additional catalyzing had small effect
- Tritium release rate increases during temperature changes
- Tritium release during normal operation (5.5MW, 700°C) is same order of magnitude as FS-1 (<1% of generation)



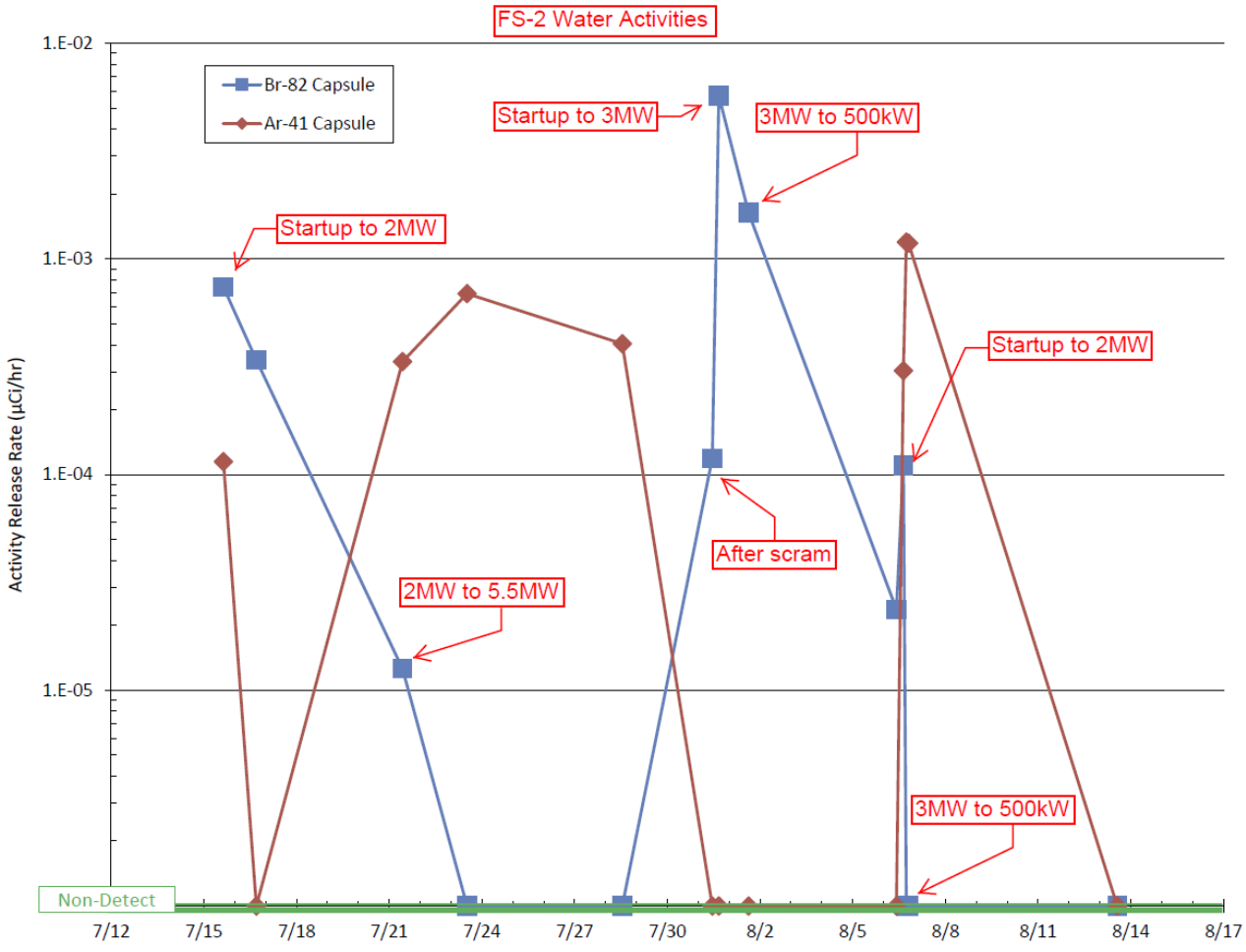
Short Half-Life Detection

- In FS-1, problem of short-lived activation products in capsule exhaust
  - Added special gas system for FS-2
- In FS-2, highest N-16 and O-19 release when flibe was solid
  - Produced by F-19 neutron activation
- Almost no detectable release at full reactor power, 700°C



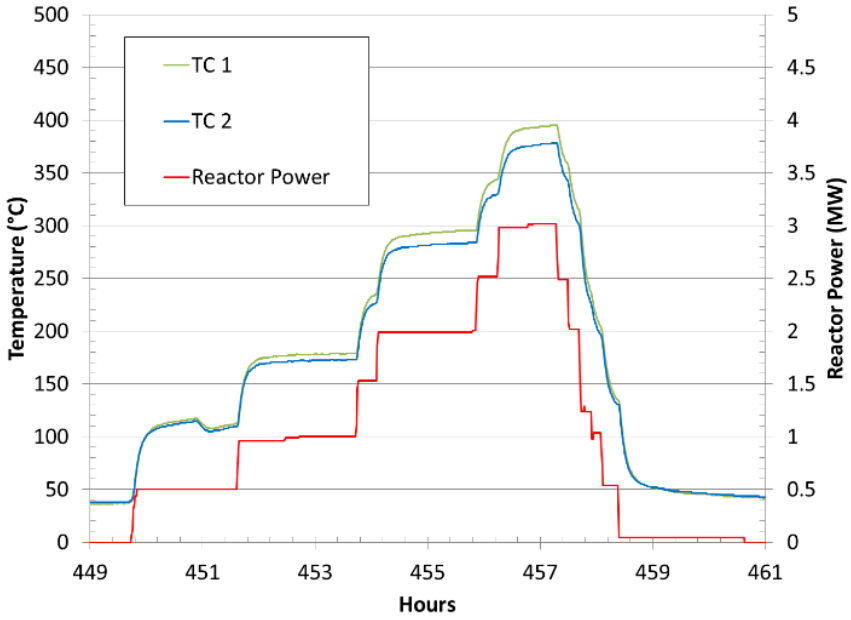
Bromine Release

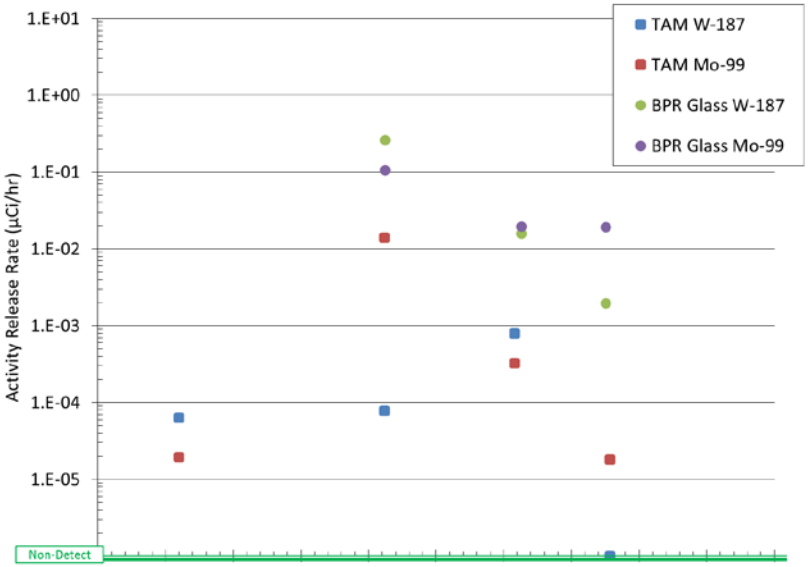
- Bromine was detected in tritium collection system
  - Only from capsule gas
  - Here contrasted with Ar-41, an expected He impurity
- Highest Br levels when at low power – flibe is solid
- Not detected at full power, 700°C



FS-2 Gaseous Release Test

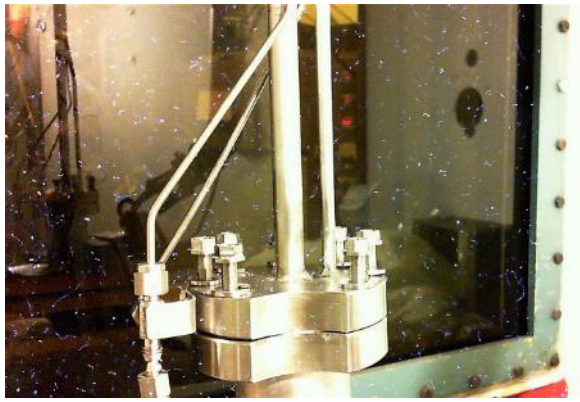
- Following the SCRAM, conducted a test to 3 MW to allow additional sampling
  - Added glass, paper, and charcoal filters prior to tritium capture bubblers
  - Activation products only seen from capsule
- Molybdenum release and capture on filters highest from 0-2MW (<200°C)
- W and Mo captured on glass and paper filters effectively, not on charcoal
- Br not captured on filters, minimal tritium capture on filters
- Experiment removed from reactor following the test

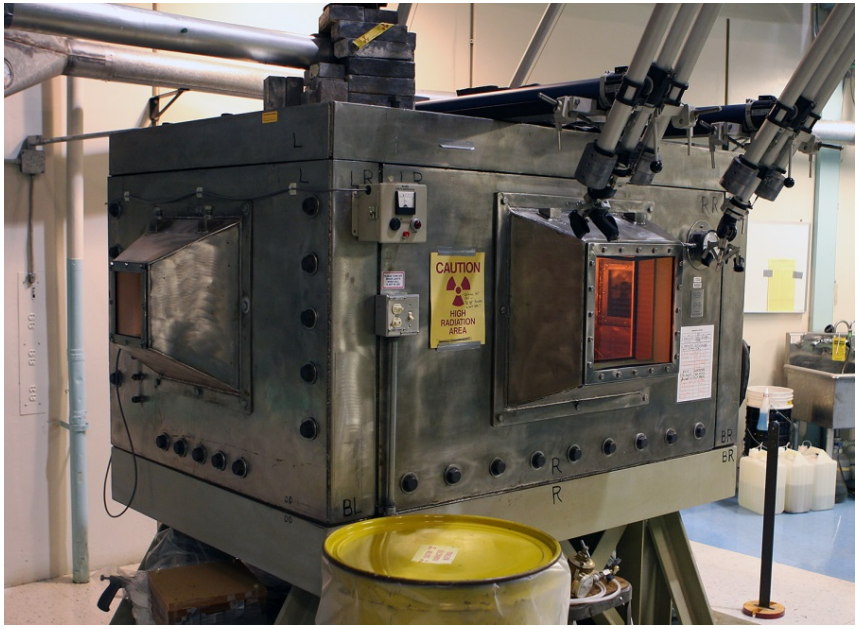




Post-Irradiation Examination

- FS-1 and FS-2 irradiation capsules extracted from in-core facility and transferred to Hot Box and Hot Cell, respectively
- Pressurized with helium to prevent moisture uptake
- Exterior condition of titanium pressure vessel and the nickel/Inconel capsule is excellent

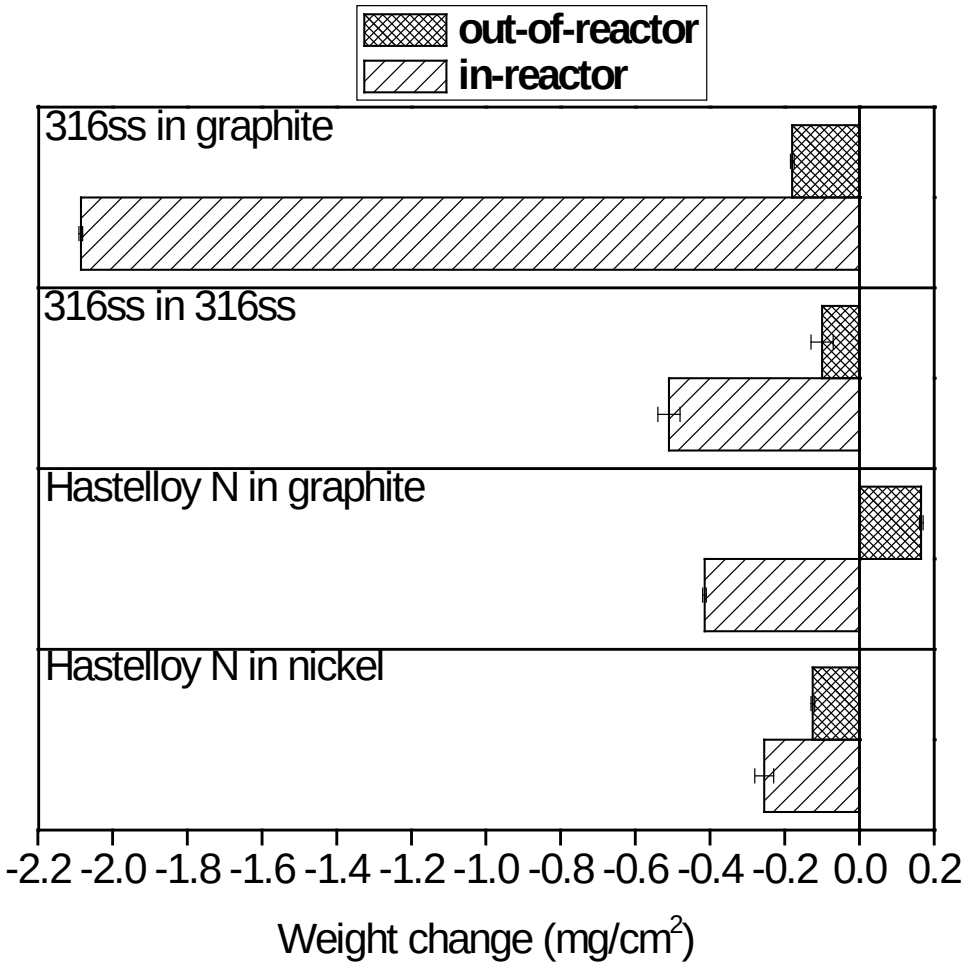


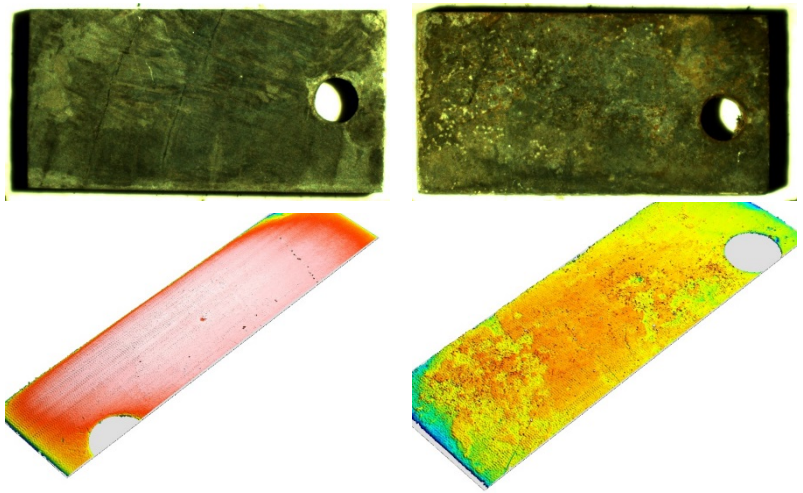


Specimen Extraction

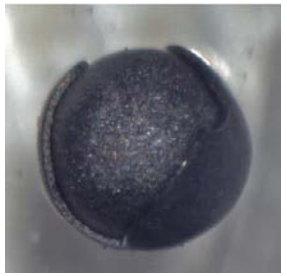
- All specimens have been removed from the FS-1 capsule and cleaned of flibe
  - Furnace operated in dry helium glove box to prevent HF generation and contain tritium
- Cleaning involved melting and collection of flibe ~500°C, followed by soaking in water at ambient conditions until weight decrease arrested
- Did not see evolution of other activation products or substantial tritium release during salt melting

Initial PIE – Corrosion & Cracking





SS316 irradiated in lined (left) and unlined (right) chambers



Surrogate TRISO particle with OPyC damage