INL/MIS-21-61623-Revision-0

In-Core Irradiation Capabilities at the Neutron Radiography Reactor

February 2021

Andrew T Smolinski

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In-Core Irradiation Capabilities at the Neutron Radiography Reactor (NRAD)

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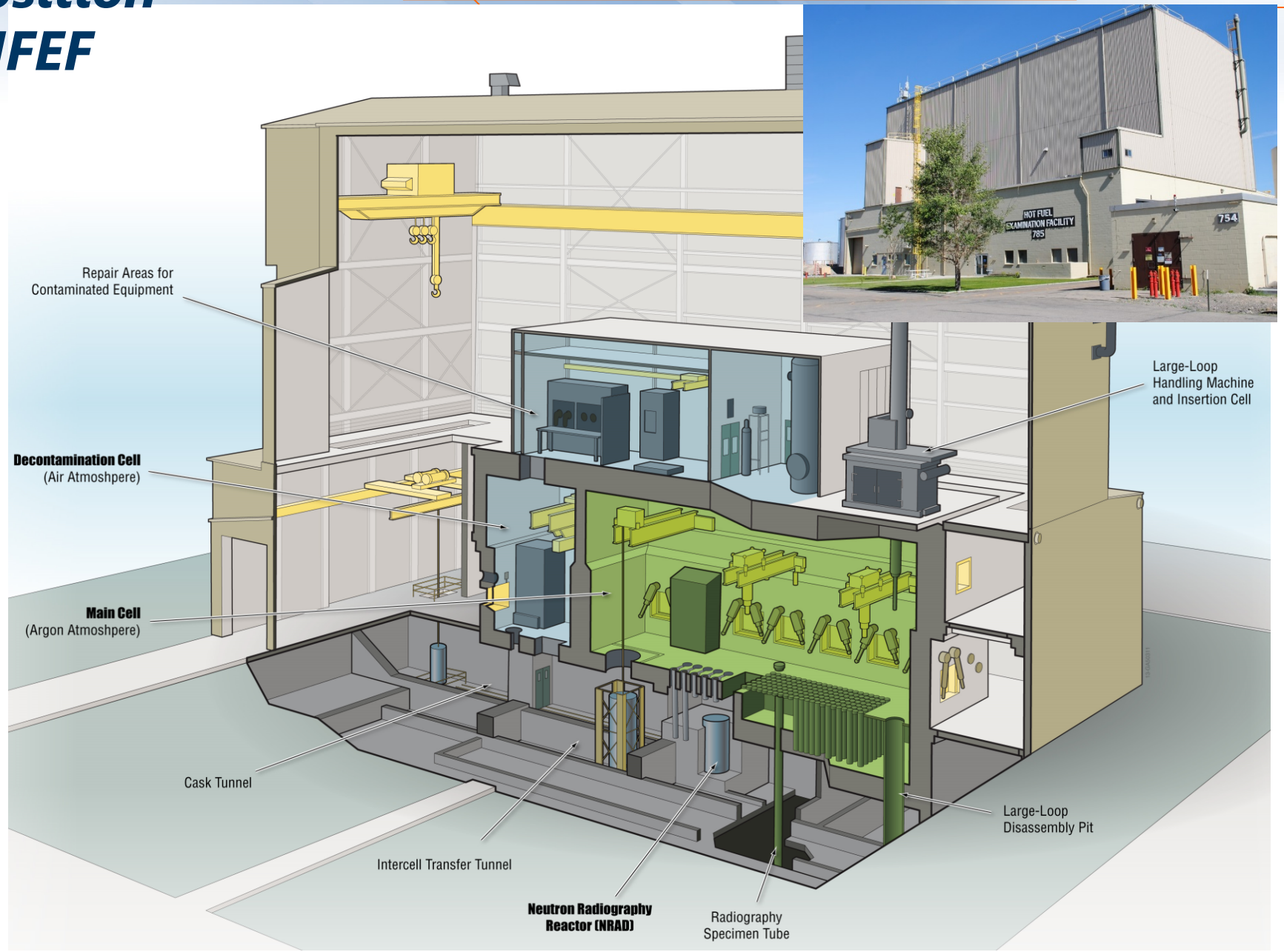
NRAD Reactor Attributes

- 250kW TRIGA® Reactor (Conversion Type)
- Cooling System:
  - Shallow Open Pool (Atmospheric Pressure)
    - Radiation levels (~2.5R/hr) prevent pool-top access during full power operation.
    - Access is permitted <1kW with RWP controls.
  - Demineralized water
    - Purification system filters and removes contaminants through mixed resin beds
  - Natural circulation through the core
  - Primary Cooling System removes excess heat from tank
  - Tank Temperatures 20-40°C (Typically ~37°C steady state)
- Reactor Fluxes (Gold Foil):
  - In-Core Position C4SW (Wet-tube) 5.2×10^{12} n/cm^2-s
  - In-Core Position F-1 (Dry-Tube) 2.1×10^{12} n/cm^2-s
  - East Radiography Station (ERS) 9.5×10^{6} n/cm^2-s
  - North Radiography Station (NRS) 4.5×10^{6} n/cm^2-s
- Direct Access to HFEF hot cell permits experiment transfer <24 Hours from end of irradiation

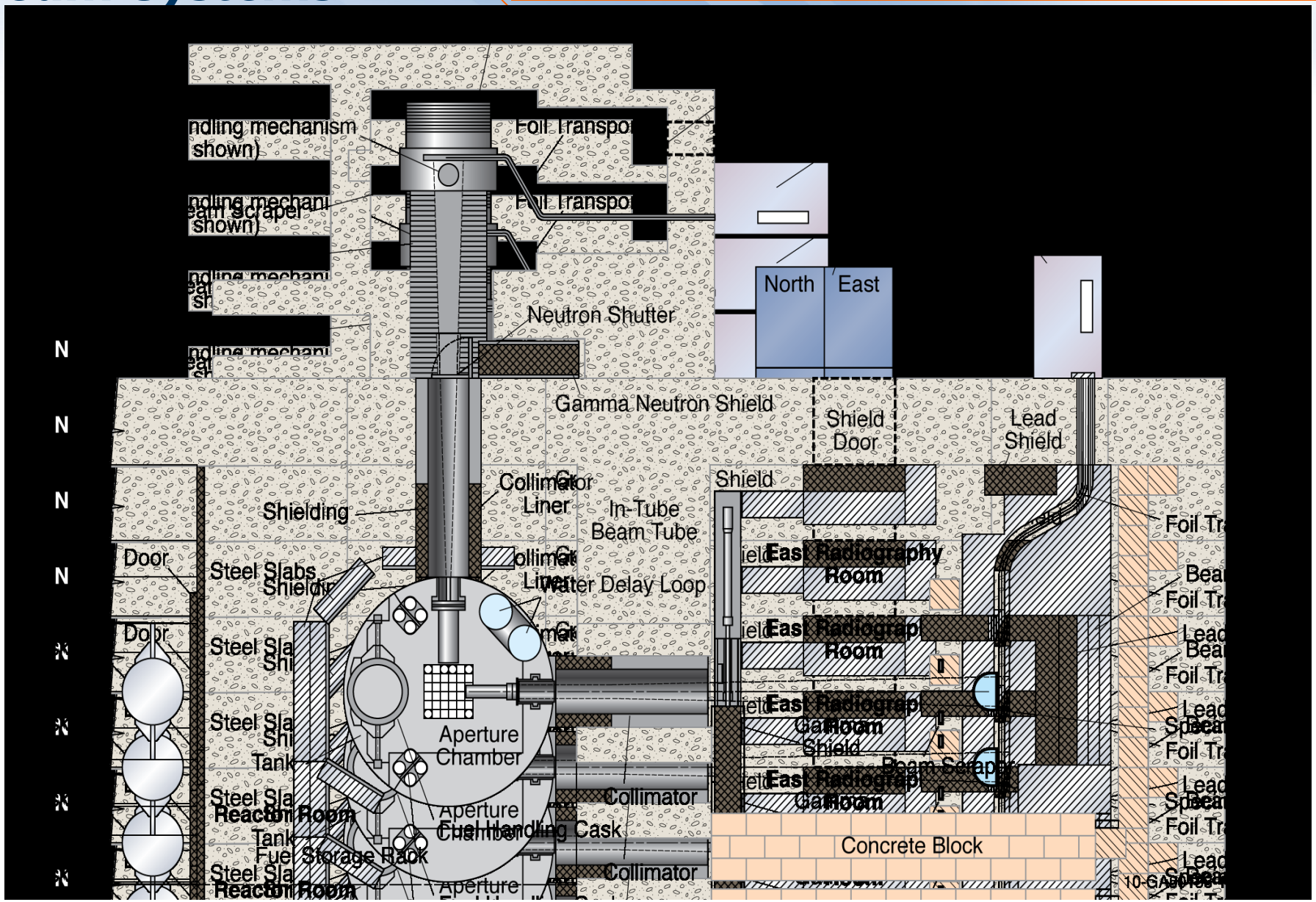
NRAD Position Within HFEF



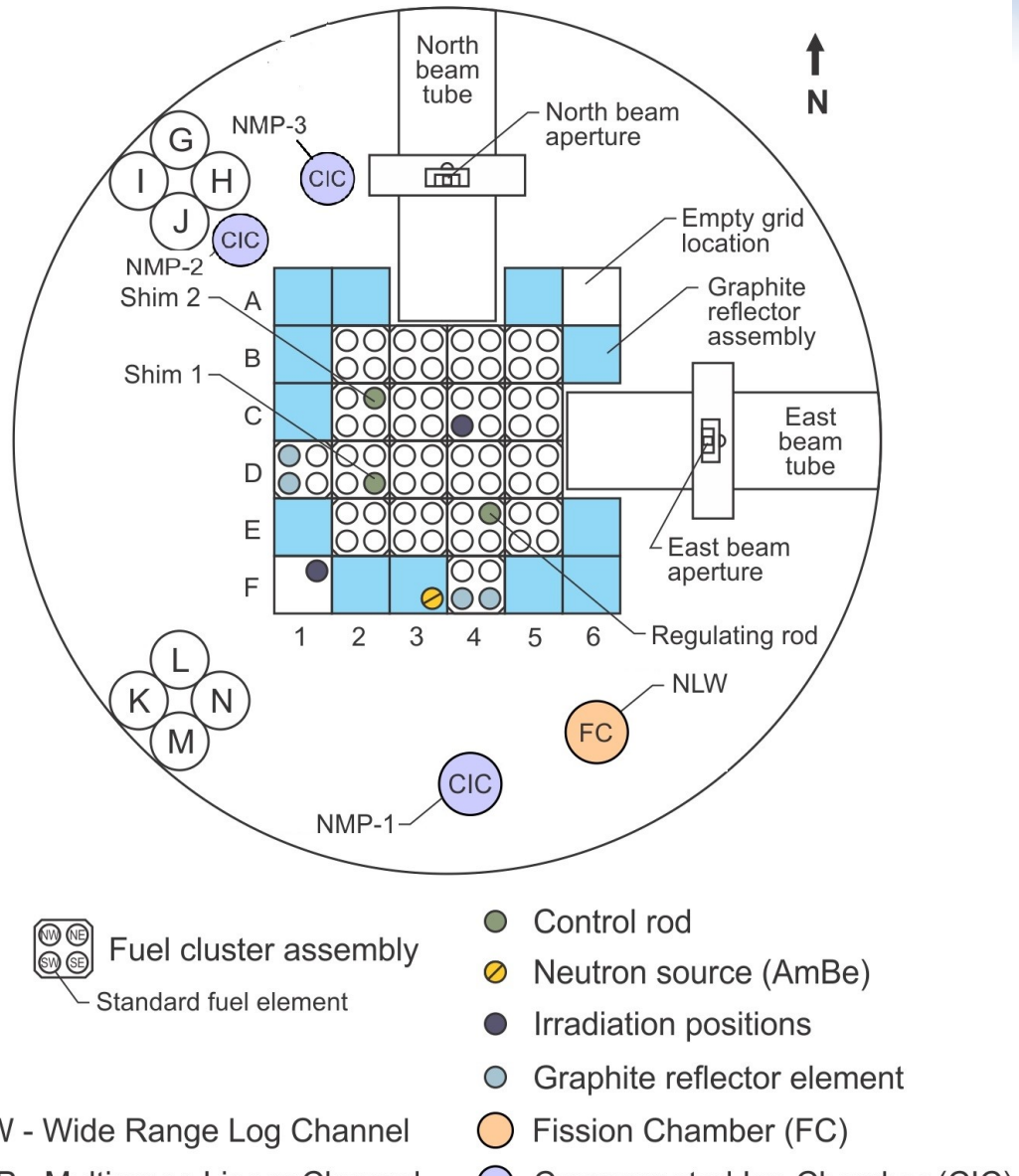
Cask Tunnel, NRAD Cask, and Decon Cell Penetrations allow for experiment transfer to hot cell in <24 hrs.

Reactor Positioned Beneath HFEF Hot Cell

NRAD Beam Systems



NRAD Core Layout

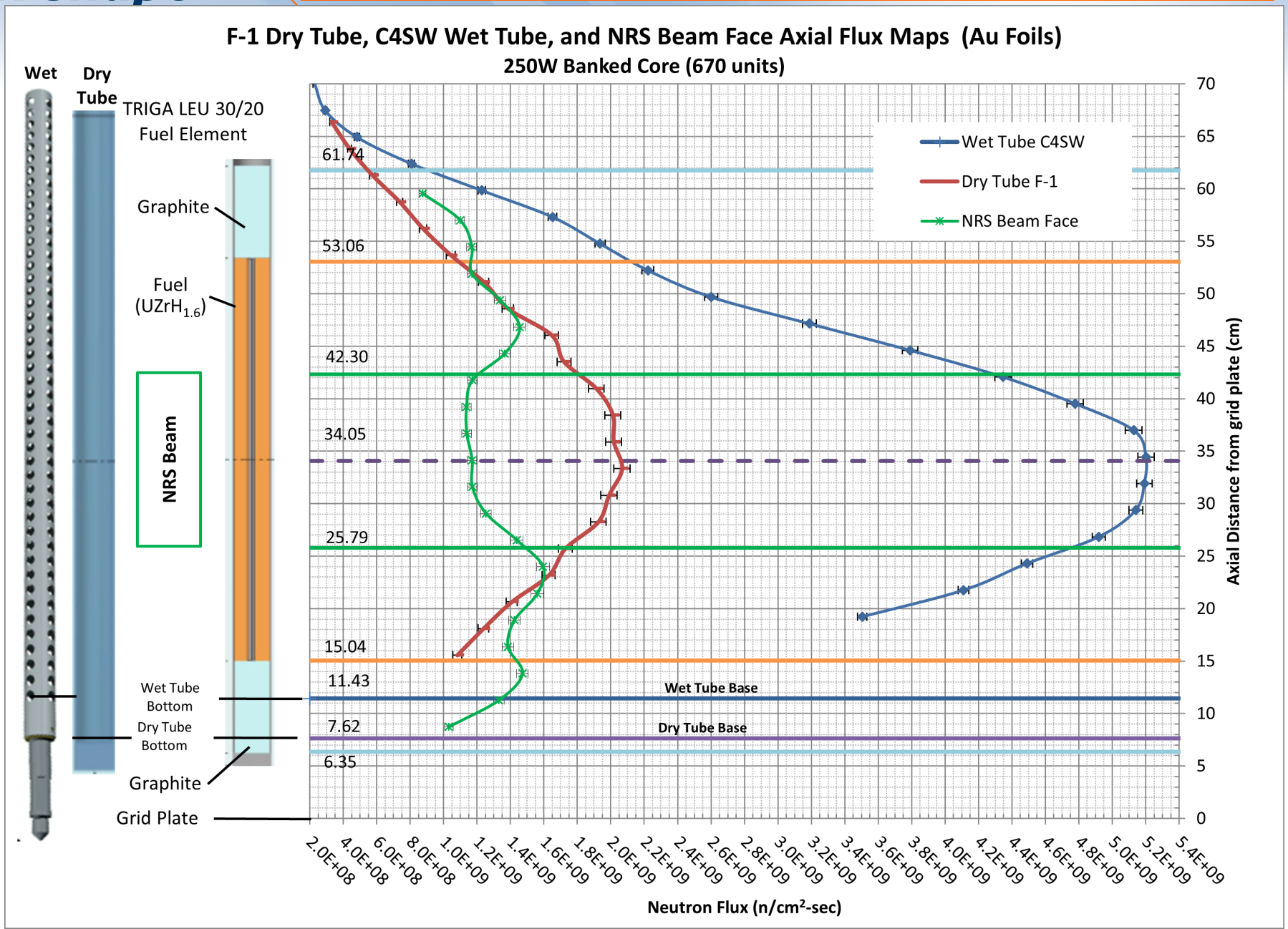


- Approved 64-element core configuration
  - 64 TRIGA® LEU SS-clad Elements
  - 4 Graphite reflector elements
  - 12 Graphite block reflectors
  - 2 beam lines
  - 2 empty grid positions (F-1, A-6)
  - 1 empty fuel element location with guide tube (C4SW)
  - 3 Control rods
- SAR change in progress to allow for core re-configuration to accommodate larger experiments
- 8 in-pool storage locations (G-M)

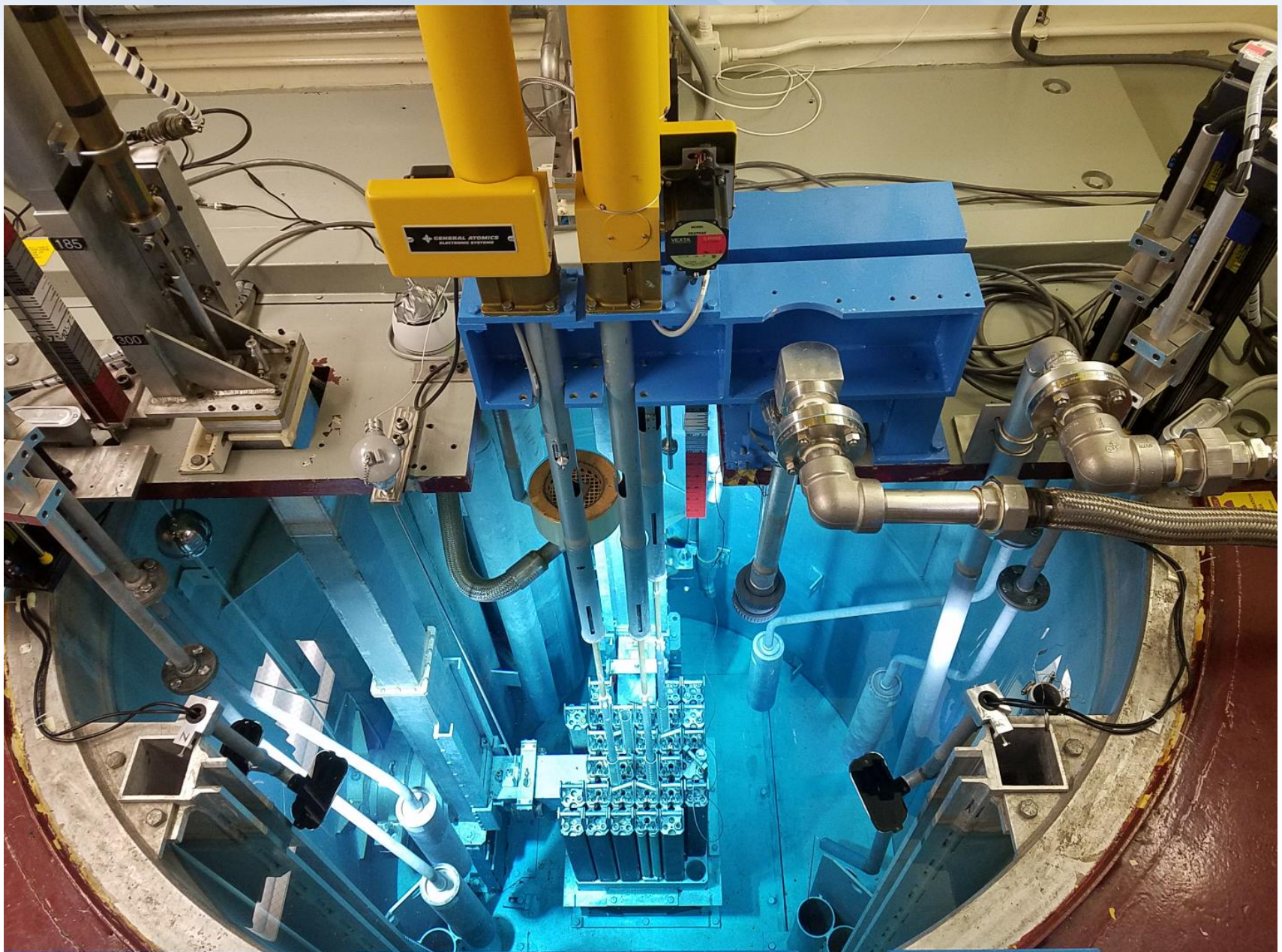
NRAD Axial Flux Shape

- ~10cm flat flux near core centerline in dry tube
- ~7 cm flat flux at core centerline in C4SW

- *NOTE: Fluxes noted in the chart are measured at 250W. Scale up 3 decades for full power fluxes.*



NRAD Reactor

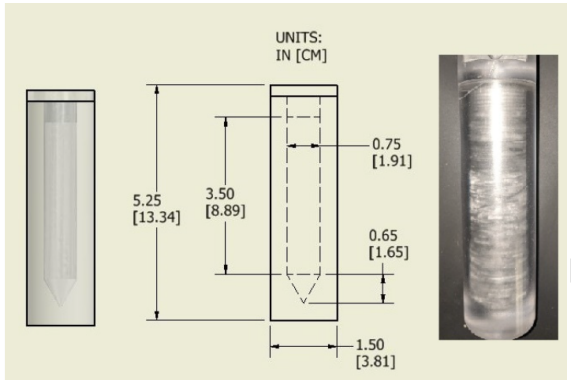


C4SW and associated wet tube is used for higher flux irradiations that require cooling.

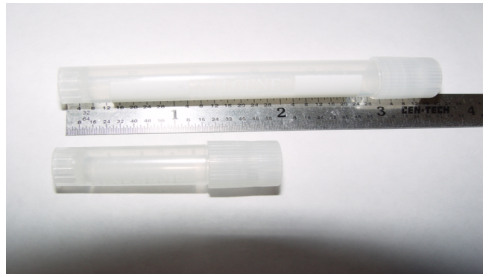
Dry Tube can be positioned in empty core position F-1 for experiments that must stay dry.

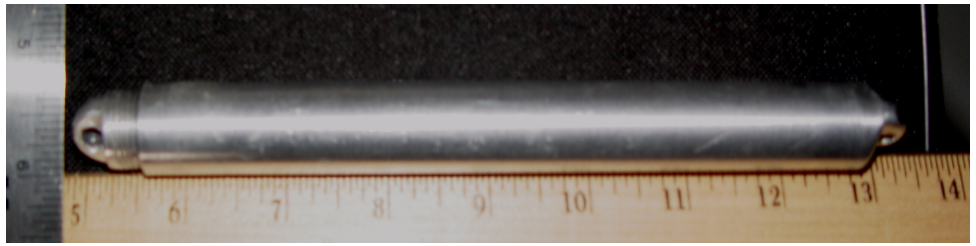
Routine Dry Tube Experiments

Example containers
Polycarbonate container



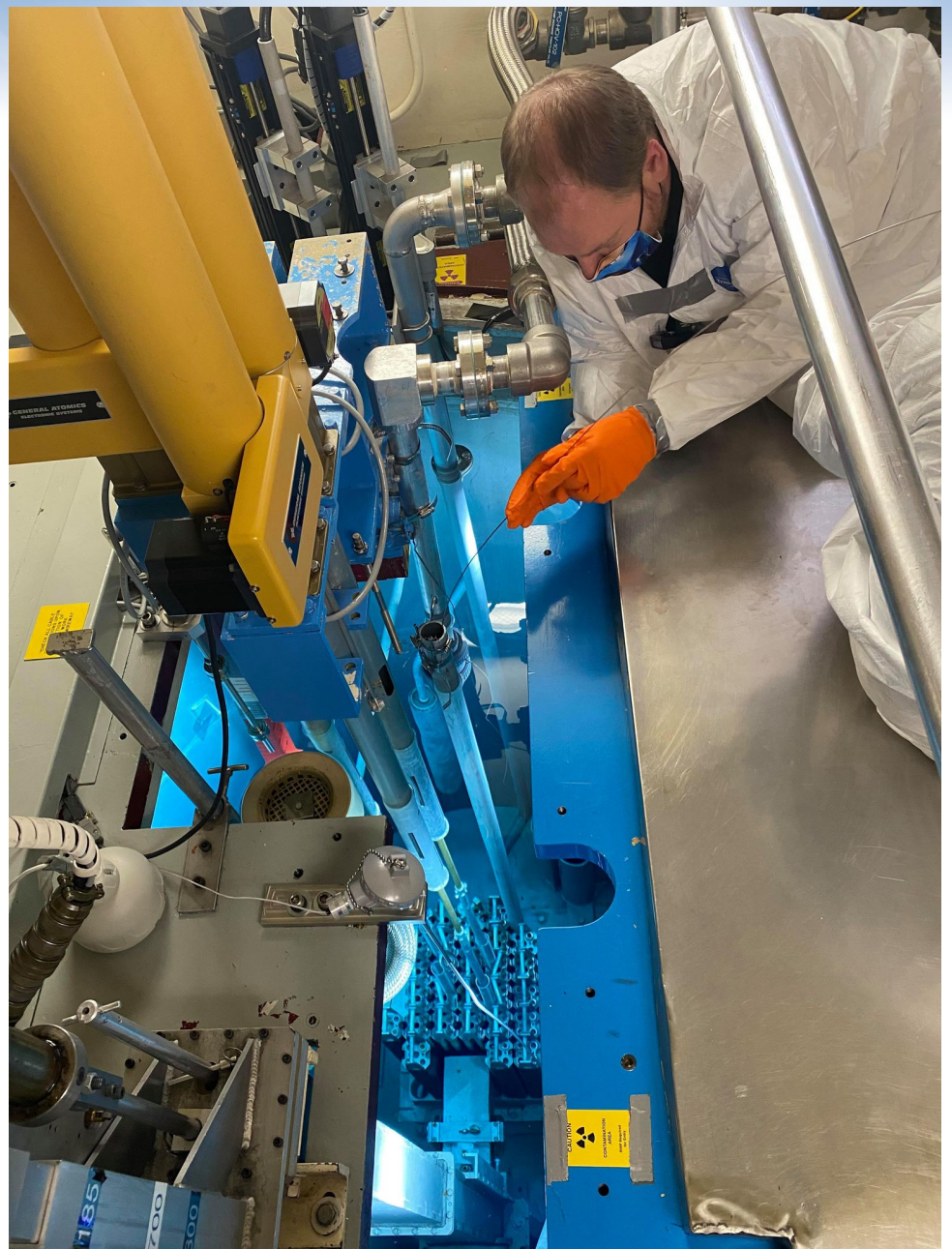
(Post-Irradiation)





Dry Tube positioned in empty core position F-1. Experiment suspended from titanium wire at core centerline.

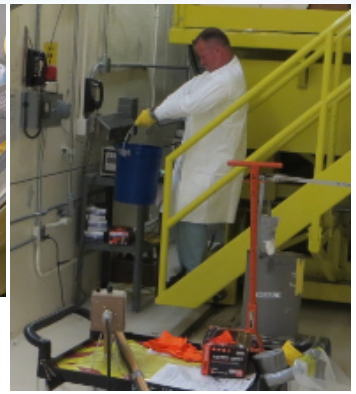
Contact handling RWP limit - <25R/hr on contact.



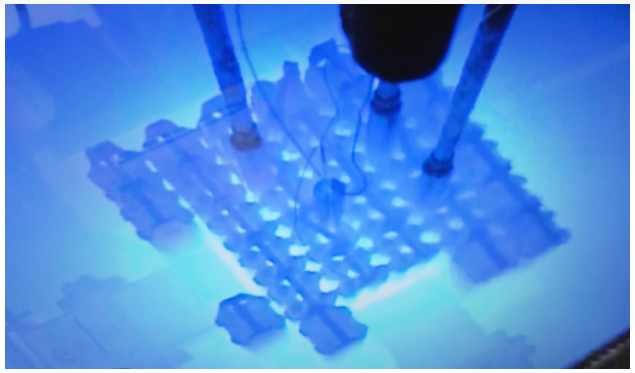
C4SW Wet Tube Experiments

Example containers
Titanium and Aluminum Available

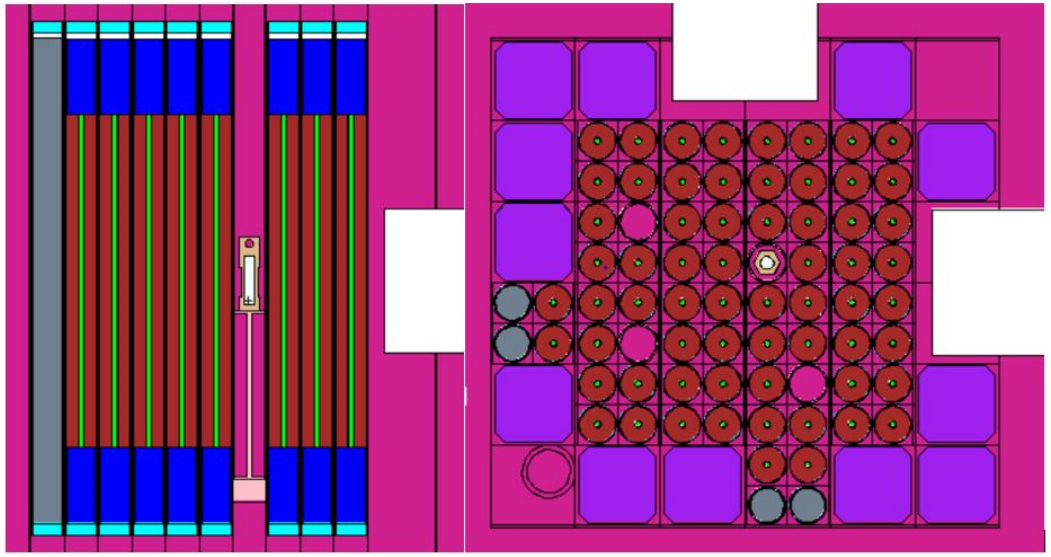
Lower Dose Sample Transfer to DAW Cask. Water bucket used for additional shielding – AGR particle re-irradiation campaign



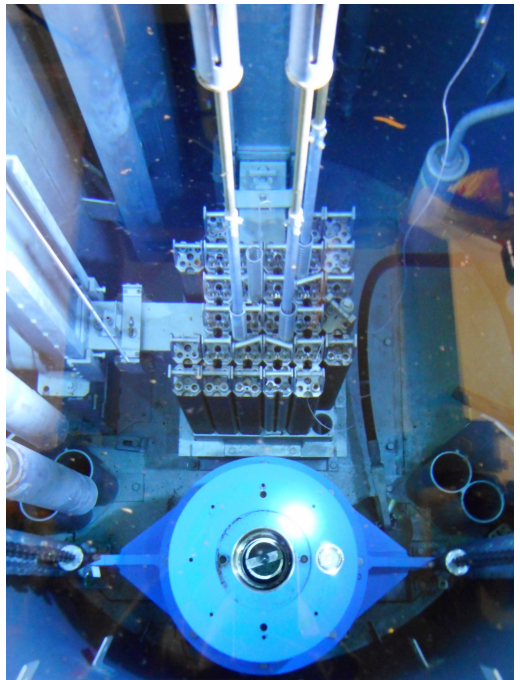
C4SW Sample Irradiation – In-tank camera



MCNP model of capsule in C4SW on Al sample stand. Stand ensures capsule stays at core centerline.



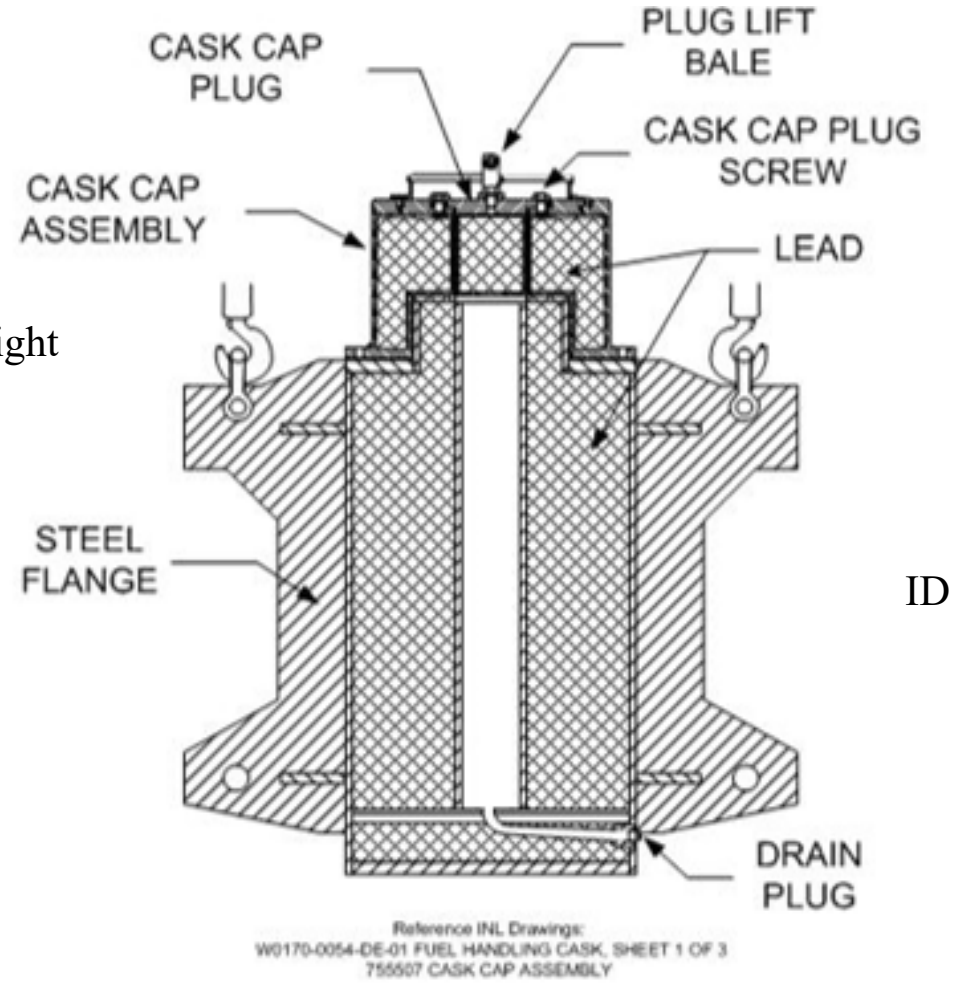
NRAD Cask on tank bottom. Plug removed for sample transfer.



NRAD Cask Transfer for High Dose Samples – AGR full compact re-irradiation campaign

NRAD Cask

- Shielding Capability:
  - 8” lead on walls
  - 6” lead top, 4” lead bottom
- 7000 lbs
- Top-Loading
- Qualified for use in HFEF/NRAD cask tunnel for transfers only.
- Internal Dimensions
  - 4.5” ID
  - 39” internal height
- Contents controlled by LST-394 Crit Safety List
  - ≤ 4 TRIGA ® Elements, OR
  - 150g MFE



NRAD Experiment Process

(NRAD-NOP-5003 NRAD Experimenter's Guide)

Experiment Proposed

In-Tank

Not Previously Approved

Experimental Safety Analysis (ESA) - (SAR-406 SARC 8.406.2)

- Description
  - Size
  - Composition
    - Mass
    - Form
    - MFE
  - Encapsulation
  - SECURED/UNSECURED
- Core Physics
  - Estimated reactivity worth
  - Effects on control rod worth
  - Effects on core shutdown margin
- SSC Impacts
  - Control rod insertion interference
  - NI efficiency or shadowing
  - Reactor shielding
- Fuel Impacts
  - In-tank location (proximity to fuel)
  - Effects on cooling flow
  - Chemical interaction
- ALARA
  - Dose consequence (MAR)
  - Pre-and Post-irradiation rad levels
    - In-tank decay time
    - Shielding – post irradiation
  - Potential failure modes (Tank water contamination)

ESA ECAR Approval:

- Reactivity Tech Checker
- System Engineer
- Industrial Safety
- Nuclear Safety
- Criticality Safety
- Radcon
- Nuclear Facility Manager

USQ the Experiment Bounds

Rx Manager Scope Approval

Previously Approved: Bounded by Previous ESA

Rx Manager Scope Approval

Experimenter/NRAD System Engineer Provides Prescription:

- In-tank location
- Power level
- Irradiation time
- In-tank decay time
- Shielding – post irradiation

Rx Manager Prescription Approval

Material Acceptance and Transfer Paperwork Development

Experiment Acceptance and Positioning

Reactivity Worth Determination and Material Irradiation

Out-of-Tank

Material Acceptance and Transfer Paperwork Development:

Experimenter/NRAD System Engineer/Radiographer Provides Prescription:

- Facility location
- Power level
- Irradiation time
- Shaper/scraper settings
- Decay time prior to handling
- Shielding – post irradiation
- Decay time prior to release

Material Positioning and Irradiation

Experiment Retrieval and Transfer

General Information:

- ESAs can bound several samples
- ECARs should be used for ESAs for In-core experiments.
- Anything that is intended to be released back to the public needs a Form 441.47 initiated and Radcon involvement up front.

NRAD In-Core Experiment Costs

(Estimates – Subject to change)

Single Shift (10 hrs) Irradiation with sample insertion, retrieval, and transfer

#	Activity Title	Labor Hours	FTE	Loaded Labor	Non-Labor	Total
1	NRAD Reactor Ops (10 hr shift)	20.00	0.01	$3,200.30	$0.00	3,200.30
2	Sample Insertion (one sample)	7.00	0.00	$1,059.97	$0.00	1,059.97
3	Sample Retrieval (One Sample)	6.00	0.00	$856.08	$0.00	856.08
4	Sample Transfer	14.00	0.01	$2,200.75	$0.00	2,200.75
		47.00	**0.03**	**$7,317.10**	**$0.00**	**$7,317.10**

#	Activity Title	Labor Hours	FTE	Loaded Labor	Non-Labor	Total
1	NRAD Reactor Ops (24-hr Coverage)	52.00	0.03	$8,598.69	$0.00	8,598.69
2	Sample Insertion (One Sample)	7.00	0.00	$1,059.97	$0.00	1,059.97
3	Sample Retrieval	6.00	0.00	$856.08	$0.00	856.08
4	Sample Transfer	14.00	0.01	$2,200.75	$0.00	2,200.75
		79.00	**0.04**	**$12,715.50**	**$0.00**	**$12,715.50**

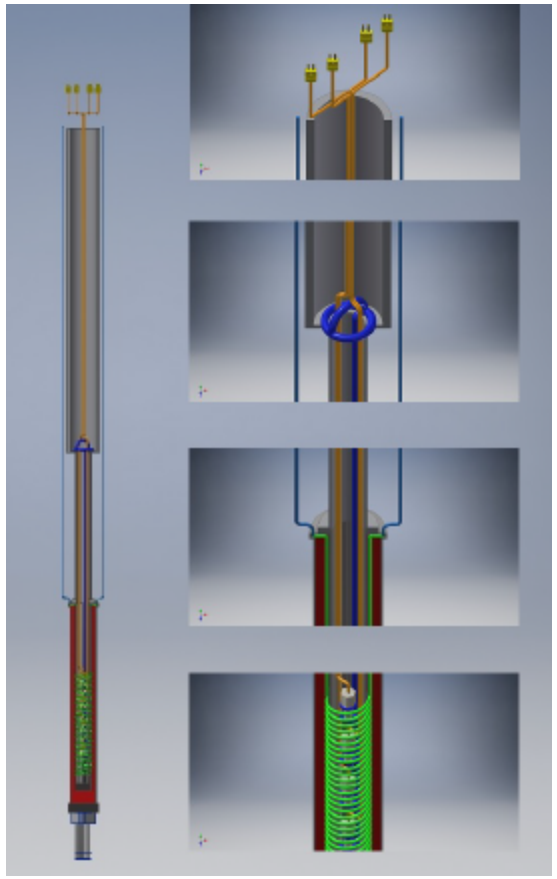
#	Activity Title	Labor Hours	FTE	Loaded Labor	Non-Labor	Total
1	ESA Development, Review, and Approval	270.00	0.15	$47,574.98	$0.00	47,574.98
		270.00	**0.15**	**$47,574.98**	**$0.00**	**$47,574.98**

7-day Continuous Irradiation with NRAD Cask Transfer for insertion and removal, and Decon cell ops

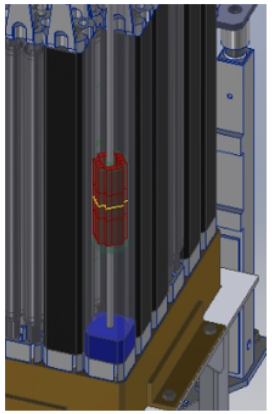
#	P6 Act-ID	Activity Title	Labor Hours	FTE	Loaded Labor	Non-Labor	Total
1		Reactor Operations	336.00	0.19	$63,180.63	$0.00	63,180.63
2		Pre-Irradiation Cask Handling System Rails Install	16.00	0.01	$2,355.53	$0.00	2,355.53
3		Post-Irradiation Cask Handling System Rails Install	16.00	0.01	$2,355.53	$0.00	2,355.53
4		Pre-Irradiation Cask Handling System Rails Removal	12.00	0.01	$1,694.14	$0.00	1,694.14
5		Post-Irradiation Cask Handling System Rails Removal	12.00	0.01	$1,694.14	$0.00	1,694.14
6		Post-Irradiation NRAD Cask Bag In/Out to Decon Cell	40.00	0.02	$6,211.38	$0.00	6,211.38
7		Pre-irradiation NRAD Cask Bag In/Out to Decon Cell	40.00	0.02	$6,211.38	$0.00	6,211.38
8		Cask Transfer to NRAD Before Irradiation	44.00	0.02	$6,486.52	$0.00	6,486.52
9		Cask Transfer From NRAD After Irradiation	44.00	0.02	$6,486.52	$0.00	6,486.52
10		Decon Cell Sample Load	10.00	0.01	$1,655.39	$0.00	1,655.39
11		Decon Cell Sample Unload	10.00	0.01	$1,655.39	$0.00	1,655.39
12		Interfacility Transfer Paperwork	17.00	0.01	$2,839.41	$0.00	2,839.41
			597.00	**0.34**	**$102,825.96**	**$0.00**	**$102,825.96**

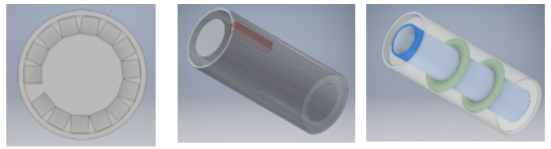
Advanced Concepts (Options being explored or in the design phase already)

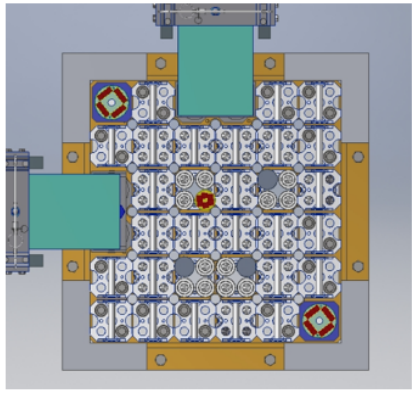
CHARIN Dry-well In-Core Heater (Capable of 900 C)

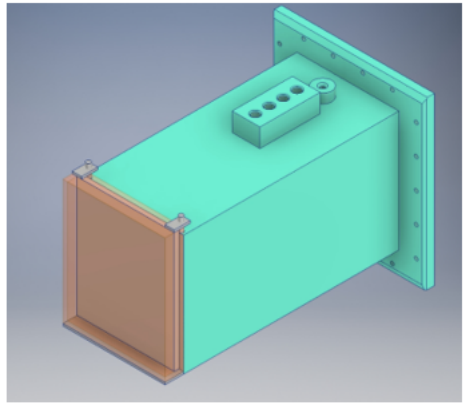


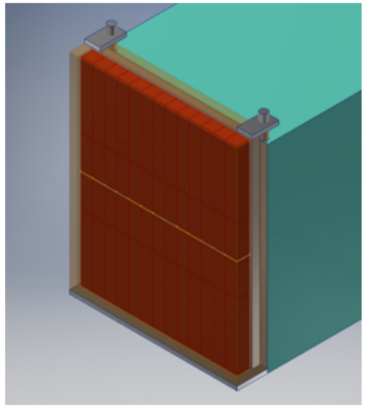
Multi-Sample Rotating Irradiators



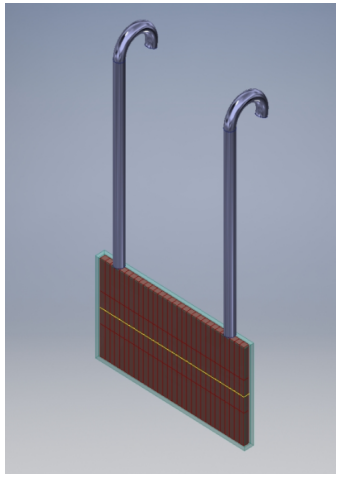


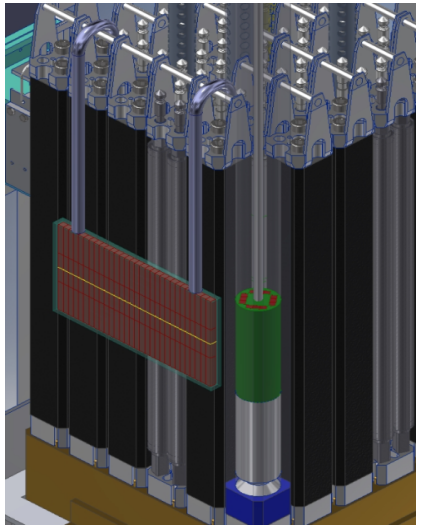






Multi-Sample Hanger





Additional Questions/Clarifications?

- Always contact the facility first to see what's possible. We're flexible.
- Contact:

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