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Readiness Reviews at the Annular Core Research Reactor (ACRR)

Continuing years of audits

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U.S. DEPARTMENT OF ENERGY

NNSA

ANNULAR CORE RESEARCH REACTOR

236 UO_2-BeO fueled elements
- Minimal fuel burnup is (<3% in ~45 years)
- 1.5 in (3.8 cm) dia. x 20.5 in (52 cm)
- 100 g ^{235}U per element – 35% enriched

Operating Power Level
- 2.4 MW_{th} Steady-State Mode
- 300 MJ Pulse Mode (6 ms FWHM)

Dry central cavity 9 inch diameter
- Neutron Flux 4E13 n/cm^2-s at 2 MW
- Neutron Fluence 6E15 n/cm^2 at 300 MJ
- 90% > 1 eV, 58% > 10 keV, 46% > 100 keV

Epithermal/Fast Spectrum
- Cavity flux energy spectrum adjusted using filter buckets (PbB, CdPoly, PolyPbC, PbPoly)

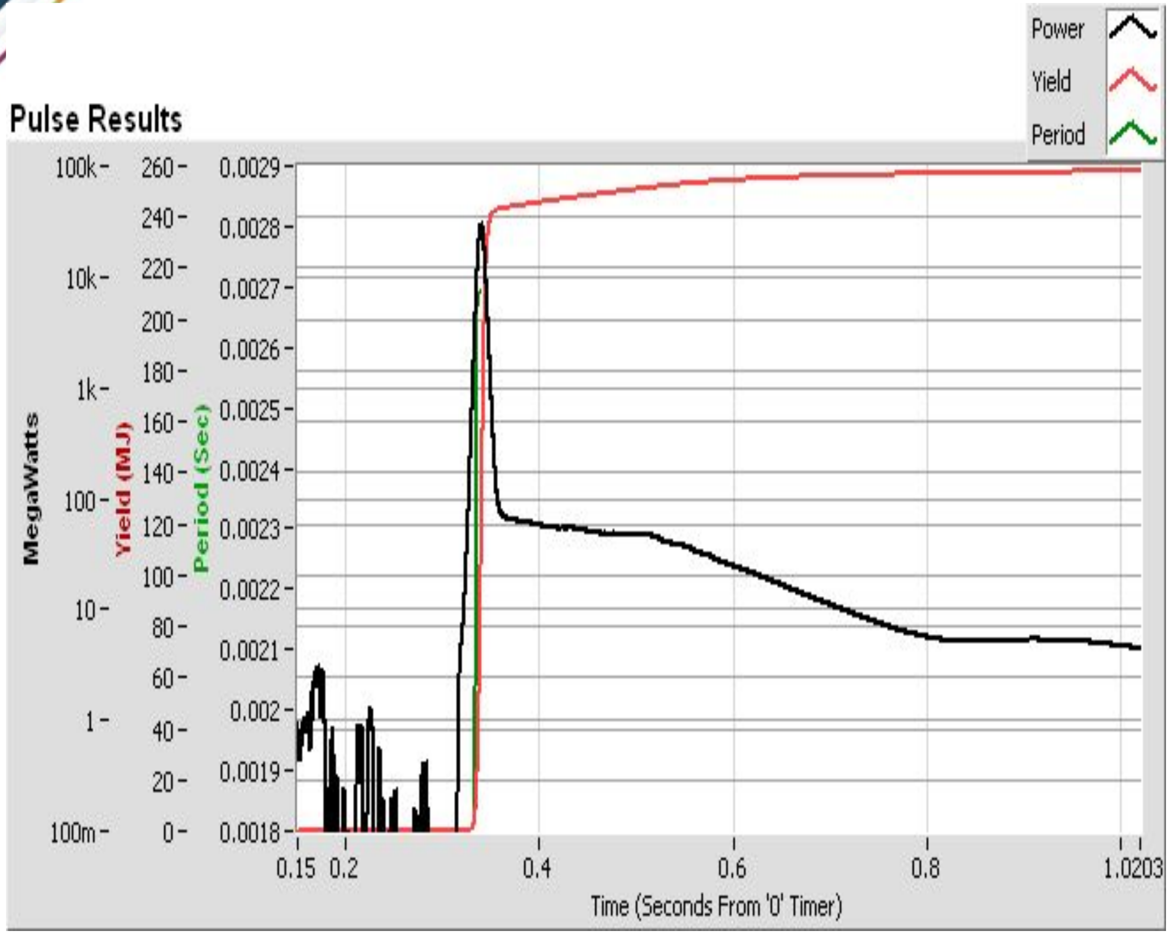
FREC-II is a 20 in diameter dry cavity
- Using TRIGA type - UZrH (previously ACPR fuel)
- 54 g ^{235}U per element – 20% enriched

ACRR is a unique, one-of-a-kind nuclear reactor facility operated by SNL for the National Nuclear Security Administration that is considered by many to be a national treasure. There is no other research reactor in the world with the attributes and capabilities of the ACRR.

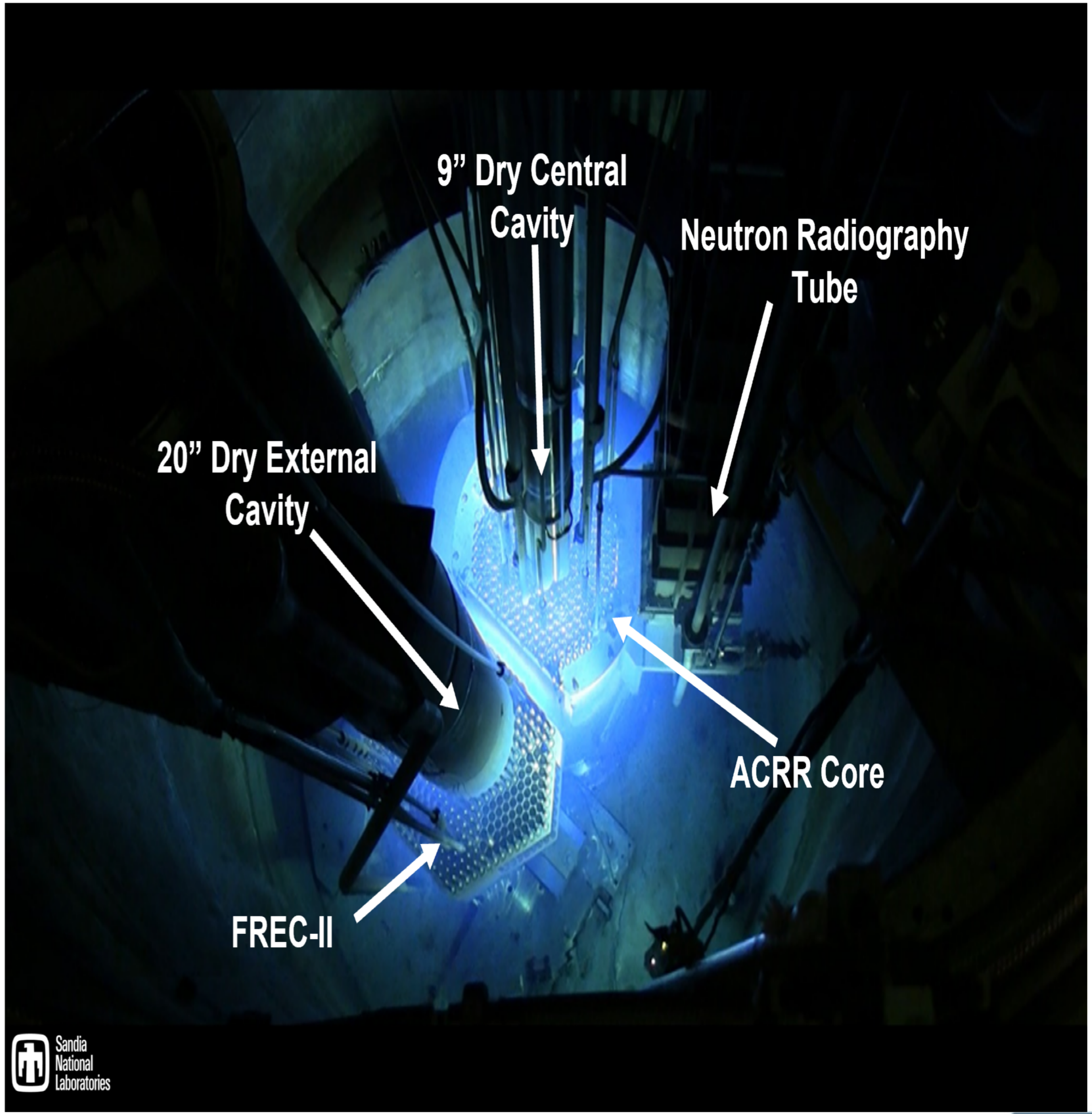
ACRR was specifically designed to meet the irradiation testing needs of the nuclear weapons program. Tests have included; Active electronics, active and passive explosives, fissile and fissionable material in large quantities, fuel melt studies, high-voltage and power, flowing sodium/hydrogen, previously irradiated materials.

ACRR has 4 major unique attributes:
1) a large dry central cavity;
2) an epithermal neutron flux;
3) a large pulsing capability; and
4) FREC-II with a larger dry cavity.

ANNULAR CORE RESEARCH REACTOR



For a 280 MJ Pulse at 33,000 MW
In Cavity: 6.06E15 n/cm^2 and 3.4E6 Rads
In PbB4C bucket: 3.7E15 n/cm^2
In FREC-II: 1.6E15 n/cm^2



WHEN IS READINESS REVIEW REQUIRED

The Readiness Review process was modeled after Naval Nuclear Propulsion and Nuclear Regulatory Commission programs and processes.

An <u>**ORR**</u> (the highest-level readiness review) must be conducted for:

(1) Initial startup of a **newly constructed nuclear facility,** requiring a new Documented Safety Analysis (DSA) & Technical Safety Requirements (TSR);

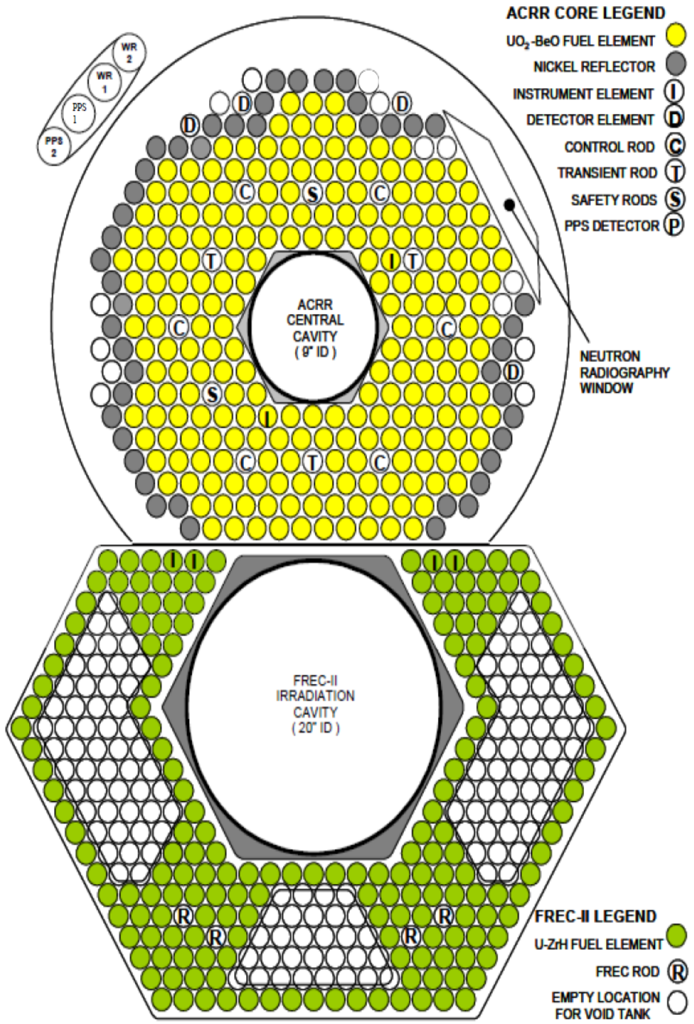
(2) **Initial startup after conversion** of an existing facility to a new nuclear mission with new DSA and TSRs;

(3) Nuclear facility or activity restart with **upgraded categorization** to HC 1, 2, or 3;

(4) **Restart after a DOE directed facility shutdown**, activity, or operation for safety reasons;

(5) **Restart** of nuclear facility, activity, or operation **after violation of a Safety Limit**; or,

(6) **Any situation deemed appropriate by DOE line management**.



WHEN IS READINESS REVIEW REQUIRED

An **RA** must be conducted for any of the following:

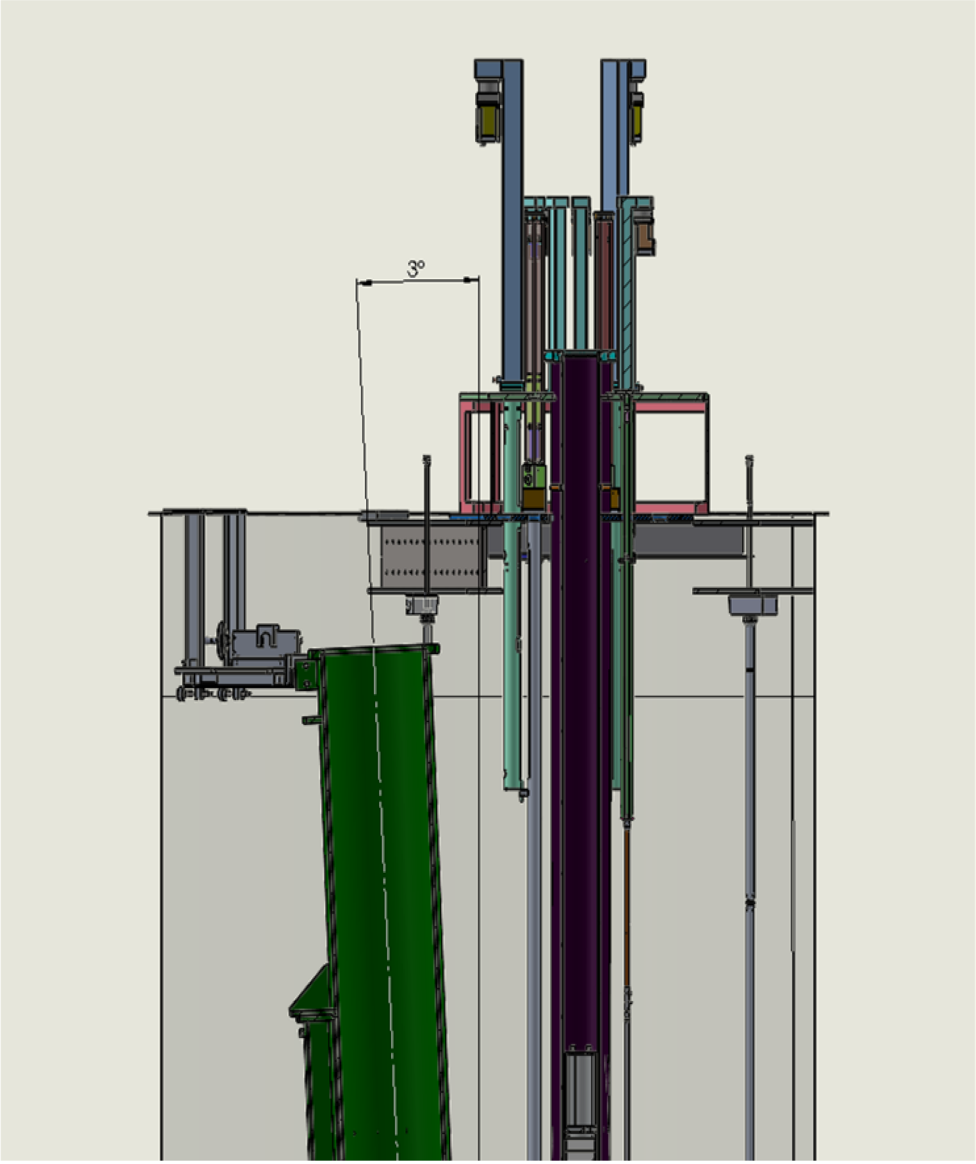
(1) **Initial startup of new HC 1 or 2** activity or operation with new DSA and TSRs;

(2) **Restart after extended shutdown** for a HC 1 or 2 facility, activity, or operation;

(3) **Facility, activity, or operation startup/restart after substantial system, or facility modification**.

Local site implementing procedures must provide a process for determining whether a modification is substantial, based on the impact of the changes in the safety basis, equipment, operating procedures, training, or staffing, and the extent and complexity of these changes, whether or not these changes resulted in a positive Unreviewed Safety Question determination; or,

(4) **Any situation deemed appropriate by DOE line management**.



ACRR Upper Model w/FREC Decoupled

Sandia's Readiness Review Process

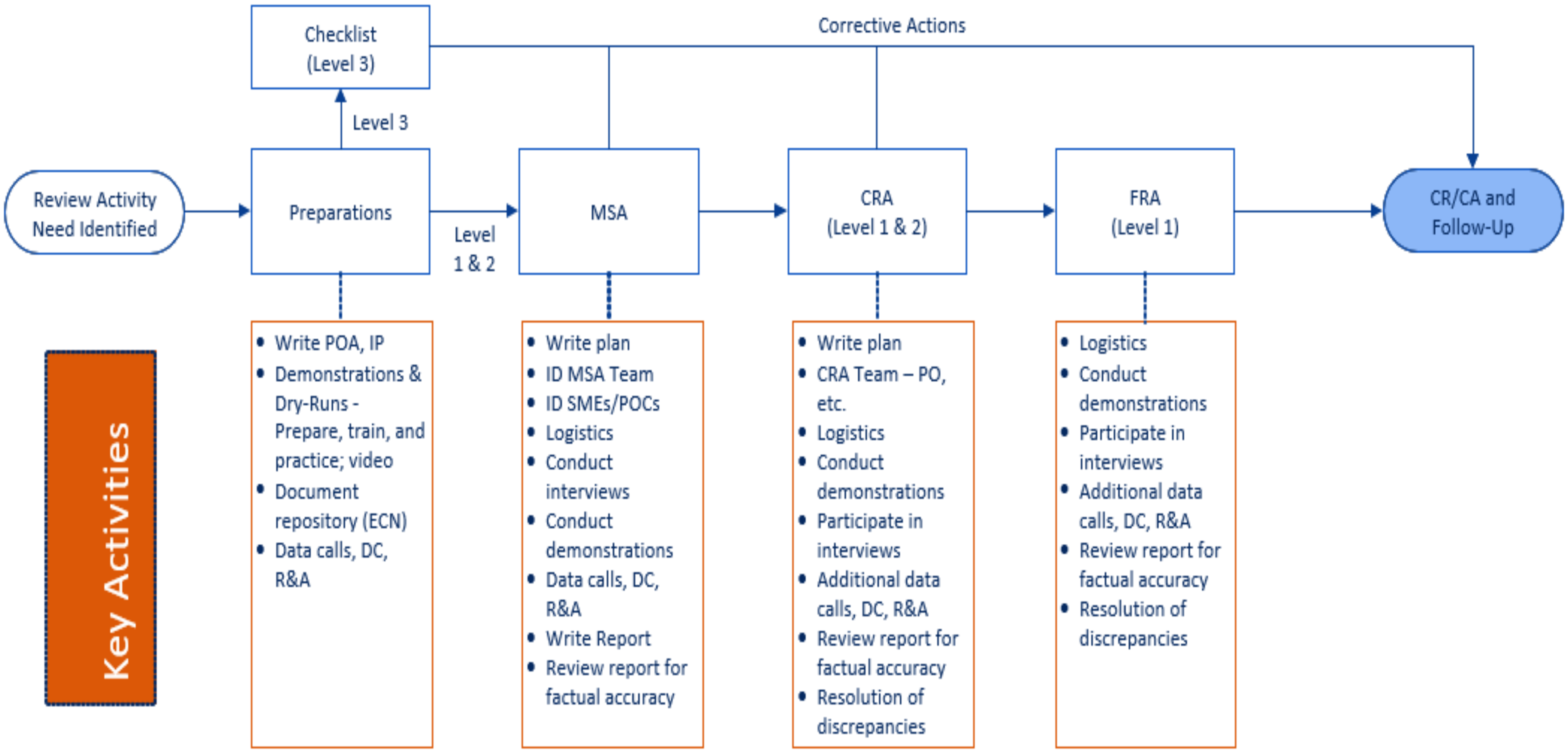
- DOE prescribes a **graded approach** process for verifying readiness for **startup or restart** of new HC - 1, 2, and 3 **nuclear facilities, activities, and operations** that have been **shut down** or **not functioned** for an extended time.
- SNL implements its readiness review graded approach process by local procedure, Implementing the Startup and Restart Process for Nuclear Facilities, Operations and Activities.
- Sandia Field Office (SFO) provides local DOE oversight.

ORR (Highest Rigor)	**Both an SNL ORR and DOE ORR are required**	**DOE is the SAA**
Level 1 RA	Both an SNL RA and an SFO RA are required	SFO is the SAA
Level 2 RA	SNL RA is required, but SFO RA is not required	The SAA is either SFO, the NFO Associate Laboratories Director or Center Director;
Level 3 RA (Lowest Rigor)	Checklist RA is required, but SFO RA is not required	The SAA shall be an NFO manager, one or more levels of above, the NFO manager of the facility, operation, or activity where RA will occur.

HC = Hazard Category
NFO = Nuclear Facility Operations
ORR = Operational Readiness Review
RA = Readiness Assessment
SAA = Startup Authorization Authority
SFO = Sandia Field Office

Sequence Of Events in Readiness Reviews

SNL Readiness Review Process



ACTIVITIES UNDERGOING ASSESSMENT

Type of Assessment	Title	Plan of Action Issued	Implementation Plan and Final Report	
			Start	End
Level 3 Checklist RA’s	Resumption of Explosive Activities	3/14/2017	3/17/2017	3/20/2017
Level 2 RA (Elevated to Level 1)	Reactivity Control System Upgrade (RCSU) Project	POA 11/30/2017		
		MSA	5/17/2018	5/20/2018
		CRA	6/18/2018	6/28/2018
		FRA	9/10/2018	9/14/2018
Level 1 RA	In-Service Fuel Cladding Inspections at the ACRRF	POA 8/26/2020		
		MSA	12/01/2020	1/04/2021
		CRA	1/15/2021	1/29/2021
		FRA	4/12/2021	4/21/2021
Level 1 RA	FREC II Operations at the ACRRF	POA, Rev. 1 12/14/2021		
		MSA	11/15/2021	11/27/2021
		CRA	1/10/2022	1/20/2022
		FRA	2/14/2022	2/17/2022
Level 2 RA	Class III Experiments at the ACRRF	POA 5/6/2022		
		MSA	5/31/2022	6/16/2022
		CRA	8/8/2022	8/16/2022
Level 1 RA	Restore Transient Rod Withdrawal (TRW) Capability	POA 10/3/2022		
		MSA	10/17/2022	10/21/2022
		CRA	11/5/2022	11/9/2022
		FRA	2/27/2023	3/3/2023

ACTIVITIES UNDERGOING ASSESSMENT

Resumption of Explosive Activities – Receipt, handling, and detonation of explosives during reactor operation.

Reactivity Control System Upgrade – This activity replaced portions of the Reactivity Control and Instrumentation and Control (I&C) Subsystems. This included replacement of a majority of the I&C system, including the existing data acquisition equipment, process control computer, operator workstations, and the network data communications devices.

In-Service Fuel Cladding Inspections – The activity was evaluation/inspection of in-service fuel elements in the ACRR and FREC-II to provide monitoring of the health and condition of the cladding for each fuel element. Fuel elements were removed from the core and examined one at a time, then returned to the core or sequestered for further evaluation.

FREC II Operations at the ACRRF – Restoration of programmatic activities for FREC when coupled.

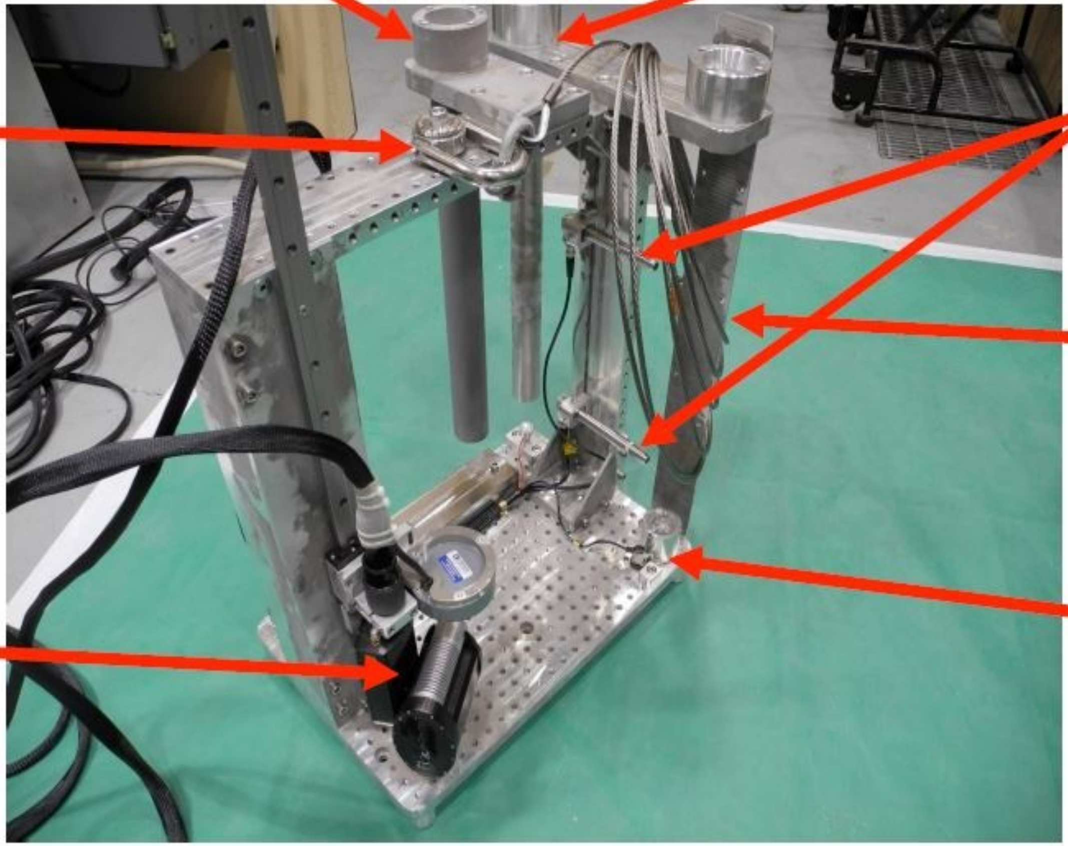
Hazard Category III Experiments at the ACRRF – The activity included Class III experiments which are canisters that contain HC-3 quantities of fissionable material in metal form.

Restoration of Transient Rod Withdrawal (TRW) Capability – TRW is a sub-mode of the ACRR Pulse Mode used for creating highly repeatable power profiles. TRW allows for programmed electro-mechanical movement of the transient rods from the reactor core at variable rod speeds, resulting in fast reactor periods up to and including prompt-critical periods. It can be used to create double pulses, higher energy output, and square waves.

FUEL ELEMENT INSPECTION - Timeline

Dec 2019	• Cladding breach found on Safety Rod 1 (SR1)
Jan 2020	• Removed SR1 from core and into storage • 16 elements were inspected around SR1, which lead to identification of a suspect Fuel Element (FE #134) with unusual discoloration and a potential crack in the clad
Sept 2020	• Inspected 42 elements using the traditional (visual) method and applied grading criteria to obtain more statistical data on potential cladding defects overall in the core
Nov 2020	• Ultrasonic method ready for deployment. Performed UT scan of FE #134 and determined no water ingress.
Dec 2020 – Apr 2021	• Performed many readiness assessments (Management, Contractor, Federal) using the Fuel Element Inspection Jig (FEIJ) and a mock element
Jun 2021 – Aug 2021	• Performed the 2021 fuel inspection campaign. Target was to inspect 169 fuel elements.

FUEL ELEMENT INSPECTION – Submerged Test Stand



Go/No-Go Gauge

Load cell weighing station

Lifting swivel hoist ring and 29' wire rope

Ultrasonic probes

Graduated scale

Camera (PTZ) and lighting with vertical movement

Rotatable saddle and encoder

FREC RETURN TO PROGRAMMATIC OPERATIONS

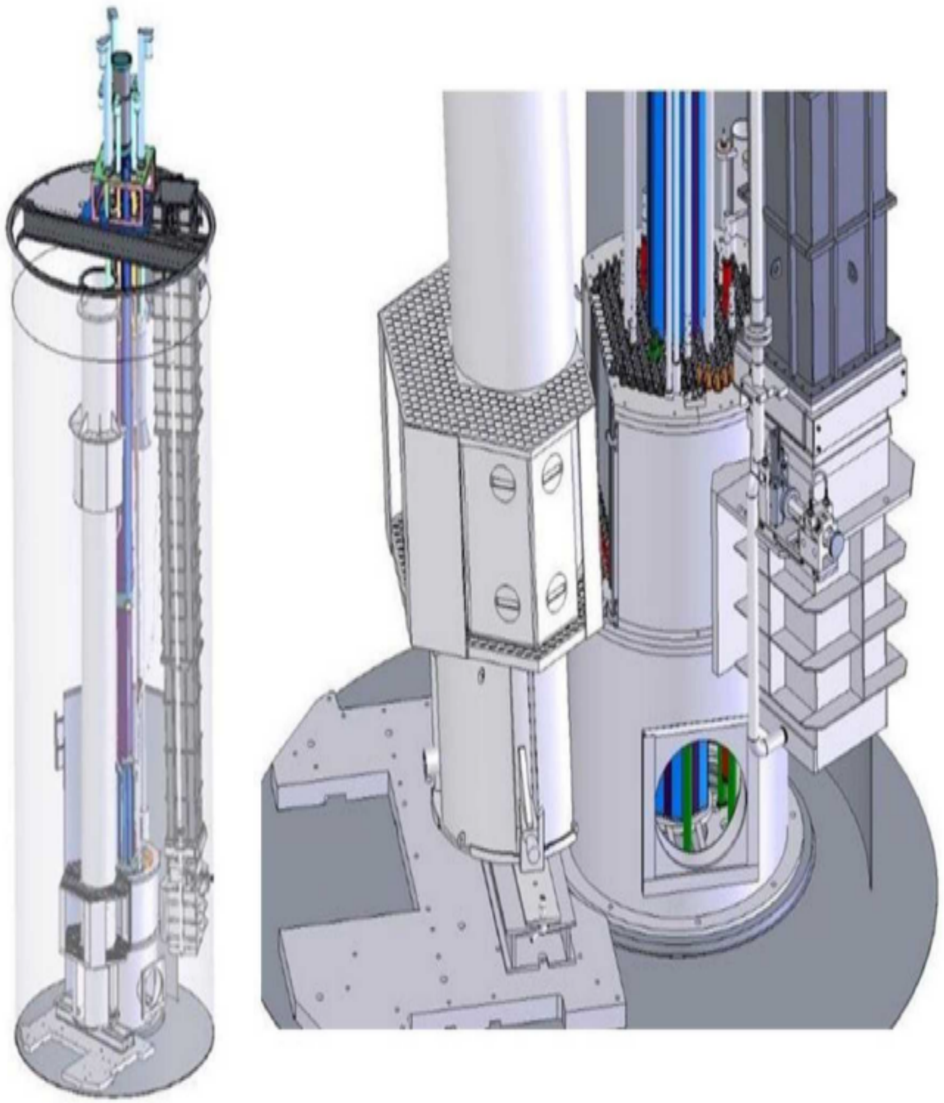
When FREC-II is installed it may be "coupled" or "de-coupled"

- When "de-coupled", FREC-II is tilted away from the core ~3 degrees and a nickel plate is attached to ACRR.
- With "coupled," a significant neutron and gamma-ray flux exists in the 20-inch, dry cavity.

FREC-II maintains 4 fuel followed neutron poison elements, that may be positioned full-in, full-out, or in between. This feature allows for radial flux tilting in the FREC cavity.

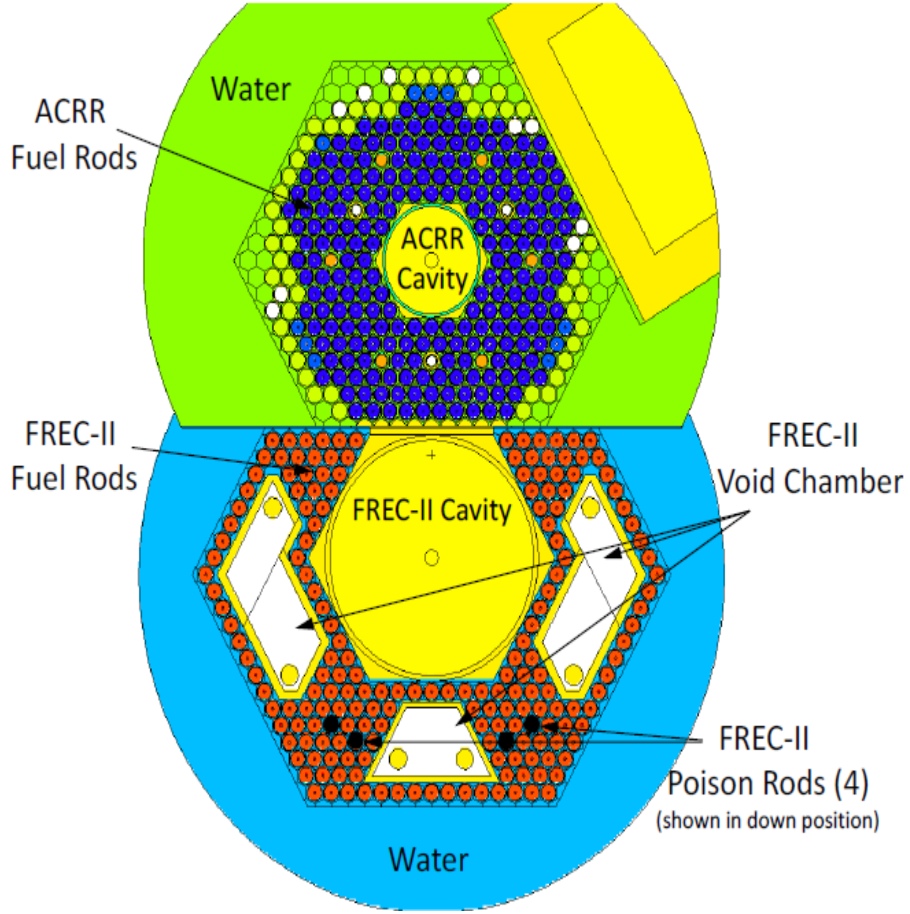
FREC-II uses U-ZrH TRIGA fuel, previously used in the Annular Core Pulse Reactor (1968 to 1978). Since U-ZrH fuel has a significant amount of hydrogen, the neutron flux in the FREC-II cavity is significantly more thermal than in ACRR.

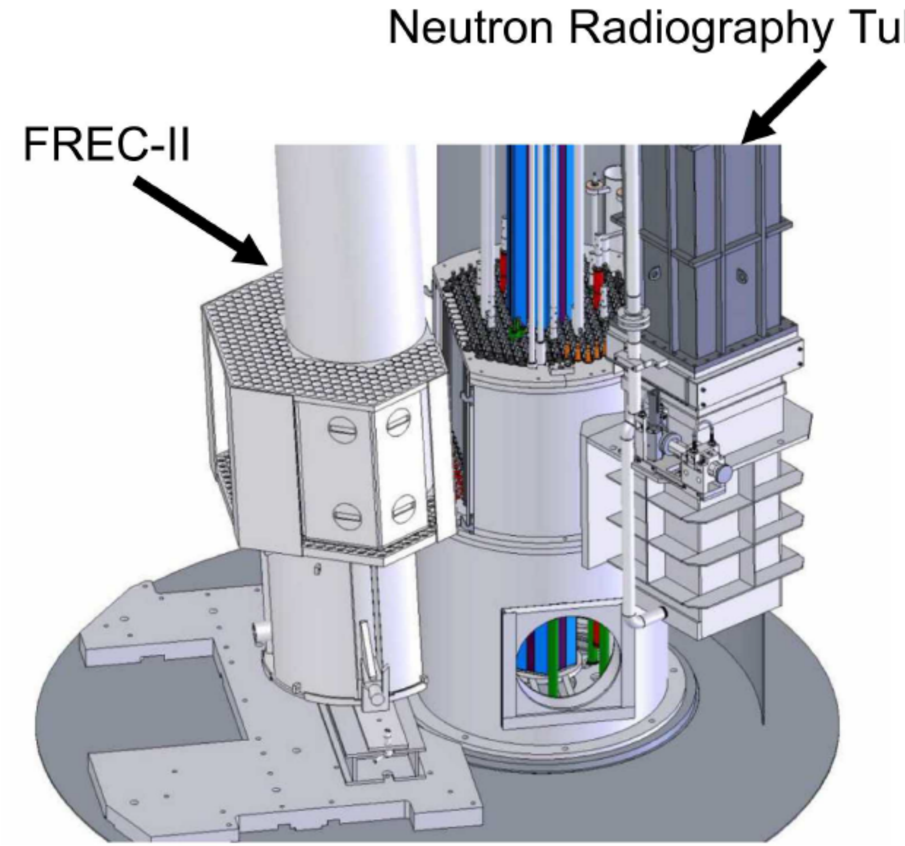
FREC-II has some advantages compared to the central cavity; 1) FREC-II can hold larger experiments; 2) Neutron & gamma-ray flux can be radially tilted (using FREC rods and experiment positioning); and 3) With experiments in FREC, ACRR can be pulsed at high powers with short pulse width while depositing a lower neutron flux on the experiment.

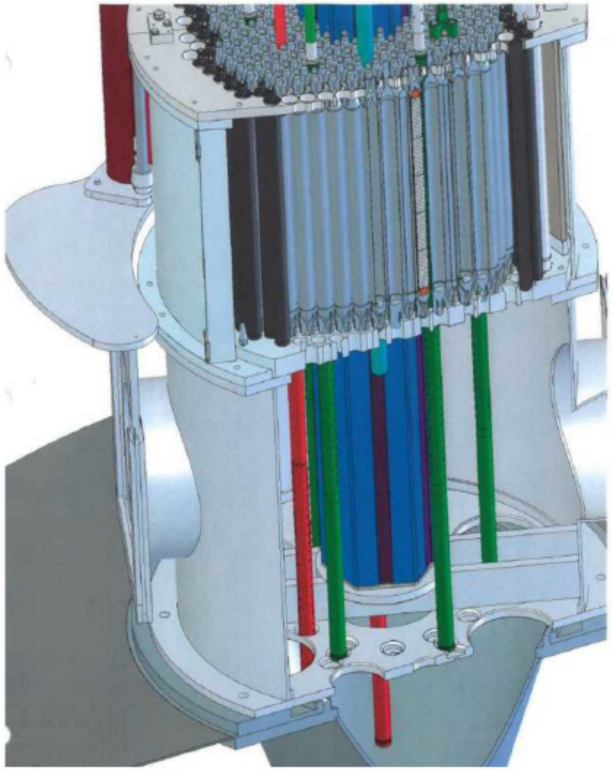


ACRR Model w/FREC Decoupled

FREC COUPLED vs. DECOUPLED

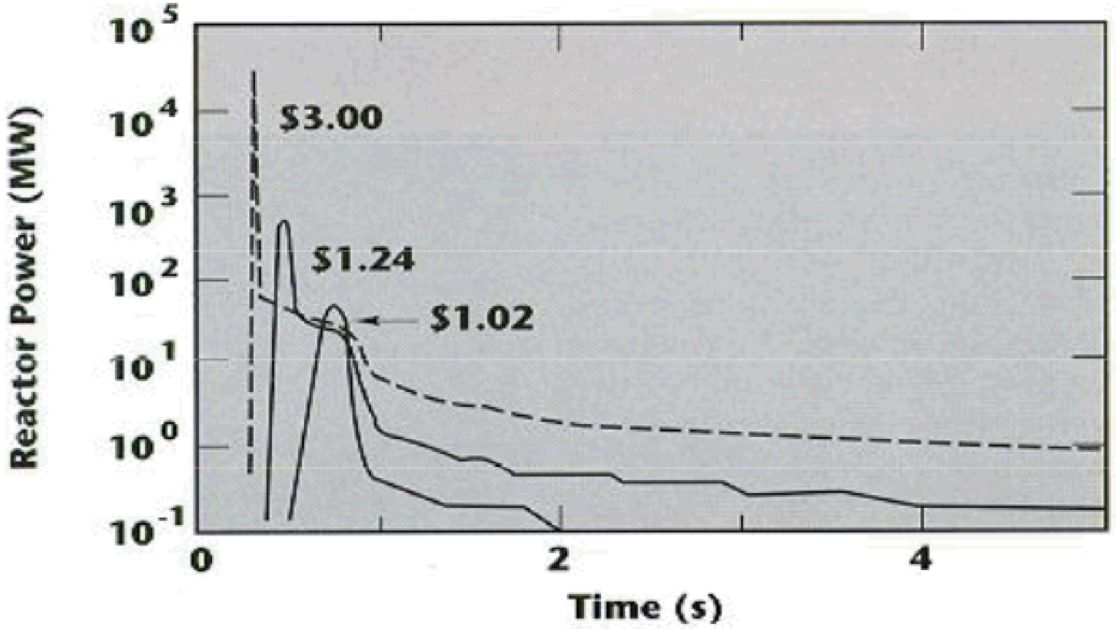




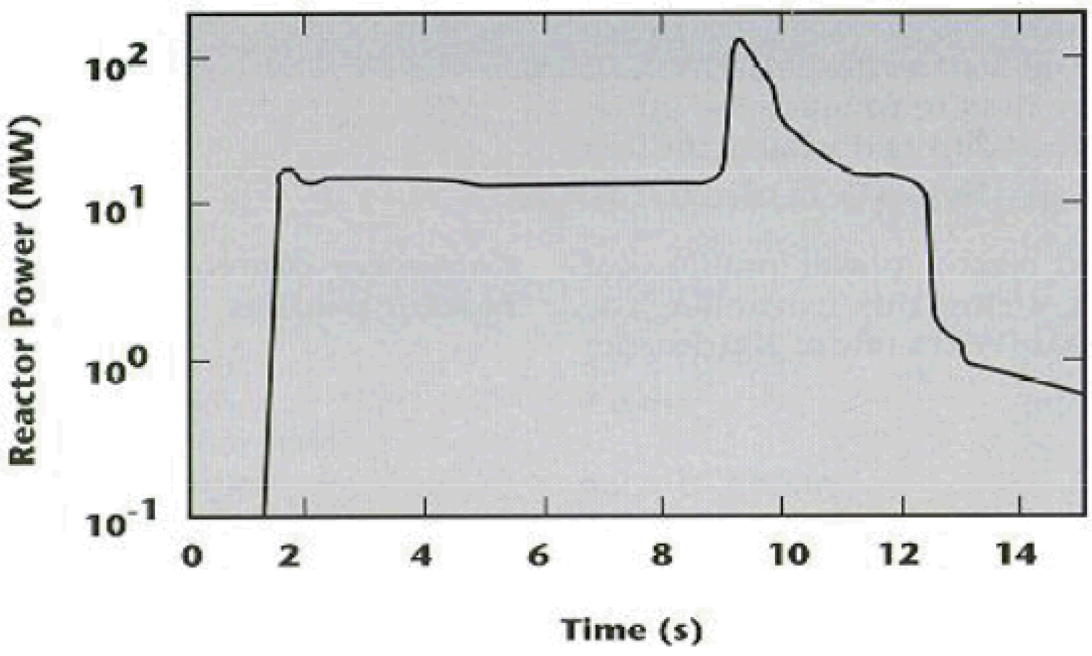


TRW OPERATION

TRW profiles
At 2 seconds ~10 MW (5 MJs/second)
At 9 seconds ~100 MW
Total Yield ~265 MJ's (~1/2 of allowed)
2.3E15 n/cm^2-s 1-MeV damage-equivalent silicon fluence and
2.3 MRad Total (Ionizing) CaF2:Mn (TLD) Dose



Normal pulse profiles
$3.00 reaches 33,000 MW, 300 MJ
$1.24 reaches 700 MW, 30 MJ
$1.02 reaches 80 MW, 2 MJ



ASSESSMENT RESULTS

Assessment Level	Title	Findings	Observations	Opportunities for Improvement	Noteworthy practices
Level 3 Checklist RAs	Resumption of Explosive Activity	3	7	2	1
	Wide Range Replacement Project	0	5	0	0
Level 2 RA (Elevated to Level 1)	Reactivity Control System Upgrade Project	10 6 4	0 8 0	0 0 0	0 0 0
Level 1 RA	In-Service Fuel Cladding Inspections at the ACRRF	0 56 1	30 30 5	0 0 0	0 0 0
Level 1 RA	Restart of Fuel-Ringed External Cavity II Operations	1 0 0	11 6 6	0 1 2	3 0 0
Level 2 RA	HC III Experiments	0 0	12 45	6 0	7 0
Level 1 RA	Restore Transient Rod Withdrawal Capability	0 1 8	9 7 18	10 0 0	9 0 3

COSTS

Cost Estimate

An SNL internal review of the costs associated with readiness assessments identified:

- Baseline preparation for a Level I RA cost ~$0.62 million
- MSA cost ~$0.514 million
- CRA cost ~$0.54 million and
- FRA cost ~$0.29 million for a total cost of ~$2 million

This internal review stated that these costs were an underestimate of the full cost (as the cost of completing corrective actions is not included). This covers the cost of staff man-hours and the contract cost for assessors.

Time spent in assessments
=
Time not spent on operations

Staff Cost

While the monetary cost is significant the cost among the staff in stress is higher.

- High turnover of personnel strains remaining resources.
- Understanding and assessing the stress developed by repeated assessments is difficult, and development of a retention plan prior to conducting these serial/concurrent assessments may have been effective in reducing the stress level among the staff and reducing the turnover.
- Unusually high staff turnover (10 reactor operators/system engineers over 4 years and 7 level I managers and 2 more senior managers) attributed to and contributing to the increased stress levels.

FEEDBACK

Significant Feedback - From the Evaluators:

- The Facility and Reactor Supervisor(s) are long-term staff members and rely heavily on institutional process knowledge in the performance of their duties. They demonstrate an expert-dependent capability that may not translate well to the next generation of Reactor Operators since much of their knowledge and actions are not definitively described and clearly cross-linked in the supporting procedures and reference documents. A significant knowledge retention process should be instituted.
- Staffing is on a positive uptrend and will support a continuation of operations in the future.
- Communications during remote assessment require constant phone calls. Audit team members, field office and contractor staff don't answer their phones as consistently as they would respond to in-person interactions of an in-person review.

FEEDBACK

Significant Feedback - From the Evaluated:

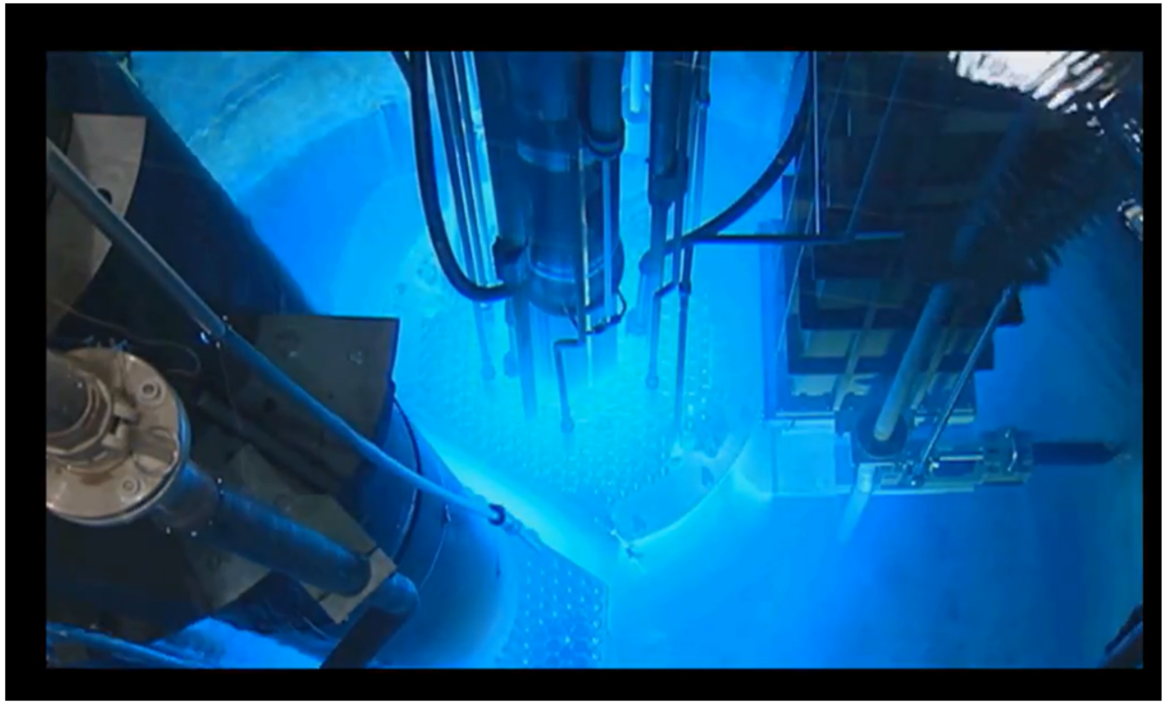
- Assessment scope creep and multiple overlapping assessments of the same areas with differing recommendations. Literally one assessment team reviewing and contradicting the recommendations of another assessment team.
- Every negative issue (finding, observation, or opportunity for improvement) in an RA must be addressed, with an entry in the condition reporting and tracking system, appropriate corrective actions, closure of these actions, and maintaining objective evidence documentation.

  Even if every response was "thanks for the input, we do that process the way we do because that is the way that works best", it would still be a very real amount of administrative time to complete.
- Rarely are assessors from a DOE-run equivalent research reactor facility. This often leads to assessors having their expectations unmet. It's up to our team to clearly manage the difference between their expectation and the actual requirements compliance, since "Expectations are not requirements".

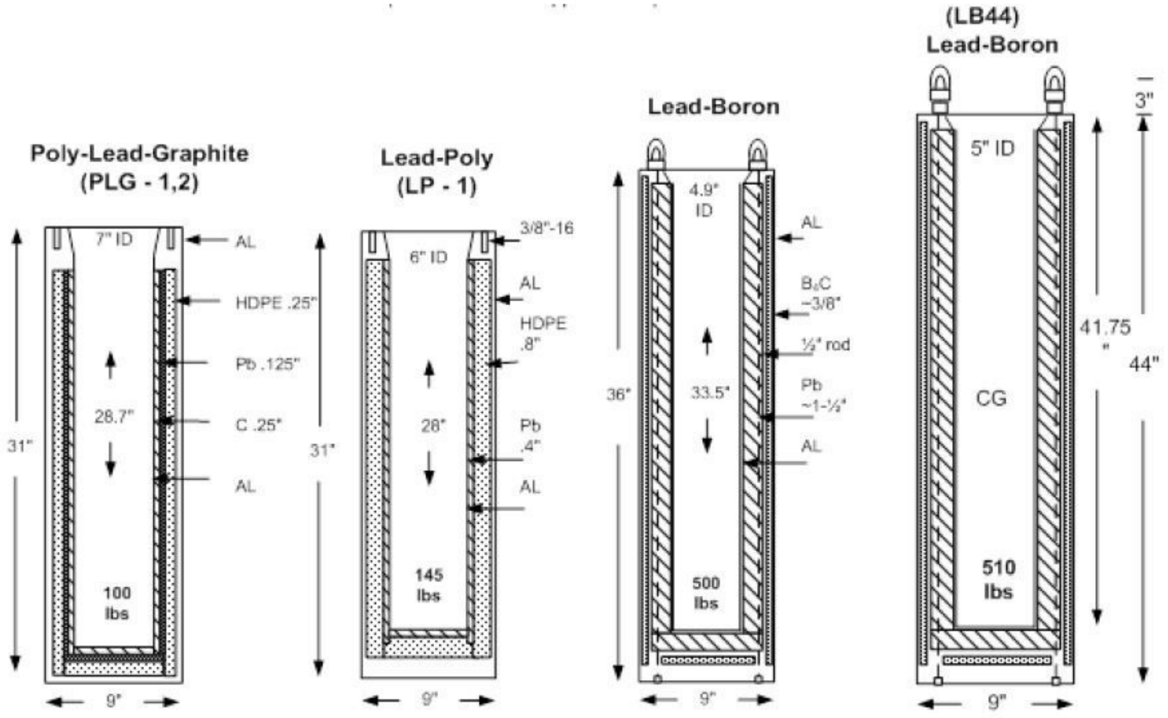
Acknowledgments

I would like to thank the dozens of support staff, assessors, managers, subject matter experts, experimenters and facility operators who prepared for and executed these multiple assessments – restoring capabilities to the facility that had been paused or the starting of new activities. While the process was onerous the full functionality of the facility has been restored.

Questions



BACKUP SLIDES



Spectrum Modifiers (Buckets) for the ACRR

Calculation	Total Neutron Fluence [n/cm^2/MJ]	1-MeV Equivalent Fluence [n/cm^2/MJ]	Ni Foil Activity [Bq/g MJ]	Gamma Dose–Si [Rad/MJ]
ACRR Free Field Central Cavity	2.161E13	8.566E12	588.72	8361.3
FREC-II Cavity Free Field	2.629E12	9.229E11	68.77	1090.0
ACRR Lead-Boron Bucket	1.163E13	6.738E12	335.51	1025.3
ACRR LP1 Bucket	2.495E13	5.017E12	369.25	5143.1
ACRR PLG Bucket	2.361E13	7.157E12	469.92	6814.1

BACKUP SLIDES

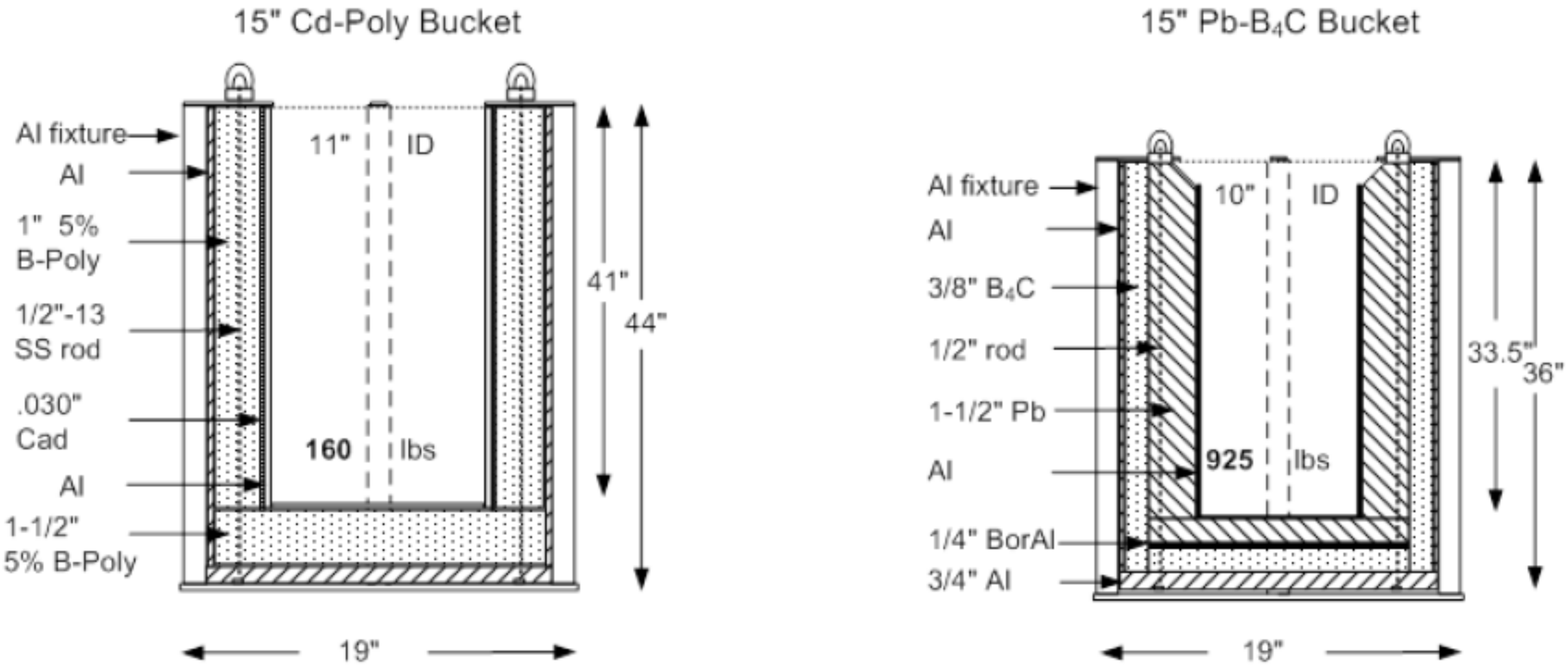


Figure 30. FREC-II Spectrum Modifying Buckets

Sample Assessment Results to Number of Corrective Actions

RCSU Readiness Review

	Results	CAs
MSA	10 Findings	62
CRA	6 Findings 8 Observations	56
FRA	4 Findings	27 + CIP

Fuel Inspection Readiness Review

	Results	CAs
MSA	30 Observations	30
CRA	51 Observations	50
FRA	1 Finding 5 Observations	13

- DOE O 425.1 contains corrective action plan requirements for findings, but not for observations
- TA-V requires CR/CA for findings and allows manager or delegate discretion for any non-findings