Utilization, Safety and Aging Management of the High Flux Isotope Reactor at Oak Ridge National Laboratory

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ORNL is managed by UT-Battelle
for the US Department of Energy

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HFIR serves a broad range of science and technology communities and will need to operate to at least 2050 until replacement capabilities are available

- **Very high flux** – available for neutron science in the world at $2.5X10^{15}N/cm^2/sec$
- **Fuel design** – breakthrough flux-trap design remains world class

232 Neutron Scattering, Material Science, Isotopes, Modeling/Simulation, and Reactor Operations Publications in FY 2014

Materials Irradiation Testing

- **Fusion Energy** – provides best available neutron spectrum for radiation damage testing on fusion components; collaboration between U.S. and Japan for over thirty years
- **Fission Energy** – research supporting next-generation commercial power reactors including accident tolerant fuel and reactor materials
- **National Security** – Neutron Activation Analysis supporting IAEA non-proliferation monitoring

1,534 Materials and NAA Irradiations in FY 2014

Reliable Source of Unique Isotopes

- **Californium-252** – HFIR supplies 80% of the world demand, which is critical for industrial, defense, and energy uses
- **Plutonium-238** – the source of power for satellites and NASA's deep space missions
- **Selenium-75, Nickel-63** – supplier of industrial, homeland security, and medical isotopes

89 Commercial and Medical Isotope Irradiations in FY 2014

Neutron Scattering

- **Cold Source**
  - Small-angle neutron scattering (2)
  - Cold triple-axis spectroscopy
  - Neutron imaging
  - Quasi-Laue Diffractometer
- **Thermal beams**
  - Triple-axis spectroscopy (3)
  - Wide-angle neutron diffraction
  - Powder diffraction
  - Single-crystal diffraction
  - Residual stress diffraction

1,994 Users conducted Neutron Scattering Experiments in FY 2014

For more information go to http://neutrons.ornl.gov/facilities/HFIR/

Reliability and aging management program implementation

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HFIR's operating strategy:
Meet the needs of the science community

AEC	DOE-ER	DOE-NE			DOE-BES		
1966–1986		2001	2003	2005	2007	2009	2014

1966–1986

- Emphasis: Maximize runtime to support isotope production mission
- Availability: >90%

2001–2005

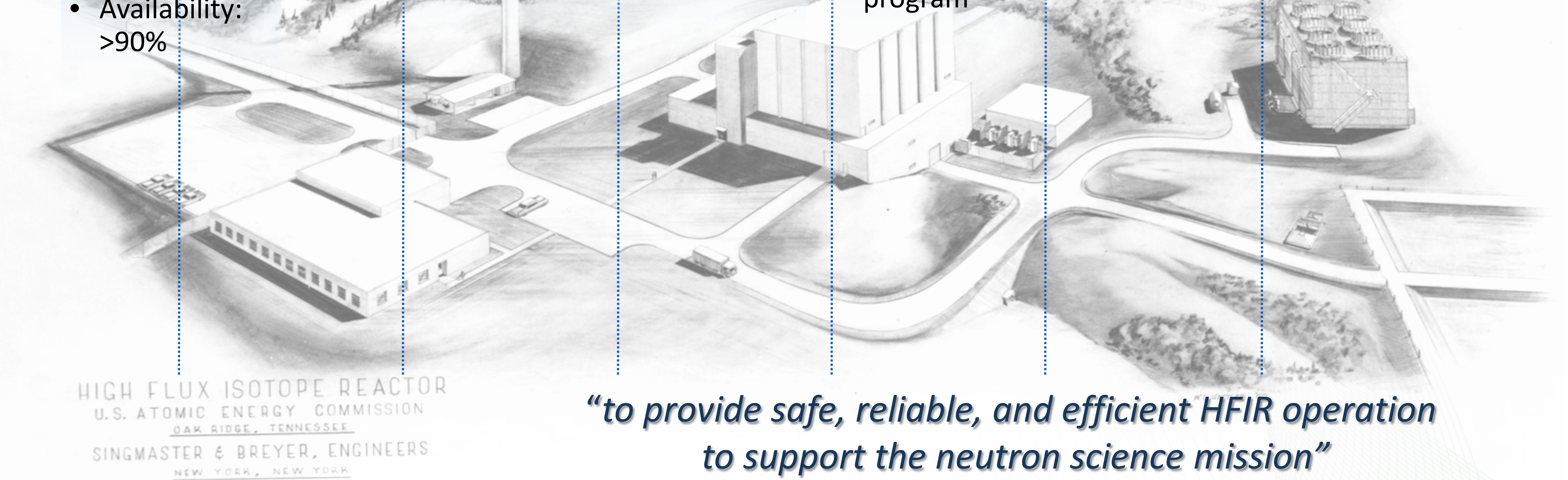
- Low reliability (missed 314 of 550 scheduled operating days)
  – Partially due to aging equipment

2005–2007

- Facility shut down for cold source construction to enable viable neutron scattering program

2007–2014

- Emphasis: Meet needs of science community via predictable operations with new cold source
- Predictability for FY 13 was 100%
- Cumulative predictability since 2007 is 98%



"to provide safe, reliable, and efficient HFIR operation to support the neutron science mission"

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HFIR is one of the few remaining multi-purpose neutron production facilities still operating in the U.S.

The life limiting component of the HFIR is the reactor pressure vessel which has a lifetime of 50 effective full power years, corresponding to 839 operating cycles

With potentially more than 85 years of operation, unique equipment issues must be addressed:

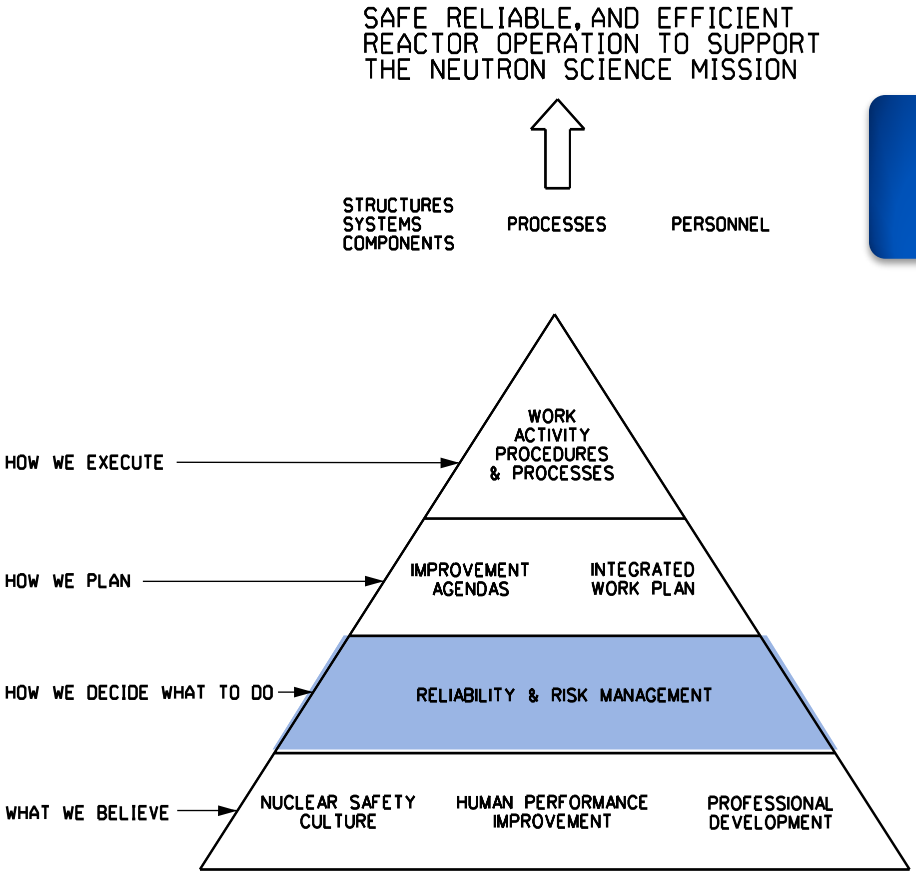
- Original equipment designed to last the life of the facility without consideration for replacement strategies
- Slow degradation & hidden failure mechanisms
- Changing regulatory requirements, potentially reducing remaining safety margin (e.g., DOE establishes new seismic hazard curves every 10 years; if the hazard curve increases, the available seismic margin is reduced.)
- Changing missions and expectations (e.g., reliability goal >90%)
- Common component failures that require a preemptive strategy to replace similar components prior to failure (e.g.; nuclear-related relays and switchgear breakers)

In 2007 a Reliability Program was initiated to improve long-term HFIR operation in order to support the neutron science mission

The initial phases of program development included

- Management team benchmarking trips to power reactors
- Engagement of staff to identify existing reliability threats
- Review of existing nuclear power industry guidance and tools related to reliability
- Establishment of a partnership with the Electric Power Research Institute
- Consultations with reliability and risk management subject matter experts

Core reliability program principles are in line with the RRD management plan



Excerpt from the RRD Management Plan

- Understand current threats to reliability
- Identify and mitigate potential threats
- Track and implement resolutions to threats
- Avoid introducing new threats to reliability

System Health Reports are an essential tool used to communicate, prioritize, and resolve threats to reliability

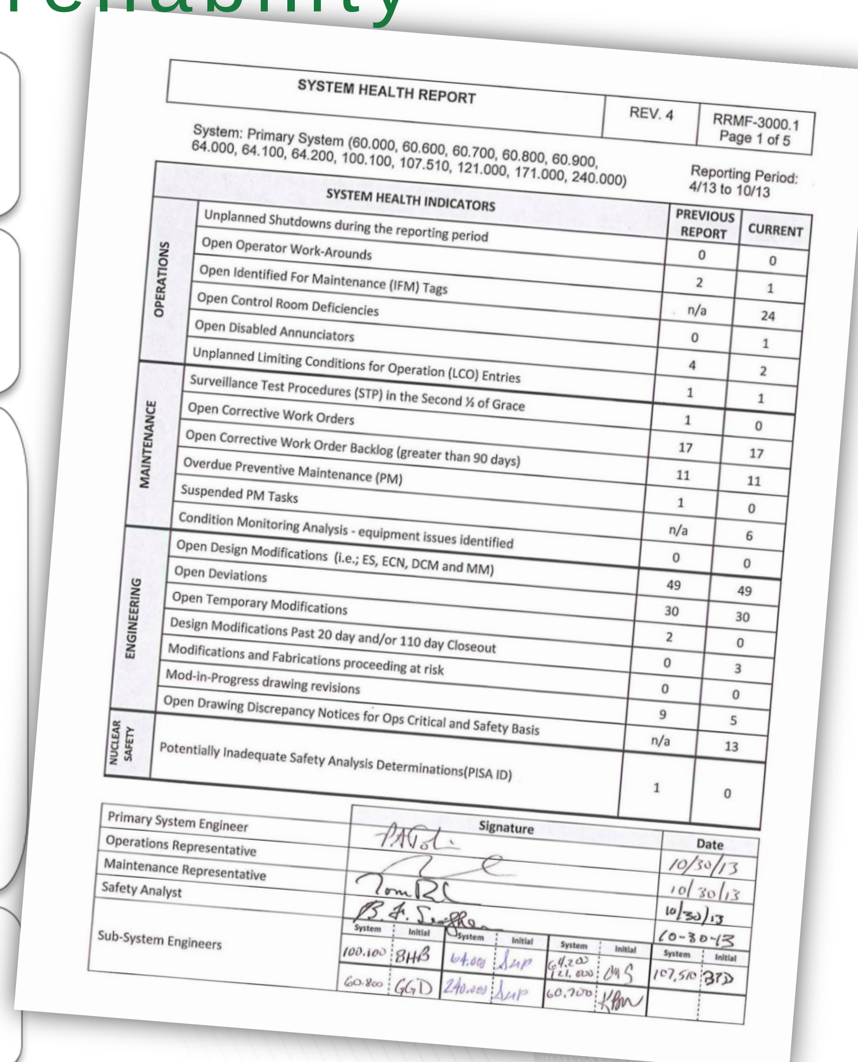
Conducted semi-annually by teams from System Engineering, Nuclear Safety, Maintenance, and Operations – Completed 8 rounds of the Health Reporting

Combined 112 existing systems into 16 system groupings to focus reporting effort

Consolidate information from existing sources and create a snapshot of the health and reliability for each of the system groupings, including:

- System Health Indicators (pictured)
- Recommendations for resolution of poor indicators
- Issues and concerns resolved since last report
- System reliability concerns including spare parts deficiencies
- Open safety basis items
- Planned work activities
- System configuration and material condition walk-downs
- Summary of overall system health

Reports are presented to the Plant Health Committee where actions are assigned, prioritized, and tracked



SYSTEM HEALTH REPORT — REV. 4 — RRMF-3000.1 Page 1 of 5

System: Primary System (60.000, 60.600, 60.700, 60.800, 60.900, 64.000, 64.100, 64.200, 100.100, 107.510, 121.000, 171.000, 240.000)

Reporting Period: 4/13 to 10/13

	SYSTEM HEALTH INDICATORS	PREVIOUS REPORT	CURRENT
OPERATIONS	Unplanned Shutdowns during the reporting period	0	0
	Open Operator Work-Arounds	2	1
	Open Identified For Maintenance (IFM) Tags	n/a	24
	Open Control Room Deficiencies	0	1
	Open Disabled Annunciators	4	2
	Unplanned Limiting Conditions for Operation (LCO) Entries	1	1
MAINTENANCE	Surveillance Test Procedures (STP) in the Second ½ of Grace	1	0
	Open Corrective Work Orders	17	17
	Open Corrective Work Order Backlog (greater than 90 days)	11	11
	Overdue Preventive Maintenance (PM)	1	0
	Suspended PM Tasks	n/a	6
	Condition Monitoring Analysis - equipment issues identified	0	0
ENGINEERING	Open Design Modifications (i.e.; ES, ECN, DCM and MM)	49	49
	Open Deviations	30	30
	Open Temporary Modifications	2	0
	Design Modifications Past 20 day and/or 110 day Closeout	0	3
	Modifications and Fabrications proceeding at risk	0	0
	Mod-in-Progress drawing revisions	9	5
	Open Drawing Discrepancy Notices for Ops Critical and Safety Basis	n/a	13
NUCLEAR SAFETY	Potentially Inadequate Safety Analysis Determinations(PISA ID)	1	0

	Signature	Date
Primary System Engineer		10/30/13
Operations Representative		10/30/13
Maintenance Representative		10/30/13
Safety Analyst		10-30-13
Sub-System Engineers	System / Initial: 100.100, 60.800, 64.000, 240.000, 64.200, 121.000, 60.700, 107.510	

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Condition Monitoring data is analyzed and reported quarterly to the PHC

Any trends identified are reported during quarterly reporting

Emergent issues are reported to the responsible System Engineer immediately

Data is available at the RRD Home Page through the Condition Monitoring Analysis Report application

CMAR

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The Plant Health Committee is tasked with monitoring plant performance and taking action to improve plant reliability

The committee meets weekly and focuses on these areas:

- System Health Reports (SHR)
- SHR Indicators
- Summary of Top SHR Team Concerns
- Condition Monitoring Analysis Reports
- Outage Critique Reports
- Post-Job MWP Reviews
- RRD Assessment Plans and Evaluations
- Plant Health and Reliability Action Tracking Review
- HFIR Top Ten List
- 3 Year Plan Review
- Personnel Safety Metrics
- Assessments related to reliability topics

PHC is comprised of members of the RRD management team and first line supervisors

- Chairman, HFIR Plant Manager
- Systems Engineering Manager
- RRD Deputy Director
- Nuclear Safety Manager
- HFIR Operations Manager
- Systems Engineering Leads
- ESH&Q Manager
- Reliability Engineering
- HFIR Maintenance Manager
- Scheduling Lead

System Health Indicators are used to highlight past achievement and predict future performance

Rollup of the system health reporting process conducted on 16 system groupings semi-annually

Operations, maintenance, engineering, and nuclear safety indicators identify trends within the indicators for a system grouping as well as trends across systems for the specific indicators

SYSTEM HEALTH REPORTING PERFORMANCE INDICATORS

From 7th round of reporting: January – July 2013

Legend:
- Remained zero or decreased
- No change
- Increased

SYSTEM HEALTH INDICATORS

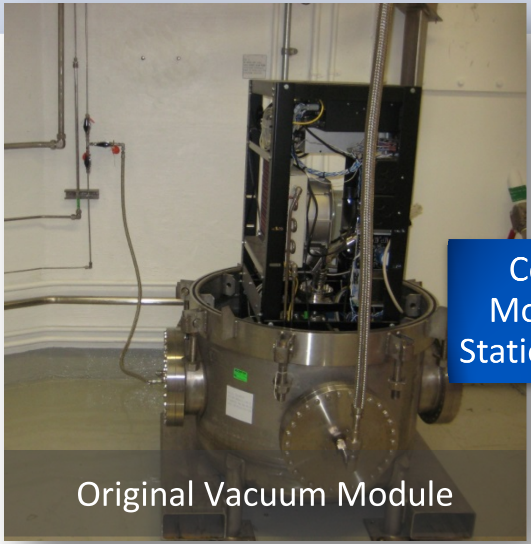
EQUIPMENT RELIABLITY SYSTEM GROUPINGS

	OPERATIONS					MAINTENANCE					ENGINEERING						SAFETY
	Unplanned Shutdowns	Open Operator Work-Arounds	Open Control Room Deficiencies	Open Disabled Annunciators	Unplanned LCO's Entries	STP's in the second ½ of grace	Open Corrective Work Orders	Open Corrective Work Orders - >90 days	Overdue PMs	Condition Monitoring	Open Design Mods	Open Deviations	Open TMs	Mods Past 20/110 Day Closeout	Mods & Fabs proceeding at risk	Mod-In-Progress Drawing Revs	PISA ID's
Normal Emergency	0	1	0	1	0	0	6	3	0	0	10	7	0	0	0	0	0
Electrical Distribution	0	0	0	0	0	0	16	12	0	0	27	7	0	0	0	7	0
Primary	0	2	0	4	1	1	17	11	1	0	49	30	2	0	0	9	1
Fire Protection	0	0	1	0	1	0	4	4	0	0	7	5	0	0	0	0	0
Lifting Devices	0	0	0	0	0	0	1	1	0	0	2	2	0	0	0	0	0
Secondary	0	0	1	0	0	0	12	9	0	0	18	5	0	0	0	5	0
Confinement & Ventilation	0	0	0	0	0	0	6	3	0	1	20	7	0	3	0	0	0
Plant Water & Liquid Waste	0	1	1	0	0	0	13	12	0	0	12	3	0	0	0	0	0
Reactor Vessel & Core Components	0	0	0	0	0	0	5	5	0	0	10	10	0	0	3	0	0
Air	0	0	0	0	0	0	5	3	1	0	6	6	0	0	0	0	0
Experiments	0	0	0	0	0	0	3	3	0	0	10	7	0	0	0	0	0
Data Acquisition	0	0	1	1	0	0	2	2	0	0	11	3	0	0	0	2	0
Pool	0	2	1	0	0	0	4	4	0	0	10	6	0	0	0	0	0
Radiation Monitoring	0	0	4	0	1	0	2	1	0	0	5	1	0	0	0	0	0
Reactor Controls	0	2	5	0	1	1	10	7	0	0	16	17	1	0	1	1	0
Cold Source	0	2	0	2	0	0	12	7	0	1	29	17	0	0	0	0	0
Round 7 TOTALS	**0**	**10**	**14**	**8**	**4**	**2**	**118**	**87**	**2**	**2**	**242**	**133**	**3**	**3**	**4**	**24**	**1**
Round 6 totals	1	13	6	6	2	0	128	74	1	3	228	120	2	1	2	22	1
Round 5 totals	1	15	5	5	3	0	114	86	3	7	235	109	3	0	1	33	0
Round 4 totals	2	17	7	5	2	1	114	77	4	4	240	119	4	1	1	22	0
Round 3 totals	0	22	16	4	5	0	132	80	1	8	254	145	2	3			
Round 2 Totals	0	39	11	6	2	2	188	86	1	4	268	142	4	3			
Round 1 Totals	1	45	18	17	8	2	167	110	1	5	259	135	3	6			

Reliability-focused design process implemented to avoid introducing new threats

Design Considerations for System Reliability - *integrates general safety and reliability principles as well as design considerations for system reliability into the existing plant modification process. Design considerations for system reliability include*

- Design to avoid single point vulnerabilities
- Design to provide flexible control systems
- Design the system to be as simple as practical
- Design components to meet the requirements of their application
- Design with maintainability in mind, considering spare parts and consumable needs



Original Vacuum Module

Cold Source Beam Room Vacuum Module Replaced with Two Vacuum Stations for Improved System Reliability

New Redundant Vacuum Stations

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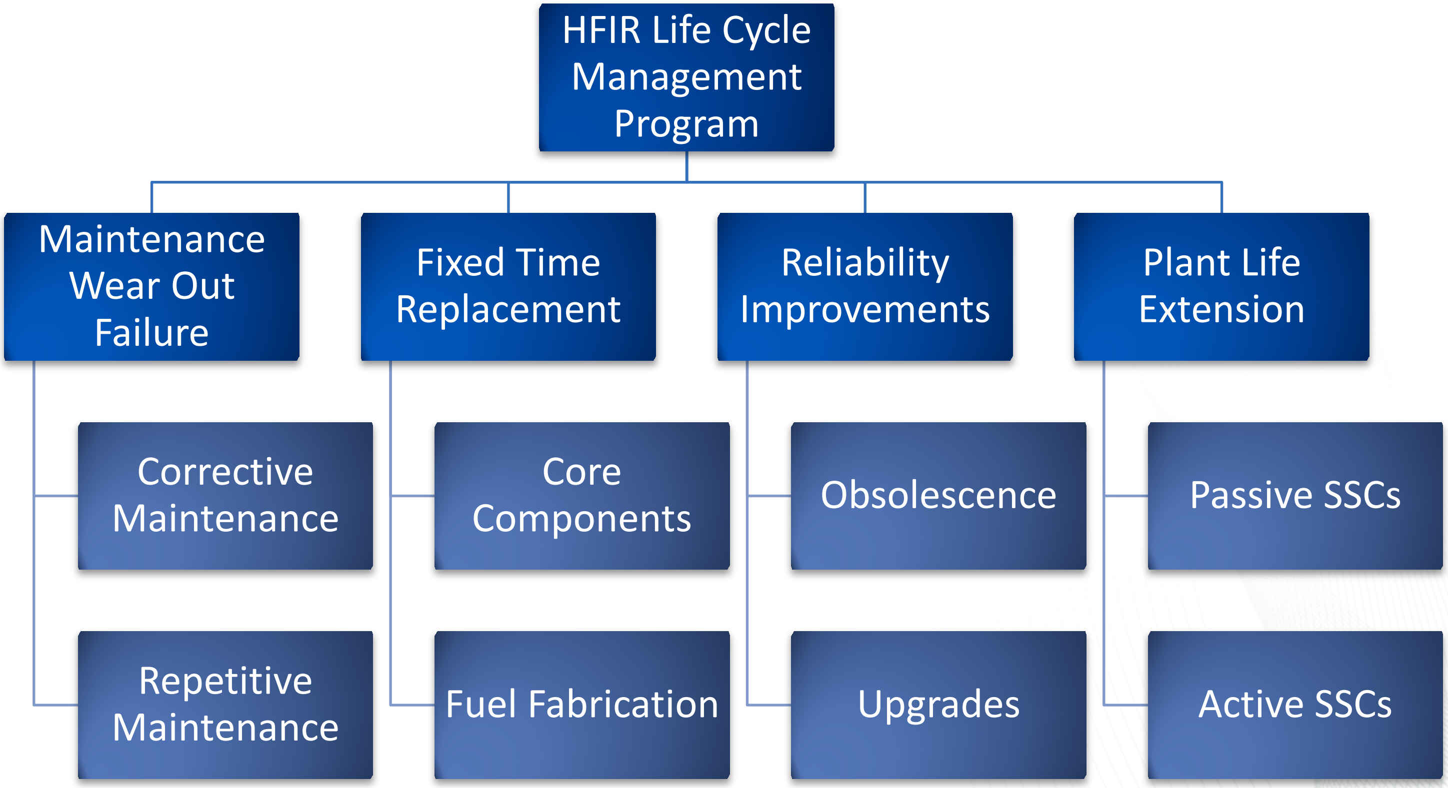
The Life Cycle Management Program was developed to address the operational stages in the life of HFIR SSCs

The HFIR LCMP is comprised of 4 basic elements using existing processes to address equipment issues

This structure is key to understanding the condition, short-term, & long-term needs of the equipment



The elements of the LCMP satisfy various DOE requirements and guidance

Outcomes include 98% predictable HFIR operations

All beginning-of-cycle startups have occurred as scheduled

The cold source has operated reliably with no unplanned reactor shutdowns

HFIR performance has improved dramatically over the last 7 years with the right people in place, strong processes, focus on equipment reliability, and assessment against the best nuclear industry practices

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Post Fukushima safety analysis and implementation

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HFIR BDBE efforts

Reviewed the Documented Safety Analysis (DSA) evaluation of BDBEs

Performed a "what if" type analysis of impact of potential BDBE NPH and other events on critical safety functions, verified via selected system walkdowns

- Expanded discussion of BDBEs to be included in the April 2015 SAR update

Evaluated impact of extended station blackout (SBO)

Evaluated ORNL and HFIR emergency management capabilities considering BDBE NPH events, including those that:

- Impact to multiple facilities
- Cause the loss of infrastructure capabilities
- Result in the unavailability of mutual aid

HSS Post Fukushima BDBE Pilot

Evaluation of Beyond Design Basis Events at the High Flux Isotope Reactor
August 2012

Context	One of the actions taken by DOE to review the safety of its nuclear facilities and to identify opportunities for improvement in light of the March 2011 accident at the Fukushima Daiichi nuclear power plant
Scope	Discussed the Documented Safety Analysis evaluation of BDBEs
	Considered the impact of Beyond Design Basis Events on HFIR Critical Safety Functions, verified via selected system walkdowns
	Evaluated impact of extended station blackout
	Evaluated ORNL and HFIR emergency management capabilities considering -Impact to multiple facilities -Loss of infrastructure capabilities -Unavailability of mutual aid
Team Members	Safety analysts, systems engineers, seismic specialists, and emergency management specialists from ORNL, DOE Office of Science, DOE Office of Nuclear Safety and DOE Office of Emergency Management and Policy.

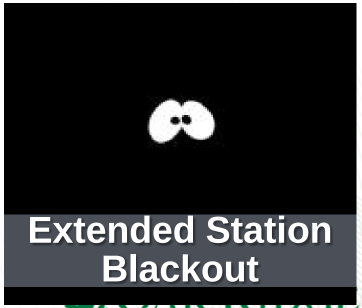
Evaluation of Beyond Design Basis Event Impacts on Critical Safety Functions

The evaluation confirmed that the HFIR safety basis adequately analyzes beyond design basis events

ORNL Emergency Management Program is robust and already incorporates BDBEs in the emergency management planning and response process

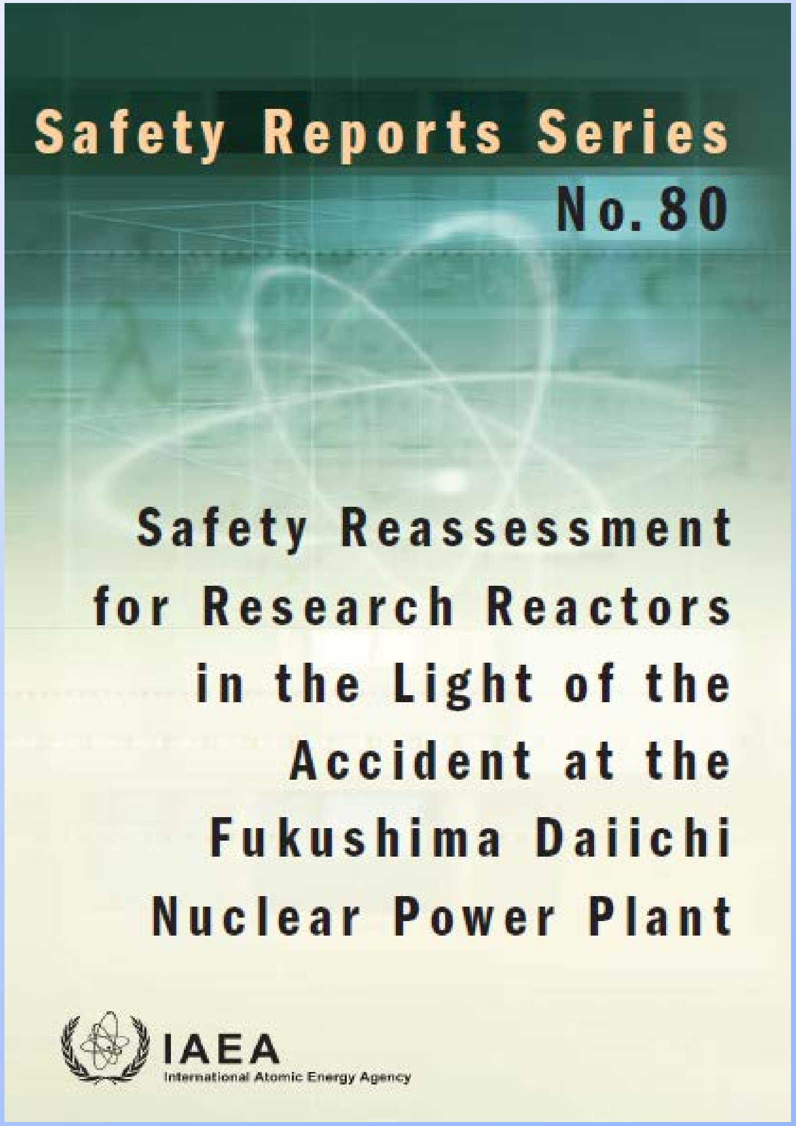
Potential areas to improve HFIR's and ORNL's capabilities to mitigate BDBEs were identified
- Areas for improvement for HFIR are captured in the HFIR Post-Fukushima Daiichi Action Plan

Process developed for during HFIR pilot (e.g., impacts on critical safety functions) has been applied throughout the DOE complex by HSS for other BDBE pilot evaluations



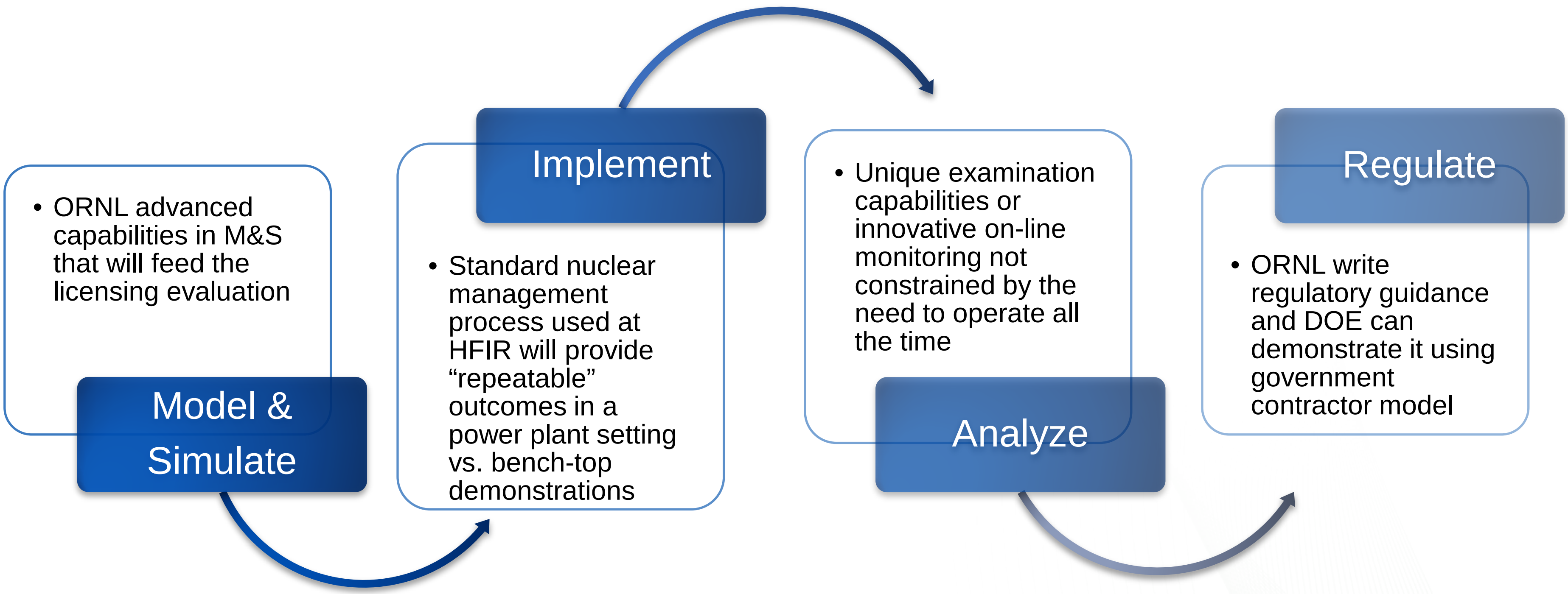
IAEA Safety Report Series No 80 (SRS 80)

- The document:
  - *Provides a set of suggestions and methods for performing safety reassessments of research reactors (ensuring harmonization of methods and approaches);*
  - *Provides information on the use of the IAEA relevant safety standards in performing such a reassessment;*
  - *Does not replace or supersede any of the existing IAEA safety standards.*



Future operations and utilization plans

ORNL provides opportunity for maturing an unproven technology in order to deploy in the power reactor field



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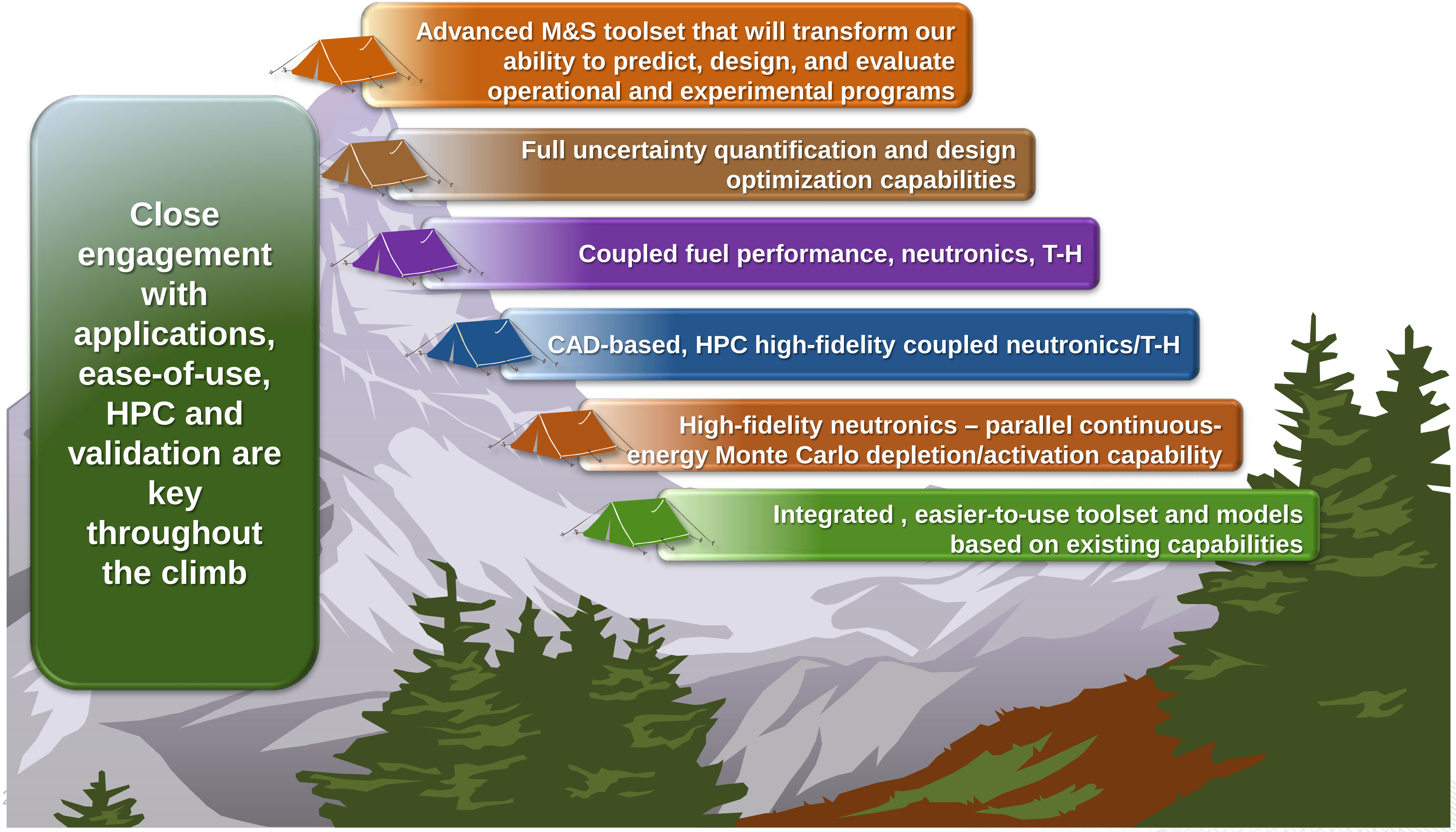
Current U.S. effort (CASL) uses modeling and simulation integration with academia, government, and industry to support the current LWR fleet



ORNL currently participating in the DOE Light Water Reactor Sustainability Program

LWRS Materials Aging and Degradation	Non-destructive Examination techniques for reactor pressure vessels and concrete structures/containment
	Reactor materials irradiation research
	Advanced welding techniques for irradiated metals
	Advanced replacement alloys

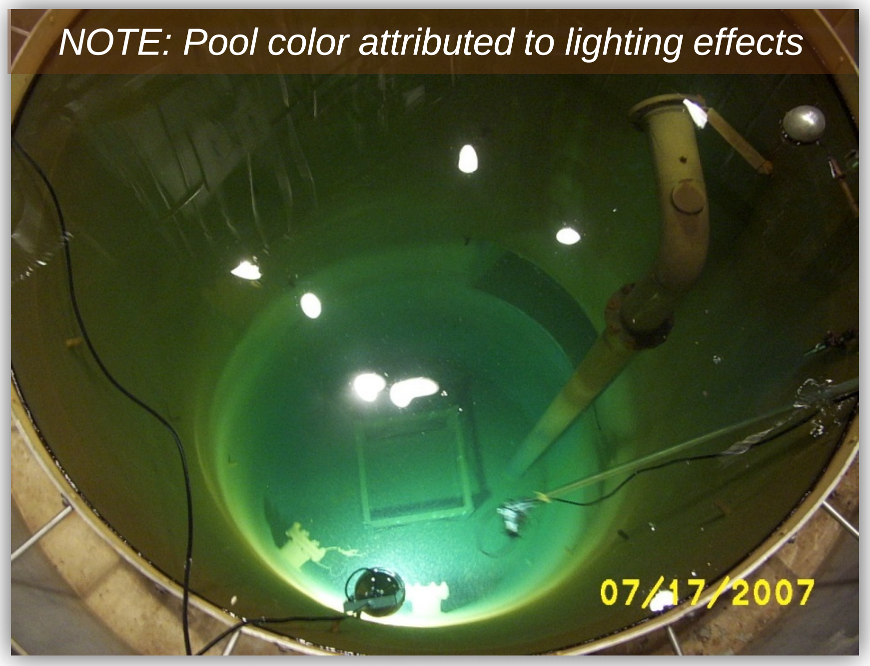
It makes sense to build the LPCF in the HFIR critical pool

HFIR	HFIR is already a DOE-regulated Category 1 nuclear facility whose safety basis can be revised to include a critical facility
	HFIR has an experienced staff including operations, design, safety, maintenance, radiation protection, waste management, and security
	HFIR has an established neutron activation analysis laboratory and staff
ORNL	ORNL has a staff with broad scientific and technical expertise in such areas as I&C, code development, and nuclear data management
	ORNL has other nuclear facilities including hot cells, gloveboxes, and laboratories
	ORNL partners with others for education and scientific advancement

Physical infrastructure exists at HFIR that would significantly lower the cost of constructing a Low Power Critical Facility

HFIR critical pool was included in original design

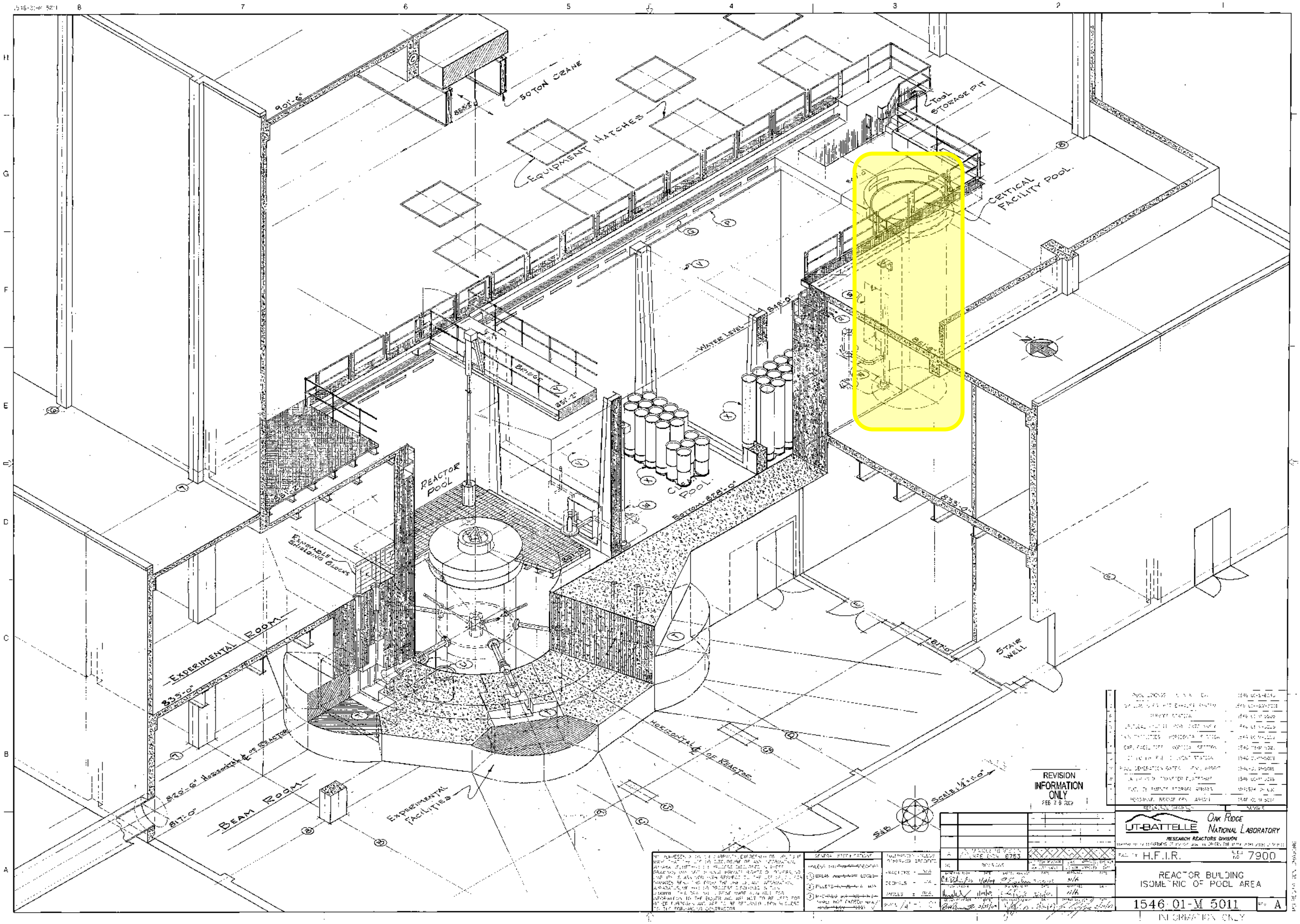
- Originally designed for 1MW HFIR core critical testing – never used
- 8-foot diameter x 25-foot depth
- 10,000 gallon demineralized water capacity
- ¼-inch thick SST lined
- Serviced by HFIR pool cooling system



Dedicated Control Room Provided with Critical Facility

- Located in shielded area in first floor experiment room
- ~18’x22’ room will provide local control of experiments and data acquisition with analysis capabilities in student-friendly environment
- Existing ports for I&C and possible ex-core experiment apparatus

HFIR reactor bay facility layout



HFIR LPCF designed to support multiple missions

➢ Flexible and state-of-the-art

- ✓ For initial testing, the HFIR LEU lead test core is proposed to be submerged inside the existing critical facility pool surrounded by control and safety elements, a reflector, and multiple data acquisition channels that will be controlled from a dedicated control room
- ✓ Following initial HFIR LEU testing, the critical facility can be reconfigured for arrangement of fuel, controls, and data acquisition

➢ Serves multiple purposes and users

- ✓ ORNL can ensure that the initial HFIR LEU lead test core and next several production cores meet design and fabrication expectations for safety and performance
- ✓ SUNRISE participants can perform experiments with other fuel to educate students, obtain nuclear data, benchmark codes, and test fuels
  - ✓ "Train the Designer" reactor
- ✓ NNSA could have a complementary and alternative critical experiment capability to the existing NNSA critical experiment facilities in the U.S.

HFIR LPCF capabilities

Different fuel assembly geometries can be tested with interchange o removable grid plate on seismically qualified support frame

Demineralized pool water supply provided for tank components with fine level control

In-line pool water heater provided

Reactivity control for HFIR fuel accomplished with control rods simil to HFIR outer control plates and inner control cylinder

Control rods can be independently controlled with drive mechanism mounted above assembly

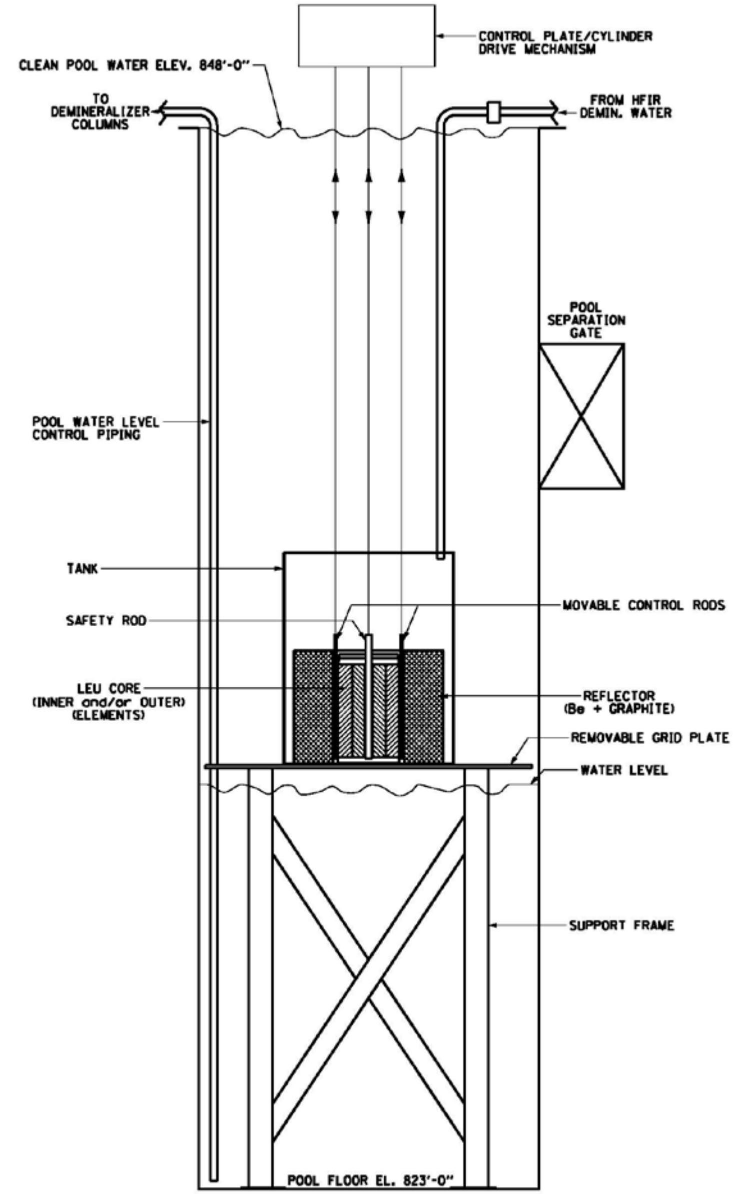
Fine, time-varying control rod positioning provided

Soluble poison capability provided

I&C provided locally to ensure criticality safety and to measure desired testing parameters

Personnel access provided for experiment setup

Transfer of fuel/irradiated hardware after testing through separation gate into HFIR east pool for storage is possible



Examples of potential experiments

Measured Parameter	Diagnostic Instrument	Number of Points	Interface to Data Acquistion / Required Control
Neutron flux, distribution and energy	Flux Traps - ^{3}He thimbles	10 -50	Pulse counting systems
	proton recoil spheres	10 -50	Pulse counting systems
Critical type flux monitoring	He3 tubes (full height of core)	5 -10	Pulse counting systems
Reactivity coefficients	balloon system and source	1 -5	Motion control
	rod jog mechanism	1 - 4	Motion control
	reactivity oscillator	1 - 4	Motion control
Delayed neutron fraction	reactivity oscillator	1 - 4	Motion control
	neutron noise analysis	1 -2	Statistical analysis
Temperature	Type T or N thermocouples	10 - 100	Micro-volt low noise

Does it make sense for HFIR to become an IAEA International Centres of Excellence based on Research Reactors

- ORNL's Purpose and Scope supports international collaboration
  - *ORNL hosts >3000 users/year including guests from sensitive countries*
- Consistent with U.S. Goals and practices since the 1950's
  - *ORNL is part of many joint collaborations and work-for-others agreements*
- Additional resources from 3rd party collaboration will benefit work already being done
  - *International participants would provide people and funding during their collaboration with ORNL resulting in*
    - *work performance that benefits ORNL development, and*
    - *participants returning to their home facility with broader knowledge, experience, and capabilities*
- Right thing to do to help solve the world's energy problems

Questions?