NIST Center for Neutron Research

February 3, 2021
Alert at the NIST Center for Neutron Research

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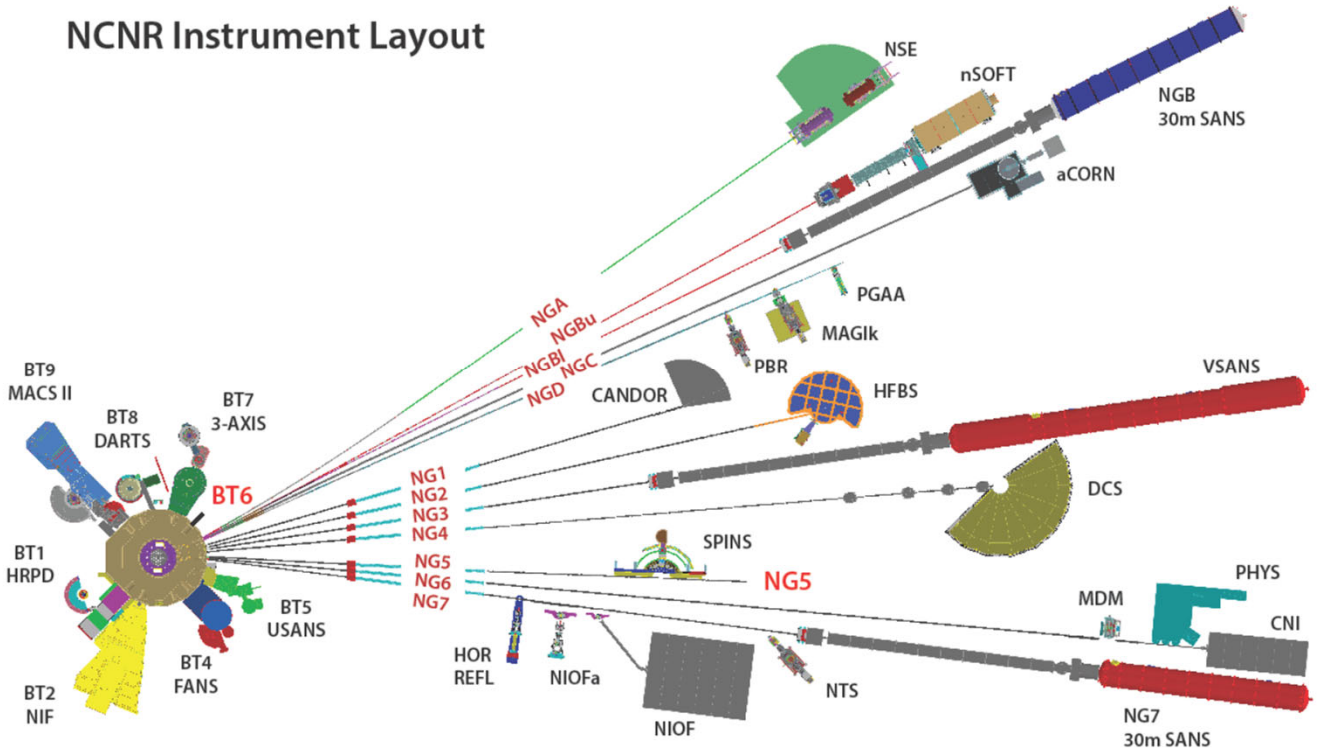
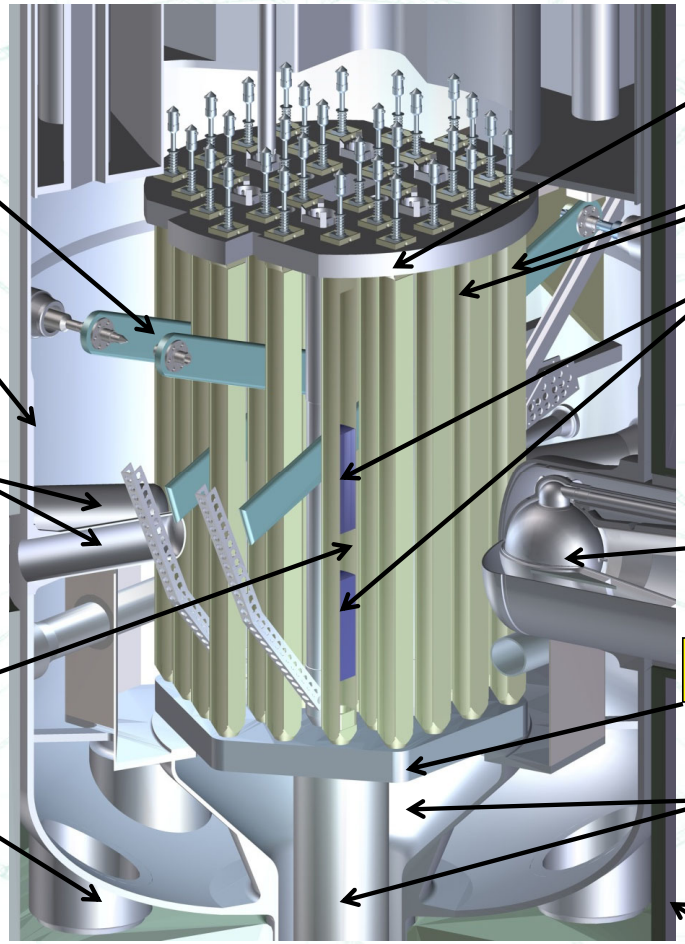
NIST

NCNR

- One of Three Major Neutron Science Centers in the US
- Hosts > 3000 research participants annually
- Neutrons supplied by 20 MW reactor
- Reactor operates on a 38 day fuel cycle



Cut-away View of the NBSR Core



Cd Shim Safety Arms (4)

Reactor Vessel

Radial Beam Tubes (9)

Split Core: 18-cm Unfueled Gap – Flux Trap

Primary Outlet (2)

Top Grid Plate

Fuel Elements (30)

Fuel Plates

Liquid Hydrogen Cold Neutron Source

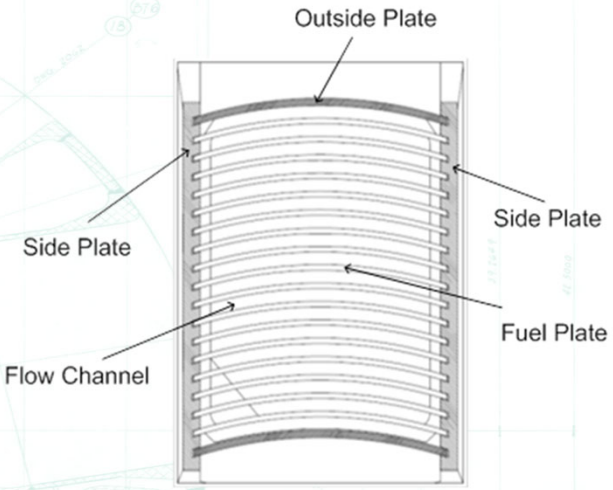
Bottom Grid Plate

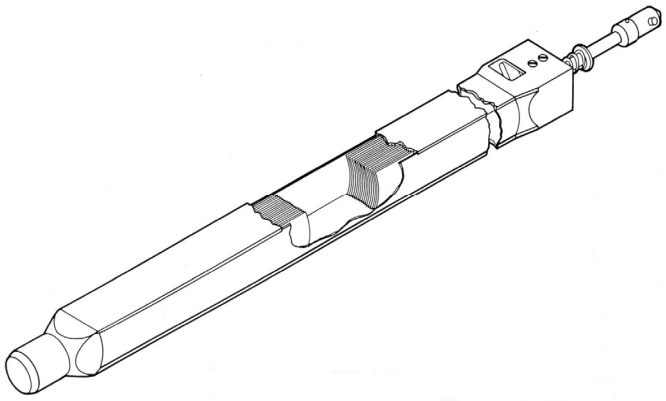
D_2O Primary Inlet Plenums

Thermal Shield

Fuel

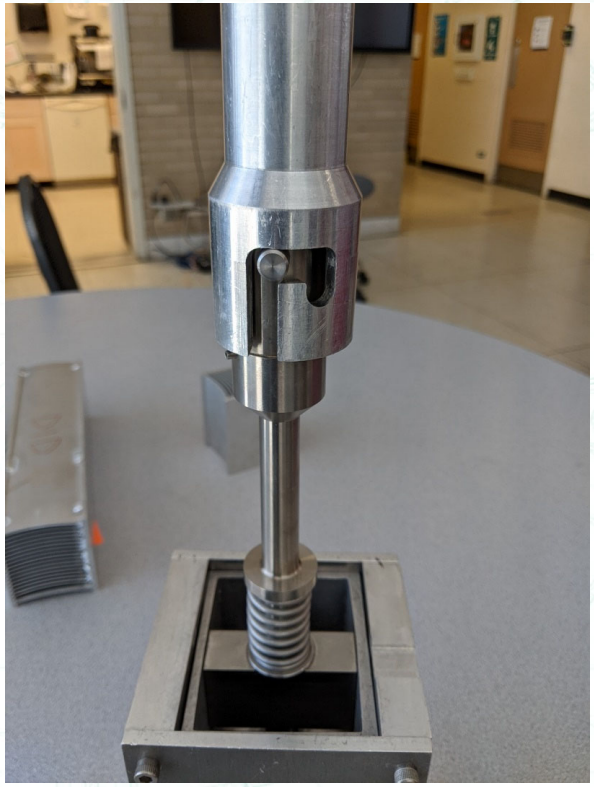
- 93% enriched, U_3O_8
  - Upper and lower fuel sections -- unfueled 18 cm gap to minimize high energy neutrons and gammas in cold neutron sources and beam tubes
- Four new fuel elements added after each 38-day cycle
- Elements in for 7 or 8 cycles





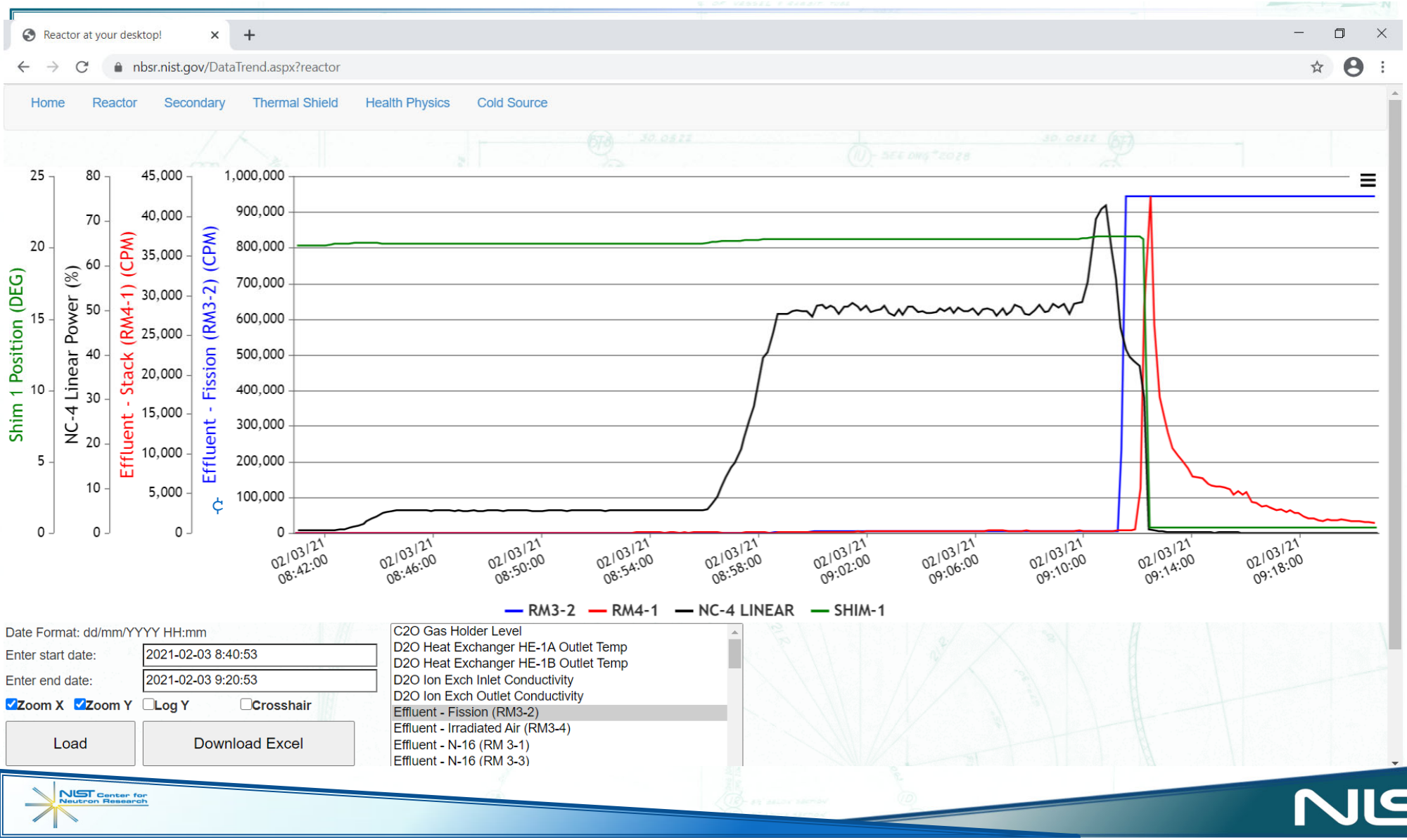
Refueling

- D_2O coolant: refueling is done blind
- All 30 elements are moved each refueling
  - Each core position has its own transfer tool
  - Elements are moved via transfer arms, lowered into core, then latched into position



February 3 event

- 9:00 Normal startup to 10 MW
- 9:06 begin ascension to full power
- 9:07 sudden drop to about 7 MW
- 9:08 release of fission products
- 9:09 major scram via stack monitor reaching 50,000 cpm
- 9:16 alert declared
- 9:21 evacuation of control room due to high radiation levels
- 9:29 NRC notified


Reactor at your desktop!
nbsr.nist.gov/DataTrend.aspx?reactor
Home
Reactor
Secondary
Thermal Shield
Health Physics
Cold Source
Shim 1 Position (DEG)
NC-4 Linear Power (%)
Effluent - Stack (RM4-1) (CPM)
Effluent - Fission (RM3-2) (CPM)
02/03/21 08:42:00
02/03/21 08:46:00
02/03/21 08:50:00
02/03/21 08:54:00
02/03/21 08:58:00
02/03/21 09:02:00
02/03/21 09:06:00
02/03/21 09:10:00
02/03/21 09:14:00
02/03/21 09:18:00
RM3-2
RM4-1
NC-4 LINEAR
SHIM-1
Date Format: dd/mm/YYYY HH:mm
Enter start date:
2021-02-03 8:40:53
Enter end date:
2021-02-03 9:20:53
Zoom X
Zoom Y
Log Y
Crosshair
Load
Download Excel
C2O Gas Holder Level
D2O Heat Exchanger HE-1A Outlet Temp
D2O Heat Exchanger HE-1B Outlet Temp
D2O Ion Exch Inlet Conductivity
D2O Ion Exch Outlet Conductivity
Effluent - Fission (RM3-2)
Effluent - Irradiated Air (RM3-4)
Effluent - N-16 (RM 3-1)
Effluent - N-16 (RM 3-3)

Event response

- All systems operated as designed
- Good response by operators and health physics staff
- Radiation levels in control room necessitated evacuation shortly after event
  - Two operators briefly stayed behind to start shutdown actions
  - Three operators and one HP re-entered later that day to complete shutdown actions
- Total of 10 staff members had contaminated clothing
  - Successfully decontaminated that day.
- Maximum personnel dose below NRC limits for radiation workers
  - Contamination of dosimetry resulted in “official” doses being higher than EPDs.

Document:	Emergency Instruction 0.3		
Title:	Emergency Classification and Criteria		
Revision:	A	Date:	12/14/15

2. Alert

2.1. Initial Criteria – any one of the following

2.1.1. RD 4-2 – Level 2

2.1.2. RD 4-1 – 50,000 CPM (FF-2 on)

2.2. Action Level Criteria

2.2.1. Actual or projected measurements at the Site Boundary which equal or exceed any of the following levels:

2.2.1.1. Radiological effluent dose: 75 mrem/24 hours

2.2.1.2. Radiation level: 20 mrem/ hour for 1 hour

2.2.1.3. 250 x Effluent Concentrations for Argon, Xenon, Krypton

2.2.1.4. 500 x Effluent Concentrations for other gases

2.2.1.5. Thyroid dose = 100 mrem

2.2.2. Fuel Cladding failure (High Helium Sweep Activity, RD 3-2 – 50,000 CPM) which is leading to the action levels listed in part 2.2.1 of this instruction.

2.2.3. Fuel handling accident outside the core with very high radiation/contamination release in accessible areas.

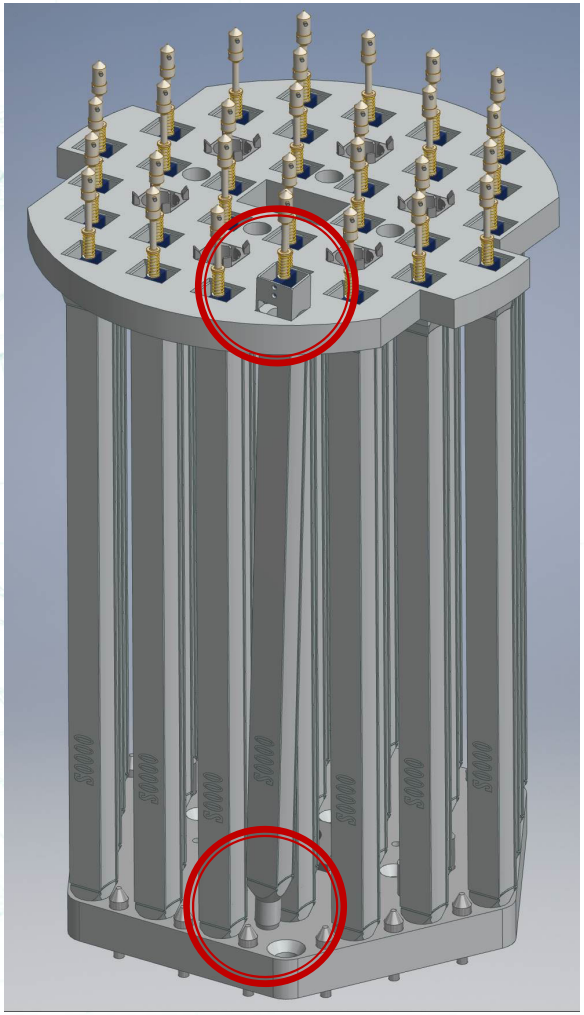
2.2.4. Security breach affecting the reactor confinement.

Boundary dose estimates

- Emergency Instructions are to take stack samples and samples at site boundary, then direct HP staff to assess activity levels.
- Samples taken -- charcoal/particulate, Cary chamber, Marinelli beaker:
  - 5 at 400 m site boundary: No I detected, very small amounts of Xe and Cs
  - 6 stack samples: No I detected. Multiple fission gases seen, mostly Kr and Xe.
- Large uncertainties in site boundary Cary chamber measurements made it difficult to certify that effluent concentrations were below Alert and NOUE levels. Eventually used stack samples and dilution factors.
  - 1532: Downgraded to NOUE
  - 1935: Terminated emergency
- Further analysis determined maximum boundary dose to be < 0.5 mrem. This was later confirmed by the NRC and NNSA NEST.

Dislocated Fuel Element in Full Core

- Latching and latch checks were done after a refueling on Jan 4.
- After-the-event review showed these checks were done incorrectly.
- Startup was delayed ~1 month because of COVID concerns
- Routine starting and stopping of primary pumps “pushed” the element into an area outside of flow.



Safety Limit

- February 23: Video surveillance showed single element out of position with apparent fuel damage.
- March 5: Concluded that 450°C fuel safety limit had been exceeded, report to NRC IAW TS 6.6.1

6.6 Required Actions

6.6.1 Actions to Be Taken in the Event the Safety Limit is Exceeded

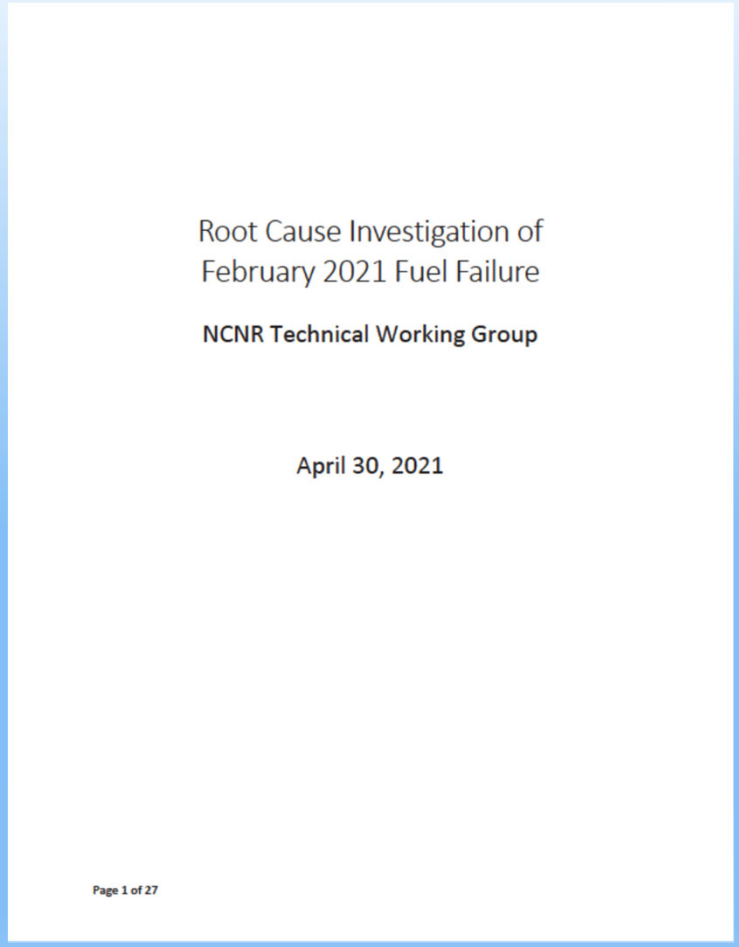
(1) The reactor shall be shutdown and reactor operations shall not be resumed until authorized by the NRC.

(2) An immediate notification of the occurrence shall be made to the Chief, Reactor Operations and Engineering and the Chief, Reactor Operations. The Chief, Reactor Operations and Engineering shall inform the NCNR director.

(3) Reports shall be made to the NRC in accordance with the specifications of Section 6.7.2. A written report shall include an analysis of the causes and extent of possible resultant damage, efficacy of corrective action, and recommendations for measures to prevent or reduce the probability of recurrence. The report shall be prepared by the Chief, Reactor Operations and Engineering and submitted to the SEC for review. The SEC shall review the report and submit it to the Director, NIST Center for Neutron Research director for approval. The Director shall then submit the report to the NRC.

Root Cause Investigation

- March 10: Internal Technical Working Group (TWG) formed to investigate root cause
- May 13: TWG report complete; letter to NRC reporting inadequacies in:
  - Training and procedures in fuel latching
  - Procedural compliance
  - Management oversight
- June 3 follow-up: finding that element could be inadvertently be unlatched by refueling tool without rotational force



Root Cause Investigation of
February 2021 Fuel Failure

NCNR Technical Working Group

April 30, 2021

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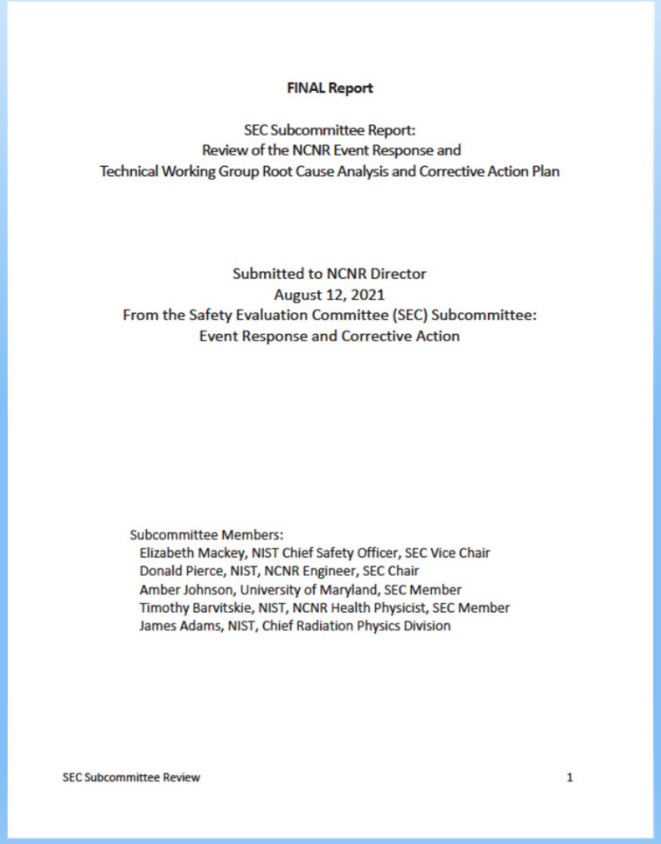
Safety Evaluation Committee (SEC) Investigation

- May 14: SEC Subcommittee formed to investigate response, root cause review and corrective actions
  - 5 people, NIST and external
- August 12: report complete;
- Two additional root causes:
  - Lack of change management program
  - Culture of complacency
- 24 recommended corrective actions



FINAL Report

SEC Subcommittee Report:
Review of the NCNR Event Response and
Technical Working Group Root Cause Analysis and Corrective Action Plan

Submitted to NCNR Director
August 12, 2021
From the Safety Evaluation Committee (SEC) Subcommittee:
Event Response and Corrective Action

Subcommittee Members:
Elizabeth Mackey, NIST Chief Safety Officer, SEC Vice Chair
Donald Pierce, NIST, NCNR Engineer, SEC Chair
Amber Johnson, University of Maryland, SEC Member
Timothy Barvitskie, NIST, NCNR Health Physicist, SEC Member
James Adams, NIST, Chief Radiation Physics Division

SEC Subcommittee Review 1

Corrective Actions -- Management

- Change management:
  - New Aging Reactor Management position
  - Organizational realignment, including 5th shift
  - Procedure overhaul, compliance audits
  - Managing changes via synthesis of ECNs, TTs, CAP
- System for skills management
  - 5th shift, operator incentives, permanent CRO

Corrective Actions -- Management

- Tools assessment
- Supervisor qualification
- Supervisor oversight training
- Continuous improvement
  - Extensive staff participation -- 19 teams of 56 NCNR staff formed to flesh out detailed corrective actions and recovery tasks.
  - Safety culture
  - Benchmarking with other facilities

Dimensional measurements of index plate

Corrective Actions -- Training

- Proficiency training
- Qualification for fuel movements
- Programs rewritten for better knowledge transfer
- Development of standards for supervisors
- Periodic management reviews of program

Corrective Actions -- Procedures

- Personnel adherence
  - Safety more integrated into procedures
  - Revision to INPO 11-003
- Rewrite fueling procedures
  - Capture details
  - Latch checks done prior to final pump restart
  - Redundant rotation check
- New procedures
  - Visual checks
  - No contact with fuel head after visual check

Corrective Actions -- Equipment

- Visual Checks
  - Testing completed
- Latch check adequacy documentation
  - Done
- Index plate modification
  - Dimensional analysis complete after fuel removal
- Discontinue use of height checks
- Modify training test stand
  - Engineering effort
- NI noise gate
  - To alert operator of abnormal signal

2021 NCNR interactions with NRC

- NRC Special Inspection Team
  - Began February 8
  - Physical or virtual presence at daily meetings, special evolutions
- February 16: Written report on event
- March 5: Conclusion that 450°C fuel safety limit had been exceeded
- May 13: report of inadequacies
- July: Start biweekly calls with NRC management
- October 1: Root causes, planned corrective actions and request for permission to restart
- October–present:
  - Supplemental reports
  - Information furnished for NRC audit process

Reactor Status

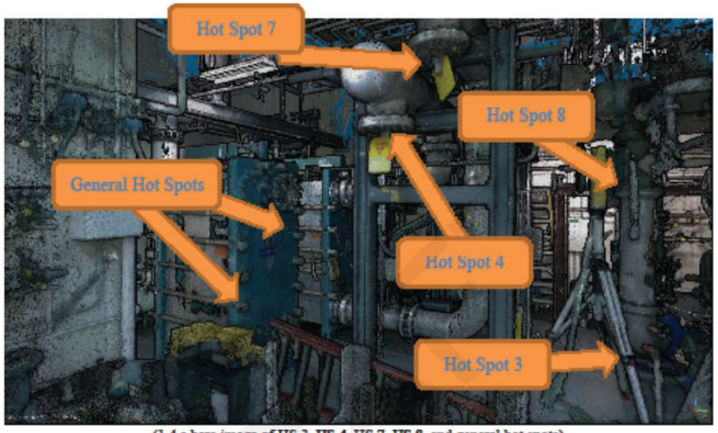
- Fuel removed from core
- In progress:
  - Cleanup of vessel and primary system using filter elements
  - Fuel reuse evaluation: backflow and inspection

Removal of damaged element on August 4

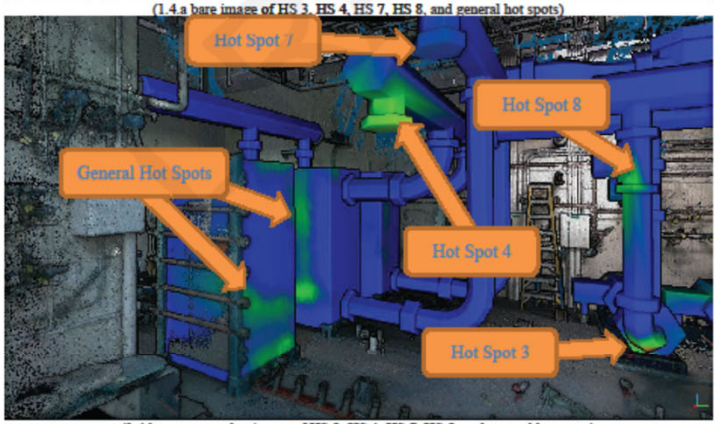
Primary Cleanup

- Primary system cleanup and fuel reuse evaluation under way
  1. Cleanup of vessel
  2. Insertion of filter elements and run primary pumps
     - May require mechanical or chemical agitation
  3. Backflow and inspection of elements to be reused

Section 1.4: Process Room HS 4 and General HS



(1.4.a bare image of HS 3, HS 4, HS 7, HS 8, and general hot spots)



(1.4.b source overlay image of HS 3, HS 4, HS 7, HS 8, and general hot spots)

Gamma scan of primary piping

Conclusion

- Feb. 3, 2021 event was unprecedented in recent U.S. research reactor history.
- NIST is committed to restart reactor when all necessary corrective actions are complete, and NRC allows.
- NIST Public Affairs has been invaluable in facilitating communications.
- External reviews found no issues with event response
- Frequent and open communications with NRC is key to recovery and restart.