UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 16, 2022

EA-21-148

Dr. Robert Dimeo, Director
National Institute of Standards and Technology
NIST Center for Neutron Research
U.S. Department of Commerce
100 Bureau Drive, Mail Stop 8561
Gaithersburg, MD 20899-8561

SUBJECT: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY – U.S. NUCLEAR REGULATORY COMMISSION SPECIAL INSPECTION REPORT NO. 05000184/2022201

Dear Dr. Dimeo:

From February 9, 2021 – March 16, 2022, the U.S. Nuclear Regulatory Commission (NRC) staff conducted a special inspection at the National Institute of Standards and Technology (NIST) Center for Neutron Research facility. The NRC staff initiated the special inspection based upon the criteria specified in NRC Management Directive 8.3, “NRC Incident Investigation Program,” following the event notification (EN 55094) received from your staff on February 3, 2021, regarding an alert declaration at the National Bureau of Standards test reactor (hereinafter the NIST test reactor). The special inspection utilized guidance in Inspection Procedure 93812, “Special Inspection Team,” and Inspection Procedure 92701, “Followup.” NIST supplemented the event notification by a 14-day report dated February 16, 2021 and amended on March 4, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession Nos. ML21048A149 and ML21070A183, respectively), which describe the circumstances that led to the alert declaration as a result of detecting fission products in the helium sweep and ventilation exhaust systems. Additionally, on March 2, 2021, in a related event notification (EN 55120), NIST informed the NRC that, based upon assessment of video surveillance of the reactor core and previously reported detection of fission products, your staff determined that the February 3, 2021, event violated the reactor’s fuel cladding temperature safety limit in the technical specifications (TSs). Subsequently, NIST supplemented this notification by a 14-day report dated March 5, 2021, and amended on May 13, 2021 (ADAMS Accession Nos. ML21064A523 and ML21133A266, respectively).

On April 14, 2021, the NRC staff issued an interim special inspection report to provide an initial assessment of our understanding of the event sequence, consequences, and the licensee’s response (ADAMS Accession No. ML21077A094). The enclosed final special inspection report presents the results of the NRC’s special inspection activities. The NRC inspectors discussed the preliminary inspection findings with you and members of your staff at the conclusion of the special inspection on Thursday, March 10, 2022. A final exit briefing was conducted during a public meeting with you on Wednesday, March 16, 2022.

Our special inspection activities confirmed that the NIST test reactor remains safely shut down and that the consequences from the February 3, 2021 event did not pose a risk to public health and safety. The inspectors review of equipment performance onsite records and interviews with the NIST staff have shown that releases of radiation during and following the event were a small fraction of regulatory limits.

The NRC inspection activities related to the violation of the TS safety limit determined that the fuel cladding reached a temperature that resulted in the partial melt of a single fuel element. Based on the event exceeding the TS safety limit referenced previously, NRC approval is required to restart the NIST test reactor. The NRC staff will conduct additional oversight activities to assess NIST's ability to safely restart and to implement appropriate corrective actions to prevent recurrence of the event. These additional oversight activities will include inspections and technical reviews and will be informed by the apparent violations and open items identified in the enclosed report.

Based on the results of this inspection, the NRC staff identified seven apparent violations (AVs), which are being considered for escalated enforcement action, including a civil penalty, in accordance with the NRC Enforcement Policy. The current Enforcement Policy is included on the NRC's website at https://www.nrc.gov/about-nrc/regulatory/enforcement/enforce-pol.html. The apparent violations are related to the NIST test reactor exceeding the fuel temperature safety limit, emergency planning, and facility changes. The circumstances surrounding these apparent violations, the significance of the issues, and the need for lasting and effective corrective action were discussed with you and members of your staff at the special inspection exit meeting on Wednesday, March 16, 2022. The apparent violations and observations for future follow-up are discussed in the Summary of Violation and Summary of Follow-up Items tables of the enclosed report.

Before the NRC makes its enforcement decision, we are providing you an opportunity to, (1) request a Pre-decisional Enforcement Conference (PEC), or (2) request Alternative Dispute Resolution (ADR). If a PEC is held, it will be open for public observation and the NRC will issue a press release to announce the time and date of the conference. If you decide to participate in a PEC or pursue ADR, please contact Travis Tate at 301-415-3901 within 10 days of the date of this letter. A PEC should be held within 30 days and an ADR session within 45 days of the date of this letter.

If you choose to request a PEC, the conference will afford you the opportunity to provide your perspective on these matters and any other information that you believe the NRC should take into consideration before making an enforcement decision. The decision to hold a predecisional enforcement conference does not mean that the NRC has determined that a violation has occurred or that enforcement action will be taken. This conference would be conducted to obtain information to assist the NRC in making an enforcement decision. The topics discussed during the conference may include information to determine whether a violation occurred, information to determine the significance of a violation, information related to the identification of a violation, and information related to any corrective actions taken or planned.

In lieu of a PEC, you may also request Alternative Dispute Resolution (ADR) with the NRC in an attempt to resolve this issue. ADR is a general term encompassing various techniques for resolving conflicts using a third party neutral. The technique that the NRC has decided to employ is mediation. Mediation is a voluntary, informal process in which a trained neutral (the "mediator") works with parties to help them reach resolution. If the parties agree to use ADR, they select a mutually agreeable neutral mediator who has no stake in the outcome and no power to make decisions. Mediation gives parties an opportunity to discuss issues, clear up misunderstandings, be creative, find areas of agreement, and reach a final resolution of the issues. Additional information concerning the NRC's program can be obtained at http://www.nrc.gov/about-nrc/regulatory/enforcement/adr.html. The Institute on Conflict Resolution (ICR) at Cornell University has agreed to facilitate the NRC's program as a neutral third party. Please contact ICR at 877-733-9415 within 10 days of the date of this letter if you are interested in pursuing resolution of this issue through ADR.

In addition, please be advised that the number and characterization of apparent violations described in the enclosed inspection report may change as a result of further NRC review. You will be advised by separate correspondence of the results of our deliberations on this matter.

In accordance with Title 10 of the *Code of Federal Regulations* Section 2.390, "Public inspections, exemptions, requests for withholding," a copy of this letter, its enclosure, and your response, if you choose to provide one, will be available electronically for public inspection in the NRC Public Document Room or from the NRC's ADAMS. ADAMS is accessible from the NRC website at https://www.nrc.gov/reading-rm/adams.html (the Public Electronic Reading Room).

If you have any questions concerning this matter, please contact Mr. Travis Tate, Chief, Non-Power Production and Utilization Facilities Oversight Branch at (301) 415-3901.

Sincerely,

Mohamed K. Shams

Digitally signed by Mohamed K. Shams
Date: 2022.03.16 10:03:55 -04'00'

Mohamed K. Shams, Director
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Docket No. 50-184
License No. TR-5

Enclosure:
Special Inspection Report No. 05000184/2022201

cc w/enclosure: See next page

cc:

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Test, Research and Training
Reactor Newsletter
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SUBJECT: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY – U.S. NUCLEAR REGULATORY COMMISSION SPECIAL INSPECTION REPORT NO. 05000184/2022201 DATED: MARCH 16, 2022

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DATE	2/25/2022	3/7/2022	3/7/2022	3/9/2022	3/10/2022
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DATE	3/11/2022	3/11/2022	3/14/2022	3/14/2022	3/14/2022
OFFICE	OGC	NRR/DANU/D			
NAME	RCarpenter	MShams			
DATE	3/14/2022	3/16/2022			

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U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION

Docket No.:	50-184
License No.:	TR-5
Report No.:	05000184/2022201
Licensee:	National Institute of Standards and Technology
Facility:	Center for Neutron Research National Bureau of Standards Test Reactor National Institute of Standards and Technology Test Reactor
Location:	Gaithersburg, MD
Dates:	February 9, 2021 through March 16, 2022
Inspectors:	Kevin Roche, Reactor Inspector (Team Lead) Michael Balazik, Project Manager Craig Bassett, Reactor Inspector Phillip O'Bryan, Reactor Inspector Carleen Parker, Allegation Specialist William Schuster, Reactor Inspector Dori Willis, Headquarters Allegation Team Lead
Assisted by:	Richard Clement, Senior Health Physicist David Jones, Senior Enforcement Specialist
Approved by:	Mohamed K. Shams, Director Division of Advanced Reactors and Non-Power Production and Utilization Facilities Office of Nuclear Reactor Regulation

Enclosure

EXECUTIVE SUMMARY

National Institute of Standards and Technology
National Bureau of Standards Test Reactor
Special Inspection Report No. 05000184/2022201

The U.S. Nuclear Regulatory Commission (NRC, the Commission) program for overseeing the safe operation of research and test reactors is described in Inspection Manual Chapter 2545, “Research and Test Reactor Inspection Program.” In response to the event notification (EN 55094) by the National Institute of Standards and Technology (NIST, the licensee), a Special Inspection Team (SIT) was established in accordance with NRC Management Directive 8.3, “NRC Incident Investigation Program.” Inspectors conducted the SIT in accordance with the objectives in a special inspection charter dated February 8, 2021, and updated March 5, 2021 , to conduct a review of the event, which includes: 1) sequence of events; 2) licensee response to the event; 3) assessment of the consequences of the event; 4) adequacy of facility procedures; 5) maintenance or outage actions preceding the event; 6) the licensee’s analysis of the root causes of the event; and 7) completed or planned corrective actions to prevent recurrence. The special inspection charter was revised on March 5, 2021 [Ref. 1] to expand the resources, technical expertise, and scope of the chartered activities in response to the March 2, 2021 event notification (EN 55120) by NIST. An interim special inspection report was issued by the NRC staff on April 14, 2021.

This final special inspection report documents the NRC staff’s inspection activities in accordance with the special inspection charter objectives outlined above. Seven apparent violations and 14 inspection follow-up items are discussed in the report.

Sequence of Events

- An updated sequence of events leading up to and immediately following the event was developed.

Licensee Response to the Event

- The licensee’s safety-related structures, systems, and components performed as designed during the event.

Consequences of the Event

- As a result of the event, members of the public and occupational workers remained safe, as any actual or potential radiation doses were within the regulatory limits established in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 20, “Standard for Protection against Radiation.”

- Two apparent violations were identified related to exceeding the fuel temperature safety limit.

Adequacy of Procedures

- Material control and accounting procedures were found to be adequate.

- Three apparent violations were identified related to inadequate fuel handling, startup, and emergency response procedures.

Related Actions that Contributed to the Event

- Two apparent violations were identified related to inadequate fuel handling within the vessel and inadequate modifications that invalidated NIST operators' ability to meet a Technical Specification requirement.

Root Cause Determination and Contributing Causes

- The licensee identified seven root causes (RCs) that contributed to the event.

- The inspectors determined that the root causes analysis/discussion was incomplete and identified safety culture issues that the licensee failed to address.

- The inspectors identified examples of inadequate audits and failure by senior management to address identified issues.

- The inspectors determined that further assessment of the root cause will be needed pending the outcome of the enforcement process.

Corrective Actions

- The licensee identified multiple corrective actions that are appropriate to prevent recurrence of a similar event.

- Because the inspectors determined the licensee's root cause analysis was incomplete, additional corrective actions will be required pending enforcement actions.

- The inspectors determined that further assessment of the details, implementation, and effectiveness of the licensee's corrective actions will be needed.

SUMMARY OF APPARENT VIOLATIONS

Table 1 shows a summary of the apparent violations identified in this report, the numerical designator, and the section in the report where the apparent violation is described in detail.

TABLE 1

Numerical Designator (Report Section)	Requirement	Description
05000184/2022201-01 (Section 4.C.i)	Apparent Violation of Technical Specification 2.1, “Safety Limit,” which states that the reactor fuel cladding temperature shall not exceed 842°F (420°C) for any operating conditions of power and flow.	The inspectors observed once-molten material in and around fuel element nozzle of element S-1175 in the J-7 grid position indicating that NIST exceeded the fuel temperature safety limit.
05000184/2022201-02 (Section 4.C.ii)	Apparent Violation of Technical Specification 3.1.3, “Core Configuration,” which states that “[t]he reactor shall not operate unless all grid positions are filled with full length fuel elements or thimbles, except during subcritical and critical startup testing with natural convection flow.”	The inspectors observed that the fuel element S-1175 was not latched, was raised approximately 3-4 inches above the upper grid plate, and was angled out of its proper position, causing it to rest on the lower grid plate surface.
05000184/2022201-03 (Section 5.b)	Apparent Violation of Technical Specification 6.4, “Procedures,” which states, in part, that “[w]ritten procedures shall be prepared, reviewed and approved prior to initiating any of the activities listed in this section [including] … [f]uel loading, unloading, and fuel movement within the reactor vessel.”	The inspectors determined that the procedure for fuel handling activities was not suitable for the circumstances and did not contain necessary information to ensure that the fuel elements were latched prior to startup. As a result, the inspectors determined that the fuel handling procedure was inadequate to ensure that the fuel element in question was latched during refueling activities on January 4, 2021.
05000184/2022201-04 (Section 5.c)	Apparent Violation of Technical Specification 6.4, “Procedures,” which states, in part, that “[w]ritten procedures shall be prepared, reviewed and approved prior to initiating any of the activities listed in this section [including] … [s]tartup, operation, and shutdown of the reactor.”	The reactor startup procedure instructs the operators to monitor for abnormal fluctuations or oscillations on nuclear channel indications. However, the inspectors found that the procedure does not provide amplifying guidance for operators to use when conducting this monitoring.

Numerical Designator (Report Section)	Requirement	Description
05000184/2022201-05 (Section 5.d)	Apparent Violation of Technical Specification 6.4, “Procedures,” which states, in part, that “[w]ritten procedures shall be prepared, reviewed and approved prior to initiating any of the activities listed in this section [including] … [i]mplementation of required plans such as emergency or security plans.”	The inspectors determined that NIST emergency response procedures were not suitable for the circumstances and caused NIST to unnecessarily (although still within the required timeframe) delay their response to the event.
05000184/2022201-06 (Section 6.a)	Apparent Violation of Technical Specification 3.9.2.1, “Fuel Handling; Within the Reactor Vessel,” which states that “[f]ollowing handling of fuel within the reactor vessel, the reactor shall not be operated until all fuel elements that have been handled are inspected to determine that they are locked in their proper positions in the core grid structure. This shall be accomplished by one of the following methods:(1) Elevation check of the fuel element with main pump flow. (2) Rotational check of the element head in the latching direction only. (3) Visual inspection of the fuel element head or latching bar.”	The inspectors determined that NIST operators failed to implement one of the methods required by the technical specifications to ensure that fuel element S-1175 was adequately latched.
05000184/2022201-07 (Section 6.b)	Apparent violation of 10 CFR 50.59, “Changes, tests and experiments,” paragraph (c)(1), which states, in part, that a licensee may make changes in the facility without obtaining a license amendment only if a change to the technical specifications is not required.	The inspectors determined that NIST made changes to the refueling tooling that should have required NIST to change the technical specifications because dimensional differences of the new tooling invalidated the capability of operators to verify that a fuel element was adequately latched.

SUMMARY OF FOLLOW-UP ITEMS

Table 2 shows a summary of the inspector follow-up items (IFI) identified in this report, the numerical designator, and the section in the report where the follow-up item is described in detail. An IFI is defined as a matter that requires further inspection because of a potential problem, because specific licensee or NRC action is pending, or because additional information is needed that was not available at the time of the inspection.

TABLE 2

Numerical Designator (Report Section)	Description
05000184/2022201-08 (Section 3.a)	Emergency response equipment issues that delayed the licensee response
05000184/2022201-09 (Section 4.C.i)	Material accounting for damaged fuel element
05000184/2022201-10 (Section 4.C.iii)	Abnormal primary system contamination
05000184/2022201-11 (Section 4.C.iv)	Shutdown cooling pump failure
05000184/2022201-12 (Section 5.a)	Material control and accounting procedures
05000184/2022201-13 (Section 5.b)	Procedure changes and associated 10 CFR 50.59 screening
05000184/2022201-14 (Section 6.c)	Inadequate training
05000184/2022201-15 (Section 7.b.i)	Design of the latching mechanism and/or controls in place to ensure that elements can be properly latched
05000184/2022201-16 (Section 7.b.i)	NIST will investigate tools capable of providing early detection of off-normal nuclear instrument behavior
05000184/2022201-17 (Section 7.b.i)	Ineffective Corrective Action Program
05000184/2022201-18 (Section 7.b.ii)	Sustainability of licensee's corrective actions
05000184/2022201-19 (Section 7.b.ii)	Safety culture weaknesses
05000184/2022201-20 Section 7.b.iv)	Ineffective responses to Safety Assessment Committee (SAC) (3rd party) audits
05000184/2022201-21 (Section 7.b.v)	Inadequate leadership responsibility

REPORT DETAILS

1. Introduction

a. Background

NIST operates the National Bureau of Standards test reactor (hereinafter the NIST test reactor) at the NIST Center for Neutron Research (NCNR) located on the NIST campus in Gaithersburg, MD. The NIST test reactor is a heavy-water (D_2O)-moderated-and-cooled, enriched-fuel, tank-type reactor designed to operate at 20 megawatts thermal (MW(t)) power. The facility operates continuously during 7-week operational cycle that consists of approximately 38 days of operation, followed by 10-day refueling and maintenance outages.

b. Event Description

On December 20, 2020, operators shut down the NIST test reactor for a refueling outage. During the refueling outage on January 4, 2021, fuel elements were shuffled within the reactor vessel during day shift. After the fuel elements were placed in each core position, height verification was performed using a height gauge to ensure that the fuel elements were fully latched in the lower grid plate. The inspectors reviewed video footage of the placement of fuel element S-1175 in the J-7 core position and determined that the fuel element was initially latched after placement. However, the inspectors observed that operators had difficulty lowering the tool to fuel element S-1175 during the subsequent height verification. Performance of this height verification likely contributed to fuel element S-1175 becoming unlatched. Further, the inspectors observed that the operators improperly performed the latch verification rotation checks on the evening shift. Through interviews and observation of the video footage of the refueling and latch verification evolutions, the inspectors determined that fuel element S-1175 was likely not fully latched in the J-7 core position at the end of fuel handling operations on January 4, 2021.

On February 3, 2021, following the refueling outage, NIST reactor operators were performing a normal reactor startup when the reactor automatically shut down in response to indications of high confinement exhaust stack radiation. Once the reactor was placed in a safe condition, all personnel evacuated the control room and reactor confinement. The reactor was then monitored by operators from the remote Emergency Control Station. NIST subsequently declared an alert in accordance with the emergency plan and procedures [Ref. 2]. During the event, six NIST reactor personnel became externally contaminated and were monitored for internal exposure to radioactive materials. Following the event, environmental monitoring was performed by NIST personnel at the confinement exhaust stack and at the 400-meter emergency planning site boundary, which is located within the fence line of the NIST Gaithersburg campus. Environmental sampling for radioactive material releases, as well as radiological surveys, confirmed that release amounts were a small fraction of the alert and notification of unusual event criteria in the emergency procedures, which led to event termination by NIST later that day.

On March 2, 2021, NIST submitted a related event notification (EN 55120) [Ref. 3] to inform the NRC that it violated the fuel cladding temperature safety limit for damaged fuel element S-1175. During subsequent visual inspection activities where NIST moved fuel elements from the reactor core to the fuel storage pool, the inspectors observed melted material deposited on the lower grid plate. The inspectors also observed that the damaged fuel element S-1175 nozzle was almost completely blocked by melted material. The inspectors noted that additional tests would need to be performed to determine the exact composition of the melted material. The damaged fuel element S-1175 is currently in a container located within the fuel storage pool awaiting shipment for further analysis. The licensee has contracted with Framatome to clean up the reactor vessel and remove the melted material from the lower grid plate, vessel, and primary piping and Framatome is in the process of completing this recovery.

c. <u>NRC Response</u>

The NRC immediately began monitoring the event at NIST after receiving the alert notification and chartered an SIT on February 8, 2021. NRC inspectors were onsite during multiple weeks from February 9 through October 18, 2021[1] to directly observe and inspect licensee event response, radiological surveys and sampling results, dose calculations, and investigation into the cause of the event. Between onsite inspections, the inspectors virtually attended NIST daily status meetings and continued to inspect the facility remotely. The NRC's interim special inspection report was issued on April 14, 2021 [Ref. 4]. This final report addresses the same charter objectives as the interim report but does not discuss any charter objectives or conclusions that remain unchanged from the interim report. The staff did update the information in the interim report where appropriate.

On October 1, 2021, [Ref. 5], NIST requested authorization to restart. The NRC staff has begun a technical review and audit in support of a determination on NIST's request to restart the test reactor and will continue those activities going forward. Although this report will close the SIT inspection, the NRC will continue to conduct routine inspections and additional oversight activities. The NRC will also conduct supplemental inspections commensurate with the safety significance of any final violations once dispositioned.

2. Sequence of Events

The inspectors interviewed licensee personnel and reviewed records to develop the sequence of events leading up to and immediately following the event described above. The inspectors note that event sequence times are considered approximate due to differences between recalled, recorded, or reported event times and unofficial data acquisition recorder times. All event sequence times listed below are provided in Eastern Standard Time (EST) (UTC-05:00).

12/20/2020 23:53:00- 00:04:00	Performed normal reactor shutdown for refueling outage.

[1] NRC inspectors conducted onsite inspection activities during the weeks of February 8, February 22, March 15, March 22, April 5, April 12, April 21, July 12, July 26, August 2, and October 18, 2021.

01/04/2021 07:56:00 - 20:15:00	Completed core refueling activities, including attempted steps to ensure that fuel elements were latched. As discussed later in this report, operators did not complete any of the required latch verification options.
01/04/2021 02/03/2021	Routinely started and stopped primary coolant pumps to maintain primary and secondary coolant temperatures to address freezing concerns in the secondary cooling tower.
01/04/2021 02/03/2021	Completed technical specification surveillances, which included routine operational checks to ensure safety and emergency systems functioned as required.
01/31/2021 02/02/2021	Conducted multiple reactor startups to 0.1 MW(t) for training.
02/03/2021 08:16:00	Commenced Reactor Startup
02/03/2021 09:10:00	Following a procedurally directed minimum 5 min wait at 10 MW(t), operators initiated raising reactor power to 20 MW(t).
02/03/2021 09:10:45	After reactor power reached approximately 87 percent (17 MW(t)) an immediate decrease was observed in reactor power (no automatic actions, no manual operator action to reduce power) to approximately 50 percent power.
02/03/2021 09:11:15	Fission Product Monitor (Radiation Monitor (RM) 3-2) (which samples helium from a layer of gas above the coolant in the reactor vessel) started to show an exponential increase in radioactivity.
02/03/2021 09:12:00	Stack Monitor (RM 4-1) (which samples air at a point located two-thirds of the way up the confinement exhaust stack) started to show an exponential increase in radioactivity.
02/03/2021 09:12:15	Stack Monitor Alarm at 50,000 counts per minute (cpm) initiated a Major Reactor Scram signal (reactor automatically shuts down, confinement doors close, ventilation system realigns).
02/03/2021 09:12:30	Irradiated Air Monitor (RM 3-4) and Normal Air Monitor (RM 3-5) (which sample air from ventilation systems serving different areas of the confinement building) started to show an exponential increase in radioactivity following realignment of the ventilation system to emergency mode, which recirculated air inside of the confinement building.
02/03/2021 09:13:00	Facility operators started evacuating the confinement building and sounded the building evacuation alarm. Prior to evacuating, facility operators ensured that the reactor was in a safe condition (i.e., reactor shut down, primary coolant pumps running to maintain cooling). The reactor was then monitored by operators from the remote Emergency Control Station located outside of the confinement building.

02/03/2021 09:16:00	NIST declared an alert in accordance with emergency procedures.
02/03/2021 09:45:00	NIST initially notified the NRC Operations Center.
02/03/2021 10:06:00	Facility health physics personnel obtained a 14-liter grab sample of air from the confinement exhaust stack.
02/03/2021 10:40:00	Facility health physics personnel obtained initial 400-meter emergency planning site boundary air samples and conducted radiation surveys.
02/03/2021 12:26:00	Facility operations and health physics personnel re-entered the confinement building to start the shutdown cooling system, realign the helium sweep system, and take radiological samples.
02/03/2021 15:32:00	Based on additional radiological sampling results, NIST determined that it did not meet the radiological conditions for an alert. NIST notified the NRC Operations Center and downgraded the alert to a notification of unusual event.
02/03/2021 19:35:00	Based on additional radiological sampling results, NIST determined that it did not meet the radiological conditions for a notification of unusual event.
02/03/2021 19:40:00	NIST notified the NRC Operations Center and terminated the event.

3. Licensee Response to the Event

a. Emergency Planning Response

The initial assessment of the licensee's emergency planning response is discussed in Section 3 of the NRC's interim special inspection report [Ref. 4].

The inspectors found that, while the NIST response to the event was in accordance with the NRC-approved emergency plan, the licensee's implementation of that plan was degraded due to issues related to inadequate emergency planning implementing procedures (as discussed in Section 5.d) and a lack of emergency equipment suitable for responding to and recovering from the event (as discussed in this section).

The NIST Emergency Plan, Section 8.5, "Emergency Equipment Maintenance," requires the licensee to maintain, inventory, and calibrate emergency equipment and provides a general list of the types of inventoried equipment [Ref. 6]. Emergency Instruction 4.4, "Emergency Equipment," provides the list and locations of emergency equipment [Ref. 7].

The inspectors determined that the licensee failed to maintain emergency equipment to respond to and recover from the potential range of events described in the emergency plan. Specifically, two gas ionization chambers that are used when assessing post-event conditions were unusable because they were contaminated or damaged such that they could not collect reliable samples which resulted in the licensee having to re-sample the environmental conditions. Additionally, high range portable survey meters available to NIST response personnel were not capable of measuring post-event radiation levels during surveys of the confinement building in accordance with Step 2.2.2.2 of Emergency Instruction 4.1, “Radiation, Contamination, Environmental Surveys” [Ref. 8]. As a result, the inspectors determined that the emergency equipment used in the response and recovery efforts degraded the licensee’s ability to effectively implement the emergency plan. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-08).

b. <u>Safety Structures, Systems, and Components Response</u>

The inspectors interviewed personnel and reviewed logs, records, procedures, and documentation to assess the response of the licensee’s safety structures, systems, and components to the event.

The inspectors determined that the fission product monitor (RM 3-2) alarmed as expected when detected activity indicated 50,000 cpm. The inspectors determined that the stack monitor (RM 4-1) alarmed as expected when the detected activity indicated 50,000 cpm, and it provided a major scram signal to the safety system as expected. The inspectors reviewed surveillance records and verified that the stack monitor (RM 4-1) was calibrated and tested by NIST procedure [Ref. 9 and 10]. Further, the inspectors determined that all the measurement and test equipment used in the calibration of the stack monitor was in calibration at the time of the surveillance.

The design of the NIST test reactor differs from typical commercial nuclear power reactors because it operates at significantly lower pressures and temperatures. The NIST test reactor is designed to operate at a pressure of approximately 3 inches of water (0.108 pounds per square inch) with a coolant outlet temperature of approximately 114 °Fahrenheit (F) [Ref. 11], as compared to commercial reactors that are designed to operate at thousands of pounds of pressure and at hundreds of degrees. Since the NIST test reactor operates below the boiling point of heavy water and near atmospheric pressure, the reactor vessel and primary coolant system are not designed to be completely closed systems (i.e., not leak tight). The reactor vessel and primary coolant system are covered by the refueling plug and have connections to the helium cover gas system, which is used to prevent the degradation of the heavy water (D_2O) primary coolant and minimize the diffusion of tritium to the confinement building. The confinement building is designed to contain radioactive material that is released from the vessel during an accident so that the ventilation system can filter out radioactive materials before exhausting confinement air to the environment such that radiological doses to the public are within the limits of 10 CFR Part 20. The inspectors determined that, upon the receipt of a major reactor scram signal, the automatic reactor protection system response (reactor automatically shuts down, confinement doors close, ventilation system realigns) occurred as required by design. The inspectors determined that these systems controlled the release pathway to the environment through filtered ventilation and the confinement exhaust stack as designed.

c. <u>Conclusion</u>

Based on interviews and document review, the inspectors determined that the licensee’s safety-related structures, systems, and components performed as designed during the event. One IFI was identified for degraded emergency plan implementation because of a failure to maintain emergency equipment and to provide adequate emergency equipment specified in the emergency plan.

4. Consequences of the Event

The inspectors interviewed personnel and reviewed logs, records, and procedures to assess the licensee's analysis of the event consequences.

a. Dose Consequences

i. Public Dose

The initial assessment of the public dose consequence is discussed in Section 4 of the interim special inspection report [Ref. 4].

The inspectors compared licensee calculated public dose results with a report developed by the Department of Energy/National Nuclear Security Administration Consequence Management Program that validated the NIST public radiation exposure calculation [Ref. 12]. Independent, third-party subject matter experts from the Nuclear Emergency Support Team, specifically the Consequence Management Home Team (CMHT) and National Atmospheric Release Advisory Center (NARAC), used three separate modeling codes to validate the public dose consequence results that NIST calculated using the HotSpot computer code in the conservative model [Ref. 13]. CMHT performed a more refined analyses using the NARAC in-house computer modeling codes known as Lagrangian Operational Dispersion Integrator (LODI) and Aeolus, as well as the Turbo Federal Radiological Monitoring and Assessment Center (FRMAC) software from Sandia National Laboratories. LODI uses meteorological data to predict concentrations of hazardous material released into the atmosphere [Ref. 14]. Aeolus uses meteorological data to predict concentrations of material released into the atmosphere, but also considers the impacts of buildings on wind flow [Ref. 15]. The Turbo FRMAC analysis tool performs complex calculations to quickly evaluate radiological hazards during an emergency response by assessing impacts to the public, workers, and the food supply, but assumes an instantaneous release of the source term and an instantaneous exposure to an individual [Ref. 16]. CMHT used parameters provided by NIST regarding the site, applicable observable meteorological data, and environmental survey and sampling data to estimate public exposure. The inspectors note that each computer modeling code used by CMHT calculated the public dose consequence at much less than 0.5 millirem (mrem) at the 400-meter emergency planning site boundary. Specifically, LODI calculated a maximum dose of 0.008 mrem, Aeolus calculated a maximum dose of 0.0075 mrem, and Turbo FRMAC calculated a maximum dose of 0.00035 mrem.

Consistent with the above, the inspectors confirmed that the highest calculated dose that could be received by a member of the public resulting from the event remains significantly less than 0.5 mrem total effective dose equivalent (TEDE), which is much less than the public dose limit of 100 mrem/year TEDE specified in 10 CFR 20.1301, "Dose limits for individual members of the public."

ii. Occupational Dose

The complete assessment of the occupational dose consequence is discussed in Section 4 of the interim special inspection report [Ref. 4]. As discussed in the interim special inspection report, the inspectors found that doses to occupational workers were a small fraction of the regulatory limits established in 10 CFR Part 20. .

iii. Dose Consequence Comparison

The complete assessment comparing dose consequences from the event with the NRC staff evaluation conducted during the facility license renewal is discussed in Section 4 of the interim special inspection report [Ref. 4]. As discussed in the interim special inspection report, the occupational dose to the NIST reactor personnel was well below the MHA analysis dose estimate and below the 10 CFR Part 20 limits.

b. Environmental Consequences

The inspectors reviewed additional environmental vegetation and water sample results that the licensee collected following the issuance of the interim special inspection report and compared them with results from prior years. The licensee vegetation and water sample results showed naturally occurring isotopes, which were consistent with previous environmental sample results prior to the event. Additionally, assessment of sample results conducted immediately following the event are discussed in Section 4 of the interim special inspection report [Ref. 4]. Based on this review of the sample results, the inspectors determined that there was no detectable impact to the environment that occurred because of the event. NIST test reactor TS3.7.2, “Effluents,” Specification (2) states an environmental monitoring program shall be carried out and shall include as a minimum, the analysis of samples from surface waters from the surrounding areas, vegetation or soil and air sampling,” to verify that operation of the NIST test reactor presents no significant risk to the public health and safety; therefore, the licensee will continue to conduct environmental sampling in accordance with the TS.

c. Other Related Consequences

i. Exceeding the Fuel Temperature Safety Limit (Unresolved Item (URI) 05000184/2021201-01)

As discussed in the interim special inspection report [Ref. 4], on March 2, 2021, the licensee submitted an event notification (EN 55120) [Ref. 3], which reported that based upon review of video surveillance of the reactor core and analysis of primary coolant samples, a violation of the fuel temperature safety limit [Ref. 17] had occurred during the February 3, 2021, event. This notification was later supplemented by a 14-day report dated March 5, 2021 [Ref. 18].

NIST TS 2.1, “Safety Limit,” states that “[t]he reactor fuel cladding temperature shall not exceed 842°F (450°C) for any operating conditions of power and flow.” This fuel temperature safety limit is set to maintain the integrity of the aluminum fuel cladding, which requires that the cladding remain below the blistering temperature of 842 degrees F (450 degrees Celsius(C). Exceeding 842 degrees F (450 degrees C) may cause the fuel cladding to blister. During the blistering process, cracks may develop in the fuel cladding that can release gaseous fission products [Ref. 19]. The interim special inspection report noted that the aluminum alloy used for fuel cladding would melt if temperatures reached a range of 1076 degrees F – 1202 degrees F (580 degrees C – 650 degrees C). This is consistent with available technical literature on the properties of the NIST test reactor fuel [Ref. 20].

The inspectors determined that contrary to NIST test reactor TS 2.1, during the February 3, 2021 event, the temperature of the reactor fuel cladding exceeded the safety limit of 842 degrees F (450 degrees C). This occurred because the reactor was operated with fuel element S-1175, in position J-7, in an unlatched condition out of the normal grid position in the reactor core. This caused the fuel element to experience conditions of inadequate flow, leading to an exceedance of the fuel cladding temperature limit. Furthermore, during the startup, operators noted a sudden drop in reactor power followed by rapid increases on several radiation monitors, including the fission products monitor (RM 3-2) and the stack monitor (RM 4-1). These readings are consistent with the fuel element experiencing damage. During remote visual inspection activities of the reactor core conducted on multiple dates in February and March 2021, the inspectors observed that fuel element S-1175 was not latched, raised approximately 3-4 inches above the upper grid plate, and angled out of its proper position, causing it to rest on the lower grid plate surface. Additionally, the inspectors observed once-molten material deposited on the damaged fuel element's latching mechanism and lower grid plate surfaces. Further, an interview with a NIST operator revealed that the remote visual inspection activities showed the presence of once-molten material deposited below the lower grid plate on the plenum. During subsequent visual inspection activities of movement of fuel elements from the reactor core to the fuel storage pool, the inspectors observed that the damaged fuel element nozzle was almost completely blocked by once-molten material. Based upon these observations and the detection of the release of fission products during the event, the NRC staff determined that NIST exceeded the fuel temperature safety limit and damaged fuel element S-1175 during the event.

<u>Apparent Violation - 01:</u> NIST test reactor Technical Specification 2.1, "Safety Limit," states, in part, "the reactor fuel cladding temperature shall not exceed 842°F (420°C) for any operating conditions of power and flow."

Contrary to the above, on February 3, 2021, the reactor fuel cladding temperature exceeded 842 degrees F during operating conditions. Specifically, because of inadequate reactor coolant system flow, fuel element number S-1175, located in position J-7 of the reactor exceeded the technical specification limit of 842 degrees F as evidenced by post event visual inspections that identified once molten material deposited on the damaged fuel element's latching mechanism and lower grid plate structures. Because of presence of the once molten material combined with the release of fission products, the inspectors determined that fuel element S-1175 was damaged resulting inadequate reactor system coolant flow. However, the final determination on how fuel element S-1175 was damaged and the composition of the once molten material will be made following a post irradiation evaluation once the element is shipped to a capable facility. The inadequate reactor system coolant flow was the result of fuel element number S-1175 being inadequately latched.

This is an apparent violation (05000184/2022201-01) pending a determination of significance by the NRC.

Additionally, the inspectors noted that the licensee has moved the damaged fuel element, S-1175, to the spent fuel pool. The inspectors observed the movement of the element and did not identify any issues of concern. The inspectors also noted that NIST will need to measure the damaged fuel element and account for any displaced material in its required annual reporting of special nuclear material inventories to the Nuclear Material Management and Safeguards System. Material control and accounting of the damaged fuel element will be evaluated during a future inspection and tracked as an IFI (05000184/2022201-09).

ii. Operation with improper core configuration

The reactor was operated with a fuel element misaligned in grid position J-7, which prevented cooling flow through the element. This misalignment was observed during the remote visual inspection activities of the reactor core discussed above. Therefore, the NRC determined that fuel element S-1175 was not properly latched during refueling activities conducted on January 4, 2021.

Apparent Violation - 02: NIST test reactor Technical Specification 3.1.3, "Core Configuration," states that "[t]he reactor shall not operate unless all grid positions are filled with full length fuel elements or thimbles, except during subcritical and critical startup testing with natural convection flow." [Ref. 17]

Contrary to the above, during the February 3, 2021 event, the reactor was operated without all grid positions filled with full length fuel elements or thimbles. This is an apparent violation (05000184/2022201-02) pending a determination of significance by the NRC.

iii. Elevated Radiation and Contamination Levels

As described in Chapter 13 of the NIST safety analysis report (SAR) [Ref. 11], the maximum hypothetical accident (MHA) postulates the complete melting of one fuel element and the release of all the fission products to the primary coolant system. Since the noble gas fission products are insoluble in water, the analysis assumes that they would accumulate in the helium space and be released to the confinement building.

As discussed in Section 3.b above, the NIST test reactor vessel and primary coolant system are not designed to be completely closed systems (i.e., not leak tight). The reactor operates below the boiling point of heavy water and near atmospheric pressure. The confinement building is designed to contain radioactive material released from the reactor vessel during an accident. Radioactive material released from the reactor vessel is filtered through high efficiency filters before confinement air is exhausted to the outside environment to limit radiological doses to the public to within 10 CFR Part 20 limits. By design, radioactive material contamination within the confinement building is expected during an accident scenario.

After the February 3, 2021, event, the NIST staff found contamination in the confinement building consistent with this analysis. Levels of contamination were highest on the reactor top and the control room located above the reactor where operators were stationed. Samples analyzed post-event showed that most of the contamination was decay products of noble gas fission products consistent with the MHA analysis. However, as discussed in the interim special inspection report [Ref. 4], the occupational dose to the NIST reactor personnel was well below the MHA analysis dose estimate and below the 10 CFR Part 20 limits. The inspectors confirmed that the NIST staff took appropriate actions to monitor radiation levels and decontaminate the confinement building during cleanup and recovery activities.

The process room contains primary piping, pumps, heat exchangers, and ion exchangers and is not normally accessed during operation. Initially, following the event, the general area dose rates in the entrance portion of the room were 200-400 mrem/hour (hr) with levels reaching as high as 2,000-5,000 mrem/hr in the immediate vicinity of primary pumps and piping. Several areas of localized radioactive material (i.e., hotspots), located in primary system piping, measured 250,000 mrem/hr or greater in the overhead near the heat exchangers. Inspectors found that radiation levels at areas adjacent to the process room were not affected. The process room was locked with the key controlled, and access to both the process room and the confinement building itself was limited to those with explicit permission from the Chief of Reactor Operations and the Facility Director. The inspectors found that posting and access control to the process room were consistent with the regulations in 10 CFR Part 20. The licensee has continued to monitor and conduct periodic surveys of the process room and has found that radiation levels have decayed over time but remain above levels seen prior to the event.

In a follow-up report submitted to the NRC [Ref. 5], NIST stated that an outside contractor experienced in decontamination and recovery work will clean up the primary system. Cleanup of the primary system will be evaluated during a future inspection activity and tracked as an IFI (05000184/2022201-10).

iv. Facility Equipment

As discussed in Section 3 of the interim special inspection report [Ref. 4], NIST operators re-entered confinement after the event to initiate shutdown cooling. Approximately one week after initiating shutdown cooling, indications available to facility operators showed that the #2 shutdown pump used to provide forced cooling to the reactor ceased providing flow. Following the failure of this pump, the facility operators used different pumps to provide forced cooling flow to the reactor, when necessary. The inspectors note that the shutdown pump is not an engineered safety feature required to provide reactor cooling post shutdown, as NIST has alternative means to provide emergency core cooling as described in Chapter 6, “Engineered Safety Features,” of the NIST SAR [Ref. 11]. The inspectors note that NIST intends to continue troubleshooting the failure of the shutdown pump along with primary system cleanup, as described above in Section 4.c.iii. This item will be reviewed during a future inspection activity and tracked as an inspector follow-up item (IFI) (05000184/2022201-11).

d. Conclusion

The inspectors found that doses to members of the public and occupational workers remain a small fraction of the regulatory limits in 10 CFR Part 20. The inspectors also found that no detectable impact to the environment occurred because of the event.

The inspectors found that the licensee exceeded the safety limit, which resulted in damage to one fuel element and contributed to the conditions in the confinement building as described above.

5. Adequacy of Facility Procedures

a. Material Controls and Accounting Procedures

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the procedures used for material control and accounting, including receipt, storage, and inspection of reactor fuel.

The inspectors found that NIST procedures were established, maintained, and followed for fuel receipt and fuel inventory in the storage pool location. Receipt of special nuclear material was conducted in accordance with NIST procedure each time unirradiated fuel elements were received at the facility [Ref. 21]. Physical inventory of special nuclear material was conducted in accordance with NIST procedure to verify the location of irradiated fuel elements in the storage pool [Ref. 22]. The inspectors noted that NIST also maintains fuel manufacturing quality assurance records that track the amount of special nuclear material in the fuel plates of each fuel element. Additional physical inventory and accounting for special nuclear material in fuel elements is maintained through recordkeeping related to fuel loading, fuel unloading, and fuel movements.

The inspectors found that NIST completed the required annual reporting of special nuclear material inventories to the Nuclear Material Management and Safeguards System. The inspectors also reviewed data sheets that calculated burnup data to fulfill the annual reporting requirement. However, inspectors did not review procedures related to meeting these reporting requirements, as required by 10 CFR Part 74, Subpart B, “General Reporting and Recordkeeping Requirements.” The inspectors noted that unirradiated fuel is typically received just-in-time from the manufacturer for refueling activities and is not stored for an extended period at the NIST test reactor such that it would be included in the annual physical inventory. Therefore, inspectors did not review procedures related to inventory of unirradiated fuel. These items will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-12).

b. Inadequate Fuel Loading, Fuel Unloading, and Fuel Movement Procedures

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the TS-required procedures used to load, unload, and move reactor fuel.

The inspectors reviewed various revisions of Operating Instruction (OI) 6.1, “Fueling and Defueling Procedures.” The inspectors also reviewed a prior version of OI 6.1 and noted that it contained detailed step-by-step instructions on fuel element movement to and from every grid plate location in the reactor vessel. However, the inspectors found that revisions of OI 6.1 dated after December 2006 did not contain the same level of detail as found in the older version. The inspectors found that later revisions of the procedure available to operators leading up to the event changed the format and added various precautions and requirements.

The inspectors noted that the licensee identified inadequate refueling procedures as a root cause of the event, as discussed in Section 7 of this report.

Apparent Violation - 03: NIST test reactor Technical Specification 6.4, “Procedures,” states, in part, that written procedures shall be prepared, reviewed, and approved prior to initiating activities to include (1) fuel loading, unloading, and fuel movement within the reactor vessel and (2) inspections and maintenance of equipment required by the TSs that may have an effect on reactor safety [Ref. 17].

Contrary to the above, on January 4, 2021, inadequate procedures were used to move fuel in the reactor vessel, which ultimately resulted in NIST exceeding the TS safety limit as discussed above in Section 4.c.i. On August 28, 2019, NIST staff had prepared, reviewed, and approved a written procedure for fuel loading activities that contained inaccurate information and did not contain the necessary information to ensure that the fuel elements were latched prior to startup. As a result, the inspectors determined that OI 6.1, Revision E [Ref. 23] was inadequate to ensure that fuel element S-1175 was latched during refueling activities on January 4, 2021. This determination is based on the following:

- OI 6.1, Revision E, Section 4.3, “Rotation Check,” instructed the operators to confirm proper orientation of the fuel element head by checking that a machined mark on the tool collar is aligned with a corresponding mark on an index plate. Through interviews with the operators, the inspectors determined that the plate on top of the reactor did not have the specified mark on it, which forced the operators to improvise and check the general orientation of the tooling. Furthermore, the procedure instructs operators to verify that the element is properly latched by checking that the tool collar is flush with the index plate. However, inspectors determined that this was also not possible given the changes to the refueling tooling that caused the refueling tool height verification to be inaccurate as discussed in Section 6.b of this report.

- The inspectors reviewed various revisions of OI 6.1. The inspectors found a historical version of operating procedure (OP) 6.1.F [Ref. 24] that contained explicit step-by-step instructions on fuel element movement to and from every grid plate location in the reactor vessel. However, the inspectors determined that subsequent revisions of OI 6.1 after December 2006 did not contain the level of detail found in the historical version. The inspectors found that revisions to the procedure made in the lead up to the event changed its format and added various precautions and requirements but did not add back the level of detail found in the earlier procedure.

- OI 6.1, Revision E, Section 4.3, and Section 4.4, “Flow Test,” did not contain sufficiently detailed instructions for operators to follow when performing TS-required fuel element latch verification checks. The procedure did not contain any precautions or requirements that directed operators to perform either Section 4.3 or 4.4 to meet the TS requirement to verify that the fuel elements were properly latched.

- OI 6.1, Revision E, Section 4, “Latch Verifications,” did not provide operators with any indications of partially unlatched elements or what actions should be taken if operators observed indications of partially unlatched elements.

This is an apparent violation (05000184/2022201-03) pending a determination of significance by the NRC.

Additionally, the inspectors note that the licensee also revised OI 6.1 two times after the event. The first revision, OI 6.1, Revision F [Ref. 25], reworded step 4.3.1 from “This test is to be done prior to the final starting of the main D_2O pumps” to “This test is to be done prior to reactor start up.” Considering the potential for unlatched fuel elements to be pushed out of normal grid plate locations by primary coolant flow, the inspectors find this change to be potentially less conservative as the licensee could perform the latch verifications at any time following fuel movement prior to startup. The subsequent revision, OI 6.1, Revision G [Ref. 26], contains instruction that the latch verifications in Sections 4.3 and 4.4 will not be used until OI 6.1 is further revised. The licensee has committed to revise the procedure to include several corrective actions that will be inspected as part of the restart activities. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-13).

c. <u>Inadequate Reactor Startup Procedure</u>

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the TS-required procedure used to start up the reactor.

The reactor startup procedure, OI 1.1, “Reactor Startup,” Revision E, [Ref. 27], states that operators should monitor for abnormal fluctuations or oscillations on nuclear channel indications. However, the inspectors found that the procedure does not provide amplifying guidance to operators for identifying indications of abnormal fluctuations or oscillations. For example:

- OI 1.1, Revision E did not contain sufficient guidance related to indicated power oscillations. Furthermore, the procedure does not contain any discussion on what amplitude/magnitude of fluctuations or oscillations are unacceptable and the possible scenarios that could cause the abnormal oscillations. During interviews with the NIST operators, the inspectors discovered that normal nuclear channel indications fluctuate between 0.8 and 1.2 percent at any given power level. During the reactor startup on February 3, 2021, the licensee initially stated that fluctuations or oscillations of up to 2 percent were present, but not observed. Further, the licensee provided that nuclear instrumentation displays on digital chart recorders; however, at normal or typical scaling, the difference between 1 and 2 percent oscillations is not readily observable by the operators. During interviews with the NIST operators, the inspectors discovered that previous experience showed that oscillations caused by an unlatched element had been observed at 5 percent of a given power level; however, this was not documented in the procedure. Additionally, no fluctuation/oscillation guidance was given to the operators based on the location of a potentially unlatched element with respect to nuclear instrumentation (i.e., fluctuations/oscillations may be smaller/larger based on distance to nuclear instrumentation).

- As a result of further inspector questioning, the licensee re-analyzed the startup data from the February 3, 2021 event and found that the power indication oscillations were larger than initially stated. As described in a supplement to NIST's restart request [Ref. 28], the licensee found that the initial assumption that the operators saw 1 to 2 percent oscillations was inaccurate because of data collection and display differences between the digital chart recorder and the data acquisition system. Subsequent data analysis found that the oscillations were closer to 5 percent, not the 1 to 2 percent discussed above.

- OI 1.1, Revision E, Step 2.2.11 instructs operators to monitor nuclear instrumentation for oscillations during reactor startup but does not provide any additional amplifying information. The inspectors noted that there was no guidance to operators on when to monitor for oscillations, the power level at which to expect oscillations to appear, what magnitude of oscillations was not acceptable, and the fact that oscillations could be indicative of an unlatched element.

The inspectors noted that the licensee identified inadequate startup procedures as a root cause discussed in Section 7 of this report and developed corrective actions to address this inadequacy including revising the startup procedure to include the necessary guidance.

<u>Apparent Violation - 04</u>: NIST test reactor Technical Specification 6.4, "Procedures," states, in part, that written procedures shall be prepared, reviewed, and approved prior to initiating activities to include startup, operation, and shutdown of the reactor [Ref. 17].

Contrary to the above, on December 31, 2020, the licensee prepared, reviewed, and approved a written procedure that was inadequate to the circumstances. Specifically, NIST staff approved a written procedure for a reactor start-up activity that was not suitable for the circumstances. Procedure OI 1.1, Reactor Startup, Revision E, did not contain requisite qualitive nor quantitative criteria for operators to ascertain what constitutes significant or abnormal reactor power oscillations during a startup after conducting refueling activities.

This is an apparent violation (05000184/2022201-04) pending a determination of significance by the NRC.

d. <u>Inadequate Emergency Planning Implementation Procedures</u>

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the TS-required procedures used for the implementation of the emergency plan.

The inspectors noted that the licensee identified inadequate emergency instructions as an observation in their root cause report as discussed in Section 7 of this report. A program improvement was recommended by the NIST Safety Evaluation Committee (SEC) to address this inadequacy through the development of guidelines that outline strategies and implementation methods sufficient in unpredictable or dynamic situations. This program improvement is discussed in the Root Cause Response [Ref. 29] but does not currently appear in either the pre- or post-restart corrective action plan.

Apparent Violation - 05: NIST test reactor Technical Specification 6.4, "Procedures," states, in part, that written procedures shall be prepared, reviewed, and approved prior to initiating activities to include implementation of required plans such as emergency or security plans [Ref. 17].

Contrary to the above, on December 14, 2015, NIST staff prepared, reviewed, and approved written procedures for the implementation of required emergency plan that were not adequate as evidenced by the following two examples:

- Emergency instruction 4.1, "Radiation, Contamination, and Environmental Surveys," steps 2.3.2.10.1 - 2.3.2.10.3 [Ref. 30] were inadequate to ensure that emergency instructions appropriately specified how to make measurements, interpret results, and perform calculations necessary to downgrade an emergency classification. As a result, on February 3, 2021, during an actual event that resulted in the declaration of an Alert, NIST staff had insufficient procedural guidance to ascertain whether to downgrade the emergency classification. This insufficient guidance resulted in the failure to promptly respond to the event, including assessment of consequences and delayed recommendations, decisions, and reports to downgrade the emergency classification.

- Emergency instruction 3.6, "Essential Personnel Evacuation" [Ref. 31], step 3.1.3 and emergency instruction 3.8, "Recovery Operations" [Ref. 32], step 2.2 were inadequate to ensure that the emergency instructions appropriately specified how to re-occupy the confinement building and determine what recovery operations required procedures. As a result, on February 4, 2021, while performing supplemental actions following an actual event, NIST staff had insufficient procedural guidance on re-entry of the confinement building following an event requiring building evacuation. This resulted in NIST sending personnel back into confinement without appropriate personnel protective equipment. In one specific instance, this was due to a lack of understanding of the impact of not securing the carbon dioxide system while using emergency ventilation, not considering the potential for carbon dioxide build-up in low lying areas, and not identifying the potential to create oxygen deficient environments in the containment building.

This is an apparent violation (05000184/2022201-05) pending a determination of significance by the NRC.

e. Conclusion

The inspectors determined that material control and accounting procedures were adequate and likely did not contribute to the event. However, the inspectors identified three apparent violations for inadequate fuel handling, reactor startup and emergency planning procedures that directly contributed to the event. Additionally, the inspectors identified inadequate emergency response procedures that impaired the licensee's ability to implement the emergency response.

6. Related Actions that Contributed to the Event

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess maintenance and/or outage actions that could have contributed to the event. Other than the maintenance and outage activities described below, the inspectors reviewed the maintenance conducted during the outage preceding the event and did not find any additional contributing activities to the event.

a. Inadequate Fuel Handling within the Vessel

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the TS-required fuel element latching checks.

The NIST reactor fuel element latch mechanisms can be in one of four different positions. These positions are 1) fully unlatched, 2) latched in the fuel element "window," 3) latched on the upper grid plate, but not fully rotated into the upper grid plate notch, and 4) latched in the upper grid plate notch (i.e., fully latched). If a fuel element is latched in the fuel element window, then it is not secured in the upper grid plate and is free to dislocate from its core position. While inspecting the reactor after the February 3, 2021 event, NIST staff found the fuel element S-1175 latch mechanism latched in the fuel element window.

On December 20, 2020, operators shut down the NIST test reactor for a refueling outage. During the refueling outage, on January 4, 2021, fuel elements were shuffled within the reactor vessel. After the fuel elements were placed into each core position, height checks were performed using a metal plate height gauge to ensure that the fuel elements were properly seated in the lower grid plate and fully latched in the upper grid plate. However, the metal plate gauge used for the height checks was not precise enough to determine whether a fuel element was fully latched or improperly latched in the fuel element window. The inspectors reviewed video footage of the placement of the S-1175 fuel element into the J7 core position and determined that the fuel element was properly latched after its initial placement. However, the inspectors observed that operators had difficulty placing the refueling tool onto the fuel element during the subsequent height check and that they likely knocked the latching mechanism from the fully latched position to the "latched in the window" position. The operators did not detect that the element was not in the fully latched position because of the inaccuracy of the height check gauge.

Later in the day on January 4, 2021, a different shift of operators attempted to perform the TS-required latch verification. Through interviews with the operators, the inspectors found that the operators assigned to perform this latch verification were unfamiliar with the procedure and had little or no experience performing the evolution. Specifically, of the two licensed operators assigned to perform the latch verification, one had never performed or been trained on the latch verification procedure, and the other had only performed the latch verification evolution one other time more than 2 years prior to January 4, 2021. The operators stated in interviews with the inspectors that no substantive pre-job brief was performed for the evolution (i.e., the details of the evolution were not discussed), and that they did not use or follow a procedure on the day of the latch checks. This is corroborated by video footage of the licensed operators performing the evolution. The inspectors also found that the crew chief did not determine if the operators knew how to perform the checks and did not ensure that the operators used a procedure while performing the evolution. Inspectors observed that the crew chief was not present at the reactor top to supervise refueling activities because he had assumed the job of control room operator during the latch verification evolution.

Through interviews with the operators and video footage of the evolution, the inspectors determined that the licensed operators did not understand the intent of the latch verification evolution. For example, the refueling procedure directs the operators to rotate the fuel handling tool only in the counterclockwise direction. This direction ensures that the fuel element is not inadvertently unlatched and ensures that the element is fully latched during the rotation check. However, the operators stated that they thought they were only supposed to perform height checks and did not perform rotation checks. Further, the inspectors observed that the operators rotated the fuel handling tool in the clockwise direction for each of the fuel elements during the evolution and even intentionally bypassed a clutch mechanism on the tool designed to prevent clockwise rotation. One operator stated that he rotated the tool in the clockwise direction because that was how he remembered being told to do it. The other operator stated that he did not question the first operator because he had no experience with the evolution and assumed that the first operator knew what he was doing. When the inspectors asked if fuel handling operations are normally performed in this manner, the licensed operators stated that it was routine for written fuel handling procedures not to be used during refueling evolutions. Instead, several NIST supervisors and crew chiefs expected operators to know how to perform fuel handling operations without written procedures. Through the interviews and observation of the video footage of the refueling and latch verification evolutions, the inspectors determined that the S-1175 fuel element was likely initially fully latched after placement into the J7 core position, but during height checks it was bumped with sufficient force to allow the latching mechanism to move to the fuel element window. As discussed above, this went unnoticed during the subsequent attempt to perform the TS-required latch check.

Furthermore, the inspectors noted that during post-event rotational latch verifications, NIST staff found that three additional fuel element latching mechanisms were not fully latched. However, these fuel elements were seated in their proper core positions. The inspectors observed that operators did not properly perform the latch checks on these three elements during the January 4, 2021 latch verification attempts. Thus, on January 4, 2021, these three fuel elements were likely latched on the upper grid plate but not fully latched into the upper grid plate notch. They did not become fully unlatched or misaligned during the subsequent pump cycles and multiple reactor startups.

<u>Apparent Violation - 06</u>: NIST test reactor Technical Specification 3.9.2.1, “Fuel Handling; Within the Reactor Vessel,” states that “following handling of fuel within the reactor vessel, the reactor shall not be operated until all fuel elements that have been handled are inspected to determine that they are locked in their proper positions in the core grid structure, which shall be accomplished by one of the following methods:

(1) Elevation check of the fuel element with main pump flow.
(2) Rotational check of the element head in the latching direction only.
(3) Visual inspection of the fuel element head or latching bar.” [Ref. 17]

Contrary to the above, on January 4, 2021, following handling of fuel within the reactor vessel, NIST staff did not perform the TS-required inspections to ascertain that fuel elements within the core grid structure were latched in their proper positions. Specifically, NIST operators failed to implement one of the three specified methods to ensure that fuel element S-1175 was adequately latched.

This is an apparent violation (05000184/2022201-06) pending a determination of significance by the NRC

b. Inadequate Facility Change

The licensee stated in the Technical Working Group root cause analysis [Ref. 33] that changes made to the refueling tooling invalidated the height latch verification method.

Section 4.4 of OI 6.1 included height checks as a method to verify that fuel elements were locked in their proper positions in the core grid structure; however, following the refueling tool replacement, height checks no longer provided a clear indication that fuel elements were locked. NIST identified the inadequacies of the height check during the root cause analyses and stated that because of changes made to the refueling tooling, the height check lacked the accuracy to distinguish the small height differences between a fully latched element and one that is partially latched. Furthermore, in the root cause response document [Ref 19] submitted as part of its restart request, NIST committed to discontinue its use of height checks as a method to verify fuel element latch status.

Apparent Violation - 07: 10 CFR 50.59(c)(1) states, in part, that a licensee may make changes to a facility without obtaining a license amendment only if, among other things, a change to the technical specifications is not required.

NIST test reactor Technical Specification 3.9.2.1, states, "following handling of fuel within the reactor vessel, the reactor shall not be operated until all fuel elements that have been handled are inspected to determine that they are locked in their proper positions in the core grid structure, which shall be accomplished by one of the following methods:

(1) Elevation check of the fuel element with main pump flow.
(2) Rotational check of the element head in the latching direction only.
(3) Visual inspection of the fuel element head or latching bar."

Contrary to 10 CFR 50.59, starting from 2016 through until 2020, the licensee made replaced the 30 refueling tools that invalidated the capability of operators to verify that a fuel element was fully latched as specified in TS 3.9.2.1(1). The licensee's procurement and use of an altered refueling tool invalidated the operator's capability to perform OI 6.1, Revision E, Section 4.4, which the licensee credited for the "Elevation check of the fuel element with main pump flow," as specified in TS 3.9.2.1(1). The licensee determined that because the replacement refueling tool had different dimensions, it lacked the accuracy to distinguish the small height differences between a fully latched element and one that is partially latched. Because the changes to the tool invalidated the height check latch verification, the licensee should have submitted a License Amendment Request to revise TS 3.9.2.1(1).

This is an apparent violation (05000184/2022201-07) pending a determination of significance by the NRC.

c. Inadequate Training

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the training that operators received.

In accordance with 10 CFR Part 55, “Operators’ Licenses,” the NRC staff prepares and administers both a comprehensive written examination and a hands-on operating test to all candidates for an operator license. The regulations specify examination topics to be included in an operator licensing written examination and the knowledge requirements for the operating tests. NUREG-1478 [Ref. 34] provides further information on both the written examination and the operating test. The written examination and operating test include a representative sample of a number topics including fuel-handling facilities and procedures. However, operators are not required to move fuel elements as part of the operating test, but may walk-through, simulate, or discuss various aspects of fuel handling.

NIST TS 6.1.4, requires that the selection, training and requalification of operations personnel shall meet or exceed the requirements of ANSI/ANS 15.4-2007 [Ref. 35]. The inspectors observed that the NIST staff failed to ensure that the training and requalification of operations personnel met or exceeded the standards of ANSI/ANS 15.4-2007 in that NIST’s “operating and oral examinations,” did not adequately test operators’ knowledge and skills to conduct maintenance tasks to verify the operability of equipment. Specifically, NIST personnel were not proficient in the latch-check operations required under TS 3.9.2.1 and did not fully understand how to detect an unlatched fuel element. Furthermore, operators did not understand the significance or possible causes of power oscillations during reactor startup. The inspectors reviewed the NIST training material and did not find any documentation or training records specifically related to refueling or to using the refueling training stand that is available for operator training. Furthermore, the inspectors found no training material that discussed procedural precautions, procedural requirements, or lessons learned related to power oscillations during startup.

These deficiencies, in part, resulted in the failure of NIST personnel to properly latch fuel element S-1175 on January 4, 2021 and the failure of operators to identify power oscillations indicative of an unlatched element during the subsequent reactor startup on February 3, 2021. A sudden drop in reactor power and rapid increases on several radiation monitors, including the fission products monitor (RM 3-2) and the stack monitor (RM 4-1), was caused by an unlatched latched fuel element. The inspectors determined that the unlatched latched fuel element S-1175 was not identified during the conduct of the surveillance activity on January 4, 2021 and was not identified during the reactor startup on February 3, 2021. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-14).

d. Conclusion

The inspectors identified two apparent violations related to inadequate fuel handling within the vessels and inadequate modifications that invalidated NIST operators’ ability to meet a TS.

7. Root Cause Determination and Contributing Causes

a. NIST Root Cause Report

NIST conducted its root cause evaluation of the event in two parts. The first evaluation was completed by an internal NCNR team called the Technical Working Group (TWG), which consisted mostly of personnel from the Reactor Operations and Engineering group and was chaired by the NCNR Chief of Reactor Operations and Engineering. The TWG conducted interviews of NCNR staff and reviewed video surveillance, procedures, reports, data, logs, historical records, and emails. The TWG report was completed on May 13, 2021 [Ref. 33] and contains a narrative and timeline of the event and the associated conditions. The TWG identified five root causes discussed in detail below. Furthermore, the TWG issued an addendum to the initial report that describes a phenomenon discovered during video surveillance incident investigation whereby an element could become partially unlatched by a relatively small impulse force from the tool used to perform latching and checks of the fuel elements [Ref. 36]. The second evaluation was performed by the Event Response and Corrective Action Subcommittee (ERCAS) of the NCNR SEC. The ERCAS was tasked to perform an evaluation considering all the available information including the TWG report. The ERCAS issued a report on August 12, 2021 [Ref. 37] and concurred with the five root causes identified in the TWG report and added two additional root causes. The ERCAS separated the root causes into the following four categories: (1) management systems (MS), (2) qualification and training (QT), (3) procedure adequacy and use (PR), and (4) instruments, equipment, and tools (IE) based on TapRoot® and National Safety Council incident investigation methods.

In total, NIST identified the following RCs , which are preceded by an alpha-numeric designator assigned by the ERCAS:

1. ERCAS-MS-RC1 – NIST identified recent changes in staff attrition, oversight of supervisory turnover, a shift rotation that dictated that the some shifts rarely performed specific evolutions (refueling) resulting in a loss of proficiency, and wear and replacement of refueling tools.
2. TWG-MS-RC2 – NIST found that interviews with operations shift staff described inconsistent supervision and inadequate supervisor training for refueling operations.
3. ERCAS-MS-RC3 – NIST identified a culture of complacency among operations staff. Operations staff lacked ownership of expectation, processes, and procedures to proactively identify necessary improvements.
4. TWG-QT-RC1 – NIST identified an inadequate training and qualification program because operations staff were not proficient in refueling operations.
5. TWG-PR-RC1 – NIST found that refueling latch-checking procedures did not capture the necessary steps to ensure that fuel elements were properly latched.
6. TWG-PR-RC2 – NIST found that operations staff did not comply with procedures and supervisors did not ensure that procedural compliance was rigorously practiced.
7. TWG-IE-RC1 – NIST identified deficiencies in the latch determination equipment. Specifically, the equipment lacked the fidelity to confirm proper latching of a fuel element.

In addition to the above root causes, NIST identified the following contributing factors (CFs):

1. MS-CF1 – Management of staffing changes (people and shifts) needs improvement to ensure adequate proficiency.
2. QT- CF1 – Some training materials used for latch checking are ineffective and others are not consistently used (e.g., qualification cards).
3. QT-CF2 – Training experience differs greatly among crews.
4. IE-CF1 – Imprecise alignment of index plate causes difficulty in tool use.
5. IE-CF2 – Height check tools lacked fidelity.
6. IE-CF3 – Subsequent study showed that inadvertently bumping the fuel head with a tool can cause unlatching.
7. IE-CF4 – Lack of hands-on training contributes to operator inexperience in loading/latching fuel.

The licensee developed corrective actions for each root cause and contributing factor and submitted them as part of the corrective action plan that is discussed in the next section of this report.

Additionally, ERCAS identified several observations (O). The observations and associated suggested program improvements (SPIs) are provided for consideration by NCNR management, and they are intended to strengthen NCNR's safety management system and associated processes. The emergency response observations (ER-Os) are as follows:

1. ER-O1 – No list of items or systems to check prior to evacuation of the control room.
2. ER-O2 – The potential for carbon dioxide (CO2) levels to build up in low-lying areas and present an oxygen (O2) deficiency hazard was not identified prior to the incident. This was investigated separately.
3. ER-O3 – Emergency Control Station (ECS) monitoring and control capabilities need improvement; there were difficulties monitoring specific reactor systems following the event.
4. ER-O4 – The emergency plan and associated emergency instructions specify emergency action levels and who makes the decision to declare or downgrade an emergency classification. They do not specify how to make measurements, interpret results, perform calculations, and make on and off-site dose estimates.
5. ER-O5 – Emergency drills and exercises are held, and follow-up critiques are conducted. Many staff are unaware of how deficiencies identified during follow-up critiques are tracked and used to form the basis for training and procedure updates.
6. ER-O6 – Emergency drills and exercises need improvement.
7. MS-O1 – Management of changes in key management and supervisory positions needs improvement.
8. MS-O2 – The career path to achieve the supervisory position of crew chief is unclear to staff, viewed as time in grade rather than competency-based.
9. MS-O3 – Processes used to modify procedures do not expressly require review by or notice to Reactor Engineering staff when engineered items are used in the procedure.

10. MS-O4 – Processes for managing the full life cycle of engineered equipment, tools, and parts need improvement.
11. MS-O5 – Management engagement needs improvement.
12. MS-O6 – Supervisor oversight is implemented inconsistently.
13. MS-O7 – Recommendations from the SAC are reviewed, dispositioned, and tracked by management. Many staff are unaware of these actions.
14. QT-O1 – Job descriptions and expectations are unclear.
15. QT-O2 – Insufficient training on normal vs. off-normal conditions.
16. QT-O3 – Communication of lessons learned is not consistently shared across crews.
17. PR-O1 – Training on the process to revise procedures and associated 10 CFR 50.59 requirements is included in requalification but not in initial training.
18. IE-O1 – No detectable indication of fuel dislocation is provided to the reactor console operator prior to fuel damage during climb to power.
19. IE-O2 – Dimensional differences between old tools and replacement tools could potentially cause difficulty and confusion during use.

b. <u>NRC Staff Assessment</u>

The inspectors conducted an independent assessment of the licensee's root cause determination. Although NIST identified several reasonable root causes that led to the February 3, 2021 event, the inspectors identified several additional observations from a review of the root cause report.

i. <u>Incomplete Root Cause Analysis</u>

The inspectors found that the licensee's root cause report failed to identify and address two additional possible root causes. To perform a systematic and complete root cause analysis of the event, the licensee should identify all possible root causes. All possible root causes should be identified and evaluated to ensure that the review is comprehensive. Even if a root cause may be easily refutable, it should still be evaluated and discussed. For example, in the TWG root cause report [Ref. 33], the licensee discusses cycling primary pumps over 40 times during a Coronavirus Disease 2019 related stand-down but does not discuss the possibility that cycling the primary pumps so many times could have caused the fuel element to become unlatched. The inspectors determined that, though unlikely to be the sole root cause, the cycling of the primary coolant pumps could have contributed to the event, especially if fuel element S-1175 was either partially or completely unlatched prior to pump cycling. Another example is that neither root cause report discusses and evaluates the possibility of a mechanical failure causing the element to become unlatched. Discussion of whether the latch mechanism appeared to fail, whether some sort of blockage prevented the element from being fully inserted, or whether worn upper grid plate notches caused the element to become unlatched should have been included. During onsite inspection, the inspectors did not observe any video footage that showed any indication of a mechanical failure preventing latching or causing fuel element S-1175 to become partially or fully unlatched.

Furthermore, while conducting interviews with the NIST staff, the inspectors discovered that NIST made design changes to the fuel element head latching mechanism. The root cause report did not contain any discussion of those changes and the possibility that they may have contributed to the element coming unlatched or otherwise contributed to the event. The inspectors note that the licensee did not commit to reviewing the design of the latching mechanism. The inspectors did note that NIST briefly discussed the design of the latching mechanism in the ERCAS root cause report and acknowledged that a re-design could be an obvious corrective action. However, the licensee then stated that great care and consideration must be taken before making changes to the existing design to avoid unanticipated adverse consequences. The inspectors note that re-designing the latching mechanism could prevent another similar significant operational event like this one from occurring in the future. The NRC staff will review the design of the fuel element latching mechanism as part of the restart analysis. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-15).

The inspectors found that the TWG root cause report briefly discusses nuclear instrument response. The TWG root cause report stated that the previous unlatching events at NIST resulted in power oscillations of 5 to 7 percent. However, the initial TWG root cause report states that operators observed 1 to 2 percent oscillations at 10 MW(t) and that these oscillations were not likely visible to operators. The report does not provide any further explanation for why those smaller oscillations were not visible or why this was acceptable. Additionally, the report does not include any information from a "normal" startup for comparison. As a result of further inspector questioning, the licensee re-analyzed the startup data from the February 3, 2021 event and found that the oscillations were, in fact, larger than initially stated. As described in a supplement to the restart request [Ref. 28], the licensee found that the initial assumption that the operators saw 1 to 2 percent oscillations was inaccurate because of data collection and display differences between the digital chart recorder and the data acquisition system. Subsequent data analysis found that the oscillations were closer to 5 percent. The inspectors determined that the licensee also included data from a "normal" startup in that supplement and observed a noticeable difference between the "normal" startup and the startup on February 3, 2021. The licensee does have a SPI to explore nuclear instrumentation signal analysis tools capable of providing early detection of off-normal behavior. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-16).

The inspectors also found that neither root cause report discusses the lack of an effective problem identification and resolution program as a root or contributing cause. The inspectors found that the lack of an effective problem identification and resolution program was a significant root and/or contributing cause to the event. The licensee had several outside audits that identified many of the same issues that the licensee's root cause reports identify, including the need for a corrective actions program. The TWG root cause report discusses two previous unlatching events, one that occurred in 1981 and one that occurred in 1993. However, through discussions with the NIST staff, the inspectors found that NIST had found elements unlatched in 1984, 1986, 1993, 2003, 2004, 2008, and 2009. Neither of the root cause reports discuss these additional unlatching events and their causes and any corrective actions that were implemented because of these events. Through discussions with the licensee staff, the inspectors found that there was little to no documentation of these other unlatching events. The inspectors examined open items in the licensee's corrective action program and found seven items dating from December 2019 to December 2020. This lack of information should have been acknowledged in the root cause report. Though NRC requirements do not mandate that test reactors (or testing facilities) like NIST have a corrective action program like the requirements for power reactors, the licensee should have analyzed the problem identification and resolution programs to assess their impact on the event. The inspectors discussed this lack of information related to problem identification and resolution with the licensee. The licensee submitted a supplement to its restart request that contained discussion of the various problem identification and resolution programs and proposed improvements [Ref. 38]. The inspectors found that the proposed improvements may have prevented the event. However, more detail and review of the effectiveness of these improvements will need to occur as part of the restart activities. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-17).

ii. <u>Safety Culture Weaknesses</u>

Although the licensee's root causes address a few specific areas of safety culture, the inspectors found that the reports did not address broader safety culture issues that contributed to the event. Specifically, the inspectors found that many of the root causes that the licensee identified are directly related to broader safety culture issues. The NRC's Final Safety Culture Policy Statement [Ref. 39] applies to all NRC licensees, applicants, and vendors. It defines Nuclear Safety Culture as "the core values and behaviors resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment." The policy statement discusses nine traits of a positive safety culture, including but not limited to leadership safety values and actions, work processes, continuous learning, and environment for raising concerns. As stated in the Final Safety Culture Policy Statement, "[a] trait, in this case, is a pattern of thinking, feeling, and behaving that emphasizes safety, particularly in goal conflict situations, e.g., production, schedule, and the cost of the effort versus safety." Under each of the traits are subcategories referred to as the attributes of a healthy safety culture [Ref. 40].

Safety culture inspectors from the NRC Office of Enforcement conducted an initial safety culture assessment of the licensee while onsite the week of October 18, 2021. During this assessment, the team conducted focus groups and interviews of over 30 personnel, reviewed the licensee root cause evaluations, and reviewed procedures, including the new procedures created as part of the corrective actions in response to the February 3, 2021 event. The inspectors identified weaknesses in the following areas:

1. Leadership Safety Values and Actions

   The most significant weakness that the inspectors identified was in the leadership safety values and actions trait. Specifically, the inspectors identified weakness in the following attributes under this trait: (1) resources, (2) strategic commitment to safety, and (3) change management [Ref. 40]. NIST personnel stated that leadership knew of the aging workforce and the impending loss of institutional knowledge. Multiple SAC reports warned the facility of the need for enhanced procedures and training programs to prepare for the retirement of many of the personnel. Furthermore, the reports also identified the need to reinforce procedure use and adherence. However, mangers did not enact a knowledge management program, did not update procedures with adequate detail, did not reinforce procedure use and adherence, and did not enact a training program with continuous learning processes.

Following discussion with the inspectors, the licensee did submit a supplement to its restart request in which it addresses leadership safety values and actions [Ref. 41]. The inspectors will continue to assess the licensee's response and safety culture as part of ongoing supplemental inspections and restart activities.

2. Work Processes

   Another weakness that the inspectors identified was in the trait of work processes. Specifically, the inspectors identified weakness in the following attributes under this trait: (1) documentation and (2) procedure adherence. The inspectors found a perception among licensee personnel that procedures are available but are not required to be used and that personnel do not follow them. The inspectors interviewed multiple operators who confirmed that it was standard practice for the operators to not use refueling procedures because they were expected to know how to do the procedures from memory. Procedures were used for evolutions considered to be complex, but the inspectors did not find any guidance or further instruction on what constitutes a complex evolution. Some operators did perform a cursory review of the procedure prior to performing the evolution. Operators confirmed that this standard of performing procedures from memory was reinforced by crew supervisors and was not corrected to enforce procedural use.

3. Continuous Learning

   The inspectors determined that the licensee, both prior to the events in early 2021 and during the implementation of the corrective actions for the events, has not conducted benchmarking outside of the NCNR facility. Benchmarking is an attribute of healthy safety culture under the continuous learning trait. This lack of benchmarking has not allowed NIST to learn from other organizations and to continuously enhance knowledge, skills, and safety performance.

4. Environment for Raising Concerns (Safety Conscious Work Environment)

   The NRC's Final Safety Culture Policy Statement defines a safety conscious work environment (SCWE) as an environment where personnel feel free to raise safety concerns, both to their management and to the NRC, without fear of retaliation, where concerns are promptly reviewed, given the proper priority, and appropriately resolved, and timely feedback is provided to those raising concerns. In contrast, a "chilled work environment" is one in which personnel perceive that raising safety concerns to their management or to the NRC is being suppressed or is discouraged and can occur because of an event, interaction, decision, or policy change [Ref. 42].

   The inspectors determined that licensee personnel are willing to raise nuclear safety concerns and feel that they are empowered to stop work when they identify issues. However, the inspectors also determined that while personnel would raise concerns, many perceived that the path to resolution was arduous. In addition, personnel stated that they did not feel heard when raising concerns because they do not always receive feedback on the resolution of issues. The ability to raise concerns at NCNR is normally through discussions with management. The inspectors determined that most personnel did not use the corrective action program and did not have any other means to raise concerns, including through a process to raise concerns anonymously. While personnel are currently willing to raise safety concerns, the initial resistance to concerns may cause personnel to feel uncomfortable raising concerns in the future, especially upon any return of the facility to operations.

Because of the identified weaknesses, the NRC staff has concerns about the sustainability of the licensee's corrective actions; specifically, the sustainability of continuous training and a continuous process for updating procedures. The existing resources do not appear adequate to provide future continuous training and procedure modifications compatible with the previous production schedule. The sustainability of the licensee's proposed corrective actions and any additional required corrective actions will be addressed as part of the supplemental and/or restart activities. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-18). The identified safety culture issues will be addressed as part of the supplemental and/or restart activities that will oversee any further actions resulting from additional corrective actions as part of the enforcement process. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-19).

iii. Licensee-Identified Observations

The inspectors assessed the licensee-identified observations referenced in Section 7.a.1 above. While the emergency response observations will not directly prevent another similar event from occurring, the inspectors determined that they would allow the licensee to implement the emergency response plan more effectively. As discussed in Section 5.d of this report, the licensee identified several SPIs related to these observations. However, the licensee did not commit to a timeline for these improvements. The NRC staff will continue to assess this area which may involve additional licensee actions because of the apparent violations identified in this report. Many of the other licensee identified observations note symptoms of the safety culture issues identified earlier in this report. However, the NRC staff will need to further assess the details and implementation of the improvements that address the identified observations.

iv. Inadequate Audits

The inspectors interviewed personnel and reviewed logs, documentation, and records to assess the NIST audit requirements and process.

NIST test reactor TS 6.2, "Review and Audit," states that "[t]he NCNR Safety Evaluation Committee is established to provide an independent review of NCNR reactor operations to ensure the facility is operated and maintained in such a manner that the general public, facility personnel and property shall not be exposed to undue risk [and that] [t]he NCNR SAC is established to provide an independent review or audit of NCNR reactor operations. This audit is to ensure that safety reviews and reactor operations are being performed in accordance with regulatory requirements and public safety is being maintained." Furthermore, TS 6.2.4, "SEC Audit Function," Specification (2) states, in part, that the SEC shall audit the "[r]esults of actions taken to correct deficiencies that affect reactor safety at a frequency of once per calendar year, not to exceed 15 months."

The inspectors observed that the NIST management failed to appropriately address deficiencies identified in independent audits conducted by the NCNR SAC and the International Atomic Energy Agency Operation and Maintenance Assessment of Research Reactors (OMARR). These deficiencies identified during the various audits were similar in nature to many of the root causes of the February 3, 2021 event that NIST identified. For example, the SEC did not take appropriate actions to resolve the following audit findings:

- OMARR report dated December 4, 2012, recommended, in part, that NCNR staff develop a plan for benchmarking, develop a plan to manage change, develop a corrective action program, develop a program to upgrade outdated procedures and training, and perform an independent safety culture assessment along with training on the Institute of Nuclear Power Operations traits of a healthy nuclear safety culture.
- SAC report dated December 2014, identified that NIST had made some progress on the OMARR recommendations, but needs to continue to make improvement in the above areas.
- SAC report dated March 2, 2017, identified many of the above issues and identified shift staffing issues, as well as the aging reactor management program lead needing more authority to ensure cooperation from all other NIST staff. While that report did not list specific recommendations to improve training, it did suggest that a more structured training program would benefit the facility.
- SAC report dated March 13, 2019, identified 14 recommendations including further development of the aging reactor management program, guidance and metrics for staff promotion, and implementation of a formal corrective action program.
- SAC audit completed October 24, 2019, identified a complacency issue at the NCNR.

The NRC staff considers that the failure of the licensee to appropriately address deficiencies identified by independent audits contributed in part to the failure of NIST personnel to properly latch fuel element S-1175 on January 4, 2021, which was subsequently damaged during plant operations. The inspectors found that NIST did identify a need to communicate the SAC recommendations to the NIST staff but did not identify or communicate any corrective actions to address the inadequate response to the audit findings. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-20).

v. <u>Inadequate Leadership</u>

NIST test reactor TS 6.1.2, "Responsibility," states that responsibility for the safe operation of the NIST test reactor shall be with the established chain of command and that individuals at the various management levels shall be responsible for the policies and operation of the NIST test reactor, for safeguarding the public and facility personnel from undue radiation exposures, and for adhering to all requirements of the operating license and technical specifications.

NIST identified several root causes as discussed above; however, the inspectors identified as an additional cause that NIST management failed to provide equipment, procedures, training, etc., to support safe operations. The inspectors concluded that the NIST test reactor leadership is ultimately responsible for providing these tools to ensure that the NIST test reactor is operated in a safe manner and that the leadership's failure to do this resulted in the failure of NIST personnel to properly latch fuel element S-1175 on January 4, 2021, which was subsequently damaged during plant operations. This item will be reviewed during a future inspection activity and tracked as an IFI (05000184/2022201-21).

c. Conclusion

The inspectors reviewed the licensee-identified root causes and found that they contributed to the event. However, the inspectors determined that the root causes analysis/discussion was technically incomplete because it did not discuss all possible root causes. The inspectors also identified safety culture issues that the licensee had failed to address in the root cause reports. Lastly, the inspectors determined that further assessment of the root causes may be needed following the enforcement process.

8. Corrective Actions

a. NIST Proposed Corrective Actions

Along with determining the root causes of the February 3, 2021 event, both the TWG root cause report [Ref. 33] and the ERCAS Final Root Cause Analysis and Corrective Action Plan [Ref. 37] identified several corrective actions to address the root causes. The licensee also proposed program improvements for consideration by NCNR management, that are intended to strengthen NIST's safety culture.

On October 1, 2021, the licensee submitted a report on the fuel failure event [Ref.5], which contains multiple enclosures outlining the licensee's proposed path forward. In Enclosure 4 [Ref. 43], NIST management concurs with all the proposed corrective actions and commits to implement all of them. This enclosure also provides additional details related to each corrective action. In Enclosure 7 [Ref. 44] and Enclosure 8 [Ref. 45] of the restart request, the licensee identifies those actions that it believes need to be completed prior to restart and those that will be completed after restart. Additionally, the licensee provides a brief status of each corrective action. The licensee's proposed corrective actions address areas such as aging reactor management and change management programs, improved training of both operators and supervisors specific to refueling and more generally to provide more consistent and structured training, and improved procedural compliance along with improving the procedures. The licensee also put in place several administrative controls and is developing a visual inspection tool to ensure that all fuel elements are verified to be latched prior to startup.

b. NRC Staff Assessment

The inspectors conducted an independent assessment of the licensee's proposed corrective actions. Although the inspectors determined that NIST had identified several reasonable corrective actions that could prevent future events like the February 3, 2021 event, the inspectors determined that additional evaluation is needed to fully assess the completeness and effectiveness of the licensee's proposed corrective actions. The licensee did propose a plan for implementation of the corrective actions related to restart. However, the NRC staff has not concurred with that plan for several reasons. First, as discussed earlier, the inspectors identified weaknesses in the licensee's root cause analysis that will need to be addressed. Also, additional corrective actions could result from the enforcement process that will need to be implemented by the licensee and assessed by the NRC staff. Additionally, NIST has proposed mostly administrative and programmatic corrective actions as opposed to technical corrective actions like redesigning the latch mechanism and engineering a method to provide operators real-time visual confirmation that elements are latched as they are performing the evolution. The authorization to restart will involve NRC inspection staff and additional NRC technical staff. A licensing audit is in progress as part of these review activities.

The inspectors determined that additional evaluation of the licensee's proposed corrective actions is needed. Many of the licensee's proposed corrective actions involve developing and/or implementing complex, new programs (e.g., change management) or considerably revamping existing programs (e.g., training). To assess the effectiveness of these proposed corrective actions accurately and completely, the inspectors will need to evaluate the implementation details of such programs. Furthermore, the licensee has yet to complete a necessary revision to operating procedures. The inspectors will need to review a sample of those revised procedures to assess the effectiveness of the revisions. Also, as discussed above, inspectors identified concerns related to sustainability of the corrective actions which will need further evaluation.

c. Conclusion

The inspectors determined that the NRC staff will need to conduct supplemental inspections following any enforcement actions and both before and after any restart determination to fully assess the effectiveness of the licensee's corrective actions.

9. Exit Meeting

The NRC inspectors discussed the inspection findings with NIST at the conclusion of the special inspection on Thursday, March 10, 2020. A final exit briefing was conducted during a public meeting with NIST on Wednesday, March 16, 2022.

REFERENCES

1. "Revision to National Institute of Standards and Technology Test Reactor Special Inspection Team Charter." ADAMS Accession No. ML21062A301
2. U.S. Nuclear Regulatory Commission. *Event Notification Report for February 03, 2021*. Retrieved from: https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2021/20210204en.html
3. U.S. Nuclear Regulatory Commission. *Event Notification Report for March 02, 2021*. Retrieved from: https://www.nrc.gov/reading-rm/doc-collections/event-status/event/2021/20210303en.html
4. U.S. Nuclear Regulatory Commission, "National Institute of Standards and Technology - U.S. Nuclear Regulatory Commission Interim Special Inspection Report No. 05000184/2021201," dated April 14, 2021. ADAMS Accession No. ML21077A094.
5. "NBSR Report on February 3, 2021 Fuel Failure Event, Root Causes, Corrective Actions, and Restart Readiness," ADAMS Accession No. ML21274A018.
6. "NBSR Emergency Plan," December 2008, as amended July 1, 2017.
7. Emergency Instruction 4.4, "Emergency Equipment," Revision A, dated December 14, 2015.
8. Emergency Instruction 4.1, "Radiation, Contamination, and Environmental Surveys," Revision A, dated December 14, 2015.
9. Instrumentation and Control Procedure RM 4-1, "Building Exhaust Stack Radiation Monitor," Revision B, dated July 26, 2018, completed July 8, 2020.
10. Technical Specification Procedures 4.4(1)(b), "Channel Test of Confinement Closure Using a Source on Detectors RD3-4, RD3-5, RD4-1," Revision A, dated February 14, 2014.
11. National Institute of Standards and Technology (NIST). 2004. *Safety Analysis Report (SAR) for License Renewal for the National Institute of Standards and Technology Reactor-NBSR*. NBSR 14, NISTIR 7102, Gaithersburg, Maryland. ADAMS Accession No. ML041120250.
12. Department of Energy/National Nuclear Security Administration, "Validation of the Public Radiation Exposure Calculation for the Incident at the National Institute of Standards and Technology Center for Neutron Research on February 3, 2021," dated April 12, 2021.
13. J. Tracey to file. "Draft Estimate of public dose for release on 2/3/21 – 2/6/21," dated February 17, 2021.
14. Lawrence Livermore National Laboratory. *Modeling System Architecture*. Retrieved from: https://narac.llnl.gov/tools/operational-modeling/system-architecture
15. Lawrence Livermore National Laboratory. *Urban and Complex Terrain Dispersion Modeling*. Retrieved from: https://narac.llnl.gov/research-and-development/urban-dispersion-modeling
16. Sandia National Laboratories. *Nuclear Incident Response Program – Turbo FRMAC*. Retrieved from: https://nirp.sandia.gov/Software/TurboFRMAC/TurboFRMAC.aspx#Features
17. Appendix A, "Technical Specifications for the NIST Test Reactor (NBSR)," Amendment No. 12, dated September 21, 2020. ADAMS Accession No. ML14204A628.
18. Letter from R. Dimeo and T. Newton to U.S. Nuclear Regulatory Commission. "Report of NCNR safety limit exceeded," dated March 5, 2021. ADAMS Accession No. ML21064A523.
19. U.S. Nuclear Regulatory Commission, "Safety Evaluation Report Related to the Renewal of Facility Operating License No. TR-5 for the National Bureau of Standards Test Reactor, National Institute of Standards and Technology," dated June 2009. ADAMS Accession No. ML090990135.

20. Peacock, H B. "Properties of U_3O_8-aluminum cermet fuel." WSRC-RP-89-981. United States. https://doi.org/10.2172/7262763. https://www.osti.gov/servlets/purl/7262763.
21. NBSR Engineering Procedure NBSR-0002-CL-00, NBSR Fuel Shipment and Fuel Acceptance Procedure, dated August 21, 2018.
22. Maintenance Procedure 2.54, "SNM Inventory," Revision C, dated March 18, 2021.
23. Operating Instruction 6.1, "Fueling and Defueling Procedures," Revision E, dated August 28, 2019.
24. Operating Procedure 6.1.F, "Transferring Fuel Elements or Experimental Thimbles," dated November 19, 1976.
25. Operating Instruction 6.1, "Fueling and Defueling Procedures," Revision F, dated March 30, 2021.
26. Operating Instruction 6.1, "Fueling and Defueling Procedures," Revision G, dated April 8, 2021.
27. Operating Instruction 1.1, "Reactor Startup," Revision E, dated December 31, 2020.
28. Document titled, "Nuclear Instrument Response," dated October 21, 2021. ADAMS Accession No. ML21294A371.
29. Enclosure 4, "Root Cause Response," Revision 1. ADAMS Accession No. ML21274A022.
30. Emergency Instruction 4.1, "Radiation, Contamination, and Environmental Surveys," Revision A, dated December 14, 2015.
31. Operating Instruction 3.6, "Essential Personnel Evacuation," Revision A, dated December 14, 2015.
32. Operating Instruction 3.8, "Recovery Operations," Revision A, dated December 14, 2015.
33. "Root Cause Investigation of February 2021 Fuel Failure, NCNR Technical Working Group," Revision 1, dated May 13, 2021.
34. NUREG-1478, "Operator Licensing Examiner Standards for Research and Test Reactors," Revision 2, dated June 2007. ADAMS Accession No. ML072000059.
35. American National Standards Institute/American Nuclear Society 15.4-2007, "Selection and Training of Personnel for Research Reactors," dated August 17,2007.
36. "Addendum to Root Cause Investigation of February 2021 Fuel Failure NCNR Technical Working Group (TWG)," dated June 3, 2021.
37. "SEC Subcommittee Report: Review of the NCNR Event Response and Technical Working Group Root Cause Analysis and Corrective Action Plan," dated August 12, 2021.
38. Document titled, "Problem Identification and Resolution," ADAMS Accession No. ML21288A553.
39. U.S. Nuclear Regulatory Commission, "Final Safety Culture Policy Statement," *Federal Register*, Vol. 76, No. 114, June 14, 2011, pp. 34773-34778.
40. NUREG-2165, "Safety Culture Language," dated March 2014 ADAMS Accession No. ML14083A200.
41. Document titled, "Safety Culture and NCNR Leadership Accountability," dated October 14, 2021. ADAMS Accession No. ML21288A554.
42. Regulatory Issue Summary 2005-18, "Guidance for Establishing and Maintaining a Safety Conscious Work Environment," dated August 25, 2005 ADAMS Accession No. ML052220239.
43. Enclosure 4, "Root Cause Response," dated September 20, 2021 ADAMS Accession No. ML21274A022.
44. Enclosure 7, "Corrective Action Plan – Corrective Actions Required Prior to Reactor Startup," ADAMS Accession No. ML21274A025.

45. Enclosure 8, “Corrective Action Plan – Corrective Actions Required Post Startup,” ADAMS Accession No. ML21274A026.

PARTIAL LIST OF PERSONS CONTACTED

Licensee

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T. Newton	Deputy Director, NCNR and Chief, Reactor Operations and Engineering
B. Remley	Health Physicist
J. Seiter	Senior Reactor Operator
R. Strader	Chief, Reactor Operations
J. Tracy	Health Physicist

INSPECTION PROCEDURES USED

IP 92701	Followup
IP 93812	Special Inspection

ITEMS OPENED, CLOSED, AND DISCUSSED

Opened

See Table 1 and Table 2

Closed

05000184/2021201-01	URI	Assessment of licensee's fuel cladding temperature analysis (TS 2.1, "Safety Limit")

LIST OF ACRONYMS USED

10 CFR	Title 10 of the *Code of Federal Regulations*
ADAMS	Agencywide Documents Access and Management System
C	degrees Celsius
CF	Contributing Factor
CPM	Counts Per Minute
ECS	Emergency Control Station
EN	Event Notification
ERCAS	Event Response and Corrective Action Subcommittee
ER-O	Emergency Response Observation
EST	Eastern Standard Time
F	degrees Fahrenheit
FRMAC	Turbo Federal Radiological Monitoring and Assessment Center
HR	Hour
IE	Instruments, equipment, and tools
IFI	Inspector Follow-up Item
IP	Inspection Procedure
LODI	Lagrangian Operational Dispersion Integrator
MS	Management Systems
MREM	Millirem
MW(t)	Megawatt (thermal)
MHA	Maximum Hypothetical Accident
NARAC	National Atmospheric Release Advisory Center
NCNR	NIST Center for Neutron Research
NIST	National Institute of Standards and Technology
NRC	U.S. Nuclear Regulatory Commission
OI	Operating Instruction
OMARR	Operation and Maintenance Assessment of Research Reactors
PEC	Pre-decisional Enforcement Conference
PR	Procedure adequacy and use
QT	Qualification and training
RC	Root Cause
RM	Radiation Monitor
SAC	Safety Assessment Committee
SAR	Safety Analysis Report
SEC	Safety Evaluation Committee
SPI	Suggested Program Improvement
SIT	Special Inspection Team
TEDE	Total Effective Dose Equivalent
TWG	NCNR Technical Working Group
TS	Technical Specification
URI	Unresolved Item