OFFICE OF NUCLEAR REACTOR REGULATION
TECHNICAL EVALUATION REPORT

Concerning The National Institute of Standards and Technology National Bureau of Standards Test Reactor Related to Reactor Restart Following Exceedance of the Fuel Cladding Temperature Safety Limit

Renewed Facility Operating License No. TR-5
Docket No. 50-184

March 9, 2023

Enclosure

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
TECHNICAL EVALUATION REPORT
CONCERNING THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
NATIONAL BUREAU OF STANDARDS TEST REACTOR
RELATED TO REACTOR RESTART FOLLOWING
EXCEEDANCE OF THE FUEL CLADDING TEMPERATURE SAFETY LIMIT

EXECUTIVE SUMMARY

On February 3, 2021, during a startup and approach to full power, the National Institute of Standards and Technology (NIST, the licensee), National Bureau of Standards test reactor (NBSR, the facility), experienced a reactor scram due to indications of high exhaust stack radiation. The NBSR remained in a stable shutdown condition following the event.

On March 2, 2021, following its review of video surveillance and primary coolant sample results, NIST informed the U.S. Nuclear Regulatory Commission (NRC, the Commission) that the February 3, 2021, event had involved an exceedance of the fuel cladding temperature safety limit in the NBSR technical specifications (TSs). The NRC's regulations in Title 10 of the *Code of Federal Regulations* Section 50.36, "Technical specifications," paragraph (c)(1)(i)(A) state, in part: "If any safety limit is exceeded, the reactor must be shut down. The licensee shall notify the Commission, review the matter, and record the results of the review, including the cause of the condition and the basis for corrective action taken to preclude recurrence. Operation must not be resumed until authorized by the Commission." The NBSR TSs include similar requirements for the licensee to shut down the reactor and not resume reactor operations until authorized by the NRC.

This technical evaluation report (TER) documents the NRC staff's review of the February 3, 2021, event and the licensee's subsequent corrective actions and outlines the basis for the NRC's authorization to resume operation of the NBSR. The staff conducted a detailed technical review of the impacts of the event on the NBSR structures, systems, and components to ensure that there is no functional damage to preclude safe operation of the facility. The staff also evaluated NIST's procedures and practices to ensure that they provide reasonable assurance that the reactor will be operated consistent with its license and the NRC's regulations. Furthermore, the NRC staff and NIST agreed to a series of additional corrective actions in response to the apparent violations identified in relation to the event. These actions are memorialized in a confirmatory order dated August 1, 2022, and the NRC continues to provide enhanced oversight of the facility. This TER documents the staff's review in each of these areas, along with other factors considered in the restart decision.

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NATIONAL BUREAU OF STANDARDS TEST REACTOR

RELATED TO REACTOR RESTART FOLLOWING EXCEEDANCE OF

THE FUEL CLADDING TEMPERATURE SAFETY LIMIT

RENEWED FACILITY OPERATING LICENSE NO. TR-5

DOCKET NO. 50-184

1.0 INTRODUCTION

By letter dated October 1, 2021 (Reference (Ref.) 2), as supplemented by letters dated October 21, 2021 (Ref. 3), December 3, 2021 (Ref. 4), June 29, 2022 (Ref. 8), August 15, 2022 (Ref. 9), and November 17, 2022 (Ref. 10), the National Institute of Standards and Technology (NIST, the licensee) submitted to the U.S. Nuclear Regulatory Commission (NRC, the Commission) a restart request for the National Bureau of Standards test reactor (NBSR, the facility). The restart request was submitted to demonstrate, through the results of the licensee's review regarding the cause of a February 3, 2021, exceedance of the NBSR fuel cladding temperature safety limit and the basis for corrective action taken or committed to be taken to preclude recurrence of this exceedance, that restart of the NBSR would be in accordance with the facility's license and NRC regulations.

1.1 Background

On February 3, 2021, during a startup and approach to full power, the NBSR experienced a reactor shutdown due to indications of high exhaust stack radiation. The NIST Center for Neutron Research (NCNR)[1] reactor operators subsequently declared an Alert in accordance with the NIST emergency plan. Once the reactor was secured, the reactor confinement building and the control room were evacuated. Following the initial evacuation, the reactor was continually monitored by reactor operators via the remote emergency control station. NCNR personnel were contaminated during the event and event response but were externally decontaminated and medically cleared to return home. Monitoring of internal contamination of NCNR personnel found no significant contamination. At 3:32 pm Eastern Time (ET) on February 3, 2021, the Alert was downgraded to a notification of unusual event in accordance with the NIST emergency procedures. At 7:35 pm ET on February 3, 2021, NIST terminated the event because all air samples were normal, which confirmed that the exit criteria described in the emergency procedures were met.

[1] The NCNR is the organization within NIST that operates the NBSR.

During the February 3, 2021, event, the facility gaseous effluent monitors detected an increase in radiation. The reactor safety system automatically responded to this increased radiation level by initiating a major scram that resulted in the automatic insertion of all four shim rods. This was accompanied by the immediate activation of the confinement isolation system, which resulted in automatic closure of all penetrations of the confinement building including the ventilation valve, process piping, guide tubes, and personnel access doors. In this manner, all the structures, systems, and components (SSCs) relied upon for safe operation of the facility functioned as designed, placed the reactor in a safe shutdown condition, and isolated containment. These automatic functions terminated the event and reduced its radiological consequences by limiting the effluent pathways. As part of the event, however, the NBSR experienced damage to one of its fuel elements. This resulted in molten fuel material reaching the lower grid plate in the immediate vicinity of the damaged fuel element by exiting through the coolant system nozzle region of the damaged fuel element and in small pieces of molten fuel material exiting the top of the upper portion of the damaged fuel element and entering the NBSR primary coolant system.

The NBSR remained in a stable shutdown condition following the February 3, 2021, event. The licensee conducted radiation and contamination surveys within the reactor building and visual inspections of the reactor core. Air samples taken at the site boundary during the event showed near background radiation levels and direct radiation measurements at the site boundary were below detectable levels. The NRC staff remains satisfied that public health and safety was protected during and after the event, and that the surrounding community remains safe.

On March 2, 2021, NIST informed the NRC in an event notification (EN 55120; available at the NRC public website (https://www.nrc.gov) under the NRC Library Tab, Document Collections, Event Notification Report Archive, Report for March 3, 2021) that following its review of video surveillance and primary coolant sample results, it determined that the February 3, 2021, event exceeded the fuel cladding temperature safety limit in NBSR technical specification (TS) 2.1, "Safety Limit." TS 2.1 states, in part: "The reactor fuel cladding temperature shall not exceed 842°F [degrees Fahrenheit] (450°C [degrees Celsius]) for any operating conditions of power and flow."

The NRC's regulations in Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.36, "Technical specifications," paragraph (c)(1)(i)(A) state, in part: "If any safety limit is exceeded, the reactor must be shut down. The licensee shall notify the Commission, review the matter, and record the results of the review, including the cause of the condition and the basis for corrective action taken to preclude recurrence. Operation must not be resumed until authorized by the Commission." Similarly, NBSR TS 6.6.1, "Actions to Be Taken in the Event the Safety Limit is Exceeded," also states, in part, that "[t]he reactor shall be shutdown and reactor operations shall not be resumed until authorized by the NRC" and that the licensee shall make reports to the NRC that "shall include an analysis of the causes and extent of possible resultant damage, efficacy of corrective action, and recommendations for measures to prevent or reduce the probability of recurrence."

Because the February 3, 2021, event resulted in the NBSR exceeding its fuel cladding temperature safety limit, the NBSR was required by 10 CFR 50.36(c)(1)(i)(A) and TS 6.6.1 to be shut down and to remain shut down until the licensee demonstrates to the NRC, through the results of its review regarding the cause of the event and the basis for corrective action taken to preclude recurrence, that restart would be consistent with the facility's license and NRC regulations.

1.2 Basis to Authorize Restart of the NBSR

As a result of exceeding the safety limit in the NBSR TSs and as required by regulation, NRC authorization is needed for NIST to restart the facility. This TER provides part of the underlying basis to authorize the restart of the NBSR. In addition to this TER, several other documents support the NRC's restart authorization and informed the development of the TER. The NRC staff evaluated NIST's procedures and practices, performed inspection activities, and engaged in alternative dispute resolution with NIST regarding apparent violations, which resulted in an agreement to a series of additional corrective actions, as memorialized in a confirmatory order dated August 1, 2021. As part of its corrective actions, NIST determined that some changes were needed to the NBSR's licensing basis to support the restart of the facility. To effectuate these changes, NIST submitted three license amendment requests to the NRC, which the NRC staff reviewed and approved separate from its review of the licensee's restart request. The documents that support the NRC's restart authorization are summarized in sections 1.4 through 1.7 of this TER and include:

- The NRC special inspection team inspection and report (Ref. 1).
- The confirmatory order (CO) (Ref. 11).
- Supplemental inspections and reports (Ref. 12 and Ref. 24).
- The safety evaluation for the latch verification requirements license amendment (Ref. 21).
- The safety evaluation for the fuel debris license amendment (Ref. 25).
- The safety evaluation for the fuel management scheme license amendment (Ref. 26).

This TER documents the NRC staff's review of the NBSR restart activities to determine if NIST has acceptably demonstrated that there is currently no functional damage at the NBSR to those features necessary for safe operation of the facility, that the completed corrective actions and license amendments provide reasonable assurance of continued safe operation and that reoccurrence of the event will be precluded, and that restart of the facility would be in accordance with the NBSR's license, as amended, and NRC regulations.

1.3 Summary of NIST Request to Restart

By letter dated October 1, 2021 (Ref. 2), NIST submitted a restart request to the NRC. This restart request specified NIST-identified root causes and corrective actions to preclude recurrence of the February 3, 2021, event. The restart request included the following:

1. A root cause investigation, which identified causes and contributing factors.
2. Proposed improvements to the latching of fuel elements.
3. Proposed actions to be taken to restore the reactor systems to operational status.
4. A fuel reuse evaluation.
5. A statement that a functional evaluation of the balance of plant systems will be performed.

In the restart request letter, NIST identified corrective actions necessary to be completed to assure restart readiness. NIST also provided a list of activities planned for recovery of the facility.

The NRC staff reviewed the restart request, determined that additional information was required, and requested that additional information (Ref. 5). The licensee responded to this staff request by letter dated December 3, 2021 (Ref. 4). To better understand the proposed corrective actions, the staff conducted a regulatory audit from December 1, 2021, through November 9, 2022 (Ref. 6). The regulatory audit allowed the staff to directly review documents and conduct onsite observations related to the restart request. A summary of items reviewed, and observations made, is provided in the audit report (Ref. 7). The licensee supplemented its October 1, 2021, restart request by letters dated December 3, 2021 (Ref. 4), June 29, 2022 (Ref. 8), August 15, 2022 (Ref. 9), and November 17, 2022 (Ref. 10).

The seven root causes that NIST identified are:

1. Change management program needs improvement.
2. There was inadequate management oversight of refueling staffing.
3. There was a culture of complacency, lack of licensee personnel ownership of continuous improvement.
4. The training and qualification program for reactor operators was not on par with programmatic needs.
5. Procedures as written did not capture necessary steps to assure latching of elements.
6. Procedural compliance was not enforced.
7. Inadequacies existed in fidelity of latch determination equipment and tools.

The corrective actions that NIST identified with respect to the root causes are:

1. Develop and implement a change management framework to evaluate sufficiency of existing change management processes, identify gaps and areas for improvement.
2. Develop system for knowledge and skills management in the presence of licensee personnel attrition.
3. Assess efficacy of all tools and determine necessary improvements.
4. Prioritize and elevate the Aging Reactor Management program emphasizing oversight of communications between groups and ensuring that maintenance and other issues identified are resolved.
5. Develop program for robust qualification of supervisors overseeing refueling operations.
6. Require training for supervisors on oversight.
7. Develop a plan for involving licensee personnel in continuous improvement of reactor operations, through participation in a preventive action program that encourages and rewards proactive efforts to improve quality, safety, and efficiency of operations.
8. Require proficiency training for reactor operators prior to all refuelings, emphasizing the importance of latching and procedural compliance.
9. Develop program for robust qualification of reactor operators and candidates in moving fuel.
10. Training materials, such as qualification cards and experience with use of fuel handling stand, should reflect learning objectives.
11. Provide consistent and structured training and immediate and continual feedback to trainees during on-the-job training to ensure comprehension of performance expectations.
12. Develop consistent standard by which all supervisors evaluate qualifications.
13. Rewrite Operating Instruction (OI) 6.1 and OI 6.2 to capture detail of fuel and latch movements to align with training.
14. Reinstitute requirement for latch checks prior to final pump restart; modify OI 2.1.
15. Institute a redundant rotation latch check, performed by a second individual.
16. Update procedures to require training for all licensee personnel on procedure adherence.
17. Revise procedures to be consistent with Institute of Nuclear Power Operations 11-003.

18. Institute a method of visual checks.
19. Document that improved latching and latch check processes provide adequate defense against unlatching.
20. Modify index plate so that it is consistently positioned in the same place and rotational fiduciary marks are clear.
21. Consider discontinuing use of height checks to verify latching.
22. Put administrative controls in place (procedures) to assure no tool contact with fuel head following final visual latch verification prior to reactor startup.
23. Increase access to the reactor top for training purposes or redesign/modify existing test stand to better simulate reactor top fuel loading/latching/latch checking experience.

The NRC staff reviewed these root causes and corrective actions identified by NIST as part of the special inspection team (SIT) as described in section 1.4 of this TER.

1.4 Summary of the Special Inspection Team

Following the February 3, 2021, event, on February 8, 2021, the NRC staff chartered and dispatched an SIT in accordance with NRC Management Directive 8.3, "NRC Incident Investigation Program," and Inspection Manual Chapter 2545, "Research and Test Reactor Inspection Program." Consistent with its charter (Ref. 19), the SIT conducted an onsite review to address the following:

1. The sequence of events.
2. The licensee's response to the event.
3. The consequences of the event.
4. The adequacy of facility procedures
5. The maintenance and/or outage actions preceding the event.
6. The licensee's determination of the root cause of the event.
7. The completed or planned corrective actions to prevent recurrence.

The SIT determined that although the fuel cladding temperature safety limit was exceeded for at least one fuel element, the resultant radiological release was well within the limits of 10 CFR Part 20, "Standards for Protection against Radiation," for any radiological dose to individual members of the public. The total radiological effluent released following the partial flow blockage to one fuel element was less than that assumed in the maximum hypothetical accident (MHA) as identified in the NRC staff's safety evaluation report for the renewal of the facility's license (Ref. 13). The SIT also determined that operators responded to the event in accordance with established procedures and in a manner that protected public health and safety. The SIT findings are summarized in a report dated March 16, 2022 (Ref. 1).

The SIT report included: (a) two apparent violations related to exceeding the fuel cladding temperature safety limit; (b) three apparent violations related to inadequate fuel handling, startup, and emergency response procedures; and (c) two apparent violations related to inadequate fuel handling within the vessel and inadequate modifications that invalidated operators' ability to meet a TS requirement. In addition to the apparent violations, the SIT also identified weaknesses in the licensee's root cause analysis as well as the proposed corrective actions. Following the issuance of the SIT report, the NRC staff and NIST engaged in an alternative dispute resolution (ADR) process and agreed to a series of corrective actions that were memorialized in a CO, as discussed in section 1.5 of this TER.

1.5 Summary of Enforcement Actions and Confirmatory Order

In response to the apparent violations identified in the SIT report, NIST engaged in an ADR process. The goal of the ADR was to allow the NRC and NIST to reach agreement on actions necessary to restore the facility to its design basis conditions. The NRC staff and NIST held three ADR sessions between May 10 and June 2, 2022.

On August 1, 2022, the NRC staff issued CO EA-21-148 (Ref. 11) to memorialize the actions identified and agreed upon during the ADR process. The CO modified the facility license, requiring actions in the following areas: communications; nuclear safety program assessment; training; procedure enhancement; benchmarking; employee engagement; leadership accountability; and technical issues related to the event and corrective actions. While all of the license modifications and required actions are to be completed by the licensee, the staff determined that a subset of those actions are necessary to be completed prior to any restart of the facility. These items are identified in the supplemental inspection plan (Ref. 12) developed in conjunction with the CO and discussed in section 1.6 of this TER.

1.6 Summary of Supplemental Inspections

The NRC staff developed a supplemental inspection plan to inform the NRC's decision on whether to authorize restart of the facility and to provide increased oversight of reactor operations until the staff determines that routine inspections are adequate. The supplemental inspection plan provides enhanced oversight in the following areas: emergency plan/event response; refueling/fuel handling; reactor startup procedures and operator actions; reactor operator requalification training; management oversight; safety committee oversight; procedure enhancement and quality; the design change process; safety culture; and security. Additionally, it identifies which inspection activities are to be completed prior to any restart of the facility.

Consistent with the supplemental inspection plan, the NRC staff sent a team of inspectors to the NBSR to assess the licensee's inspection and testing program and the licensee's readiness for restart. The objectives of the supplemental inspection team included determining if: (1) the corrective actions have been properly executed; (2) the revised inspection procedures support the TS-required verification of fuel latching; and (3) sufficient safety culture improvements address the deficiencies stated in the SIT inspection report.

The NRC team of inspectors concluded that for the actions that were required to be completed prior to any restart and necessary for the restart decision, the licensee adequately implemented the corrective actions. The NRC staff's findings and observations are summarized in the first quarterly inspection report (Ref. 24). The inspection report closed the following supplemental inspection activities:

1. the emergency plan and event response
2. fuel handling including the refueling/fuel handling supplemental inspection objectives
3. operational procedures contain more information and the precritical and reactor startup procedures are adequate to ensure safe operation of the facility
4. operator licensing supplemental objectives and management oversight objectives
5. corrective actions supplemental objectives and the remaining open items related to the corrective actions are not required for restart and will be closed in a subsequent report
6. safety culture supplemental inspection objectives, prior to restart, are closed, and the remaining open items, related to safety culture, are not required for restart and will be closed in a subsequent report after completing those inspections

The NRC staff plans to continue conducting supplemental inspections and issuing quarterly inspection reports until the staff determines that routine inspections are sufficient to ensure safe operation.

1.7 Summary of the License Amendments Supporting the Restart Decision

As part of its corrective actions, NIST determined that some changes were needed to the NBSR's licensing basis to support the restart of the facility. To effectuate these changes, NIST submitted three license amendment requests to the NRC, which the NRC staff reviewed separate from its review of the licensee's restart request. The staff approved each license amendment after determining that (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) there is reasonable assurance that such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public. The staff has not identified any additional corrective actions for which license amendments may be required prior to authorizing the resumption of operation of the NBSR.

Fuel Element Latching Verification

On July 21, 2022, the NRC issued Amendment No. 13 to the NBSR license that revised the TSs related to the latching verification of fuel elements (Ref. 21). Specifically, the amendment revised the TS 3.9.2.1 fuel element latch verification requirements to require a rotational check followed by a visual inspection. A discussion of Amendment No. 13 as it relates to latch verification is included in section 2.3.1.1 of this TER.

Operation with Fuel Element Debris

On February 1, 2023, the NRC issued Amendment No. 14 to the NBSR license that revised the facility safety analysis report (SAR) to address potential impacts to facility equipment as described in chapter 5, "Reactor Coolant Systems," of the SAR and changes to the facility radiation sources as described in chapter 11, "Radiation Protection and Waste Management," of the SAR, as a result of some debris remaining in the NBSR primary coolant system following the February 3, 2021, event and the licensee's cleanup efforts (Ref. 25). A discussion of Amendment No. 14 as it relates to reactor components is included in section 2.2.1.2 of this TER.

Core Loading Analysis Methodology

On March 2, 2023, the NRC issued Amendment No. 15 to the NBSR license that revised the facility SAR to authorize the use of a specific method to perform core loading analyses of the NBSR. The amendment was necessary because the proposed core loading patterns following the February 3, 2021, event deviated from the four new fuel elements per operating cycle described in the SAR. A discussion of Amendment No. 15 as it relates to the reactor fuel is included in section 2.1.2 of this TER.

1.8 Regulatory Evaluation

The NRC staff considered the following statutes, regulations, licensing basis, and guidance during its review of the licensee's restart request.

The Atomic Energy Act of 1954, as amended, Section 182.a states that:

> In connection with applications for licenses to operate … utilization facilities, the applicant shall state such technical specifications, including … such … information as the Commission may, by rule or regulation, deem necessary in order to enable it to find that the utilization … of special nuclear material will be in accord with the common defense and security and will provide adequate protection to the health and safety of the public. Such technical specifications shall be a part of any license issued.

The regulations in 10 CFR 50.36(c) state that TSs for utilization facilities will include items in specific categories, including "safety limits," which are defined at 10 CFR 50.36(c)(1)(i)(A) for nuclear reactors as "limits upon important process variables that are found to be necessary to reasonably protect the integrity of certain of the physical barriers that guard against the uncontrolled release of radioactivity."

The regulations in 10 CFR 50.36(c)(1)(i)(A) also state, in part, that:

> If any safety limit is exceeded, the reactor must be shut down. The licensee shall notify the Commission, review the matter, and record the results of the review, including the cause of the condition and the basis for corrective action taken to preclude recurrence. Operation must not be resumed until authorized by the Commission.

Commission authorization to resume operation after the exceedance of a safety limit does not confer additional authority upon a licensee than it already possessed under its existing license and is not a licensing action. Therefore, the results of a licensee's review regarding the cause of the condition and the basis for corrective action taken to preclude recurrence must demonstrate that restart would be in accordance with the licensee's license and the NRC's regulations.

NBSR TS 2.1 states, in part, that "[t]he reactor fuel cladding temperature shall not exceed 842°F (450°C) for any operating conditions of power and flow." NBSR TS 6.6.1 states, in part, that "[t]he reactor shall be shutdown and reactor operations shall not be resumed until authorized by the NRC" and that the licensee shall make reports to the NRC that "shall include an analysis of the causes and extent of possible resultant damage, efficacy of corrective action, and recommendations for measures to prevent or reduce the probability of recurrence."

The regulations in 10 CFR 50.36(c) also state that TSs for utilization facilities will include items in the category of "limiting safety system settings [LSSSs]," which are defined at 10 CFR 50.36(c)(1)(ii)(A) for nuclear reactors as "settings for automatic protective devices related to those variables having significant safety functions." NBSR TS 3.2.2, "Reactor Safety System Channels," provides the LSSSs for the NBSR.

Section 13.1, "Maximum Hypothetical Accident," of the NRC staff's safety evaluation report for the renewal of the NBSR license (Ref. 13) analyzes the MHA as a complete blockage of flow to one fuel element by unspecified means. In the MHA, the flow blockage is assumed to result in the complete melting of all the fuel plates in the fuel element and the release of all fission products to the primary coolant. Section 13, “Accident Analyses,” of NUREG-1537, “Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors,” Part 2, “Standard Review Plan and Acceptance Criteria” (Ref. 18), provides that for high-powered reactors, the MHA includes a scenario when fuel cooling is compromised so that the cladding overheats leading to failure of the cladding fission product barrier. The MHA assumes that all fission products in the fuel element are released. This results in fission product release into the reactor coolant and subsequently into the facility air.

2.0 REVIEW OF STRUCTURES, SYSTEMS, AND COMPONENTS

To determine, in part, if the NBSR can be authorized to restart, the NRC staff reviewed the SSCs that were potentially impacted by the February 3, 2021, event to ensure that the licensee adequately addressed the impacts of the event. This review focused on SSCs that could have been impacted by the molten fuel material generated during the event and the potential pathways through which that material could have been transported. The staff evaluated the SSCs present in those areas as discussed in sections 2.1 and 2.2 of this TER. In addition to evaluating impacts on the SSCs from the event, the staff also reviewed the fuel element latching mechanism design to ensure that it is adequate to preclude inadvertent un-latching as discussed in section 2.3 of this TER.

Additionally, the NRC staff evaluated three license amendment requests that NIST submitted to the NRC after determining that specific changes were needed to the NBSR’s licensing basis to support the restart of the facility. As described in section 1.2 of this TER, although the staff approved each of these license amendments separate from the licensee’s restart request, the license amendments are part of the basis for an NRC decision whether to authorize restart of the facility, and they support the conclusion in this section (i.e., that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public).

2.1 REACTOR FUEL

2.1.1 Introduction

The NBSR is a deuterium oxide (heavy water) moderated and cooled, enriched fuel, tank-type reactor designed to operate at a thermal power level of 20 megawatts (MW). The core is comprised of 37 fuel element locations; however, seven fuel element locations are adapted for thimble tubes and 30 locations are available for fuel element assemblies. These locations are arranged in a hexagonal configuration consisting of three concentric rings. The two inner rings have six fuel element locations each and the outer ring has 18 fuel element locations.

The NBSR’s fuel is a materials testing reactor (MTR) plate-type fuel. The fuel is enriched uranium oxide (U_3O_8) mixed in aluminum powder contained in aluminum clad plates. The fuel contains 35 weight-percent uranium. The fuel elements contain 17 curved plates in each of an upper and lower fuel section separated by a gap. The core design is thus a split core with uranium fuel placed above and below the vertical center of the core. This design results in thermal neutron flux reaching a peak in the center of the gap between the lower and upper fuel sections. Both sections of fuel in each assembly are contained in a vertical channel made of two curved, unfueled plates and two side plates. A channel fits into a unit cell of 3.2 x 3.9 inches, and its height is approximately 68.8 inches.

The fuel is cooled by up-flow forced convection. The reactor may operate for short periods at power levels up to 500 kilowatts (kW) without coolant flow, and below 10 kW the heat load is insufficient to heat the coolant significantly without forced convection cooling. Nozzles are attached to the bottom of each fuel element, and the nozzles are seated in the lower grid plate and spring loaded down by a latching mechanism. Nominally 4-percent of the cooling flow into each channel will bypass the channel via a gap between the lower grid plate and bottom nozzle, which is caused by the hydraulic lift forces produced on the fuel assembly by the cooling flow.

The safety basis for fuel integrity in the NBSR includes operating experience with the MTR fuel type, direct experimental evidence derived from mechanical, nuclear, and thermal-hydraulic testing of the fuel type, and a combination of operating and safety limits derived from the NBSR safety analysis.

According to the NBSR SAR (Ref. 14), the design basis of the thermal hydraulic design of the NBSR is that there shall be no fuel damage during normal operation, and no fuel damage resulting in the release of fission products from any credible accident. The reactor has a parametric set of limiting conditions for operation (LCOs), based on ensuring that the fuel cladding temperature remains below 450°C. The licensee ensures that the cladding remains sufficiently cooled using two criteria, which are avoidance of departure from nucleate boiling on the cladding outer surface and avoidance of the onset of flow instability.

The NBSR core configuration and fuel management schemes are described in section 4.5.1.1 of the NBSR SAR. The core support hardware configuration permits the installation of thirty fuel elements, and each cycle operates with a full complement of thirty fuel elements. In addition, NIST generally uses a fuel loading strategy know as its Original Fuel Management Scheme (OFMS). Under the OFMS, four fresh fuel elements are loaded into each restart core and four spent fuel elements are discharged. Roughly half of the fuel is burnt for eight cycles and the other half for seven cycles before being discharged. The core has a set loading and shuffle pattern, and a set length, so that each cycle is highly similar to the previous in terms of nuclear and postulated transient thermal hydraulic characteristics. The normal operating cycle for the NBSR is 7 weeks, with continuous operation at its licensed power level for approximately 38 days. The remaining approximately 11 days are used for maintenance activities and refueling.

The NRC staff evaluated the impacts to the fuel elements that were in the core during the February 3, 2021, event to determine if the fuel performance would still be consistent with the current licensing and design basis of the facility and evaluated the MHA in the NBSR licensing basis to ensure that it remains appropriate and bounding.

2.1.2 Evaluation of the Reuse of the Fuel

On February 3, 2021, during the initial power accession following refueling at the NBSR, fuel element number 1175 in location J-7 of the core overheated since it was not properly seated such that coolant flow into the bottom of the fuel element was blocked. This resulted in partial melting of the fuel element, as supported by observations from visual inspections performed on March 5, 2021. Additionally, during its audit (Ref. 7), the NRC staff also observed thermal-hydraulic and neutronic calculations, performed using methods consistent with those used in the NBSR SAR (i.e., Monte Carlo N-Particle (MCNP) neutronics analyses and RELAP-5 thermal-hydraulic analyses). The results of these analyses indicate that, while the fuel element that experienced melting underwent a significant reduction in coolant flow prior to heating above the melting temperature, the flow to the remainder of the elements in the core was not significantly affected. The staff considers the damaged element to have been rendered unusable by its physical characteristics alone. A significant amount of molten fuel material and cladding material accumulated at the bottom inlet nozzle of the damaged fuel element, rendering the fuel assembly uncoolable and potentially un-installable in the NBSR core configuration. Additionally, enough fuel material melted so as to significantly alter the geometry such that the assembly can no longer be considered to contain an array of plate-type fuel, which would be contrary to NBSR TS 5.3, “Reactor Core and Fuel,” Specification (1), which states, in part, that the “core consists of 30, 3.0 x 3.3 inch … MTR curved plate-type fuel elements….”

In its letter dated August 15, 2022 (Ref. 9), the licensee stated, in part:

> [A] decision was made not to use fuel elements that were present in the core on February 3, 2021, in the initial startup core. NBSR fuel elements are normally in the reactor for either 7 or 8 fuel cycles prior to discharge. As a result, we have a number of 7-cycle elements in storage available for use in the reactor that can be used for one additional 38-day cycle at 20 MW. We have made the determination that we can use a combination of twenty 7-cycle elements and ten new elements in the initial startup core. Note that the use of ten new elements equals a total mass of 3.5 kg [kilograms] of [Uranium]-235, well below the license limit of 5 kg for unirradiated fuel.
>
> An evaluation, given in Engineering Change Notice (ECN) 1241, has shown that parameters such as power peaking and excess reactivity fall within the envelope of all normal operation and accident analyses given in the NBSR SAR. A [10 CFR] 50.59 evaluation has been made and is part of this ECN. Subsequent cores will consist of a combination of (other) 7-cycle elements, the (newer) fuel from the previous core, and up to 6 new elements. It is expected that it will take about ten fuel cycles to reach a typical equilibrium NBSR core configuration. All these cycles will be configured and analyzed so that all safety-related parameters listed in the NBSR SAR will fall within the envelope of the [10 CFR] 50.59 evaluation.

On February 1, 2023, NIST submitted a license amendment request for approval of an alternative fuel management scheme to design fuel cycle loading patterns using more than the four fresh fuel element loading pattern described in the NBSR SAR and approved in the license renewal.

Separately, the licensee verbally notified the NRC staff that subsequent core designs would not include any of the fuel that was present in the reactor during the February 3, 2021, event. However, the staff determined that this notification is immaterial because NIST could at any point in the future design a core that includes fuel that was present in the reactor during the event (1) as long as that fuel remains in NIST’s possession and (2) in the absence of any requirement in the NBSR license precluding such use.

The NRC staff did not identify any specific regulatory or licensing basis requirement that would preclude NIST from later inserting viable fuel elements that were present in the reactor during the February 3, 2021, event into the NBSR core and operating the reactor. Within this context, the staff understands viable fuel elements as being those that have been determined to have not been adversely impacted by the February 3, 2021, event such that the components (e.g., fuel cladding) of the fuel element will continue to perform their design-basis functions under conditions of normal operation, including allowances for anticipated operational occurrences and accidents. Based on the staff’s observations, some, but not all, of the fuel elements present in the reactor during the February 3, 2021, event could be viable. The presence of probable fuel material debris or damage, such as cladding scratches or dented nozzles, suggests that some of these fuel elements may not be appropriate for reuse. See the staff's audit report (Ref. 7) for more information related to NIST's fuel cleaning and inspection activities.

The NRC staff evaluated the above-referenced ECN-1241 documentation, among other engineering change notifications, as part of its enhanced oversight activities. In addition, the licensee referred to an evaluation prepared under 10 CFR 50.59, "Changes, tests, and experiments." The regulations in 10 CFR 50.59(c)(2) set forth criteria under which, if any are satisfied, prior NRC approval is required for a change in the facility as described in the SAR. The staff determined that the core loadings described above constitute changes that would fall under this requirement. As such, the licensee would need to evaluate any change, including the potential reuse of fuel that was present in the reactor during the February 3, 2021, event, under 10 CFR 50.59 and request a prior license amendment from the NRC if any of the criteria in 10 CFR 50.59(c)(2) are satisfied.

The supplemental inspection plan (Ref. 12) includes a section related to the "Design Change Process." Specifically, the NRC's enhanced oversight will review the licensee's change process program and evaluate the effectiveness of the licensee's Engineering Change Management Program. The results of these inspection activities will be included in quarterly inspection reports. Any violations will be identified and resolved upon discovery per the inspection process.

2.1.3 Conclusion

Because NIST remains under enhanced NRC oversight, the NRC staff will be able to review the supporting documentation for any use in the core of fuel elements that were present in the reactor during the February 3, 2021, event. Based on the NRC's regulations, NIST's stated intent to not reuse fuel in the upcoming cycle, and the NRC's continuing, enhanced oversight, the staff has determined that there is reasonable assurance that NIST will not reuse fuel elements that were present in the reactor during the February 3, 2021, event without first evaluating whether this could adversely affect public health and safety. Therefore, the staff did not consider the implications of the reuse of the fuel that was present in the reactor during the February 3, 2021, event as part of its evaluation of an NBSR restart authorization. Accordingly, this issue does not prohibit the resumption of operation of the facility.

2.2 REACTOR SUPPORT SYSTEMS

2.2.1 Primary Coolant System

2.2.1.1 Introduction

The NBSR primary coolant system is designed to circulate heavy water through the reactor to transfer heat from the core to the secondary coolant system. A description of this system and its design functions is provided in section 4.2, "Reactor Core," of the NBSR SAR (Ref. 14).

In response to NRC staff audit questions, by letter dated June 29, 2022 (Ref. 8), the licensee provided to the NRC a report of its analyses regarding the impact of the February 3, 2021, event on the reactor vessel, reactor vessel internals, primary coolant system, and undamaged fuel assemblies. This report includes a figure depicting the configuration of the damaged fuel element and the once-molten fuel material and globules from the fuel element and a description of how small pieces of the molten fuel material entered the primary coolant system. Additionally, the licensee provided details of the activities that it has performed and intends to perform to remove debris from the reactor vessel and primary coolant system.

By letter dated October 19, 2022 (Ref. 23), NIST submitted a license amendment request to the NRC to update sections of the NBSR SAR to reflect that some debris from the February 3, 2021, event remains in the primary coolant system even after the licensee's cleanup efforts. The license amendment request proposed changes to the SAR that considered both the mechanical effects and potential dose consequences related to this debris.

On February 1, 2023, separate from the licensee's restart request, the NRC issued Amendment No. 14 to update sections of the facility SAR to reflect the presence of some debris in the NBSR from the February 3, 2021, event (Ref. 25). The NRC staff's safety evaluation for that license amendment concludes that after the February 3, 2021, event and the licensee's cleanup efforts, the licensee has demonstrated that the piping and piping components of the primary coolant system of the NBSR are capable of performing their intended design functions in accordance with the facility's license, and this supports the staff's restart determination and is summarized below. The staff's review for Amendment No. 14 related to the potential radiological impact and effluent release due to debris remaining in the NBSR primary coolant system is summarized in section 2.2.3 of this TER.

2.2.1.2 Evaluation of Debris in the Primary Coolant System

The issuance of Amendment No. 14 (Ref. 25) supports the NRC staff's review of the licensee's restart request. A summary of the staff's safety review for Amendment No. 14 is provided below. As documented in the staff's safety evaluation accompanying Amendment No. 14, the staff's review focused on the following three topics; a summary of the staff's assessment for each topic is provided below:

- Debris type that entered the primary coolant system
- Amount of debris remaining in the primary coolant system
- Impact of remaining debris on components in the primary coolant system

Debris type that entered the primary coolant system

Based on its review, the NRC staff determined the following in its safety evaluation accompanying Amendment No. 14:

- It is reasonable that the large globules of once-molten fuel material generally remained in the area of the lower grid plate and the damaged fuel element and did not enter the primary coolant system of the NBSR.
- It is reasonable that the small pieces of molten fuel material that exited through the top of the upper portion of the damaged fuel element did not exceed 0.1 inch in at least one dimension.
- The clean-up efforts taken by the licensee (e.g., foreign object search and retrieval and installing 20-micron filters in all of the fuel element positions) were appropriate and reasonable, having proven to be effective in reducing dose rates in the process room and in removing debris from the primary coolant system that resulted from the February 3, 2021, event.
- However, given the uncertainty associated with the precise amount of material from the damaged fuel element that (1) entered the primary coolant system and (2) has been

removed from the primary coolant system during clean-up activities, it is assumed that some debris remains in the system. Accordingly, the licensee addressed this condition through changes to SAR chapter 5.

<u>Amount of debris remaining in the primary coolant system</u>

Based on its review, the NRC staff determined the following in its safety evaluation accompanying Amendment No. 14:

- The licensee determined the maximum possible quantity of debris in the primary coolant system by weighing the damaged fuel element and comparing it to its design basis.
- The licensee's assumption of 66 grams of debris remaining in the primary coolant system is conservative because this estimate does not account for the debris that was removed via the licensee's clean-up efforts.

<u>Impact of remaining debris on components in the primary coolant system</u>

Based on its review, the NRC staff determined the following in its safety evaluation accompanying Amendment No. 14:

- The NBSR Main Heat Exchangers (i.e., HE-1A, HE-1B, and HE-1C) are capable of performing their intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system resulting from the February 3, 2021, event, because of the small size and quantity of remaining debris versus the volume in the primary coolant system and because the licensee has an appropriate means of performance monitoring to ensure proper functionality of the Main Heat Exchangers.
- The pumps in the NBSR primary coolant system are capable of performing their intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system resulting from the February 3, 2021, event, because the small size and quantity of remaining debris is significantly less than the volume of coolant in the primary coolant system and because the design and construction of these pumps is tolerant of small amounts of solids suspended in pumped fluid.
- The NBSR primary coolant system piping is capable of performing its intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system resulting from the February 3, 2021, event, because the small size and quantity of remaining debris is significantly less than the volume of coolant in the primary coolant system and because of the diameter of piping in the primary coolant system.
- The valves in the NBSR primary coolant system are capable of performing their intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system resulting from the February 3, 2021, event, because of the small size and quantity of remaining debris versus the volume in the primary coolant system and because the licensee has an effective means of periodic performance monitoring to ensure proper functionality of the valves.
- The instruments in the NBSR primary coolant system are capable of performing their intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system resulting from the February 3, 2021, event, because of (1) the small size and quantity of remaining debris versus the volume in the primary coolant system, (2) the separation and redundancy of instrumentation, (3) the design of the temperature, pressure, and level instrumentation being insensitive to primary coolant

flow, and (4) periodic performance monitoring that will ensure proper functionality of the instrumentation associated with the flow of the primary coolant.

Based on its determinations summarized above, the NRC staff concluded in its safety evaluation accompanying Amendment No. 14 that SAR chapter 5, as amended, provides an adequate description and assessment to allow operation of the NBSR with the remaining debris from the February 3, 2021, event, and that the heat exchangers, pumps, valves, piping, and instrumentation in the primary coolant system remain capable of performing their intended design function, as described in SAR chapter 5, with the remaining debris in the primary coolant system.

2.2.1.3 Conclusion

Based on the above, the NRC staff has determined that the licensee has demonstrated that the primary coolant system of the NBSR is capable of performing its intended design functions in accordance with the facility's license, as amended, and NRC regulations. Therefore, with respect to the primary coolant system, the staff concludes that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

2.2.2 Reactor Vessel and Reactor Vessel Internals

2.2.2.1 Introduction

The NBSR reactor vessel internals include: the upper grid plate with latching mechanisms; the lower grid plate with holes to seat fuel elements; reactor shim safety arms; an inner plenum region; and an outer plenum region. A description of these components and their design functions is provided in section 4.3, "Reactor Vessel," of the NBSR SAR.

In response to NRC staff audit questions, by letter dated June 29, 2022 (Ref. 8), the licensee provided to the NRC a report of its analyses regarding the impact of the February 3, 2021, event on the reactor vessel, reactor vessel internals, primary coolant system, and undamaged fuel assemblies. This report includes a figure depicting the configuration of the damaged fuel element and the once-molten fuel material and globules from the fuel element and a description of how small pieces of the molten fuel material entered the primary coolant system. Additionally, the licensee provided details of the activities that it has performed and intends to perform to remove debris from the reactor vessel and primary coolant system.

In support of its review of the restart request, the NRC staff evaluated below whether, after the February 3, 2021, event and the licensee's corrective actions, the licensee has demonstrated that the reactor vessel and reactor vessel internals of the NBSR are capable of performing their intended design functions in accordance with the facility's license, as amended.

2.2.2.2 Evaluation of the Reactor Vessel and Reactor Vessel Internals

Upper Grid Plate, Lower Grid Plate, Inner Plenum, and Outer Plenum

In its letter dated June 29, 2022, the licensee stated that when the fuel melted, most of the molten fuel material gathered in the volume that is bounded by the inside of the cylindrical nozzle of the damaged fuel element and the lower grid plate on which the cylindrical nozzle rested. The licensee explained that since the cylindrical nozzle was somewhat inclined with respect to the lower grid plate, some of the molten fuel material made its way out of the damaged fuel element and solidified underwater, thereby obstructing further molten fuel material flow between the nozzle and the lower grid plate. The licensee also stated its determination that there was enough molten fuel material present in the damaged fuel element to “trap” the melt (after solidification) in a conical zone in the nozzle and that the molten fuel material was not able to melt the nozzle (an aluminum tube with a wall thickness of about 3/16 inches). Based on its review of the information provided by the licensee and its inspection of videos and images, the NRC staff determined that it is reasonable to conclude that the large globules of once-molten fuel material on the lower grid plate reached the lower grid plate only by exiting through the nozzle region of the damaged fuel element. The impact of the large globules of once-molten fuel material on the lower grid plate is discussed below.

Additionally, the licensee stated that it determined that the entirety of the fuel plates in the damaged fuel element likely melted except for the upper one inch of the upper fuel plate bundle, which does not contain any uranium oxide. After the bulk of the fuel element melted, an array of slits in the upper portion of the damaged fuel element remained, which the licensee confirmed by video observation of the top of the damaged fuel element. The licensee explained that as the February 3, 2021, event progressed, it is assumed that the interaction of coolant with the molten fuel created sudden unstable steam flashes within the damaged fuel element and that the ensuing steam was jetted through this array of slits. These steam flashes carried small pieces of the molten fuel material, which was limited to a particle size of 0.1 inch in at least one dimension due to the configuration of the slit array, through the top of the damaged fuel element. The NRC staff reviewed chapter 4, “Reactor Description,” and figure 4.2.3, “Fuel Element Assembly,” of the NBSR SAR and determined that the licensee’s description of an array of slits in the upper portion of the damaged fuel element is accurate. Based on the design of the fuel element assembly and the licensee’s video footage, the staff finds it reasonable that small pieces of molten fuel material exited through the top of the upper portion of the damaged fuel element and did not exceed 0.1 inch in at least one dimension.

The licensee explained that once the small pieces of molten fuel material were transported outside of the damaged fuel element, they entered a relatively low flow area in the reactor vessel and started moving toward the exit plumbing at the bottom of the vessel. Based on the size of the pieces of molten fuel material and the fact that they were fully submerged during the event, the NRC staff determined that it is reasonable that this material quickly solidified upon dispersal and that once it entered the reactor coolant system it did not contain sufficient size and heat to metallurgically or thermally impact the ability of the upper and lower grid plates and the inner and outer plenums to perform their intended functions.

The licensee explained that upon removal of the damaged fuel element there was no visible damage to the lower grid plate and that there was no visible evidence of melting anywhere on the lower grid plate and that the once-molten fuel material appears to have solidified immediately after coming into contact with the lower grid plate. This was supported by visual inspection of the once-molten fuel material plug (i.e., in the conical nozzle region) from below the damaged fuel element. The licensee confirmed that the globules that escaped from the nozzle of the damaged fuel element were mostly in the immediate vicinity of the damaged fuel element and that none of the globules were bonded metallurgically to the lower grid plate. The licensee explained that upon the removal of the damaged fuel element, it was clear from the visual inspection that the aluminum oxide layer that has built up over the lifetime of the reactor on the lower grid plate was not damaged as a result of contact with the once-molten fuel material from the damaged fuel element.

As documented in its audit report (Ref. 7), the NRC staff reviewed photos and videos of (1) the contact area between the damaged fuel element and the lower grid plate, (2) the removal of the damaged fuel element from its resting position on the lower grid plate, and (3) the surrounding area of the lower grid plate and the damaged fuel element. Additionally, the staff reviewed photos and videos associated with the clean-up activities performed by the licensee's contractors. The licensee's description of the visual evidence of the damaged fuel element and the lower grid plate is consistent with the staff's observations of these photos and videos. Based on the licensee's descriptions and the photos and videos that the staff reviewed, the staff has determined that it is reasonable to conclude that the globules of once-molten fuel material generally remained in the area of the lower grid plate and the damaged fuel element and that those particles of once-molten fuel material that were transported in the reactor vessel and coolant system did not contain sufficient size and heat to metallurgically or thermally impact the ability of the upper grid plate and the inner and outer plenums to perform their intended functions.

Additionally, the NRC staff noted that as part of the licensee's clean-up activities, all fuel elements were off-loaded and the fuel positions were filled with dummy fuel elements that doubled as filters and that have the same interface with the upper and lower grid plates as actual fuel elements. The licensee confirmed that it did not experience any difficulty with the fit of the dummy fuel elements in the upper and lower grid plates. Thus, the staff has determined that it is reasonable that the once-molten fuel material did not result in dimensional changes to the lower grid plate.

The licensee explained in its letter dated June 29, 2022, that given the situation of once-molten fuel material contacting the lower grid plate, the worst-case scenario would be the component locally losing its metallurgical temper (i.e., that its temper would go from "T6" (annealed 6061 aluminum followed by T6 tempering - heat treatment to maximum hardening) to "O" (annealed 6061 with no tempering)). The licensee evaluated this scenario and determined that such a potential localized change in temper would not affect the functionality of the lower grid plate. The licensee explained that the typical reason for specifying a temper of T6 is that it is easier to machine and indicated that annealing from T6 to O would not impact the function of the lower gride plate. The NRC staff reviewed chapter 4 of the NBSR SAR and noted that the function of the lower grid plate is generally described as (1) maintaining accurate positioning of the fuel elements, the reactivity control devices, and the experimental thimbles and (2) ensuring that the fuel can only be loaded in predetermined locations in the grid plates with limited lateral movement. The staff determined that it is unlikely that localized annealing from T6 to O of the lower grid plate occurred and that the functionality of the lower grid plate was impacted because it was fully submerged in cold coolant and has a significant thermal mass compared to the once-molten fuel material from the damaged fuel element.

Based on its review, the NRC staff determined that it is reasonable to conclude that the once-molten fuel material from the damaged fuel element did not impact the ability of the upper grid plate, lower grid plate, inner plenum, and outer plenum to perform their intended functions because (1) the lower grid plate is constantly submerged in cold coolant with a significant thermal mass compared to the once-molten fuel material, (2) photos and videos from the removal of the damaged fuel element indicate that once-molten fuel material was not bonded to the lower grid plate, (3) of the visual condition of the lower grid plate following the removal of the damaged fuel element, (4) there were no fit issues during the installation of the filter elements (i.e., dummy fuel elements designed for filtration during clean up), and (5) the debris that exited the top of the damaged fuel element was not of sufficient size and heat to metallurgically or thermally impact the upper grid plate and the inner and outer plenums.

Reactor Shim Safety Arms

As described above, based on the design of the fuel element assembly and the licensee's video footage, the NRC staff determined that it is reasonable that pieces of molten fuel material exited through the top of the upper portion of the damaged fuel element and did not exceed 0.1 inch in at least one dimension. Based on the size of this dispersed molten fuel material, which was fully submerged during the event, the staff determined that it is reasonable that this material quickly solidified upon dispersal and once it entered the reactor coolant system it did not contain sufficient size and heat to metallurgically or thermally impact the ability of the reactor shim safety arms to perform their intended functions.

However, the NRC staff noted the potential for the molten fuel material dispersed through the top of the damaged fuel element to have long-term impacts on the movement of the reactor shim safety arms. In its letter dated June 29, 2022, the licensee stated that a regularly recurring (i.e., semi-annual) surveillance as prescribed in the NBSR TSs is related to the determination of the 5-degree drop times for fully withdrawn shim arms. Specifically, TS 4.2.1 (1) states: "[t]he withdrawal and insertion speeds of each shim arm shall be verified semi-annually" and TS 4.2.1 (2) states: "[s]cram times of each shim arm shall be measured semi-annually." Additionally, the staff noted that section 4.2 of the NBSR SAR describes that the NBSR has two emergency shutdown mechanisms—the primary one uses the reactor shim safety arms while the secondary one is called the moderator dump system. The staff noted that TS 4.3.3, "Moderator Dump System," specifies that "[t]he Moderator Dump valve shall be cycled annually," which provides a means to verify that the moderator dump system can perform its function as a back-up to the reactor shim safety arms if the reactor shim safety arms cannot be inserted. In its letter dated June 29, 2022, the licensee stated that it will perform the required reactor shim safety arms surveillance at the nominal beginning of the first five reactor cycles after restart and keep track of trends and then continue to monitor the 5-degree drop times for all shims in accordance with the TSs (i.e., with a semi-annual surveillance). Therefore, although the staff determined that it is reasonable to conclude that molten fuel material did not impact the ability of the reactor shim safety arms to perform their intended functions, the periodic verification of the insertion time and speed of each reactor shim safety arm required by the TSs and the availability of the moderator dump system provide additional assurance that the intended functions of the reactor shim safety arms are maintained and that long-term degradation from the February 3, 2021, event, if extant, will be detected in a timely manner.

Clean-up of the Reactor Vessel and Reactor Vessel Internals

In its letter dated June 29, 2022, the licensee explained the measures that it took to clean up the once-molten fuel material from the damaged fuel element within the region of the reactor vessel and reactor vessel internals, which included the following:

- Picking up large (Diameter (D) > 0.25 inches) particulate matter using foreign object search and retrieval (FOSAR) tools at the lower grid plate.
- Vacuuming smaller (0.06 inch < D < 0.25 inch) particulate matter using eductor driven vacuum at the upper and lower grid plates (i.e., a vacuum wand driven by an eductor system operated by a pump that moved the heavy water already present in the reactor vessel).
- Installation of 20-micron filters in all of the fuel element positions (note: U_3O_8 fuel particles are larger than 44 microns). When the pumps run, all primary coolant passes

though these filters while being circulated and the four (parallel) primary pumps were run individually as well as in all possible permutations of one through four pumps.

As documented in its audit report (Ref. 6), the NRC staff observed the licensee's contractors performing clean-up activities, including their ability to identify and retrieve relatively small debris in difficult to access regions within the reactor vessel. Additionally, the licensee's contractors provided an explanation of the approach used during their clean-up activities around the reactor vessel and reactor vessel internals (e.g., inspection and mapping of as-found condition, vacuuming at several different quadrants and elevations within the reactor vessel, manual debris removal with tooling). The licensee also provided an explanation on a mock-up of the vacuum/filtration system that was used by the contractors for clean-up of its ability to capture fine debris. The staff noted that the use of FOSAR tools and an eductor driven vacuum for the removal of large debris (D > 0.06 inches) from the damaged fuel element was performed in a methodical and systematic manner that reasonably ensures the removal of this debris from the area of the reactor vessel and reactor vessel internals. Additionally, the staff noted that the filter elements installed in each fuel element position are capable of and reasonably assure the removal of finer debris (D < 0.06 inches) from the damaged fuel element that circulated in the reactor vessel.

Based on the above, the NRC staff finds that the clean-up actions taken by the licensee were appropriate and reasonably demonstrated to be effective in removing debris from the area of the reactor vessel and reactor vessel internals that resulted from the February 3, 2021, event.

2.2.2.3 Conclusion

Based on the above, the NRC staff has determined that the licensee has demonstrated that the reactor vessel and reactor vessel internals of the NBSR are capable of performing their intended design functions in accordance with the facility's license, as amended, and NRC regulations. Therefore, with respect to the reactor vessel and reactor vessel internals, the staff concludes that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

2.2.3 Evaluation of Debris Remaining in the Primary Coolant System

2.2.3.1 Introduction

In its letter dated August 15, 2022, the licensee stated that the cleanup of the debris in the primary coolant system had reached the point at which no discernable debris can be removed without direct mechanical means. The licensee also stated that the largest single piece remaining would have a mass of less than 0.14 grams. The licensee stated that if the largest remaining piece of debris were to become dislodged from a location outside of the core and then transported to the active core region, the debris could fission and release fission products to the primary coolant system. Once the fission products were in the primary coolant system, the helium sweep would remove the fission products from the space above the coolant entering the containment area. Eventually, assuming normal ventilation alignment, the fission products would be released to the atmosphere through the main stack. The licensee stated that the off-site dose resulting from such a scenario would be negligible. However, in order to ensure the early detection of this radiological release, the licensee stated that the major scram (i.e., reactor scram with confinement isolation) setpoints for the Normal Air, Irradiated Air, and Stack effluent monitors would be reduced from the normal setpoint of 50 thousand counts per minute (kcpm) to 5 kcpm. The confinement isolation that would occur with a major scram would further reduce the potential for any off-site dose consequences.

By letter dated October 19, 2022 (Ref. 23), NIST submitted a license amendment request to the NRC to update sections of the NBSR SAR to reflect that some debris from the February 3, 2021, event remains in the primary coolant system even after the licensee's cleanup efforts. The license amendment request proposed changes to the SAR that considered both the mechanical effects and potential dose consequences related to this debris.

On February 1, 2023, separate from the licensee's restart request, the NRC issued Amendment No. 14 to update sections of the facility SAR to reflect the presence of some debris in the NBSR from the February 3, 2021, event (Ref. 25). The NRC staff's safety evaluation for that license amendment concludes that the licensee had evaluated the potential radiological impact and effluent release due to debris remaining in the NBSR primary coolant after the February 3, 2021, event and the licensee's cleanup efforts; this supports the staff's restart determination and is summarized below. The staff's review of Amendment No. 14 related to the capability of the piping and piping components of the NBSR's primary coolant system to perform their intended design functions in accordance with the facility's license despite the presence of this debris is summarized in section 2.2.1 of this TER.

2.2.3.2 Summary of Evaluation of Debris License Amendment Request with respect to Radiological Impact

As stated in its safety evaluation for License Amendment No. 14, the NRC staff notes that the licensee has the potential to operate the NBSR with effluent releases exceeding the 10 CFR 20.1101(d) as low as is reasonably achievable (ALARA) dose constraint. If the ALARA dose constraint is exceeded, the regulations require that the license report the exceedance and promptly take appropriate corrective action to ensure against recurrence. Evaluations of the licensee's performance including those timeframes during and/or soon after any startup of the NBSR will be performed as part of the NRC's ongoing enhanced oversight of the NBSR.

The debris license amendment request proposed, in part, to revise NBSR SAR section 11.1.1 to describe the radiological effect of fuel material in the primary coolant system. Specifically, the proposed changes to the SAR describe the potential for fission products to be generated in the reactor vessel from fuel material in the reactor vessel. The proposed changes further describe the capability of monitors to detect these fission products, the use of the lower radiation monitor setpoint (i.e., 5 kcpm) during startup, and that the reactor operator would take action to shut down the reactor upon the detection of excessive fission product gases. Based on the above, the NRC staff concluded that the proposed changes to the SAR were acceptable with respect to the licensee's ability to meet the ALARA public dose constraint in 10 CFR 20.1101(d). The staff also concluded that, even with fuel material remaining in the primary coolant system, NIST has a sufficient radiological control program in place and implemented to meet the requirement of 10 CFR 20.1101(b) that the licensee achieve occupational doses and doses to members of the public that are ALARA.

2.2.3.3 Conclusion

Based on the above, the NRC staff has determined that the licensee has demonstrated that the NBSR is capable of performing its intended design functions with respect to potential radiological impact and effluent release due to debris remaining in the NBSR primary coolant in accordance with the facility's license, as amended, and NRC regulations. Therefore, with respect to this issue, the staff concludes that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

2.3 LATCHING MECHANISM

2.3.1 Latching Mechanism Design and Latching Process

2.3.1.1 Introduction

Section 4.2.5, "Core Support Structure," of the NBSR SAR provides that in addition to the force of gravity, each fuel element is held in place by a locking mechanism located at the top of each assembly. The current NBSR fuel element design employs a latching bar that is rotated to lock the fuel element in the upper grid plate. Following fuel handling, it is necessary to ensure that this bar is properly positioned so that a fuel element cannot be lifted out of the lower grid plate, which would lead to a reduction in flow to the element after pump flow is initiated.

At the time of the February 3, 2021, event, TS 3.9.2.1 required verifying the latching bar position 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; or (3) visual inspection of the fuel element head or latching bar. After the February 3, 2021, event, the licensee proposed to revise TS 3.9.2.1 to read as follows (Ref. 15):

> 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. This shall be accomplished by both of the following methods:
>
> (1) Rotational check of the element head after final latching rotation by the refueling tool, followed by
>
> (2) Visual inspection of the fuel element head or latching bar verifying that the element is in the latched position.

On July 21, 2022, the NRC issued Amendment No. 13 to the NBSR license to incorporate this proposed TS change (Ref. 21). The NRC staff provided its safety evaluation of the proposed TS change with the letter forwarding the license amendment to NIST. As discussed in that safety evaluation, the staff determined that the proposed TS change will provide verification that each fuel element is locked in position during the refueling process.

Upon the movement of a fuel element to its intended position in the core grid, the final mechanical manipulation is to push down on the fuel element head using the pickup tool to compress the spring on the head to move the latch to below the bottom of the upper grid plate. The tool is then rotated counterclockwise about 45 degrees to its full stop position thus moving the latch underneath the notch in the upper grid plate. The tool is then raised slightly to release the spring and set the latch into the notch. Prior to the removal of the tool from the fuel element head, consistent with TS 3.9.2.1, as amended, a rotational check of the azimuthal position of the collar affixed to the tool is performed against fiduciary marks on a sleeve inserted into the element position in the index plate. After the rotation checks are complete and all tools are placed in their stowed positions, consistent with TS 3.9.2.1, as amended, the visual inspection is performed by setting a camera to "record" and placing it into the fuel transfer system. This camera is systematically moved through the fuel transfer system and, in turn, positioned immediately over each fuel element position. The camera is retrieved after it has traversed the entire system. The video is then uploaded and reviewed by an operator. The operator, along with a second person, visually verifies and documents that each fuel element is latched.

The amendment to TS 3.9.2.1 prescribing the latch checking process described above provides reasonable assurance that the NBSR will not be operated until a redundant inspection is made to verify that all fuel elements are latched in their proper position in the core grid. Two checks are performed to ensure that the fuel elements are latched. Both checks are based on a determination of the angular orientation of the fuel head and, hence, the position of the latch bar. The angular orientation of the fuel head and latch bar of a latched fuel element is distinguishable from that of an unlatched fuel element. In the first check (the rotational check), a mechanical tool is used to determine the angular orientation of the latch bar by comparing it to a reference angle and thus ensuring that the fuel element is latched in the core grid based on its angular orientation. The second check (the visual inspection) is a visual (non-contact) inspection of the angular orientation of the head of each fuel element. The visual inspection provides additional and independent verification that each fuel element is latched in the core grid and does not have the potential to affect the latching of any fuel element.

In addition to amending TS 3.9.2.1, the licensee initiated an engineering study to determine if a benefit would arise from a redesign of the NBSR fuel element head. In particular, the licensee established Corrective Actions and Reactor Recovery Items Team 5a to identify any deficiencies in the fuel head and latch mechanism design, and to explore possible improvements. This team has not made a final recommendation regarding proposed changes to the fuel head design. However, the team has identified two areas of potential design improvement: (1) a modification to improve the engagement with the upper grid latch slots and (2) mitigation of the stored spring torsion. The team is continuing to develop recommendations for possible improvements to the NBSR fuel element head design and latching process. Any such design modifications would be evaluated in the future and are not addressed in this TER.

2.3.1.2 Evaluation of the Latching Mechanism

In addition to approving the amendment to TS 3.9.2.1, the NRC staff evaluated the adequacy of the NBSR latching mechanism design and the latching process, including auditing NIST documents and information, and conducting teleconferences to discuss those documents and information with NIST personnel. The staff also participated in an observation at the NBSR on April 13, 2022, of exercises of the fuel element latching process using revised procedures in response to the February 3, 2021, event, and the amendment to TS 3.9.2.1. The licensee supplemented its restart request on December 3, 2021 (Ref. 4), with responses to staff requests for additional information. Upon reviewing these responses, the staff requested that the licensee make available for the staff's review documents related to the fuel element head design and the latching process, including design specifications, demonstration and testing plans, procedures, and reactor operator and supervisor training. Specifically, the staff requested the following:

a. Design specifications and diagrams for the latch checks, as amended, and the camera system.

b. Demonstration and testing plan for the latch checks and camera system, and records of the completion of the demonstration and testing plan.

c. Amended procedures for the refueling operation, including rotational checks and visual inspections, with a step-by-step process for latching each fuel element by the reactor operator and for a follow-up verification of the latching of each fuel element by a senior reactor operator.

d. Amended standards for supervisory oversight of the refueling operation.

e. Training plan for initial qualification and annual requalification proficiency demonstration for reactor operators and supervisors for performance of the rotational checks and visual inspections, and records of the completion of the reactor operator and supervisor training.

f. Previous and amended NBSR OI 6.0, “Refueling Operation.”

Based on this information, the NRC staff evaluated the NBSR latching mechanism design and the latching process as described in the following section.

NBSR Fuel Element Head Design and the Fuel Element Latching Process

As currently designed, each NBSR fuel element employs a latching bar that is rotated to lock the fuel element in the upper grid plate. Following fuel handling, the latching bar is positioned so that the fuel element cannot be lifted out of the lower grid plate, which would lead to a reduction in flow to the element after pump flow is initiated. In its letter dated December 3, 2021, the licensee described its plans to improve the latching process through rotational checks and visual inspections. The licensee stated that both processes would be demonstrated and tested, along with required operator training, prior to the loading of fuel in preparation for any restart of the NBSR. The licensee indicated that the tool to be used for the rotational checks would have clear markings that would match newly installed markings on the reactor index plate. The licensee also stated that updated procedures would be used via the reader-worker method, which would involve the procedures being read aloud step-by-step. Additionally, the licensee stated that reactor supervisors would be trained with standards put in place for supervisory oversight to ensure that procedures and procedural adherence policies are being followed.

The NRC staff reviewed the documents and informational items initially made available by the licensee and provided follow-up information requests and questions to the licensee. In response to these discussions, the licensee implemented additional improvements to the procedures for the fuel element latching process. To review these documents in more detail, the staff conducted an audit of numerous NIST procedures and other documents related to the process for performing fuel element latching during the refueling of the NBSR made available by NIST in an electronic reading room. For example, the staff reviewed OI 1.1.0, “Reactor Startup Checklist,” OI 6.1.7, “Rotational Latch Checks,” OI 6.1.8, “Visual Check of Fuel Element Latch Bar,” OI 6.1.9, “Visual Inspection Analysis,” and several other NIST documents.

On April 13, 2022, the NRC staff participated in an onsite observation of the fuel element latching process using the procedures that were revised in response to the February 3, 2021, event, and the amendment to TS 3.9.2.1. As part of the verification of the proper latching of each fuel element, a camera is placed over each fuel element to record its position. After the camera has traversed the entire fuel system, the video is uploaded and reviewed to verify that all fuel elements are properly latched in the core grid structure. The licensee is conducting repetitive exercises for the fuel element latching process to adequately train the reactor operators on the process. From its observation, the staff determined that the new procedures and their implementation provide a deliberate method of verifying fuel element latching in the NBSR.

Based on the audit and the onsite observation of the fuel latching process, the NRC staff finds that the NIST procedures provide acceptable instructions for fuel element latch verifications for the current NBSR fuel element head design. A detailed description of the staff's review of the NIST procedures and other documents is provided in the staff's audit report dated November 28, 2022 (Ref. 7). Based on its review, the staff finds that the current NBSR fuel element head design with the revision to TS 3.9.2.1 and the implementation of the improved NIST fuel element latching procedures provide reasonable assurance of the successful completion of the fuel element latching process with proper latching of the NBSR fuel elements prior to NBSR startup.

In its letter dated December 3, 2021, the licensee indicated that it established a team to evaluate future improvements to the current fuel element head design and the latching process. During teleconferences, the NRC staff discussed the progress of these activities with the licensee. The development and implementation of future improvements to the current NBSR fuel element head design and the latching process will be subject to NRC oversight.

NIST Reactor Operator and Supervisor Training Improvements

In its letter dated December 3, 2021, the licensee identified measures being put into place to ensure reactor operator proficiency for the refueling activity. These measures are: (1) training and qualification of supervisors; (2) implementation of an annual qualification of all operators in moving fuel with the operators demonstrating their proficiency to a senior reactor operator; (3) implementation of a continuous learning program; and (4) periodic management reviews of the effectiveness of the training and refueling qualification programs. In response to a follow-up request by the NRC staff, the licensee made available to the staff the documentation establishing these measures and the controls established to verify their implementation and the periodic assessment of their effectiveness. For example, the licensee revised the procedures for initial and periodic proficiency training for reactor operators and supervisors to provide more specific provisions for training and proficiency evaluation.

Based on its review, the NRC staff has determined that the training process for the initial and periodic proficiency for reactor operators and supervisors for the refueling activity provides reasonable assurance of the capability of the NBSR operators and supervisors to perform their required functions with respect to fuel element latching and, therefore, provides additional assurance for the staff's finding of reasonable assurance of proper latching of the NBSR fuel elements. The ongoing proficiency training for NBSR operators and supervisors will be subject to NRC oversight.

Technical Specifications Change

As discussed above, separate from the licensee's restart request, the NRC staff issued Amendment No. 13 to the NBSR license to incorporate the revision to TS 3.9.2.1 to ensure the proper latching of the NBSR fuel elements. As discussed in the staff's safety evaluation accompanying Amendment No. 13, the TS change, along with the improved procedures and training discussed above, provides reasonable assurance of proper latching of the NBSR fuel elements.

2.3.1.3 Conclusion

Based on the above, the NRC staff has determined that the licensee demonstrated that there is reasonable assurance that the fuel elements can be latched under the current NBSR fuel element head design in accordance with the facility's license, as amended, and that the improved fuel element latching procedures and training, and their implementation, provide additional assurance of fuel element latching. Therefore, with respect to latching mechanism design and latching process, the staff concludes that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public. To verify continued improvement in NBSR operations and refueling, the staff will track the following activities in its oversight role: (1) the development and implementation of possible improvements to the NBSR fuel element head design and refueling process in the future and (2) the establishment and implementation of periodic proficiency training for NBSR operators and supervisors.

2.4 DESIGN BASIS AND TECHNICAL SPECIFICATION REVIEW

2.4.1 Introduction

As described in the SIT inspection report (Ref. 1), the NRC staff determined that the NBSR SSCs that are important to safety (e.g., the reactor protection system) functioned as designed during the February 3, 2021, event. Additionally, the staff evaluated the NBSR LSSSs to confirm that changes to the LSSSs were not necessary. The staff also evaluated the MHA in the NBSR licensing basis to ensure that it remains appropriate considering the event.

2.4.2 Evaluation of the Limiting Safety System Settings

The NBSR TSs include LSSSs designed to provide protective action if any combination of the principal process variables should approach the safety limit. The LSSSs include limits on reactor power level, reactor outlet temperature, and forced coolant flow. None of the LSSSs process limits were exceeded during the February 3, 2021, event, but the fuel temperature safety limit was exceeded. Given that, the NRC staff considered the effectiveness of the LSSSs and determined that they remain sufficient to ensure that the safety limit is not exceeded, provided that the LCOs are also met. In the case of the February 3, 2021, event, TS 3.1.3, "Core Configuration," was not met. TS 3.1.3 states, in part: "The 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." Following the February 3, 2021, event, the fuel element in core position J-7 was discovered to be resting on the grid plate and not in its required grid position. As a result of not meeting TS 3.1.3, this fuel element did not receive sufficient cooling as assumed in the development of the LSSSs, specifically, forced coolant flow during operations above 10 kW. Therefore, the staff concludes that since an LCO, which ensures "the lowest functional capability or performance levels of equipment required for safe operation of the facility," was violated during the event, the failure to comply with that LCO resulted in the LSSSs' inability to provide a protective action prior to exceeding the safety limit. Accordingly, since an LCO was violated, the results of the February 3, 2021, event do not invalidate the LSSSs provided in the NBSR TSs.

Conclusion

Based on the above, the NRC staff finds that the NBSR LSSSs continue to meet 10 CFR 50.36(c)(1)(ii)(A) and that no changes to the LSSSs are necessary. Therefore, with respect to LSSSs, resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

2.4.3 Evaluation of the Maximum Hypothetical Accident

To ensure that the MHA in the NBSR licensing basis remains appropriate considering the February 3, 2021, event, the NRC staff compared the February 3, 2021, event to the MHA. The MHA is similar to the event since it is a postulated complete blockage of coolant flow to one fuel element.

The blockage of coolant flow to a fuel element would result in a rapid decrease in reactivity as the coolant in the fuel element boils and is expelled from the fueled region of the element. As fuel temperature rises, local boiling of the coolant would occur and would cause power fluctuations. The analysis of the MHA assumes that none of these factors lead to a shutdown of the reactor. Instead, the reactor would shut down because the fission product monitor would alarm after the failure of the fuel element cladding and the release of fission products, followed by the effluent air exhaust monitors in the stack alarm, which results in an automatic scram and confinement isolation.

Under this scenario, normal ventilation is automatically secured (see TS 1.3.26.1 and TS 3.2.2), confinement is isolated, and emergency ventilation is automatically established by the high stack activity. This condition is assumed for the duration of the accident. At this stage, it is necessary to consider the timing and nature of the fission product release to the confinement building. Since the MHA does not involve a release of primary coolant, the important fission products are the noble gases and iodine. All the noble gas fission products from the entire fuel element are assumed to be released into the primary coolant and then to quickly collect in the helium space at the top of the reactor vessel. The maximum dose to the public at the 400-meter exclusion boundary zone from the MHA is conservatively calculated to be 6.4 milliroentgen equivalent man (mrem).

Like the MHA, the February 3, 2021, event at the NBSR involved the blockage of coolant flow to one fuel element. Partial fuel plate melting released fission products and resulted in Krypton gas being observed at the stack monitor, solid material being deposited on the lower grid plate that appeared to have been once molten and then resolidified, and radioactive effluent being released to the environment. The once-molten material was distributed on the lower grid plate near the bottom nozzle of the improperly placed fuel element. The once-molten material did not reach other areas of the lower grid plate since it quickly solidified in the presence of the primary coolant. NIST calculated the total dose to the public during the event to range from 0.00035 mrem to 0.0008 mrem, which is a small fraction of the hypothetical MHA dose consequence and is also a small fraction of the 10 CFR Part 20 public dose limit of 100 mrem.

Conclusion

The NRC staff compared the assumptions and conservatisms considered in the MHA to the actual February 3, 2021, event and compared MHA doses and event doses. The staff determined that the assumptions in the MHA analysis continue to be conservative relative to the event primarily because the MHA assumes a complete loss of fuel element inventory compared to only a partial loss during the February 3, 2021, event. Additionally, the staff determined that the maximum dose calculated from the MHA is significantly more than the actual doses from the event. Based on the above, the staff finds that the MHA in the NBSR licensing basis remains appropriate and valid and that no changes are necessary. Therefore, with respect to the MHA, resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

3.0 ENHANCED OVERSIGHT

As highlighted in section 1.4 of this TER, the SIT identified violations as well as weaknesses in NIST's root cause analysis and proposed corrective actions outlined in the licensee's restart request (Ref. 2). These deficiencies were addressed through the ADR process, memorialized in the associated CO, and confirmed via supplemental inspection.

3.1 Alternative Dispute Resolution and Confirmatory Order

As discussed in section 1.5 of this TER, in response to the SIT apparent violations, NIST opted to pursue the ADR process. The goal of ADR is to allow both parties to reach an agreement on actions necessary to return the facility to safe operations. One of the outcomes of the ADR process was CO EA-21-148, which, among other actions, modified the license to require NIST to complete specific tasks prior to and following any restart of the NBSR. The CO acknowledged and formalized corrective actions completed by NCNR. As discussed in section III of the CO, NCNR completed the following corrective actions and enhancements to preclude recurrence of the exceedance of the fuel cladding temperature safety limit:

1. NCNR Safety Culture

   NCNR personnel secured funding for its Nuclear Safety Culture Improvement Program (NSCIP), addressing problem identification and resolution, root cause investigations, training, procedures, and oversight.

   The NSCIP provides additional assurance that NCNR will improve the change management process, address the issues of cultural complacency and lack of licensee personnel ownership, and ensure licensee personnel ownership of continuous improvement. The NRC staff expects that the benchmarking required by the CO will provide NCNR with knowledge and insight to address the safety culture performance concerns and enhance NCNR's ability to prevent recurrence of a similar event.

2. Management

   NCNR leadership has engaged the larger NIST organization to secure additional funding related to the corrective actions, including hiring of additional personnel, and to aid in the NBSR clean-up and recovery. NCNR has initiated hiring actions to establish a fifth operating shift dedicated to training and maintenance. This action provides additional assurance that NCNR reactor operators receive training on infrequently performed tasks and eliminates the "shift lock" that resulted in inexperienced personnel performing a task (e.g., latch verification) incorrectly because of lack of experience with the specific task.

   NCNR hired a new Chief of the Aging Reactor Management (ARM) program. This position will provide oversight of the communications between engineering and operations to help ensure that identified issues are resolved. The ARM program provides additional assurance that any future facility changes are completely reviewed and evaluated for potential impacts on the reactor SSCs via 10 CFR 50.59 and license amendments, as appropriate.

3. Corrective Action Program

   NCNR implemented a "Safety Good Catch/Good Idea" program to increase its personnel's use of the corrective action program. This program provides additional assurance that licensee personnel will approach problems with a questioning attitude, addressing one of the root causes of the February 3, 2021, event.

   NCNR established an Engineering Change Management Program to improve 10 CFR 50.59 evaluations and screenings. The establishment of this program addresses apparent violation 7 in the CO, "Apparent violation of 10 CFR 50.59, 'Changes, tests and experiments,' paragraph (c)(1)," by providing an enhanced review of proposed facility changes with particular emphasis on the applicable regulatory requirements.

4. Procedures

   NCNR modified the procedures guiding the conduct of operations in order to strengthen the oversight role that supervisors perform and to ensure personnel training. NCNR developed a procedures writers' guide ensuring improved clarity of instructions. NCNR updated specific, identified startup procedures. These procedure improvements provide additional assurance that reactor operators will follow instructions clearly articulated in the procedures in a manner consistent with safe reactor operations, including responses to off-normal observations from trend reviews and enhanced instructions.

5. Technical Actions

   NCNR conducted proficiency training for all reactor operators, emphasizing the importance of latch verification, procedure use, and procedure compliance. NCNR established proficiency requirements for reactor operators performing fuel handling, including latch verification checks.

   NCNR performed a latch improvement safety analysis, identifying that the improved latching and latch verification process ensured adequate defense against fuel element unlatching. Fuel element unlatching is the technical root cause of the February 3, 2021, event. These actions, along with the revised TS requirements, provide additional assurance that fuel elements will not be in the unlatched condition when the reactor is operated.

The CO also modified the NIST license to require NIST to complete specific actions within a specific time period following the issuance of the CO. The purpose of these actions is to provide additional assurance that the NBSR will be operated safely. These actions are in section V of the CO and include, but are not limited to, the following:

1. Communications

   The NIST director will communicate to NIST employees the specific strategy to improve NCNR's safety culture. A deficiency in safety culture was a contributing factor to the February 3, 2021, event. The development of the safety culture improvement strategy includes the need for the affected personnel to be aware of the plan and how it will be implemented. This action enhances safety culture and the associated behaviors at NCNR.

2. Nuclear Safety Program Assessments

   NCNR will hire an independent, third-party consultant(s) to assess safety culture and the NCNR nuclear program. The results of the assessments will be used to enhance the nuclear safety program at NCNR with particular emphasis on achieving a positive safety culture and its associated attributes.

   The NRC staff's review of the NIST root cause investigation into the February 3, 2021, event identified that an inadequate safety culture was a significant contributor to the actions leading to the event. The nuclear safety program assessments will provide additional assurance that NIST will address the behaviors and actions associated with improving safety culture at NCNR.

   NCNR will also develop and implement an observation program emphasizing procedure oversight and use, a comprehensive corrective action program including incorporation of feedback from NRC staff on the developed program, a program for NCNR employees to raise concerns, and a formal program to monitor the nuclear safety culture.

   These developed and implemented programs will enhance NCNR personnel behaviors focusing on improving safety at the facility. These actions reinforce the unique aspects of the nuclear safety necessary to ensure safe operation of the NBSR.

3. Training

   NCNR will develop and provide additional reactor operator training. All licensed reactor operators will be trained on the performance of fuel loading and latch checking procedures. NCNR will modify its requalification program to require testing and evaluations consistent with the industry standard American National Standards Institute/American Nuclear Society (ANSI/ANS)-15.4 "Selection and Training of Personnel for Research Reactors" (Ref. 28). These actions provide additional assurance that the NBSR will be operated safely.

4. Procedures

   Prior to any restart of the NBSR, NCNR will develop and implement a written procedure that covers procedural use and adherence. Procedure use and quality was a contributing factor to the February 3, 2021, event. Development of a guidance procedure and the continuous review and improvement of the facility's procedures consistent with this guidance procedure will provide additional assurance that the reactor operators will consistently perform their tasks in a manner to ensure safe reactor operations.

5. Benchmarking

   NCNR will perform ongoing benchmarking of at least one programmatic area including visits and observations at another similar facility. At least one NCNR personnel will attend one of the relevant industry conferences.

   The NRC staff inspection and review of the NCNR organization identified that NCNR personnel did not have a comprehensive understanding of implementing strong safety-focused behaviors. Benchmarking and observation will enhance the NCNR understanding of strong positive performance in these areas. The benchmarking will provide additional assurance that the NCNR organization will function in a manner to ensure safe reactor operations.

6. Employee Engagement

   NCNR will establish a rewards program to encourage a change in its personnel's behavior to focus more attention on safety observations and recommendations to improve safety conditions at the facility. Engagement of the NCNR personnel related to safety of the facility, including the reactor, will provide additional assurance of the safe operations of the NBSR.

7. Leadership Accountability

   NCNR will take various actions to improve leadership accountability including safety culture training for all senior leaders and plans to address staffing challenges. These actions provide additional assurance that the NBSR will be operated safely.

8. Technical Issues

   NCNR will assess options to replace its reliance upon administrative controls/actions to ensure that fuel assemblies are adequately latched. NCNR will implement condition-based monitoring of nuclear instrumentation for early indication of mechanical anomalies associated with operating the reactor. The anomaly monitoring action addresses the missed opportunity related to a potential early indication that a fuel element was not properly latched in the core. Focusing attention and utilizing software to identify off-normal reactor conditions from the nuclear instrumentation will provide additional assurance that the reactor will be operated safely and within its design criteria.

   NCNR will assess the configuration management process related to incorporation with the enhanced problem identification and resolution processes. The lack of coordination between configuration changes and reactor operations directly contributed to the failure to properly latch and verify the latching of a fuel element leading to the February 3, 2021, event. This action will provide additional assurance that changes to the facility are properly evaluated to ensure safe reactor operations.

3.2 Supplemental Inspections

3.2.1 Introduction

As discussed in section 1.6 of this TER, the NRC staff developed a supplemental inspection plan for the NBSR. The purpose of the supplemental inspections is to inform the staff's decision to authorize restart of the facility and to provide increased oversight of reactor operations until the staff determines that routine inspections are adequate to ensure safe operations. The supplemental inspection plan categorizes inspection activities as pre-startup activities or activities that will continue following any restart and will be inspected under the enhanced oversight. The pre-startup activities were identified as ones that directly contributed to causing the February 3, 2021, event (e.g., inadequate fueling procedures). In the other activities (e.g., conduct safety culture inspections following a third-party assessment), the staff will continue to monitor under enhanced oversight to ensure that the licensee is adequately implementing the corrective actions required by the CO and committed to be implemented by the licensee.

3.2.2 Overview of Procedure Inspections

Procedure inadequacy was one of the factors primarily contributing to the February 3, 2021, event as identified in the NIST root cause report and observed by the NRC staff in the SIT report. Prior to the February 3, 2021, event, the NBSR procedures did not capture the necessary steps for ensuring that fuel elements were latched. Also, procedural compliance by NBSR personnel was not enforced. NIST identified multiple corrective actions to prevent recurrence of a similar event. During its inspection, the SIT interviewed NBSR personnel and reviewed logs, documentation, and records to assess the procedures used for material controls and accounting; fuel loading, fuel unloading, and fuel movement; reactor startup; and emergency planning. The SIT determined that material control and accounting procedures were adequate and likely did not contribute to the February 3, 2021, event. However, the SIT identified three apparent violations for inadequate fuel handling, reactor startup, and emergency planning procedures that directly contributed to the event. Additionally, the SIT identified inadequate emergency response procedures that impaired the ability of the NBSR personnel to implement the emergency response. In response, NIST reviewed and revised all of the NBSR operating procedures with particular emphasis related to the proper latching of fuel elements.

As discussed in section 3.1 of this TER, NIST developed procedure writing guidance and revised NBSR procedures utilizing that new guidance. The NRC staff reviewed these revised procedures during the supplemental inspections and found them to be consistent with the revised guidance. These procedure improvements provide additional assurance that reactor operators will follow instructions clearly articulated in the procedures in a manner consistent with safe reactor operations, including responses to off-normal observations from trend reviews and enhanced instructions.

3.2.3 Overview of Additional Supplemental Inspection Activities

In addition to the supplemental inspections related to procedures, the supplemental inspection plan identifies inspection activities in emergency planning and event response, refueling and fuel handling, startup activities, operator licensing, management oversight, corrective action programs and processes, safety committee oversight, design change processes, and safety culture. In each of these areas, the NRC staff identified activities that needed to occur prior to any startup and other activities that the staff will continue to monitor under enhanced oversight. For example, the staff inspected the licensee to ensure that the safety-conscious work environment was improving prior to authorizing the restart of the facility and the staff will perform additional safety culture inspections following the licensee completing a third-party safety culture assessment. Under the increased oversight of the facility, the staff will be able to monitor the progress of the licensee to ensure safe operations of the facility. The staff will continue increased oversight until the NRC determines that routine inspections in accordance with NRC Inspection Manual Chapter 2545 are sufficient.

3.2.4 Quarterly Inspection Report

The NRC staff issued a quarterly inspection report (Ref. 24) that provides a summary of its supplemental inspection activities and documents its review of all of the activities required to be completed prior to any restart.

Conclusion

As described in the quarterly inspection report (Ref. 24), the NRC staff has determined that the licensee adequately implemented the corrective actions that were required to be completed prior to any restart. Also, as described in this section, the staff will continue increased oversight to monitor the progress of the licensee to ensure safe operation of the facility. Therefore, the staff concludes that there is additional assurance that the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

3.3 Reactor Operator Requalification Program Improvements

One of the requirements in the CO is for NCNR to modify its requalification plan to specify that every “reactor operating test or evaluation” portion of the licensed operator requalification training must include “other reactivity tasks including fuel movements, insertion and removal of experiments, and rod exchange or movements without power change” as one of the five tasks selected from the ANSI/ANS-15.4 standard outlining the selection and training of personnel for research and test reactors. This action will bolster the operators training and ability to operate the facility safely.

Additionally, separate from the February 3, 2021, event, NIST submitted a request (Ref. 27) to revise the NBSR reactor operator requalification program addressing updates to the mental health requirements for medical evaluation. In addition, the review addressed program issues related to regulatory requirements (10 CFR Part 55, “Operators’ Licenses”) and guidance documents (ANSI/ANS-15.4). During this review, the NRC staff focused on “On-the-job training” requirements to improve the requalification program including in the areas of latch verification and reactor startup and, also, requirements for reactor operators and senior reactor operators to, on a quarterly basis, perform each other’s functions to improve operator proficiency when performing tasks. In making improvements to the reactor operator requalification program there is additional assurance that the NBSR will be operated safely under its existing license.

4.0 CONCLUSION

Based on the information available from the licensee’s submittals, the NRC staff’s regulatory audit and its inspections, the amendments to the NBSR license, the CO, and the staff’s supplemental inspections, the staff has determined that the results of the licensee’s review regarding the cause of the February 3, 2021, event and the basis for corrective action taken or committed to be taken to preclude recurrence of the exceedance of the fuel cladding temperature safety limit, demonstrate that restart would be in accordance with the facility’s license, as amended, and NRC regulations. The licensee demonstrated that there is currently no functional damage at the NBSR to those features necessary for safe operation of the facility. The licensee also demonstrated that reasonable assurance of continued safe operation is ensured by completion of the items identified in the CO as being required prior to any restart. The completed corrective actions and enhancements to preclude recurrence of the exceedance of the fuel cladding temperature safety limit include the areas of safety culture; management; the corrective action program; procedures; and technical issues. The completed technical issues corrective actions include the following: proficiency training for all reactor operations personnel; creation of new emergency instruction procedures; performance of latch improvement safety analysis; assessment of refueling tools; analysis of no-flow height checks to verify latching; added requirement to perform latch checks prior to final pump start; required rotation latch checks; added TS-required visual latch checks; added fiduciary marks to ensure that alignment pin orientation is known; and modified procedures to ensure no tool contact with the fuel head following the final visual latch verification. In addition, any operation following restart will be subject to increased NRC oversight as outlined in the supplemental inspection plan.

Based on the above, the NRC staff concludes that no further licensing actions are required and that the NBSR will be operated consistent with its license, as amended, and the NRC's regulations, upon the authorization of restart. Therefore, the resumption of operation of the NBSR under its existing license will not be inimical to the common defense and security or to the health and safety of the public.

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