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

November 28, 2022

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

SUBJECT: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY – REPORT ON THE REGULATORY AUDIT RE: RESTART REQUEST FOLLOWING EXCEEDANCE OF CLADDING TEMPERATURE SAFETY LIMIT (EPID: L-2021-LLN-0000)

Dear Dr. Dimeo:

By letter dated October 1, 2021 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21274A018), as supplemented by letters dated October 15 and 21, 2021 (ML21288A552 and ML21294A371, respectively), the National Institute of Standards and Technology (NIST) requested authorization from the U.S. Nuclear Regulatory Commission (NRC) to resume operations of the National Bureau of Standards test reactor (NBSR), Facility Operating License No. TR-5. The requested action would allow the NBSR to resume operations after exceedance of the cladding temperature safety limit per Title 10 of the *Code of Federal Regulations*, Part 50, Section 50.36, "Technical specifications."

Enclosed is a report on the regulatory audit conducted by the NRC staff from December 1, 2021, through November 9, 2022, to gain a better understanding of the actions described in the restart request. The audit followed the plan provided by letter dated December 14, 2021 (ML21341B353). The audit report does not authorize restart of the facility or make any licensing findings or conclusions.

If you have any questions, please contact me at (301) 415-3936, or by electronic mail at patrick.boyle@nrc.gov .

Sincerely,

Patrick G Boyle Signed by Boyle, Patrick on 11/28/22

Patrick G. Boyle, Project Manager
Non-Power Production and Utilization Facility Licensing Branch
Division of Advanced Reactors and Non-Power Production and Utilization Facilities
Office of Nuclear Reactor Regulation

Docket No 50-184
License No. TR-5

Enclosure:
As stated

Cc: See next page

cc:

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Test, Research and Training Reactor Newsletter
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SUBJECT: NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY – REPORT ON THE REGULATORY AUDIT RE: RESTART REQUEST FOLLOWING EXCEEDANCE OF CLADDING TEMPERATURE SAFETY LIMIT (EPID: L-2021-LLN-0000) DATED: NOVEMBER 28, 2022

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ADAMS Accession No. ML22322A218 **NRR-106**

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NAME	PBoyle	JBorromeo	PBoyle
DATE	11/21/2022	11/28/2022	11/28/2022

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OFFICE OF NUCLEAR REACTOR REGULATION

REGULATORY AUDIT REPORT

REGARDING REVIEW OF THE RESTART REQUEST

FACILITY OPERATING LICENSE NO. TR-5

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

NATIONAL BUREAU OF STANDARDS TEST REACTOR

DOCKET NO 50-184

Location: National Institute of Standards and Technology (NIST) Center for Neutron Research (NCNR), Gaithersburg, MD, for in-person meeting and observations; and for the virtual portion of the audit: U. S. Nuclear Regulatory Commission (NRC) Headquarters, Rockville, MD, as well as remote login to the NRC secure network.

Dates: December 1, 2021 – November 9, 2022

NRC Audit Team Members:
On Yee, Materials Engineer
Thomas Scarbrough, Senior Mechanical Engineer
Renee Li, Senior Mechanical Engineer
Ryan Nolan, Senior Nuclear Engineer
Joseph Messina, General Engineer
Patrick Boyle, Project Manager

Licensee Representative Audit Team Members:
Robert Dimeo, Director of NCNR
Thomas Newton, Deputy Director of NCNR and Chief of Reactor Operations and Engineering
Paul Brand, Chief of Reactor Engineering
Randy Strader, Chief of Reactor Operations
Steve Dewey, Chief of Health Physics
Andrew Gahan, Chief of Aging Reactor Management

Background

By letter dated October 1, 2021 (Agencywide Documents Access and Management System Accession No. ML21274A018), as supplemented by letters dated October 15 and 21, 2021 (ML21288A552 and ML21294A371, respectively), NIST requested authorization to resume operations of the National Bureau of Standards test reactor (NBSR), Facility Operating License No. TR-5. The requested action would allow the NBSR to resume operations after exceedance of the cladding temperature safety limit (SL) per Title 10 of the *Code of Federal Regulations*, Part 50, Section 50.36, “Technical specifications.” This regulatory audit is intended to assist the NRC staff in making an independent assessment regarding the decision to permit the restart of the NBSR.

On February 3, 2021, following a 6-week outage for reactor refueling, operators were performing an NBSR startup with the reactor operating at 10 megawatts (MW) (50 percent power) when the reactor automatically tripped offline at 0909 Eastern Standard Time (EST) in response to indications of high exhaust stack radiation. Later, NIST determined that one NBSR fuel element experienced partial melting of some of the fuel plates within the fuel element assembly. NIST also determined that some of the once molten material exited the fuel assembly, deposited on the lower grid plate, and redistributed throughout the primary water system.

The regulatory audit was intended to assist the NRC staff in gaining understanding, verifying information, and/or identifying information that will require docketing to inform a regulatory decision related to authorization of the NBSR to resume reactor operations.

In addition to this audit report, the NRC staff prepared a safety evaluation describing the review of a license amendment request (LAR) submitted by NIST to modify the technical specifications for NBSR operation. The NRC staff also prepared a technical evaluation report (TER) that described the NRC staff review of the proposed restart of the NBSR by NIST. Those NRC staff evaluations will be issued separately.

Regulatory Audit Basis

The purpose of this audit is to evaluate whether the licensee's corrective actions, inspections, evaluations, test results, and acceptance criteria conducted in response to the events on February 3, 2021, which resulted in the NBSR exceeding the cladding temperature SL are consistent with the NRC regulations in 10 CFR Part 50, and address the applicable guidance provided in NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," Part 2, "Standard Review Plan and Acceptance Criteria" (ML042430048).

Audit Activities

In response to the restart request submitted by NIST, the NRC staff developed questions which were provided to NIST in a letter dated November 18, 2021 (ML21294A277). The NRC staff audit team used these questions as a starting point for the audit. A virtual kick-off of audit was conducted on December 1, 2021, during the regularly scheduled meeting between NCNR and NRC staff. The scope of audit activities was discussed and the method to identify audit participants was agreed upon. The audit plan identified the NRC branches who would be involved with the audit, but the plan did not name specific individuals.

In a letter dated December 3, 2021 (ML21340A009), NIST provided its response to the NRC request for supplemental information regarding the proposed NBSR restart. Upon review of the information provided by NIST, the NRC staff determined that an audit review of the supporting NIST documents was necessary to reach a safety decision on the proposed NBSR restart. In a letter dated December 14, 2021 (ML21341B353), the NRC informed NIST that the NRC staff would conduct a regulatory audit starting on December 1, 2021, and continuing as necessary, to gain a better understanding of the actions described in the restart request. The NRC letter indicated that the audit may include review of documentation, observation of the facility, and discussions with facility personnel and management. The NRC letter also provided an audit plan with the details of the objective and scope of the audit.

NIST established an online reference portal that provided authorized NRC staff limited read-only access to certain materials owned by and under the control of NIST. Within this audit report, the reference portal will be called the electronic reading room (eRR). The purpose of the eRR is to enhance the NRC's ability to perform its regulatory licensing responsibilities in a timely and efficient manner by providing it with access to reference materials. If the NRC staff determined that information viewed or accessed through the eRR is necessary for formal evaluation or otherwise needed to support the NRC's regulatory decision, the NRC staff requested that NIST formally submit such information in accordance with 10 CFR 50.4, "Written Communications."

Three technical review areas were established to group the questions in this audit. Each of the review areas are discussed in the enclosed attachments. Attachment 1 covers the area associated with the primary coolant system, reactor vessel, and internals. Attachment 2 describes the NRC staff audit review of the fuel element latching mechanism and process. Attachment 3 includes the fuel within the reactor core during the February 3, 2021, event.

On November 9, 2022, the audit activities were closed out during the regularly scheduled meeting between NCNR and NRC staff.

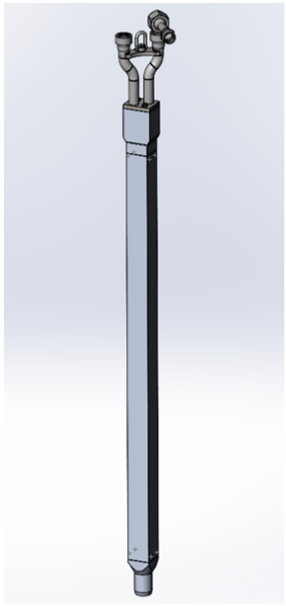
Primary Coolant System
Reactor Vessel and Internals
Audit Review Areas

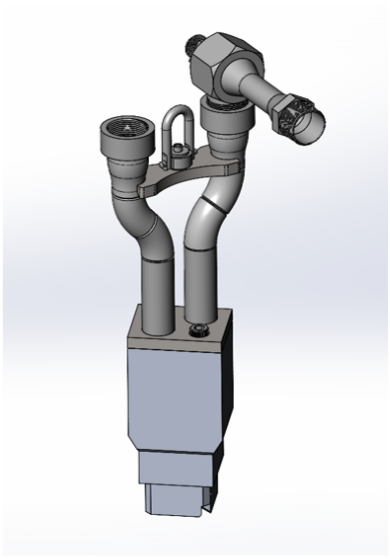
Background

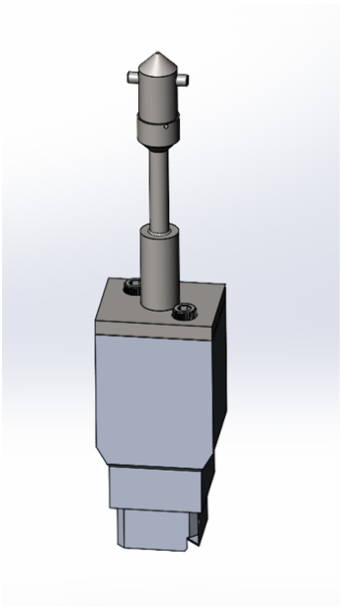
During its audit of the request to restart the NBSR, the staff's review focused on the metallurgical and physical impacts to the vessel internals and core support structures from the damaged fuel element, and the impact of the debris that was introduced to the coolant system from the damaged fuel element. An on-site portion of the audit was also conducted on February 4, 2022, to facilitate discussions of staff audit questions related to the reactor internals and core support structures and observe on-going cleanup activities of the NBSR. The objective was to obtain an improved understanding of (1) the layout/design of the NBSR vessel, vessel internals, and core support structures, (2) the metallurgical impact and debris impact of the event and damaged fuel element on the NBSR vessel, vessel internals, and core support structures, and (3) the clean-up activities of the damaged fuel element and debris in the NBSR.

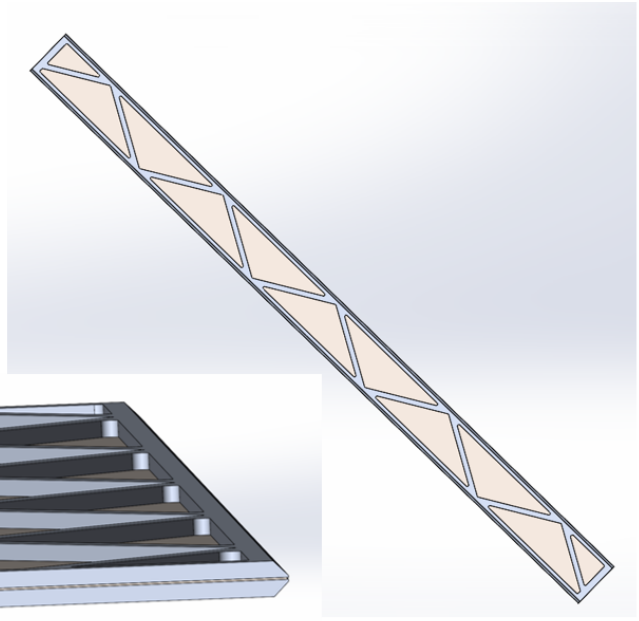
During its on-site audit, the NIST staff provided an explanation regarding the design and layout of the NBSR and the details of the 2021 event. During this explanation, the NIST staff addressed audit questions related to the location and potential thermal impact of the once molten material to the vessel internals, the debris transported throughout the NSBR, the inspections and associated results in the area of the damaged fuel element, and the on-going and planned clean-up activities to remove debris from the damaged fuel element.

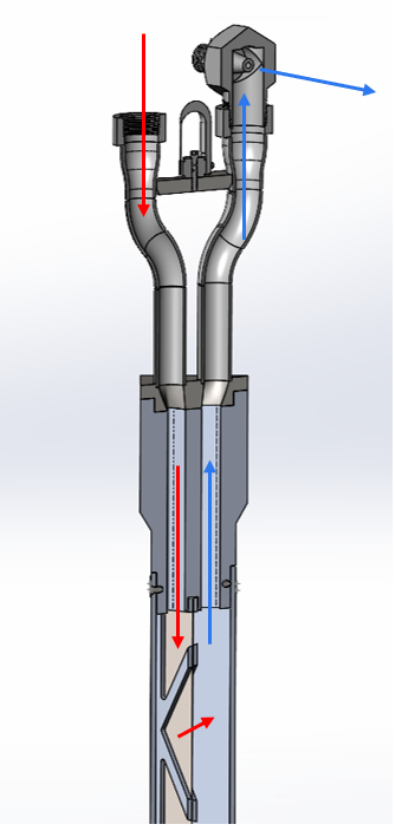
Following this discussion, a walkdown of the C-200 level was performed where cleanup activities were being conducted by NIST contractors. The NRC staff observed the NIST contractors performing clean-up activities, specifically, their ability to identify and retrieve relatively small debris in difficult to access regions. Furthermore, the NIST contractor retrieved previously recorded video of the removal of the large globules of once-molten material in the area of the damaged fuel element. Of particular interest to the NRC staff, was the condition of the lower grid plate in the area of the large globules of once-molten material and the damaged fuel element. Additionally, the NIST contractor provided an explanation of the systematic approach used during their clean-up activities of the NBSR (e.g., inspection and mapping of as-found condition, vacuuming at several different quadrants and levels of NBSR, manual debris removal with tooling). Additionally, the NIST staff provide an explanation on a mock-up of the vacuum/filtration system used for clean-up and its ability to capture finer debris from the NIST reactor. Below are diagrams and depictions of the tooling used by the contractor as part of its cleanup activities.







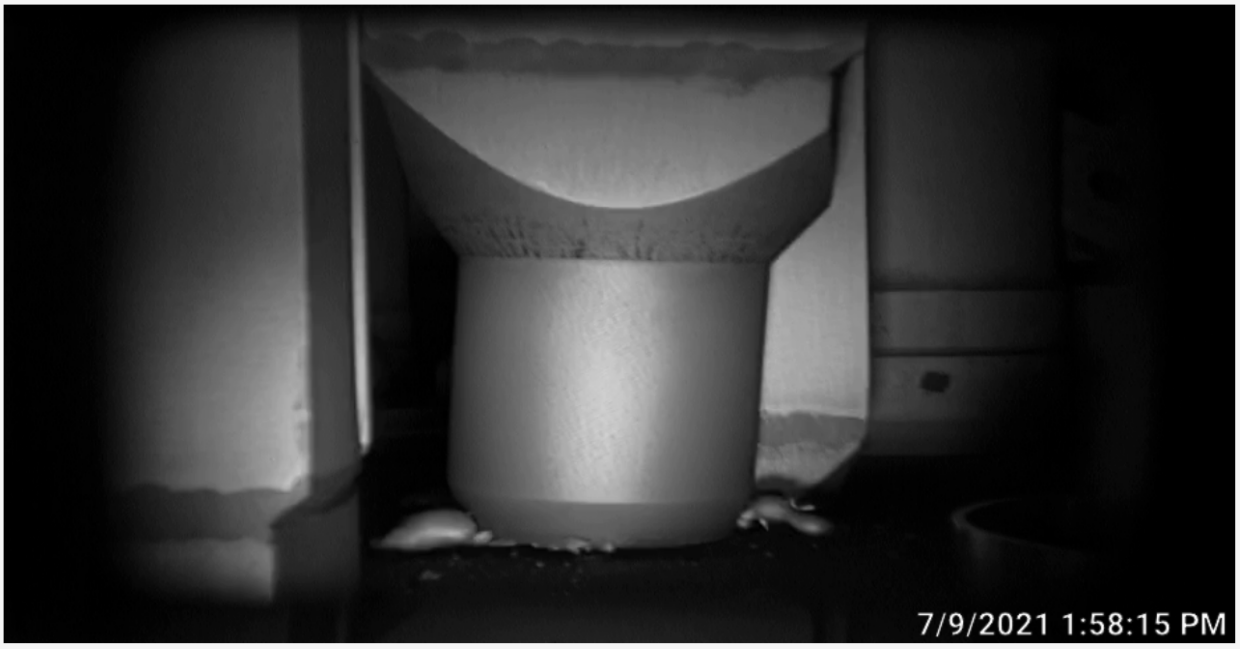




The NRC staff discussed with the licensee its questions during virtual conferences and during the on-site potion of the audit related to the above-mentioned focus areas and made relevant observations that are discussed below.

The licensee explained that material from the damaged fuel element can be addressed in two categories. The first is the once-molten material contacting the lower grid plate in the area of the nozzle of the damaged fuel element was resting on the lower grid plate. The second is debris that exited through the top of the damaged fuel element. Based on photos provided by the licensee, the NRC staff observed that for the first category of material, in general, the larger once-molten material debris was localized and limited to only the area where the nozzle of the fuel element rested on the lower grid plate. Based on photos and video during the removal of the damaged fuel element from the reactor core, the NRC staff observed the following:

- removal of the damaged fuel element from its as-found location was not difficult (i.e., once-molten material was not welded or bonded to the lower grid plate)
- much of the once-molten material remained attached to the nozzle of the damaged fuel element as it was removed from the reactor core
- the condition of the lower grid plate did not appear to be distorted, discolored or deformed in area of the once-molten material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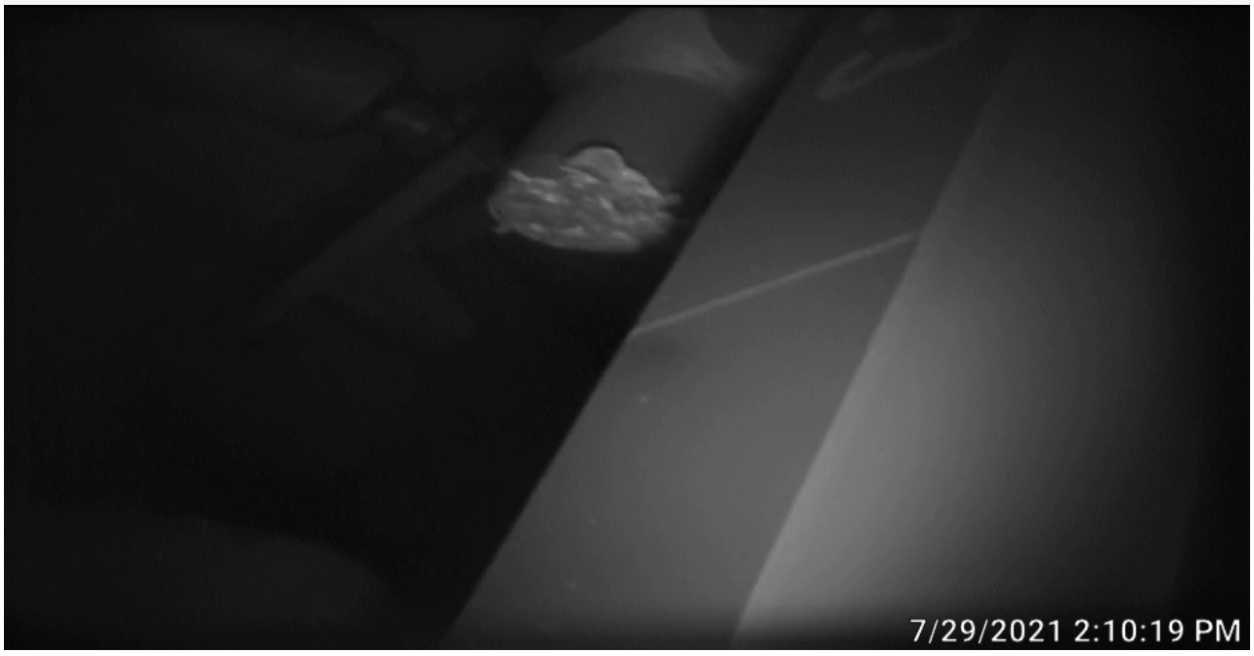
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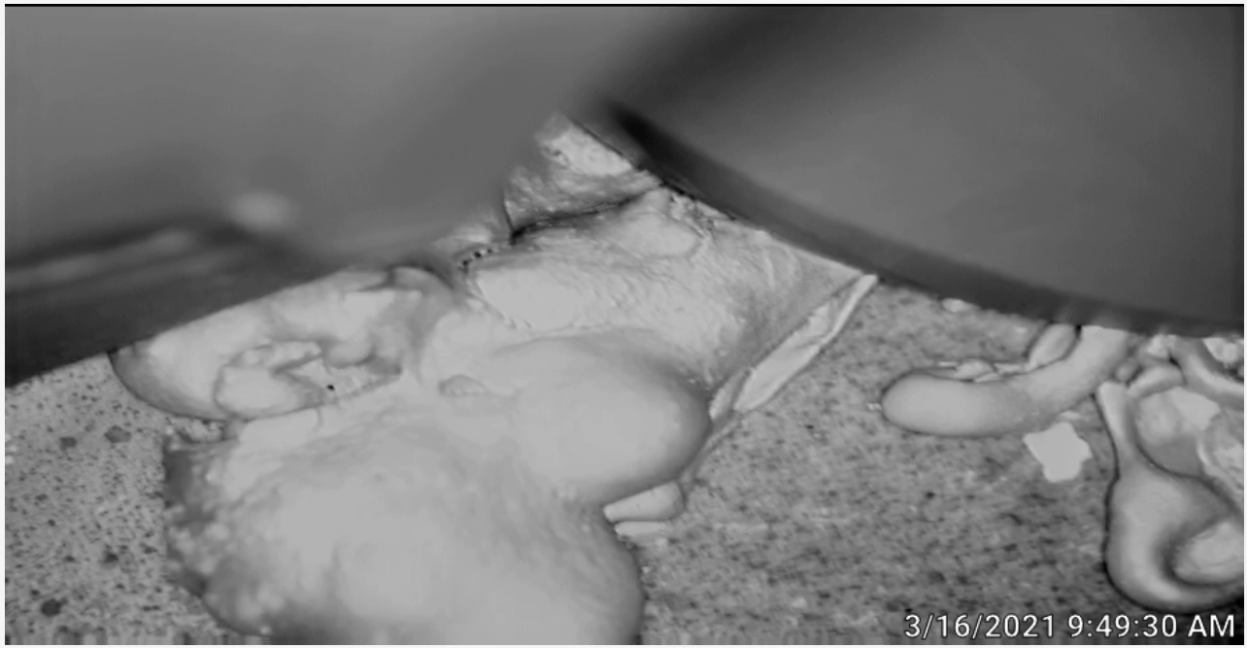
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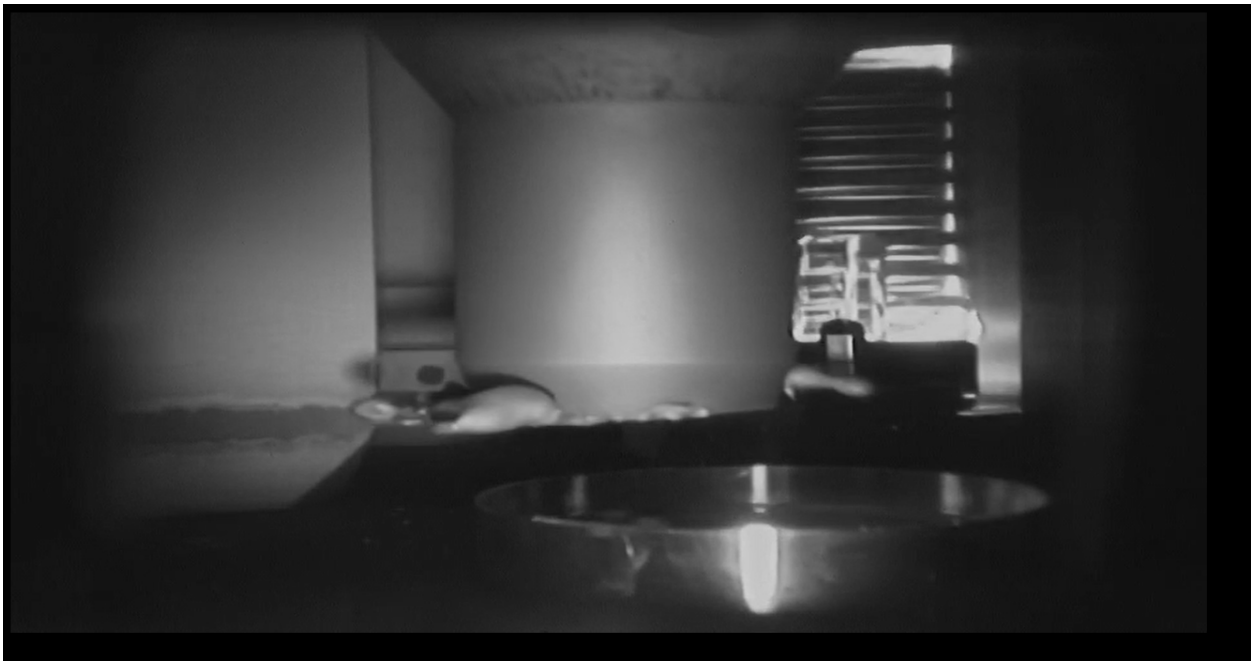
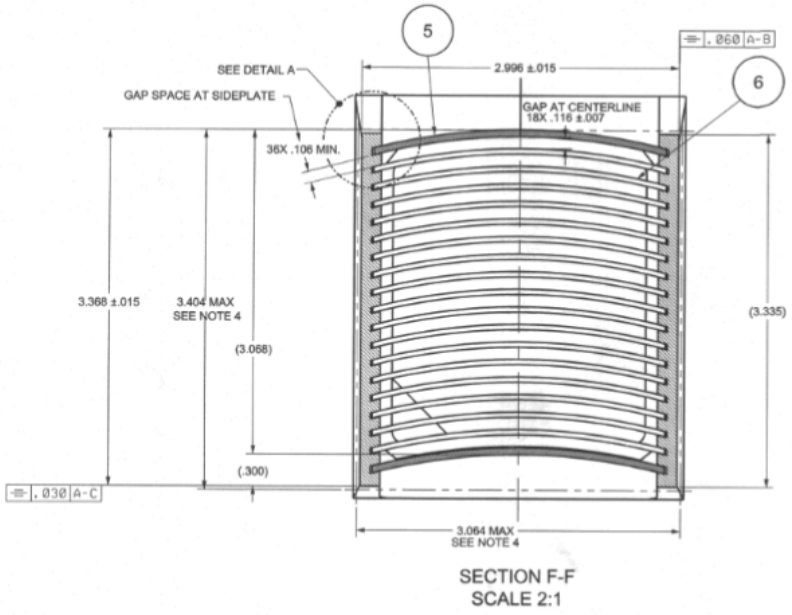


During its audit, the licensee explained that the size of the material from damaged fuel element from the second category was limited to the spacing in between the fuel channels. The NRC staff reviewed drawings provided by the licensee and noted that it is a reasonable, due to the design of the fuel element top, that the spacing in between the fuel channels acted like a sieve. Additionally, the NRC staff observed that this would reasonably prevent debris larger than this gap from entering and circulating in the coolant system. The licensee explained that this debris remained fully surrounded by reactor coolant for the duration of the event and was circulated throughout the reactor coolant system.



During its audit, the NRC staff discussed with the licensee the impact of the debris to components in the primary coolant system. The licensee explained that pump performance has

been as anticipated based on the pump curves with a correction due to the flow resistance through the filters is slightly higher than through a fuel element. Further, the licensee confirmed that radiation surveys near the pumps do not show high radiation levels indicating there is no radioactive material residing in the pumps. Additionally, the licensee explained that all valves that are required to be functional in accordance with the Technical Specifications have been tested and passed. Further, many other primary system valves have been opened and closed without any anomalies and there has been very limited debris detected near valves based on radioactivity. With respect to heat exchangers, the licensee explained that pressure drops across the primary side of the heat exchanger behaves predictably and in accordance with the heat exchanger specification and that significant clogging that can impact heat transfer would be noted as a significant source of radiation, which has not been observed.

The NRC staff noted that following the activities from its contractors, the licensee installed in each fuel position dummy fuel elements that double as filters and that have the same interface with the upper and lower grid plates as real fuel elements. The licensee indicated that at no point did it experience any difficulty with the fitment of the dummy elements in the upper and lower grid plates. Once these filter elements were installed, the licensee explained that it started the pumps and debris was caught by the filters and was measurably moved away from some of the hot spots in the process room, but work continues to make the process room accessible for day-to-day operations. The staff noted that additional measures taken by the licensee included the following:

- Ultrasonic cleaning of several hotspots in the process room, followed by running the primary pumps, which moved water through the 20-micron filters.
- Minor disassembly and/or replacement of plumbing components that show major internal contamination (e.g., heat exchangers, pumps, check valves).
- Draining portions of the primary coolant system based on dose rates.
- Admitting carbon dioxide to the system in an attempt to float debris, which is then caught in the filters. Helium sparging was used to assist with the removal of carbon dioxide from the system.

During its audit, the licensee summarized the results of its efforts to remove debris from the primary coolant system. The NRC staff noted the following regarding these results:

- All visible pieces of debris were removed from the vessel and a full visual inspection of the vessel indicated no further debris.
- Filter elements captured debris when the primary pumps were run.
- Debris was measurably moved away from some of the hot spots in the process room and reduction in dose was observed.
- Ultrasonic cleaning had limited effectiveness, but ultimately resulted in a reduction of the dose rate in a few areas of the process room.
- Helium sparging resulted in the reduction of the dose rate in a few areas of the process room, in particular the heat exchanger components; carbon dioxide sparging resulted in no significant change to the dose rate levels in the process room.
- Removal of accessible components and draining in specific locations of the primary coolant system had varying results with minor reduction in the dose rates in some areas, and significant reduction in the dose rates in other areas, especially by the HE-1C flange area.

NBSR Fuel Element Latching Mechanism
Audit Review

1. Background

As part of the NRC staff audit, the Mechanical Engineering and Inservice Testing Branch (EMIB) in the Division of Engineering and External Hazards (DEX) of the NRC Office of Nuclear Reactor Regulation (NRR) evaluated specific aspects of the NIST proposal to restart the NBSR. In particular, the EMIB staff reviewed numerous NIST documents and information supporting the NBSR restart that were made available by NIST in the eRR.

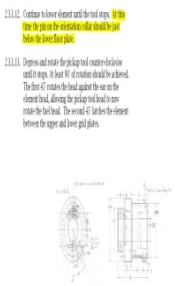
The NRC staff conducted several virtual teleconferences to discuss those documents and information items with NIST personnel. The NRC staff also participated in an observation at NIST on April 13, 2022, of exercises of the fuel element latching process using improved procedures. This audit report input provides the results of the EMIB staff review of the NIST documents, information made available by NIST within the scope of the audit, and results of the staff observation of fuel element latching exercises. The individual NIST documents and information items reviewed by the EMIB staff as part of this audit are listed at the end of this audit report section.

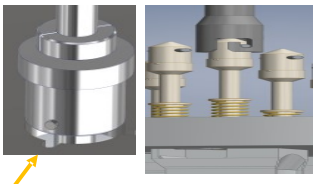
The current NBSR fuel element design employs a latching bar that is rotated to lock the fuel element in the upper grid plate. Following fuel handling, it is necessary to ensure that this bar is properly positioned so that a fuel element cannot be lifted out of the lower grid plate, which would lead to a reduction in flow to the element after pump flow is initiated. A combined rotational and visual inspection is used to provide redundancy in verifying the latching bar position.

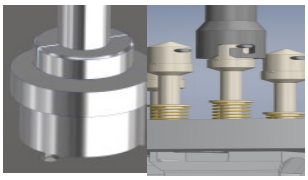
NIST described the fuel element latch design in a presentation titled “Element Latching System Overview and Tolerance Analysis” (Revision 0, dated April 9, 2021) in Slides 6 and 7 as shown below.

Latching – Step 2.3.1.12

From OI 6.1 Rev E:







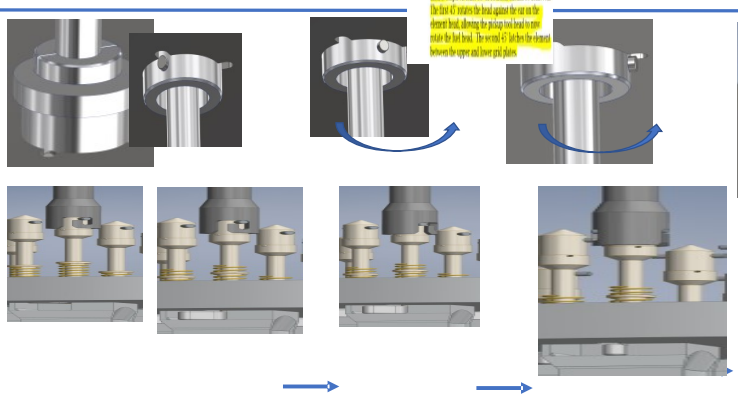
This pin enters passage slot on index plate.

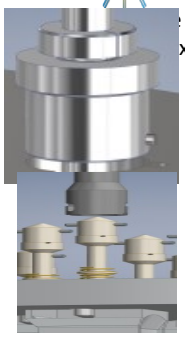
About 0.6” of vertical travel by tool.

Element pin rises out of pin nest.

End state of 2.3.1.12 is met.

Latching – Step 2.3.1.13





to lift out
xit slot.

1st
45°

2nd
45°

Latch is in groove at end

Latch is up at start of 2.3.1.13

To mandate the combined rotational and visual check of the latched fuel element in the proper sequence, NIST proposed a modification to NBSR Technical Specification (TS) 3.9.2.1, “Within the Reactor Vessel,” in TS 3.9.2, “Fuel Handling,” to read as follows:

> 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.

The license amendment revising the latching verification TS 3.9.2.1 was issued on July 21, 2022 (ML22181A128).

Upon 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 and compress the spring on the head to move the latch to below the bottom of the upper grid. 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. The tool is then raised slightly to release the spring and set the latch into the notch. Prior to removal of the tool from the fuel element head, 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, a new camera is set to “record” and is then placed 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 uploaded and reviewed by an operator. The operator, along with a second person, will verify and document that each fuel element is latched.

The revised NBSR TS 3.9.2.1 provides increased assurance that the NBSR shall 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 assure 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 distinguished from that of an unlatched element. In the first check (rotational check), a mechanical tool is used to determine the angular orientation of the latch bar, comparing it to a reference angle, thus assuring that the fuel element is latched in the core grid based on its angular orientation. The second check (visual check) is a visual (non-contact) inspection of the angular orientation of the head of the fuel element. The visual inspection provides additional and independent verification that each fuel element is latched in the core grid.

NIST has initiated an engineering study to determine if a benefit would arise from a redesign of the NBSR fuel element head. NIST established Corrective Actions and Reactor Recovery Items (CARRI) Team 5a to identify any deficiencies in the fuel head and latch mechanism design and explore possible improvements. The NIST team has not made a final recommendation regarding proposed changes to the fuel head design. However, the NIST team identified two areas of potential design improvements including (1) a modification to improve the engagement with the upper grid latch slots, and (2) mitigation of the stored spring torsion. The NIST team is continuing to develop recommendations for possible improvements in the future to the NBSR fuel element head design and latching process. Confirmatory Order (CO) EA-21-148

(ML22206A213), Section V, paragraph 8.a required NIST to provide an assessment of options to address reliance on administrative controls to ensure fuel element latching. The response to the CO did not identify any additional engineering changes related to latch verification.

2. NBSR Fuel Element Latching Mechanism Audit Review

Upon review of the information provided with the NIST letter dated December 3, 2021, the NRC staff requested that NIST make documents available for review related to the fuel element head design and latching process, including design specifications, demonstration and testing plans, procedures, and reactor operator and supervisor training. Specifically, the NRC staff requested the following:

a. Design specifications and diagrams for the improved latch check method and camera system.
b. Demonstration and testing plan for the improved latching process and camera system, and records of the completion of the demonstration and testing plan.

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

d. Improved standards being prepared for supervisor oversight of the refueling operation.

e. Training plan for initial qualification and annual requalification proficiency demonstration for NIST reactor operators and supervisors for performance of the improved latching process and camera system, and records of the completion of the reactor operator and supervisor training.

f. Previous and updated Operating Instruction 6.0, “Refueling Operation.”

The EMIB staff review of the documents and information made available by NIST is described below:

a. NBSR Fuel Element Head Design and Improvements to the Fuel Element Latching Process

In the current design, 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. As part of information provided with its letter dated December 3, 2021, NIST described its plans to improve the latching process for the current fuel element head design including rotational and visual checks. NIST stated that both processes would be demonstrated and tested, along with required operator training prior to the loading of fuel in preparation for NBSR restart. NIST indicated that the tool to be used for the “latch check” would have clear markings that will match newly installed markings on the reactor index plate. NIST described the improved procedures to be read step-by-step in a sequential process with use of a reader-worker method. NIST stated that reactor supervisors would also be trained with standards put into place for supervisor oversight to ensure that procedures and adherence policies are being followed.

The EMIB staff reviewed the documents and information items initially made available by NIST and provided follow-up information requests and questions to NIST during teleconferences. In response to discussions with the EMIB staff, NIST implemented additional improvements to the procedures for the fuel element latching process. NIST also reported that it will implement a marking activity to improve the visual identification of each fuel element using the overhead camera during the refueling operation. During this audit, the EMIB staff reviewed the NIST procedures to confirm that the fuel element latching process will provide reasonable assurance of proper latching of the NBSR fuel elements.

On April 13, 2022, the EMIB staff participated in an onsite observation at NIST of the fuel element latching process implementing improved NIST procedures. In particular, the EMIB staff observed how the NIST personnel followed Operating Instruction (OI) 6.1.7, “Rotational Latch Verification,” OI 6.1.8, “Visual Check of Fuel Element Latch Bar,” and OI 6.1.9, “Visual Inspection Analysis,” to perform the latch check verification for all of the 30 fuel elements. 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.

For the rotational latch verification, the NRC staff observed how the latch verification sleeves are inserted into the index plate holes and compared to the clutch tool’s collar to ensure that the fuel elements are fully latched. Specifically, a check of the alignment of the clutch tool collar slot relative to the fully latched (Green) triangle marking on the sleeve (refer to the OI 6.1.7 figures below) was performed for each fuel element. For the visual check and the visual inspection analysis, the staff observed how the camera/video systems were assembled and used to perform the visual check of the position of each individual fuel element. After the video was completion for all 30 fuel elements, the NRC staff observed how the video was uploaded and reviewed to determine the position of each fuel element and to ensure it was fully latched. The EMIB staff considered that NIST is implementing a deliberate method to verify fuel element latching in the NBSR. NIST is conducting repetitive exercises for the fuel element latch process to train the reactor operators on the new process.

Figure 3, “Proper Latch Indication,” in OI 6.1.7 (Revision 3) provides a visual depiction of a properly latched fuel element as shown below:

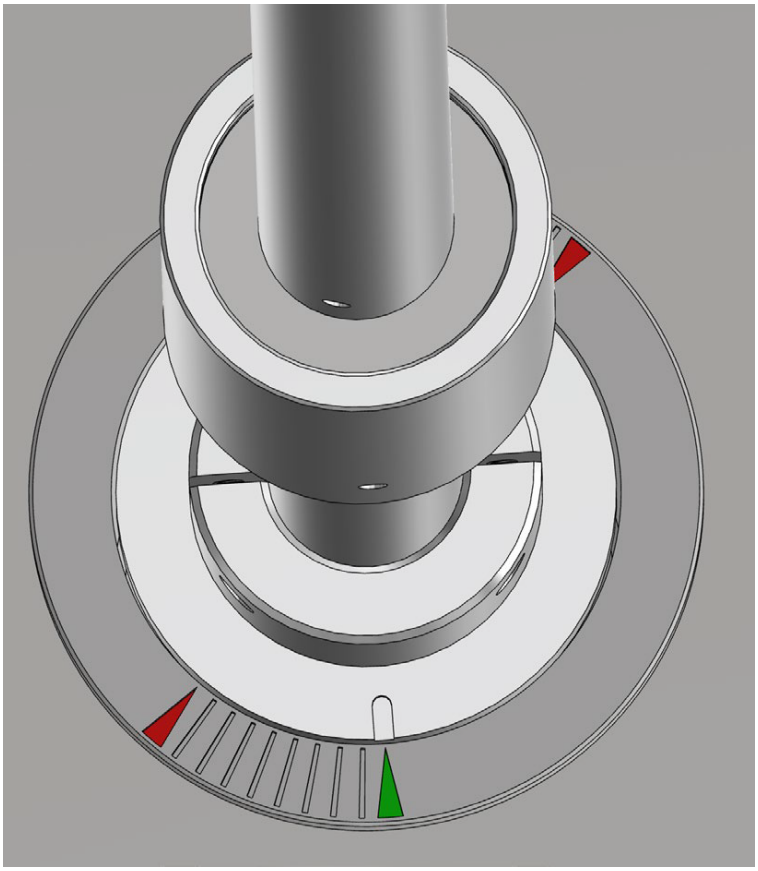


Figure 3 - “Proper Latch Indication,”

Figure 4, “Improper Latch Indication,” in OI 6.1.7 (Revision 3) provides a visual depiction of an improperly latched fuel element as shown below:

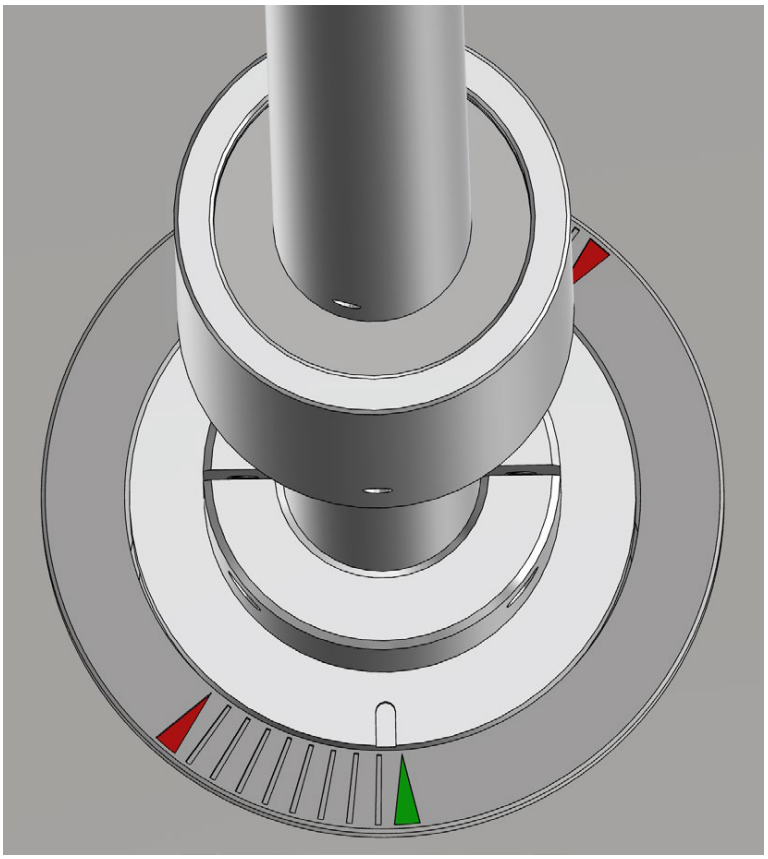


Figure 4 - “Improper Latch Indication”

On August 4, 2022, NIST issued OI 6.1.9 (Revision 3), “Visual Inspection Analysis,” to provide more detailed instructions for the visual latch check verification process. In Section 3, “Personnel Requirements,” OI 6.1.9 states that the procedure will be performed by two workers who understand the refueling and latching process and are competent in the media player and PowerPoint. In Subsection 5.1.2 of Section 5.1, “Limitations,” OI 6.1.9 states that this procedure must be completed by two independent analyzers to satisfy the requirements of OI 1.1.0, “Reactor Startup Checklist.”

In its instructions for the visual verification process, OI 6.1.9 includes figures that show accepted and rejected positions for the visual latch check verification.

Figure 13, “Completed Sheet for Fuel Head Visual Inspection Analysis – Accepted,” in OI 6.1.9 (Revision 3) shows the accepted position for the visual latch check verification as follows:

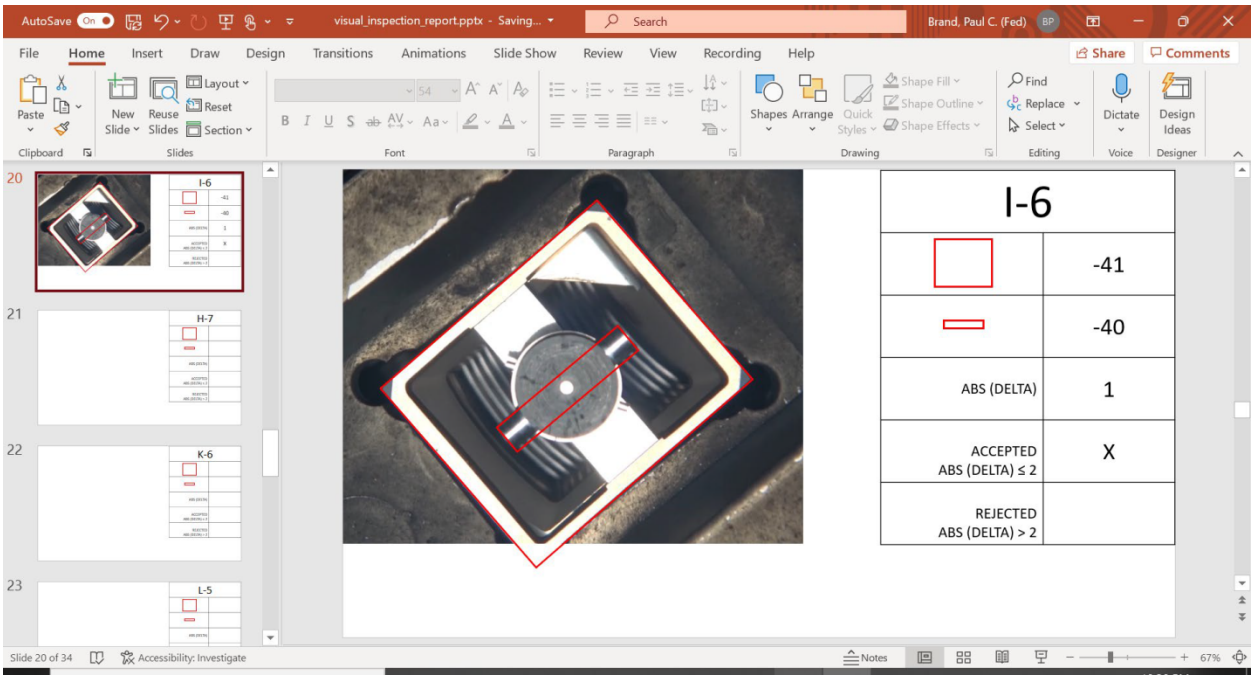


Figure 13 - “Completed Sheet for Fuel Head Visual Inspection Analysis – Accepted,”

Figure 14, “Completed Sheet for Fuel Head Visual Inspection Analysis – Rejected,” in OI 6.1.9 (Revision 3) shows an example of a rejected position during the visual latch check verification as follows:

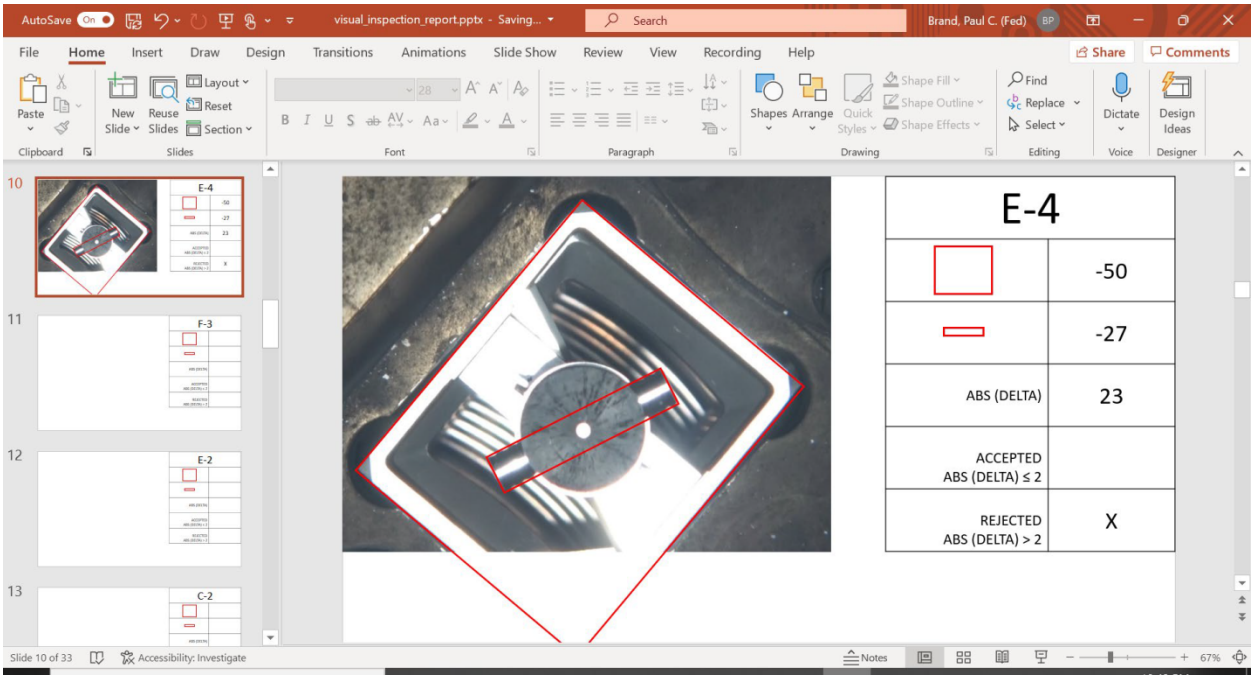


Figure 14 - “Completed Sheet for Fuel Head Visual Inspection Analysis – Rejected,”

The photographs in these figures provide a clear demonstration that each fuel element is properly latched or is rejected as part of the visual latch check verification analysis.

Section 7.10, “Completing the Template,” in OI 6.1.9 states that when all elements that are a part of the subject inspection have met the disposition of either accepted or rejected, the required table will be completed as part of a report as shown in Figure 15. Section 7 in OI 6.1.9 concludes by stating that the reactor may not be started until there is visual proof that all fuel elements are properly latched as required by the NBSR Technical Specifications.

Figure 15, “NBSR Fuel Element Latch Visual Inspection Report,” in OI 6.1.9 (Revision 3) appears as follows:

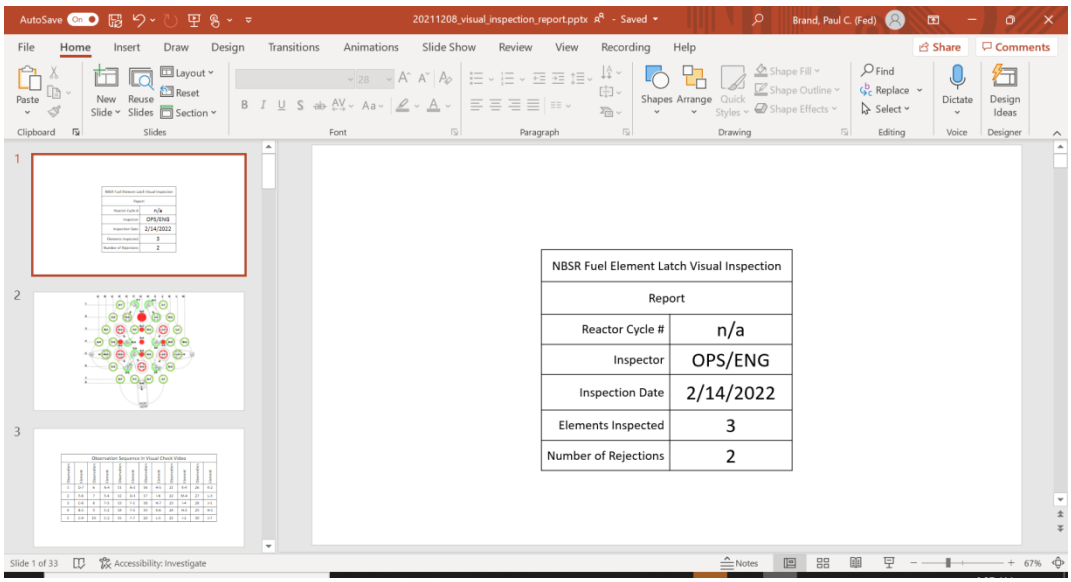


Figure 15, “NBSR Fuel Element Latch Visual Inspection Report”

On August 18, 2022, NIST updated OI 1.1.0 (Revision 2), “Reactor Startup Checklist,” to specify that two analyzers will each complete the instructions in OI 6.1.9 for an independent visual latch check verification. As part of completing OI 1.1.0, both analyzers will initial their completion of OI 6.1.9 prior to reactor startup. Therefore, OI 1.1.0 provides a second verification of the proper latching of each fuel element during the fuel element latching process.

In performing this audit, the EMIB staff reviewed numerous NIST procedures for the fuel element latching process during the refueling of the NBSR. For example, the EMIB staff reviewed OI 1.1.0, 6.1.7, OI 6.1.8, OI 6.1.9, and other NIST documents as part of this audit. The EMIB staff conducted video conferences with NIST personnel to discuss the fuel element latching process and specific process improvements. In addition, the EMIB staff participated in an onsite observation at NIST of the fuel element latching process to demonstrate the improved NIST procedures on April 13, 2022. Based on this audit, the EMIB staff finds that the current NBSR fuel element head design with the revision to NBSR 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 prior to NBSR startup.

b. NIST Reactor Operator and Supervisor Training Improvements

As part of the information provided with its letter dated December 3, 2021, NIST described measures put into place to ensure reactor operator proficiency for the refueling operations. These measures include (a) training and qualification of supervisors, (b) implementation of an annual requalification of all operators in moving fuel with the operator demonstrating their

proficiency to a senior reactor operator, (c) implementation of a continuous learning program, for NBSR refueling operations, and (d) periodic management reviews of the effectiveness of the training and refueling qualification programs. In response to a follow-up request by NRC staff, NIST made available in the eRR the documentation establishing these measures and the controls to verify their implementation and periodic assessment of their effectiveness. For example, NIST 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 EMIB staff considers that the training process for the initial and periodic proficiency for reactor operators and supervisors for the refueling operation will provide reasonable assurance of the capability of the NBSR operators and supervisors to perform their required functions.

c. Technical Specification Change LAR

As part of the information provided with its letter dated December 3, 2021, NIST described its plan to submit a license amendment request (LAR) to revise TS 3.9.2.1 to improve the requirements for verifying that all fuel elements are fully latched. At a public meeting on December 7, 2021, the NRC staff provided feedback regarding the proposed TS revision. On December 23, 2021, as supplemented on January 11, 2022, and June 8, 2022, NIST submitted the LAR to modify the NBSR TS 3.9.2.1 to improve the rotational and visual checks of proper fuel element latching for the NBSR. On July 21, 2022, the NRC staff issued Amendment No. 13 to the NBSR license to incorporate the proposed TS change (ML22181A128). The NRC staff provided its safety evaluation of the proposed TS change with the letter forwarding the license amendment to NIST. As discussed in the SE, the NRC staff found that the proposed TS change will provide verification that each fuel element is locked in position during the refueling process.

3. NBSR Fuel Element Latching Mechanism Audit Conclusion

Based on the audit review described above, the EMIB staff concludes that the current NBSR fuel element head design with the revision to NBSR TS 3.9.2.1, and the improved NIST fuel element latching procedures, will provide reasonable assurance that each fuel element is properly locked in position during the NBSR refueling process. To verify continued improvement in NBSR operations and refueling, the EMIB staff recommends that the NRC staff track the implementation of the following NIST activities: (1) the development and implementation of possible improvements to the NBSR fuel element head design and refueling process, and (2) the establishment and implementation of periodic proficiency training for NBSR operators and supervisors at NIST.

4. NIST Documents Reviewed During NBSR Fuel Element Latching Mechanism Audit

Operating Instruction 1.1.0 (Revision 2), “Reactor Startup Checklist.”

Operating Instruction 6.1.7 (Revision 3), “Rotational Latch Checks.”

Operating Instruction 6.1.8 (Revision 2), “Visual Check of Fuel Element Latch Bar.”

Operating Instruction 6.1.9 (Revision 3), “Visual Inspection Analysis.”

NIST Engineering Analysis, “In-Vessel Tests 1 and 2,” undated.

Maintenance Procedure 5.39 (Revision 2), “Visual Check of Fuel Element Latch Bar.”

Maintenance Procedure 5.40 (Revision 2), “Partially Latch Element for Visual Tool Verification.”

Statement of Work, “Provide video documentation showing all elements are latched following fuel manipulations such as refueling,” undated.

Longevity Test Summary, undated.

Pool Test Summary, undated.

Radiation Test Summary, undated.

Summary of Equipment Selection, undated.

Administrative Rule 2.0 (Revision 1), “Conduct of Operations Training.”

Administrative Rule 4.2 (Revision 1), “Fuel Manipulation Requalification Requirements.”

Requalification Program for the NBSR License TR-5 (dated March 2009).

NBSR fuel element latch design presentation “Element Latching System Overview and Tolerance Analysis” (Revision 0, dated April 9, 2021).

Tolerance Stackup - Tool and Element, Revision 1, dated March 31, 2021

Reactor Fuel in Core During the Event
Audit Review Areas

Staff in the Division of Safety Systems participated in the regulatory audit of the NIST NBSR Restart Readiness Review to aid in evaluating the acceptability of (1) NIST's analyses of the nuclear and thermal-hydraulic aspects of the fuel misloading event, and (2) NIST's plans regarding the potential reuse of fuel that was loaded in the core at the time of the February 3, 2021, event, i.e., planned fuel reuse. As discussed below, the NRC staff adjusted its review of planned fuel reuse based on two supplemental submittals, in which NIST personnel indicated that they did not plan to reuse any fuel present in the reactor on February 3, 2021.

Fuel Cooling and Reactivity Analysis

The NRC audit of NIST restart readiness activities took place from December 2021 through November 2022. Regarding the fuel cooling and reactivity analysis, the NRC staff requested an initial set of documents in a November 18, 2021, letter to NIST (ML21340A010). In response to this request, NIST made an initial set of documents available for staff audit. Based on ongoing recovery activities and coordination with NRC staff, NIST made additional documents available for NRC staff audit. The NRC staff performed a site visit to observe fuel flushing and inspection activities on April 13, 2022. Based on supplementary submittals from NIST dated June 29, 2022, and August 15, 2022 (ML22227A150), the NRC staff updated its draft audit documentation. The NRC staff also used the information NIST submitted in these supplemental letters to narrow its request for additional information necessary to complete the TER in support of NBSR restart.

In response to the November 18, 2021, NRC staff request for supplemental information (ML21340A010), the licensee made available the documents listed below:

- "Analysis of Cooling Flow Through 29 Fuel Elements with Fuel Element 1175 Dislodged," dated February 10, 2022.
- "RELAP5 Analysis of Reduced Flow," dated March 2, 2021.
- February 3, 2021, "Event Analysis," document undated.
- Microsoft Excel File, "Reactivity Search When Move 10 cm Up," document undated.
- Microsoft PowerPoint File, "NCNR Fuel Flushing and Inspection Stand Design," document undated.
- Process Instrument Data, including graphic files of reactor outlet and inlet temperatures, outlet, outer, and inner plenum flows, and calculated thermal power, from February 3, 2021.

Following the team's April 13, 2022, site visit and observation of NIST's fuel element flushing and inspection activities, and following conclusion of all fuel element flushing and inspection activities, NIST personnel made available for NRC staff audit the following additional documentation:

- Selected documents related to Framatome fuel flushing and inspection activities:

  - FS-NCNR-002, Revision 0, “Site Support Requirements for NCNR Flushing and Inspection Stand,” dated April 1, 2022
  - FOPS-457, Revision 2, “Video Recording Log (DVR Specific),” document undated
  - FOPS-555, Revision 0, “NCNR Fuel Flushing and Inspection Log,” document undated
  - FOPS-556, Revision 0, “NCNR Fuel Flushing and Inspection System Setup and Checkout,” document undated
  - 02-9343487-D-001, “NCNR Fuel Element Flushing and Inspection Stand Assembly,” dated April 14, 2022
- Selected videos and still images of fuel flushing and inspection
- Completed version of FOPS-555, Revision 0, “NCNR Fuel Flushing and Inspection Log,” dated April 13 through April 20, 2022
- Microsoft Excel File, “Fuel Debris Characterization (1).xlsx,” document undated
- “NIST Fuel Element Flushing and Inspection On-Site Report,” dated April 11 to April 22, 2022.
- “Fuel Element Dislodged from the Lower Grid Plate,” describing a RELAP5 analysis, document undated
- “NBSR Audit Questions Fuel Reuse Round 2,” document undated

The cooling flow analysis (hand calculation) was considered by the review team as a supplement to an existing analysis submitted by letter dated December 2, 2021 (ML21340A007). While the submitted analysis reflected design flow rates contained in the FSAR, the updated analysis provided during the audit was prepared using measurement data obtained from the event. The analysis calculates the pressure drop across the inner and outer plenum and flow coefficients through the fuel elements and the open orifice exposed by dislodged fuel element 1175. The analysis concludes that the dislodged fuel element results in an inconsequential reduction in coolant flow through the undamaged elements and there is no significant risk of other fuel elements having insufficient flow to remain cooled**.**

The NRC staff noted that the hand calculation used a plot and several correlations without sufficient documentation for the staff to confirm they are applicable and appropriate. Additionally, the hand calculation did not address the potential impact of bypass flow. Also, the NRC audit team had requested that NIST staff make available documents or analyses that provide a stronger tie between the basis for conclusions of continued operability of the existing, apparently undamaged fuel, which relies on a bulk cooling analysis and a heat transfer analysis of local conditions, and the safety basis in the NIST NBSR licensing basis (FSAR) and Technical Specifications (TS). The basis for safety regarding thermal hydraulics for the NBSR relies on critical heat flux and onset of flow instability. These critical safety parameters are not readily inferred from bulk coolant characteristics, but rather from complex correlations based on local flow and heat transfer conditions.

In response to the aforementioned NRC staff observations the licensee provided references to the correlations used in the hand calculation and made available a Microsoft Word Document that summarized the RELAP5 flow calculations. The licensee stated both hand calculations and computer-based thermal-hydraulic analysis using RELAP5 were performed to determine the effect of flow to each fuel element with a single core position empty. The RELAP5 scenario modeled flow restriction to a single element in the outer plenum and balanced the core flow to the remaining 29 fuel elements with an open orifice representing the unoccupied position in the lower grip plate. A steady-state run was performed using this modified RELAP model and the results were compared to the hand calculation. Both calculations determined that the flow reduction on the 29 remaining elements was less than 1.5%. Even with this reduction, flow to all elements was almost twice that required to be above the licensing basis of departure from nucleate boiling and the critical heat flux ratio for all elements was well above 5. Additionally, the licensee stated that while normal bypass flow of 4% was omitted from the hand calculation, it was included in the RELAP5 analysis. Finally, the licensee clarified that the minor reduction in flow to the elements is well within minimum flow parameters of TS 2.2(3) related to critical heat flux and onset of flow instability figures of merit. Specifically, total flow at full power should be at least 1200 gallons per minute (gpm) for the inner plenum and 4700 gpm for the outer plenum. During the February 3, 2021, event, the inner plenum flow was 2220 gpm and the outer plenum flow was 6300 gpm. Therefore, a reduction of 1.5% as determined by the calculations is insignificant compared with the TS safety limit allowable flow. The staff observed the RELAP5 model was consistent with the model used in licensee's safety analysis and the flow results agree well with the hand calculation.

Revision 2 of the root cause analysis report submitted by letter dated October 1, 2021 (ML21274A019) provided a summary description of the analyses performed that replicated the insertion of negative reactivity observed during the event and verified it was most likely due to the onset of significant voiding, which caused a complete voiding of coolant inside the element that reduces neutron moderation. The NRC staff audited document titled, "February 3, 2021, Event Analysis" which investigated observed power oscillations and steep negative reactivity insertions. Based on analytical and numerical solutions the analyses concluded the power oscillations could have been caused by a loose piece in the core or an unlatched fuel element, and the amount of negative reactivity insertion during the event was between 30 and 50 cents. The report speculates this could be equal to losing moderator within a single element. The staff observed that the neutronics analyses provided an indication that NIST had analyzed the conditions caused by the misaligned fuel element with sufficient accuracy.

Fuel Cleaning Process and Site Observation

The audit team visited the NCNR on Wednesday, April 13, 2022, to observe the fuel examination and flushing evolutions. Framatome installed an inspection and flushing stand in the spent fuel pool. This stand was designed to allow a fuel assembly, when installed, to tilt into alignment with cameras at either end of the assembly, to permit visual inspection of the fuel plates. When upright, a fitting can be coupled to the top of the fuel assembly so that a blower nozzle can be connected to the assembly for backflow flushing. The fitting is connected to a submersible pump installed in the pool. The bottom of the assembly is connected to a canister filter to collect any flushed debris before the flushing water is returned to the pool.

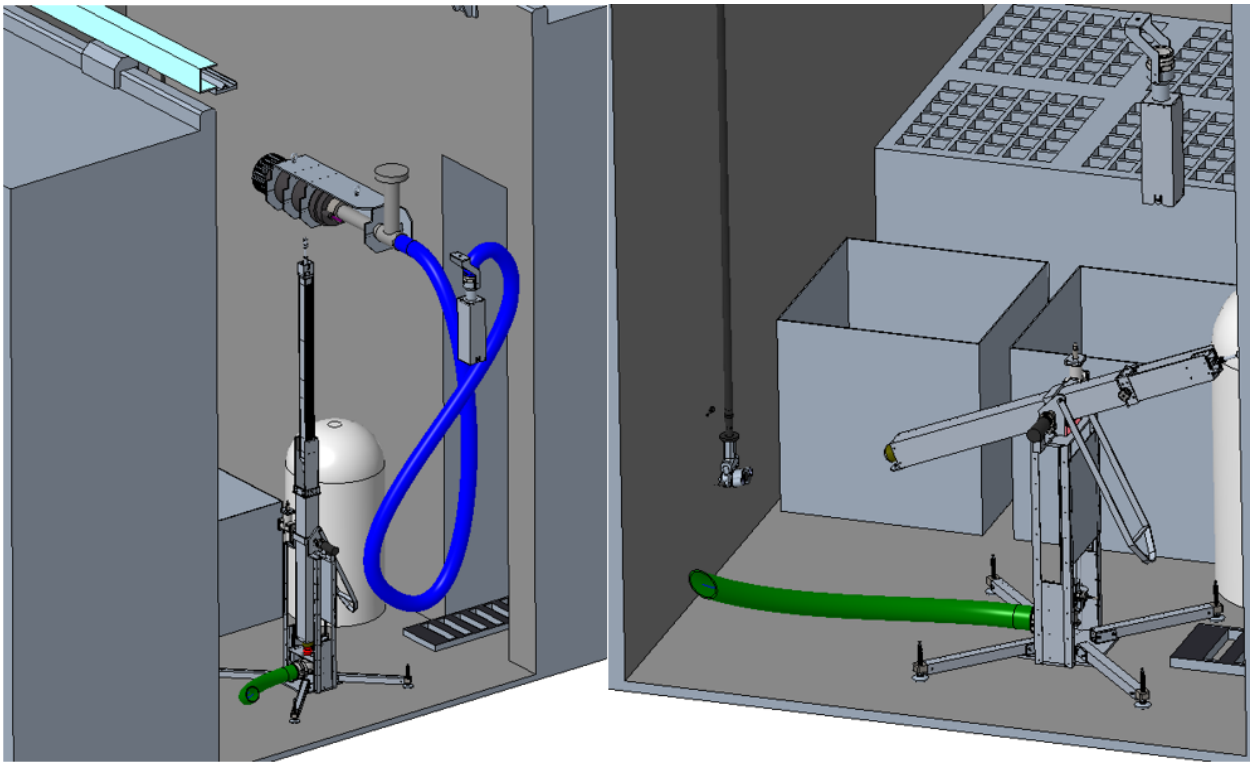


Figure 1. Fuel Flushing and Inspection Stand.

In the image above, the left side shows the assembly with a fuel bundle being loaded into the upright position. The blower is connected to the blue tube, and the green tube is the bundle outflow. On the right, a bundle is shown in the inspection position with a camera positioned (left side of right image) to inspect the lower portion of the bundle. The right image also shows the spent fuel rack (rear) and two bins where scraps are placed.

The NRC audit team observed the pre- and post-flushing inspections and actual flushing of Fuel Element 1151 onsite. In the upper fueled region, technicians identified deposits in the region between two fuel plates. In the lower fueled region, technicians identified debris in one location. The element was flushed with approximately 400 gallons per minute (gpm) flow, which exceeds the normal, upward flow of 267 gpm in each outer plenum element and 383 gpm in each inner plenum element. During the post-flushing inspection, technicians determined that the debris in the lower fueled region had been removed, leaving behind visible scratching on the fuel cladding on multiple plates. The material in the upper fueled region remained in place. Furthermore, technicians identified additional indications of material between other plates in the upper fueled region.

The NRC audit team clarified with NIST personnel how the above observations were being addressed. According to NIST, Fuel Element 1151 was returned upright for additional flushing. In accordance with procedure, if the initial flush does not remove foreign material, the bundle is flushed again for ten minutes. This additional flushing did not remove all material in Fuel Element 1151, and NIST was therefore unable to determine the bundle was suitable for reuse. In addition, NIST indicated that the scratching in the lower fuel region would also be evaluated, but that it was not in the fueled region. NIST will continue to evaluate the next steps for Fuel Element 1151, including potentially replacing it. Meanwhile, NIST continued to flush two additional fuel elements the same day. The first additional element was determined to be clean

in the pre-flushing inspection, and the second was found to have debris, which was removed by flushing.

Post-Inspection Review

Following the completion of the flushing and inspection procedures, NIST personnel made available for NRC staff audit a preliminary disposition for the fuel. Four elements were identified as clean and, at the time, cleared for reuse. Three elements were identified as having probable fuel debris and were not cleared for reuse without further cleaning. The remaining 22 elements were determined to contain very small but visible debris. In comparison to a baseline inspection of other elements that were in the spent fuel pool but not present in the reactor, NIST personnel concluded that these 22 elements appeared somewhat similar to the condition of the other elements. Additionally, it was observed that 3 of the 22 elements with small debris had dented nozzles. Shown below is an image of Element 1155, which is believed to contain a nugget of fuel material. Also shown below is an image of Element 1157, in which superficial scratching can be seen on the element. NIST personnel indicated that, where observed, scratching did not appear to be indicative of cladding failure.

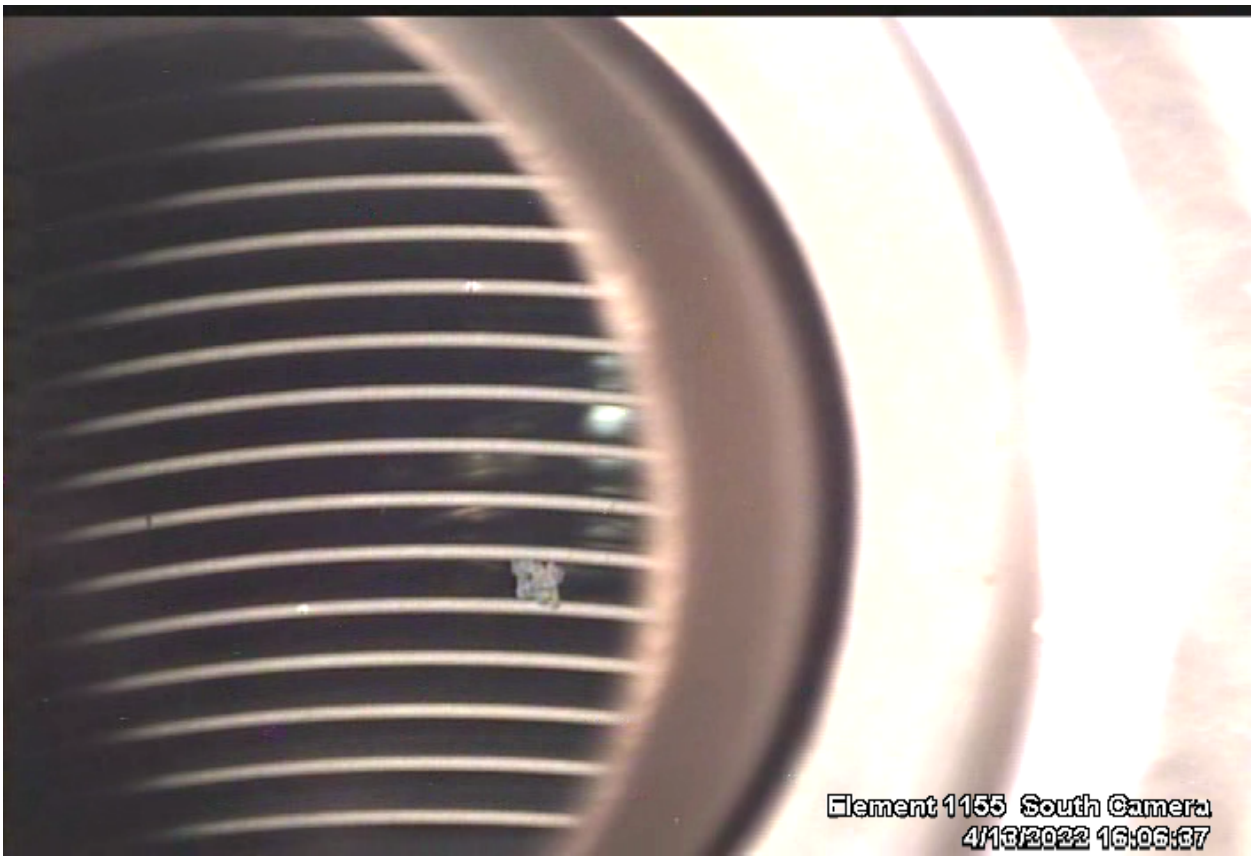


Figure 2. NIST personnel identified Element 1155 as likely containing fuel material.

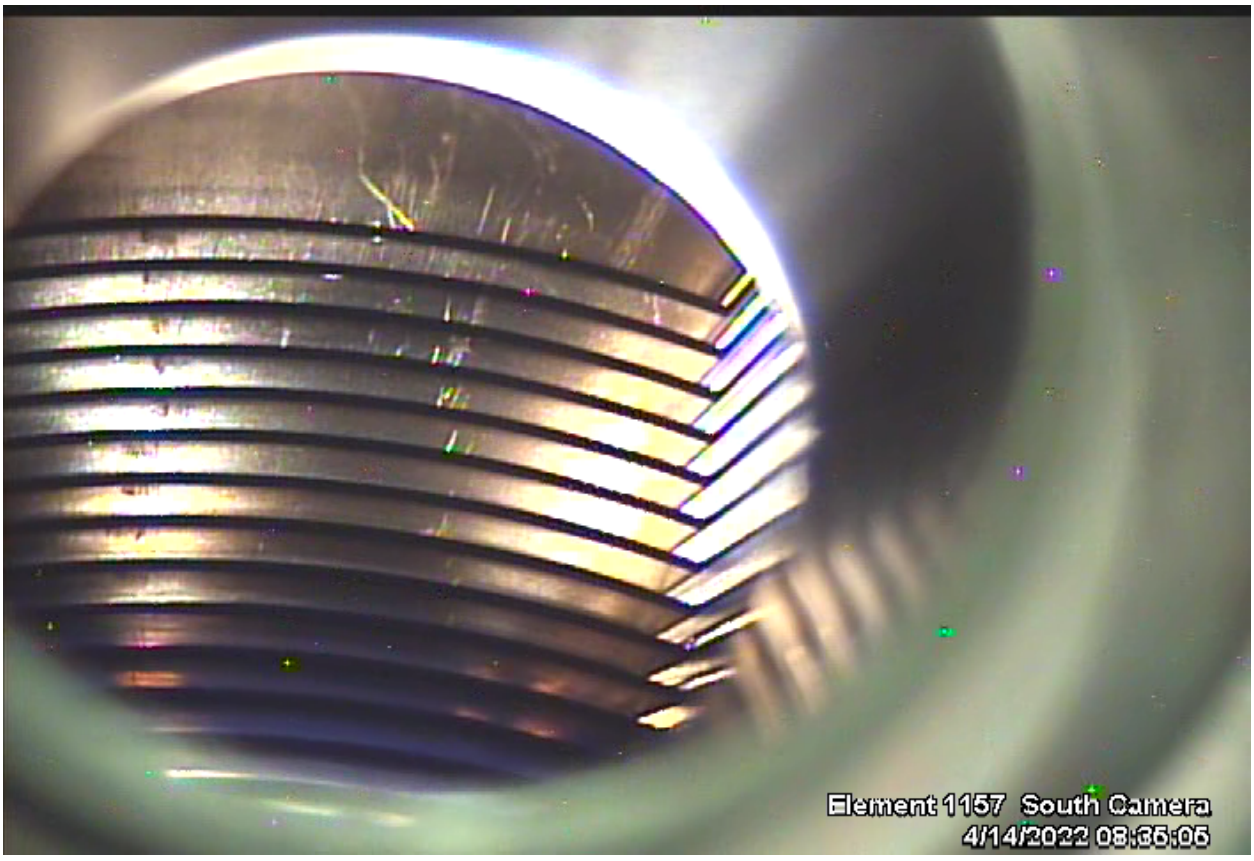


Figure 3. Superficial (i.e., not compromising cladding integrity) scratching observed on Element 1157.

Following the inspection, NIST personnel made NRC staff aware that a parallel evaluation was being performed to determine whether initial startup could be made using a combination of new and existing 7-cycle elements that were not in-pile during the February 2021 event. In a letter dated June 29, 2022, NIST stated

> The backflow of the fuel elements that were in the reactor during the event of February 3, 2021, was not fully successful. Therefore, NIST will not reuse any fuel elements that were present in the reactor core on February 3, 2021, until a final disposition for these elements is determined. NIST will use a combination of new elements and seven cycle elements for the initial startup core. The refueling scheme as planned will be evaluated and performed under 10 CFR 50.59 and will not require any license amendment or changes to the NCNR Physical Security Plan.

In its letter dated August 15, 2022, NIST provided further clarification concerning its plans for fuel reuse:

> As mentioned in our report to NRC on June 29, 2022, a decision was made to not use fuel elements that were present in the core on February 3, 2021, in the initial startup core…. 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.
>
> […]

> An evaluation, given in Engineering Change Notice (ECN) 1241, has shown that parameters such as power peaking and excess reactivity values fall within the envelope of all normal operation and accident analyses in the NBSR SAR… 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… All of 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.

Seven cycle elements are considered highly exposed. According to NIST NBSR TS 3.1.4, "Fuel Burnup," the average fission density shall not exceed $2x10^{27}$ fissions per cubic meter. The basis includes that "Extensive testing of fuel plates has been performed to determine the limits on fission density as a function of fuel loading. Several measurements of swelling in fuel plates show that NBSR fuel, which is moderately loaded at 18% is well below the curve that represents the allowable limit of burnup.

The NRC staff performed a literature search to identify a source for the data supporting this specification. Among other sources identified, the NRC staff located "Irradiation Behavior of Uranium Oxide – Aluminum Dispersion Fuel," a paper presented at the 1996 International Meeting on Reduced Enrichment for Research and Test Reactors. A figure included in this paper indicates that, at the volume fraction of U_3O_8 loaded in the NBSR fuel, data suggest that breakaway swelling of the fuel leading to cladding failure is unlikely.

Conclusion and Recommended Approach for TER

The information gathered during the audit indicated that NIST's plans regarding fuel use remain in flux. However, the NRC staff has identified an adequate amount of information concerning analyses of the February 2021 event that will be meaningful in evaluating the NBSR restart. Any evaluation should include a review of the following:

- Most up-to-date bulk cooling analysis
- Most up-to-date fuel cladding heat transfer analysis
- RELAP5 analyses summarized during audit
- Disposition plans for fuel flushing and inspection results
    - Summary of key activities and observations
    - Representative photographs
    - Criteria used to clear fuel for reuse

Additionally, the NRC staff anticipates that a review of ECN 1241, referenced in the licensee's August 15, 2022, letter, will be required to support ongoing inspection activities. The NRC staff will leverage the insights and information contained therein in its TER input.

If NIST does not reuse fuel that was in-pile during the February 3, 2021, event, with the exception of providing oversight of ECN 1241 or similar evaluations, the above review activities would be unnecessary.