LESSONS LEARNED ON NBSR LICENSING ACTIONS

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After the incident in February 2021, NBSR implemented three license amendment requests (LAR) to update the reactor license. The first LAR was to modify previous latch verification requirements in the Technical Specifications (TS). Originally TS required operators to perform one of the three methods, namely the elevation check, rotational check, or visual inspection for latch verification. Specifically, the first amendment revised the TS to require a rotational check followed by a visual inspection. Even after extensive cleanup following the incident, there was potential fuel debris left in the NBSR primary systems. Hence, a second LAR evaluated the safety and operational impacts of such debris remaining within the primary system. Fuel debris was also found on several fuel elements and all fuel elements in the core during the incident were deemed unusable. Therefore, a third LAR evaluated the use of specific methodologies to perform core loading analyses of the NBSR. This latest LAR included an engineering procedure and detailed analysis methods to evaluate Alternative Fuel Management Schemes (AFMS) core loadings for the NBSR. We will present our lessons learned throughout the application and implementation of these LARs for the NBSR.

1. Introduction

Research reactors, such as the National Bureau of Standards Reactor (NBSR), are a valuable resource for scientific research. The NBSR, which is hosted by the National Institute of Standards and Technology (NIST) Center for Neutron Research (NCNR), is a 20 MW reactor that uses heavy water moderation and reflection. It first achieved critical operation on December 7, 1967 and uses highly enriched uranium fuel. The NCNR is an important part of the nuclear scientific and commercial community, providing powerful scientific instruments for testing and research in the field of neutron scattering. The NCNR's facilities and expertise have played a key role in advancing many areas of advanced material research, both in the United States and around the world. On February 3rd, 2021, the NBSR reactor experienced a fuel element failure accident that resulted in the release of fission products and fuel material into the primary cooling system. In this paper, we present the lessons learned from the License Amendment Requests (LAR) that were completed as part of the recovery and restart authorization. There had been three LARs completed during the last 2 years, focused on three key topics: the fuel latching verification methods, the potential existence, and the safety impact of fission products in the primary coolant, and a new core loading scheme for the start-up of the reactor. After the successful completion of safety-related changes in operations, protocols, communications, and training, and the approval of the three LARs, NCNR received restart authorization on March 10, 2023. This paper provides basic descriptions of the LARs and lessons learned throughout the applications of the amendments.

1.1. LAR #1: Visual Inspection for Latch Verification

The Reactor Operations and Engineering (ROE) group discovered that the current rotational latch verification check was insufficient to guarantee the latch status of the fuel elements once they were placed inside the vessel in reaction to the incident at the NCNR that took place on February 3, 2021[1]. The discovery that the pickup tool's physical contact with the latch during latch verification could be a potential reason for unlatching led to the creation of a non-contact method of verification. Corrective actions identified the need for improvements in latch verification methods and requiring both rotation and visual checks. Hence, the Technical Specifications (TS) for latch verification were the focus of the first LAR. Operators had to previously use an elevation check, a rotational check, or a visual inspection to confirm latches in the original TS. Therefore, the first amendment mandated rotational inspections for TSs, followed by visual inspections. On July 21, 2022, the U.S. Nuclear Regulatory Commission (NRC) released NBSR license Amendment No. 13, which updated the latching verification requirement.

1.1.1 Rotation Check

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 via 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^o 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, thus setting the latch into the notch. See Figure 1.

Figure 1: Fuel element head latched into a mockup of the upper grid plate.

1.1.2 Visual Check

After the rotation checks are complete and all tools are in their stowed positions, a newly constructed camera system is set to “record” and is then placed into the fuel transfer system. This camera system is then systematically moves through the fuel transfer system and in turn positioned immediately over each element position. Once the camera has traversed the entire system it is retrieved. The video is uploaded and reviewed by an operator. The operator, along with a second person, verifies and documents that each element is shown to be latched. A photo of the video results of a test with a fully latched element in the core position is shown in Figure 2.

Figure 2: Video capture of the element in the latched position

1.2. LAR #2: Potential Existence of Fission Products in Primary Coolant

As previously mentioned, there had been fission products and fuel material released to the primary cooling system during the event on February 3rd, 2021. Since the event, a multi-step cleaning of the NBSR was completed. Other than bulk particle collection via remote handling tools, 20 microns steel mesh filters were used to further clean fine dispersed material within the primary cooling system. Collected particulates using remote handling tools and filters were weighed to attempt to account for the missing material within the core and cooling pipes.

The damaged fuel element was weighed in the pool after the incident. The measured weight was compared to the average weight of 15 other undamaged fuel elements measured in the pool [2]. Unfortunately, there is no pre-event dry-weight information for fuel element #1175. The standard deviation from the in-pool measurements was 19 grams, converted to dry weight, the standard deviation is about 30 grams. Based on measurements, a maximum of 200 grams of fuel and clad mixture were determined to be missing from the damaged element [2]. Therefore, it is plausible to assume that some particulates would be dispersed through the primary coolant and within the Holdup Pan even after cleanup is completed. Fissile

Uranium in these particulates would undergo fission and potentially release fission products once the reactor is operational. Hence, the second LAR, which was issued on February 1, 2023, as Amendment No. 14, evaluated the safety and operational impacts of such debris remaining within the primary system. The safety analysis for this LAR has two components. First is the effects of friable unclad fuel present in the reactor plumbing, which might potentially affect the dose at the Site Boundary because of the potential for the production and the release of fission products from it. The second component is the potential effects of friable unclad fuel in a mechanical sense, in that it might create an obstruction to a System Structure or Component (SSC) that is important to the safe operation of the NBSR.

Only two accidents analyzed in the NBSR Updated Final Safety Analysis Report (UFSAR) show results of the release of radioactivity: the loss of coolant accident (LOCA) and the maximum hypothetical accident (MHA) [3]. NEI 21-06 Rev - 1 section 4.3.3 in part mentions "An increase in consequences from a proposed activity is defined to be no more than minimal if the increase is less than or equal to 10 percent of the difference between the current calculated dose value in the UFSAR and the regulatory guideline value" [4].

The MHA considers the melting of an entire 8-cycle fuel element. The dose at the 400 m boundary for the MHA is a total of 6.8 mrem, and 3.5 mrem within the first day. The other accident that could be affected is the "Loss of Primary Coolant" LOCA event, where a major rupture in the cold leg of the primary system is assumed, which leads to the draining of the reactor core. In this case, if the entire inventory were to leak out in this manner, a person at the site boundary would receive less than 6.5 mrem, and doses to personnel from the debris would be insignificant compared with tritium doses.

Both the MHA and LOCA accidents result in a total dose of less than 6.5 mrem at the site boundary on the first day. By contrast, it is estimated that the presence of remaining fuel material would result in a site boundary dose being at most 0.13 mrem (assuming a full day of operation while releasing through the stack), which conservatively assumes the reactor continues to operate. This is a change of only 2% from the MHA and LOCA. The maximum permissible annual dose limit to the public is 10 mrem accepted in the updated FSAR. The ten percent of the difference between the regulatory guideline value of 10 mrem and the newly calculated dose value for the MHA and LOCA is 0.32 mrem and 0.35 mrem, respectively. As stated before, the additional dose due to the existence of unclad fuel material products in the primary coolant is 0.13 mrem, which is less than ten percent of the difference between the calculated dose value in the UFSAR and the regulator guideline value for both scenarios MHA and LOCA. Therefore, the consequences for MHA and LOCA from the proposed change are no more than minimal.

None of the other accidents analyzed in the UFSAR are more than minimally affected by the presence of fuel particles in the primary system, as a) the mass and size of fuel material are too insignificant to cause any reactivity effects in the reactor, cause flow blockage effects in the system, or limit mechanical devices (i.e. shim arms) if it were to be dislodged and b) the presence of this material does not affect normal operating parameters nor would cause any additional dose to the operating personnel.

1.3. LAR #3: Alternative Fuel Management Schemes

After the incident in February 2021, debris was found on several fuel elements and all of the fuel elements in core loading 654 were deemed unusable. At this point, only the 7th cycle and fresh fuel elements are available in the NBSR inventory. Hence, there was a need to develop a series of Alternative Fuel Management Schemes (AFMS) to enable the NBSR to approach the equilibrium core as described in the UFSAR, so that the Original Fuel Management Scheme (OFMS) can be later reached. These AFMS core loadings do deviate from the OFMS, for instance, the number of fresh fuel elements, their locations, the types of used elements (7th cycle, 6th cycle, etc.), and their locations may be changing amongst other core configuration characteristics. Any such AFMS is a modification in how the NBSR core performs its design function of producing 20 MW and therefore requires a License Amendment Request (LAR). Furthermore, Technical Specifications Section 5.3 Basis bullet (1) in part states that “Significant changes in core loading patterns would require a recalculation of the power distribution to ensure that the CHFR would be within acceptable limits.“ [5]. To that end, a new section was inserted in the NBSR UFSAR, “4.5.1.1.3 Alternative Fuel Management Schemes (AFMS)”, which describes bounding conditions for any AFMS. Hence, the third LAR introduced an engineering procedure, namely “NBSR-0018-DOC-00 NBSR Alternative Fuel Management Schemes Analysis Procedure” which described the OFMS and AFMS, a basis for the analysis providing limitations to evaluate potential AFMS, detailed safety analysis for a demonstration AFMS, along with a discussion of results and conclusions to be included in subsequent Engineering Change Notice (ECN)’s dealing with AFMS core loadings. The engineering procedure provides a basis to analyze core loading patterns so that none of the Technical Specifications (TS) are exceeded.

2. Summary

Three license amendment requests (LAR) were put in place by the NBSR, following the incident in February 2021 to enable the reactor to resume. The first LAR changed the Technical Specifications (TS) of earlier latch verification criteria. The NBSR license's Amendment No. 13 updated the TS governing the latching verification of fuel elements. Any of the three methods, namely the elevation check, rotational check, or visual inspection for lock verification were previously required. The first amendment, which was approved by the NRC on July 21, 2022, specifically changed the TSs to require a rotating check followed by a visual examination. The second LAR, which was published on February 1, 2023, as Amendment No. 14, assessed the safety and operational effects of such debris remaining in the primary system. The final LAR assessed the effectiveness of using a particular technique to carry out core loading studies of the NBSR. This latest LAR, which the NRC released on March 2, 2023, as Amendment No. 15, contains an engineering procedure and thorough analysis techniques to assess Alternative Fuel Management Schemes (AFMS) core loadings for the NBSR. Any core loading that differs from the standard core loading technique is referred to as AFMS. We will present the lessons learned from applying and putting these LARs into practice for the NBSR.

3. Disclaimer

References

[1] NCNR Technical Working Group, “Root Cause Investigation of February 2021 Fuel Failure,” NCNR, Gaithersburg, Maryland, Apr. 2021.

[2] J. Jurns, “Determining mass of material lost from fuel element 1175 from the NCNR February 3rd, 2021 reactor incident.,” NIST NCNR, Gaithersburg, Maryland, Oct. 2021.

[3] NIST, “Safety Analysis Report (SAR) for License Renewal for the National Institute of Standards and Technology Reactor - NBSR; NBSR 14.” National Institute of Standards and Technology (NIST)., Jan. 2023.

[4] H. Lane, “Guidance for Implementation of 10 CFR 50.59, ‘Changes, Tests and Experiments,’ at Non-power Production or Utilization Facilities,” NEI, Washington, D.C., NEI 21-06 Revision 01, Dec. 2021.

[5] NCNR, *TR-5 Technical Specifications for the NIST Test Reactor (NBSR*. Gaithersburg: NCNR, 2017.