UNITED STATES DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Gaithersburg, Maryland 20899-

June 29, 2022

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: NBSR restart request

Ref: Docket 50-184, TR-5 Facility License

Sirs/Madams:

In our October 1, 2021, letter (Accession Number ML21288A555), we requested NRC permission to restart the reactor upon completion of listed corrective actions. As part of those corrective actions and as part of ongoing dialogue with NRC, we have performed analyses of the impact of the February 3, 2021, fuel failure event on the reactor vessel, reactor vessel internals and undamaged fuel assemblies. The report of these analyses is attached.

Respectfully,

Thomas Newton
Deputy Director, NIST Center for Neutron Research

I declare under penalty of perjury that the foregoing is true and correct.

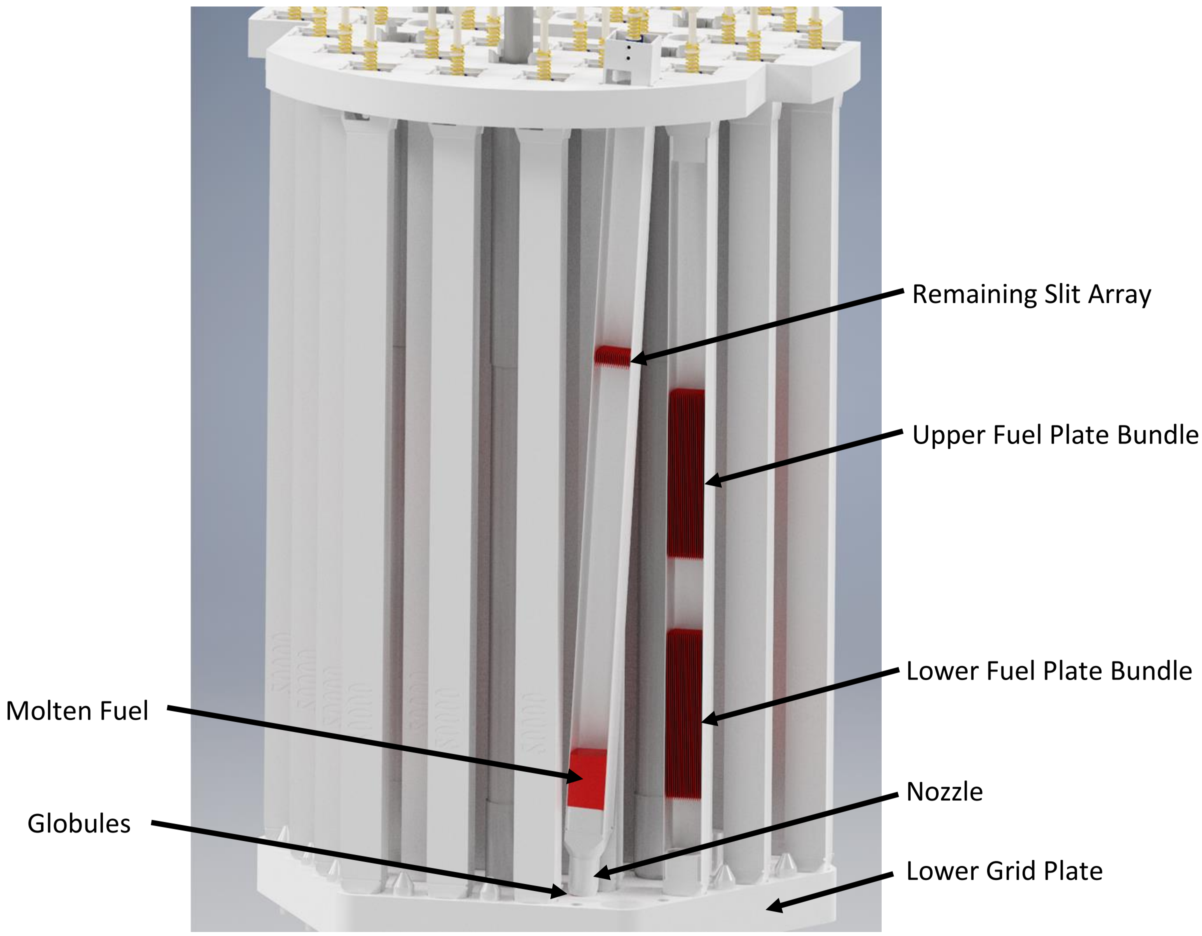
Executed on June 29, 2022

NIST

Impact on Reactor Vessel, Reactor Vessel Internals and Fuel assemblies

Melted Fuel exiting the element nozzle

It is assumed that when the fuel melted, most of the melt gathered in the volume that is bounded by the inside of the cylindrical nozzle of the element and the lower grid plate onto which the cylindrical nozzle rested (and the top of the liquid column). Since the cylindrical nozzle was somewhat inclined with respect to the lower grid plate, some of the molten material made its way out and solidified under water, thereby obstructing further molten material flow between the nozzle and the lower grid plate. It is also assumed that the extent of the melting of the fuel plates comprises the entire fuel plates except the upper one inch of the upper fuel plate bundle, which does not contain any Uranium Oxide (and therefore generates no heat). After the bulk of the fuel element had melted, the part that was left standing formed an array of slits. Video observation of the top of the damaged element confirms the presence of this array.



It is further assumed that the interaction of cooling water with the molten fuel that was kept molten (or at least very hot) in the lower part of the fuel element, since it was still undergoing a nuclear reaction, created sudden unstable steam flashes (as in a geological geyser) and that the ensuing steam was jetted through the slit array that is defined above. These steam flashes carried small pieces of the molten material with it through the slit array that is defined in the previous paragraph. The slit array is sized such that the limit of the particle size of the ejected particles cannot exceed 0.1 inch in at least one dimension. Ample visual evidence has been obtained by remote video to confirm this. Based on under-water weight measurements of the damaged element and interpretation of the remote video of the globules, it is believed that the total mass of the small particulate matter that left the fuel element exceeds the mass of large globules at the bottom of the fuel element near the nozzle.

As discussed above, the debris size is limited to 0.1 inch in at least one dimension, which is the distance between adjacent plates in a fuel element. Once this debris was transported outside the fuel pack (or what was left of it), it quickly solidified. At this point it entered a relatively low flow area in the reactor vessel and started moving towards the exit plumbing at the bottom of the vessel.

Potential for annealing the lower grid plate

As discussed above, there was a significant thermal mass of fuel material (uranium oxide plus aluminum) gathering in the nozzle of the fuel element. We proved subsequently that there was enough molten material present to “trap” the melt (after solidification), because the top flooded a conical zone in the nozzle (which at its base has a larger diameter than the cylindrical zone). This material has been unable to melt the substance of the nozzle (an aluminum tube with wall thickness of about 3/16”). Upon removal of the damaged element, it became clear that there was no visible damage to the lower grid plate either: there was no visible evidence of melting anywhere on the lower grid plate. This was further supported by inspecting the view of the once-molten plug from below the element using a video camera. The once molten material appears to have solidified immediately after coming into contact with the lower grid plate. Thus, the worst-case scenario is that the lower grid plate locally lost its metallurgical temper. In that sense the worst that could have happened is that the temper went from T6 to O, which has no effect on the functionality of the lower grid plate, which is limited to maintaining its shape. The typical reason for specifying the lower grid plate at T6 is that T6 is easier to machine. For the function of the lower grid plate, it makes no difference. Note this scenario (annealing from T6 to O) is still quite unlikely, because the lower grid plate is constantly submerged in cold water and has a significant thermal mass compared to a molten set of fuel plates belonging to one element.

Function of the lower grid plate equal to form

The function of the lower grid plate is limited to its form. A full scale anneal from T6 to O (which is very unrealistic) does not jeopardize that function in any way.

Sometime after the February 3, 2021 incident all fuel elements were offloaded and transported to the spent fuel pool. After this evolution, the fuel positions were filled with dummy fuel elements that double as filters and that have the same interface with the upper and lower grid plates as real fuel elements. At no point did we experience any difficulty with the fitment of the dummy elements in the upper and lower grid plates, thus proving that no dimensional changes to either the lower and upper grid plate resulted from the February 3, 2021 incident.

Both the upper and lower grid plates were inspected with the use of video cameras. All debris larger than 1/16” in diameter was removed. The globules (lower grid plate) were removed with remote control Foreign Object Search and Retrieval (FOSAR) equipment. Smaller debris (both lower and upper grid plate) was removed using a vacuum wand driven by an eductor system operated by a pump that moved the heavy water already present in the reactor vessel. The globules that had escaped from underneath the damaged element were found mostly in the immediate vicinity of the damaged element. None of the globules were bonded metallurgically to the lower grid plate, supporting the notion that not much heat was transferred from the molten aluminum to the lower grid plate. It was very clear from the visual inspection that the aluminum oxide layer that has built up over the lifetime of the reactor has not been damaged as a result of the encounter with the liquid fuel mixture. This further supports the notion that the maximum effect of the melt touching the lower grid plate is the possible annealing of a small portion of the lower grid plate from T6 to O. Even that seems unlikely, but can serve as an upper bound, because such would not negatively affect the function of the lower grid plate.

Debris gathering on the Upper Grid Plate

The total mass of once molten material that gathered on top of the upper grid plate (after making its way through the slit array that was left standing) is much lower than the total mass that was in touch with the lower grid plate (both the globules and the mass that remained trapped inside the failed element). The upper grid plate is much further removed from the reactor core than the lower grid plate. It is clear from the morphology of the small debris that was found on top of the upper grid plate that this debris arrived on top of the plate as a spongy solid and was no longer kept liquified due to the lower neutron flux present. Note that the small size and the low neutron flux collaborate toward that outcome. As a result, there is no credible way that the debris found on top of the upper grid plate can alter the metallurgy of the upper grid plate (i.e. not even the temper: if the as-installed temper was T6, it still is T6).

The debris that left the damaged element through the slit array (fuel plate remnants) found its way into the primary coolant loop and was pumped around. As the pumping went on, this traveling debris found places to settle. These locations are the source of significant radiation in the Process Room. As of this writing, NCNR is still in the middle of the cleanup efforts that aim to make the Process Room accessible for routine reactor operations (such as required calibrations). Once all the fuel elements were removed from the core, the fuel element positions were filled with stainless steel filters and the pumps were started. 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.

Framatome performed cleaning at several levels:

1) Picking up large (D > 0.25”) particulate matter using FOSAR tools at the lower grid plate.
2) Vacuuming smaller (0.06”< D < 0.25”) particulate matter using eductor driven vacuum at the upper and lower grid plate.
3) Inspection and backflushing all fuel elements that were present in the reactor during the incident (with the exception of the damaged fuel element). This technique was only marginally

successful, leading to a conservative plan to not initially use any elements that were present in the reactor during the incident. Other possible cores not involving elements that were in the reactor during the incident are being modeled as of the time of this writing.

4) Ultrasonic cleaning of several hotspots in the Process Room, followed by running the primary pumps, which moves water through the (20 micron) filters that temporarily occupy the fuel positions. Ultrasonic cleaning was somewhat successful, but very difficult to apply in the hottest areas, without significant personal dose commitment.

Although several areas in the primary system have seen significant improvement, as of this writing we cannot conclude that the contaminants in the primary from the fuel damage incident of February 3, 2021 have been completely eliminated. NCNR intends to reduce the contaminants as low as possible with the techniques described. However, proving that the primary contamination has been reduced sufficiently will require low power testing, which is the subject of a separate submission: the restart plan.

Filter insertion

After cleanup efforts by Framatome concluded, NIST installed 20 micron filters in (all) the fuel element positions (note: U_3O_8 fuel particles are larger than 44 microns). This means that when the pumps run all primary water has to pass though these filters while being circulated. The four (parallel) primary pumps were run alone, and in all possible permutations of one through four pumps. With the pumps running the process room was continuously monitored for changes in the background radiation. Minor improvements were observed, particularly in the discharge leg of the pump that was not running during the February 3, 2021 incident. Effectiveness of the cleaning operation is measured in terms of how the background in the Process Room improves. After we restart the reactor and low power testing starts, cleaning effectiveness will be assessed in terms of the cleanliness of the effluent that leaves confinement. Note that there are two operational reasons why the reactor needs to be cleaned to a certain level:

1) The effluent through the stack (presumably caused by debris participating in future nuclear reactions) must be in accordance with applicable regulations.
2) The Process Room needs to be accessible to work in so that NIST can perform applicable calibrations and surveillances.

NIST intends to keep the filters in the fuel grid until it has convinced itself that there is nothing more that can be done by flowing the primary (while simultaneously agitating the debris in some fashion). Techniques for further cleaning will include, but are not limited to:

1) Minor disassembly and/or replacement of plumbing components that show major internal contamination (Heat exchangers, pumps, check valves)
2) Admitting carbon dioxide to the system in an attempt to float debris, which is then caught in the filters.
3) Possible installation of a major filtration loop that can filter the primary in the course of an hour, rather than days.

4) Review and optimize operations in the Process Room in terms of ALARA (Time/Distance/Shielding).

NIST has no significant experience with remaining debris of such levels that it impedes normal operations. However, we will develop long-term debris removal plans as needed to reduce levels to normal.

Role of the Storage Vessel

The Primary Coolant Purification system pumps primary water directly from the Storage Vessel to an emergency vessel that is situated at an elevation well above the reactor vessel. It is comprised of several pumps, a cartridge filter, an ion exchange column and another cartridge filter. If the entire refill flow goes through the filter it takes 10 hours to fill the reactor vessel. It is expected that after all the work that has been done with the reactor vessel a lot of debris might have assembled in the storage vessel. Removing this debris is a task for which we currently seeking a contract with Framatome.

Cleanup of Primary Plumbing

Based on a detailed visual inspection performed by Framatome after they performed the cleanup of the upper and lower grid plate it was concluded that all globules sized 1/16" and larger had been removed. The inspection of the lower grid plate (which is where the globules were gathered) was performed with NIST personnel participating and witnessing.

The backflow of the fuel elements that were in the reactor during the event of February 3, 2021 was not fully successful, to the point that a decision was made to redesign the fuel loading scheme for restart. The remaining small debris in the primary system, which has given rise to considerable background radiation in the Process Room is also still largely in place. Our next attempt will be to stream carbon dioxide through the primary system with the pumps running. This is an unproven technique, with a potential for a high payoff.

Potential damage to Stationary Reactor Vessel Internals.

The upper and lower grid components are not impacted by any remaining debris that may be located on top of them (which is particulate matter smaller than 0.06" in diameter). Furthermore, calculations have shown that particulate matter that could barely escape the slit array on top of the damaged element (i.e. have the same size) will have trouble passing through the plena, because the water velocity in the plena is very low compared to the velocity in the fuel elements.

The question of cleaning up particulate debris will be addressed in the restart plan, which will include extensive low power testing. Measuring effluents will feature prominently in this plan.

Potential damage to Reactor Shim Safety Rods

A regularly recurring surveillance that is prescribed in the Technical Specifications concerns the determination of the 5-degree drop times for fully withdrawn shim arms. NIST will commit to performing this surveillance at the nominal beginning of the first five reactor cycles after restart and keep track of trends. After that NIST will continue to monitor the 5-degree drop times for all shims in accordance with the present Technical Specification.

The shim safety arms are the only components that have moving parts that are anywhere near the location where debris came from the damaged element during the February 3, 2021 event. The regulating rod is the only other moving component in the core and 1) was far away from the damaged element and 2) serves no safety function.

Fuel re-use

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 10CFR50.59 and will not require any license amendment or changes to the NCNR Physical Security Plan.