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Director James K. Olthoff, PhD.
United States Department of Commerce
National Institute of Standards and Technology
Gaithersburg, MD 20899

Subject: Unplanned Shutdown of the NIST Reactor, February 3, 2021

Dear Dr. Olthoff,

As requested, I am providing my assessment of the circumstances of the unplanned shutdown of the National Institute of Standards and Technology (NIST) reactor on Feb 3, 2021. It covers "the conditions that allowed the unplanned shutdown to occur, NIST Center for Neutron Research's (NCNR) emergency response to the incident, NIST's organizational response to the incident, and the efficacy and completeness of the proposed actions" as requested in your charge letter.

I appreciate the efforts of NCNR and NIST staff to provide information on all aspects of this event and the associated response. It is clear that everyone we spoke with is committed to a safe return to operations of the reactor.

I hope this assessment is helpful, do not hesitate to ask if you have any questions.

Sincerely,

Thomas Mason
Director

cc: Rob Dimeo, Director of the NIST Center for Neutron Research

NIST NCNR Reactor Incident Review – T.E. Mason, Los Alamos National Laboratory

This report summarizes my assessment of the circumstances of the unplanned shutdown of the National Institute of Standards and Technology (NIST) reactor on Feb 3, 2021. It covers "the conditions that allowed the unplanned shutdown to occur, NIST Center for Neutron Research's (NCNR) emergency response to the incident, NIST's organizational response to the incident, and the efficacy and completeness of the proposed actions" as requested in the charge letter from James Olthoff. It is based on material shared with the consultants via a SharePoint site, online briefings held in December 2021 and January 2022, and an in person visit to NCNR on February 1, 2022, which gave us an opportunity to interact with and ask questions of NCNR and NIST staff. This summary does not delve into all aspects of the charge but rather focuses on the issues I see as being most important and well aligned with my background and experience. The specifics of the mechanics of fuel element latching and steps to prevent reoccurrence appear to be well understood and undergoing rigorous technical review by both NCNR and NRC. As result I will focus more on institutional cultural, organizational, and emergency response concerns which have broader implications for the future of safe operations for both NCNR and NIST.

It is important to recognize that while this was a very serious incident, by far the most serious in the history of the NIST reactor and probably the most serious operational upset at a research reactor in decades, it did not result in any offsite impacts with the dose at the site boundary essentially at the limit of detection. Nor did it result in harm to the health and safety of the staff on the NIST campus as a whole and the NCNR reactor operations staff in the control room who did receive appreciable radiation doses are unlikely to experience any long-term health impacts, the maximum dose received was below the regulatory limit. More serious impacts were avoided due to the robust design of the reactor and its safety systems and the fact those systems were well maintained and operated as designed to shut down the reactor once the conditions for a scram were triggered and contain the release of fission products. The negligible offsite impact along with effective communications with external stakeholders has meant there has not been a loss of confidence in the surrounding communities which is important for the long-term future of NIST and the reactor. It suggests that prior efforts by NIST to cultivate a positive view of the institution in the community have been of benefit in the context of an operational upset. It is worth noting that events which were arguably less serious operationally but did result in very small but measurable offsite impacts at the HFBR at Brookhaven National Laboratory in New York and DR-3 at Risø National Laboratory in Denmark resulted in permanent closure of those reactors due to the resultant loss of confidence in the surrounding communities. The absence of offsite impact should not be taken as a reason for not responding aggressively to the issues surrounding this event and the assessment that follows is intended to provide impetus and support to further strengthen the operations of the reactor and NIST.

Resources, Procedures and Training

The proximate cause to the incident was the improper latching of a fuel element during fuel reloading leading to it dislodging during the reactor startup. The loss of cooling to the fuel element once it was unseated from the reactor base plate led to fuel melting, distribution of debris through the primary cooling system, and release of fission products. Proper installation of the fuel elements to ensure cooling is maintained is fundamental to the safety of operating any reactor. The factors leading to improper latching identified by the NCNR team include inadequacy of training and lack of detailed procedures for that aspect of refueling. These factors arose due to inadequate staffing, a loss of experienced operations staff over recent years, and complacency flowing from a sustained record of routine operations. While the reduction of experience amongst reactor operators certainly contributed to this event there were precursor events (at least two) where problems with fuel rod latching were observed that did not progress due to intervention prior to fuel damage that occurred over a period of decades at a time where the staff was more experienced. The failure to properly resolve the root causes of those prior events, leading to the Feb. 3 2021 incident, indicates deeper problems with nuclear safety culture at NCNR that are acknowledged by the management team.

The response to this incident by NCNR management has been comprehensive addressing both the specifics of the fuel latching and steps needed to prevent recurrence and the more challenging operational and cultural issues that have broader implications. The specific measures to prevent recurrence include rewriting, or in some cases writing, more detailed procedures not just for refueling but for many reactor operations that had not been described previously at that level of detail. In addition, and importantly there are plans to add a fifth shift to reactor operations so that the rotation will include an additional period of day shift without reactor operating responsibilities to continuously update training and qualifications. Both management and the reactor operations staff regard this fifth shift as essential to improving operational rigor. The reactor operations staff are skeptical that the needed resources (financial as well as the needed staff to fill funded positions) will be realized. This skepticism, in part, is derived from the fact that the current four shift operating schedule has been chronically understaffed for a long period of time. Due to staffing limitations, it has been a common occurrence to have shifts operating with the NRC minimum of two licensed operators while normal staffing level would be four. In some cases, there are four including unlicensed trainees, but the normal operating cadence has included recurring instances with only two operators on shift. This limited staffing has been exacerbated by the fact that as the user program has grown, additional tasks have fallen to the operators to assist users outside of normal operating hours (for example with crane operations). While there may be circumstances where illness or resignation might lead to a temporary inability to full staff a shift it is not acceptable for that to be a normal operating condition. The fact it is the minimum NRC permitted complement does not excuse this and settling for simple compliance is not the hallmark of an excellent safety culture. This represents an instance of normalization of deviation.

The chronic shortfall of reactor operations staff is due a combination of increased turnover of staff, the time taken for new staff to be qualified as licensed operators, and the challenges of recruiting and retention for a skill set very much in demand in the private sector with salaries that the federal system cannot compete with. Some use has been made of non-base compensation tools to help compensate however NIST management should consider a review of where the reactor operator positions fit within the federal HR system. These roles, by virtue, of the training requirements, shift rotation, and the gravity of the responsibility are certainly unique within NIST as well as the overall civilian federal system. The fact that loss of qualified operators to the Nuclear Regulatory Commission is one element of the retention challenge suggests that there may be options within the federal system that would help with this problem.

Skepticism about management's ability to secure the necessary financial resources for a fifth shift can also be traced to staff observation of the difficulty in resolving long standing safety concerns of a non-nuclear nature (examples cited include ladders and stairwells). This reflects a NIST challenge of deferred maintenance and insufficient funding to address infrastructure deficiencies that is not limited to NCNR however the inadvertent message sent to staff that impacts the nuclear safety culture is that safety is not as important as the marquee scientific investments that do attract funding.

NCNR has prided itself on running a very lean operation that is very cost effective in comparison to other neutron facilities. It has been successful at upgrading its instrumentation and scientific infrastructure so that despite becoming operational in 1969 it remains state of the art in 2022. Reactor operations and the associated regulatory framework has not evolved at the same pace. The regulatory light touch and the associated lean operating staff levels, procedures, and training have been much more static and need enhancement to meet 21st century expectations. This will come with a cost and NIST will have to decide if it is willing to accept the cost of operating a high consequence nuclear facility on its campus. That cost is more than just the NCNR operating budget, there are institutional implications in areas as diverse as human resources, emergency management, environment safety and health that go beyond what is demanded of a non-nuclear scientific laboratory in terms of overhead and management focus.

Emergency Response

Before discussion aspects of the emergency response, it is probably useful to review a brief summary of the timeline (more detail is included in the attachment provided at the request of the consultants and attached below). At 0916 on Feb 3, 2022 the alert was declared and the building evacuated. The Senior Reactor Operator declared an emergency and became Incident Commander per the NRC approved Emergency Management Plan. At 1030 the NIST Emergency Operations Center (EOC) was activated to provide additional support as needed during the emergency. At 1532 the incident was downgraded to Notice of Unusual Event and the EOC stood down. Four hours later at 1935 the emergency was terminated and the Senior Reactor Operator's Incident Commander role ended. The following day, Feb 4, an attempt was made to re-enter the confinement area which had to be aborted due to elevated CO_2 levels in the basement which resulted in an oxygen deficiency hazard that had not been recognized in the pre-entry planning. On February 5 NIST organized an Incident Response Team (IRT) which continues to the present to provide senior management oversight and assistance to the ongoing recovery effort. Within this timeline the aborted re-entry on Feb 4 is noteworthy because over the course of the whole incident it represents the gravest threat to life that occurred, it also took place at a time when the emergency was formally ended but the IRT not yet stood up.

The Emergency Response to any emergency at NIST falls under the NIST Emergency Management Plan (NIST O 2201.00) which in turn is governed by the Department of Homeland Security National Incident Management System (NIMS)/Incident Command System (ICS) concepts. I am most familiar with Emergency Response planning at Department of Energy (DOE) facilities but as that also falls under the NIMS/ICS framework as required under DOE order 151.1D I believe my conclusions should also be applicable to NIST. There are aspects of the timeline outlined above that are surprising in comparison with operating policies at DOE facilities and may have contributed to the near miss upon re-entry to the confinement area.

At the DOE sites I am familiar with that operate nuclear facilities a nuclear emergency would certainly result in activating the EOC under the Emergency Director as occurred at NIST. What status it activated to (1 – full, 2 -minimum, or 3 -monitoring) would depend on the nature of the incident but it would remain activated until the Termination Criteria were met as determined by a corresponding checklist but never before the local emergency was ended (as occurred in this case). The EOC would typically remain active at least until re-entry to the control room had been accomplished and that would be performed under the Re-entry and Recovery Procedure. There would also be development of a Preliminary Recovery Plan to be formally handed off to the recovery manager. The role of the EOC is, during the local emergency phase, to provide needed institutional support to the Incident Commander – manage external communications and tackle other matters to allows the IC to focus on the emergency event. Following termination of the local emergency response those roles continue at least until handoff for recovery is implemented. One would also expect a Hot Wash and after-action report from the EOC to inform future planning.

The re-entry to confinement did involve discussion amongst the re-entry team, the operations staff present when the incident occurred, reactor engineering, management etc so there does not appear to have been a lack of communication. However, most of the discussion focused on nuclear and radiological hazards and the Oxygen Deficiency hazard was overlooked. The subsequent re-entry did bring in the NIST Office of Safety, Health, and the Environment (OSHE) expertise and fire department who had the training and equipment needed to operate in that environment. While it is possible that even had the EOC been active the hazard might have been missed it is precisely the role of the EOC to muster those institutional resources who possess the needed expertise and equipment. Fortunately, in this instance the re-entry team was alert to unanticipated conditions and quickly evacuated when they noticed difficulty breathing. There is a very short window between difficulty breathing and unconsciousness, brain damage, and fatality.

The apparent disconnect between nuclear emergency response and NIST institutional emergency response that was a vulnerability when planning for confinement re-entry is probably at least in part due to the relative independence of NCNR as a separately regulated entity within NIST as discussed in the context of NIST Institutional Risk Management below. The emergent CO_2 hazard is an example of the fact that nuclear safety cannot be clearly separated from industrial safety. It was a worker safety hazard within the purview of the NIST OSHE and the Fire Department but arose as a consequence of a response to a nuclear safety issue, the turning off of the ventilation system prior to evacuation while leaving the purge gas system active. There is clearly a need to better integrate emergency planning and there should be a thorough review (perhaps including peer review) to verify that integration and insure consistency with NIMS/ICS particularly with respect to re-entry, termination, and preliminary recovery planning. Validation of smooth integration should be an objective of periodic exercises which should include reactor relevant scenarios on a fairly regular basis.

In light of the fact that off normal operating conditions can lead to CO_2 accumulation in the basement consideration should be given to the installation of Oxygen Deficiency monitors in the appropriate locations. It appears that the possibility of interlocking the purge gas system with the ventilation is also being examined which might also help avoid this situation in the future.

NIST Institutional Risk Management

NCNR is unique within NIST which otherwise does not have a nuclear operations footprint, while there are some radiological facilities, they have neither the hazards nor the regulatory framework of a nuclear reactor. NCNR holds the NRC license for the reactor not NIST. As a result, this has led to a structure where NCNR operates in many respects as a somewhat independent entity within NIST at least as regards nuclear safety. This arrangement makes sense for many reasons, one would not expect NIST to have significant nuclear operations expertise outside of NCNR and it doesn't make sense to develop a parallel organization solely for that purpose. Given that situation it is important to recognize and mitigate the vulnerabilities that may result. NCNR does draw on expertise in OSHE related to industrial and laboratory safety as well as capabilities the fire department has. However, operating as a nuclear island within the organization means there are limited resources available to tackle matters in that arena and NCNR itself is not a large organization. This is perhaps a bit of a blind spot in the NIST Institutional Risk Management framework.

It was surprising to learn the NCNR had only been added to the NIST Risk Matrix shortly before the incident and only then in the context of an ageing reactor that might not meet beam delivery needs of the scientific community. The fact it represents the highest hazard operation across all of NIST seems not to have been formally recognized. While the NRC license and NCNR design are predicated on the absence of a possibility of offsite impact the potential adverse consequence of a serious accident in terms of NIST reputation and risk to staff should elevate the visibility and management attention. The primary independent oversight mechanism is the SAC but it only meets once a year and seems primarily to inform NCNR as opposed to NIST senior management. Consideration should be given to enhancing the role of the SAC perhaps by augmenting its annual meetings with targeted deep dives into topics of concern making use of the broader external peer community. In addition, there needs to a be a greater visibility on the part of NIST management into the unique hazards and challenges faced by operating a nuclear reactor in a relatively open campus located in a dense suburban environment. Note that it would not make sense to fold NCNR into NIST facilities operations, that would likely have adverse impacts on both reactor operations and balance of plant due to the significant differential in requirements for operational rigor and the associated cost differential. Other mechanisms to explore better integration should be explored. There also needs to be a recognition that non-nuclear safety needs can impact nuclear safety directly and indirectly, I expect NRC would take an interest in an accident involving a ladder needed to access nuclear systems for example. In the minds of some staff there seems to be some conflation of lack of action on industrial safety issues with lack of action to address reactor operations staffing shortfalls – both being taken as examples of lack of management commitment to safety.

Conclusions

The response to this event by NCNR management has been robust and comprehensive with demonstrated ownership of the issues identified by NCNR and NIST senior management. The root causes and corrective actions extend well beyond the specifics of the fuel latching problem that triggered the Feb 3 event to include not only procedural and training deficiencies but also cultural aspects that developed slowly and will take time to address. The 19 Corrective Action and Recovery Items teams are tackling a wide range of topics that together should allow safe resumption of reactor operations. This is a substantial body of work, and some aspects will extend beyond reactor restart date. With the reactor being shut down it can be the primary focus of the entire reactor operations team and NCNR management supplemented as needed under the auspices of the IRT from NIST resources. However, once the reactor restarts the focus will necessarily shift to reactor operations and may lead to difficulties sustaining the needed improvements post restart when reactor operations and the user program are resumed. Adding a fifth shift will help but it will take time to recruit and train the new staff. To ensure needed improvements are sustained into the operating phase there may need to be tradeoffs in terms of resources and reactor operating cadence that will be difficult decisions to make. However, if focus dwindles post restart, history may repeat itself.

The main line of effort to improve the operational safety culture at NCNR is the development of more detailed procedures for operations that had previously not be well defined and the training the accompanies those more rigorous procedures. There are many areas of activity that need this increased rigor and the cost that goes with it. It is important to remember that the goal is to better optimize for a safer work environment, and it is possible to overcorrect – going too far can actually degrade safety if overly complex, prescribed procedures result that are difficult to understand and follow. The Institute of Nuclear Power Operations (INPO) has studied this and documented in their cumulative impact report.

The restart itself is by no means straightforward. Exactly what will be needed is still uncertain as unexpected conditions may emerge as the cleanup progresses. The contamination of the primary cooling system and associated radiation levels make this a set of operations that must be carefully planned and executed in a disciplined way. Upsets during the cleanup could erode confidence that has already been shaken by the event. There may also be difficulties balancing the risk of cleaning up and the risks left in terms of ALARA and future operations as well as possible variability in the residual radiation. It will not be possible to return to totally pristine state (of course in some sense it hasn't been pristine since first criticality).

The NCNR is an important component of the nation's scientific infrastructure. It is important to resume operations to allow the contributions made by NCNR to continue however that can only be done if the issues revealed by this incident are addressed. Furthermore, the facility is robust and has been well maintained but will not last forever. Given the long timeline for a replacement it is appropriate to be thinking about and planning for replacement even as NCNR is returned to service.

Overall timeline of fuel failure event

Date/time	Reactor actions	NIST actions
January 4		
0800	refueling	
1500	Latch checks	
February 3		
0816	Reactor startup begins	
0909	Fission product release	
0916	Alert declared; building evacuated	
0929	NRC notified	NIST management notified
~1030		Incident command center established (ESO)
~1300	Building reentry to complete shutdown activities	
1532	Downgraded to Notice of Unusual Event (NOUE)	
1713		Email announcement to NIST staff by Jim Olthoff
1935	Terminated emergency	
February 4		
0800	Initial briefing on status, possible building reentry to assess radiation conditions	
1430	Entry into confinement; CO_2 issues forced evacuation	
February 5		
		Incident Response Team formed
February 6		
0920	Entry into confinement with SCBAs, escorted by NIST FD	
0930-0940	Restarted normal ventilation	
February 8		
	Began ~daily entries into confinement	IRT initial meeting
February 9		
	NRC Special Inspection begins	
		Briefing on event to Congressional staff and city reps
February 10		
		NIST town hall meeting
		Briefing on event to House Science Committee Staff