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

August 23, 2013

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

Subject: Report of NCNR Violation of Limiting Conditions for Operations

Ref: NRC Event Report 49257, Docket 50-184, Facility License TR-5

Sir:

On August 8, the NCNR (NIST Center for Neutron Research) violated the following Limiting Conditions for Operations of the TR-5 Technical Specifications (TS) during a reactor refueling procedure:

1. TS 3.1.3, Core Configuration,
2. TS 3.3.1, Primary and Secondary [Cooling System],
3. TS 3.9.2.1, [Fuel Handling] Within the Reactor Vessel.

The initial report was made to the license Project Manager (Mr. Xiasong Yin) and the NRC Operations Center the next day after it was reported to the NCNR Chief of Reactor Operations and Engineering. The initial report was made in accordance with 10 CFR50.36 and TR-5 TS 6.7.2.d. The Acting Chair of the NCNR Safety Evaluation Committee was informed on August 8 and the Chair of the Committee was informed on August 19.

Circumstances of Violation

The NBSR (NIST Research Reactor) uses four shim blades or arms to control reactivity. These shim arms contain cadmium metal as the poison material which is clad in 6061 alloy aluminum. During reactor operation at 20 MW the cadmium is depleted by neutron absorption and the shim arms lose negative reactivity worth. After 28 operational cycles (approximately 4 years) of 20 MW operations the shim arms must be replaced. Replacing all four shim arms at one time requires the NBSR core to be fully unloaded and the fuel placed into a storage pool.

After the shim arms are replaced the reactor is reloaded with the previously stored and partially spent fuel elements. The shim arms are manufactured under a quality assurance program but the NCNR's conservative assumption is the new shim arms may contain insufficient cadmium poison to control the NBSR with all 30 fuel elements in the reference core condition (xenon free and at ambient temperature) until verified. To assure a safe core reloading and monitor for anomalous conditions, the reactor (with new shim arms) is loaded under a procedure typically called an inverse-multiplication or 1/M ("one over M") experiment. In this operation the subcritical neutron multiplication of the reactor is monitored while fuel is sequentially added to

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the core. The increase in the number neutrons detected is a function of the multiplication factor (M) of the reactor by the relationship

$$\text{Neutron Count Rate} = M*(\text{Initial Neutron Count Rate}).$$

Plotting the inverse of M or 1/M will ideally produce a straight, decreasing curve that tends to zero as criticality is approached. The curve is rarely linear due to geometric effects such as detector locations. The relationship between the inverse multiplication value to the core reactivity and multiplication factor is

$$1/M = 1 - k_{eff} = \rho/(\rho-1).$$

Thus, the inverse multiplication curve monitors the core total reactivity and permits the reactor operator to evaluate the reactivity of the inserted shim arms as the fuel is loaded into the grid plate. The curve is plotted with the number of fuel elements as the independent variable providing an estimate of the number of fuel elements for criticality. With the shim arms inserted, the estimated critical position should agree with previous experiments but will overestimate the number of fuel elements required due to the large negative reactivity of the inserted shim arms. When the shim arms are fully withdrawn another inverse multiplication curve is produced that is offset from the lower curve which allows the operator to evaluate total shim arm reactivity worth.

On August 7, the NCNR began the process of reloading the reactor core following normal shim arm replacement. The NCNR used an approved procedure (RP-20) titled "Reloading Plan After Installation of New Shims" that establishes the conditions and steps to load the core while monitoring conditions using the inverse multiplication method. The essential steps of the procedure are listed below (note this is a summary and not the actual procedure):

1. Establish initial conditions for fuel handling including instrumentation checks.
    a. Lower reactor vessel level to dry refueling level.
2. Limitations and Precautions
    a. Do not exceed a power level of 10 kW.
    b. Suspend loading operations if neutron multiplication increases by a factor of 5 after each element.
    c. Do not operate primary coolant pumps until loading is completed.
3. Load 4 fresh fuel elements from fuel storage vault.
4. Load 12 elements from spent fuel pool into reactor grid plate and calculate 1/M value for all detectors after loading each element. Plot 1/M data.
5. Withdraw shim arms until fully removed from core or reactor is critical. Plot 1/M data or note critical position of shim arms. Fully insert shim arms.
6. Load an additional 8 elements from spent fuel pool into reactor grid plate and calculate 1/M value for all detectors after loading each element. Plot 1/M data.
7. Withdraw shim arms until fully removed from core or reactor is critical. Plot 1/M data or note critical position of shim arms. Fully insert shim arms.
8. Load remaining 6 fuel elements from spent fuel pool into the reactor grid plate and calculate 1/M value for all detectors after loading each element. Plot 1/M data.

9. Withdraw shim arms until the reactor is critical. Note critical position of shim arms. Fully insert shim arms.

Due to equipment problems the reactor was partially loaded on August 7 and the procedure was completed on August 8. Following the essential steps outlined above, the NCNR reactor went critical on Step 7 and Step 9 on August 8. The reactor grid plate was partially loaded on Step 7 and fully loaded on Step 9 (total of 30 fuel elements).

During shift turnover on the morning of August 9 it was mentioned to the Chief of Reactor Operations that the reactor could be considered to be operating when it went critical the day before and not all grid positions were filled. The Chief of Reactor Operations informed the Chief of Reactor Operations and Engineering who agreed that Technical Specification 3.1.3 had been violated. Upon further review, it was concluded that three Limiting Conditions for Operations (LCO) were violated during the performance of the procedure RP-20.

It was also concluded that these particular license conditions had been violated during the performance of nearly every shim arm replacement (Six total with details below) since 1980. The particular technical specifications that were violated are given below with the particular specifications highlighted in BOLD.

3.1.3 Core Configuration

Applicability: Core grid positions

Objective: To ensure that a failed shim arm does not adversely affect core reactivity and cooling flow is maintained.

Specification

The reactor shall not operate unless all grid positions are filled with full length fuel elements or thimbles.

3.3.1 Primary and Secondary [subsection of Section 3.3, Coolant System]

Applicability: Primary fluid systems

Objective: To prevent degradation of primary systems' materials.

Specifications

The reactor shall not be operated unless:

(1) The reactor vessel coolant level is no more than 25 inches below the overflow standpipe.

Exception: To permit periodic surveillance of the effectiveness of the moderator dump, it is necessary to operate the reactor without restriction on reactor vessel level.

(2) The D_2 concentration in the Helium Sweep System shall not exceed 4% by volume.

(3) All materials, including those of the reactor vessel, in contact with the primary coolant shall be compatible with the D_2O environment.

3.9.2.1 Within the Reactor Vessel [Subsection of Section 3.9.2, Fuel Handling]

Applicability: Fuel element latching

Objective: To ensure that all fuel elements are latched between the reactor grid plates.

Specifications

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 one of the following methods:

(1) Elevation check of the fuel element with main pump flow.
(2) Rotational check of the element head in the latching direction only.
(3) Visual inspection of the fuel element head or latching bar.

All three violations are related by the condition of the reactor at the time of the violation. The reactor was subcritical through most of the core loading procedure; however, the reactor did become critical at some point in the procedure and was thus "operating."

Background Information Leading to Violation

Several long term (30+ years of NIST service) senior reactor operators were interviewed and records reviewed from initial criticality to determine the background of this evolution and the root cause of the violation.

The first inverse multiplication procedure was performed during initial startup testing beginning with initial core loading to critical in December 1967. The initial physics and low power testing program was reviewed and approved by the U.S. Atomic Energy Commission (AEC) and the results summarized in the 1968 NBSR Annual Report.

NIST (NBS at that time) was issued a provisional reactor operating license (TR-5) for the NBSR on August 22, 1967 that was valid for 18 months. This license permitted reactor operation up to 10 MW for initial fuel loading, initial nuclear program testing and rise to full power operation with an equilibrium core. The provisional license TS included section 8.0, Technical Specification Exceptions (Attachment A). This section permitted reactor operation to 10 kW and waived or deleted many sections of the Limiting Conditions for Operations to allow initial fuel loading and low power reactor physics testing. The introduction to TS 8.0 states:

> "This section shall apply during the initial startup and power operation phase. Once 10 MW equilibrium conditions have been reached and the initial nuclear test program completed, this section shall no longer be part of these Technical Specifications."

A request to the AEC for a full-term license was made in April, 1969 and a request for additional information (RAI) letter was received from the AEC in October of 1969. A full-term license (15 years) was issued to the NBS on June 30, 1970 and incorporated by reference the TS issued with the provisional license. The licensing document issued by the AEC required specific changes to the provisional TS that included several changes to the surveillance periodicity and the issuance of a new page (page ii) of the TS table of contents (Attachment B). The revised table of contents did not include a Section 8.0 but there were no explicit instructions to delete or remove Section 8.0 from the TS in the letter from the AEC.

Due to the relatively extensive changes to the provisional TS, a decision was made by the NBSR line management to rewrite the entire provisional TS incorporating all changes mandated by the AEC to the individual specifications and bases as a new document. This document was authorized by the Deputy Chief Nuclear Engineer on July 31, 1970. Although the newly issued and locally approved TS used the revised table of contents shown in Attachment B, the NBSR-issued TS included a TS 8.1, Technical Specifications Exceptions (Attachment C). It appears that TS 8.1 remained a part of the NBSR maintained and approved document until a new license was issued in 1984.

This section (TS 8.1), although incorrectly included in the July 1970 version, did include the introductory paragraph quoted above. It is possible, but cannot be proven, that interpreting the introductory paragraph of TS 8.1 and the safety basis incorrectly by NBSR managers and reactor operators could lead one to believe that TS 8.1 was included in the 1970 license to permit a program of low power (less than 10 kW) reactor physics testing as necessary.

In August 1979, the NBSR reactor was shutdown to investigate a damaged shim arm (No. 1). All four shim arms were replaced over the next several months. As this was the first time the shim arms were replaced since initial criticality, it was necessary to procure equipment and write procedures for this operation. The new shim arms were installed and the reactor core was reloaded in February 1980. An inverse multiplication loading was performed and the core was loaded in three steps (9, 11, and then 10 elements). The procedure, called a reload plan, was approved by the NBSR Hazards Evaluation Committee (HEC) in meeting #214 on February 20, 1980. The reactor core was fully loaded with 30 elements before the reactor was taken critical by the withdrawal of shim arms.

It is possible, but cannot be proven today, that TS 8.1 was considered to be part of the TR-5 license and a procedure was written essentially repeating an inverse multiplication test from the 1967 AEC-approved nuclear testing program. For this first shim arm replacement, the grid plate was full before the reactor operated; however, the required fuel element latch checks of TS 3.3 were not performed prior to operating the reactor. The latch checks were performed (as noted in the reactor operator's log) during the following shift in preparation for a low power reactor startup for shim arm calibrations. Thus, only TS 3.3 was violated during this operation in 1980. The 2004 and 2013 versions of RP-20 are essentially identical to the procedure approved by the HEC in 1980 including the precaution not to exceed a power level of 10 kW.

The NBSR relicensed for an additional 20 years on May 16, 1984. The license issued incorporated the previous TS and all amendments so the NBSR continued to maintain an updated, reviewed and locally approved copy of the 1984 TS for reactor operation and license compliance. The 1984 version of the TR-5 TS maintained by the NBSR facility did not include a TS 8.1. Reactor maximum operating power level was increased from 10 to 20 MW in 1984 and the number of operating hours each year was increased causing the shim arms to deplete at a higher rate.

In August 1987, shim arms were replaced and the core was reloaded by performing an inverse multiplication and programmed reloading procedure. It is highly likely that the procedure used was the previously approved 1980 reload procedure. The reloading was performed in five steps (12, 6, 4, 4, and 4 elements) with shim arms withdrawn fully or until critical after each step. For this loading, the reactor went critical with 26 fuel elements in the grid plate. When the reactor was operating there were four empty grid positions, reactor vessel level was greater than 25 inches below the overflow standpipe and fuel element latching checks had not been performed. Two TS were violated during this operation. As will be explained later, the reactor vessel level was not a violation until the 2009 TR-5 license was issued.

In 1995, shim arms were replaced and the reactor was critical using the regulating rod during reloading with 22 elements loaded and all shim arms withdrawn fully from the core. An additional four elements were added and the reactor was critical with 26 elements in the grid plate. In 2000, following shim arm replacement the reactor achieved criticality with 26 elements in the core and in 2004 the reactor was critical on 24 fuel elements loaded in the grid plate.

In 2008, the replacement shim arms were radiographed using a neutron beam for the first time. These radiographs were used to verify that cadmium had been installed as required in the shim arms. Because the shim arms were shown to contain cadmium the reactor was reloaded using a procedure that did not perform an inverse multiplication evaluation as the core was loaded. In the most recent violation of August 2013, the shim arms were not radiographed and the reactor was reloaded using the procedure of 2004 which violated the TS as previously detailed.

The 1970 and 1984 TR-5 TS had the same LCO (TS 3.2) for the Reactor Coolant System and prohibited reactor operation

> (4) With a reactor vessel coolant level more than 24 in. below the overflow standpipe level, except during periods when operations at power levels up to 10 kW with no reactor flow are permitted (see section 2.1 of these specifications).

Section 2.1 of the 1970 and 1984 licenses permitted reactor operation at power levels of up to 10 kW with reduced flow (including no flow) if decay heat is insufficient to cause significant heating of the reactor coolant. In 2009, the TR-5 TS 3.3.1 was modified to formally allow the specific exception previously found only in the 1970 and 1984 bases. The basis only considered no flow reactor operation at less than 10 kW for "periodic surveillance of the effectiveness of the moderator dump". Thus, operating the reactor prior to 2009 at power levels below 10 kW in natural circulation with low reactor vessel level and low decay heat was permitted by the TR-5 license.

Root Cause

NBSR management was responsible for making changes as directed by the AEC to the TS in 1970 and should have removed TS 8.0 rather than carrying it forward as TS 8.1. This error added a license condition that was not authorized by the AEC. Because it appeared to be included in the full-term license the TS allowed a misinterpretation of the statement, "This section shall apply during the initial startup and power operation phase." The TS bases provide additional information and the reasons for such a specification but were not part of the technical specifications. The basis for TS 8.0 in the 1967 provisional license and incorrectly carried forward in the 1970 NBSR version states:

> "These specifications are written for a reactor operating at power levels up to 10 MW. During the initial startup period, certain specifications must be suspended in order to permit required testing at zero and low power. These suspensions will not affect safety requirements for the facility..."

As the full-term license appeared to allow zero and low power operations with suspended TS it is possible the 1980 reload procedure was written with consideration of TS 8.1 and the allowed exceptions. Further evidence of this is the procedural precaution to not exceed 10 kW during the core reloading.

The root cause of these violations was reactor management's failure to establish sufficient administrative procedures and properly control reactor license documents. Contributing to the violations was the lack of detailed, routine review and consideration of any changes to external administrative limits during the preparation and approval of reactor procedures.

Many of the NBSR operational procedures have not changed significantly over the more than forty years of operation. A major reason for this has been the reluctance by reactor managers and operators to change what appeared to be working. In the past year, prior to the August violation, the NCNR Reactor Operations and Engineering (ROE) group had begun a formal program of procedural review and update. The procedure to reload the core after installation of new shim arms (RP-20) had been reviewed by many of the licensed reactor operations staff and was approved for use by the Chief of Reactor Operations on July 17, 2013. The procedure was reviewed by operations staff for content and functional accuracy but no licensed operator identified that the procedure would violate the TS. This indicates a weakness in the NCNR reactor procedure review and approval process but also in reactor operator training.

Corrective Action

Ultimately, the NCNR intends to request changes to the TR-5 TS that will permit core loading using the inverse multiplication procedure. The inverse multiplication procedure is standard practice for loading a reactor core and all reactor operators licensed by the NRC are expected to know how to perform the procedure and the required calculations to determine criticality.

Immediate corrective actions will include briefing all licensed reactor operators and reactor line management on the circumstances of the violation and the root cause. All licensed operators will

be given a written test on the current license TS within 30 days with the questions heavily weighted on Limiting Conditions for Operations. Failure of this examination will result in the operator performing his licensed duties under the direct supervision of a licensed SRO until such time as the operator completes remedial training and passes another written exam on the same subject.

Effective immediately, all frequently or routinely used procedures will be reviewed prior to their use by the Chief of Reactor Operations or the Chief of Reactor Operations and Engineering who will verify the procedure does not violate any TR-5 TS. Other procedures will be reviewed following new review and approval guidelines once those are promulgated.

NCNR will review and revise the written procedure that governs the preparation, review and approval of procedures at the NCNR. All written procedures required by TS 6.4 will be re-reviewed under this new guidance and will include the review and approval of the NBSR Safety Evaluation Committee (SEC) even if the procedure is unchanged and was previously approved by the HEC or SEC.

Conclusion

The NCNR will present the circumstances of the violation and the corrective actions at the next scheduled SEC meeting in September. The NCNR's NRC Inspector, Craig Bassett, has been informed of the violation, will receive a copy of this letter, and intends to fully review the violation at the next facility inspection in November. Please contact me or Sean O'Kelly, NCNR Deputy Director, if you have additional questions or require further information.

Sincerely,

for

Rob Dimeo, Director
NIST Center for Neutron Research

Attachments

cc: NCNR Safety Evaluation Committee Chair
Xiasong Yin, Nuclear Regulatory Commission
Craig Bassett, Nuclear Regulatory Commission

8.0 TECHNICAL SPECIFICATIONS EXCEPTIONS

This section shall apply during the initial startup and power operation phase. Once 10 MW equilibrium conditions have been reached and the initial nuclear test program completed, this section shall no longer be a part of these Technical Specifications.

8.1 Up to 10 KW

The following sections of these Technical Specifications shall be modified as indicated at initial reactor power levels below 10 KW.

a. Delete the Minimum Flow requirements of Sections 2.1 and 2.2.

b. Delete the confinement integrity requirements of Section 3.1.

c. Delete the requirements of Section 3.2, which relate to shutdown cooling flow, heat exchanger isolation capability, reactor vessel level, and secondary system radiation monitoring and sampling.

d. Delete the core grid positions requirement and the temperature and void coefficient requirements of Section 3.3, Specifications a. and b.

e. Delete the following requirements of Table I of Section 3.4:

Low Reactor Vessel D_2O Level

Low Flow Reactor Outlet

Low Flow Reactor Inlet, Inner Plenum

Low Flow Reactor Inlet, Outer Plenum

f. Delete the Emergency Cooling System requirements of Section 3.5.

g. Delete the requirement for monitoring the secondary cooling system of Section 3.6

h. Delete the fuel handling requirements of Section 3.8 until full flow is established.

i. Delete the requirement for a helium sweep gas radiation monitor of Section 3.11.

Attachment A: 1967 Tech. Spec. 8.0

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5.0 SURVEILLANCE STANDARDS

5.1 Confinement System
5.2 Reactor Coolant System
5.4 Reactor Control and Safety System
5.5 Reactor Emergency Cooling System
5.6 Secondary Cooling System
5.7 Post-Incident and Gaseous Waste Systems
5.8 Radiation Monitoring System
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6.0 DESIGN FEATURES

6.1 Site Description
6.2 Reactor Coolant System
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7.0 ADMINISTRATIVE CONTROLS

7.1 Organization
7.2 Hazards Evaluation Committee
7.3 Safety Review Committee
7.4 Procedures
7.5 Action to be Taken in the Event a Safety Limit is Exceeded
7.6 Action to be Taken if a Limiting Safety System Setting is Exceeded or a Limiting Condition of Operation is Violated
7.7 Action to be Taken in the Event of an Abnormal Occurrence
7.8 Reporting Requirements
7.9 Records

Attachment B. Table of Contents for 1970 full-term license

NATIONAL BUREAU OF STANDARDS | TECHNICAL SPECIFICATIONS

Reactor Operations Section | T.S. 8.1

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APPROVED BY: [signature] DATE ISSUED: 7-31-70 SUPERSEDES ISSUE DATED: 8-3-67

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Low Flow Reactor Outlet

Low Flow Reactor Inlet, Inner Plenum

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f. Delete the Emergency Cooling System requirements of Section 3.5.

g. Delete the requirement for monitoring the secondary cooling system of Section 3.6.

h. Delete the fuel handling requirements of Section 3.8 until full flow is established.

i. Delete the requirement for a helium sweep gas radiation monitor of Section 3.11.

Attachment C. 1970 Tech. Spec. 8.1 added by NBSR