UNLICENSED/ALUMINUM FUEL EVENT AT THE UNIVERSITY OF TEXAS AT AUSTIN TRIGA REACTOR

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On October 17, 2022, a records review indicated the reactor (licensed for stainless-steel clad fuel) operated with two aluminum clad elements from January to October. There was no evidence of cladding failure. Operations were suspended for immediate corrective actions, investigation, and development of corrective actions for return to normal operations. The investigation developed the timeline leading to the event, and uncovered management and safety culture issues. Comprehensive corrective actions were developed and implemented. In the course of implementation, the NRC performed a special inspection that resulted in an apparent violation (under consideration for escalated enforcement action) related to the aluminum fuel utilization, and a Severity Level IV notice of violation (lacking Reactor Oversight Committee review related to 10CFR50.59). Normal operations were restored on December 1, 2022. The facility has acknowledged the apparent violation and responded to the notice of violation. Long term corrective actions are in progress.

1. Introduction

The reactor at the Nuclear Engineering Teaching Laboratory (NETL) at The University of Texas at Austin (UT) is a TRIGA Mark II reactor licensed to operate up to 1.1 MW with stainless-steel clad fuel. A NETL reactor manager retired (on an accelerated schedule) September 9, 2022. A NETL staff member, senior reactor operator, was appointed as interim reactor manager. On October 27, the new reactor manager found records of aluminum-clad fuel elements in the core. The elements were removed from the core, visually inspected, and placed in pool storage. The reactor operated from January to October 2022 with the aluminum elements installed, generating 24 MWD of energy. Pulsing operations over the interval were performed 37 times, with twenty-four $3.00 reactivity pulses. The Associate Director suspended normal operations pending resolution and notified the USNRC Non-Power Utilization Facility (NPUF) branch while the Director notified the Reactor Oversight Committee (ROC). The Director developed (and periodically updated) a summary of the event and NETL response. During event investigation a fuel element surveillance was discovered to have been performed using an unreviewed and unapproved procedure, so a comprehensive assessment of procedure performance issues was performed. The unapproved procedure could have resulted in unacceptably degraded fuel elements in the core, and even if the elements were identified exceeding the elongation limit the aluminum-clad fuel utilization demonstrated the lack of a mechanism to prevent using unqualified fuel. Although resolved by corrective action for the aluminum-clad fuel utilization, this was unambiguously inadequate controls with potential for an unsafe condition and reported as such [1]. Following revision, review, and approval of the fuel inspection procedure, all fuel elements in the core configuration were inspected. The USNRC commissioned a Special Inspection Team (SIT) while the fuel inspection was in progress [2]. Normal operations resumed on December 1, 2022. The SIT report was completed on January 1, 2023, with a Severity Level IV violation [3]. A notice of violation for utilization of the aluminum clad fuel was issued under separate cover [4].

2. Discovery and Immediate Response

Discovery of Aluminum-Clad Fuel in the NETL Core

The Department of Energy fuels assistance program issued a request for information on current status and projected needs for reactor fuel at NETL in September 2022. While validating the current core configuration on October 17, the new reactor manager noted records of two aluminum clad fuel elements loaded in the core during the January 2023 maintenance period. The reactor manager removed and inspected the elements, visually verifying the elements were aluminum-clad and undamaged. He notified the Associate Director, who suspended normal operations pending investigation and resolution. The Associate Director reviewed reportability requirements of the facility technical specifications.

Assessment of Reportability

NETL technical specification reportability requirements reference the approved Limiting Safety System Settings (LSSSs) and Limiting Conditions for Operation (LCOs); since the aluminum-clad fuel is not authorized for use at NETL most of the reporting criteria as written did not apply. The reporting criterion "*An observed inadequacy in the implementation of administrative or procedural controls such that the inadequacy causes or could have caused the existence or development of an unsafe condition with regard to reactor operations*" was considered. The 'unsafe condition' was interpreted as actual or potential for fuel element to reach the 500°C Safety Limit (SL) for aluminum clad fuel.

A recent NRC audit determined coupled NETL neutronics and thermal hydraulic analysis acceptable for technical review with the reports submitted to support relicensing [4]. The analysis used the Monte-Carlo N-Particle code (MCNP) to derive power distribution and the TRAC/RELAP Advanced Computational Engine code (TRACE) to calculate thermal hydraulic performance at fuel element power (see Figure 1). Instrumented Fuel Elements (IFEs) in the B ring have monitored fuel temperature at or near the hot channel since initial criticality. Records of the fuel temperature at steady-state full power operation over the period January to October 2022 consist of 245 readings from 382°C to 391°C. Operating records and data from the analysis were used to evaluate maximum temperatures in the aluminum-clad fuel during utilization. The aluminum clad element with the highest power generated 86% of the power generated in the IFE. The current IFE and the hot channel element power levels differ by 0.9%. Coupled TRACE and MCNP simulations indicate that, with a maximum temperature of 386°C in the core, the fuel element in position C6 had a maximum temperature of 352°C and in position D1 a maximum temperature of 335°C. With 391°C maximum fuel temperature during full power steady state operation, the aluminum-clad fuel integrity was not challenged. Even at the maximum fuel temperatures recorded in the IFEs there was no potential challenge during steady state operations.

The maximum temperature during TRIGA pulsing operations occurs near the surface of the fuel element while the IFE thermocouples are located near the center. TRACE calculations were used to develop a correlation between the maximum fuel temperature and the temperature at the thermocouple location during a pulse (see Figure 2). The maximum hot channel fuel temperature during pulsing at $3.00 reactivity addition during the aluminum-clad fuel element utilization did not exceed 420°C (see Figure 3).

TRACE pulsing analysis uses a representative fuel element to establish reactor kinetics. A core peaking factor applied to the representative element generates the hot channel for thermal hydraulic calculations. Consequently, TRACE hot channel analysis is limited to a single material composition and the model does not support calculations of aluminum-clad fuel in an otherwise stainless steel-clad fuel core. Since the bulk of the core was stainless-steel clad fuel, stainless-steel clad fuel kinetics were assumed to be the dominant factor in limiting the maximum core power and consequently the maximum fuel temperature during pulsing operations. While the aluminum-clad element response to a pulse may differ from the response of stainless-steel clad fuel, the similarity of the steady-state responses suggests the differences are not large. The feature of TRIGA fuel that allows pulsing is a cell disadvantage factor that varies with temperature such that higher fuel temperature reduces the fission rate (power generation) within the element. The current version of MCNP does not have the capability to use enough temperature dependent cross sections to allow calculating a realistic power distribution for fuel elements at different temperatures across the core. Generation of power in hotter channels is therefore expected to be biased high. The best available information indicated utilization during pulsing did not have actual or potential ability to reach the SL.

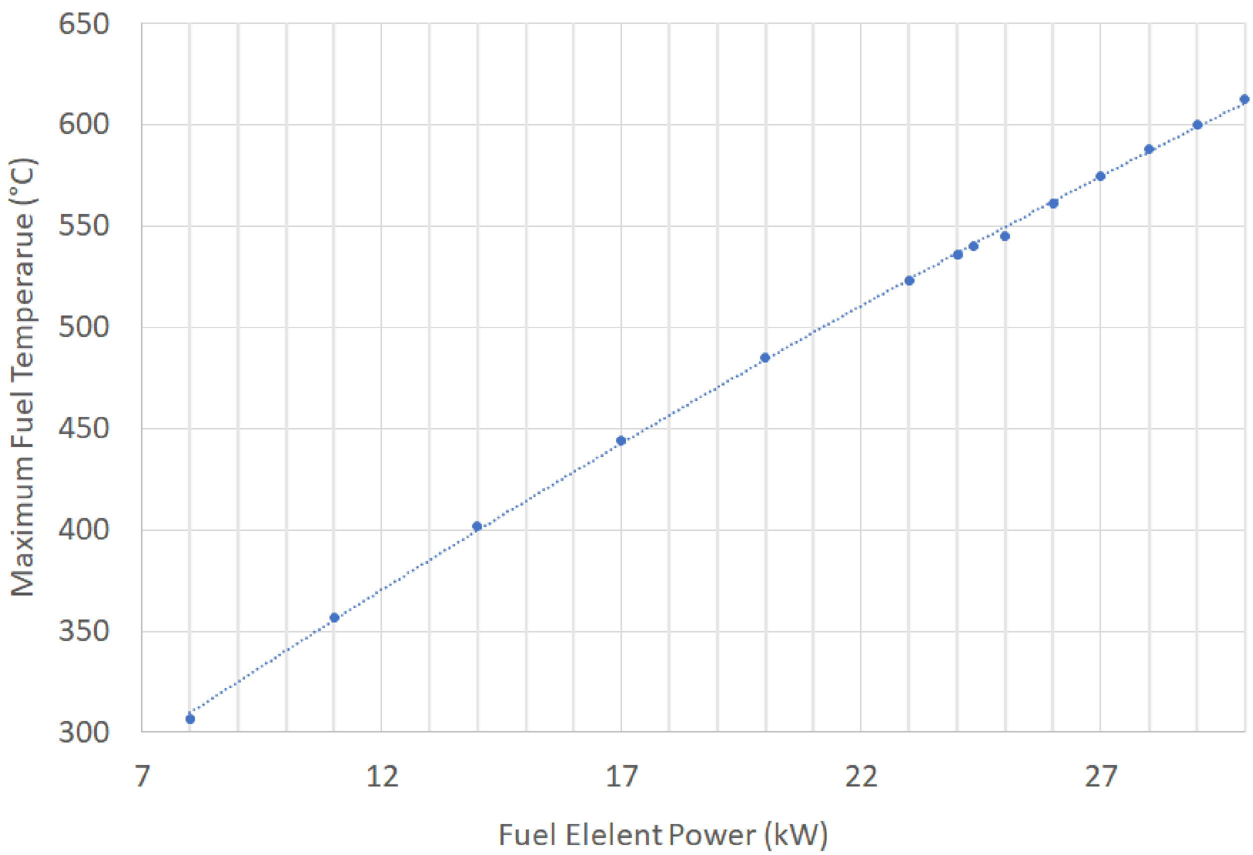

Figure 1: Maximum Fuel Element Temperature at Fuel Element Power

Consideration of Administrative Controls

This assessment was narrowly focused on determining if the event signaled actual or potential *unsafe condition with regard to reactor operations* during this utilization. The conclusion that there was no actual or potential challenge to the SL from this utilization is based on the current core configuration and administrative controls in effect. The current core configuration has been 113 and 114 fuel elements during the tenure of the reactor manager who loaded the aluminum elements, while the previous reactor manger (from 1999-2016) performed the aluminum fuel receipt inspection and would not have loaded the elements in the core. Reactor power is administratively limited to 900 kW to prevent spurious scrams. TRACE calculations indicate the element temperature will approach the aluminum clad fuel element SL with an element power level of 21 kW, which corresponds to an unlikely peaking factor of 2.6 in a 113-element core at 900 kW. If a peaking factor of 2 is assumed (less incredible but still improbable) reactor operation that would result in an approach to the SL would require a power level of 1.19 MW, above the license power level limit and above the scram setpoints for three power level channels. Reaching the temperature SL for the aluminum-clad fuel elements during steady state operations is therefore not possible without an unlikely peaking factor coincident with failure of three independent power level channels. A technical specifications LCO restricts operation in the pulse mode to less than 15 seconds which limits the maximum temperature following the pulse, the actual setpoint is 4 seconds. The LCO is required during the pulse mode to terminate operations if pulse operations do not terminate automatically; there have been over 600 pulses at the UT reactor with no failures to terminate a pulse. While the approved NETL reactor SLs, LSSS, and LCOs are not appropriate for aluminum-clad fuel with a SL of 500°C, with the administrative controls in effect there does not seem to be a reasonable scenario where the aluminum clad fuel element SL could be reached.

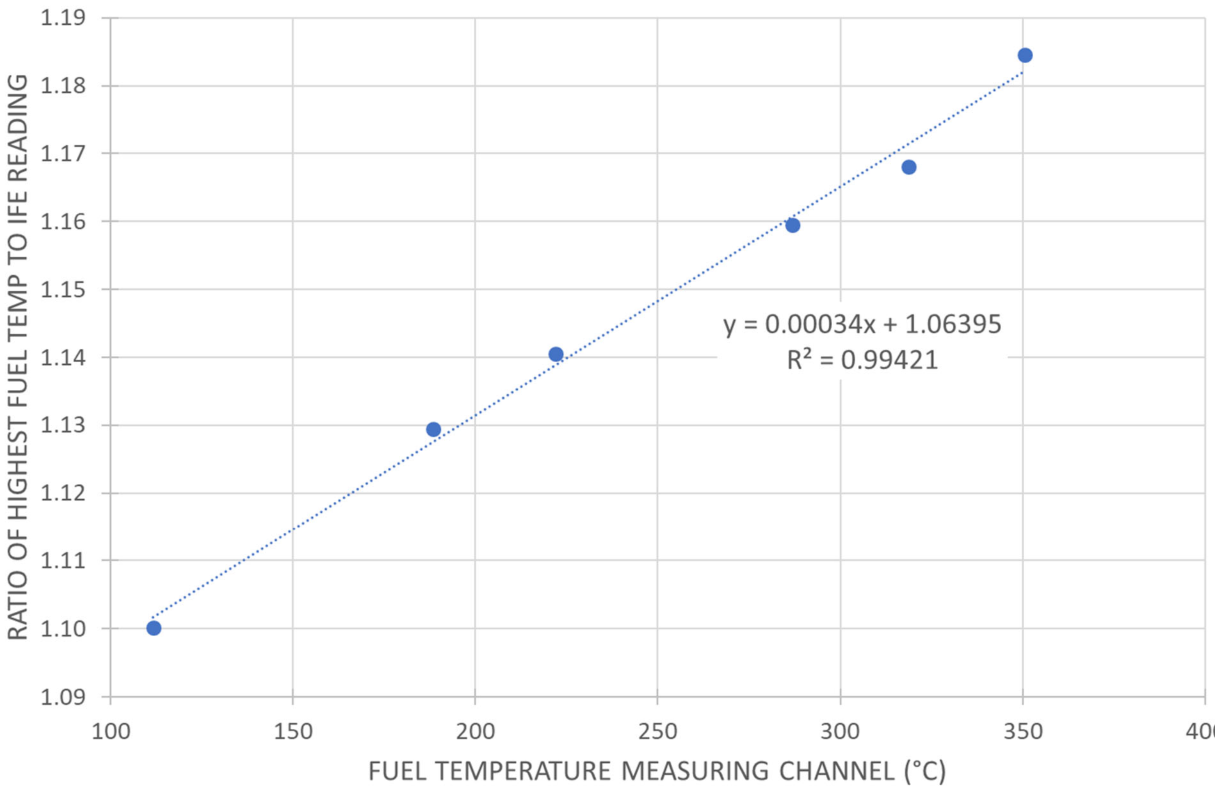

Figure 2: Ratio of Peak Fuel Temperature to Temperature at IFE Thermocouple Position (TRACE)

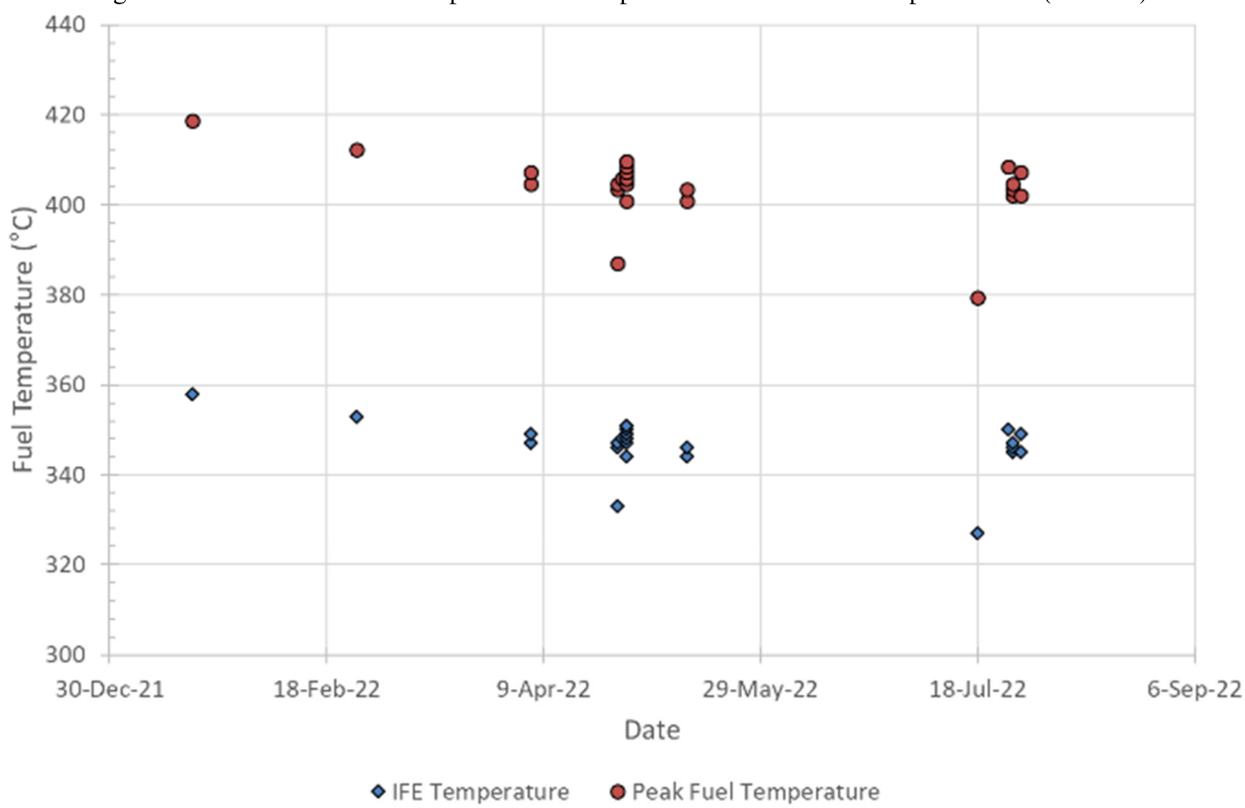

Figure 3: Peak IFE (Fuel Temperature Channel) and Corresponding Maximum Temperature f
or $3.00 Pulses January-October 2022

Facility Perspective

This assessment for reportability does not minimize the significance of the event. The aluminum-clad fuel use was an unanalyzed condition that violated the license and technical specifications. Safety margins for aluminum-clad fuel are significantly lower than safety margins for NETL stainless-steel clad fuel. NETL reactor SLs, LSSSs, and LCOs are not appropriate for aluminum-clad fuel. The assessment was not based on bounding calculation for limiting core conditions that would support licensing the aluminum-clad fuel and would not be acceptable as a license basis. The Associate Director informed the Director of the assessment and recommended that, although it did not appear to be a reportable event under the language of the technical specifications, the situation was significant and warranted an immediate notification of the NRC NPUF branch. The NRC program manager and the assigned inspector were immediately notified.

3. Event Summary

The Director developed an event summary, updated the summary as information was developed, and provided the summary to the NRC and ROC. The summary documents a historical timeline for the aluminum clad fuel at NETL, beginning with the receipt of shipment. A timeline of communication with the NRC and ROC was documented. NETL staff and management documented five issues of non-compliance. The lead non-compliance was utilization of the aluminum-clad fuel in the core with the remainder related to the discovery of substituting the approved fuel inspection procedure with an unreviewed, unauthorized, and inadequate method. The summary documents the safety significance of operating with aluminum-clad fuel, the procedure performance issues, and mitigating factors. The results of root cause analysis were documented. A simple barrier analysis was performed initially, but the complexity of emergent issues identified during investigation prompted a review of potential causes from Management Oversight and Risk Tree Analysis [15]. The proximate cause was an inappropriate element selected for installation, with a root cause of procedural inadequacy, i.e., lack of controls on unqualified elements. The contributing causes were complex, many common to both the aluminum-clad element utilization and the fuel surveillance issues with a consistent thread of safety culture issues. The corrective action plan provided specific actions for resumption of normal operations. Four corrective actions establish controls to prevent future use of unqualified fuel, two corrective actions address performing the fuel inspection with an approved procedure, one corrective action broadly assesses surveillance procedure compliance, and one corrective action raises operator awareness of the nuclear safety culture principles in the context of this experience. The summary included fuel temperature analysis and documented the review for reportability.

4. Investigation and Procedure Performance Assessment

Receipt at NETL

The University of Illinois at Champaign Urbana (UICU) transferred the aluminum-clad fuel elements to NETL in 2004 during decommissioning of the UICU TRIGA reactor. The aluminum-clad elements were identified explicitly in shipping records and documented as AL-SFE (Aluminum-Standard Fuel Elements) in the NETL B159 spreadsheet documenting fuel serial numbers in storage locations. Anticipating resumption of spent fuel shipments to Idaho, in 2018 receipt facility personnel inspected and reported results to the reactor manager, including the aluminum-clad fuel.

Fuel Inspection Surveillance System

The biennial fuel inspection surveillance in 2018 was difficult. The inspection equipment used a set of strain gages mounted on an inspection stand to measure fuel element length and radial distortion. The system was transferred from the original UT TRIGA I reactor on the main UT campus, and the configuration did not allow strain gage measurements with IFEs, control rod fuel followers, or streamlined fuel elements. In 2018 the measuring system components were obsolete and failing. The reactor manager successfully tested the ability to optically measure fuel length at the precision required to determine elongation.

Installation of the Aluminum-Clad Elements

Following the 2022 fuel inspection, excess reactivity was not adequate to support a planned experiment. A core reconfiguration was developed to replace high-burnup fuel with less-burned elements. The reactor manager identified two elements with high U-235 content but did not identify or recognize the aluminum-clad designation or question why previous campaigns to increase excess reactivity had not used the elements. The reconfiguration expanded restart requirements; time pressure may have contributed to the inappropriate selection of the aluminum-clad elements.

Fuel Inspection Surveillance Records

Fuel movement and inspection records were examined. None of the replacement elements in 2022 had previous NETL use, all required fuel inspection before use. During inspection neither the reactor manager nor support staff recognized the somewhat subtle differences in relatively unused aluminum cladding and stainless-steel cladding. The 2020 and 2022 inspection records did not include length or elongation values. NETL staff were unable to locate initial length measurement values for the elements loaded in the core to increase excess reactivity. The previous reactor manager indicated that he had performed the surveillances in 2020 and 2022 (including elements used to increase excess reactivity) and all fuel elements met elongation criteria. In discussion with licensed staff that supported the inspections, it was clear that the 2020 and 2022 inspections used a camera to perform measurements, although the procedure was not revised.

Procedure Issues

The discovery of a failure to appropriately revise the procedure, the failure to use an approved operating procedure for a surveillance, and the failure to record data that demonstrated fuel elements met technical specifications suggested the aluminum-clad fuel element utilization might have occurred in the context of broader performance issues. The reactor manger was directed to assess technical specification surveillances for possible performance issues.

The review noted many procedures were difficult to follow or understand. Multiple procedures contained deficiencies, including a procedure that could not be performed as written (corrected with a minor change and performed during the review), multiple minor procedure changes that did not comply with administrative procedure requirements, and a minor procedure change that deleted data records required in a procedure step. The revision and performance of the fuel inspection surveillance was identified as a condition for resumption of normal operations. Where initial length data could not be located, fuel elements could not be compared to initial values and therefore would be removed from the core configuration prior to reactor operation.

5. Fuel Inspection Surveillance

Fuel Inspection Procedure Development and Approval

The fuel inspection surveillance procedure was revised and submitted to the ROC for review and approval. While the ROC was performing the review, the Associate Director found records of initial-length measurement for some of the elements in shipping records, and the reactor manager located the remaining records in a legacy file stored behind fuel records.

Using the ROC approved surveillance procedure, NETL personnel inspected all fuel elements in the core over about three weeks. The NRC commissioned a SIT for November 7 through December 8 (one week of offsite preparation, one week onsite, the rest of the inspection off-site). A secure cloud storage application was used to share information supporting the offsite portions and a UT computer was dedicated to support NRC connectivity restrictions for the onsite inspection. The fuel inspection surveillance was completed with the NRC SIT on-site.

Discovery of Safety Significance

The elongation limit is based on identification of elements distorted by enough internal pressure that cladding might exceed yield strength from pressure generated during operation. During the fuel inspection it finally became clear to NETL management that the previous reactor manager evaluated elongation by comparing the length of fuel elements to a measurement standard, not by comparing the length after a burnup interval to initial fuel element length. This explained how the 2020 and 2022 surveillances could have been performed with initial length records that could not be found. Since elongation was not actually determined in performance of the 2020 and 2022 fuel surveillance, fuel elements exceeding the elongation criterion would have been undetected and loaded in the core either during the previous two years or, if the practice remained unidentified and uncorrected, in the future.

The causes of the procedure issues overlap with the causes of the utilization of aluminum-clad fuel. Even if degraded elements were identified in surveillance performance, the installation of the aluminum-clad fuel elements demonstrated that controls would not be adequate to prevent use in the core. This event was reported on November 2, 2022, as "An observed inadequacy in the implementation of administrative or procedural controls such that the inadequacy causes or could have caused the existence or development of an unsafe condition with respect to operations" as a lack of control over fuel elements under the umbrella first noted in utilization of the aluminum clad fuel. The 14-day report was the summary report updated to November 16, 2022 [6].

Bubbles

Near the end of fuel inspections, the SIT requested to view one of the aluminum elements. As the element was elevated from the pool storage rack to the inspection stand, bubbles were observed evolving at a slow rate with the inspectors present. When the element was placed in the inspection stand the bubbles stopped. The underwater camera was positioned to inspect the element and revealed a bubble approximately ¼ in. in diameter trapped in a lip formed by the cladding over the lower end fitting.

Pool water samples from days before and the day of the observation did not indicate unusual contamination, the off-gas monitor and the reactor bay air particulate detector did not indicate elevated levels. The difference in water pressure as the element was elevated might have caused hydrogen to evolve through a flawed or porous weld or caused trapped gas to expand out of the lower end fitting area. Radiolytic decomposition of water or release of air from the fuel handling tool as it is maneuvered into position could be alternate sources of trapped gas. Since the situation was stable, the fuel inspection continued with the intent to explore how to sample the gas when the inspection was complete. When the inspection was complete 2-days later the bubble was no longer present.

6. Resumption of Normal Operations

Once the fuel element inspection was complete NETL staff submitted the plan for resumption of normal operations to ROC review, Friday before Thanksgiving. The ROC reviewed and approved a minor change to the fuel handling procedure to establish controls for management oversight of planning core configurations and to identify and segregate fuel disqualified for use. The ROC reviewed and approved the proposed list of surveillances and corrective actions for resumption of normal operations. NETL staff tentatively scheduled completion of surveillances before Thanksgiving, with a safety culture briefing the following week and return to normal operations December 1. NRC management requested time to review status prior to resumption of normal activities which did not impact the schedule. Resumption of normal operations occurred on December 1, 2022.

7. Follow-up Activities

Procedure Upgrade

The procedures were adequate for the level of knowledge of the reactor mangers from 1992 to 2016 who participated in every aspect of the facility from construction and commissioning through decades of operation. The procedures are less transparent to later staff with less experience at the facility. Most NETL procedures are rule-based and not descriptive of or modeled on processes. Many procedures have steps that are paragraphs. Many procedures have material not actually needed to perform the procedure. Objectively, the procedures were essentially references and not guidance for performance. The current procedure format uses a paragraph structure modeled after the Code of Federal Regulations. Most of the approved procedures have not been revised in decades, some since the facility was built. The 10CFR50.59 process was poorly integrated in procedure control after identification in 2010 that procedure changes are subject to review. Poorly written and confusing procedures are not conducive to verbatim procedure compliance. Based on the results of the procedure assessment it was decided a general procedure upgrade is necessary, but not for resumption of operations. The first procedure upgrade is in progress; the a revision to the procedure to control procedures has been drafted, with format, guidance, and a writer's guide adapted from the Procedure Professionals Association [8]. The revised procedure includes explicit guidance from the Nuclear Energy Institute for applying the 10CFR50.59 process to non-power facilities endorsed by the NRC. [8] Guidance for digital upgrades will be integrated in the procedure when development is complete and endorsed.

Corrective Action Management

Guidance from NRC [10, 11], Institute of Nuclear Power Organization [12, 13], International Atomic Energy Agency [14] and DOE [15] was reviewed to prepare a discussion of nuclear safety culture principles. Issues that require immediate action are brought to the attention of the Director, Associate Director, reactor manger or lab manager. Issues that do not require immediate action are discussed at a bi-weekly staff coordination meeting. However, systematic tracking of corrective actions was not well-developed at NETL. The NETL reactor manager developed a method for corrective action tracking using an enterprise Microsoft 365 application. Priorities are recorded in the application. The system automatically generates emails for notification of assignments, upcoming due dates, and overdue items. Progress can be updated, and completion records are archived for reporting and retrieval. A corrective action report is generated by the reactor manager for review at staff meetings. A facility technical specification requires periodic ROC audit of corrective actions, and a report will be provided to the ROC at routine review meetings or on request.

Level IV violation, 10CFR50.59 Review

The NRC Special Inspection Report cited a Level IV violation based on failure to have ROC review determinations that three facility changes do not involve an unreviewed safety question as required by technical specifications. The three facility changes included restoring a fan flow rate during a building maintenance activity, modification to bring the fire control system up to the design basis in the Safety Analysis Report (SAR) and moving a server from a remote location to within the facility. The reactor manager had written "50.59 does not apply" on the forms but wrote "No" next to each of the determination criteria. These three changes are exempt from the 10CFR50.59 process, but the form was incorporated in

2010 in a procedure without guidance which left the use of the form subject to interpretation. Independent of the inspection, the revised implementation of 10CR50.59 as described resolves the issue.

Notice of Violation

On May 10, 2023, a Notice of Violation, Severity Level III, was issued for the use of aluminum-clad fuel.

8. Conclusion

On discovery of unlicensed aluminum-clad fuel in the NETL core, the staff moved rapidly to restore the core configuration to the design basis, assess safety significance, determine reportability, and open lines of communication to the NRC and ROC. A comprehensive investigation discovered that procedures had not been properly managed, resulting in potential for an unsafe condition. A corrective action plan was developed and implemented to resolve significant deficiencies before return to normal operations. The facility has developed a more systematic corrective action program, a procedure upgrade initiative, and a program to improve operations by emphasizing safety culture principles with operations staff.

9. References

[1] USNRC Licensee Event Report 56198, November 2, 2022

[2] UNIVERSITY OF TEXAS AT THE AUSTIN RESEARCH TEAM CHARTER, November 6, 2022 (ADAMS ML22307A305)

[3] UNIVERSITY OF TEXAS AT AUSTIN – U.S. NUCLEAR REGULATORY COMMISSION SPECIAL INSPECTION REPORT NO. 05000602/2022201, January 25, 2023 (ADAMS ML22347A311)

[4] EA-2-134 UNIVERSITY OF TEXAS AT AUSTIN – NOTICE OF VIOLATION, May 1, 2023 (ADAMS ML23219A243)

[5] UNIVERSITY OF TEXAS AT AUSTIN – REPORT ON THE REGULATORY AUDIT RE: RENEWAL OF FACILITY OPERATING LICENSE NO. R-129 (EPID NO. L-2017-RNW-0032), March 7, 2023 (ADAMS ML2302A171)

[6] 14-DAY REPORT: 2022 ALUMINUM FUEL EVENT AND FOLLOWUP, November 16, 2022 (ADAMS ML22333A623)

[7] DOE-NE-STD-004-92, DOE GUIDELINE – ROOT CAUSE ANALYSIS GUIDANCE DOCUMENT, February 1992 (U.S. Dept, of Energy, Office of Nuclear Energy, Nuclear Safety Policy & Standards)

[8] PPA AP-907-005, PROCEDURE WRITER'S MANUAL Revision 2, February 2016 (Procedure Professionals Association)

[9] NEI 21-06, Guidelines for 10CFR50.59 Implementation at Non-Power Production or Utilization Facilities, August 2021 (Nuclear Energy Institute)

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