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November 16, 2022

US Nuclear Regulatory Commission (NRC)
Washington, D.C. 20555
Attention: Document Control Desk

SUBJECT: Docket 50-602, 14 Day Report

Sir:

In accordance with the Technical Specifications for The University of Texas Nuclear Research Reactor, enclosed is a 14-day report for event number 56198 reported to the Headquarters Operations Officer on November 2, 2022.

Sincerely,

William S. Charlton, Ph.D.
Director, Nuclear Engineering Teaching Laboratory

A020
NRR

14-DAY REPORT: 2022 ALUMINUM FUEL EVENT AND FOLLOWUP

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November 16, 2022

1 INTRODUCTION

On October 18, 2022, the University of Texas at Austin (UT-Austin) notified the U.S. Nuclear Regulatory Commission (NRC) that the UT-Austin Nuclear Engineering Teaching Laboratory (NETL) staff had identified potential non-compliances with Technical Specifications while shutdown and had suspended operations. On October 17, 2022, NETL operations staff discovered that two (2) aluminum-clad standard TRIGA fuel elements had been loaded into the core (in locations C6 and D1) on January 4, 2022 and the reactor had operated with those elements in an unanalyzed condition from January 6, 2022 to October 17, 2022. This is a non-compliance of the NETL technical specifications which states[1]:

> Definition 1.5, Fuel Elements, Standard: "A fuel element is a single TRIGA element of standard type. Fuel is U-ZrH clad in stainless steel clad. Hydrogen to zirconium ratio is nominally 1.6."
>
> LCO 3.1.4, Fuel Elements part a. "In measuring the elongation, the length exceeds the original length by 2.54 mm (1/10 inch)." and part b. "In measuring the transverse bend, the bend exceeds the original bend by 1.5875 mm (1/16 inch)."[2]
>
> Design Section 5.3.1 Fuel Elements part c.: "Cladding: 304 stainless steel, nominal .020 inches thick."
>
> Bases A.3.1.4: "The elongation limit has been specified to assure that the cladding material will not be subjected to stresses that could cause a loss of integrity in the fuel containment and to assure adequate cooling flow. The limit of transverse bend has been shown to result in no difficulty in disassembling the reactor core."

Upon discovery, the reactor was immediately shutdown, the fuel elements were removed, and the elements were inspected for damage. There was no damage to the elements. The fuel elements are safely stored at the facility.

Analysis has indicated that the fuel remained below the safe temperature limit for its design during all operations from January 6, 2022 to October 17, 2022 and that operation with this fuel could not have caused the existence or development of an unsafe condition with regard to reactor operations.

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[1] "Facility Operating License, Docket No. 50-602, University of Texas at Austin, License No. R-129," US Nuclear Regulatory Commission, Agencywide Documents Access and Management System [ADAMS] Accession No. ML14136A073 (December 1990).

[2] NOTE: NUREG-1537 specifies a larger tolerance, at 1/8 in. for both bend and length elongation

The Limiting Safety System Settings (LSSS) for the NETL reactor are:

1. a maximum temperature monitored by instrumented element in the B or C ring of 550 °C,
2. a maximum steady-state power level of 1.1 MW, and
3. a maximum transient (pulsed) reactivity insertion of 2.2% Δk/k.

Analyses were performed for normal operation (pulsing and non-pulsed) with the elements in the C6 and D1 location, normal operations with one of the elements in the hottest location of the core (the B1 position), normal operation with the aluminum clad elements in the hottest location of the core (the B1 position) and the two instrumented fuel elements (IFE's) in the coldest location allowed by technical specifications (positions C8 and C9), and under design basis accident conditions (Loss of Coolant Accident). In all conditions the fuel was protected by the high power scram or by the facility design maintaining peak aluminum clad fuel temperature below 500°C.

2 EVENT TIMELINE

In 2004, a shipment of fuel was received from the University of Illinois at Urbana-Champaign (UIUC) that included 2 aluminum clad fuel elements, which were placed in spent fuel storage. An informal tracking mechanism, using an MS Excel file titled "B159.xls", was updated to reflect the elements received including notation that 2 elements are aluminum SFE (standard fuel elements). Note that at the time, NETL staff were aware of the aluminum-clad fuel elements not being useable in the NETL core, but accepted receipt of the elements, we believe, because that was necessary in order to acquire the useable stainless steel clad elements which were also included in the shipment. It is believed that the intention was to ship the aluminum clad fuel elements to Idaho for disposal at some later date.

In 2018, UT received 2 shipments (19 elements each) of lightly irradiated TRIGA fuel elements from spent fuel interim storage at INL.

Also in 2018, all irradiated fuel inventory that was in the wells was moved to the reactor pool racks (except for 2 canned elements stored in a separate well) in anticipation of pending shipment to DOE (this included the two aluminum-clad standard fuel elements which were present in NETL inventory).

Representatives of the INL interim storage facility performed onsite inspection of irradiated fuel designated for return to DOE as spent fuel in August 2018. During the INL inspection to support spent fuel shipment, NETL operations staff performed all fuel handling during the inspection and the aluminum clad elements were identified and documented in the inspection report as such.

In January 2022, the biennial fuel inspection required by Technical Specification was performed (completed January 4, 2022). Following the fuel inspection, 10 fuel elements, including the two aluminum fuel elements, were installed in the core on January 4, 2022 in a campaign to increase excess reactivity. These aluminum-clad elements were chosen for insertion because they were listed on the B159.xls file as having a low burnup (in column O of the "Historic Fuel data" tab in that file). The B159.xls file also lists (in column B of the same tab) the notation "Al SFE" intending to specify that the elements were aluminum-clad elements. This notation was missed by the operations staff when choosing these low burnup elements to insert into the core. The NETL procedures do not include instructions to verify that elements being moved into the core or measured are only stainless steel cladding. NETL procedures do not require an independent review by NETL management that the core loading is only with qualified fuel. Thus, a mistake by a single individual following the approved NETL procedures led to errors in the loading of the core, and there was not a procedure in place to identify that error prior to reactor startup in January 2022.

The location of the aluminum-clad elements present in the core was discovered on October 17, 2022 by the Acting Reactor Manager (the previous Reactor Manager had resigned from UT-Austin as of September 9, 2022), and the situation was reported to the Associate Director. Reactor operations were suspended, pending resolution (identification and completion of corrective action to restore the core to the required configuration). The Acting Reactor Manager removed the aluminum elements, performed visual examination of the elements, and verified current fuel inspection for all elements in the core was completed on January 4, 2022. However, a record of inspection was not immediately available for the elements inserted to increase excess reactivity; the previous reactor manager was contacted and confirmed inspection had been completed on January 6, 2022 as part of the fuel load process.

The discovery of the aluminum-clad fuel elements in the UT-NETL reactor occurred when the new Reactor Manager was reviewing and updating fuel records and procedures. The Reactor Manager was working to update and improve upon documentation and procedures to be more consistent with his plan for management of the reactor facility. While updating the B159.xls file to reflect all element locations in the fuel movement log, he identified that the two aluminum-clad elements were in the reactor core. This discovery was not procedure-driven but occurred as a result of the new Reactor Manager's initiative to update NETL records management. If not discovered in this way, the location of the aluminum-clad fuel elements in the NETL reactor core would not likely have occurred until annual maintenance was performed in January 2023.

The investigation following the identification of the non-compliance associated with operation using the aluminum-clad fuel identified procedural non-compliance issues. Following the 2018 fuel inspection of standard fuel elements made by electronic measurements (strain gage) as identified in the procedure, the electronic measurements were discontinued based on successful testing of the go/no-go gauge (required by the procedure) to evaluate bend and an underwater camera and scale to measure elongation. The length and bend data were not recorded as required by the procedure (only if the element passed the bend and elongation test was recorded). The procedure had not been revised to reflect the change in test method. Consequently a 50.59 evaluation was not implemented, although it would likely have screened out the change for the need of prior NRC review. The usage of the strain gauge probably would not have indicated that the two elements were aluminum clad instead of stainless steel, but the failure to control procedure changes and compliance as required indicated a less than adequate self-critical attitude with a failure in attention to detail. The Associate Director therefore directed a comprehensive review of procedure and procedure performance to identify other potential issues.

3 REPORTING TIMELINE

October 17, 2022 (~2:00 PM): NETL Associate Director contacted via phone call the UT-NETL NRC Program Manager (Andrew Waugh and later Geoffrey Wertz) on the day of the discovery at approximately 2:00 PM local time to inform them of the possible non-compliance and to discuss reportability of the incident. Following that phone call and based on the available evidence and Technical Specifications 6.6.2, NETL determined that the incident was not reportable to the NRC, but UT-NETL staff would keep NRC informed as we proceeded through analysis, corrective actions, and eventual restart. It was determined that the usage of aluminum-clad fuel in the C6 and D1 locations in the UT-NETL core could not have "caused the existence or development of an unsafe condition with regard to reactor operations" because the peak fuel temperature of the aluminum clad fuels would stay below 500°C in the event that the Instrumented Fuel Element (IFE) at B6 scrammed at 550°C and that at no time during pulsing operations would the peak fuel temperature anywhere in the core exceed 420°C.

October 18, 2022 (8:34 AM): UT-NETL staff provided the initial version of a summary document to NRC Staff (Geoffrey Wertz and Andrew Waugh). That summary detailed the incident, our initial root cause findings, our initial corrective action plan, and our review of reportability. NETL staff also informed the UT-Austin Reactor Oversight Committee (ROC) of the potential non-compliance issue and suspension of operations. The ROC was also provided a copy of the summary document.

October 21, 2022 (8:30 AM): UT-NETL staff met with US NRC staff (Geoffrey Wertz, Andrew Waugh, and Kevin Roche) to provide an update on the UT-NETL situation and continued analysis. This included updated MCNP and TRACE analysis of the fuel temperatures under steady-state and pulsing operations.

October 25, 2022 (3:36 PM): UT-NETL staff provided an updated summary document to the UT-Austin ROC as well as a revised MAIN-5 procedure for review and approval.

October 26, 2022 (9:00 AM): UT-NETL staff provided an updated summary report of the event via email. UT-NETL staff met with US NRC staff (Geoffrey Wertz, Andrew Waugh, Kevin Roche, and Travis Tate) to provide an additional update on the UT-NETL situation, to step the NRC staff through the analysis in the most recent summary document provided, and answer questions regarding that summary update document.

October 26, 2022 (1:00 PM): UT-NETL staff met with US NRC staff (Andrew Waugh, Kevin Roche, Travis Tate, Josh Borromeo, Mohamed Shams, and Jeremy Brown) to provide an additional update on the UT-NETL situation. NRC expressed concerns because the event involved an unanalyzed condition for the UT-NETL core (note that this would be a reportable condition for a power reactor). This condition is not specified as reportable in the UT-NETL license, but the NRC expressed concerns that (1) the safety margin for the aluminum-clad fuel had not remain sufficiently large during operation and (2) that the inadequate controls at NETL "could have caused the existence or development of an unsafe condition with regard to reactor operations". NETL staff agreed to continue analysis of possible ways in which an unsafe condition could have been caused. NETL staff agreed to seek guidance from both the UT Reactor Oversight Committee (ROC) and US NRC prior to commencing restart operations to ensure the reactor is operated safely.

October 31, 2022 (1:00 PM): UT-NETL staff provided updates to the ROC and met with ROC members to discuss the non-compliance issues and corrective action plan.

November 1, 2022 (11:30 AM): UT-NETL staff met with members of the ROC to discuss the corrective action plan and reportability analysis including hypothetical "what if" scenarios.

November 2, 2022 (8:34 AM): UT-NETL staff contacted the NRC Headquarters Operations Center by telephone and informed them of a potential reportable occurrence in which NETL had identified inadequacies in the procedures and administrative controls such that the inadequacies could have caused the existence or development of an unsafe condition with regard to reactor operations. After investigation of the event, development of the corrective action plan, and progress on implementing the corrective action plan, NETL staff identified changes in procedures and administrative controls that would have been adequate to prevent insertion of disqualified fuel in NETL reactor core. While analysis has shown that the insertion of aluminum clad fuel did not have the potential to cause the existence or development of an unsafe condition, insertion of other fuel disqualified by surveillance activities could potentially have caused the existence or development of an unsafe condition with regard to reactor operations. Thus, NETL management determined on November 1, 2022 that this could potentially be classified as a reportable event under the category *"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"*.

4 NON-COMPLIANCES

We identified five non-compliance issues:

1. Fuel that is not specified for use at the UT-NETL reactor was used in the core

2. Procedure violation, fuel inspection method was not conducted in accordance with (IAW) procedure

3. Procedure violation, records of fuel inspection required by the procedure were not generated

4. Procedure violation, failure to revise procedures IAW administrative controls (including 50.59)

5. Failure to complete a 50.59 evaluation for usage of aluminum clad fuel at the UT-NETL reactor

The first of these was identified immediately from the discovery of the two aluminum-clad fuel elements in the UT-NETL core. The remaining four non-compliances were discovered during the conduct of the cause analysis and subsequent internal investigations for this event.

5 SAFETY SIGNIFICANCE

1. PRIMARY - NETL operated from January 6, 2022 to October 17, 2022 with the reactor core in an unanalyzed condition. While calculations indicate this specific configuration could not have caused the existence or development of an unsafe condition, NETL's controls were not adequate to prevent the use of the unqualified fuel elements in the core.

2. SECONDARY - 1st Line Supervisor Failure to follow procedures:

   Fuel inspection procedure as written was not performed

   Change control process (that invokes 50.59) was not followed

3. MITIGATION

a) The go/no-go test is commonly used in TRIGA facilities and is adequate to meet the Technical Specifications requirements and is consistent with the Technical Specifications basis

b) Aluminum clad fuel is commonly used at TRIGA reactors, and there has been no evidence of fuel degradation since installation in January

c) Although the values were not recorded, the length measurement was performed and there has been no evidence of fuel degradation

d) Initial analysis indicates aluminum fuel does not exceed the temperature safety limit in the C6 or D1 positions for operations since installation

6 ROOT CAUSE

A root cause analysis was performed on October 17, 2022 immediately following discovery of the aluminum-clad fuel elements in the UT-NETL core. That root cause analysis involved a holistic approach studying the broader questions on what led to conditions in which the UT-NETL insertion of aluminum-clad fuel elements into the core was possible and what opportunities were missed to prevent this event from occurring. That root cause analysis has continued to be updated as more information was made available. We identified the following causes for this event:

A. Proximate Cause
    1. Inappropriate element selected for installation
B. Root cause
    1. Procedural inadequacy: Lack of administrative, procedural, or engineering controls designed to keep elements not qualified for use out of the core
C. Contributing causes
    1. Lack of attention to detail:
        - Failure to recognize the aluminum elements labeled in the B159.xls file while selecting elements for use
        - Failure to question why the elements with a high uranium content (exceeding most of the fuel elements previously to restoring core excess reactivity) were not in use
    2. Procedure inadequacies:
        - This event occurred in the context of procedures that were adequate when personnel experience was high (the previous reactor manager had been employed at UT-Austin since before the NETL was built)
    3. Inadequate administrative or engineered controls
        - No administrative or engineered barriers were implemented that segregate or limited operator access to disqualified fuel
    4. Inadequate safety conscious work environment:
        - This event occurred in the context of procedure revisions improperly implemented

- This event occurred in the context of noncompliance with administrative and technical procedures

5. Lack of management oversight:
    - This event was a single point failure that could have been prevented with a second check on planned utilization of fuel
    - Management oversight and audits did not identify degradation of the safety conscious work environment

7 CORRECTIVE ACTION PLAN

1. Remove aluminum fuel elements

   Completed: 10/17/2022

2. Revise the surveillance procedure for fuel element inspection:

   a. Remove the strain gage measurements from the procedure and

   b. Provide an approved alternative for the measurements

   Completed: 11/01/2022

3. Perform the revised surveillance for the core configuration prior to startup

   Status: Approval complete 11/01/2022, fuel inspection in progress

4. Review other procedures that satisfy Technical Specifications surveillances, to evaluate if other non-compliances have been introduced in performance

   Completed: 10/28/2022

5. Conduct control rod worth calibrations

   Status: Schedule pending completion of fuel inspection

6. Include in the B159.xls file

   a. Date of last fuel inspection

   b. A 'qualified' or 'disqualified' flag to indicate fuel elements not to be used in the core

   Completed: 10/18/2022

7. Review the event with staff, emphasizing the importance of procedural compliance, the change control process for procedures, the application of license and Technical Specifications as administrative controls, and the incorporation of this into NETL culture

Status: TBD, prior to restart

8. Revise the fuel handling procedure to require fuel not in a tested configuration (i.e., not installed at the last control rod worth calibration) to be verified prior to installation:

   a. Qualified/disqualified for use

   b. Inspection completed within prior 2 years

   c. Core loading only with qualified fuel verified by NETL management prior to startup

   Status: In progress

9. Develop a method to designate fuel racks with visible indications that the contents are not allowed to be used in the core

   Status: In progress

8 FUEL TEMPERATURE ANALYSIS

The analysis described in this section details the potential temperature of aluminum-clad fuel elements at a variety of locations in the NETL core (including the C6 and D1 locations in which the two elements were located), under two core configurations (including the 113-element core configuration while the aluminum clad elements were in the core), and under various operating conditions (including steady-state and pulsing as well as loss of coolant accident) to determine the potential for damage to aluminum clad fuel located anywhere in the core and under a variety of safety-related conditions. Analysis of the fuel temperature is required because aluminum-clad fuel has a lower acceptable fuel temperature than stainless steel clad fuel. Aluminum-clad TRIGA fuel has been used in TRIGA reactors since the beginning of the TRIGA programs but with a lower limit on fuel temperature compared to stainless steel clad TRIGA fuel. NUREG-1537 states "For aluminum-clad $UZrH_{1.0}$ LEU 8 w/o TRIGA fuel, NRC has accepted that the peak fuel temperature should not exceed 500°C".[3]

8.1 Analysis for Pulsing Operations

An assessment of peak fuel temperatures that occurred during pulsing operations while the aluminum fuel was loaded in the core was made based on TRACE calculations (as described in Appendix A and using Fuel Specifications from Appendix B). Peak temperatures for (1) the whole fuel matrix and (2) the location of the thermocouple were identified for a series of pulsed reactivity calculations. The ratio of the element peak and the thermocouple peak temperatures was calculated for each pulsed reactivity. A correlation between the ratio and the IFE measured temperature was identified (Figure 1). The peak fuel temperature in the core for each $3.00 pulse during calendar year 2022 was evaluated using the measured temperature (from the IFE) and the correlation. The results are shown in Figure 2. Thus, the peak fuel temperature was below 420°C in all fuel elements for all pulses in 2022.

[3] "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors: Format and Content," U.S. Nuclear Regulatory Commission, NUREG-1537 Part 1, Appendix 14.1.

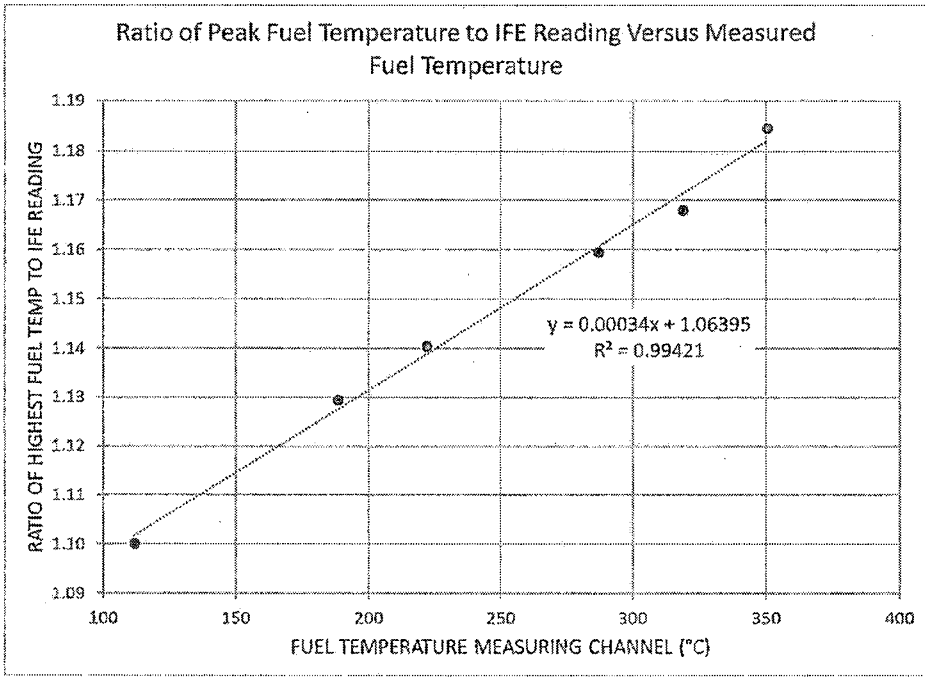

Figure 1: Ratio of Peak Fuel Temperature to Indicated Fuel Temperature versus Indicated Fuel Temperature Calculated Using TRACE

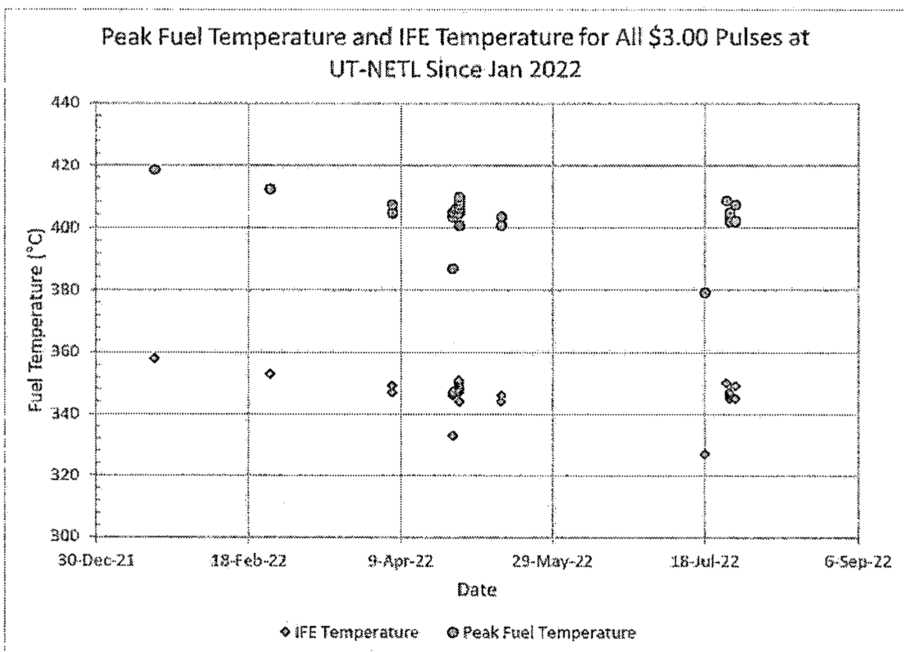

Figure 2: Indicated Fuel Temperature and TRACE Calculated Peak Fuel Temperature for All $3.00 Pulses During the Period Jan-Sep 2022

The IFEs are located in the B ring, where the maximum power is generated. The aluminum fuel elements were inserted in the C and D rings, which generate less power than any elements in B ring and result in lower temperatures. Since the peak fuel element temperature of the IFE was below 420°C, the values in the aluminum elements were significantly less than 420°C for all pulses with no potential for exceeding limiting temperature for pulsing aluminum elements. This also demonstrates that aluminum clad fuel elements located anywhere in the NETL core would not have exceeded the 500°C limit during any pulsing operations.

8.2 Analysis for Non-Pulsing Operations

8.2.1 Normal Operation Up to 1.1 MW with Aluminum-Clad Fuel Elements in C6 and D1

For non-pulse operation, the LSSS setting is a temperature which, if exceeded, causes a reactor scram to be initiated preventing the safety limit from being exceeded. The UT-NETL Fuel Temperature LSSS is 550°C as measured in an IFE located in the B or C ring. During the time period of interest, NETL was operating with two IFEs (one in B3 and one in B6) with the LSSS at 550°C. An MCNP simulation was performed with the 113-element core configuration on January 6, 2022 with the two aluminum clad fuel elements in C6 and D1 to calculate power peaking factors (PF) for each fuel element location. PF is the ratio of peak fission energy in the element of interest to the fission energy in the average rod. The positions of primary interest to this analysis are the B1, B3, B6, C6, C8, C9, and D1 positions. B1 and B6 are the hottest positions in the core. B3 is the position of the second IFE. C6 and D1 were the positions of the aluminum clad fuel elements from January 6, 2022 to October 17, 2022. C8 and C9 are the coldest fuel positions in the C-ring. The power peaking factors for these locations are given in Table 1.

TRACE simulations were used to acquire fuel element temperatures for fuel elements with various total element power. The temperature of a stainless steel clad or aluminum clad fuel element at a specific fuel element power is given in Table 2. A plot of the data in Table 2 is shown in Figure 3. As can be seen, there is a significant decrease in element temperature for aluminum clad fuel compared to stainless steel clad fuel due to the much higher thermal conductivity of the 1100 aluminum alloy compared to stainless steel type 304.

Table 1. Power Peaking Factors for Positions of Interest in NETL Core

Position	Power Peaking Factor (PF)
B1	1.750
B3	1.594
B6	1.734
C6	1.496
C8	1.418
C9	1.353
D1	1.395

Table 2. Steady-state fuel element temperature for stainless steel and aluminum clad fuel at varying fuel element powers.

	Fuel Element Temperature (°C)	
Fuel Element Power (kW)	**Stainless-Steel Clad**	**Aluminum Clad**
7.96	258.7	212.6
9.73	303.8	247.6
13.27	351.1	273.6
13.78	359.7	279.3
15.93	396.4	303.8
16.84	411.8	314.1
17.70	426.3	323.9
19.47	455.8	344.0
21.69	492.3	368.9
24.34	535.7	398.6
25.18	549.2	407.9
25.24	550.2	408.6
25.31	551.4	409.4
25.44	551.6	410.8
25.62	554.4	412.8
25.66	555.2	413.3
26.55	571.1	423.0
28.13	601.7	442.9
29.11	617.9	454.0
29.18	619.1	454.9
29.26	620.4	455.8
29.41	620.9	457.6
29.62	624.3	459.9
29.67	625.1	460.5
30.69	644.2	472.2
31.86	680.6	495.9
33.0	700.2	509.3

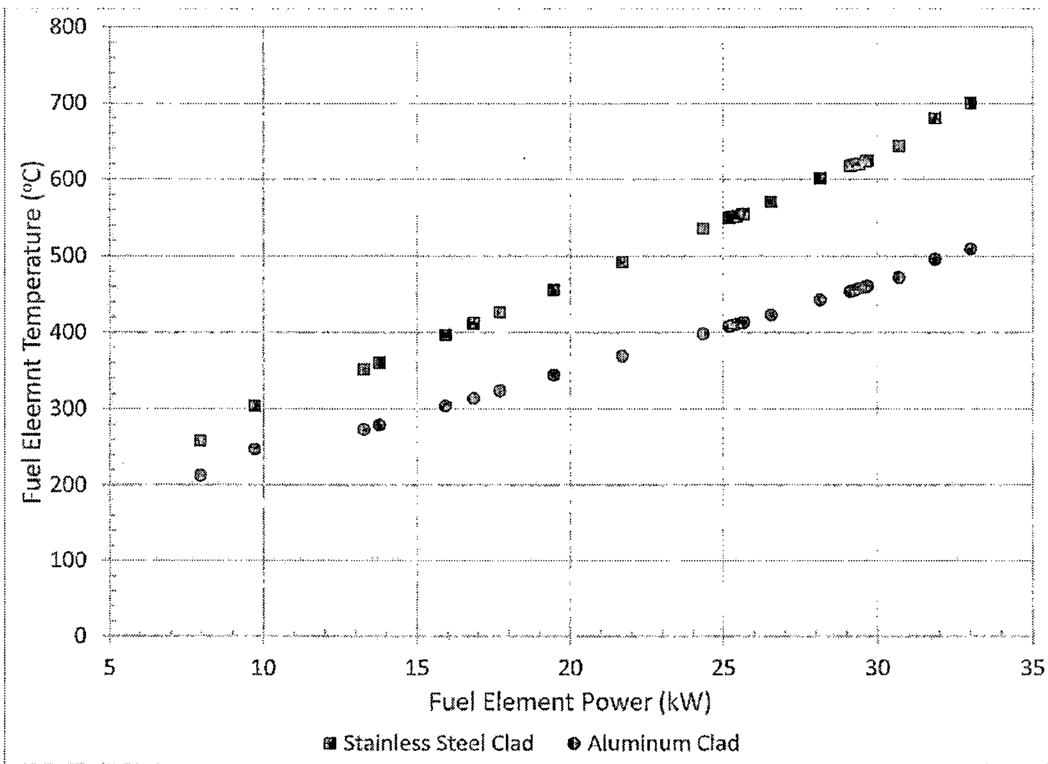

Figure 3: Expected Fuel Element Temperature Versus Element Power for Stainless Steel Clad and Aluminum Clad Standard TRIGA Fuel.

The neutronic and thermal hydraulic data produced above was used to calculate expected aluminum-clad fuel element temperatures for a variety of core configurations. The goal was to assess the possibility of an aluminum-clad fuel element exceeding the 500°C temperature limit in non-pulsing operations. The NETL core is protected by a high power scram (at 1100 kW) and a high temperature scram (at 550°C on either of the installed IFEs). The first two analyses are performed up to the 1.1 MW power limit at which a high-power scram would initiate. The last four analyses were performed assuming the high-power scram did not function and the core was only protected by the high-temperature scram. These last four are potential hypothetical "what if" scenarios including one scenario in which the core configuration was changed to an 84-element core.

8.2.2 Operation at up to 1.1 MW with Aluminum-Clad Elements in C6 and D1

From the MCNP simulation, the ratio of fission energy produced in the aluminum clad fuel elements at C6 and D1 to the fission energy produced in the IFE at B6 (the hottest IFE) was 0.863 and 0.804, respectively. During normal operation (which is 950 kW for the NETL), the IFE's measure fuel temperatures below 410°C. The TRACE simulation calculates a fuel temperature of a stainless steel clad IFE at B6 as 411.8°C at 1100 kW which corresponds to an average power per element of 9.73 kW (for a 113-element core) and a power in the B6 element of 16.84 kW. This calculated IFE temperature at 1100 kW of 411.8oC agrees well with the observed IFE temperatures below 410°C at 950 kW. If the IFE was measuring a temperature of 411.8°C (expected temperature at the licensed power limit of 1100 kW), then the fuel temperature in the aluminum clad fuel elements at C6 and D1 would be expected to be 287.9°C and 276.6°C, respectively. Thus, the aluminum clad elements during normal operation had fuel temperatures well below the 500°C limit.

8.2.3 Normal Operation Up to 1.1 MW with Aluminum-Clad Fuel Element in B1

If one of the aluminum-clad elements was located in the B1 position (which is the hottest position in the core and essentially equal in power to the B6 position), then the aluminum clad element would have had a temperature of 315.9°C at full license power of 1100 kW. This demonstrates that aluminum clad fuel elements located anywhere in the NETL core would not have exceeded the 500°C limit during any non-pulsing operations below 1.1 MW.

8.2.4 Operation in Excess of 1.1 MW with Aluminum-Clad Elements in C6 and D1

Simulations show that for the IFE at B6 to reach a temperature of 550°C in the current 113-element core configuration, the reactor power would be 1649 kW and the hottest element in the core would have a single element power of 25.2 kW. If the fuel temperature at B6 in this core configuration increased to 550°C to initiate a reactor scram from the LSSS for fuel temperature, the temperature of the aluminum-clad fuel elements at C6 and D1 would reach 370.2°C and 353.7°C, respectively. Thus, even in the event of reaching the LSSS for fuel temperature, the aluminum-clad elements in C6 and D1 remained well below the 500°C limit for aluminum clad TRIGA fuel.

8.2.5 Operation in Excess of 1.1 MW with Aluminum-Clad Element in B1

This next analysis (and the two following) was to determine the maximum possible temperature of an aluminum clad fuel element if located anywhere in the core at the point where the IFE would cause a high temperature scram (at IFE temperature of 550°C). At a total reactor power of 1649 kW, the IFE at B6 would reach 550°C and initiate a high temperature scram. If one of the aluminum-clad elements was located in the B1 position (again the hottest position in the core and essentially equal in power to the B6 position), then the aluminum clad element would have had a temperature of 411.2°C at a reactor power of 1649 kW. This demonstrates that aluminum clad fuel elements located anywhere in the NETL core would not have exceeded the 500°C limit during any non-pulsing operations up to the initiation of a high temperature scram with the IFE located at B6.

8.2.6 Operation in Excess of 1.1 MW with Aluminum-Clad Element in B1 and IFEs in C8 and C9

Analysis was also performed placing one of the aluminum-clad elements in the B1 position (again the hottest position in the core and essentially equal in power to the B6 position) and placing one IFE in the C8 position and the other IFE in the C9 position (the lowest power element positions in the C-ring). This is the most limiting condition possible with the 113-element core configuration. While NETL always operates with the IFEs in the B-ring, the LSSS states "a maximum temperature monitored by instrumented element in the B or C ring of 550°C" and the NETL license states in 3.2.3 Reactor Safety Systems that 2 operable Fuel Temperature Channels are required for operation in all modes. In this configuration, the IFE at C8 will reach 550°C (initiating a reactor scram) prior to the IFE at C9. So this analysis was to predict the highest possible temperature that an aluminum-clad fuel element would be subject to the case that the IFEs were placed in the worst possible position in a 113-element core. If the IFE at C8 had a temperature of 550°C, then the aluminum-clad element at B1 would have a temperature of 481.4°C which is only 19°C below the 500°C limit. While this is still below the fuel temperature limit for an aluminum-clad standard TRIGA fuel element, it does show a significant decrease in safety margin in this very limiting condition.

8.2.7 Operation in Excess of 1.1 MW with Aluminum-Clad Element in B1 and IFE s in C3 and C7 in an 84-Element Core

This analysis was to predict the highest possible temperature that an aluminum-clad fuel element would be subject to in the case that the IFEs were placed in the worst possible position in the most limiting core configuration possible. The Limiting Core Configuration (LCC) for the NETL reactor is an 84-element core. This is the configuration that provides just under the license limit of $7.00 core excess reactivity. In this configuration, the hottest element is located at B5 (with a PF=1.691) and the lowest power elements in the C-ring are at C7 (PF=1.220) and C3 (PF=1.338). In this configuration, the IFE at C3 will reach 550°C (initiating a reactor scram) prior to the IFE at C7. If the IFE at C3 had a temperature of 550°C, then the aluminum-clad element at B5 would have a temperature of 496.3°C which is only 3.7°C below the 500°C limit and within the margin of error of the TRACE code. Also, it should be noted that variations in the core loading could alter the PF values in this 84-element core. Thus, in this Limiting Core Configuration, it would not be possible to ensure that an aluminum-clad fuel element would remain below the 500°C temperature limit.

8.3 Analysis for Loss of Coolant Accident (LOCA)

The final analysis completed was to consider the temperature of the aluminum-clad fuel elements under a loss of coolant accident condition. The NETL core was simulated assuming full-power operations for 30 days (8 hours per day and 5 days per week for 30 days) and with the 113 element core. The reactor was then shutdown at initiation of the LOCA and heat was produced from decay heat. Peak fuel temperatures for the aluminum-clad elements were calculated assuming the following four cooling conditions: (1) with water cooling for only 1 second following initiation of reactor SCRAM, (2) with water cooling for only 60 second following initiation of reactor SCRAM, (3) with water cooling for only 600 seconds following initiation of reactor SCRAM, and (4) with water cooling for only 1200 seconds following initiation of reactor SCRAM. (Note that the NETL reactor pool contains over 11,000 gallons of water.) The calculated peak fuel temperatures versus time after SCRAM are shown in Fig. 4. Under the worst possible cooling conditions, the peak fuel temperature is just below 450°C and remains below 500°C for all cases considered.

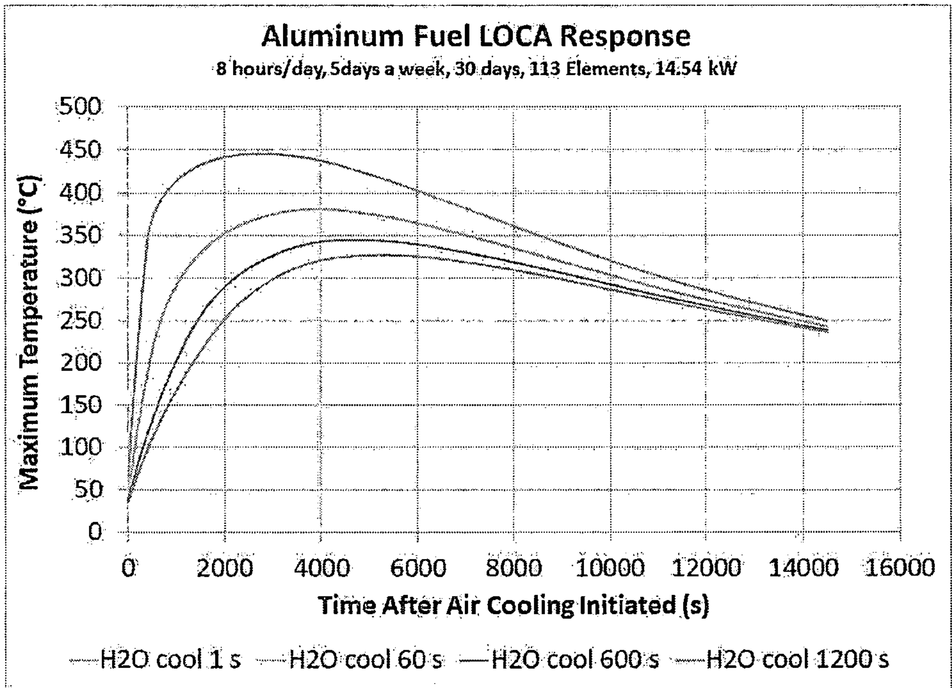

Figure 4: Expected Fuel Element Temperature Versus Element Power for Stainless Steel Clad and Aluminum Clad Standard TRIGA Fuel.

8.4 Assessment from Analysis Cases

MCNP and TRACE simulations were performed to assess the possible safety significance of operation of the NETL core with two aluminum-clad fuel elements inadvertently inserted into the core. In the actual event that occurred, two partially burned aluminum-clad elements were inserted into the NETL core in positions C6 and D1 with the reactor in a 113-element configuration and with IFEs located at B3 and B6. Analysis was performed for this configuration in pulsing and steady-state operation, for more limiting configurations based on potential hypothetical "what if" scenarios, and for a loss of coolant accident. The following conclusions can be drawn from the results:

1. In pulsing operations with the current 113-element core configuration, the insertion of two aluminum-clad fuel elements in the hottest location of the NETL core would lead to a fuel element temperature below 420°C and well below the 500°C limit.
2. In steady-state operations with the current 113-element core configuration, the insertion of two aluminum-clad fuel elements in the hottest location of the NETL core and the IFEs located in the B3 and B6 positions would lead to a fuel element temperature below 412°C and well below the 500°C limit.
3. In steady-state operations with the current 113-element core configuration, the insertion of two aluminum-clad fuel elements in the hottest location of the NETL core and the IFEs located in the C8 and C6 positions (the lowest power positions in the C-ring) would lead to a fuel element temperature below 482°C and below the 500°C limit.
4. For loss of coolant accident with the current 113-element core configuration, the peak fuel temperatures for the two aluminum-clad fuel elements reached a maximum of under 450°C

with only 1 second of water cooling available after initiation of the reactor SCRAM. Thus the rods remained well below the 500°C limit.

5. In steady-state operations in the Limiting Core Configuration (LCC) of 84-elements, the insertion of two aluminum-clad fuel elements in the hottest location of the NETL core and the IFEs located in the C3 and C7 positions (the lowest power positions in the C-ring) would lead to a fuel element temperature below 493°C which is only slightly below the 500°C limit (and within calculational uncertainty of the methods used here).

All of the cases involving the NETL core configuration present on the dates of the event in question resulted in aluminum-clad fuel element temperatures well below the 500°C limit. Thus, the event in question did not causes nor could it have caused the existence or development of an unsafe condition with regard to reactor operations.

While all of the cases considered are below the fuel temperature limit for an aluminum-clad standard TRIGA fuel element, the cases in which the IFEs are placed in the C-ring (in the 84-element core) showed fuel temperatures could reach near 500°C and possibly over 500°C. Thus, it was concluded that insertion of aluminum-clad fuel in other core configurations would potentially have caused the existence or development of an unsafe condition with regard to reactor operations but not with the 113-element core present during the time of the event.

9 REVIEW FOR REPORTABILITY

Technical Specifications 6.6.2, Special Reports, Criteria and Evaluation:

a. *Operation with actual safety-system settings for required systems less conservative than the limiting safety system settings specified in the technical specifications.*

The actual safety-system settings and limiting safety system settings specified in the technical specifications were as follows:

Setting	Limiting safety system settings specified in the technical specifications	Actual safety-system settings
maximum temperature monitored by instrumented element in the B or C ring	550 °C	550 °C
maximum steady-state power level	1.1 MW	1.1 MW
maximum transient (pulsed) reactivity insertion	2.2% Δk/k	2.1% Δk/k

Thus, Safety-System Settings were not affected. - Does not apply

b. *Operation in violation of limiting conditions for operation established in technical specifications unless prompt remedial action is taken.*

Fuel type is not a Limiting Condition for Operation; fuel type is defined and listed as a design specification while the Limiting Condition for Operation applies to fuel damage, and prompt remedial action was taken on discovery – Does not apply

c. *A reactor safety system component malfunction which renders or could render the reactor safety system incapable of performing its intended safety function unless the malfunction or condition is discovered during maintenance tests or periods of reactor shutdowns.*

No Safety System malfunction, although discovered while shutdown - Does not apply

d. *An unanticipated or uncontrolled change in reactivity greater than one dollar. Reactor trips resulting from a known cause are excluded.*

No unanticipated or uncontrolled change in reactivity - Does not apply

e. *Abnormal and significant degradation in reactor fuel, or cladding, or both, coolant boundary, or confinement boundary (excluding minor leaks) where applicable which could result in exceeding prescribed radiation exposure limits of personnel or environment, or both.*

No degradation in fuel or cladding - Does not apply

f. *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.*

The inadequacy in the implementation of procedural controls applies only to (1) the use of TRIGA aluminum-clad fuel and (2) a change in the method for testing fuel degradation. Analysis in section 8 showed that at no time could these inadequacies have caused the existence or development of an unsafe condition with regard to reactor operations.

This event (the insertion of aluminum clad fuel in the C6 and D1 positions) did not have the potential to cause the development of an unsafe condition with respect to protecting the health and safety of the public or facility staff. We did not identify any inadequacies in <u>implementation</u> of administrative or procedural controls that could have caused the existence or development of an unsafe condition with regard to reactor operations. Therefore, this was not reportable 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 regard to reactor operations.* However, while the implementation of the existing procedures and administrative controls was adequate, NETL staff identified on November 1, 2022 (in the course of the investigation into this event) inadequacies in the procedures and administrative controls themselves which do not adequately prevent insertion of disqualified fuel in the NETL reactor core. For this reason, NETL management had chosen to consider this a reportable event under this category and had reported it to the NRC Headquarters Operations Center on November 2, 2022.

The Technical Specifications Basis for acceptance of measurements on fuel (A.3.1.4 Fuel Elements) is:

> *The elongation limit has been specified to assure that the cladding material will not be subjected to stresses that could cause a loss of integrity in the fuel containment and to assure adequate coolant flow. The limit of transverse bend has been shown to result in no difficulty in disassembling the reactor core.*

As a result of examining procedural compliance 10 elements were found to be installed in the core with no discernable reference for determining elongation in the working records, and no values recorded to support future elongation measurements. (Bend measurements use a go/no-gauge and were likely conducted as required). Historical measurements show a clear trend of elongation for some elements progress with burnup. If the surveillance proceeded into the future as conducted (from 2018 to 2022) then internal stresses could increase undetected terminating in a possible loss of containment integrity. Therefore a notification was made of "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" when the installation was identified and verified. Two of the elements with no prior measurements and no record of measurement supporting installation were aluminum clad. The direct cause of installation of the aluminum elements and the failure to conduct surveillance activity required to assure fuel element cladding integrity was inattention to detail and failure to follow the approved procedure. An unauthorized procedure was used that did not provide instruction adequate to meet the requirements of the Technical Specification surveillance, so a contributing cause was an administrative failure to control procedure revision in accordance with the approved process.

NETL staff was able to recover reference data from 2004 shipping records and other fuel measurements from the original decommissioned UT-Austin reactor. The working documents have been revised to reflect the reference measurement. All elements in the core are being examined and measured using a standard method and elements that will replace those disqualified for use will be measured (either to establish a reference value or to compare to a reference value, as appropriate) before installation.

10 CONCLUSIONS

The insertion of aluminum-clad fuel elements in C6 and D1 could not have caused the existence or development of an unsafe condition with regard to either steady-state or pulsing reactor operations. However, NETL administrative and procedural controls to mitigate the possibility of insertion of disqualified fuel into the UT-NETL core were found to be inadequate.

APPENDIX A – METHODS USED IN FUEL TEMPERATURE ANALYSIS

For this analysis, the MCNP 6.2 code was used for calculating fission rates in individual fuel rods throughout the NETL core. This code has been used for a variety of simulations for the NETL core in the past including calculation of control rod worths, power peaking factors, neutron flux spectra in experimental locations, and gamma dose rates at experimental locations. The results from these simulations have been benchmarked to a variety of measured values in the past 5 years and most recently were used to calculate neutron flux spectra and axial variation in the UT NETL central thimble with comparison to measured values. Generally, the results from these simulations agree to within ±8% of the measured values. The MCNP input decks used in this analysis were based on the input decks from these previous analyses with modifications for insertion of the aluminum clad fuel elements into the simulation.[4] Thus, we expect MCNP simulations for the aluminum-clad fuel event to similarly have an accuracy of within ±8%.

Thermal hydraulic modeling of the UT TRIGA was performed with TRAC/RELAP Advanced Computational Engine (TRACE). Thermal hydraulic characteristics were developed from classical methods and corrections for UT TRIGA geometry using the computational fluid dynamics code FLUENT. Distribution of fission activity was developed from transport calculations in MCNP 6.2. TRACE is designed to perform best-estimate analyses of operational transients and accident scenarios by modeling physical geometry and thermodynamic conditions. TRACE is the NRC's flagship thermal-hydraulics analysis tool consolidating and extending the capabilities of NRC's 3 legacy safety codes: TRAC-P, TRAC-B and RELAP. NETL staff have used TRACE over the past five-years for thermal-hydraulic analysis of the NETL core including in support of relicensing. TRACE results have generally compared favorably with measured values for the core.[5]

The flow channel unit cell cross section is based on the typical fuel element geometry, as illustrated in Fig. A1 (unit cell and the surrounding fuel elements). Some unit cell locations in the grid plate have different structures. The central thimble is not fueled, the transient rod does not contain fuel, and the fuel followers (which are generally not fully inserted in the core) have 80% of the fuel mass contained in standard fuel elements. This analysis uses a hot channel and assumes no interaction between adjacent unit cells. Any interaction between unit cells with fuel and adjacent unit cells with less or no fuel contributes a larger area where convection flow is the result of heat transfer from the fully fueled cell, resulting in enhanced heat removal from the fully fueled cell. Thus, from this standpoint the analysis here is conservative. As illustrated, the unit cell analysis is based on a fuel element and the surrounding flow area (end fittings have more complex geometry) circumscribed by a hexagon with an inner radius of ½ of the pin-to-pin pitch. The complex geometries of the fuel element end fittings are approximated as hydrodynamic characteristics.

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[4] "Analysis of the Neutronic Behavior of the Nuclear Engineering Teaching Laboratory Reactor at the University of Texas," Radiation Center report, Oregon State University (March 2021).

[5] P.M. Whaley and W.S. Charlton, "Thermal Hydraulics Analysis of the University of Texas (UT) TRIGA Reactor," Nuclear Engineering Teaching Laboratory report, University of Texas at Austin (October 17, 2022).

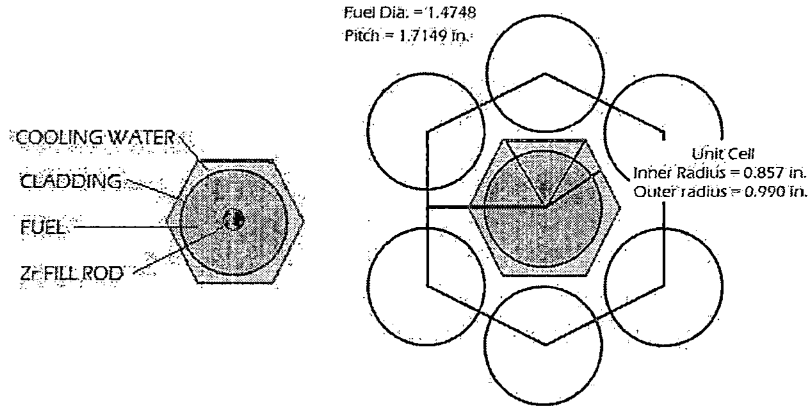

Figure A1: Flow Channel for UT TRIGA Fuel Elements

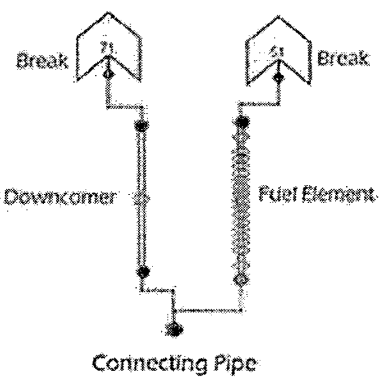

Figure A2: TRACE Model

TRACE analysis is based on modeling a set of representative TRACE components with characteristics specified by the user to model the system. The UT TRIGA model uses Break, Pipe, Heat Structure, and Power components. These TRACE components were assembled as shown in Figure A2 to model the thermal hydraulic performance of the unit cell flow channel.

An example of a comparison of TRACE steady-state calculation results to measured values is given in Table A1. This shows the fuel temperatures measured in the IFE's located at B03 and B06 in December 2015 compared to TRACE simulations of the same core configuration. Comparison of the calculated and observed data indicates TRACE can predict steady-state behavior with reasonable accuracy (generally within ±8% of measured temperature values).

Table A1: Trace Calculated and IFE Measured Fuel Temperature Comparison

POSITION	FUEL ELEMENT	ELEMENT POWER (kW)	IFE INDICATED FUEL TEMP (°C)	TRACE CALCULATED FUEL TEMP (°C)	% DIFFERENCE BETWEEN MEASURED AND CALCULATED
B03	10878	13.24	325	345	-6.15%
B06	10708	13.61	364	354	2.74%

Another example is shown in Figures A3 and A4 for TRACE transient results. The results of TRACE simulations for the NETL core for four pulse reactivity insertions are compared to measured data from over 300 historical pulses conducted at NETL. While there is significant scatter in power level and temperature data with some outliers, the results overall show excellent agreement. Thus, we expect the TRACE simulations to provide a reasonably accurate estimate for the aluminum-clad fuel event.

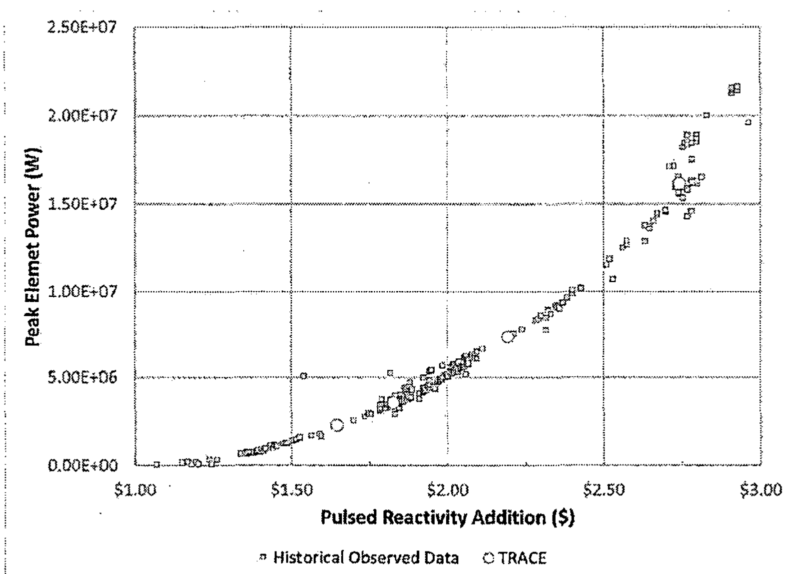

Figure A3: Peak Element Power Level versus Pulse Reactivity Addition from UT TRACE Calculation Compared to Observed Historical Data

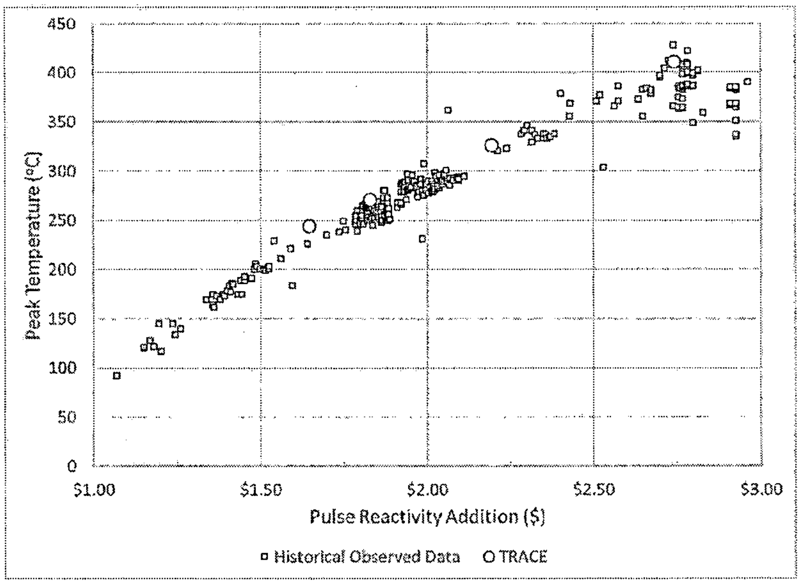

Figure A4: Peak Fuel Temperature versus Pulse Reactivity Addition from UT TRACE Calculation Compared to Historical Data

APPENDIX B – FUEL ELEMENT SPECIFICATIONS

The design of standard stainless steel clad fuel utilized in the NETL is shown in Figure A5. Stainless steel clad elements used at NETL all have fuel alloy length of 38.1 cm. The characteristics of standard fuel elements are shown in Table A2. Table 2 also lists nominal characteristics for aluminum-clad TRIGA fuel. As can be seen there are several notable differences including slightly lower uranium content, lower H content, use of a burnable poison disk, no Zr rod, shorter fuel length, and slight change in fuel and rod dimensions. However, the most critical difference for this analysis is the change in cladding material and cladding thickness. The aluminum clad fuel elements have a significantly thicker clad than the stainless steel clad fuel elements. This change in clad thickness and material could have a significant impact on heat transfer out of the fuel element. 1100 Alloy Aluminum has a lower melting point than stainless steel type 304, but 1100 Alloy Aluminum has a much higher thermal conductivity (222 W/m-K versus 16.2 W/m-K at 37°C).[6] For the analyses performed here, the fuel elements were modeled using the data in Table 2 with the exception that the fuel isotopics were changed to match the listed uranium content and burnup for each fuel element (including the low burnup given for the aluminum clad fuel).

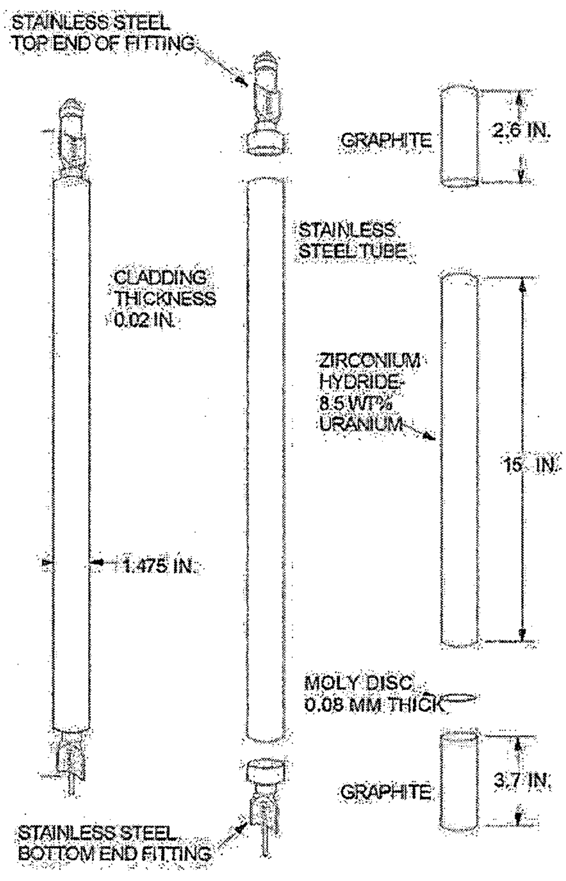

Figure A5: TRIGA stainless-steel clad fuel element design used in analysis.

[6] Thermal conductivity data for illustrative purposes only and was from MatWeb Material Property Data at http://www.matweb.com.

Table A2. Nominal Characteristics of Stainless Steel and Aluminum Clad Fuel Elements

Fuel Element Type	**8.5% Stainless Steel Clad**	**8% Aluminum Clad**
Fuel – moderator material	U-$ZrH_{1.6}$	U-$ZrH_{1.0}$
Uranium content	8.5 wt%	8.0 wt%
^{235}U enrichment	19.75%	19.75%
Average ^{235}U per element	39 g	36 g
Burnable poison	None	1% samarium/ 99% aluminum wafers
Poison wafer thickness	N/A	0.13 cm
Shape	Cylindrical	Cylindrical
Length of fuel meat	38.1 cm	35.6 cm
Diameter of fuel meat	3.63 cm	3.58 cm
Outer diameter of element	3.75 cm	3.76 cm
Zirconium core diameter	0.635 cm	None
Cladding material	Stainless Steel 304	Type 1100 Al
Cladding thickness	0.0508 cm	0.076 cm
Graphite Slug Outer Diameter	3.63 cm	3.60 cm
Upper Graphite Slug Length	6.60 cm	9.40 cm
Lower Graphite Slug Length	9.40 cm	9.40 cm
Molybdenum disc thickness	0.08 cm	N/A