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Attachment A

Oregon State University

Responses to NRC RAI Letter of October 22, 2021

1. **a) Provide a description of the reactivity worth measurement method for the transient rod and explain any uncertainties associated with this measurement method.**

The transient rod reactivity worth is measured via the rod pull method. There is very little uncertainty in this method as it utilizes an electronic timer directly connected to the fission chamber to measure the time it takes power to increase by a factor of four, which is then turned into period, which is then used to calculated reactivity. The timer has 1 millisecond resolution with minimal error (±0.5 ms, or 0.05%). The control rod height is measured from 0 to 100% withdrawn with 0.1% resolution with an error of ~0.05%. The total error of this method is estimated to be less than 1%. Note that the SAR's previously quoted 14% error was due to utilizing stopwatches and a paper chart recorder, which introduced significant human error.

b) Provide a discussion whether measurement error of the transient rod worth was considered in the analysis of the proposed TS pulse limit of $2.30.

This error was not considered significant (less than 1%). Historically, the rod pull method with the associated timer has proven very repeatable (there is an example of this from 8/23/21 where the transient rod worth was re-measured and exactly matched the value measured on 8/20/21).

2. **a) Provide an explanation on the resultant change in pulse peak power and maximum fuel temperature for the proposed pulse reactivity insertion TS limit of $2.30 considering the change in the prompt negative coefficient at core end-of-life.**

The pulsing analysis was performed at BOL, MOL and EOL using outputs from MCNP neutronic analysis which incorporated the changing prompt negative coefficient. The analysis showed that the MOL had the highest pulse peak power and maximum fuel temperature of 830°C at $2.30 and thus was the limiting configuration. The prompt negative coefficient used in the thermal hydraulic analysis for EOL was approximately 10% lower than the MOL coefficient. MOL has the highest core excess reactivity and this is likely the dominating factor in why pulse peak power is highest at MOL.

In addition, a $2.30 pulse insertion at the end of core life was not considered operationally feasible as there will not be enough core excess at the end of life to perform a $2.30 pulse. In order to pulse, the safety, shim and regulating rods must be able to achieve criticality without the transient rod and there will not be enough core excess to achieve criticality on three rods alone.

b) Provide an explanation what other core characteristics that could change over core life that may affect the maximum fuel temperature for a pulse reactivity insertion of $2.30. As these other core characteristics change over core lifetime, clarify whether a $2.30 pulse at core end-of-life would exceed the 830 degrees C (1526 degrees F) temperature limit.

Axial and radial profiles change over time and these changes are accounted for in the SAR analysis. The point is moot as a $2.30 pulse insertion at the end of core life is not considered feasible as there will not be enough core excess available to pulse.

c) Provide an explanation of any differences between how the instrumented fuel element (IFE) is modeled in the reactor neutronics and thermal hydraulic analyses compared to the standard TRIGA fuel element in the core. If any differences are identified, provide an explanation whether any events described in Chapter 13, "Accident Analysis," of the SAR are impacted.

The IFE is neutronically and thermal hydraulically modeled in the exact same fashion as a standard fuel element. This is a conservative analysis as the IFE has less fissile material than a standard fuel element due to the installed thermocouples and their respective channels, thus an IFE modeled as such would produce less heat/power.

d) Confirm the limiting core configuration of the OSU TRIGA reactor (OSTR) and briefly described how it was determined.

The LCC was determined by examining three different core configurations (Normal, ICIT, CLICIT; all three dependent on the contents of B1 grid location) at beginning of life (BOL), middle of life (MOL) and end of life (EOL). These nine different cases were analyzed for core excess reactivity, hottest channel, hot channel power, hot channel peaking factor, axial peaking factor, radial peaking factor, and an effective peak factor which is a product of the three aforementioned peaking factors. The case that had the highest effective peak factor was considered the LCC. Future core alterations are compared to this LCC to determine if they are within this SAR (as updated) analysis

3. **Provide an explanation of the "understood conservatism" applied to the analysis for the determination of the $2.30 pulse limit.**

   The SAR thermal hydraulic analysis utilized the Groeneveld 2006 tables as well as the highly conservative Bernath correlation to determine the maximum power-per-element while keeping DNBR below 2. The outputs of this analysis were then utilized to determine peak pulse characteristics. Additionally, conservativism was built into the thermal hydraulic model based on the geometric characteristics. Examples of this include use of the hot channel surrounded by fuel elements of equal power (see RAI #28 in Accession #ML082350345) and in the inclusion of the largest epistemic uncertainties on geometric dimensions such as the gap and cladding thicknesses which would lead to higher temperatures within the fuel (see RAI #37 in Accession #ML082350345). This resulted in a rod that produced the hottest conditions while taking into consideration all uncertainties.

4. **Provide a description on how the mechanical block and electrical interlock for the transient rod is set, including any surveillances that are performed, to prevent pulse reactivity insertion from exceeding $2.30 thereby limiting maximum fuel temperature below 830 degrees C (1526 degrees F) as stated in TS 3.1.4, "Pulse Mode Operation.".**

   The transient rod bracket (mechanical and electrical interlock) is physically set to the transient rod height that corresponds to the administrative limit of $2.25, typically immediately after annual control rod calibrations are performed. With the other three rods fully inserted and the transient rod shock absorber fully down, the operator applies air to the transient rod and withdraws it until upward motion stops via a physical interlock (bracket) as well as the electrical switch cutting off power to the "up" button, thereby stopping upward transient rod motion. The percentage withdrawn is checked against the most recent control rod calibration data to ensure the control rod worth at this point is within the administrative limit of $2.25. If it is not, the bracket height is adjusted and the process is repeated. In addition, the bracket height is checked before performing the first pulse of any given day to ensure that it is still set at or below $2.25.

5. **For pulse mode operation, clarify any reactor parameters readily available to the operator to verify the inserted pulse reactivity does not exceed the proposed $2.30 limit thereby ensuring the maximum fuel temperature of 830 degrees C (1526 degrees F) is not exceeded. For any reactor parameters identified, describe any associated instrumentation along with any surveillances performed on the instrumentation.**

   The operator monitors the peak power and integrated energy of the pulse via the nvt circuit. These values are recorded with each pulse and can be compared to previous pulses. The nvt circuit is part of the percent power channel, which is annually calibrated per Technical Specification 4.1.a and undergoes a channel test as part of the startup checklist prior to the start of each day's operation to ensure that the channel is operable per Technical Specification 4.2.d.

6. **a) Provide a basis to support square-wave mode of operation without requiring the operation of the fuel element temperature safety and measuring channel provided by the IFE.**

An IFE is not needed to protect the reactor for two reasons. First, procedurally square-wave involves operation of the reactor by raising reactor power from below 1 kW to full power of 1 MW by rapidly inserting less than $1.00's worth of reactivity. This is clearly less than the reactivity worth initiated during a pulse. Second, during square-wave mode, all of the safety and measuring channels required to be operable for steady-state mode are also required to be operable for square-wave mode (Technical Specifications Section 3.2.2, Table 1). Operating experience has shown that an overpower SCRAM from the two independent power level safety channels will occur long before a SCRAM would have been initiated by the IFE-provided safety channel, as the fuel temperature measurement is far "slower" than the power measurement. Also, pulse analysis throughout the updated SAR shows that fuel temperature does not come close to the LSSS of 510°C during a square-wave insertion of less than $1.00 (see prompt peak fuel temperature of 448°C for $1.50 insertion in Table 4-31(New) in Addendum of Accession #ML082350345).

b) Provide an explanation of all calculational, measurement, operational, and trip setpoint setting uncertainties that are accounted for in establishing the power level scram setpoint that supports square-wave mode of operation.

The error associated with the measurement of the voltage and display of power is approximately ± 0.1%, which corresponds to the lowest resolution of the display. This is the reason that the trip setpoints for the safety and percent power channels are administratively set at no higher than 105.9% of 1 MW. However, the real uncertainty is created by the establishment of 100.0% power during the annual calorimetric calibration of reactor power. Current procedures require adjustment of the fission chamber height when the calculated power differs from the measured power by 1.5%.

This methodology was previously analyzed in SAR Section 13.2.2.2.3 and the removal of the IFE does not affect this methodology.

c) Provide an explanation where any uncertainties are accounted for in the power level scram setpoint (for example, in the safety analysis calculations or in the physical scram setpoint).

The primary method for accounting for the uncertainties in the power level scram setpoints reside in the fact that the set point is set to 106% of 1.0 MW_{th}, 4% below the licensed power limit of 1.1 MW_{th}. Analysis provided in our SAR (as updated) of a simultaneous withdrawal of all four control rods (Section 13.2.2.2.3) results in a reactivity insertion of $1.23, much less than the licensed limit of $2.30 (830°C). The removal of the IFE does not affect this methodology.

d) For the events analyzed in OSU's SAR, Chapter 13, confirm whether the fuel element temperature as provided by the IFE or the power level safety channel function would terminate the event.

Analysis provided in RAIs of the conversion SAR (see Table 4-31(New) in Addendum of Accession #ML082350345) specifically has figures which show the calculated maximum IFE temperatures as a function of reactivity insertion. This table shows that an overpower SCRAM from the two independent power level safety channels will occur long before a SCRAM would have been initiated by the IFE-provided safety channel. The IFE LSSS does not actuate until the fuel temperature exceeds 510°C, at which time the power channel SCRAMs will have already initiated.

e) For any identified events where the fuel element temperature safety channel currently terminates an event analyzed in OSU's SAR, Chapter 13, provide an analysis of the power level safety channel trip that would terminate the event if the IFE safety function is removed.

There are no identified events where the fuel element temperature safety channel terminates an event analyzed in the SAR (as updated).

f) Provide a description of any OSU procedures or documents that establish the power level scram setpoints.

The trip setpoint is created by establishing the voltage on a bistable that corresponds to 105.9% of 1.0 MW_{th}. The procedure is provided by the power channels' respective manuals (Thermo-Fisher Scientific manual for the safety power channel, Gamma-Metrics manual for the percent power channel). This voltage setpoint was established in 1996 and hasn't been changed since. However, the setpoint is checked daily before the first startup of the day by initiating a test signal into the safety channel (per Technical Specification 4.2.d) that slowly ramps power to 110%.

7. **a) Confirm whether any analysis or events described in Chapters 4 or 13 of the SAR were reanalyzed as a result of proposing to remove the IFE high temperature scram function.**

The high temperature scram function has no bearing on any of the Chapter 4 or 13 analyses. The power channel scrams were used in the analyses as they are the ones that would initiate first, rendering the high temperature scram as irrelevant because of the low temperatures achieved.

b) Provide an explanation on which event described in Chapter 13 of the SAR has the minimum margin to current TS 2.1, "Safety Limit-Fuel Element Temperature," that states "the temperature in a TRIGA® fuel element shall not exceed 2,100° F (1,150° C) under any mode of operation."

The event in Chapter 13 that has the minimum margin to current TS 2.1 is an event involving a Maximum Reactivity Insertion (Section 13.2.2.2.1), which is determined to be a pneumatic withdrawal of the transient rod (commonly referred to as a pulse). This is analyzed in Chapter 4 and shows that the temperature in a TRIGA® fuel element shall not exceed 830°C during a maximum reactivity insertion of $2.33, which is considerably less than 1,150°C.

c) Confirm that the removal of the IFE does not impact the reactor's protective function to mitigate or detect the impacts of a blockage or significant flow reduction in a coolant flow channel regardless of the credibility of such an event in OSU's fuel. If removal of the IFE at the OSTR is removing a protective function that would prevent the mitigation or detection of a blockage or significant flow reduction in a coolant flow channel, provide justification why it is acceptable to remove the IFE from the OSTR.

The removal of the IFE does not impact the reactor's protective function to mitigate or detect the impacts of a blockage or significant flow reduction in a coolant flow channel regardless of the credibility of such an event in OSU's fuel. The IFE was designed to simply provide temperature information in the axial center of a fuel element in the B-ring, which is central to the core and thus the hottest region of the core. It is unlikely that the IFE could display increased temperatures even if the flow blockage or significant flow reduction occurred immediately next to it as the OSTR fuel is cooled through natural convection flow. A fuel flow blockage is difficult, if not incredible, as the water would simply convectively flow from neighboring holes in the lower gridplate to around the fuel cladding and up through the flutes on top of the fuel as well as openings in the upper gridplate. Also, during fuel handling and inspections, cameras are used to verify that fuel is properly seated. In summation, it is unlikely that the IFE could experience a blockage or prevent the impact of a blockage. It could only detect a blockage involving itself. It provides no credible detection methods for any other fuel in the core.

8. **In the LAR, OSU didn't propose changing LC 2.C.(1) to reflect the proposed TS 3.1.4 reactivity insertion limit of $2.30.**

   Provide a proposal to LC 2.C.(1) to reflect the proposed TS reactivity insertion limit of $2.30 or justify why a change to LC 2.C.(1) is not needed.

   This is requested in Attachment B in the RAI response.