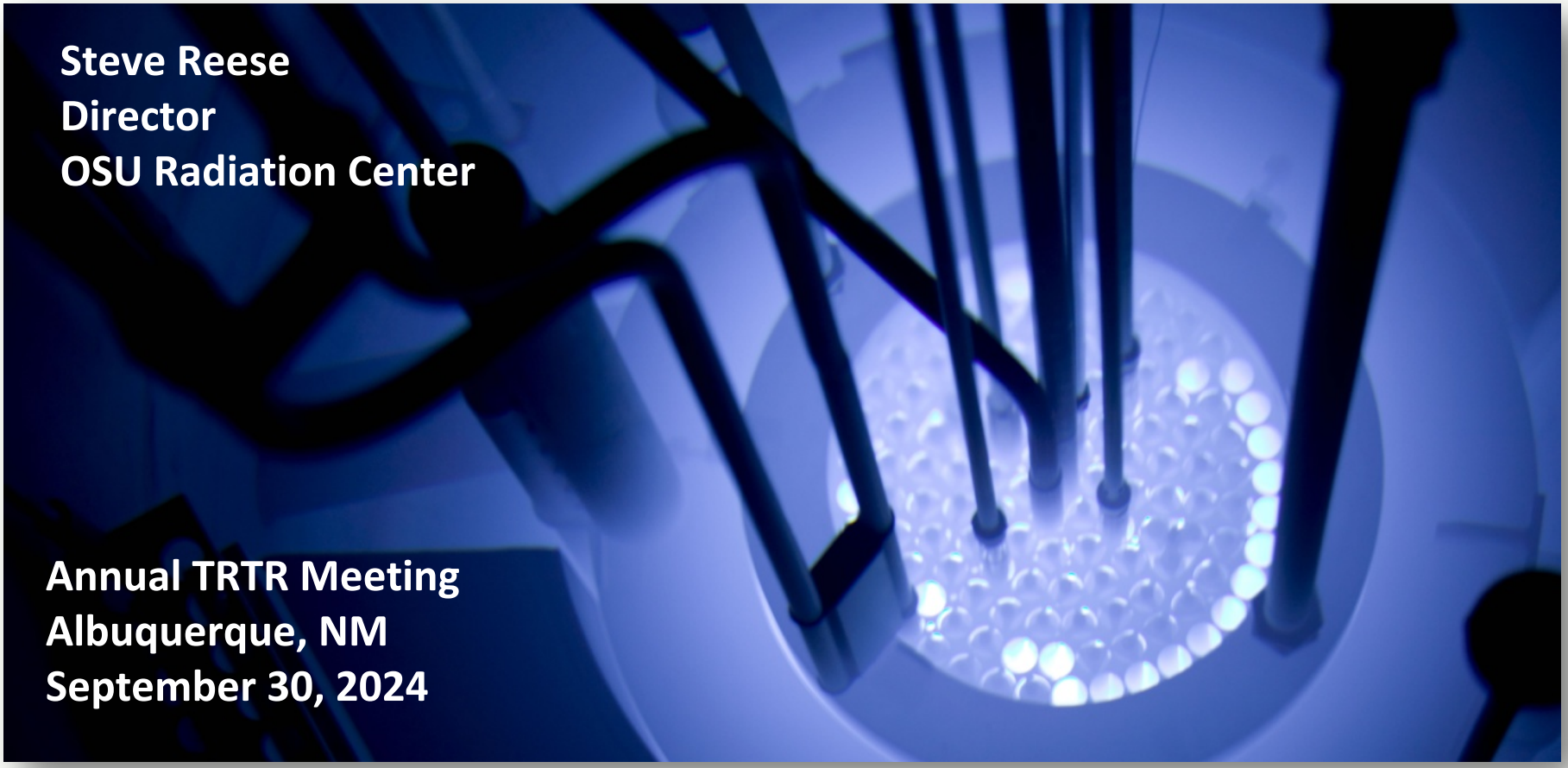
Separate Operating Issues Caused by Operator Error and Mechanical Failure



Steve Reese
Director
OSU Radiation Center

Annual TRTR Meeting
Albuquerque, NM
September 30, 2024

Two Events

The first event involved a stuck **control rod**.

The second event involved an inadvertent reactivity insertion during a **square wave**.

Both resulted in potential violations.

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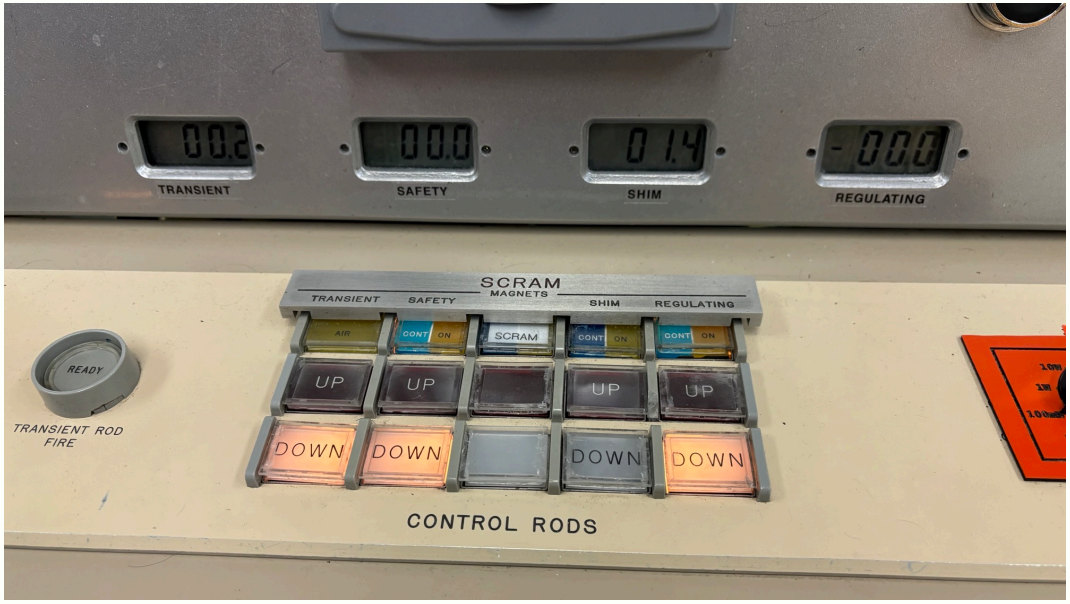
Control Rod Event - Background

The operator was shutting the reactor down and drove the rods in as normal, but the shim rod would not go lower than 1.0% withdrawn and would not illuminate the DOWN light.

The operator withdrew the key, which removed magnet power, but the rod would still not go to 0%. The Development Engineer was called to help investigate the issue.



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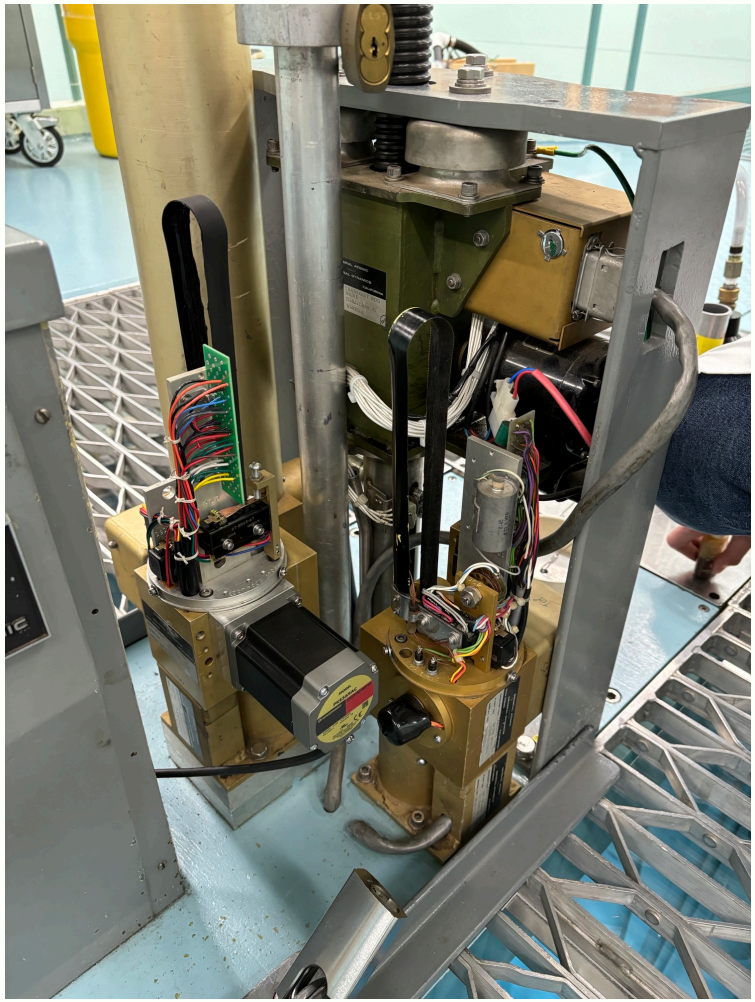
Control Rod Event - Background

Stuck button? Misaligned foot switch? These have happened before.

The **operator joined the Development Engineer on the reactor top**. The Development Engineer felt binding on the shim rod and, with a slight movement of the armature, was able to release the tension, allowing the rod to fully insert the remaining 1.0% (0.15”).



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Control Rod Event - Inspection

The next morning, the staff disassembled the shim rod drive assembly and inspected the parts. They discovered a nylon “seat” had been broken into pieces, which likely caused the from hitting bottom. Proceeded to look at the other two rod seats.

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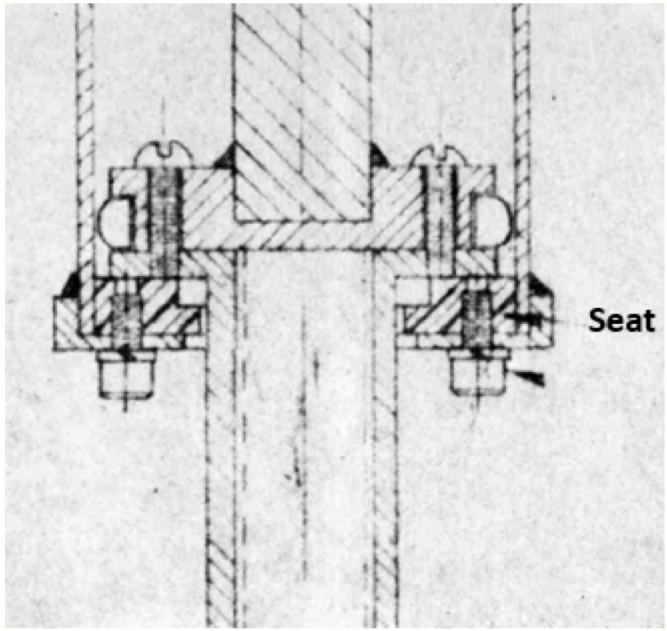
Control Rod Event - Inspection

Four screws that are supposed to fasten to the seat were missing from the safety and shim rods (the regulating rod screws were still intact). These screws fasten directly into the seats and since those seats had degraded, they had fallen out at an unknown point in time.



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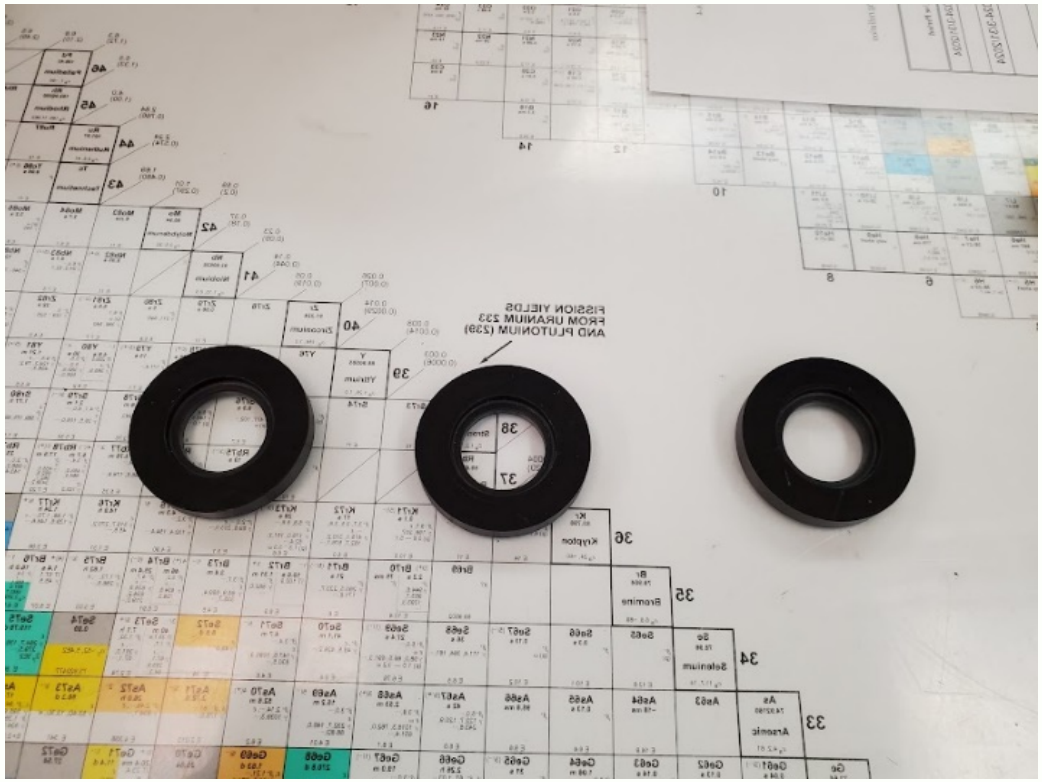
Control Rod Event – Seat Replacement

General Atomics was able to provide a drawing for the seat that afternoon (Hat tip to Mr. Gormley). The Development Engineer fabricated three new seats out of Delrin, rather than nylon.



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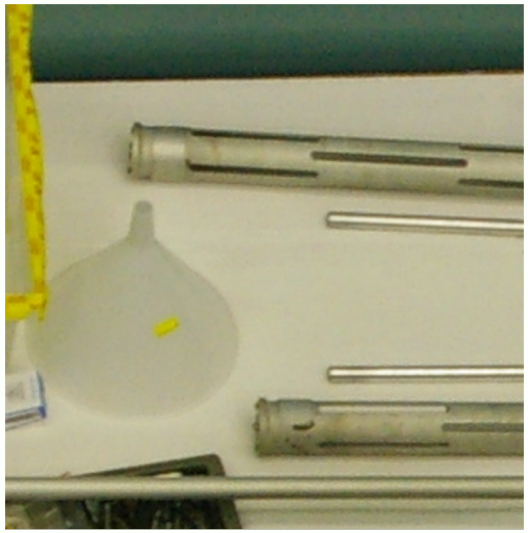
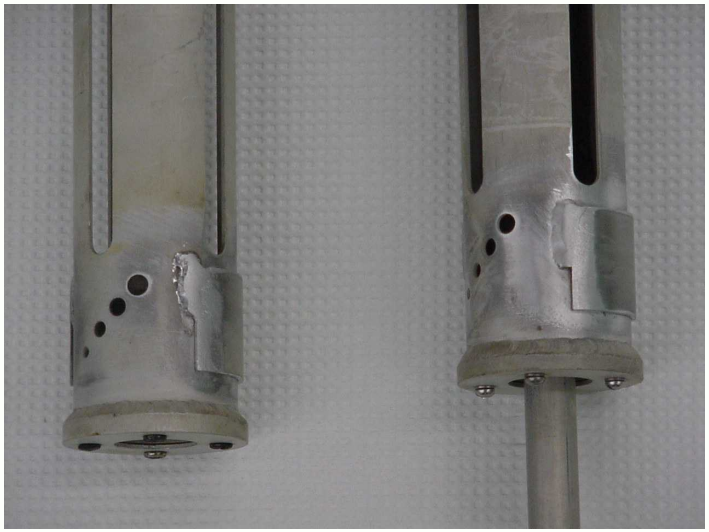
Control Rod Event - Missing Screws

Unable to find any of the missing screws.

Pictures from 2000 (dashpot repair) and 2008 (LEU refuel) show that the screws were intact at that time, though the safety and shim rods did not appear to have the appropriate screws installed.





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Control Rod Event - Technical Specification Violation

Technical Specification 6.1.3.a.1

The minimum staffing when the reactor is not secured shall be a reactor operator or the senior reactor operator on duty (Duty SRO) in the control room.

Technical Specification 1.20 (Definition of Reactor Secured)

The reactor is secured when…

1. *The four (4) neutron absorbing control rods are fully inserted*

The operator left the console for approximately 4 minutes. Because the shim rod was not fully inserted, this is likely a Technical Specification violation.

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Control Rod Event - Corrective Actions

Notification: Self reported the next day to the NRC Headquarters Operation Center. Also informed our NRC Program Manager and Inspector, as well as the Reactor Operations Committee.

Replacement: All seats were replaced with Delrin and secured with stainless steel socket-head screws, and rods tested for operability.

Training: All licensed operators were reminded that if the rods do not all indicate approximately 0.0% with the DOWN lights illuminated, then they will need to stay at the console until full rod insertion can be assured.

Inspection: Specifically looking at screws and seats during biennial control rod inspections.

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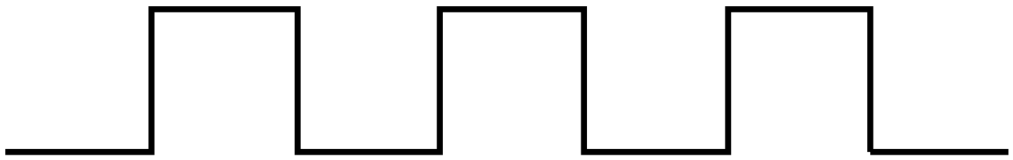
Square Wave Event – Square Wave Mode

Transient operations are divided into pulse mode and square wave mode.

Square Wave mode was designed to quickly increase reactor power to a desired level, usually from low power to full power of 1 MW.

It is labeled Square Wave because the power trace mimics an electronic square wave, with log power immediately increasing from low power (100 W) to full power (1 MW).



Square Wave Event - Transient Mode Operation Set-up

Both transient modes are set up in a similar fashion:

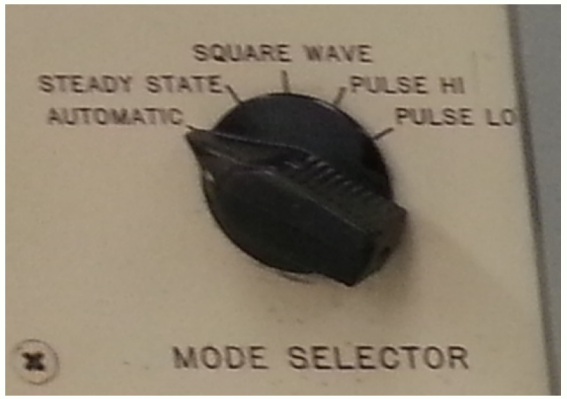
- Reactor critical at 100 W on three rods, leaving the air off of the transient rod.
- Operator raises transient carrier (not the rod) height that corresponds to the desired reactivity insertion.
- For pulse mode, insertions can go up to license limit of $2.30.
- For square waves, the suggested insertion is $0.80, which yields a fast period (about 0.8 seconds), but square wave mode is designed for a fast period.

Square Wave Procedure

Normal order of operations to perform a square wave:

1) ensure the mode switch is in Steady State,
2) set flux demand below desired power (typically 80-90%),
3) set the range switch to the desired power (1 MW),
4) set the mode switch to Square Wave,
5) fire the transient rod to perform the square wave.

When fired, the rod withdrawals to the prescribed height. The servo works by first inserting for 1.5 s then drives the reg rod to meet demand power.



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Square Wave Event – Procedure Out of Order

Now if Steps 3 and 4 are performed out of order:

1) ensure the mode switch is in Steady State,
2) set flux demand below desired power (typically 80-90%),
3) set the mode switch to Square Wave,
4) set the range switch to the desired power (1 MW),
5) fire the transient rod to perform the square wave.

If the mode switch is moved to Square Wave ***before*** the range switch is adjusted, the regulating rod will insert for 1.5 seconds then begin to withdraw to match power.

Result: A reactivity insertion while reg rod moving.

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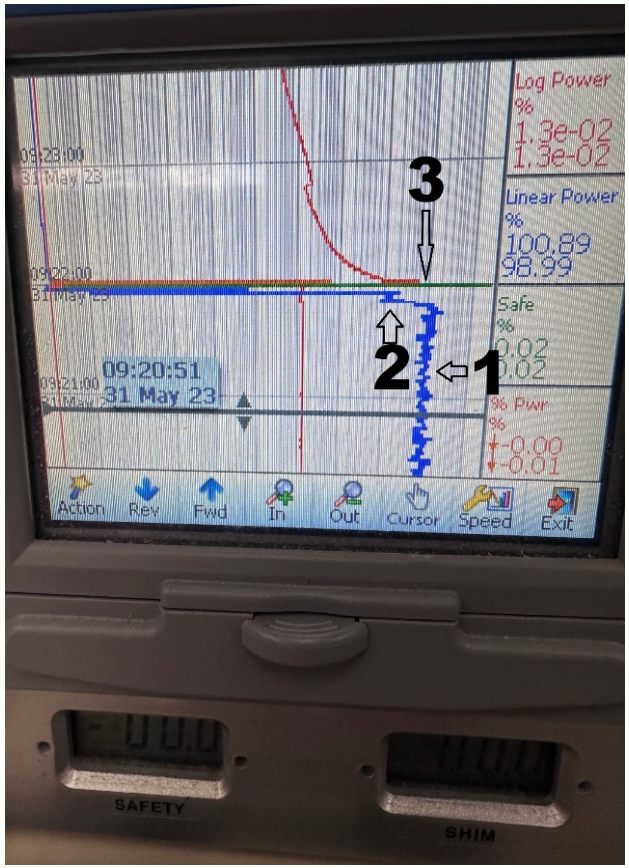
Square Wave Overpower Event

On 5/31/23, an SRO and operator trainee performed a square wave out of order.

Point 1 shows the reactor at 100% of 100 W. At this time, the operator moved the flux controller to 90% and mode switch to Square Wave.

Point 2 shows that because the linear power was above 50% of demand, the regulating rod inserted for 1.5 seconds then controlled power at 90%, the demand set by the operator.



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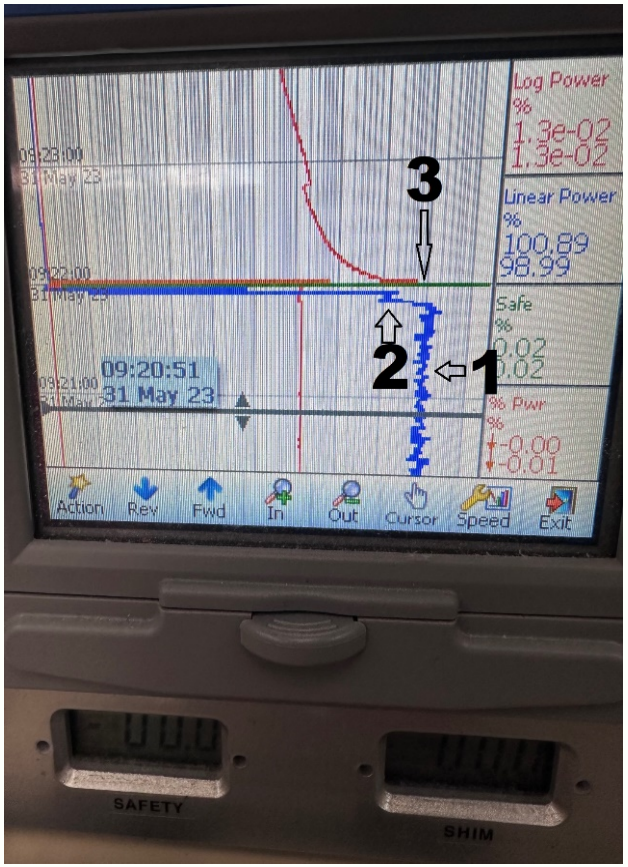
Square Wave Overpower Event

Within a few seconds after adjusting the range switch, the operator fired the transient rod and received safety and percent power scrams. Note that this all happened within 10 seconds.



Point 3 shows the safety power spike (green). The recorder sample rate is 1 Hz and the safety channel read 145.91% for one sample.

Reactor power likely exceeded the steady-state limit of 1.1 MW.

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Square Wave Event – Reactivity

When the mode switch was moved to Square Wave, the regulating rod moved from 70.9% to 77.0% in four seconds, which equates to $0.18 of reactivity.

This means that the square wave overpower event inserted approximately $0.98 of reactivity ($0.80 by the transient rod and $0.18 by the regulating rod).

An alternate calculation was performed the inhour equation for the given power increase and estimated a reactivity insertion of $0.96.

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Square Wave Event - Technical Specifications

Technical Specification 3.1.1 (Steady-State Operation) states "**The reactor power level shall not exceed 1.1 MW except for pulsing operations**."

The applicability of this specification states "**This specification applies to the energy generated in the reactor during steady-state operation.**"

Definition 1.28 "Steady-State Mode (S.-S. Mode)" states "**Steady-state mode shall mean operation of the reactor with the mode selector switch in the steady-state or automatic position**."

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Square Wave Event - Technical Specifications

Reflecting on this, the applicability's "…during steady-state operation." ***should say*** "…during all modes except Pulse Mode."

Initial thought was that it did not violate this specification as the applicability and objective of this specification clearly state that this applies to only steady state operations.

However…

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Square Wave Event - Safety Analysis Report Description

Chapter 7 Instrumentation and Control Systems

"The OSTR may be operated in one of three modes.

- steady state mode — steady state operation of the reactor at power levels not exceeding 1.1 MW(t)
- **square wave mode — step insertion of reactivity rapidly that raises reactor power to a steady-state level up to 1.1 MW(t),**
- pulse mode — a large step insertion of reactivity rapidly raises reactor power to create a short duration reactor power pulse of high power (several thousand megawatts)"

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Square Wave Event - Safety Evaluation Report Description

Chapter 4.1 Summary Description

"The OSTR can be operated at a maximum steady-state power of 1.1 MW(t), or pulsed up to a peak power of about 2500 MW(t), or operated in a square-wave mode **(in square-wave mode the reactor power is quickly raised using the pulsing transient rod to a power level within the steady-state power limit)**."

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Square Wave Event - Corrective Actions

Notification: Self reported the next day to the NRC Headquarters Operation Center. Also informed our NRC Program Manager and Inspector, as well as the Reactor Operations Committee.

Training: Immediate training on the event to all operators.

Procedures: Revised to add more safety checks and make the evolution more deliberate.

Engineered Solution: Eliminated Square Wave Mode from the console and from the technical specifications.

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Questions?

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