Power Calibration Method Analysis

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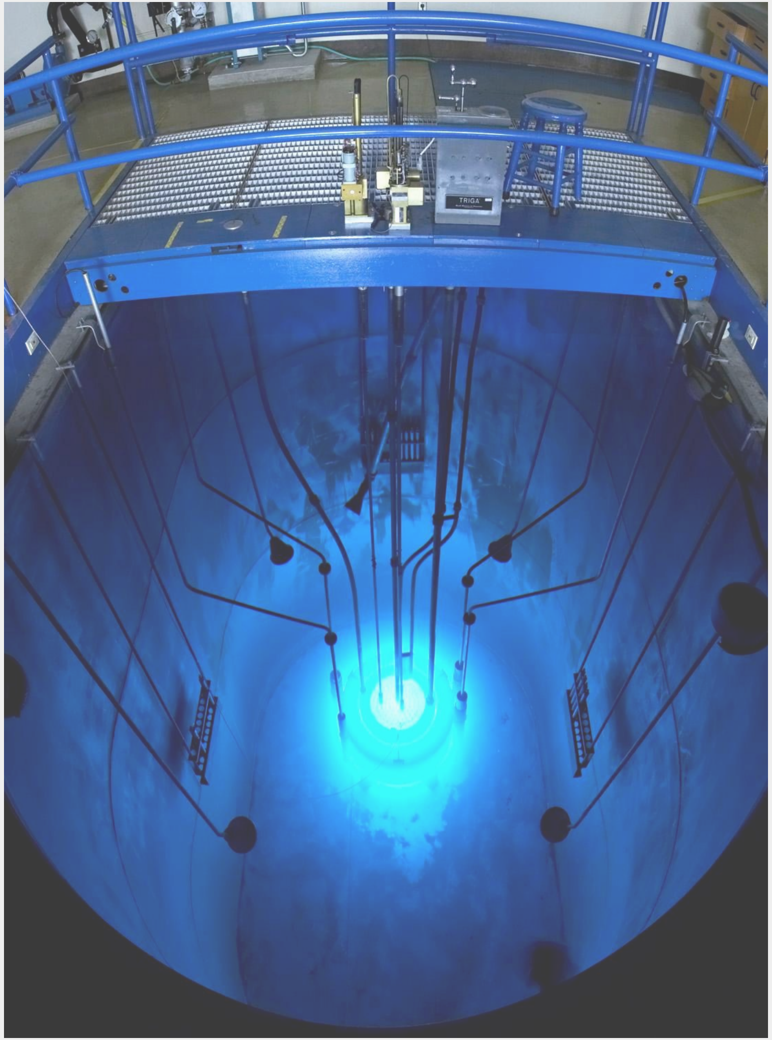
Outline

- ★ Background information
- ★ The procedure we use
- ★ Issues discovered
- ★ The procedure changes suggested
- ★ Plans for Implementation
- ★ CFR 50.59 process so far



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Background Information

Background

What is a Power Calibration?

★ Operating a Reactor relies on nuclear instrumentation capable of relying what power level, in wattage, we are at in real time.

★ Reed Research Reactor (RRR) has **three** nuclear power channels to perform this function.

★ Each power channel is calibrated semi-annually, this procedure is known as our **power calibration**.

Background

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Why do a Method Analysis?

- ★ Throughout 2021, I was conducting tests to compare our nuclear instruments efficiencies.
  - Mainly used the power calibration procedure in this process.
  - I did the procedure many times back to back, which was unusual.
  - Discovered inconsistencies in the data from the procedure itself, which posed a roadblock in my tests.
- ★ 2022 was spent exploring why these inconsistencies occurred, and how we can improve our methods of calibration to ensure stable results.

The Current Power Calibration Procedure

Current Procedure

Power Calibration Procedure

- ★ In summary, the procedure is simple:
  - ○ Take temperature data of the pool to compute change in heat,
  - ○ Convert this to thermal power (used as control),
  - ○ Compare to power channel readings from same time,
  - ○ Adjust power channels accordingly if needed.
- ★ In practice, it's a little more complicated.

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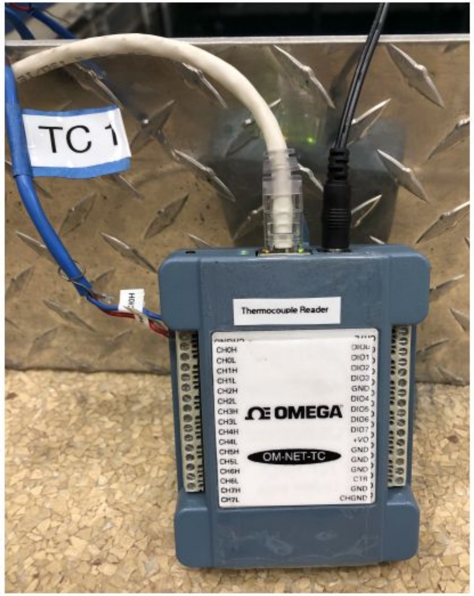
Taking Thermal Data

- ★ 6 thermocouples in pool at varying depths
- ★ Analog thermocouples connected to digital display operator can see to take live data
- ★ Two sets of temperatures taken:
  - ○ Temperature of each thermocouple before operating,
  - ○ Temperature of each after operating for several (2-4) hours.



Analog to digital thermocouple reader.

Current Procedure

Other recorded values

- ★ Besides the thermocouples temperature, other values recorded include:
  - Pool water level,
  - Power reading from each power channel,
  - Reactivity worth of the control rods,
  - Time of taking both data sets.

While at Power

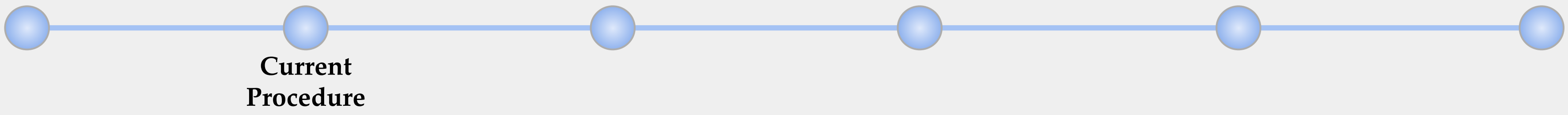
Time 1	Pool Level	TC 1 (°C)	TC 2 (°C)	TC 3 (°C)	TC 4 (°C)	TC 5 (°C)	TC 6 (°C)	TC 7 (°C) *Console*

Indicated power Linear:	________ kW	Safety Rod:	________ %	$ ________
Indicated power Percent Power:	________ kW	Shim Rod:	________ %	$ ________
Indicated power Log Wide Range:	________ kW	Reg Rod:	________ %	$ ________
Potentiometer value:	________	Core excess:		$ ________
Indicated power Log Power Range:	________ kW	Control rods banked (± 0.5%)	[__]	
Potentiometer value:	________			

Time 2	Pool Level	TC 1 (°C)	TC 2 (°C)	TC 3 (°C)	TC 4 (°C)	TC 5 (°C)	TC 6 (°C)	TC 7 (°C) *Console*

Indicated power Linear:	________ kW	Safety Rod:	________ %	$ ________
Indicated power Percent Power:	________ kW	Shim Rod:	________ %	$ ________
Indicated power Log Wide Range:	________ kW	Reg Rod:	________ %	$ ________
Potentiometer value:	________	Core excess:		$ ________
Indicated power Log Power Range:	________ kW	Control rods banked (± 0.5%)	[__]	
Potentiometer value:	________			

Excerpt of calibration form for recording data.



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Converting Data to Calibration Information

- ★ Turning these numbers into the information we seek requires thermal physics equations.
- ★ We use a handy spreadsheet made for our staff
  - ○ No by-hand math required!
  - ○ Results instantly after operating!

Current Procedure

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The Spreadsheet Used

Date		

Initial data

Time 1		
Time is power is reached		hh:mm
Ch 0		°C
Ch 1		°C
Ch 2		°C
Ch 3		°C
Ch 4		°C
Ch 5		°C
Console		°C
Average Temp	#DIV/0!	°C
Pool Height		mm

Final data

Time 2		
Time at end of operation		hh:mm
Ch 0		°C
Ch 1		°C
Ch 2		°C
Ch 3		°C
Ch 4		°C
Ch 5		°C
Console		°C
Average Temp	#DIV/0!	°C
Pool Height		mm
Linear		kW
Percent		kW
Log: Wide Range		kW
Log: Power Range		kW

Percent Error		
#ERROR!	%	#ERROR!
#ERROR!	%	#ERROR!
#ERROR!	%	#ERROR!
#ERROR!	%	#ERROR!

Informational Cells

Constants Used in Calculations		
Core Volume	499220.1016	cm^3
Area of the tank	119380.41	cm^2
ΔHv	2458	Joules/gram
Cp	4.186	Joules/(gram °C)

Calculating Qin		
Specific volume at Avg Temp 1	#ERROR!	cm^3/g
Specific volume at Avg Temp 2	#ERROR!	cm^3/g
Mass at Time 1	#ERROR!	g
Mass at Time 2	#ERROR!	g
Mass of Evaporation	#ERROR!	g
Qin	#ERROR!	Joules

Wait? What's actually being calculated?

$$Q_{in} = m_T \cdot C_p \cdot \Delta T + m_E(\Delta H_v + C_p \cdot \Delta T)$$

Qin = the heat input of the reactor
mT= the water mass in the tank
Cp = the specific heat of the water
ΔT = the change in bulk water temperature,
mE = the mass of the water that evaporated
ΔHv = the latent heat of vaporization

White cells are values that are constant, and the names and units of input parameters. DO NOT EDIT THESE CELLS.

Yellow cells require user input (follow SOP 33)

Blue cells are calculated numbers. Once all of the yellow cells are filled, the blue cells will display numbers. DO NOT EDIT THESE CELLS.

The green cell is the calculated power in kW. DO NOT EDIT THIS CELL.

Calculated Power

Calculated Power		
Time at power	0.00	s
Power	#ERROR!	kW

Current Procedure

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Preliminary checks and Precautions

★ The procedure is straightforward, but we have to be careful of many things:

Preliminary

No operations above 5 watts for 48 hours	[___]	No irradiations in progress using the reactor	[___]
Secondary off for at least one hour	[___]	Primary pump on	[___]
Underwater lights are off	[___]	Core excess at 5 W: $ __________	

Current Procedure

Issues discovered

Issues
Discovered

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1 - The Thermal Equation

$$Q_{in} = (m_T \cdot C_P \cdot \Delta T) + (m_E \cdot C_P \cdot \Delta T) + (m_E \cdot H_v)$$

Heat from water in tank

Heat from water that evaporated

Heat that got used to evaporate water

Where m is mass, C is specific heat capacity of water, T is temperature, H is a constant.

- ★ In the equation, last two terms are unnecessary and needlessly complicates the procedure.
- ★ It would be difficult to measure the amount of water that evaporated, so we use an estimate.

Issues Discovered

2 - The System is Not Isolated

- ★ Primary water system stays on to continue mixing water.
- ★ Introduces an entire system the water could lose/gain heat from.
  - Heat loss through pipes
  - Heat gain through primary system water pump
  - Heat loss/gain through our water cleanup loop
- ★ Most of this cannot be measured, or can only be roughly estimated.

Issues Discovered

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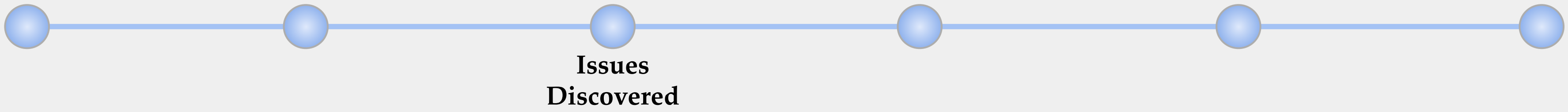
3 - Insufficient Mixing

★ Using primary system as a pool mixer was not its intended purpose:

  - "Deflector" nozzle in system is used to swirl water and delay radioactive N-16 from reaching the surface.
  - This swirling motion does not adequately mix the water to evenly distribute heat.

★ Main pool temperature thermocouple and power calibration thermocouples are always at least 1℃ apart from each other (on opposite sides of the pool).



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4 - Thermocouple Location

- ★ Thermocouples are lined on the West wall of the pool.
- ★ Being on the edge results in:
  - ○ Temperature readings more sensitive to uneven mixing,
  - ○ Potential heat loss through the pool wall, causing a colder reading.

Issues Discovered

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The Suggested Procedure Changes

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Drop Last Two Terms of Thermal Equation

$$Q_{in} = (m_T \cdot C_P \cdot \Delta T)$$

Heat from water in tank

Where m is mass, C is specific heat capacity of water, and T is temperature.

★ This leaves us with a simpler equation similar to what other TRIGA reactors currently use.

Suggested Changes

Replace Primary System with External Mixer

- ★ Turning off the primary system during the procedure will isolate the system.
- ★ An external mixer will input negligible heat gain and perform better than the current setup.

Example of pool mixer used by Oregon State.
"Grainger Open Drum Mixer"

Move Thermocouple Array to Middle of Pool

- ★ This will mitigate any problems with the edges of the pool being cooler
- ★ But, we will need to take precautions!
    - ○ The thermocouples are thin wires. Moving around or becoming tangled in a mixer is not ideal.

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Plans for Implementation

Implementation

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Still Early in the Process!

- Currently undergoing a 10 CFR 50.59 evaluation
- Some things are in discussion:
    - Which mixer model will be purchased?
    - How will we suspend it above the pool?
    - How will we safely create a new thermocouple array?

Implementation

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Next Steps

- ★ Work with the Reed College machine shop to design an over-the-pool structure for mixer and thermocouples.
- ★ Submit Evaluation to the Reed Reactor Operations Committee.
- ★ After approval: begin procedure rewrites, spreadsheet edits, and construction!

Implementation

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Introduction — **Current Procedure** — **Issues Discovered** — **Suggested Changes** — **Implementation** — **Thank you!**