Analysis of In-Situ TRIH Biases

by

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Our paper describes a novel method to determine the constant systematic error (bias) in the temperature RTDs of the Reactor Inlet Headers (TRIH). This is done by analysing the TRIH responses to a reactor run-up. This method provides an independent check for TRIH biases which are directly measured by removing the RTDs from their thermowells, placing them in an oven, and comparing their responses to a high-precision RTD.

Overall, work on assessing TRIH errors has resulted in a significant reduction in PHT boundary condition uncertainties and a subsequent decrease in required operating margins.

1.0 METHOD

The method corrects the TROHs for bias and uses them to determine the bias of the TRIHs at zero power. Below is a description of the method:

1.1 The biases of the four TROHs are determined by observing their responses to the Nov'96 run-up. When the ROH becomes saturated, the TROH reading is compared to the saturation temperature at PROH to find the bias.

1.2 The TROH readings during the power ramp are corrected for their biases assuming there is no power-dependent component to the bias.

1.3 The corrected TROHs and uncorrected TRIHs are used to compute the single-phase enthalpy change across the core at various power levels in the run-up.

1.4 The enthalpy change is extrapolated to zero reactor power and adjustments are made for heat losses to the moderator and end shields, and for heat added by the PHT pumps. The enthalpy bias of the RIH ($\Delta H_{TRIH.BIAS}$) is determined by equation (1) below:

$$\left[\Delta H_{TRIH.BIAS} = (H^{C}_{ROH} - H^{U}_{RIH}) - \Delta H_{PUMPS} + \Delta H_{MOD+SHIELDS} \right]_{REACTOR\ POWER\ =\ ZERO} \quad \textbf{(1)}$$

Where: $\mathbf{H^{C}_{ROH}}$ is the enthalpy of the ROH corrected for constant bias

$\mathbf{H^{U}_{RIH}}$ is the enthalpy of the RIH uncorrected for bias

$\mathbf{(H^{C}_{ROH} - H^{U}_{RIH})}$ is the extrapolated enthalpy change across the core at zero power

$\mathbf{\Delta H_{PUMPS}}$ is the enthalpy addition by the PHT pumps between the headers at zero power

$\mathbf{\Delta H_{MOD+SHIELDS}}$ is the enthalpy loss to the moderator and end shields at zero power

1.5 The enthalpy bias is converted to a temperature bias using the specific heat of D_2O (c_p) at measured temperature and pressure.

2.0 RESULTS

2.1 Computed Biases

Below is a summary of the computed TRIH biases for PLGS in November 1996:

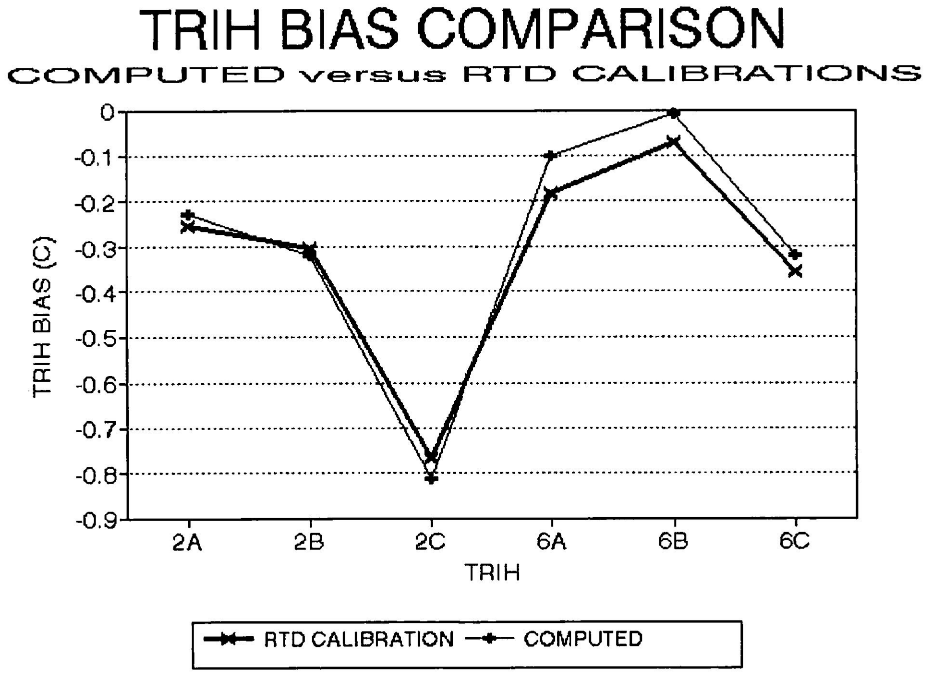
RTD NAME			COMPUTED TRIH BIAS (°C)
TE NAME	USED IN THIS REPORT	AI #	
63331-TE-27A	TRIH2-A	1224	-0.23
63331-TE-27B	TRIH2-B	2406	-0.32
63331-TE-27C	TRIH2-C	3100	-0.81
63331-TE-28A	TRIH4-A	1226	+0.31
63331-TE-28B	TRIH4-B	2407	-0.21
63331-TE-28C	TRIH4-C	3101	+0.05
63331-TE-29A	TRIH6-A	1227	-0.10
63331-TE-29B	TRIH6-B	2410	-0.01
63331-TE-29C	TRIH6-C	3102	-0.32
63331-TE-30A	TRIH8-A	1230	+0.08
63331-TE-30B	TRIH8-B	2411	+0.07
63331-TE-30C	TRIH8-C	3103	+0.00

The average TRIH bias is -0.12°C (thus the RTDs read on average too high).

2.0 RESULTS (Cont'd)

2.2 Comparison of Computed Biases to RTD Calibrations

On 14-19 Feb 97, the RTDs in RIH2 and RIH6 were calibrated by Engineering Materials and Diagnostics. [1] The RTDs were removed from their thermowell and put in a furnace and compared to a Standard Platinum Resistance Thermometer (SPRT). Below is a comparison of the RTD calibration biases versus the RTD biases computed here for RIH2 and RIH6.



The biases from the independent methods closely agree. The one-sigma deviation of their differences is ±0.04°C. There appears to be little if any systematic differences. These results also indicate that the biases do not change significantly over time since these tests were conducted about three months apart.

3.0 ANALYSIS OF RIH-ROH ENTHALPY CHANGE

Computing Bias for TRIH2-A

For example, below is a table of TRIH2-A and TROH3 data during the November 96 run-up.

REACTOR POWER (%)	TRIH UNCORRECTED	TROH CORRECTED FOR BIAS (See Note 1)	H^{U}_{RIH2A} (See Note 2) kJ/kg	H^{C}_{ROH3} (See Note 3) kJ/kg	$H^{C}_{ROH3} - H^{U}_{RIH2A}$ (kJ/kg)
2.5	261.5	262.47	1101.4	1106.3	4.9
50	261.7	286.47	1102.3	1222.9	120.6
77	263.7	299.97	1111.7	1293.9	182.2
89	264.5	306.27	1115.5	1328.3	212.8

Note 1: TROH3 was corrected for a bias of -0.83°C (Section 5.0)

Note 2: The RIH enthalpy was computed using:

$$H_{RIH} = 4.711429 * T_{RIH} - 130.6619$$

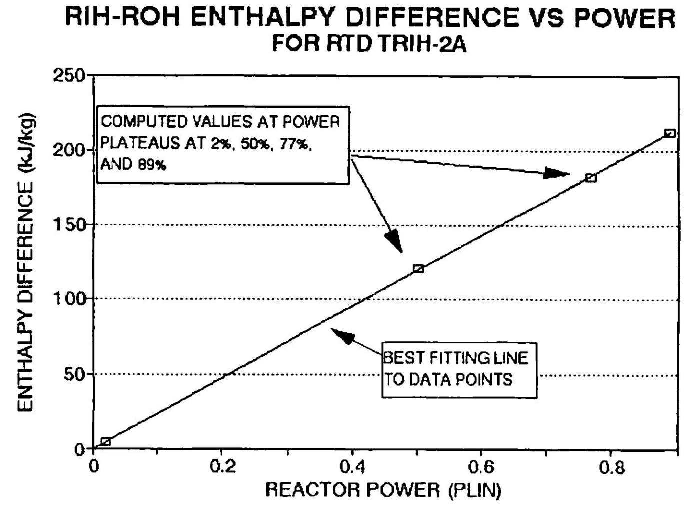
Note 3: The ROH enthalpy was computed using:

$$H_{ROH} = -1.007827 * T_{ROH} + 0.010685 * T^{2}_{ROH} + 634.718$$

Plotting Enthalpy Change Across the Core for TRIH2-A and TROH

Below is a plot of ($H^{C}_{ROH} - H^{U}_{RIH}$) versus reactor power:

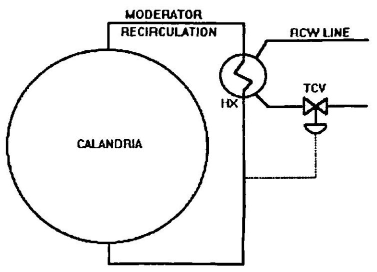
The function is extrapolated to zero power. In this analysis the Y-intercept of the best-fitting line is used to determine ($H^{C}_{ROH} - H^{U}_{RIH}$) at zero power for Equation (1).



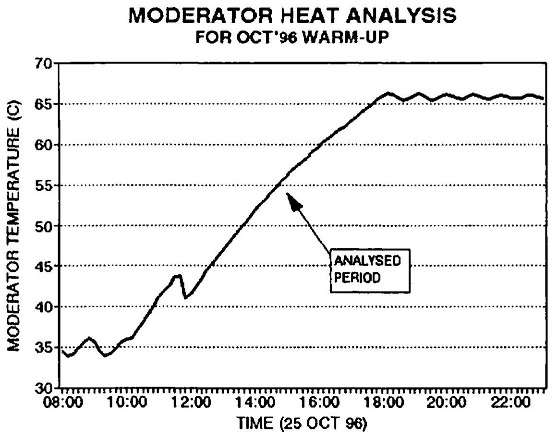
4.0 ADDITIONAL HEAT LOSSES OR GAINS

4.1 HEAT LOSS TO MODERATOR

To determine the thermal heat input into the moderator at zero power the temperature increase of the moderator during the October 96 warm-up was analyses. The total heat input to the moderator was computed over a four hour period before the moderator temperature setpoint was reached and the TCV controlling RCW flow was closed (see Figure). Therefore the moderator temperature response is due to the thermal heat transfer from the PHT.



Below is a plot of the moderator temperature response.



Computing Enthalpy Loss to Moderator

At 12:40 hrs, Mod Temp: 45.2°C = 175.3 kJ/kg

(at Calandria Pressure)

At 16:40 hrs, Mod Temp: 61.8°C = 245.3 kJ/kg

Difference (ΔH): 70 kJ/kg (over four hours)

Total thermal power to moderator = $\frac{\Delta H * M_{mod}}{\Delta time}$

= 70.0 kJ/kg * 300,000 kg / 14,400 s

= 1.5 MW

Header-to-Header Enthalpy Loss: = Power / Core Flow (8800 kg/s) = -0.2 kJ/kg

4.0 ADDITIONAL HEAT LOSSES OR GAINS (Cont'd)

4.2 HEAT LOSS TO SHIELDS

Estimated thermal power to shields: 3.3 MW (from HBAL run at low power)

Header-to-Header Enthalpy Loss: = Power / Core Flow (8800 kg/s) = -0.4 kJ/kg

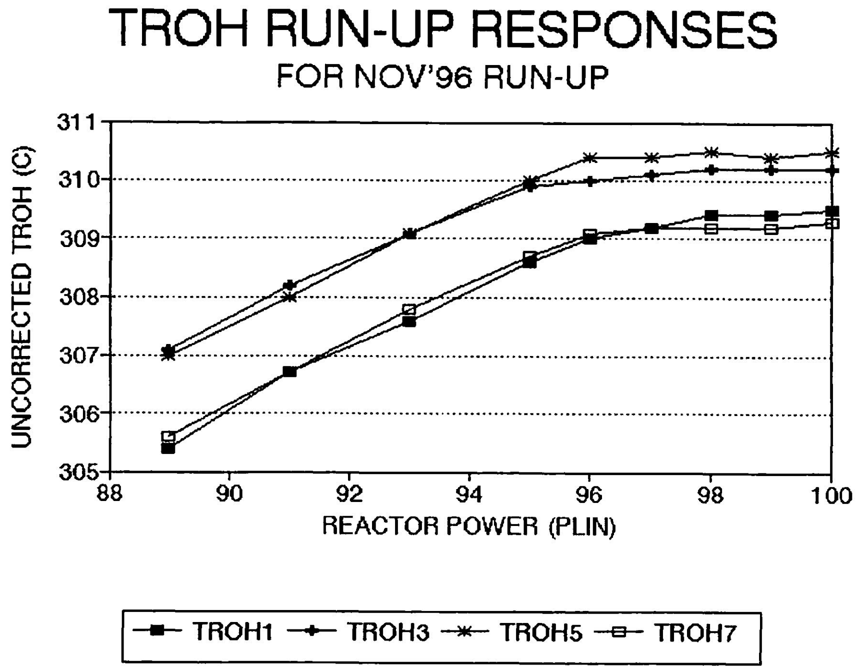
4.3 HEAT GAINED FROM PHT PUMPS

Estimated thermal power deposited between the headers: 7.0 MW

Header-to-Header Enthalpy Loss: = Power / Core Flow (8800 kg/s) = +0.8 kJ/kg

5.0 ANALYSIS of TROH BIASES

Below is a plot of the TROH responses to the power ramp in November 96:



It is apparent from the "flattening" of the TROH responses to increasing power that all four ROHs entered saturation before full power. Below is a table of the TROH bias computations:

ROH	(A) PROH AT FP[1] (MPa[g])	(B) COMPUTED SATURATION TEMPERATURE[2]	(C) ACTUAL TROH READING AT FP (°C)	(D) COMPUTED TROH BIAS [(B)-(C)]
1	9.852	309.70	309.45	+0.25
3	9.808	309.37	310.20	-0.83
5	9.860	309.75	310.45	-0.70
7	9.807	309.36	309.25	+0.11

[1] The average PROH pressure at 100% FP was used to determine T_{SAT}. A better method would be to determine the pressure at the TROH location using NUCIRC as detailed in Section 6.0 on Error Sources

[2] The saturation temperature was computed using the following relation:

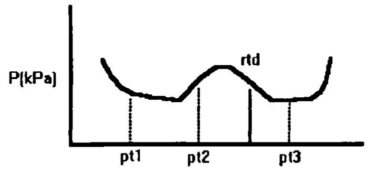
$$T_{SAT} = 7.359524 * PROH^{100\%\ FP} + 236.4537$$

6.0 DISCUSSION OF ERROR SOURCES

Below is a summary of the estimated error sources in the analysis:

1) **Assuming the TROH biases remain constant at varying reactor powers.** The RIH and ROH RTDs are inset in a thermowell and this should reduce the power dependence of the RTD bias. However, ambient air and neighbouring feeders may cause variation of the RTD bias with increasing power. The magnitude of this error is not known.

2) **Errors Determining ROH Saturation Temperature (T_{SAT}).** The average PROH pressure was used to determine T_{SAT}. A better method would be to determine the pressure at the TROH location using a code such as NUCIRC (see Figure). This refinement can be used in later revisions.



PRESSURE PROFILE ACROSS ROH

3) **Errors in Header-to-Header Heat Gains or Losses.** The heat gains or losses due to the PHT pumps and Moderator/Shields losses have only been estimated in this report. It is expected that the one-σ uncertainty in these estimates could be as high as $\pm$4 MW which results in a one-σ TRIH bias uncertainty of $\pm$0.10°C.

4) **Calculation of Reactor Power.** To avoid biasing the results, PRTD was not used to compute power during the run-up. Below is how power was calculated at each plateau:

At 2.5%	- Relative responses of channel outlet RTDs
At 50, 77%, 89%	- Boiler Power (DTABs 329-333)

It is estimated there is a one-σ power uncertainty of $\pm$1.0% at each plateau. This results in a one-σ TRIH bias uncertainty of $\pm$0.25°C.

7.0 REFERENCES

1. JIM CARTER, "Reactor Inlet Header RTD Calibration", EMR/97/18