SHUTDOWN COOLING TEMPERATURE PERTURBATION TEST FOR ANALYSIS OF POTENTIAL FLOW BLOCKAGES

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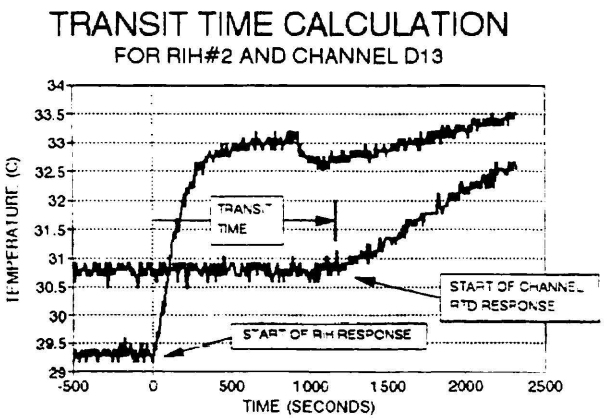
ABSTRACT

This paper details the method and results of the "shutdown cooling test" in October 1995. This novel test was conducted at PLGS while the reactor was shutdown and shutdown cooling (SDC) water was recirculating to find potential channel blockages resulting from the introduction of wood debris. This test discovered most of the channels that contained major wood and metal debris.

1.0 Test Method

The cooling water flow through the SDC heat exchangers was throttled for about five (5) minutes to create a "step" change in the SDC temperature of about 4°C. The path of the temperature interface was followed through the Reactor Inlet Headers (RIH) to the channel feeder outlets by monitoring the response of the RTDs. A "transit" time ($T_{transit}$) was defined for each channel as the time for the temperature interface to travel from the RIH exit (feeder inlet) to the feeder outlet RTD. Below is a plot of the RIH and feeder RTD responses for channel D13. The defined transit time is shown:



Since the volume (V_i) of the piping from the feeder inlet to the feeder outlet RTD is known [1], the volumetric SDC flow rate for channel i (w_i) can be computed from:

$$w_i = \frac{V_i}{T_{transit,i}}$$

These flows are about 1/200th of the normal operating PHT flows. Over five tests, the calculations were "fine-tuned" by incorporating the following effects:

- Fitting a known function to the RTD response plots to pinpoint the temperature increase time (the "knee"). See 4.1 for details.
- Accounting for the RTD response delays. See 4.1 for details.
- Accounting for RIH residence time which is a function of non-linear cross sectional flow. See 4.2 for details.
- Accounting for transit time delay due to heat losses to the PHT piping. See 4.3 for details.

Programs "SDCTEST" and "HMOVIE" were written to do the computations. To flag potentially plugged channels, the computed channels flows[1] (w_i) were compared to the following:

- symmetric channels: Symmetric channels have similar piping configurations and their flow resistances should be approximately equal. Therefore a large flow difference between symmetric channels could indicate a partially blocked channel.

- SDC flows before introduction of the wood debris: Fortunately, two weeks before the introduction of the wood debris, an unrelated test was conducted on the SDC system which created a temperature perturbation similar to this test. This allowed the channel SDC flows to be computed **before** the introduction of the wood debris and compared to those computed afterwards.

It is believed that the method was tuned to the point where it could find flow blockages as low as 20%.

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[1] All channel flows were normalized to the total SDC flow for that pass to correct for differences in pass SDC flow rates.

2.0 Test Results

The following table shows the channels that were flagged as having a potential flow blockage from the test [2] and the recovered debris from that channel.

Table: Channels with Computed Blockages and Debris Later Found

CHANNEL	COMPUTED FLOW BLOCKAGE (PERCENT)	DEBRIS LATER FOUND
A14	45	minor debris
E18	45	large hardwood piece with screws attached
E20	50	angle bracket
F19	50	bracket
G20	40	minor debris
L16	25	large hardwood pieces and screws
L20	40	minor debris
L22	40	angle bracket
M21	35	large hardwood fragment
W10	70	no debris - channel flow stagnated

Six of the nine channels flagged as having flow blockages were found to have large pieces of debris lodged in the feeders. W10 flow was found to have stagnated and was immediately re-established using the fuelling machine. There were 6 channels (A12,B15,C14,G14,S15,Q15), which contained large debris which were not flagged with this method. Possibly SDC flow was maintained within the test precision (20%) in these channels.

3.0 Conclusions

The SDC test is a useful method for finding potential gross flow blockages while the reactor is shutdown. The test is relatively simple to execute and does not require any unsafe operational manoeuvres. It demonstrated its usefulness by discovering most of the channels that contained major wood and metal debris at PLGS.

This test could be incorporated into the Flow Verification Procedures to be performed following any outage in which the PHT system is opened up. Currently no channel flow verification is done before raising reactor power.

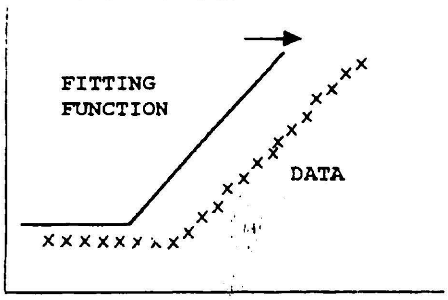
4.0 "FINE-TUNING"

4.1 Determination of RTD Response Times

The RTD signal is noisy and it is difficult to determine exactly when the temperature interface has reached the RTD. To improve the accuracy in finding this point, the following method was used:

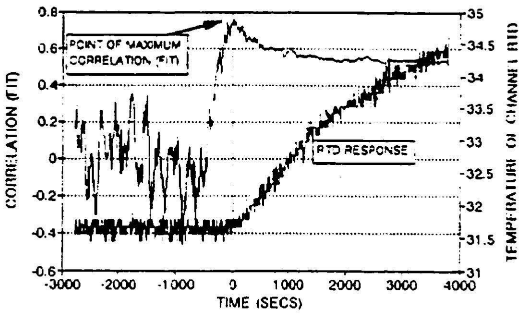
1) A "fitting function" was developed which approximates the shape of the RTD response. This fitting function is moved along the X-axis of the temperature plot until it has a maximum correlation with the RTD temperature plot. This is shown in the figures below.

PROCEDURE FOR FINDING TEMPERATURE INTERFACE



FINDING TEMPERATURE INTERFACE

BY FITTING CORRELATION



Initially, a 100-second linear fitting function was used as follows:

$f(t) = 0$ for t= -50....0 seconds

$f(t) = t$ for t= 0....+50 seconds

Later, to improve the accuracy, the fitting function was changed to model the dynamic response of each RTD as follows:

$f(t) = 0$ for t= -50....0 seconds

$f(t) = 1-\exp\{-t/c_i\}$ for t= 0....−50 seconds

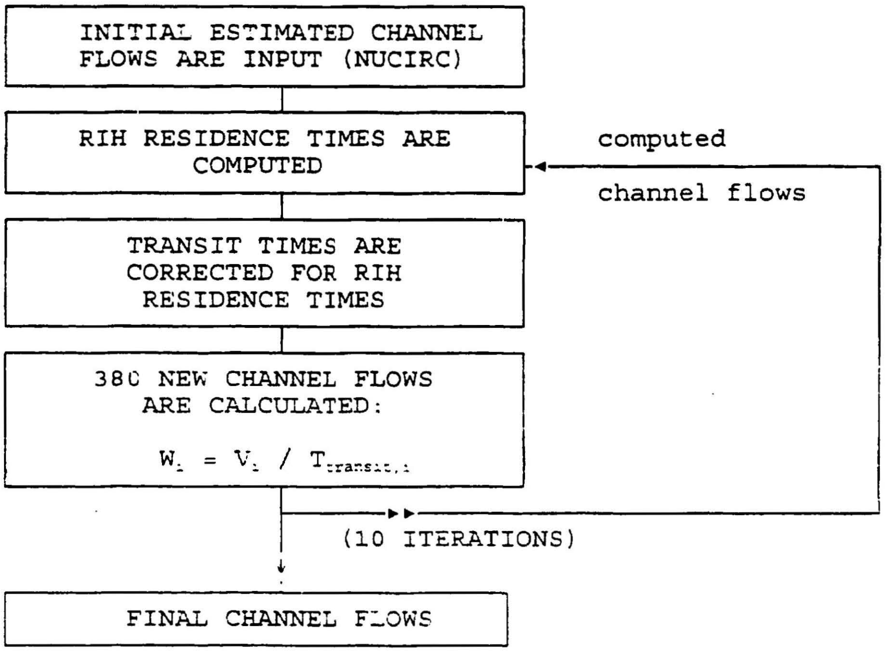
where c_i is the dynamic response component for RTD_i which is known from earlier analysis. [3] Its value is in the order of 2-5 minutes. This changed the computed flow rates by up to ±5%, although it has not been verified whether the modification has improved the results.

2) The "knee" in the fitting function was defined as the time when the RTD first responds to the SDC temperature change.

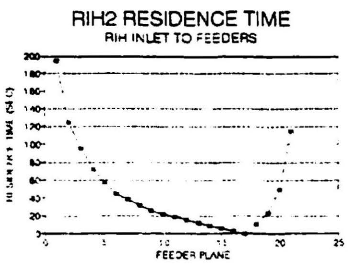
4.2 Computing RIH Residence Times

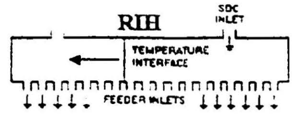
To correctly compute the transit time from the feeder inlet to the feeder outlet we must know the time for the temperature interface to travel across the RIH. This time, defined as RIH Residence Time, is a function of the cross sectional area of the header, and the temperature interface velocity. The temperature interface velocity is not constant, but is a function of the total flow of the feeders downstream of the interface. For example, the interface velocity slows as it reaches the end of the header.

The RIH residence time for each channel was found by an iterative process shown below:



Ten iterations was found to provide adequate convergence of flows. The following plot shows the TRIH residence times at each feeder plane for RIH2. The residence time is defined as zero at Plane 17 since this is approximately where the SDC inlet is located.





4.3 Analysis of Heat Transfer Delays

To improve the method for finding the transit time, it was necessary to correct for the impact of heating of the PHT piping (header-to-header) when a slug of 4°C warmer coolant traverses from the RIH to the feeder outlet.

Results

Analysis [4] showed the effect of heat transfer is to slow down the temperature interface. It was concluded that multiplying the transit times by a constant of 0.9 would correct for this delay. This result did not affect the relative channel flow differences but did affect the absolute flows.

5.0 References

1. W. Hartmann, 95 Channel Flow/Volume/Transit Time NUCIRC Predictions, E-mail to J. Handbury, 24 Oct 95.
2. J. Handbury, Core Monitoring Report #12, 16 Nov 95
3. J. McCullogh, Dynamic Response Assessment of Channel Exit RTDs, PIR 94-016, 26 Aug 94.
4. R. Dam, Evaluation of SDC Transient Times Using SOPHT for NB Power, Memo to E. Young/J. Handbury, 17 Nov 95.