National Institute of Standards and Technology
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MANAGING SYSTEMATIC ERRORS IN THE NBSR THERMAL POWER CALORIMETRIC MEASUREMENTS

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Disclaimer

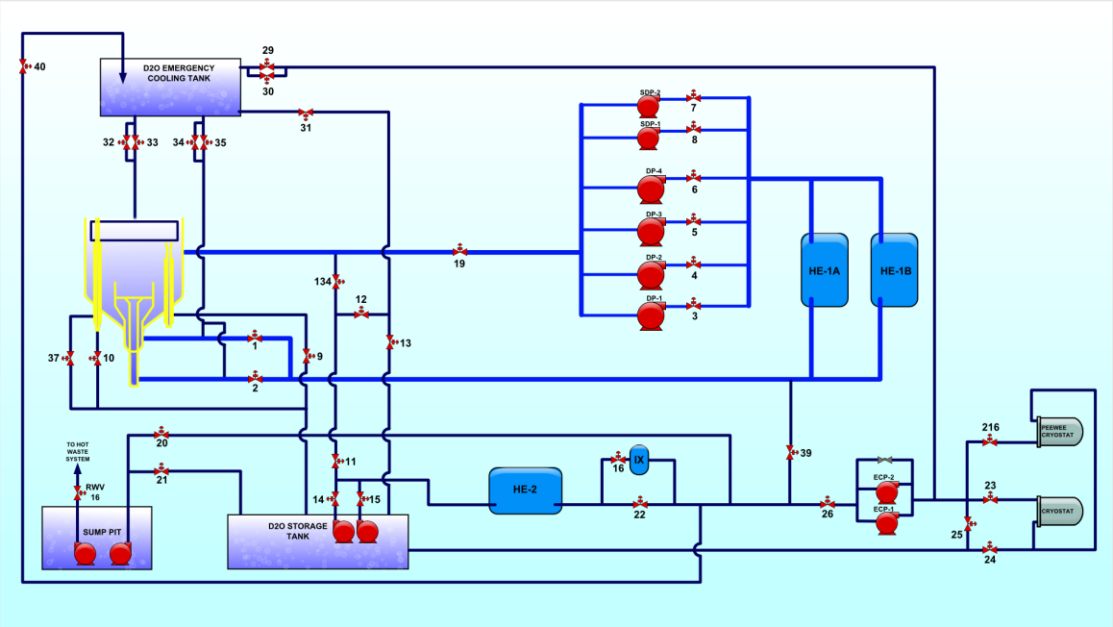
Certain commercial equipment, instruments, or materials are identified in this study in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

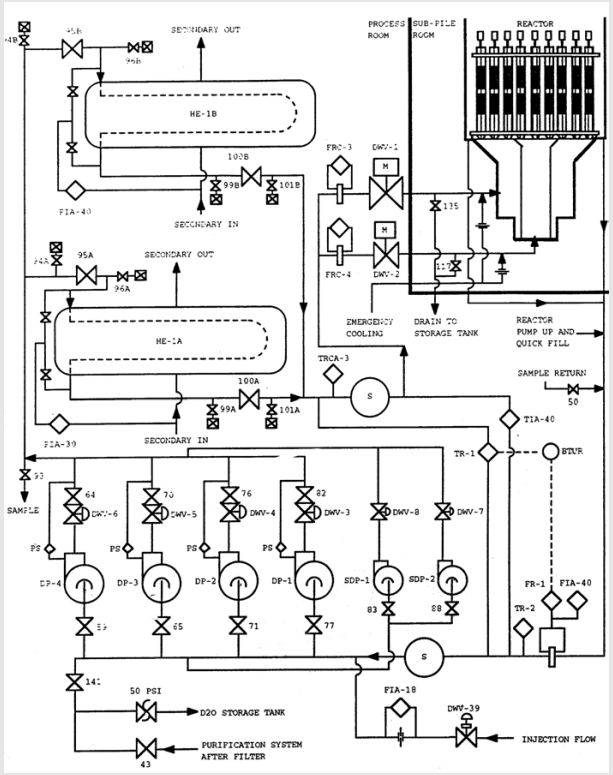
NIST NCNR

Resolve Systematic Errors in the NBSR Instrumentation

- Sustainable
- State-of-art
- Redundant
- Defense-in-depth
- Reliable
- Accurate
- Safe
- Compatible with NRC Guidelines

GOALS

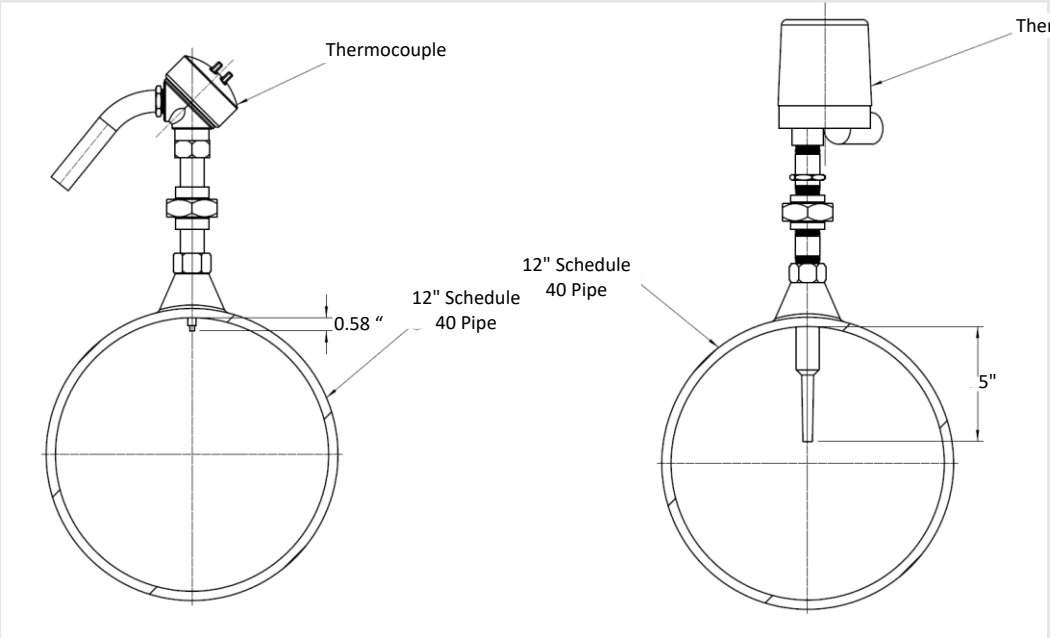




Primary System

- installation of a set of new heat exchangers in 1994
- improper immersion depth
- low quality thermocouples without proper junction bonding
- the secondary calorimetric was showing a reactor thermal power of about 29 MW
- New Thermowell assemblies with proper immersion
- Secondary loop calorimetric currently measures 20 MW ± 3 MW

Inconsistency Between Primary and Secondary Calorimetric



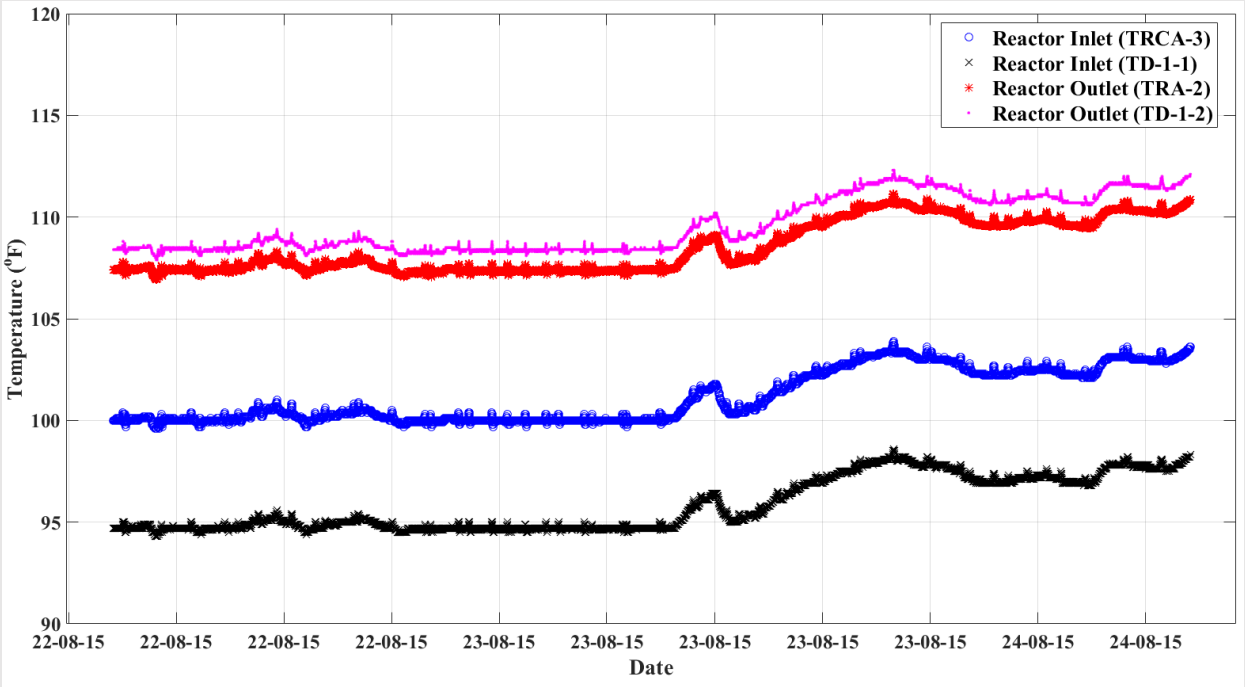
EXISTING THERMOCOUPLE ASSEMBLY

NEW THERMOCOUPLE ASSEMBLY

Inconsistency Between Primary and Secondary Calorimetric

- digital recorder unit called the BTUR
  - two RTD s to measure the temperature differential
  - Venturi flow meter for primary flow
- inconsistent temperature readings were found
- thermodynamic analyses inconclusive
- thermal bath revealed which RTD sensors had drifted
- the BTUR was reading higher than the actual
- the immersion length for some was less than ideal

Systematic Errors in the Primary Loop Instrumentation



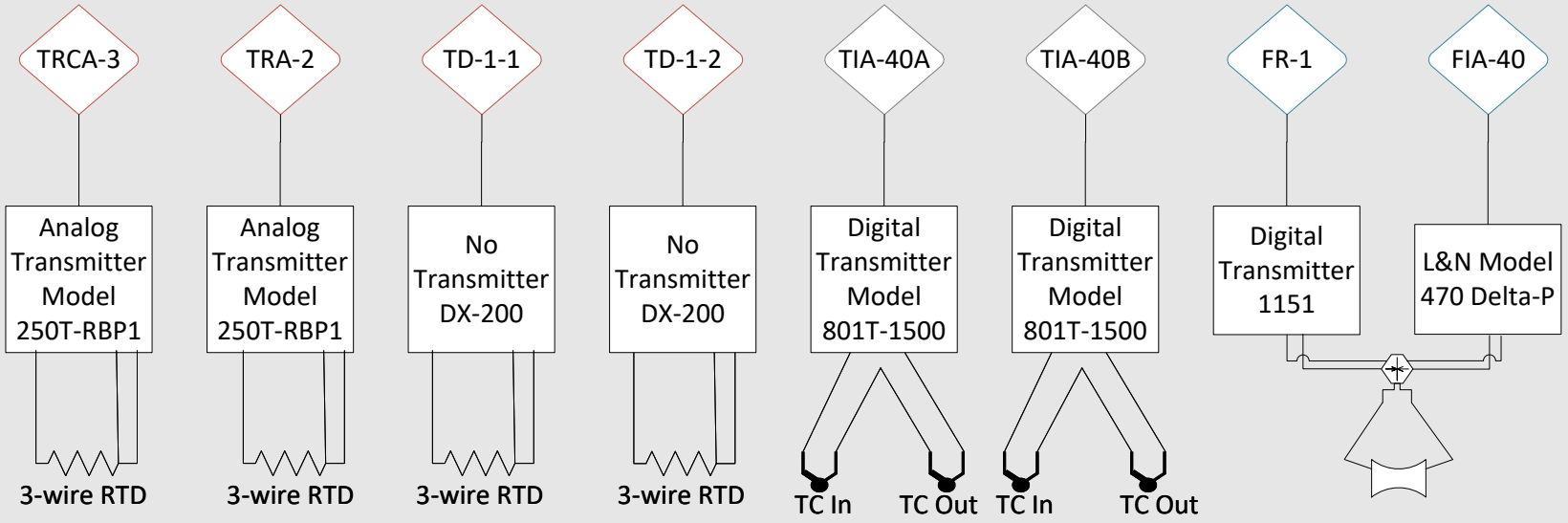
Primary Loop Inlet and Outlet Temperature Readings During August 2015

- existing calibration procedures
  - did not require a traceable physical source
- long-term drift went largely unnoticed
  - BTUR individual temperature data not being displayed for direct comparison to other data points

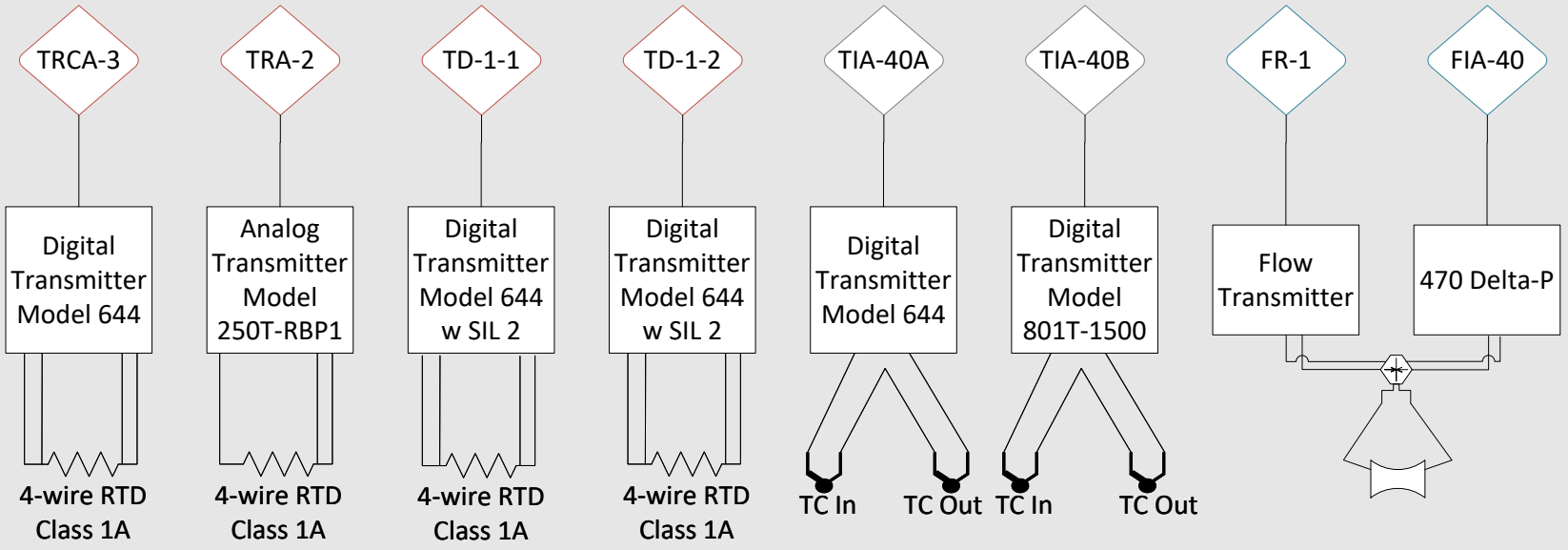
ROOT CAUSE ANALYSIS

- Drifted RTDs were replaced
- the calibration procedures were updated
- adequate data display modifications were implemented
- Thermowells were replaced for optimum immersion lengths
- spring loaded mechanisms to ensure proper contact
- stepped thermowells improving response times
- reactor operator log sheets updated to allow direct comparison of important parameters

IMPLEMENTATION OF CHANGES



IMPLEMENTATION OF CHANGES - PREVIOUS



IMPLEMENTATION OF CHANGES - CURRENT

- consisting of digital and analog transmitters for temperature and flow
- changes were documented in several Engineering Change Notices (ECN), five of which required 50.59 evaluations.
- satisfies
  - Defense-in-depth
  - Redundancy
  - Reliability
  - Diversity
  - Accuracy

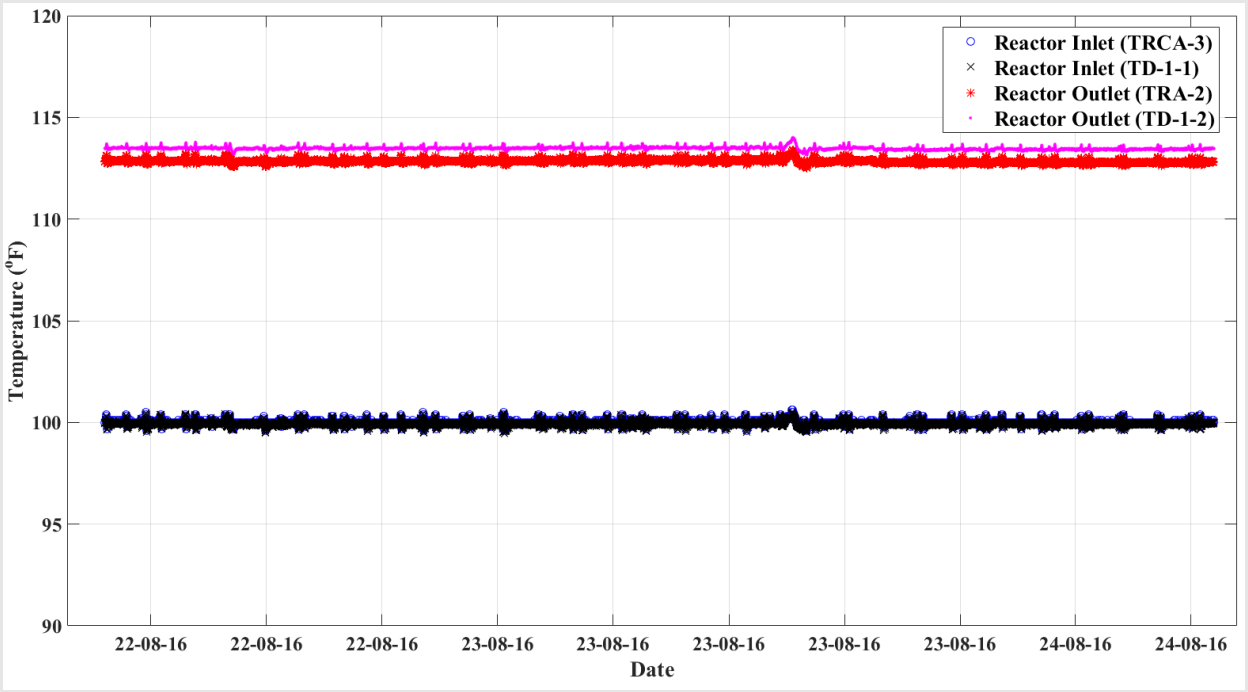
IMPLEMENTATION OF CHANGES

- **Defense in Depth**: Reactor primary coolant temperatures are measured by RTD and thermocouples.
- **Redundancy**: Primary loop temperature and flow are being monitored by multiple sensors.
  - The reactor primary coolant inlet temperature: TRCA-3 and BTUR inlet
  - The reactor primary coolant outlet temperature: TRA-2 and BTUR outlet
  - The reactor primary coolant Delta-T temperature: TIA-40A, TIA-40B, and BTUR
  - The reactor primary coolant flow: two transmitters FR-1, FIA-40 measure pressure difference for a venturi instrument

IMPLEMENTATION OF CHANGES

- **Reliable**: Average probability of failure on demand (PFD_{AVG}) for the new digital transmitters, considering undetected failures of hardware, is $1.3x10^{-4}$ probability of failure per hour (PFH). Compared to PFD_{AVG} of $2.6x10^{-3}$ PFH for the previous transmitter .
- **Diversity**: The primary instrumentation system uses different brand digital (Rosemount 644, and Acromag 250R-JL00) and analog (Acromag 250T-RBP1) transmitters for temperature sensors. Primary coolant flow is measured by two different transmitters a nuclear grade (Weed instruments) and an another analog (L&N Model 470).
- **Accuracy**: Rosemount 644 transmitters are used for BTUR inlet, BTUR outlet, TRCA-3 employ Callendar-van Dusen RTD sensor matching. The expected total measurement uncertainty of these sensor-transmitter systems is about 0.2 F.

IMPLEMENTATION OF CHANGES


Reactor Inlet (TRCA-3)
Reactor Inlet (TD-1-1)
Reactor Outlet (TRA-2)
Reactor Outlet (TD-1-2)
Temperature (°F)
120
115
110
105
100
95
90
22-08-16
22-08-16
22-08-16
23-08-16
23-08-16
23-08-16
23-08-16
23-08-16
24-08-16
24-08-16
Date

RESULTS

- implemented sustainable, state-of-the-art upgrades
- resolved systematic errors in the NBSR reactor thermal process instrumentation
- instrumentation provides redundant, diverse, reliable and highly accurate measurements of primary and secondary process conditions
- resolved the calorimetric inconsistency between primary and secondary loops

DISCUSSION

- improving accuracy in inlet flow measurement sensors
- Installation of a triple redundant RTD
- Replace the temperature sensors in the primary heat exchanger outlets
- Correct for small thermal power transients from the strainer system
- Install a VFD based flow controller

FUTURE WORK

- Any questions, comments?????

Thank you for your time