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AMS Fact Sheet: RTD Cross Calibration Method

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1.0 RTD CROSS CALIBRATION PROCEDURE

Cross calibration is a test of the consistency of a group of temperature sensors that are measuring the same process. The test is performed in nuclear power plants to ensure that accurate temperature information is provided to the plant control and safety systems. The test is performed at one or more temperatures that shall include a temperature that is near the plant's normal operating conditions to provide an assessment of the accuracy of the sensors under service conditions. The testing can be performed during plant shutdown or heat up, and AMS does not need any temperature plateaus or hold points to acquire quality data; our equipment can acquire data "on-the-fly" thereby helping to reduce the test time and also the critical path time.

To perform a cross calibration test, the sensors are connected to the AMS cross calibration test equipment (Figure 1) and the outputs of a group of redundant sensors are measured at isothermal or temperature ramp conditions and converted to corresponding temperatures. The temperatures are then averaged and the deviation of each individual sensor from the average temperature is calculated. Any sensor that exceeds pre-specified deviation criteria is removed from the average and the process is repeated as necessary to identify all the sensors which fail to meet the deviation criteria. The sensors which fail to meet the deviation criteria are referred to as outliers and are either replaced with newly calibrated sensors, or their calibrations are corrected to bring them in line with the other redundant sensors in the group. The calibration correction may be done using the cross calibration data at several widely spaced temperatures to develop new calibration tables for the outliers.

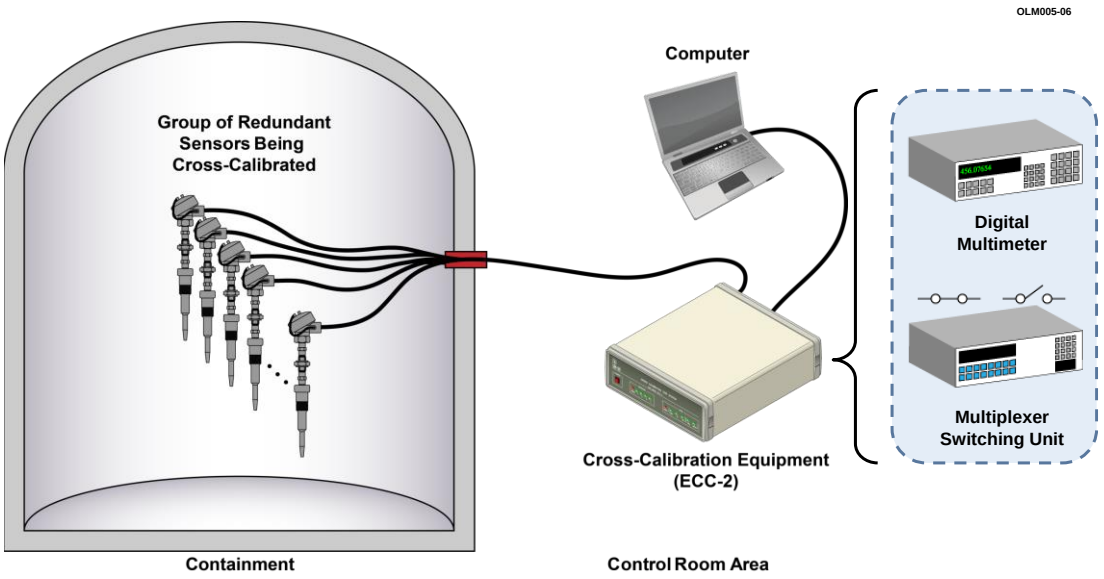

Figure 1. Illustration of AMS Cross Calibration Test Equipment

1.1 Cross Calibration Test Procedure

Cross calibration tests are performed using a sensor scanning system involving a computer, a multiplexer, and a precision digital multimeter. The sensor elements to be tested are connected to the multiplexer, and data are collected according to the following general procedure. This procedure can be modified, as necessary, to accommodate unique plant needs or requirements.

1. Sequence through all sensors, measure their outputs, and convert to equivalent temperatures. This step results in obtaining one cross calibration pass.
2. Repeat Step 1 to obtain four passes.
3. Average the four temperature measurements for each sensor.
4. Average the temperature indications of the narrow range RTDs. This average is the best estimate of the plant's primary coolant temperature under the conditions tested.
5. Subtract the average temperature identified in Step 4 from the temperature indications of each sensor. The results are referred to as the deviation of each sensor and are denoted by ΔT. The ΔT is an indication of the accuracy of the sensor's calibration assuming that the average temperature of the narrow range RTDs correctly represents the reactor coolant temperature.
6. If the deviation of any narrow range RTD element exceeds a pre-specified criteria (e.g. ± 0.5º F), remove the element's temperature indication from the cross calibration data and repeat from Step 4 to obtain a new average temperature.
7. Repeat Step 6 until all narrow range RTD elements which have ΔTs greater than the pre-specified criteria have been eliminated from the average.

Note that only the narrow range RTDs are typically used in estimating the true value of the process temperature for the cross calibration tests. This is because the narrow range RTDs should be more accurate than the other temperature sensors that may be included in the cross calibration test.

The result of this procedure is referred to as a cross calibration run. Table 1 shows a typical cross calibration run for several RTDs and thermocouples tested in a pressurized water reactor. The ΔT's identified in a cross calibration run are used as the preliminary results of the cross calibration tests. In order to obtain optimum accuracy in the results of the cross calibration tests, the raw temperature data should be corrected to account for plant temperature stability and uniformity during the time when the cross calibration tests were performed. AMS has developed a proprietary procedure to implement these corrections and estimate the accuracy of the cross calibration results as described in the following sections.

Table 1. Typical Cross Calibration Run
Temperature Plateau: 282.0°C

Item	Temperature (°C) *1				Average Temp. (°C)	Deviation ΔT (°C) *2
	Pass 1	Pass 2	Pass 3	Pass 4		
Narrow Range RTDs						
1	280.3278	280.3274	280.3087	280.2956	280.315	**-0.063**
2	280.4091	280.3942	280.3853	280.3797	280.392	**0.014**
3	280.3616	280.3621	280.3426	280.3305	280.349	**-0.029**
4	280.3660	280.3655	280.3440	280.3347	280.353	**-0.026**
5	280.4729	280.4599	280.4608	280.4571	280.463	**0.084**
6	280.3664	280.3329	280.3427	280.3274	280.342	**-0.036**
7	280.3392	280.3276	280.3230	280.3178	280.327	**-0.051**
8	280.4709	280.4574	280.4504	280.4453	280.456	**0.078**
9	280.3308	280.3312	280.3047	280.3029	280.317	**-0.061**
10	280.4369	280.4355	280.4081	280.4118	280.423	**0.045**
11	280.3765	280.3584	280.3477	280.3440	280.357	**-0.022**
12	280.4593	280.4584	280.4375	280.4296	280.446	**0.068**
Wide Range RTDs						
13	280.0733	280.0612	280.0538	280.0352	280.056	**-0.322**
14	280.6964	280.6871	280.6741	280.6602	280.679	**0.301**
15	280.3290	280.3281	280.3067	280.3039	280.317	**-0.061**
16	280.4881	280.4899	280.4704	280.4686	280.479	**0.101**
Core Exit Thermocouples						
17	280.6723	280.6674	280.6261	280.6431	280.652	**0.274**
18	280.6301	280.6082	280.5928	280.6025	280.608	**0.230**
19	280.7786	280.7802	280.7640	280.7526	280.769	**0.390**
20	280.5482	280.5660	280.5474	280.5474	280.552	**0.174**
21	280.8232	280.8110	280.7940	280.7907	280.805	**0.426**
22	280.8978	280.8588	280.8483	280.8248	280.857	**0.479**
23	280.7680	280.7607	280.7445	280.7380	280.753	**0.374**
24	281.1411	281.1394	281.1394	281.1086	281.132	**0.754**
25	280.8037	280.7940	280.7510	280.7656	280.779	**0.400**

Average Temperature Indicated by the Narrow Range RTDs = 280.378 °C

Notes:
1. The temperatures noted above are expressed in °C or °F at the client's request.
2. The deviation column in this table is equal to the average temperature of each sensor minus the average temperature of the narrow range RTDs.

2.0 CROSS CALIBRATION DATA CORRECTION

The preliminary results of the cross calibration tests are obtained in terms of RTD deviations as the cross calibration test is performed. To obtain more accurate results, the data will be analyzed using the detailed analysis described in this section. The detailed analysis involves numerical algorithms developed by AMS to correct the cross calibration data for any significant temperature instability and non-uniformity that may exist in the plant when the cross calibration tests are performed. These corrections are consistent with NUREG-0800 which provides the position of the U.S. Nuclear Regulatory Commission (NRC) on the RTD cross calibration technique.

2.1 Correction of Cross Calibration Data

In-plant cross calibration of RTDs is based on the assumption that, at isothermal plant conditions, the average temperature of a sufficient number of redundant RTDs reflects the true temperature of the process. There are several possibilities which can affect the validity of this assumption:

1. Errors in the resistance versus temperature tables used in cross calibration tests to convert the resistance of the RTDs to temperature.
2. Systematic drift in the calibration of RTDs. This can occur if all the RTDs drift together in the same direction upward or downward.
3. Fluctuations and drift in the primary coolant temperature that could be occurring while cross calibration data were taken at the plant.
4. Temperature non-uniformity between the various RTDs. Since the cross calibration method assumes that all RTDs are at the same temperature, any significant departure from this assumption can cause errors in the results of cross calibration tests.

In cross calibration testing of a group of RTDs that have been used in a plant for one or more fuel cycles, the first and second possibilities mentioned above may be accounted for by removing one or more of the RTDs from the plant and calibrating it in a laboratory. Another alternative would be to replace one of the RTDs with a newly-calibrated RTD and repeat the cross calibration tests at the end of the outage while the plant is heating up toward power operation.

Another way to rule out the second possibility is to depend on the experimental data published in the NUREG/CR-5560 report. The data in NUREG/CR-5560 indicates that the drift of a group of nuclear-grade RTDs is predominately random rather than systematic and bias errors are therefore unlikely to occur in the results of the cross calibration tests except for any bias in the cross calibration test equipment.

The third and fourth possibilities listed above may be resolved by implementing numerical techniques to correct the cross calibration data for plant temperature instability and temperature non-uniformity as described below.

2.2 Correction for Plant Temperature Instability

Temperature fluctuations or drift during cross calibration tests almost always occur. It is not realistic to expect that the plant temperature can be controlled perfectly to remain at steady state.

The method used for temperature instability corrections depends on the plant conditions under which the data were acquired. If the plant temperature is changing at a slow and constant rate, ramp data acquisition is used. Ramp data acquisition automatically compensates for the changes in plant temperature while the data is being acquired. If the plant is being maintained at stable, isothermal conditions, plateau data acquisition is used and the plant temperature fluctuations are compensated for during the detailed analysis.

To minimize the effect of plant temperature fluctuations on the cross calibration results, the standard deviation of the fluctuations in the cross calibration data is calculated for each run after implementing the instability corrections mentioned above. If this standard deviation is larger than a default acceptance criterion, then the run is rejected.

2.3 Correction for Plant Temperature Non-Uniformity

This correction is made to account for any gross differences that may have existed during the in-plant cross calibration tests between the hot leg and cold leg temperatures in each loop or across the reactor. These differences can occur due to incomplete mixing of the reactor coolant or differences in the heat removal of the steam generators. If there are no significant temperature differences, then non-uniformity corrections are not necessary. If there is a non-uniformity problem, then the data are corrected for temperature differences between the hot leg RTDs and the cold leg RTDs or for the temperature differences between the reactor coolant loops, as appropriate.

3.0 PRESENTATION OF FINAL CORRECTED RESULTS

AMS' advanced analysis software automatically performs fluctuation and drift corrections as well as uniformity corrections and calculates the rms values of the RTD deviations after each of these corrections. The correction method that results in the smallest rms value of RTD deviations is then selected as the final result of the cross-calibration test. The AMS analysis software automatically prints the final results of the cross calibration tests in tables such as Table 2.

4.0 PLANT COMPUTER RTD CROSS CALIBRATION

Traditionally, cross calibration data has been acquired using data acquisition equipment connected to test points in the instrumentation cabinets. The traditional cross calibration method, while highly accurate, requires the plant to lose indication when the data is being acquired, and costs the plant time during shutdown and/or startup to remove the temperature channels from service and then restore them after the tests are complete. Recent advances in plant computer technology have made it possible to perform cross calibration tests using data from the plant computer. Using data from the plant computer for cross calibration saves the plant startup and shutdown time, while producing results that are comparable to the traditional method. Depending on the configuration of the RTDs in the plant and whether their indication provides input to the plant computer, this particular method may also be evaluated for use at nuclear power plants for additional time and cost savings.

Table 2. Typical Cross Calibration Results

Results at Each Temperature (°F)				
Item	RTD Tag Number	340 °F	450 °F	540 °F
1	2NCRD5420	0.030	0.001	-0.055
2	2NCRD5421	-0.066	-0.081	-0.106
3	2NCRD5422	0.244	0.231	0.140
4	2NCRD5430	-0.107	-0.075	0.006
5	2NCRD5440	-0.101	-0.076	0.015
6	2NCRD5460	0.004	0.026	0.074
7	2NCRD5461	0.309	0.258	0.236
8	2NCRD5462	-0.090	-0.123	-0.014
9	2NCRD5470	-0.159	-0.121	-0.182
10	2NCRD5480	-0.064	-0.040	-0.115
11	2NCRD5500	-0.016	-0.029	0.020
12	2NCRD5501	-0.037	-0.073	-0.015
13	2NCRD5502	-0.047	-0.043	-0.016
14	2NCRD5510	0.365	0.283	0.098
15	2NCRD5520	-0.266	-0.137	-0.088
16	2NCRD5540	0.283	0.056	-0.166
17	2NCRD5541	0.579	0.382	0.179
18	2NCRD5542	0.032	-0.062	-0.132
19	2NCRD5550	-0.208	-0.165	0.089
20	2NCRD5560	-0.107	-0.211	0.030
21	2NCRD5850	-0.174	-0.317	-0.636
22	2NCRD5860	-0.224	-0.129	-0.146
23	2NCRD5870	-0.467	0.486	-0.383
24	2NCRD5880	-0.047	0.403	0.240
25	2NCRD5900	-0.062	0.151	0.328
26	2NCRD5910	-0.206	0.232	0.427
27	2NCRD5920	-0.049	-0.040	-0.072
28	2NCRD5930	0.004	-0.124	0.176