GEND-INF--024

DE83 004265

GEND-INF-024

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REVIEW OF TMI-2 RESISTANCE TEMPERATURE DETECTORS ACCIDENT DATA AND IN-SITU TESTING

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November 1982

Published on Behalf of the GEND Group
by
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

950 1781

Prepared for the
U.S. Department of Energy
Three Mile Island Operations Office
Under DOE Contract No. DE-AC07-76ID01570

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ABSTRACT

Since temperature measurements are a key to understanding the TMI-2 accident and subsequent plant conditions, survivability and performance of the 16 resistance temperature detectors (RTDs) in the reactor-building air-handling system have been investigated. This report describes that investigation, presents and analyzes the data recorded by the 16 RTDs during and after the accident, discusses in-situ tests conducted on the RTDs, and presents observations on the test results.

ACKNOWLEDGMENTS

The author gratefully acknowledges the constructive comments, significant assistance, and technical support provided by EG&G Idaho, Inc., personnel. Invaluable contributions and critiques were also received from individuals at General Public Utilities, the University of Tennessee, Technology for Energy Corporation, Oak Ridge National Laboratory, and United Engineers and Constructors. Faculty and students in the Electrical Engineering Department at the University of Idaho assisted in the difficult task of transcribing the accident data.

CONTENTS

ABSTRACT ii

ACKNOWLEDGMENTS iii

INTRODUCTION 1

Planning Effort 1

System Components 5

CURRENTLY AVAILABLE ACCIDENT DATA 7

IN SITU TESTING OF RESISTANCE TEMPERATURE DETECTORS 16

OBSERVATIONS ON IN SITU TESTING 19

APPENDIX A--BIBLIOGRAPHY OF TERMINAL STRIP CONTAMINATION AND CORROSION LITERATURE 23

FIGURES

1. Air handling system resistance temperature detector 2

2. Detector-to-recorder interconnections 6

3. Temperature profile for sump pump room resistance temperature Detector AH-TE-5010 8

4. Temperature profile for letdown cooler resistance temperature Detector AH-TE-5011 8

5. Temperature profile for RC drain tank resistance temperature Detector AH-TE-5012 9

6. Temperature profile for impinge barrier resistance temperature Detector AH-TE-5013 9

7. Temperature profile for resistance temperature Detector AH-TE-5014 near equipment hatch 10

8. Temperature profile for A/C plenum outlet resistance temperature Detector AH-TE-5015 10

9. Temperature profile for primary shield resistance temperature Detector AH-TE-5016 11

10. Temperature profile for primary shield resistance temperature Detector AH-TE-5017 11

11. Temperature profile for primary shield resistance temperature Detector AH-TE-5018 12

12. Temperature profile for primary shield resistance temperature Detector AH-TE-5019 12

13. Temperature profile for top ceiling resistance temperature Detector AH-TE-5020 13

14. Temperature profile for top ceiling resistance temperature Detector AH-TE-5021 13

15. Temperature profile for southeast stairwell resistance temperature Detector AH-TE-5022 14

16. Temperature profile for west stairwell resistance temperature Detector AH-TE-5023 14

17. Temperature profile for A/C plenum outlet resistance temperature Detector AH-TE-5027 15

18. Temperature profile for southeast stairwell resistance temperature Detector AH-TE-5088 15

TABLES

1. TMI-2 reactor building resistance temperature detector locations 3

2. Detector drawing and cable listing 4

3. Strip chart recorder calibration measurement data 16

REVIEW OF TMI-2 RESISTANCE TEMPERATURE DETECTORS ACCIDENT DATA AND IN SITU TESTING

INTRODUCTION

During and following the TMI-2 accident, a number of instruments failed or were suspected of providing erroneous readings. Because of this, industry focused on the behavior of instrumentation under adverse conditions. To better understand failure mechanisms, the Technical Information and Examination Program (TI&EP), Instrumentation and Electrical Equipment Program, proposed that surveillance be implemented to monitor the status of selected TMI-2 instruments during the Unit-2 cleanup and recovery process. This monitoring would provide insight into instrumentation performance under adverse conditions.

This report deals with a small portion of the total Instrumentation and Electrical Program at TMI-2: the data recorded by the 16 reactor building air handling system resistance temperature detectors (RTD) during and after the accident, in situ tests conducted on these RTDs, and analysis and observations on the test data.

RTDs contain platinum resistance elements sensitive to temperature change; as their temperatures increase, their resistances increase in exact and repeatable proportions. Since temperature measurements are one key to understanding the accident and subsequent plant conditions, a study of the performance of the plant RTDs was made.

Planning Effort

The RTDs examined are located throughout the reactor building air handling system, and range in elevation from the 282- to 353-ft elevation. Figure 1 shows a typical RTD assembly. Table 1 lists the RTDs by instrument tag number and indicates the plant location and elevation of each.

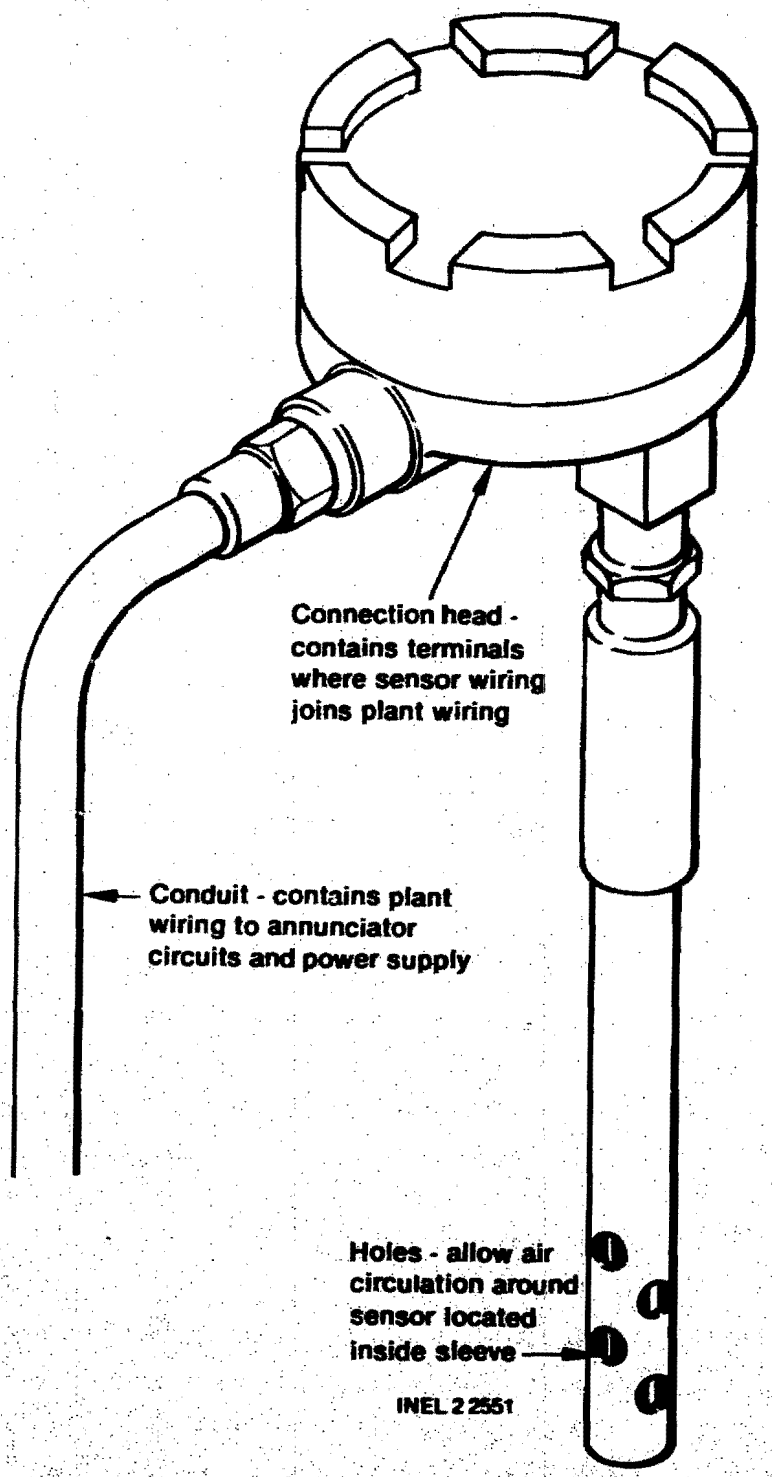


Figure 1. Air handling system resistance temperature detector.

TABLE 1. TMI-2 REACTOR BUILDING RESISTANCE TEMPERATURE DETECTOR LOCATIONS

RTD	Location	Elevation
AH-TE-5010 (ambient air)	Sump pump	282
AH-TE-5011 (ambient air)	Letdown cooler	282
AH-TE-5012 (ambient air)	RC drain tank	282
AH-TE-5013 (ambient air)	Impinge barrier	282
AH-TE-5014 (ambient air)	Near equipment hatch	310
AH-TE-5015 (outlet temperature)	A/C plenum outlet	319
AH-TE-5016 (ambient air)	Primary shield concrete	282
AH-TE-5017 (ambient air)	Primary shield concrete	282
AH-TE-5018 (ambient air)	Primary shield concrete	282
AH-TE-5019 (ambient air)	Primary shield concrete	282
AH-TE-5020 (ambient air)	Top ceiling	353
AH-TE-5021 (ambient air)	Top ceiling	353
AH-TE-5022 (ambient air)	Southeast stairwell	330
AH-TE-5023 (ambient air)	West stairwell	330
AH-TE-5027 (outlet temperature)	A/C plenum outlet	305
AH-TE-5088 (ambient air)	Southeast stairwell	310

The first step in the investigation was to verify physical placement and wiring for each of the RTDs. The RTD system check began with studying available engineering drawings and developing loop or interconnect diagrams tracing each RTD to the strip chart recorder in the control room. All terminals, wire colors, cable numbers, and cabinets were checked, verified, and confirmed. Each RTD readout was identified by its own plotter point number on the control room strip chart recorder; the numbers appear in Table 2. Table 2 also lists each RTD, its Reactor Building cable number, extension cable number, and the numbers of the block diagram and penetration diagram

TABLE 2. DETECTOR DRAWING AND CABLE LISTING

Detector	Plotter Point	Block Diagram	Penetration Diagram	Cable	Extension Cable
AH-TE-5010	8	3024-57	3045-37R	TD-250-1	TD-1009-1
AH-TE-5011	9	3024-57	3045-37S	TD-251-1	TD-1010-1
AH-TE-5012	10	3024-57	3045-37S	TD-252-1	TD-1011-1
AH-TE-5013	7	3024-57	3045-37T	TD-249-1	TD-1012-1
AH-TE-5014	15	3024-57	3045-37T	TD-257-1	TD-1013-1
AH-TE-5015	5	3024-57	3045-37T	TD-247-1	TD-1014-1
AH-TE-5016	3	3024-57	3045-37T	TD-245-1	TD-1015-1
AH-TE-5017	1	3024-57	3045-37T	TD-243-1	TD-1016-1
AH-TE-5018	2	3024-57	3045-37T	TD-244-1	TD-1017-1
AH-TE-5019	4	3024-57	3045-37T	TD-246-1	TD-1018-1
AH-TE-5020	11	3024-57	3045-37U	TD-253-1	TD-1019-1
AH-TE-5021	12	3024-57	3045-37U	TD-254-1	TD-1020-1
AH-TE-5022	14	3024-57A	3045-37U	TD-255-1	TD-1021-1
AH-TE-5023	13	3024-57A	3045-37U	TD-256-1	TD-1022-1
AH-TE-5027	6	3024-53A	3045-37U	TD-248-1	TD-1023-1
AH-TE-5088	16	3024-57A	3045-37U	TD-258-1	TD-1024-1

on which it is drawn. (All 16 RTDs are sketched on Flow Diagram 2041, and Connection Diagram 3355-12. All 16 RTDs use Reactor Building Penetration 604.)

System Components

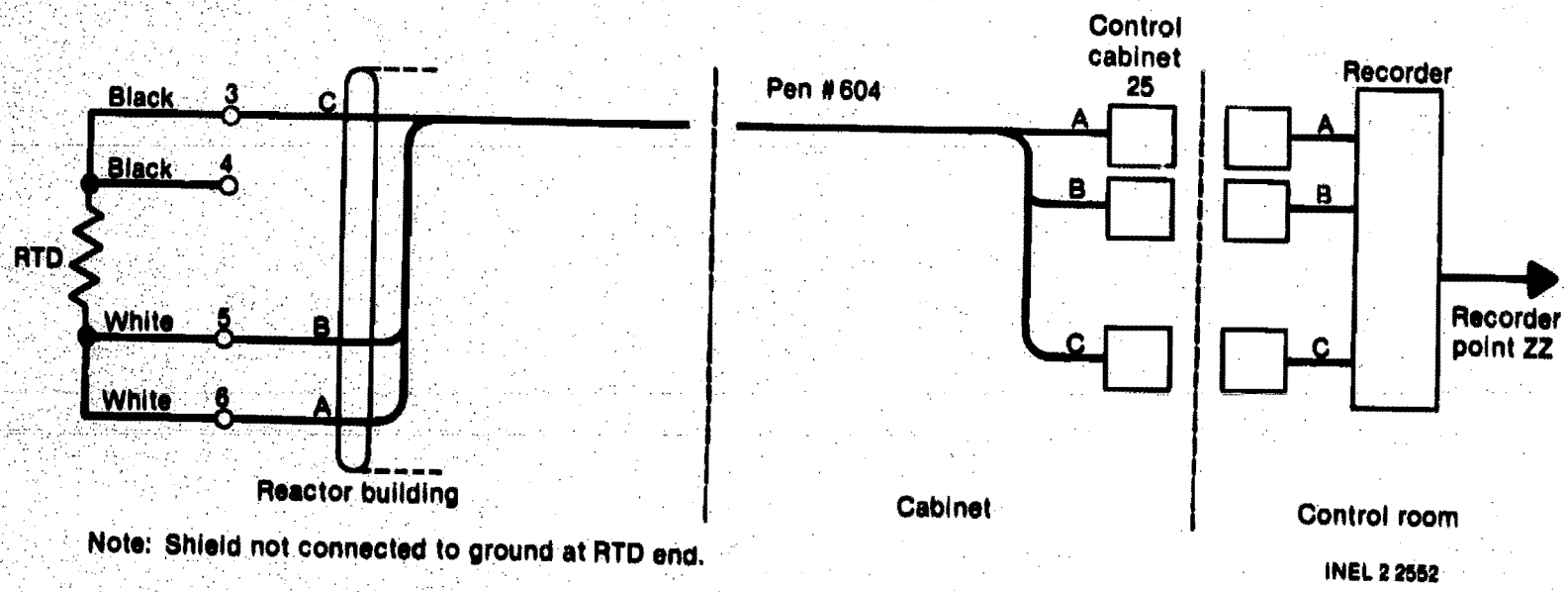
The air handling system RTDs are all Rosemount Series 78 sensors, having a single element with four lead wires. The RTDs conform to the International Platinum Temperature Scale No. IPTS-68, with an alpha coefficient of 0.00385 ohms/ohm/°C. The normal range of these RTDs is -100 to 660°C and they are nominally 100 ohms at 0°C.

RTD data are recorded on a strip chart placed in Control Cabinet 25 in the Unit-2 Control Room. The RTD-to-recorder interconnects are shown in Figure 2.

The recorder is a Bristol 550 Dynamaster multi-point unit, which is a servo-operated null balance potentiometer and bridge instrument. The recorder, calibrated in degrees Fahrenheit, sequentially records 24 variables on a 12-in. strip chart and is ranged for 0 to 200°F.

The RTDs are connected to the recorder with three wire cables, as shown in Figure 2. An RTD is input to a commutator switch that rotates, connecting each of the RTD's three wires to the signal conditioner. Therefore, although each RTD has an individual calibration, the recorder must be calibrated to the standard IPTS-68 curve, since there is only one zero and one span adjustment.

The recorder prints one temperature point each 15 s. With 24 points being printed for a complete cycle, it takes 6 min to cycle and repeat an individual temperature point.



Note: Shield not connected to ground at RTD end.

Figure 2. Detector-to-recorder interconnections.

CURRENTLY AVAILABLE ACCIDENT DATA

The data from the plant strip chart recorders recorded during and after the accident have been transcribed onto floppy discs. The Electrical Engineering Department of the University of Idaho transcribed the data in the following way. The data from a 16mm film cartridge were projected and focused and photo enlargements made. The enlargements were then recorded onto a graphics tablet, where the tablet stylus was used to identify the location of reference coordinates and the data of interest. Two individuals each entered all data, a computer compared the two entries, and any difference in data between the two entries for a given time period was reviewed and corrections made as necessary.

The data transcription effort was completed the last week in June 1982. An initial review detected errors in the time base of the data, which were corrected. Plots of the corrected data are included here as Figures 3 through 18. Since these data were recently plotted, the full analysis effort has not yet begun. However, the plotted data indicate that certain locations, such as RTD 5012 (Figure 5) in the reactor coolant drain tank room, experienced many temperature changes. Other locations showed no temperature change, such as primary shield RTDs 5016-19 (Figures 9 through 12), which are located in the D-rings. The data also indicate that during the hydrogen burn, top ceiling RTD 5020 (Figure 13), behaved unexpectedly and recorded a negative-going trace, probably because of spray activity; most other locations, including the other top ceiling RTD, recorded a positive-going trace.

These data are now under review for information related to various facets of the accident, some of which are as follows:

- Hydrogen burn ignition location
- Long-term calibration drift
- Output shift related to corrosion and contamination
- Reactor building air circulation.

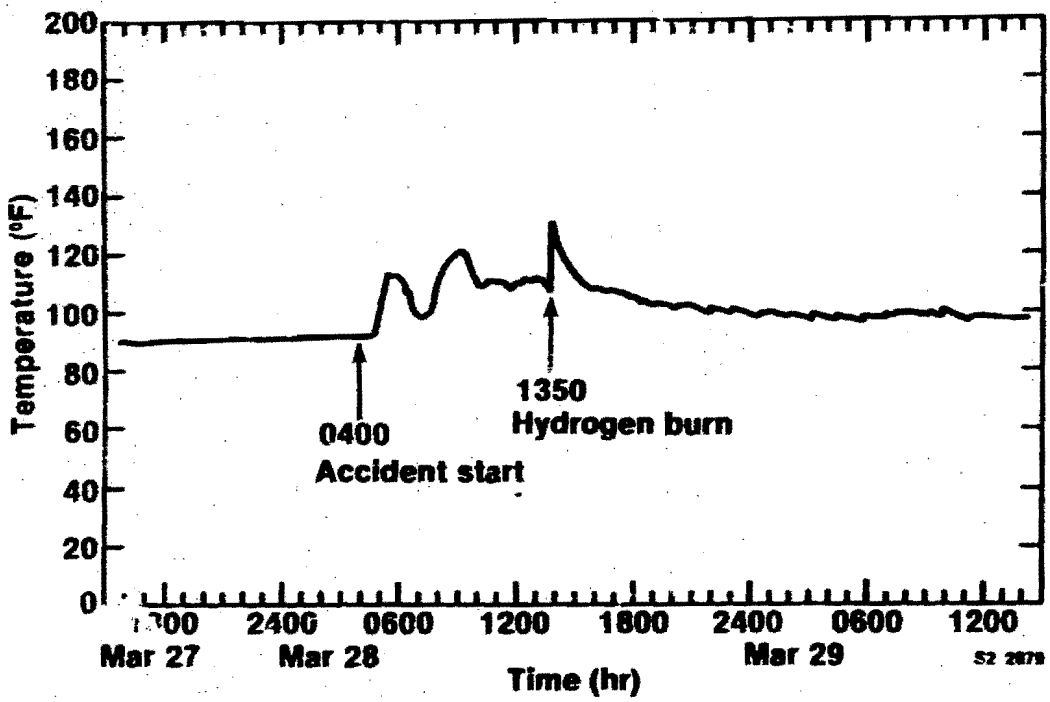


Figure 3. Temperature profile for sump pump room resistance temperature Detector AH-TE-5010.

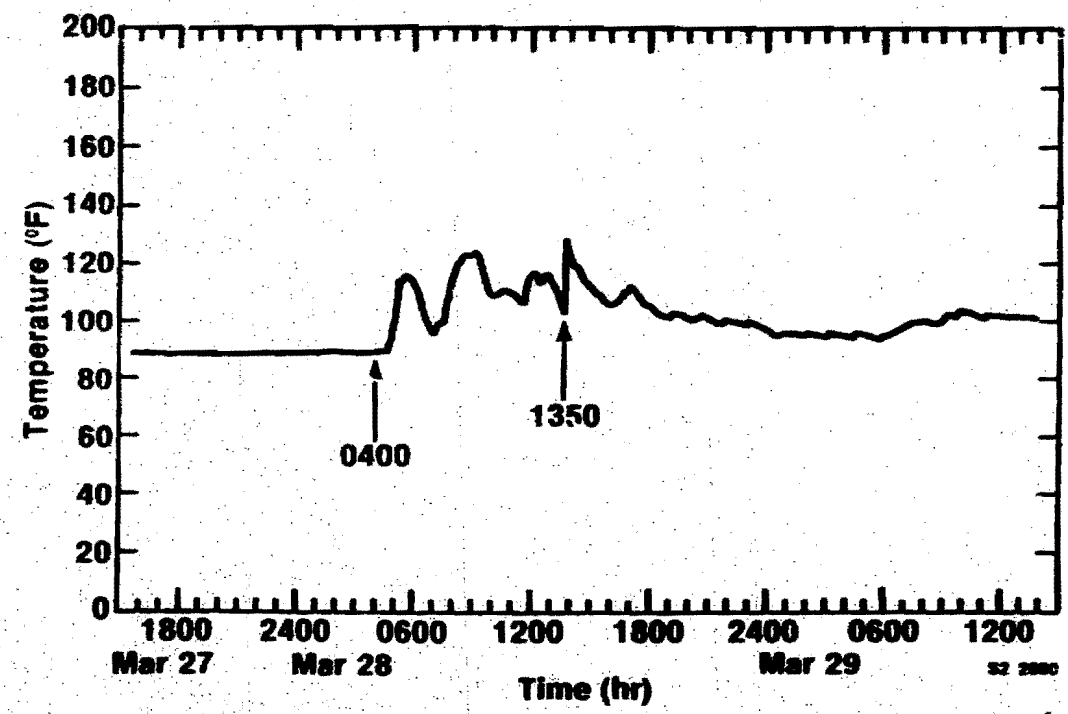


Figure 4. Temperature profile for letdown cooler resistance temperature Detector AH-TE-5011.

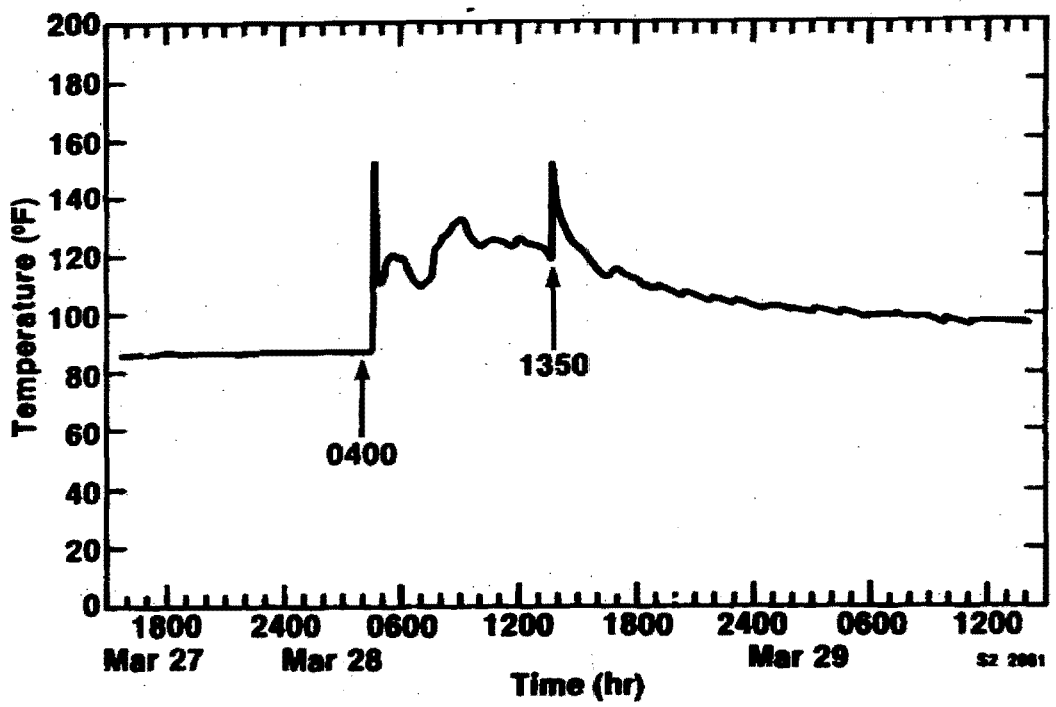


Figure 5. Temperature profile for RC drain tank resistance temperature Detector AH-TE-5012.

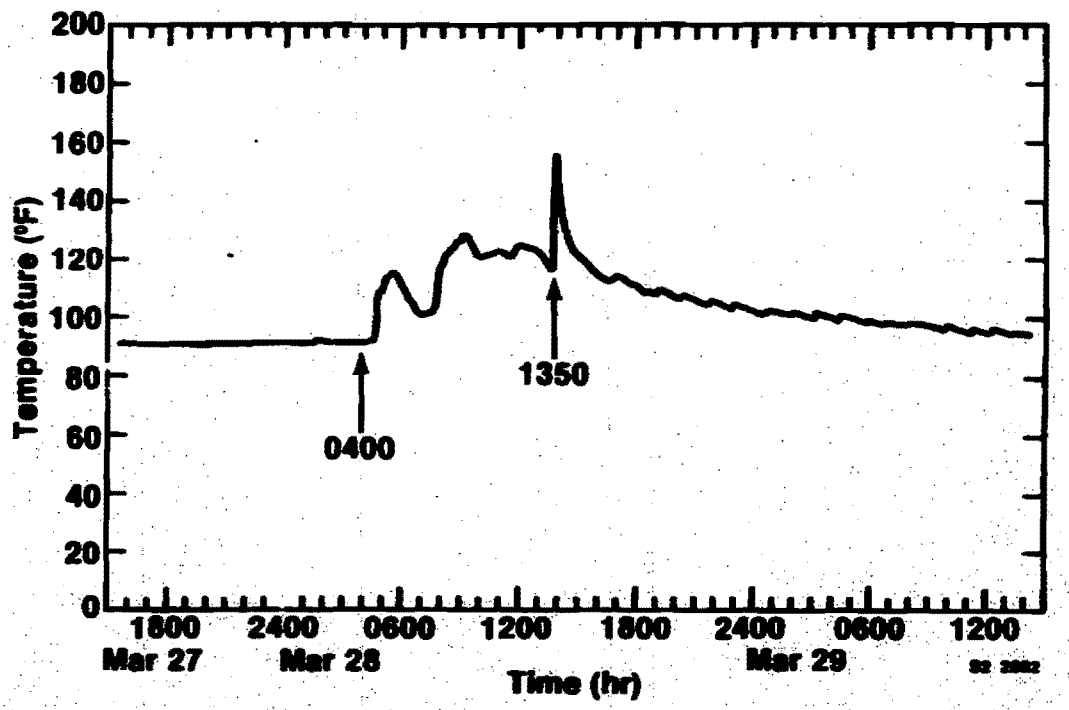


Figure 6. Temperature profile for impinge barrier resistance temperature Detector AH-TE-5013.

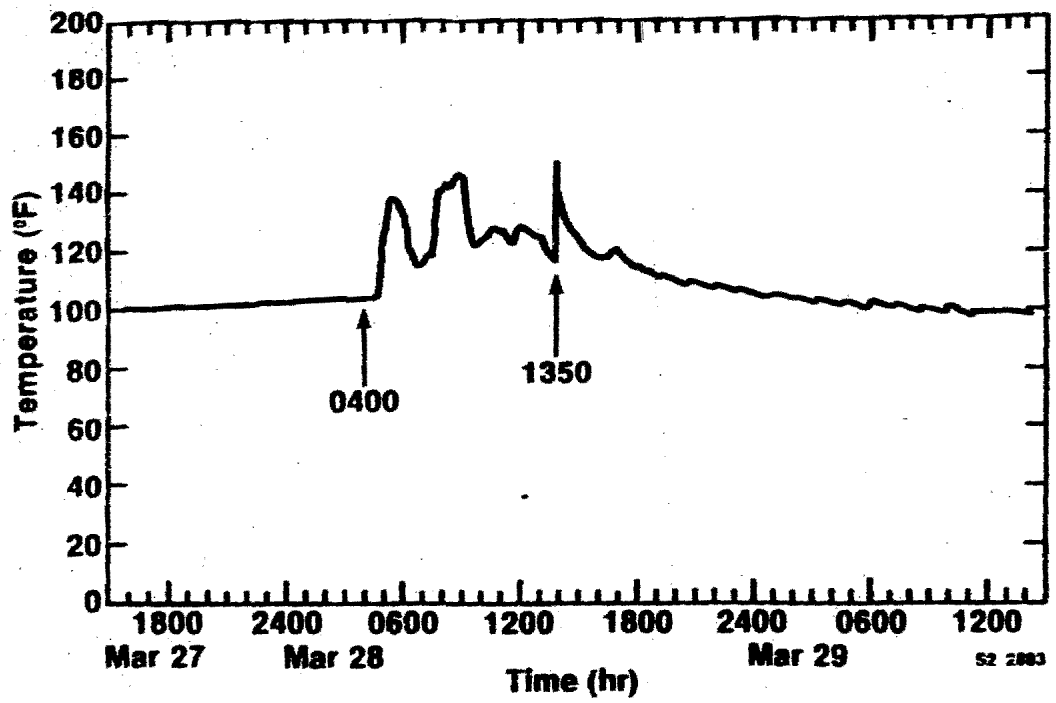


Figure 7. Temperature profile for resistance temperature Detector AH-TE-5014 near equipment hatch.

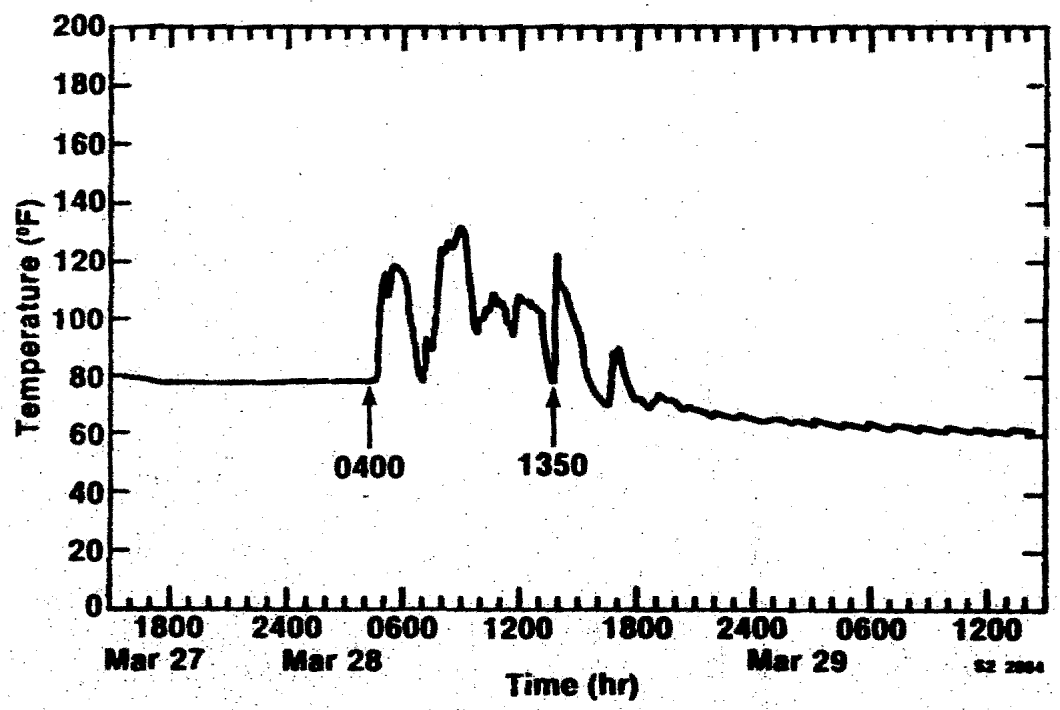


Figure 8. Temperature profile for A/C plenum outlet resistance temperature Detector AH-TE-5015.

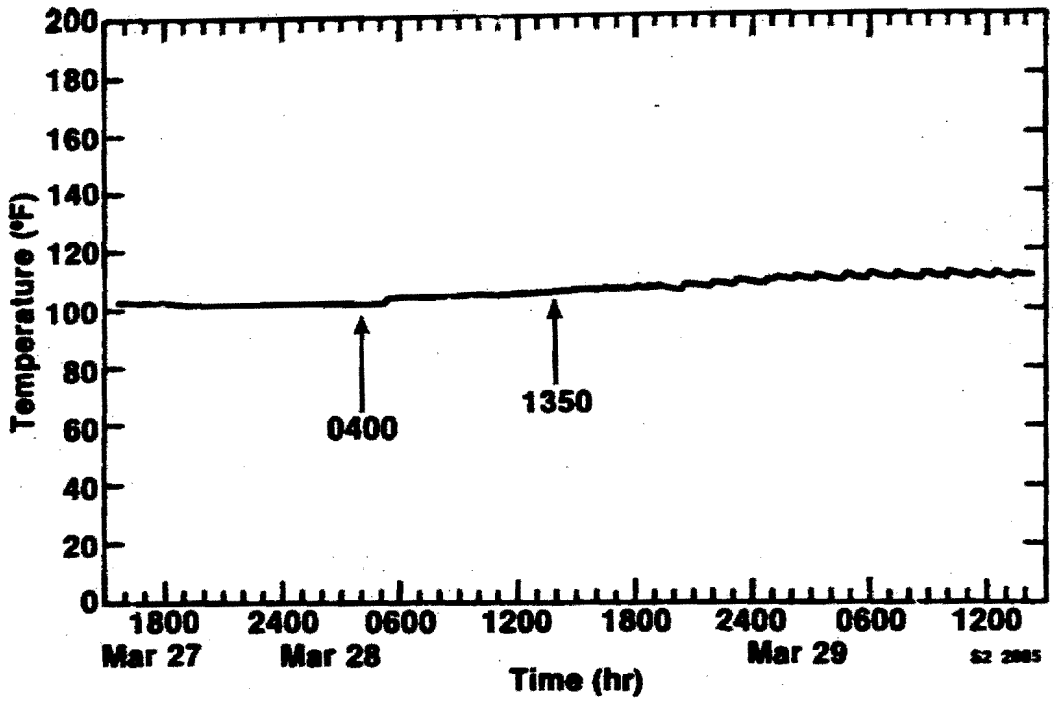


Figure 9. Temperature profile for primary shield resistance temperature Detector AH-TE-5016.

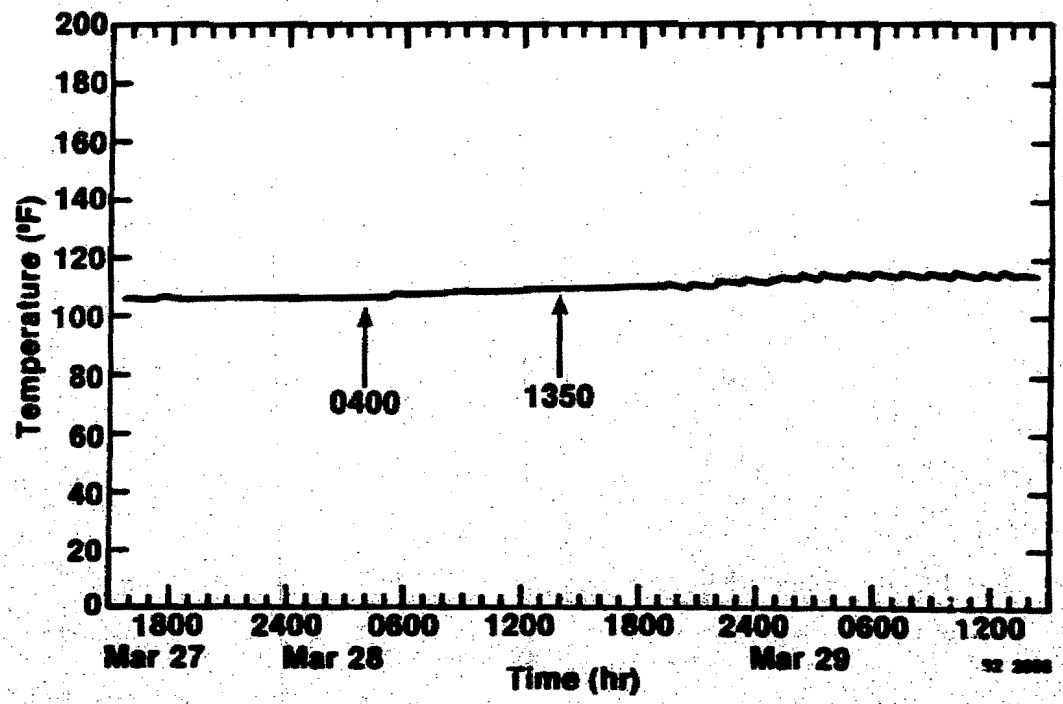


Figure 10. Temperature profile for primary shield resistance temperature Detector AH-TE-5017.

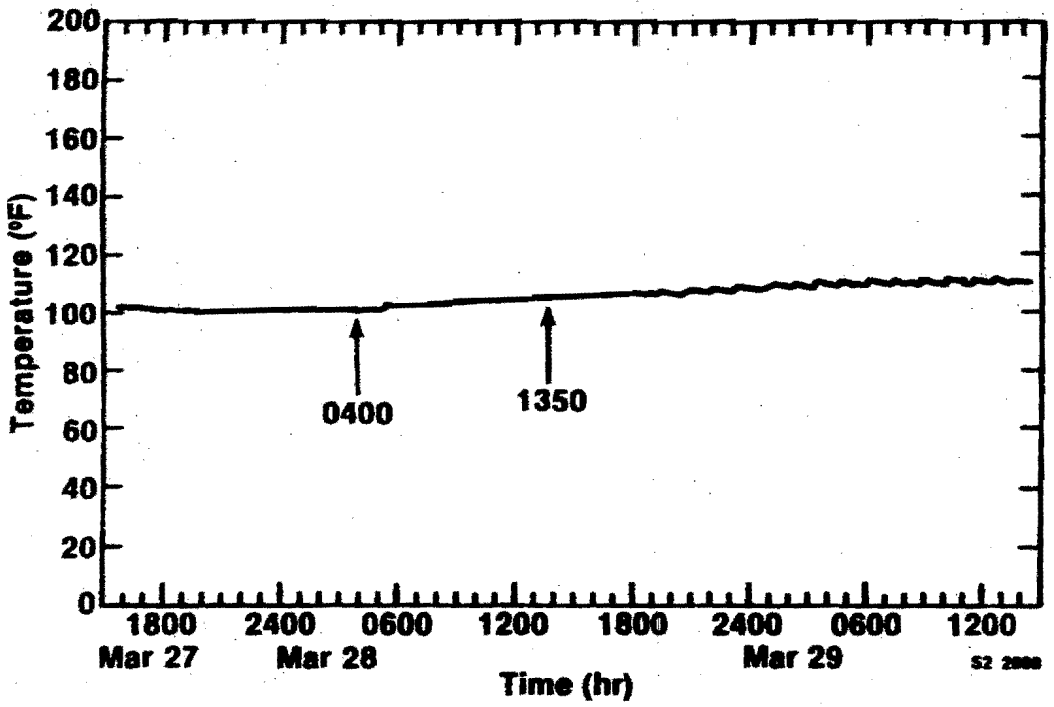


Figure 11. Temperature profile for primary shield resistance temperature Detector AH-TE-5018.

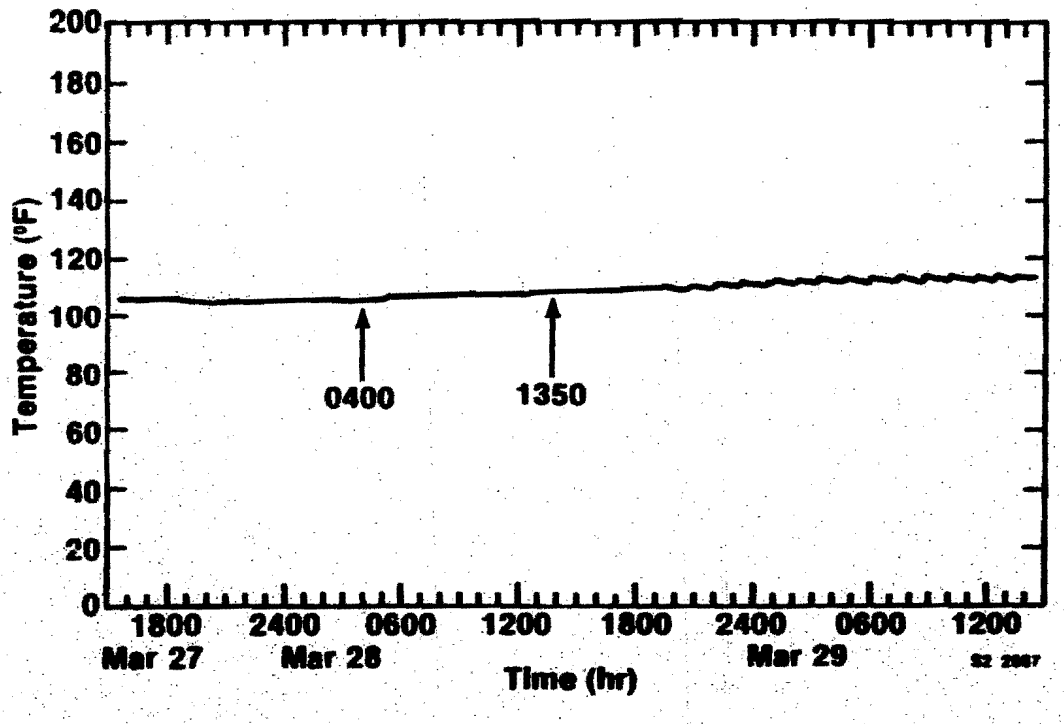


Figure 12. Temperature profile for primary shield resistance temperature Detector AH-TE-5019.

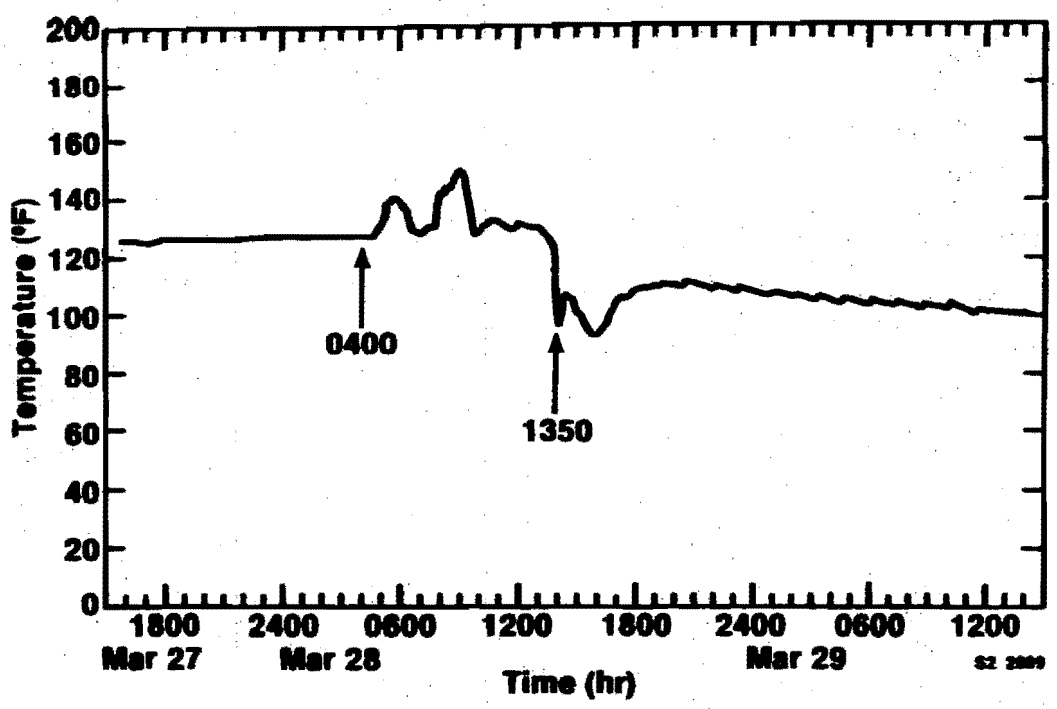


Figure 13. Temperature profile for top ceiling resistance temperature Detector AH-TE-5020.

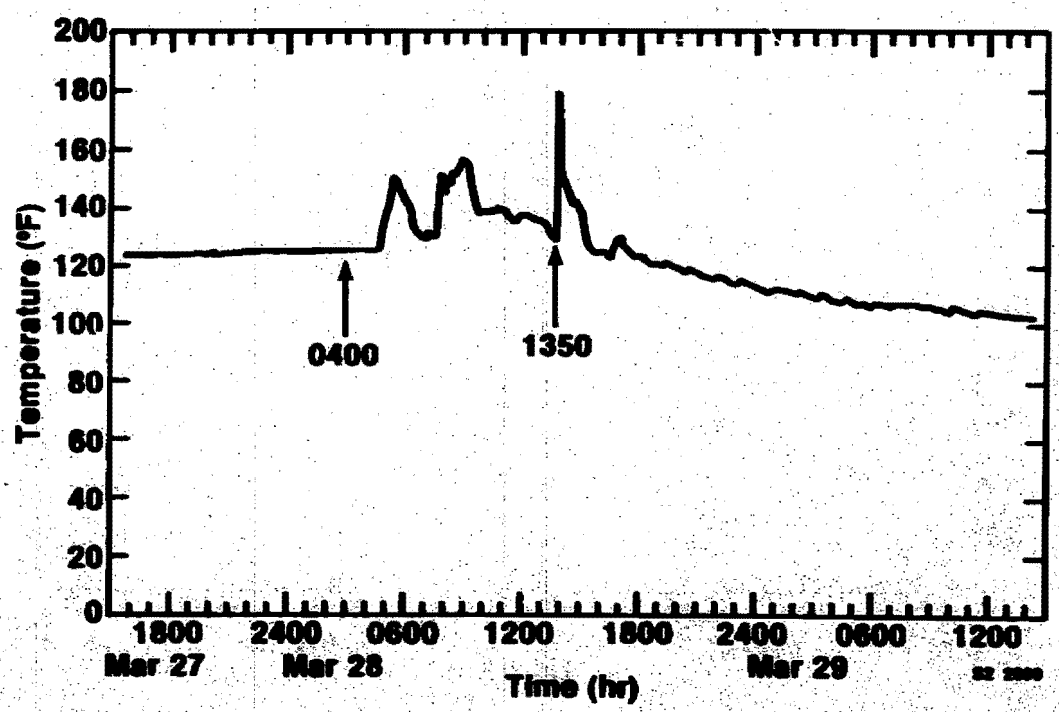


Figure 14. Temperature profile for top ceiling resistance temperature Detector AH-TE-5021.

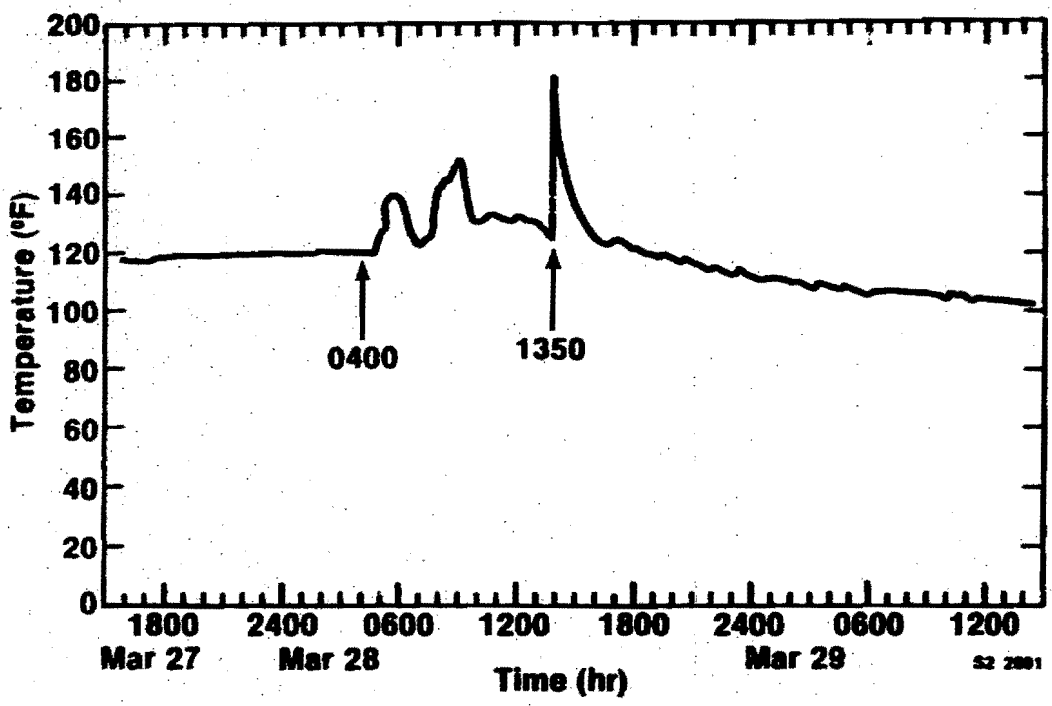


Figure 15. Temperature profile for southeast stairwell resistance temperature Detector AH-TE-5022.

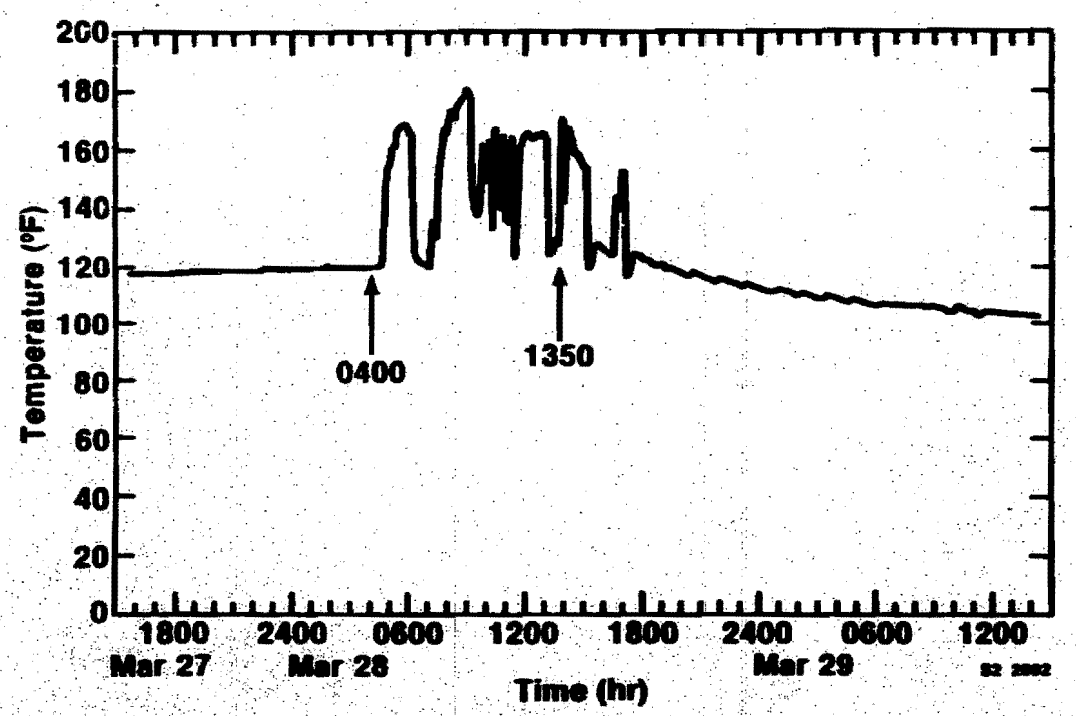


Figure 16. Temperature profile for west stairwell resistance temperature Detector AH-TE-5023.

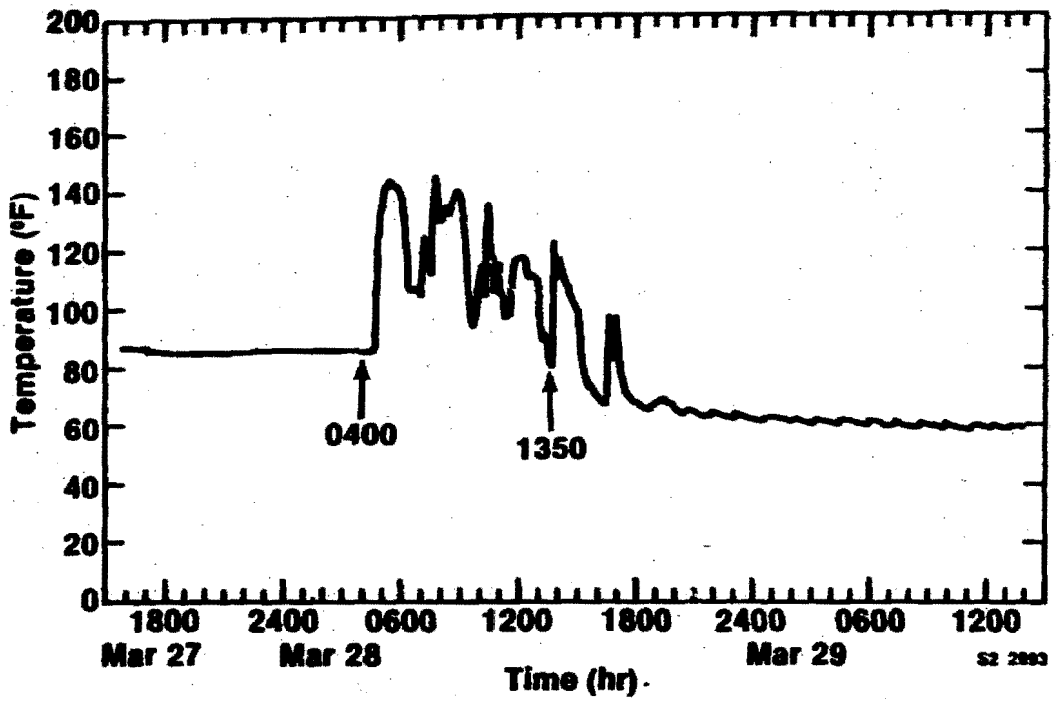


Figure 17. Temperature profile for A/C plenum outlet resistance temperature Detector AH-TE-5027.

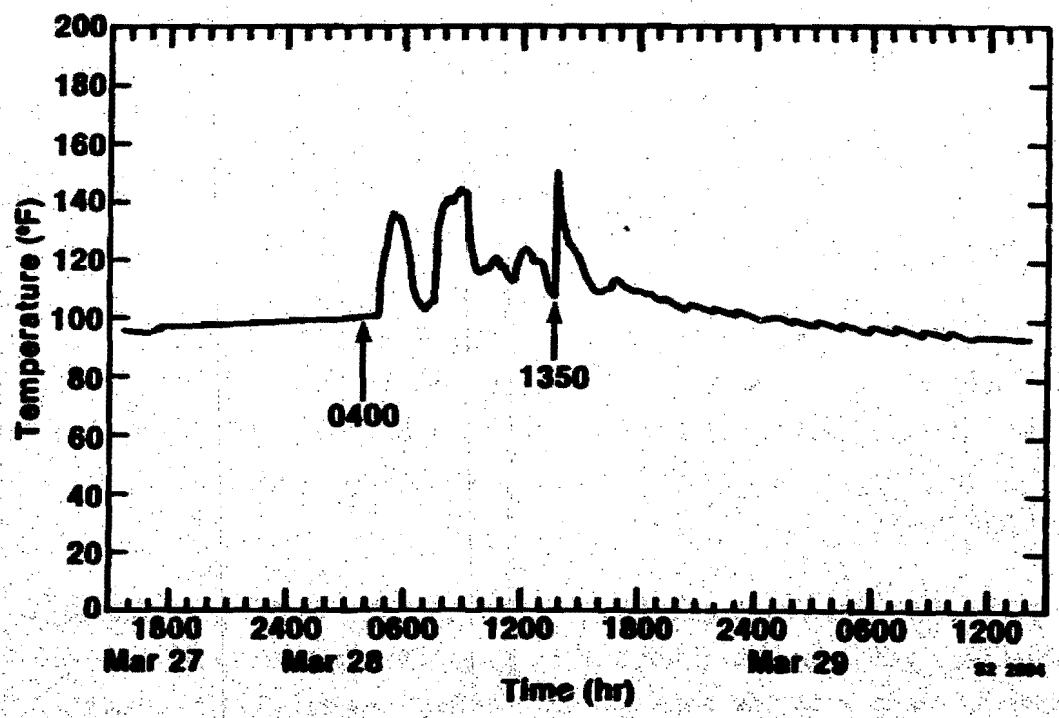


Figure 18. Temperature profile for southeast stairwell resistance temperature Detector AH-TE-5088.

The strip chart recorder was calibrated using GPU Containment Air Temperature Surveillance Procedure 4602-R14, Rev. 1, June 9, 1981. The calibration yielded no indication that problems existed with the strip chart recorder. The device, calibrated to measure in degrees Fahrenheit, had a maximum error of 1°F from its previous calibration in 1977. The results of the calibration are shown in Table 3.

TABLE 3. STRIP CHART RECORDER CALIBRATION MEASUREMENT DATA

Percent of Span	Temperature (°F)	Input (ohms)	Desired (°F)	Actual (°F)	Error (°F)	Allowed (°F)
0	0	92.93	0	0.0	0.0	±4
20	40	101.76	40	39.0	1.0	±4
40	80	110.53	80	80.0	0.0	±4
60	120	119.24	120	120.5	0.5	±4
80	160	127.90	160	161.0	1.0	±4
100	200	136.49	200	199.0	1.0	±4

GPU first performed the calibration using a General Radio decade resistance RTD simulator box. The recorder check was then run again using a four-wire RTD simulator. This unit was connected the way the actual RTD is: two separate leads to the contacts on one side of the recorder inputs, and one lead to the other side. No change was noted between input methods for identical resistance values.

While GPU's Surveillance Procedure 4602-R14 does not call for the measurement of RTD resistance, RTD resistance was measured at this time by the GPU Instrumentation and Control staff. EG&G Idaho equipment used for other surveillance tasks was made available to GPU technicians for RTD resistance tests.

EG&G Idaho equipment consisted of a Fluke 2180A digital thermometer with battery pack for isolation and a Fluke 2020 thermal printer. This equipment, along with the previously mentioned General Radio decade

resistance RTD simulator, a Fluke 8050A digital voltmeter (DVM), and a Fluke 8500A DVM, were all used during the RTD measurements. The 8500A DVM was supplied by GPU.

An RTD was connected to the control room strip chart recorder, and the temperature indication on the strip chart was translated into resistance. The RTD was then disconnected from the recorder, and the determined resistance was dialed into the decade box, which in turn was connected to the recorder. As expected, the decade box readout indicated the same temperature as the actual RTD, since the resistance was calculated from the displayed temperature, and recorder calibration had been previously verified.

The Fluke digital thermometer was first calibrated to the actual resistance for each individual RTD tested. Plant records were consulted to determine the actual resistance for each RTD at a given temperature, and then these individual resistances were compared to the calibration curve to derive each RTD's resistance at 0°C. This individualized calibration procedure was in accordance with the Fluke manual.

After individual calibration, each RTD was then connected to the Fluke 2180A Digital Thermometer and a resistance reading was taken. These readings were lower than the calculated resistance displayed on the recorder. For example, RTD AH-TE-5020 had a resistance reading of 2 ohms lower than the calculated resistance displayed by AH-TE-5020 on the recorder. This lower resistance was duplicated on the other Fluke digital voltmeters. The RTDs that were tested showed that the resistance, cross-checked with all Fluke meters, did not agree with the temperatures displayed on the strip chart.

The resistance decade box was used to duplicate the various resistances that were obtained by directly reading the RTDs. These resistances were then input into the recorder one at a time. The resistances obtained by direct measurements were all lower than what the recorder temperatures indicated: in each case, the recorder showed a higher temperature than what the

known resistances should have yielded. Six RTDs were read directly in this manner resulting in resistances deviating 0.5 to 2 ohms from resistances derived from recorder temperatures.

It should be noted that three meters were used to read detector ohms. To arrive at detector ohms, it was necessary to subtract the lead resistance from the total measurement. This was possible because the three-conductor cable has two of the conductors tied to one side of the detector. By measuring the total resistance of Conductors B and C (see Figure 2), one can arrive at detector resistance algebraically. As stated, all meter readings were consistent, but different from calculated recorder resistances.

OBSERVATIONS ON IN SITU TESTING

The principle of temperature measurement for an RTD is that a change in its resistance is proportional to a change in temperature. This resistance change, which is precise and repeatable when circuit characteristics remain unchanged, is usually measured by passing a known current through the sensing element and measuring the voltage drop across it.

In situ testing indicated that a problem existed with the RTD measurement of temperature. RTD resistances were different when measured with the strip chart recorder system than when any of the Fluke meters were used. A check of the instrument literature for all units showed that the strip chart recorder uses a constant current slightly greater than 1 mA, whereas the Fluke meters used constant currents of 3 to 3.5 mA.

While such differences in current should not ordinarily cause differences in resistance and temperature readings, the accident environment at TMI may have caused abnormal conditions for the RTDs. The RTDs, when installed at TMI-2, were not required to be sealed against high humidity and the other environmental conditions that existed during and after the accident. Although the actual condition of the RTDs and associated wire and circuit components is not known, it is conceivable that they might have experienced chemical contamination and corrosion at terminals and penetrations. If such corrosion and contamination are present, two possible explanations for the differences in resistances obtained during in situ measurements are credible:

- Chemical corrosion of the terminals would cause an increase in the measured RTD resistance. That is

  $$R_T = R_1 + R_2$$

  where

  R_1 = normal RTD resistance

  R_2 = corrosion resistance.

While such an increase in resistance would be recorded on the 1-mA strip chart recorder, the 3.0-mA to 3.5-mA current of the Fluke meters could minimize the effect of the extra resistance, causing a lower resistance reading at the digital thermometer.

- Contamination of the terminals could result in a parallel resistance effect. That is

$$R_T = \frac{(R_1)(R_3)}{R_1 + R_3}$$

where

R_1 = normal RTD resistance

R_3 = parallel contamination resistance.

The applied voltage (constant current) would see a lower resistance for increasing values.

Both conditions probably exist at TMI in the RTD circuits. This could actually have given a lower resistance reading when the direct resistance measurements were made using the 3 to 3.5 mA of the Fluke meters than when the 1 mA of the strip chart recorder was used. The changes in effects from both corrosion and contamination would be gradual and therefore not noticed.

Undetected changes in circuit parameters due to possible corrosion and chemical contamination may effect other types of sensor displays. Appendix A lists 16 documents that discuss terminal strip contamination and corrosion in nuclear plants. This corrosion is a potentially dangerous situation, which could lead to ambiguous indications in the control room. The observations made here could have an impact on plants with normally high temperature and humidity operational environments or that may have raised normal temperature and humidity for short times. This latter condition would be expected if there were unnoticed leaks over long time periods. This kind of leakage has been a problem in nuclear power plants in recent years.

All air handling system RTDs at TMI are functional and, based on preliminary testing and available data, no change to any RTD has been detected. The corrosion and contamination problems and subsequent investigations are not a part of this task. However, the presence or absence of corrosion and contamination in terminal boxes, connection heads, and penetration assemblies will be confirmed in the course of other tasks in the Instrumentation and Electrical Equipment Program, and their effects on circuit performance will be assessed.

APPENDIX A

BIBLIOGRAPHY OF TERMINAL STRIP CONTAMINATION AND CORROSION LITERATURE

BIBLIOGRAPHY OF TERMINAL STRIP CONTAMINATION AND CORROSION LITERATURE

A computer search of various data bases was performed by the Idaho National Engineering Laboratory Technical Library. The search was by the headings, "Terminal Strip" or "Terminal Block," with subsets "Surface Contamination" and "Corrosion." Numerous volumes exist under each of the titles individually, but combinations failed to turn up a single reference. The terms "Terminal Strip" and "Terminal Block" were dropped, and "Insulator" was tried in combination with the previously mentioned terms. This yielded 11 references; however, all 11 addressed the unrelated topic of transmission line insulator problems.

Although it was not listed in any data base searched, even under the author's name, a copy was available of NUREG/CR-1682, Electrical Insulators in a Reactor Accident Environment, by Otmar M. Stuetzer of Sandia National Laboratory. This document was developed in part from information obtained at TMI-2 after the accident. While the observations made earlier in this report are supported by the Stuetzer report, the latter does not contain a detailed investigation into the voltage and current levels one would encounter in instrumentation systems. These values would be less than 50 mA, and usually 10 V dc or less. The writer understands through discussions with M. Murphy of Sandia National Laboratory that Sandia is currently researching the area of terminal strip surface contamination and corrosion.

The following is a bibliography of documents reviewed during this task:

Atwood, C. L., Estimation for the Binomial Failure Rate Common Cause Model, NUREG/CR-1401, April 1980.

Characteristics of Instrumentation and Control System Failures in Light Water Reactors, EPRI NP-443, August 1977.

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