183
3-4-81
JWS

ornl

②
R2409

Lh. 2361

ORNL/TM-7288

OAK
RIDGE
NATIONAL
LABORATORY

UNION
CARBIDE

Temperature Instrumentation and Telemetry for Thermal Striping Test Specimens

R. M. Carroll
T. W. Kerlin
J. M. Rochelle
R. L. Shepard

MASTER

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A03 Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of its employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-7288
Dist. Category
UC-79, -m

Contract No. W-7405-eng-26

INSTRUMENTATION AND CONTROLS DIVISION

TEMPERATURE INSTRUMENTATION AND TELEMETRY
FOR THERMAL STRIPING TEST SPECIMENS

R. M. Carroll	J. M. Rochelle
T. W. Kerlin*	R. L. Shepard

*Department of Nuclear Engineering, University of Tennessee; also
Analysis and Measurement Services Corp., Knoxville, Tennessee

NOTICE: This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

Date Published: March 1981

OAK RIDGE NATIONAL LABORATORY

Oak Ridge, Tennessee 37830

Operated by

UNION CARBIDE CORPORATION

for the

DEPARTMENT OF ENERGY

ef
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

HIGHLIGHTS

A 356-mm-long section of 3-1/2 in., schedule 80, type 304 stainless steel pipe was instrumented with four, type K insulated junction thermocouples embedded at precise locations in the inner wall of the pipe. The sheath diameter of the thermocouples was 0.81 mm and their response times were ~22 ms. After the thermocouples were embedded, response times were measured by plunging the pipe section into a bath of liquid metal. The response times varied from 0.21 to 1.27 s, depending on the embedded depth. A new analytical method was developed to calculate the response time for the test condition, wherein the bath simultaneously heated the pipe segment but became cooled by the insertion of the pipe segment. A short-range radio transmitter-receiver, which added 27 ms to the response time, was installed to transmit the thermocouple signals. The new computer analysis technique and the telemetry response time were verified by measuring the thermocouple response time with two different methods while the pipe segment was plunged into a large circulating water bath.

CONTENTS

	<u>Page</u>
1. INTRODUCTION	1
2. INSTRUMENTATION OF SPECIMEN	2
2.1 Selection, Fabrication, and Characterization of the Thermocouples	2
2.2 Installation of the Thermocouples in the Test Specimen . .	3
3. MEASUREMENT OF RESPONSE TIME	4
3.1 Test Considerations	5
3.2 Test Apparatus and Procedure	5
3.3 Description of Instrumentation	5
4. RESULTS OF TESTS	7
4.1 Data Reduction Requirements	7
4.2 Results	7
4.3 Limitations of Bath Capacity	11
5. CALCULATION OF RESPONSE TIME FROM NONSTEP TESTING	11
5.1 Method of Calculation	11
5.2 Application of Calculation Method to Test Results	12
6. TELEMETRY OF THERMOCOUPLE SIGNALS FROM TSTS	13
6.1 Design Requirements and Approach	13
6.2 Description of Telemetry System	14
6.3 Verification of System Calibration Response Time	17
7. PROOF AND ACCEPTANCE TESTS OF COMPLETED SYSTEM	17
7.1 Water Bath Plunge Test	17
7.2 Comparison of Direct and Telemetered Signals	18
8. DISCUSSION OF RESULTS	20
8.1 Experimental Uncertainties	20
8.2 Data Processing Uncertainties	20
8.3 Estimate of Confidence in Final Results	21
9. CONCLUDING REMARKS	22

1. INTRODUCTION

Thermal striping, caused by the mixing of hot and cold sodium at the exit of breeder reactor cores, imposes stresses on components in the upper internal structures.¹ The thermal striping problem is to determine whether stainless steel or Inconel Alloy 718 components must be used. Stainless steel components are expected to be suitable if the temperature fluctuations are less than 14-28°C (25-50°F) in magnitude and lower than 1 Hz in frequency. However, if the temperature fluctuations exceed 28°C and 1 Hz, Inconel Alloy 718 components must be used, but they are difficult and costly to fabricate and weld. Several studies previously performed by Argonne National Laboratory (ANL) and Oak Ridge National Laboratory (ORNL), using hot- and cold-stream mixing tee's, strongly indicate that thermal striping conditions may require the use of Alloy 718.

At their thermal striping test facility (TSTF), the Westinghouse Advanced Reactor Division (W-ARD) is making engineering studies to obtain failure data on samples of stainless steel and Inconel Alloy 718 pipe subjected to cyclic stress produced by rotating the pipe between jets of hot and cold sodium.

For this purpose, ORNL was requested² to embed stainless steel sheathed, MgO insulated junction, type K (Chromel-P/Alumel) thermocouples of known response times at precise locations in the walls of a thermal striping test specimen (TSTS). The thermocouple sheaths were to be solidly bonded to the TSTS, and the thermocouples were to be as small as practicable to avoid interfering with the heat flow patterns in the walls of the TSTS.

More specifically, ORNL was requested to instrument a pipe segment so as to measure the temperature transients at different depths in the pipe wall. Since the temperature signals were to be measured while the pipe rotated, thermocouples could not be connected directly between the pipe segment and the recording instrument. Commutation was judged impracticable because sodium vapor would be present and short circuits between slip rings could develop. Radio transmission of the thermocouple signals was selected as the most reliable technique of temperature measurement.

Grounded junction thermocouples, although they have the fastest response, could not be used because electrical noise in the rotating pipe would be coupled into the measuring circuit and obscure the temperature signal. Thus, sheathed, insulated junction thermocouples were to be embedded at specified depths in the pipe wall. The response time (the time to register 63.2% of a step temperature change) of the embedded thermocouples would have to be measured both directly and via the radio transmitter-receiver.

If the time-dependent temperature is known as a function of the pipe wall thickness, the cyclic stress can be calculated from a knowledge of the physical properties of the pipe. To obtain a precise knowledge of a transient temperature profile implies that sensors of fast and known response times must be embedded at specified depths in the pipe wall.

This report relates the methods used by the ORNL Instrumentation and Controls Division and the experimental data acquired on the response times of the installed thermocouples. From these measured response times, the output signals may be deconvoluted to obtain the actual wall temperatures during exposure to sodium thermal cycling.

2. INSTRUMENTATION OF SPECIMEN

2.1 Selection, Fabrication, and Characterization of the Thermocouples

To improve their response time, the type 310 stainless steel sheaths on twelve thermocouples were swaged from 1.02 mm (0.040 in.) OD to 0.81 mm (0.032 in.) at the junction end. A nickel sleeve was swaged onto the reduced section of the thermocouple sheath about 20 mm from the junction. The location of the thermocouple junction in relation to the sleeve and to the weld closure was measured by using enlarged x-ray photographs of the thermocouples. Figure 1 shows a schematic cross section of the thermocouple with the sleeve swaged onto the sheath.

ORNL DWG. 81-5822

Fig. 1. Dimensions of Thermocouple 2, Typical of Those Used in the TSTS.

The response times of the swaged thermocouples were measured when the thermocouples were plunged into a liquid eutectic alloy of 62.5% Ga-21.5% In-15% Sn (GIT) at 100°C. GIT, a liquid at room temperature, has excellent wetting properties. Its density is $6.4 \times 10^3 \text{ kg/m}^3$, and its thermal diffusivity is $3.91 \text{ } \mu\text{m}^2/\text{s}$ (calculated from electrical conductivity). Although its thermal diffusivity is about 15 times less than that of sodium, we selected this alloy as the heat transfer fluid because we believe that the surface wetting is the dominant factor in heat transfer for liquid metals. Our choice of GIT was justified by an experiment where we plunged a fast response thermocouple into baths of sodium and GIT and measured the same response times.

The four thermocouples with the best combination of fast response times and small junction-to-weld closure distances were selected for installation in the test specimen (Table 1).

Table 1. Dimensions of thermocouples in the TSTS

Thermocouple No.	Junction to Weld Closure (mm)	Junction to Sleeve (mm)	Response Time (ms)
1	1.14	18.77	22.5 ± 0.9
2	1.09	19.25	29.6 ± 0.4
3	1.19	18.49	20.9 ± 0.3
4	0.97	18.85	22.1 ± 0.7

2.2 Installation of the Thermocouples in the Test Specimen

The TSTS was a 356 mm long section of 3-1/2 in., schedule 80, type 304 stainless steel pipe closed on one end (Fig. 2). To install the thermocouples on the inside of the pipe at 178 mm from the open end, four 0.89-mm-diam holes were drilled by an electric discharge (ELOX) method at 1.57-rad (90°) intervals to within 0.25 mm of the outer surface.

The thermocouples were inserted into the holes, and the entire test specimen was placed in a vacuum furnace. The thermocouple sheaths were joined to the inside of the drilled holes with Microbraz 50.

After the brazing was completed, the depth of each thermocouple junction within the TSTS wall was measured by using a cathetometer to measure the distance between a reference sleeve (Fig. 1) and the inner wall (Fig. 2). From the data of Table 1, the junction distance from the outer surface was determined with a maximum error of 0.08 mm (see Table 2).

Fig. 2. Placement of Thermocouples in the TSTS.

Before the final test specimen was assembled, test specimens were vacuum brazed and sectioned to give assurance that the hole diameter and braze temperature were the right combination to give a solid braze penetration the entire depth of the hole.

Table 2. Thermocouple location in TSTS

Thermocouple No.	Position (rad)	Junction to Outer Surface (mm)
1	0.00	0.584
2	1.57	2.438
3	3.14	2.616
4	4.71	0.406

3. MEASUREMENT OF RESPONSE TIME

The problem was to devise a method of measurement of response times of the embedded thermocouples under in-service conditions while a sudden temperature change was imposed on the outer surface of the TSTS as the specimen rotated in jet streams of liquid sodium sprayed on its outer surface. This in-service condition was simulated as a bench test by plunging the TSTS into a bath of liquid metal (GIT).

3.1 Test Considerations

The mass of the TSTS was more than the amount of liquid metal (GIT) available for these tests; obviously, the temperature of the bath would be changed by insertion of the TSTS into the bath. Therefore, the results from plunge tests of the massive (5 kg) TSTS with embedded thermocouples could not be treated in the same manner as those from plunge tests of single thermocouples, because the mass of the bath could be considered infinite in comparison to the mass of the sheathed thermocouples which were tested for response time before they were embedded (Sect. 2).

Two methods were used to cope with the limited amount of GIT: (1) the GIT bath was placed in a large, stirred water vat which supplied heat to the GIT bath, thus minimizing the bath temperature change; and (2) a mathematical method was devised to use a measured GIT bath temperature along with the temperature of the embedded thermocouples from which the response times were calculated as though an infinite bath had been used.

3.2 Test Apparatus and Procedure

A stainless steel thimble was constructed from a 4-in., schedule 40 pipe segment and closed with a cap. The thimble was suspended in a vat (50 gal drum) filled with heated, stirred water (Fig. 3), and about 350 ml of GIT was poured into the bottom of the thimble.

The TSTS and the bath thimble fitted together with a 1 mm annulus. Two vertical grooves in the thimble allowed an electrical continuity level detector and a fast response thermocouple (20 ms) to be installed in the annulus. The level detector and thermocouple were located so that they would be at the same elevation as the TSTS thermocouples when the TSTS was dropped into the thimble.

To perform a plunge test, the TSTS was positioned as shown in Fig. 3. The water vat was heated to 80°C. The section of the TSTS where the thermocouples were embedded was cooled by a fan because heat was being conducted along the length of the TSTS from its lower section in contact with the top of the thimble. As the TSTS was dropped into the thimble, there was little heat exchanged across the air-filled annulus. However, when the bottom of the TSTS was plunged into the pool of GIT at the bottom of the thimble, the level of the GIT rose rapidly, displacing air from the annulus and establishing good thermal contact between the thimble and the TSTS.

When the GIT level reached the elevation of the embedded thermocouples, the level detector actuated ("triggered") the thermocouple emf recorders.

3.3 Description of Instrumentation

The output voltages of the thermocouples were referenced to an ice bath (Fig. 4). Before each test, the output of each thermocouple was nearly nulled with a measured bucking voltage. The voltage above the

Fig. 3. Plunge Test System.

Fig. 4. Measurement of emf vs Time for TSTS Response Tests. Five individual systems recorded the simultaneous response of five thermocouples.

nulling threshold was amplified and fed to a digital recorder. When the GIT bath trigger started the recorders, the amplified voltage difference between the start and stop of the test was recorded.

The output of the GIT bath thermocouple was recorded by a Tracor Northern NS570-1 digital signal analyzer with 1024, 12-bit words. The outputs of the four embedded thermocouples were recorded by a Biomation 1015 waveform recorder with four separate channels of 1024, 10-bit words each.

The amplification of each thermocouple signal was calibrated by substituting known millivolt sources in place of the thermocouples. A recording yielded a digital value corresponding to a known input voltage.

After each test, the memories of the digital recorders were transferred to magnetic tape storage. The data stored on the magnetic tape were later computer processed, when, with correction for recorder speed, signal threshold, amplification and thermocouple calibration, the data were translated to a record of temperature ($^{\circ}\text{C}$) versus time.

4. RESULTS OF TESTS

The time during which the temperature was recorded after the GIT bath trigger was actuated is the "data time span." The time spans were selected so that they would be about five times longer than the estimated response times of the thermocouples. When the TSTS was plunged into the GIT bath, the response times of the thermocouples were different; those with junctions located nearer the outer surface of the TSTS (Table 2) responded faster (Fig. 5).

4.1 Data Reduction Requirements

After exploratory tests, time spans of 5, 2, 1, and 0.5 s were selected in order to obtain recorded data over a period of about five response times for each of the thermocouples. Examples of the responses of the four embedded thermocouples (TCs) in relation to the bath temperature are shown in Figs. 5-8.

4.2 Results

As can be seen in Figs. 5-8, the length of some records was too short to show the complete response of the slower responding thermocouples. Conversely, the length was too long for some of the faster responding thermocouples; all the information was compressed into the initial part of the record. For completeness, calculations of the response times were attempted for all thermocouples in all tests, even for those with obviously inappropriate time spans (Table 3). (In Table 3, tests 1 to 5 are omitted because they were made to observe temperature changes over periods of 200 s.)

ORNL DWG. 81-5826

Fig. 5. TSTS Test 6. Temperature vs time for 5 s after specimen is plunged into 76°C GIT bath (bath is still cooling as the recording ends).

ORNL DWG. 81-5827

Fig. 6. TSTS Test 10. Temperature vs time for 2 s after specimen is plunged into 87°C GIT bath.

ORNL DWG. 81-5828

Fig. 7. TSTS Test 15. Temperature vs time for 1 s after specimen is plunged into 78°C GIT bath.

ORNL DWG. 81-5829

Fig. 8. TSTS Test 16. Temperature vs time for 0.5 s after specimen is plunged into 77°C GIT bath.

Table 3. Response times (63%) of thermocouples
embedded in the test specimen

Test No.	Data Time Span (s)	Response Times (s)			
		TC 1	TC 2	TC 3	TC 4
6	5	0.357 ^a	1.330	1.393	0.162 ^a
7	5	0.216 ^a	1.320	1.290	0.129 ^a
8	5	0.322 ^a	1.162	1.122	0.313 ^a
9	2	0.292	1.09 ^b	0.695 ^b	0.241
10	2	0.247	1.237 ^b	0.810 ^b	0.250
11	2	0.222	1.110 ^b	0.694 ^b	0.189
12	1	<i>c</i>	<i>d</i>	<i>d</i>	0.138
14	1	0.266	<i>d</i>	<i>d</i>	0.211
15	1	0.209	<i>d</i>	<i>d</i>	0.227
13	0.5	0.213 ^b	<i>d</i>	<i>d</i>	0.131 ^b
16	0.5	0.220 ^b	<i>d</i>	<i>d</i>	0.185 ^b
17	0.5	0.196 ^b	<i>d</i>	<i>d</i>	0.199 ^b

^aThe time span is so long in relation to the response time that the solution is marginal.

^bThe time span is so short in relation to the response time that the solution is marginal.

^cThe data were lost during the recording.

^dThe time span is so short in relation to the response time that the solution will not converge.

4.3 Limitations of Bath Capacity

The GIT was at the temperature of the water vat when it was displaced upward in the annulus between the thimble and the TSTS (Fig. 3). The temperature of the GIT at the midplane of the TSTS (where the thermocouples were embedded) was measured by a thermocouple protruding into the annulus. Although the details of the bath temperature-time patterns were different for these tests (Figs. 5-8), the overall patterns were alike. The temperature remained nearly constant for about 20 ms and then dropped comparatively rapidly, which was completed in about 0.25 s, and was followed by a slow decrease in temperature for about 5 s. About 10 s after the plunge, the temperature slowly recovered over the next 90 s.

The temperature of the GIT in the annulus dropped about 10°C after the start of each test because heat did not flow from the water vat into the thimble as fast as heat flowed from the GIT into the TSTS. The cooling of the bath slowed the rate of temperature rise of the TSTS and, thus, the response time. Analysis must compare the driving temperature of the bath with the response temperatures in the TSTS.

5. CALCULATION OF RESPONSE TIME FROM NONSTEP TESTING

Tests are often made to determine the response time of processes or sensors. The common procedure is to subject the process or sensor to a step change and to determine the time required to reach 63.2% of the total change in response. However, in some cases, it may be impossible or impractical to produce a step change in a process input or in the environment around a sensor, in which cases, the time varying, nonstep input must be accounted for in processing the data to obtain the response time. To do this, the input and output signals are analyzed to derive a mathematical representation that describes the process dynamics, from which the total change that would have occurred for a step input is determined and the response time is calculated. A development and application of such a method are presented below.

5.1 Method of Calculation

A well-established method for characterizing input-output relations is that of time series models. An appropriate time series model for the present application is an autoregressive, moving average model:

$$y_i = \sum_{j=1}^M a_j y_{i-j} + \sum_{j=1}^N b_j u_{i-j} ,$$

where

y_i = output at the i th sampling time,

u_i = input at the i th sampling time,

a_j = a coefficient that relates previous outputs to the present output (called an autoregressive term),

b_j = a coefficient that relates previous inputs to the present output (called a moving average term).

Least-squares techniques are usually used to evaluate the a_j and b_j from test data.

For the present problem, a model with two autoregressive terms and one moving average term was adopted:

$$y_i = a_1 y_{i-1} + a_2 y_{i-2} + b_1 u_{i-1} .$$

The identification of the coefficients was accomplished by using a least-squares approach.

5.2 Application of Calculation Method to Test Results

The calculation method in Sect. 5.1 was embodied in a BASIC language computer program adapted to a PDP-10 computer. The program was tested with computer-generated data sets of known response times. When it was discovered that the computer program was not stable for the 1024-word data records, the records were converted to a 10-word-averaged record of 102 words. Figures 5-8 are plots of the 102-averaged words obtained from the original 1024-word records.

When computer-generated data sets of known response times were analyzed, in some cases a stable value of the computed response could not be attained. There are three possible reasons for this instability, as follows:

1. The response time was too short for the sampling rate, i.e., only three measurements were made in a time equal to one response time (case A).
2. The response time was too long for the sampling rate, i.e., all 100 measurements were made in a time equal to one-half the response time (case B).
3. There was excessive measurement noise, i.e., nonsignificant signal variation would affect the acceptable ranges of cases A and B (case C).

Stable values of the calculated response time (when cases A, B, or C did not apply) were within 1% of the known value.

When case B applied, a stable value of the calculated response could be obtained by using a multiple of the sampling rate. This amounted to an extrapolation of the calculation, but a plateau of correct values was obtained over a range of multiples until at very large multiple values of the sampling rate, errors were as high as 10%.

All data in Table 3 were calculated with multiples of 1, 2, 5, and 10 of the sampling rate. If all four calculations gave stable values that were about the same, the value calculated by the 1 multiple was used. If a plateau of values was obtained, the value obtained by the lowest multiple of the sampling value was used. If a plateau was not obtained, the value calculated by the lowest multiple to obtain a stable value of the computed response was used.

6. TELEMETRY OF THERMOCOUPLE SIGNALS FROM TSTS

6.1 Design Requirements and Approach

W-ARD's thermal striping test facility is designed to rotate the instrumented test specimen at selected speeds to 63 rad/s. Data are transmitted across the rotating interface by wireless telemetry, which avoids the high noise and stray thermal emf's often encountered when low-level thermocouple signals are directly coupled through mechanical slip rings.

Any of several short-range telemetry coupling techniques (microwave, electrostatic, magnetic induction, optical, acoustic, etc.) could solve the problem, but short-range, rf telemetry (101 MHz) was selected primarily because it is the one best developed and it is commercially available. Other outstanding features of this technique are small battery-operated transmitters, noncritical antenna alignment, and high speed multiplexing capability.

6.2 Description of Telemetry System

The telemetry system components were purchased from the Acurex Corp., as follows: one 219Q transmitter, two 312A transmitter batteries, one 155K-1 FM tuner with rackmount kit, and one, each, 188A, 118L, and 119L-1 electronics for demultiplexing and signal conditioning. These parts were specified and purchased by W-ARD on the basis of recommendations by the Instrumentation and Controls Division, which also designed and supplied an interface circuit board assembly for mounting and interconnecting the transmitter module, thermocouple cables, batteries, and transmitting antenna.

The 219Q transmitter is 38.1 mm long and 19 mm OD, with type K thermocouple input channels and a 0 to 1000°C calibrated measurement range.

The FM transmitter carrier (101 MHz) carries a total of ten channels (six data, one sync, one zero, one calibrate, and one cold-junction reference) via time division multiplexing, with a time allotment of 200 μ s per channel maximum. The system measurement inaccuracy is specified at $\pm 2\%$ of the reading for a 25 to 125°C cold-junction temperature (same as the transmitter temperature) range. The transmitter is battery powered at 5.4 to 6.0 V dc, with 7 mA nominal current drain; the discharge time should be at least 250 h with the 312A cells.

Thermocouple cables are terminated with miniature thermocouple connectors attached to a custom connector block located on the inward side of the TSTF drive shaft, as shown in Fig. 9. Connections from this block to the transmitter interface circuit board are via No. 20 stranded thermocouple extension wires. The wires pass through a center hole in the drive shaft and terminate in crimp plugs that mate with input jacks on the transmitter board, as illustrated in Fig. 10. Thus, the thermocouple inputs can be easily disconnected to permit complete removal of the transmitter assembly, if required.

The thermocouples should have insulated junctions because the Alumel side is grounded at the transmitter module interface board. Should a junction become grounded, the resulting measurement error will depend on local common mode interference effects, which are not predictable.

As shown in Fig. 10, the transmitter circuit components are mounted in an aluminum housing (18.3 cm OD and 3.3 cm high) which bolts directly to the TSTF drive shaft pulley. The outer side of the housing is covered with an epoxy glass fiber circuit board on which is printed a concentric disk pattern to form the transmitting antenna shown in Fig. 11. The outer disk (17.3 cm OD $\times$ 7.6 cm ID) connects to the transmitter antenna terminal, and the inner disk (6.35 cm OD) connects to circuit and machine grounds. Also shown in Fig. 11 is the receiving antenna board, which is identical with the transmitting antenna except that the receiving board has a rear-mounted BNC connector for attachment of the tuner input cable (e.g., RG-59). The spacing between the transmitter and receiver antennas should initially be 50 mm or less to facilitate locking on the 101 MHz carrier. After the carrier is locked, the antenna spacing can be increased to several feet.

Fig. 9. Rear View of Transmitter Electronics Mounted on TSTF Drive Shaft Pulley.

Fig. 10. Plan View of Transmitter Electronics in Aluminum Housing, with Front Antenna Cover Plate Removed.

Fig. 11. View of Fully Assembled Transmitter Package (left) and Receiving Antenna Disk (right).

A slide switch is located on the interface board for grounding each unused transmitter input and for grounding all inputs while thermocouples are being connected and disconnected. This precautionary procedure should help prevent damage to the FET inputs of the nonrepairable transmitter module. The inputs are grounded when the switches are in position "1" with the white dot visible.

An on-off switch is located at the periphery of the transmitter housing for energizing and deenergizing the transmitter module. To conserve battery life, the switch should be *off* when the transmitter is not in use.

Seven RG-174 cables were supplied by the Instrumentation and Controls Division for connecting the six demultiplexed outputs (via the CH1 connector on the Acurex model 188 chassis) to data recording equipment. These outputs are driven directly from integrated circuit operational amplifiers in the 188 which tend to develop spurious low-level oscillations when loaded directly with the RG-174 cables. To suppress these oscillations, a 100 Ω resistor was inserted in series with each output within the Amphenol cable connector that mates with the CH1 connector. Any voltage division between these resistors and the input impedance of the user's data recording equipment will proportionally reduce the total system gain.

Cable 7, which connects to pin J of CH1, can be used for viewing a test waveform.

6.3 Verification of System Calibration Response Time

The output-input system gains for each channel were checked at about 50 and 100% of full scale (1000°C) by disconnecting the thermocouples and injecting appropriate dc millivolt input calibration signals. Based on the 100% full-scale measurements, the system gain sensitivity was $1.992 \text{ mV/}^\circ\text{C} \pm 0.1\%$ for every channel. With this gain factored in, the computed measurement inaccuracies at 50% of full scale were less than $\pm 1\%$ for all channels. For these tests, the transmitter (and cold junction) temperature was about 25°C.

The response time of each telemetry system channel was checked by disconnecting the thermocouples, injecting a fast-rising, 10-mV (peak-to-peak) square wave, and observing the rise time at the demodulated-demultiplexed output. The square wave was superimposed on a 30 mV dc input bias. In all cases, the 10 to 90% rise time was about 60 ms, which corresponds to a first-order time constant of 27 ms and a -3 dB bandwidth of 5.9 Hz. This bandwidth was also verified by checking the system frequency response with sine wave input signals. The bandwidth quoted on Acurex data sheets for the 219 Q transmitter is 25 Hz.

Analysis of the Acurex circuit shows that the system response time is dominated by the sample and hold capacitors, designated C16-C21 on the model 118 demultiplexer circuit board. Reduction of this capacitance from the 3.3 μF factory value to 0.47 μF decreased the 10-90% output rise time to about 9 ms, but with some degradation in signal-to-noise ratio. The capacitors, and therefore the response time, were returned to the original, factory-installed values before the system was delivered to W-ARD.

7. PROOF AND ACCEPTANCE TESTS OF COMPLETED SYSTEM

7.1 Water Bath Plunge Test

A part of our task was that we compared the response time measured by telemetry to that measured directly. Because the GIT bath required a computer analysis of the plunge tests, we devised another plunge test where the TSTS was plunged into a rotating tank of warm water. Although the heat transfer rate is not as high in water as in GIT, the moving water directly in contact with the outer surface of the TSTS eliminated the $\sim 10^\circ\text{C}$ temperature drop observed in the GIT tests.

The water bath was selected for two reasons, as follows: (1) to compare the telemetered data to directly recorded data obtained from the same temperature transient, and, for this purpose, the nature of the transient was not essential, and (2) to verify that the computed response for the GIT bath was correct by comparing the computed response time to a directly measured response time.

7.2 Comparison of Direct and Telemetered Signals

For these tests, one set of lead wires from the thermocouples was connected to the instrumentation amplifier, which was connected to one channel of a four-pen strip chart recorder. Another set was connected to the FM transmitter. The output from the FM receiver was connected to an adjacent channel of the recorder. The amplifiers were adjusted to give the same gain on the recorder for the same temperature. In this manner, two thermocouples could be measured at the same time using the four-pen recorder.

Plunge tests were made with the recorder speed set at 0.4, 1.0, and 2.4 s/cm. Figure 12 shows an example of the responses of thermocouples 1 and 4 at a chart speed of 0.4 s/cm. The response times of the four thermocouples were determined by graphical analysis and tabulated in Table 4. These tabulated results show that the graphical analysis was too crude to enable determination of the telemetry lag by a comparison of the response times. A better way to determine the telemetry lag would be to compare the maximum difference in the times for the signals to rise to the same amplitude (Table 4). The faster responding thermocouples 1 and 4 show a lag time of about 30 ms, the expected lag. The lag time could not be measured for the comparatively slowly responding thermocouples 2 and 3 because the measurement error was greater than the ~30 ms lag time.

The directly measured response times of the thermocouples measured in the water plunge test are about 150 ms (av) longer than the times measured in GIT--an expected result. The directly measured response times confirm the calculated response times for the GIT plunge tests.

Table 4. Comparison of response times
of direct and telemetry signals

	Response Time(s) for Thermocouples			
	1	2	3	4
Graphical direct	0.39 ± 0.04	1.35 ± 0.2	1.5 ± 0.2	0.36 ± 0.05
Graphical telemetry	0.57 ± 0.05	1.2 ± 0.2	1.45 ± 0.35	0.44 ± 0.04
Maximum lag from amplitude comparison	0.038	Negative	Negative	0.030

Fig. 12. Response of Thermocouples 1 and 4 Measured by Direct and Telemetry Methods During a Plunge of the TSTS into a Flowing Water Bath at 95°C.

8. DISCUSSION OF RESULTS

The response times of Table 3 include experimental variations between tests as well as computational errors. The sources and magnitude of the errors will be discussed below.

8.1 Experimental Uncertainties

At the start of the plunge test into the GIT bath, the TSTS was at steady state conditions, but not isothermal. There were two temperature gradients in the TSTS: (1) a longitudinal gradient due to the closed end of the TSTS being inserted into the heated thimble, and (2) a circumferential gradient due to one-sided cooling by a fan directed at the midsection of the specimen (Fig. 3).

During the tests, the TSTS would float in the GIT bath; the TSTS had to be forced downward to submerge the midsection where the thermocouples were embedded. Variations in the submerging force caused the liquid metal to surge and flow both longitudinally and circumferentially in the annulus, thus causing an uneven temperature distribution in the TSTS. The surges of GIT (with different temperatures) account for the irregular and non-reproducible bath temperatures shown in Figs. 5-8.

The temperature of the bath was measured at only one point, that is, the midplane of the submerged TSTS (Fig. 3) where the TSTS thermocouples were embedded around the circumference of the specimen. Thus, the measured bath temperature was not exactly equal to the driving temperature for the TSTS thermocouples (because the annulus temperature may have varied owing to variations in the submerging force, as explained previously, and because the temperature distribution of the TSTS may have been initially uneven).

We can not estimate the errors caused by the difference between the measured driving temperature and the actual driving temperature. Because of the random nature of the surges in the annulus, we believe that the errors would be observed as a larger standard deviation from the mean rather than as a biased mean value of the response time.

Since the computation of the response time did not require absolute measurements, there were no errors caused by calibration uncertainties. The time scale of the digital recorders, checked by recording a square wave of known frequency, was accurate to within 0.3%.

8.2 Data Processing Uncertainties

The response times of the embedded thermocouples were calculated by using a computer program that allowed for the variation of the bath temperature in relation to the response rate of the embedded thermocouples.

The use of data with known response times proved the computer analysis correct to about 1% over a wide range of combinations of sensor response time and recorded data time span. If, however, the data time span was more than ten times as long as the response time, or if the data time span was only about as long as the response time, errors caused by the computer analysis could be as high as 10%.

The data of Table 3 are noted to indicate those tests where the combination of the data time span and the response time might produce the largest computer errors. Table 5 shows that the uncertainties in the computer analysis do not have large effects on the mean values. If the noted (*a* and *b*) data of Table 3 are excluded, the mean response times of all thermocouples are still within the error limits of the mean of the response times determined by use of all data.

Table 5. Mean response times calculated from Table 3 data

Thermocouple No.	1	2	3	4
Number of tests	11	6	6	12
Mean response time, all tests, s	0.251	1.208	1.001	0.198
Standard deviation	0.052	0.104	0.309	0.055
Number of tests	5	3	3	6
Mean response time, <i>a</i> and <i>b</i> excluded, s	0.247	1.271	1.268	0.209
Standard deviation	0.033	0.094	0.137	0.041

The main effect of excluding the noted data is that the standard deviation becomes smaller, especially for thermocouple 3. We accept the best values of the response time to be those listed in the lower section of Table 5, which do not include the data measured for excessively long or short time spans.

8.3 Estimate of Confidence in Final Results

The experimental and computational errors for the measurements of the direct response time are included in the standard deviations listed in Table 5. The additional response time introduced by the telemetry system was measured as 27 ± 1 ms. The water bath plunge tests confirmed both the telemetry response time and the computer calculations of the response time in GIT. The final result and the total errors are listed in Table 6.

Table 6. Mean telemetered response time for
a GIT plunge test

Thermocouple No.	1	2	3	4
Mean response time, s	0.274	1.298	1.295	0.236
Standard deviation	0.034	0.095	0.138	0.042

9. CONCLUDING REMARKS

Insulated junction thermocouples with the sheaths swaged to 0.81 mm OD were successfully embedded into the walls of a pipe section (TSTS) so that the location of the junction was known to a precision of 0.08 mm. Sectioned test samples gave assurance that the braze securing the thermocouples in the pipe wall had penetrated the full depth and circumference of the annulus between the thermocouple sheath and the well drilled in the pipe wall.

The response times of the embedded thermocouples were measured with a plunge test into a bath of liquid metal, a test believed to approximate the heat transfer during service conditions. A computer analysis technique was developed to compensate for changing bath temperatures during response tests.

A short-range radio transmitter-receiver was installed to transmit the thermocouple signals. The telemetry system added 27 ms to the thermocouple response time. The telemetry response time and the computer analysis technique were verified with plunge tests in a large circulating water bath.

REFERENCES

1. This problem is summarized by P. R. Huebotter (ed.), "Report of the National Task Force on Thermal Striping in LMFBRs," ANL-CT-78-46 (1978).
2. W-ARD, "Specifications for Instrumentation and Calibration of Thermal Striping Test Specimen," Purchase Order No. 284798 (Feb. 23, 1979).

ORNL/TM-7288
Dist. Category
UC-79 and -79m

INTERNAL DISTRIBUTION

1. R. L. Anderson	22. R. L. Moore
2. K. R. Carr	23. A. J. Moorehead
3-7. R. M. Carroll	24. N. R. Parrott
8. J. A. Conlin	25. A. W. Renshaw
9. U. Gat	26-30. J. M. Rochelle
10. J. H. Holladay	31. G. S. Sadowski
11. J. L. Horton	32-36. R. L. Shepard
12-16. T. W. Kerlin	37. J. M. Turley
17. R. C. Kryter	38-39. Central Research Library
18. B. C. Leslie	40. Document Reference Section
19. R. E. MacPherson	41-42. Laboratory Records
20. C. D. Martin	43. Laboratory Records, ORNL RC
21. N. D. McCollough	44. ORNL Patent Office

EXTERNAL DISTRIBUTION

- 45-46. Director, Division of Reactor Development and Technology, U.S. Department of Energy, Washington, D.C. 20545
47. Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37830
- 48-228. Given distribution as shown in TID-4500 for categories UC-79 and -79m (25 copies - NTIS)