NUREG/CR-0398
ORNL/NUREG/TM-243

Multirod Burst Test Program Progress Report for April–June 1978

J. L. Crowley

Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreements DOE 40-551-75 and 40-552-75

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

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

NUREG/CR-0398
ORNL/NUREG/TM-243
Dist. Category R3

Contract No. W-7405-eng-26

Engineering Technology Division

MULTIROD BURST TEST PROGRAM PROGRESS REPORT FOR APRIL—JUNE 1978

J. L. Crowley

Manuscript Completed — October 13, 1978
Date Published — November 1978

NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555
Under Interagency Agreements DOE 40-551-75 and 40-552-75

NRC FIN No. B0120

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

CONTENTS

FOREWORD

This report summarizes progress and preliminary results of the Multirod Burst Test (MRBT) Program [sponsored by the Division of Reactor Safety Research of the Nuclear Regulatory Commission (NRC)] for the period April—June 1978.

Work on this program was reported initially in Volume I of a four-volume series entitled *Quarterly Progress Report on Reactor Safety Programs Sponsored by the NRC Division of Reactor Safety Research*. Prior reports of MRBT activities in this series are

Report No.	Pages	Period covered
ORNL/TM-4729	70—72	July—September 1974
ORNL/TM-4805	102—110	October—December 1974
ORNL/TM-4914	78—104	January—March 1975
ORNL/TM-5021	76—98	April—June 1975

Beginning with the report covering the period July—September 1975, work on this program is reported as *Multirod Burst Test Program Progress Report*. Prior reports in this series are

Report No.	Period covered
ORNL/TM-5154	July—September 1975
ORNL/NUREG/TM-10	October—December 1975
ORNL/NUREG/TM-36	January—March 1976
ORNL/NUREG/TM-74	April—June 1976
ORNL/NUREG/TM-77	July—September 1976
ORNL/NUREG/TM-95	October—December 1976
ORNL/NUREG/TM-108	January—March 1977
ORNL/NUREG/TM-135	April—June 1977

In mid-1978 a duplicate report identification system was instituted whereby an NRC report number is also assigned to NRC-sponsored work. Previous reports issued in this category include

NUREG report No.	ORNL report No.	Period covered
NUREG/CR-0103	ORNL/NUREG/TM-200	July—December 1977
NUREG/CR-0225	ORNL/NUREG/TM-217	January—March 1978

Topical reports pertaining to research and development carried out as a part of this program are

1. R. H. Chapman, compiler, *Characterization of Zircaloy-4 Tubing Procured for Fuel Cladding Research Programs*, ORNL/NUREG/TM-29 (July 1976).
2. W. E. Baucum and R. E. Dial, *An Apparatus for Spot Welding Sheathed Thermocouples to the Inside of Small-Diameter Tubes at Precise Locations*, ORNL/NUREG/TM-33 (August 1976).
3. W. A. Simpson, Jr., et al., *Infrared Inspection and Characterization of Fuel Pin Simulators*, ORNL/NUREG/TM-55 (November 1976).

The following limited-distribution quick-look reports have been issued under this program:

1. R. H. Chapman, compiler, *Quick-look Report on MRBT No. 1 4 × 4 Bundle Burst Test*, Internal Report ORNL/MRBT-2 (September 1977).
2. R. H. Chapman, compiler, *Quick-look Report on MRBT No. 2 4 × 4 Bundle Burst Test*, Internal Report ORNL/MRBT-3 (November 1977).
3. R. H. Chapman, *Quick-look Report on MRBT No. 3 4 × 4 Bundle Burst Test*, Internal Report ORNL/MRBT-4 (August 1978).

SUMMARY

The third 4 × 4 bundle (B-3) was assembled and prepared for testing y April 11, 1978. The test was aborted, however, because of excessive leakage of the fuel pin simulators at the lower gland seal. The bundle had been heated a few days earlier for a test of the revised steam system piping, and all leak rates were satisfactory until the second heatup on the test date. Bundle 1 had also been heated twice before the burst test with excessive seal leakage on only one fuel pin simulator. After more extensive seal tests were performed, it was concluded that performance of the compressive gasket used in the geometry of B-1, B-2, and B-3 is marginal because of the large difference in the thermal coefficient of expansion between Zircaloy and stainless steel. However, since a seal geometry change was not possible in the repair of B-3, numerous methods that might be applied to B-3 with a minimum of risk to the internal simulator thermocouples were investigated.

The combination of materials selected for the B-3 repair consisted of a flat copper washer with Teflon backing to act as a sealant. The special tools and techniques needed to safely remove the lower gland and replace the seals were developed in preparation for making this repair in July.

Work continues on the extensive software changes necessary for the use of a new data-acquisition system to be installed by the Thermal Hydraulic Test Facility project this fall. In the upgraded data-acquisition system, a PDP-11/34 minicomputer will be used which will require that software be written in FORTRAN instead of the FOCAL language presently being used.

The design was completed for a single-rod test flange and test vessel incorporating a heated shroud, and materials are being ordered for its fabrication. The power supply procured for the shroud is due to be shipped during the next report period.

MULTIROD BURST TEST PROGRAM PROGRESS REPORT FOR APRIL—JUNE 1978

J. L. Crowley

ABSTRACT

The burst test of the third (B-3) 4 × 4 bundle was aborted when excessive leakage of the lower glands developed on the scheduled test date. After extensive development tests, a replacement seal has been chosen, and special tools and procedures have been established for the repair in the very close confines of the lower bundle. The actual repair and burst test of B-3 are expected to take place early in the next report period.

The preparation of software continues for the upgrading of the data-acquisition system from the present PDP-8, which uses FOCAL language, to the PDP-11, which uses FORTRAN.

The design was completed and materials were ordered for incorporating a heated shroud in future single-rod tests.

1. INTRODUCTION

R. H. Chapman

The objectives of the Multirod Burst Test (MRBT) Program are (1) to delineate the deformation behavior of unirradiated Zircaloy cladding under conditions postulated for a loss-of-coolant accident (LOCA) and (2) to provide a data base that can be used to assess the magnitude and distribution of geometrical changes in the fuel rod cladding in a multirod array and the extent of flow channel restriction that might result. Data are being obtained from single-rod and multirod experiments that include possible effects of rod-to-rod interactions on ballooning and rupture behavior; a tentative test matrix was given in a previous report.[1] Although the test matrix includes tests of large bundle arrays, these will be held in abeyance until a definite need is established on the basis of the results of the smaller test arrays. Also, tests with boiling-water reactor (BWR) cladding will be deferred until completion of the pressurized-water reactor (PWR) cladding tests.

Approximately 50 single-rod burst tests have been conducted with a heating rate of ∿28°C/sec; experimental details and preliminary results of these tests have been routinely reported without regard to their validity. (All published reports pertaining to this research program are listed in the Foreword of this report.) All the tests were then evaluated for validity and the results were summarized in a previous report.[2] It is suggested that readers using the results obtained in this program be aware that some data points have been removed as a result of the evaluation.

Four steady-state, single-rod creep rupture tests were conducted at ∿760°C to determine if large ballooning occurs over extended lengths of test specimens heated with internal fuel pin simulators (FPS). Test conditions were varied to cause failure at creep times of 49, 103, 162, and 250 sec. Two transient (∿28°C/sec) burst tests were conducted with the same internal fuel simulators for comparison. Initial conditions for these tests were adjusted to cause failure at approximately the same temperature as in the creep-rupture tests. The results were presented in a previous report.[3]

Two transient burst tests using each of the two fuel simulators were conducted at nominal heating rates of 5 and 10°C/sec during this report period to bridge the span between the creep tests (∿0°C/sec) and the 28°C/sec transient burst tests. Initial pressure conditions for these tests were adjusted to cause failure at ∿760°C for comparison. The results of these low-heating-rate tests were discussed in the preceding progress report.[4]

The major emphasis of this report period was to be the test and examination of B-3 (the third 4 × 4 bundle). However, the test was delayed because of leakage problems with the lower gland seals. The emphasis was then changed to the development and testing of a seal and the tools and techniques necessary for the repair of B-3.

2. PROGRAM PLANS AND ANALYSIS

2.1 Programmatic Activities

J. L. Crowley

The major emphasis during this report period was on determining the cause and solution of the B-3 gland leakage problem. The examination of B-2 was continued, and the design criteria were established for incorporating a heated shroud in single-rod tests.

Recent test results were presented by R. H. Chapman at the NRC Quarterly Cladding Review and Experimenter's Workshop held at ORNL on April 25 and 26.

The ASTM Zirconium Conference at Stratford-on-Avon was attended by Chapman, who presented a paper, "Zircaloy Cladding Deformation in a Steam Environment with Transient Heating." He also visited other nuclear laboratories in the United Kingdom and West Germany.

2.2 Transient Digital Simulation of Multirod Bundles

R. D. Dabbs
R. A. Hedrick   M. D. White

In order to assess the effect of the surrounding environment on the FPS spatial and temporal temperature distribution, a transient digital simulator of the Multirod Burst Test Facility (MBTF) is being developed. The computer program will calculate the temperature distributions in the FPS and heated shroud as well as the thermodynamic and hydrodynamic states of the cooling steam. It will also be used to establish steam conditions for planning MRBT experiments. Programming is 90% complete.

3. DEVELOPMENT AND PROCUREMENT

3.1 Fuel Simulators

P. T. Jacobs R. W. McCulloch

3.1.1 Schedule

Site preparation is nearly complete for the Fuel Rod Simulator Development Laboratory at ORNL, with receipt and installation of the equipment estimated to be completed by the end of July. MRBT fuel simulators will be the first to be assembled. A ten-week period is allotted to produce eighty acceptable units, with the starting date contingent upon completion of the laboratory and receipt of simulator materials.

3.1.2 Material status

Two components of the simulator have not yet been received: the inner boron nitride (BN) preforms and the stainless steel sheath. One thousand inches of outer preforms have been received and the remainder will be shipped with the inner preforms by the end of July. The tubing vendor quoted an inspection date of July 24, which represents a five-week delay in the original schedule, partially due to a factory maintenance shutdown. Efforts are being made to prevent a further slip in schedule.

3.1.3 Development status

3.1.3.1 Components. The changes mentioned in the last report in the dimensions of the Kanthal Al ribbon used to wind the coil and the changes in the outside diameter of the coil have been incorporated into the design because of favorable test results with prototype simulators. These changes also necessitated changes in preform dimensions.

Changes to the power terminals for the heating element are being evaluated. Various designs of swaged junctions at the copper–nickel interface have been considered. Swaged junctions offer good mechanical strength and electrical continuity without the introduction of a braze material. A combination that shows promise is 3.2-mm-OD copper inserted

25 mm into the nickel. Shorter penetration depths have been used (6 and 12 mm), but they appear to be more sensitive to movement during swaging.

A smaller diameter (3.2-mm) copper lead on both ends of the simulators is being considered (1) because copper with the same diameter as that of the coil has a history of spalling during the filling of outer preforms, requiring a sheath for protection, and (2) because fabrication is simplified. This change does not appreciably increase the electrical resistance of the copper lead. The diameter chosen is a standard commercial size and is the size required on the lower Ceramaseal fitting, thus eliminating the need for swaging. At the upper end of the simulator, swaging will still be required because of the ID of the ceramic bead insulator (2.9 mm), but only one swaging pass will be required and it can be performed after the unit is assembled. The outer preforms pressed by the ORNL Metals and Ceramics Division and the first batch from Eagle-Picher Industries, Inc., have been used in the production of prototype fuel simulators. Most preforms have been preferentially soft at one end, making them very fragile; as a result, many are broken during shipment and during simulator fabrication. Eagle-Picher has been advised of the problem and is attempting to solve it before pressing the remaining order of outer preforms. Failures in other types of prototype simulators fabricated by vendors and visible black specks in the preforms made from HCM-type BN powder have resulted in further investigations of the powder purity. Apparently, nonmagnetic but electrically conductive particles of sufficient diameter to cause insulation problems are still present in the powder. Although no means of removing all the particles has been found, the powder has been sieved to remove all particles larger than 0.18 mm. This gives a powder that is adequate for preform pressing but is of a size that decreases the probability of insulation resistance shorting. All outer BN preforms for fuel simulators to be produced locally will be pressed with this sieved powder.

PT-13-type (TS-1325, camphor treated) BN powder was used as a substitute for HCM-type powder to press the outer preforms for MR-5. Although the resulting preforms have a lower density than HCM preforms, they have other advantages. The preswage infrared scans on MR-5 were not appreciably different from the postswage scans. This offers the

possibility of producing an unswaged simulator that would eliminate the problems associated with swaging (variation in coil parameters and sheath straightness).

3.1.3.2 Tooling and fabrication. Minor changes are incorporated into the fabrication procedure and tooling with each iteration on a new simulator. Two areas of concentration have been the minimization of variation in wound coil parameters when filling inner preforms and the simplification of fabrication to operations that can be handled by one man. Progress has been noted in both areas, but more work is required.

In the interim until all components are received, work has begun with material on hand. Coil winding mandrels have been fabricated and coils will be wound on them to be swaged with the new swaging equipment; terminal material is also being prepared for swaging. When the swaging unit arrives, final preparations can be completed. Before preproduction assembly, a number of units will be assembled consecutively to familiarize all those associated with the process and to further evaluate the fabrication procedure.

3.1.3.3 Prototype fuel simulators. Four simulators were built during the quarter (MR-3 through -6) to evaluate design changes and to establish assembly information for preproduction simulators. Fixed coil parameters were

1. winding the same type (dimensions and material) of ribbon onto the same-diameter mandrel;
2. swaging coils on mandrels using the same dies and shims;
3. swaging simulators using alternate passes with the same die and shim configuration from the same initial to the same final diameter;
4. tamping preforms for inner and outer fill at the heated length with the same tamp energy [61,300 J/m^2 (350 in. lb./in.^{2})];
5. with the exception of MR-3, cutting all coils to the same length (85 cm) and stretching them the same amount (3.81 cm) prior to inner preform fill.

Parameters that varied were

1. techniques used in restraining the coil during inner preform fill and terminal spot welding;
2. type of treatment, powder used, and supplier of BN preforms;
3. outer preform fill techniques (tamp energy, number of preforms inserted between tamps, and number of tamps) in the terminal areas of the simulator;
4. terminal design.

Three of the four simulators satisfied the infrared scan criterion (±1.5% deviation from mean temperature at ∿400°C); the unit with low insulation resistance, MR-4, failed this test. Baseline data for certain fabrication parameters were obtained, and fabrication techniques were improved and documented in anticipation of preproduction.

Some success was achieved in correlating simulator parameters obtained from x-radiographs with the axial temperature profile determined by infrared inspection for the prototype MR-3. The parameters (turns per centimeter and eccentricity) were constant compared to variation in coil OD. By comparing the plots for axial temperature and coil OD vs axial position along the coil, it was apparent that "cold" spots in the infrared scan correspond well with reductions in the coil diameter; ordinarily, there is enough variation in other parameters to preclude a comparison of this type. These results accent the importance of beginning with and maintaining uniform coil parameters during fabrication.

The prototype simulator MR-5 has been selected for single-rod burst testing for further design evaluation. Several other prototypes will also be tested in single-rod experiments to validate design changes for the preproduction units.

3.2 Lower Seal Development for Repair of B-3

J. L. Crowley A. W. Longest

Bundle B-3 was installed and checked out for the burst test scheduled for April 11, 1978. However, because of excessive leak rates that developed just before the planned application of power to the bundle, the

test was aborted; the test attempt is described in Sect. 5. The bundle repair will be attempted in July. This section will discuss briefly the search for an acceptable method of repairing the leaks while also minimizing the risk to the very fragile internal thermocouples. A total of 75 seal assemblies of various configurations and materials were tested in an effort to provide assurance of success before selection and application to B-3 repair.

The gasket used in B-3 (and some of which had been used in B-1 and B-2) was a copper "O" ring which has nonstandard dimensions but is manufactured commercially. Before being used in the assembly of FPS, this type of gasket had been successfully tested at the expected temperature and pressure for single cycles. However, more extensive tests done after the abortion of the B-3 test revealed that multiple thermal cycles generally caused leakage. In most tests, leakage occurred after heatup on the second thermal cycle, while others survived as many as six cycles with no leakage problem. A detailed evaluation of numerous tests led to the conclusion that the commercial copper gasket, as used in the B-3 configuration, was marginal at best. (Note: Subsequent development tests have indicated that gasket confinement geometry is at least as important as the gasket itself; however, for the B-3 repair, a revision of the seal geometry was not an available option.)

Parallel investigations of various sealing methods and materials for the repair of B-3 lower seals were planned for as early a date as possible; a secondary objective was to determine a satisfactory solution for future bundles. Thus, some of these tests will continue after the repair and burst test of B-3 have been completed.

A number of tests were outlined and executed to evaluate various gasket materials and geometries. During the same period, the use of an epoxy-filled seal sleeve assembly external to the leaking gaskets was investigated. The epoxy approach was attractive because of the low risk it would place on disruption of the thermocouples attached to the inside of the Zircaloy tubes; a disadvantage was that simultaneous treatment of all 16 seals would be required and that no retreat would be possible after the epoxy was applied.

The epoxy system, containing about 68 wt % aluminum powder for added strength, showed good performance in a single unit for several temperature cycles up to a limited temperature of 260°C. However, difficulty was encountered in the preparation and testing of a multiple-unit mockup of the bundle. A typical single-unit test assembly is shown in Fig. 3.1, and the multiple-unit mockup is shown in Fig. 3.2. This system was abandoned for another when it became apparent that several time-consuming iterations might be necessary before it could be applied to the B-3 repair.

Other sleeve assemblies external to the gasket area were tested with various combinations of Teflon inserts and aluminum cones. However, the best of these combinations survived only ∿9000 kPa internal pressure (B-3 would require ∿12,000 kPa) at 340°C; Fig. 3.3 shows some of these combinations.

The search for improved gasket materials and configurations included variations of copper, silver, aluminum, gold-plated stainless steel, and several high-temperature elastomers. Some of these materials and shapes are shown in Fig. 3.4. A combination of materials, consisting of a flat copper washer with Teflon backing on the ID, was selected for use on B-3. The Teflon, applied as a tape wrapping, held the washer concentric during installation; more importantly, it was found that the Teflon served as a sealant, flowing into the small crevice that apparently develops under the copper washer on repeated thermal cycling. This method was pursued and successfully demonstrated as an adequate solution for B-3 both in several single-unit tests and in a seven-unit assembly subjected to the pressure, temperature, and steam atmosphere which must be withstood by B-3. The use of this method during the B-3 repair will be attempted in July and will be described in the next progress report.

ORNL PHOTO 6741-78

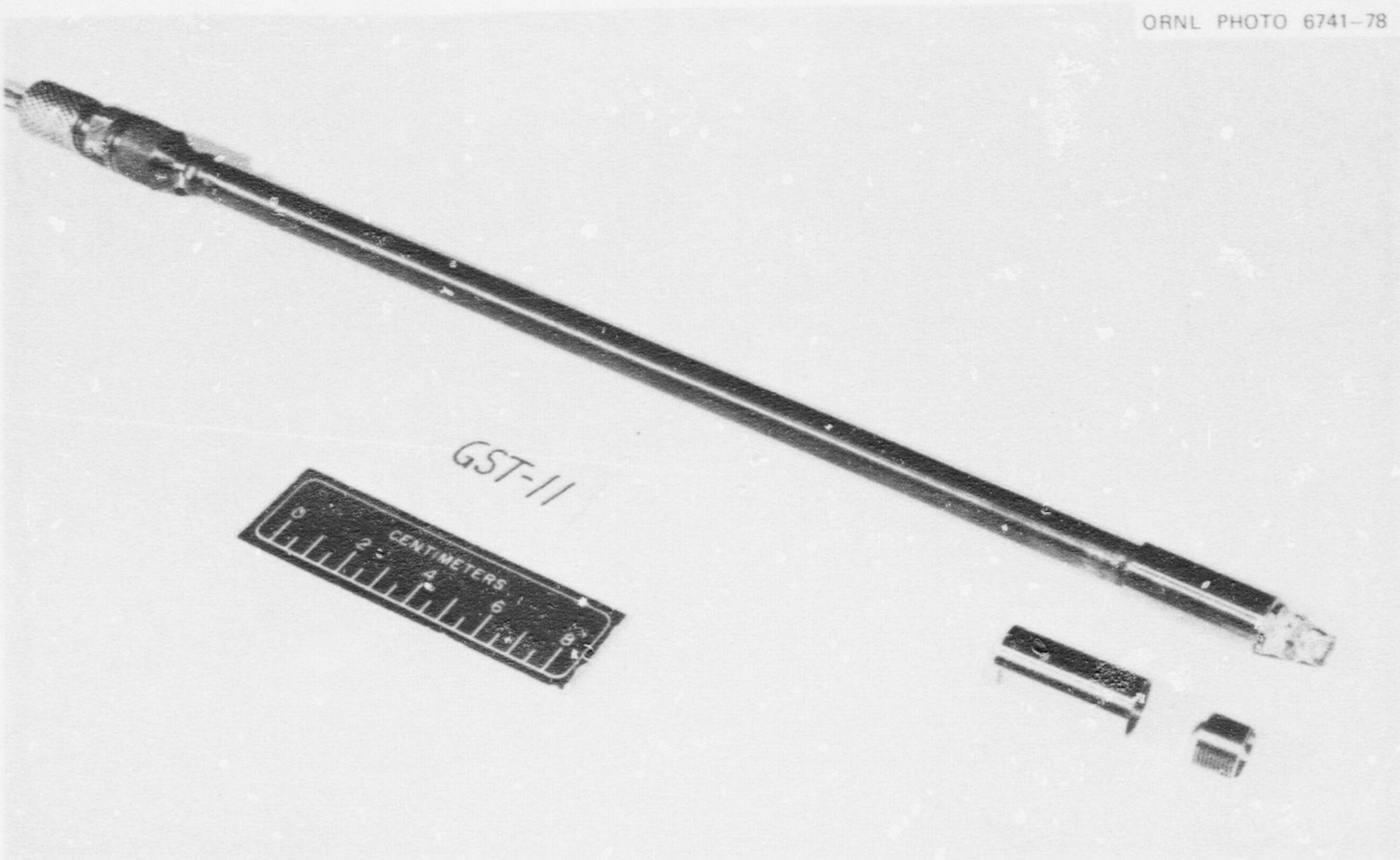

Fig. 3.1. Typical single-unit epoxy and sleeve system assembly ready for autoclave testing.

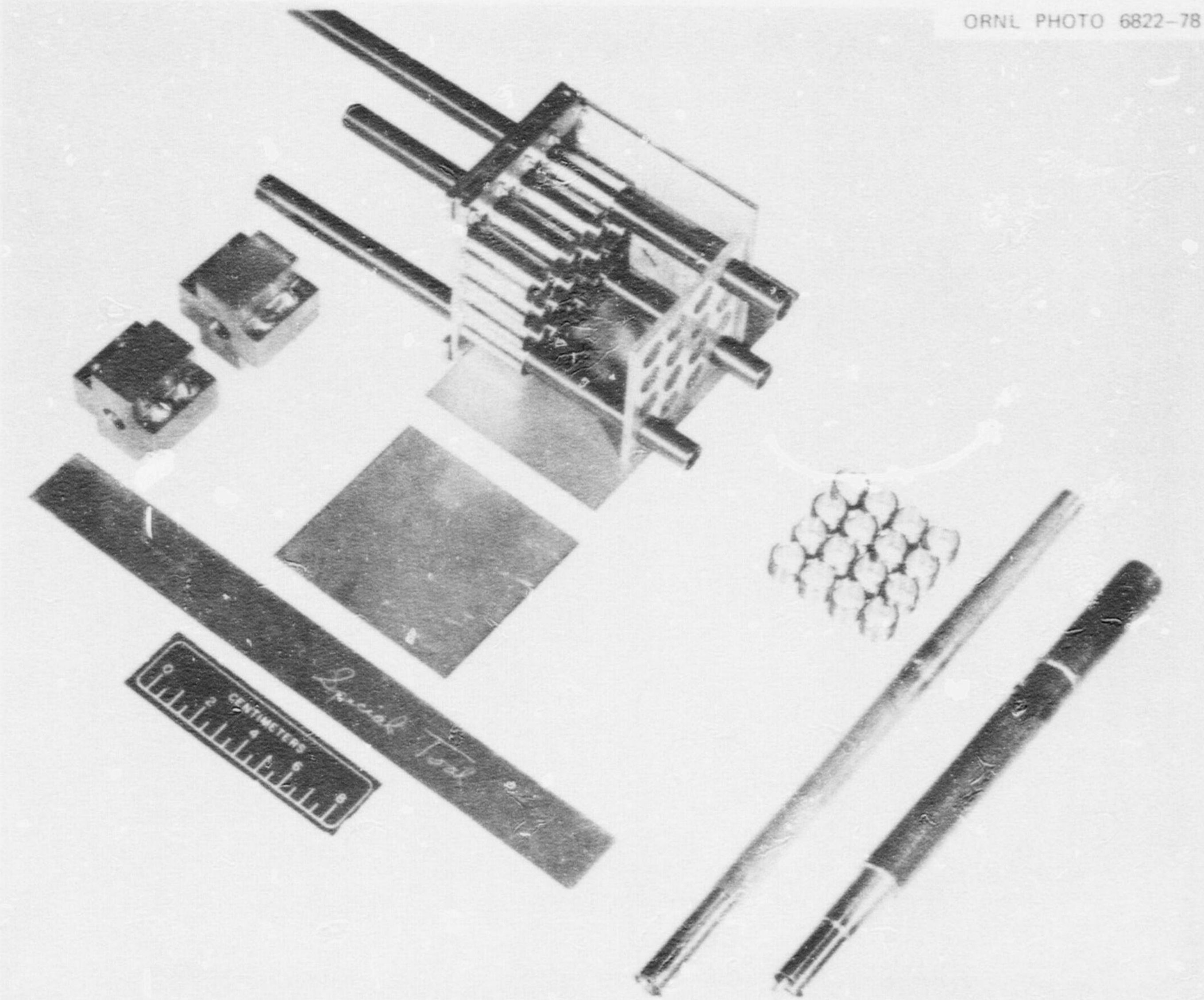

Fig. 3.2. Multiple-unit epoxy and sleeve system mockup for B-3 repair. Tools necessary for application and confinement of epoxy are also shown.

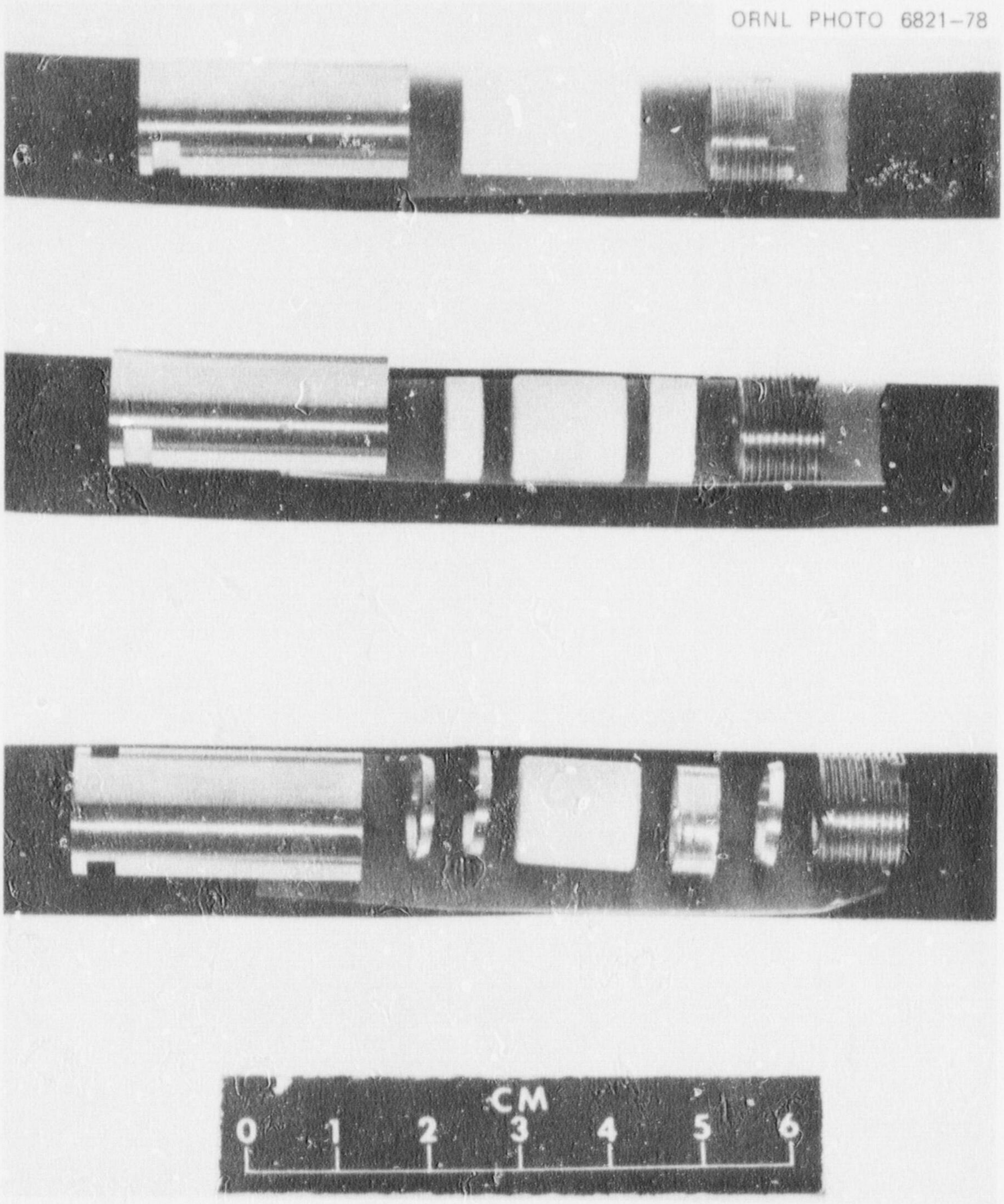

Fig. 3.3. Three sleeves and subassemblies tested for possible use in B-3 repair. Top — Teflon insert; center — Teflon insert with Teflon cones; bottom — Teflon insert with aluminum cones.

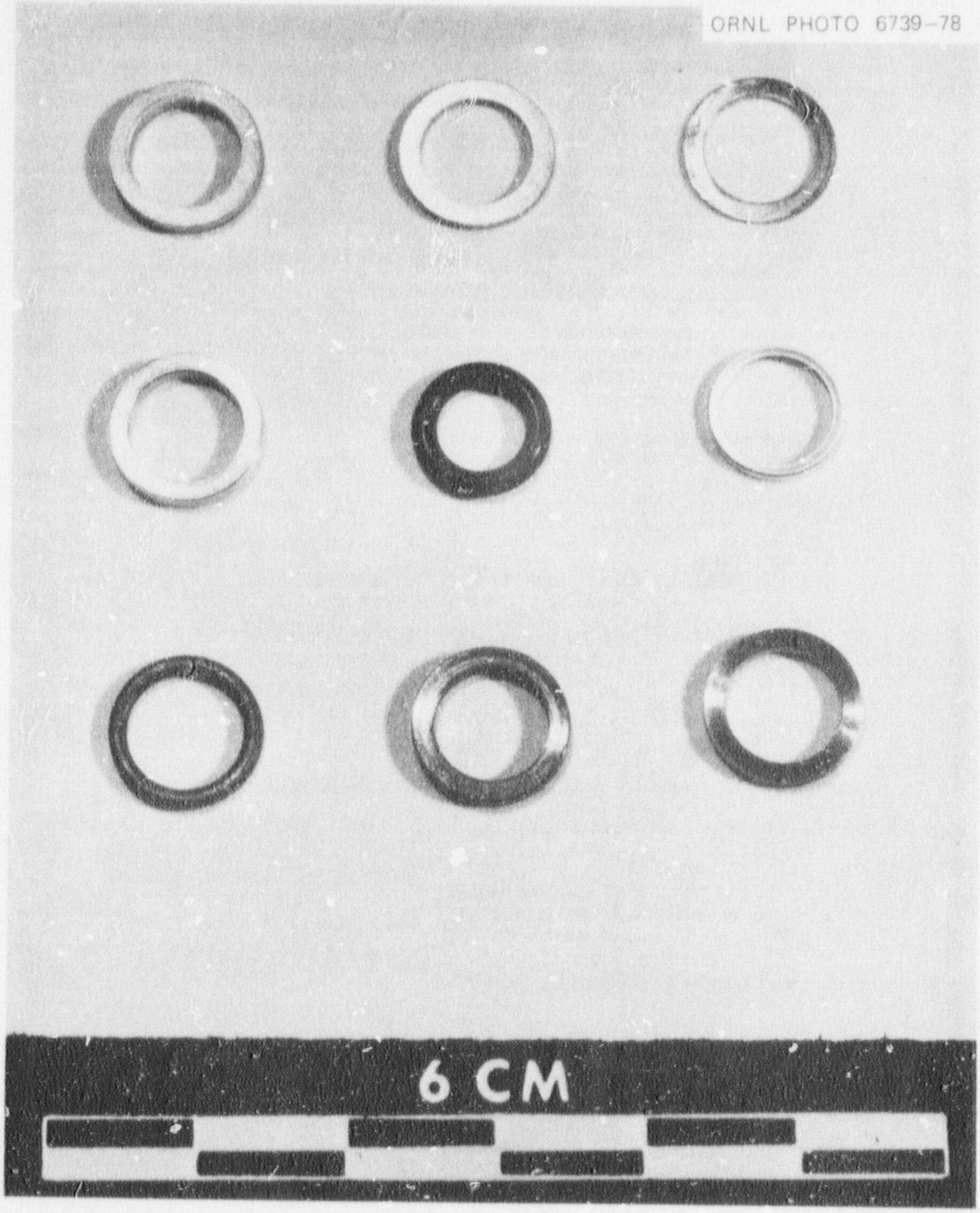

Fig. 3.4. Some seals tested for use in B-3 repair. Top — gold-plated stainless steel; center — aluminum washer, elastomer "O" ring, and metal "V" ring; bottom — copper "O" ring and washers.

3.3 Thermocouple Development and Procurement

K. R. Carr* R. L. Anderson*
J. H. Holladay* T. G. Kollie†

3.3.1 Shroud thermocouple "composite" calibration derivation

The problem of decalibration of the type S shroud thermocouples was described in an earlier report,[3] along with two possible solutions. One solution, that of replacing the wire near the sensing junction with new uncontaminated wire, was implemented for 4 × 4 Bundle 3 and will be used for subsequent bundles. The principal features to be considered for analysis in this method are shown in Fig. 3.5. Prior to the burst test,

---

*Instrumentation and Controls Division, ORNL.

†Y-12 Development Division.

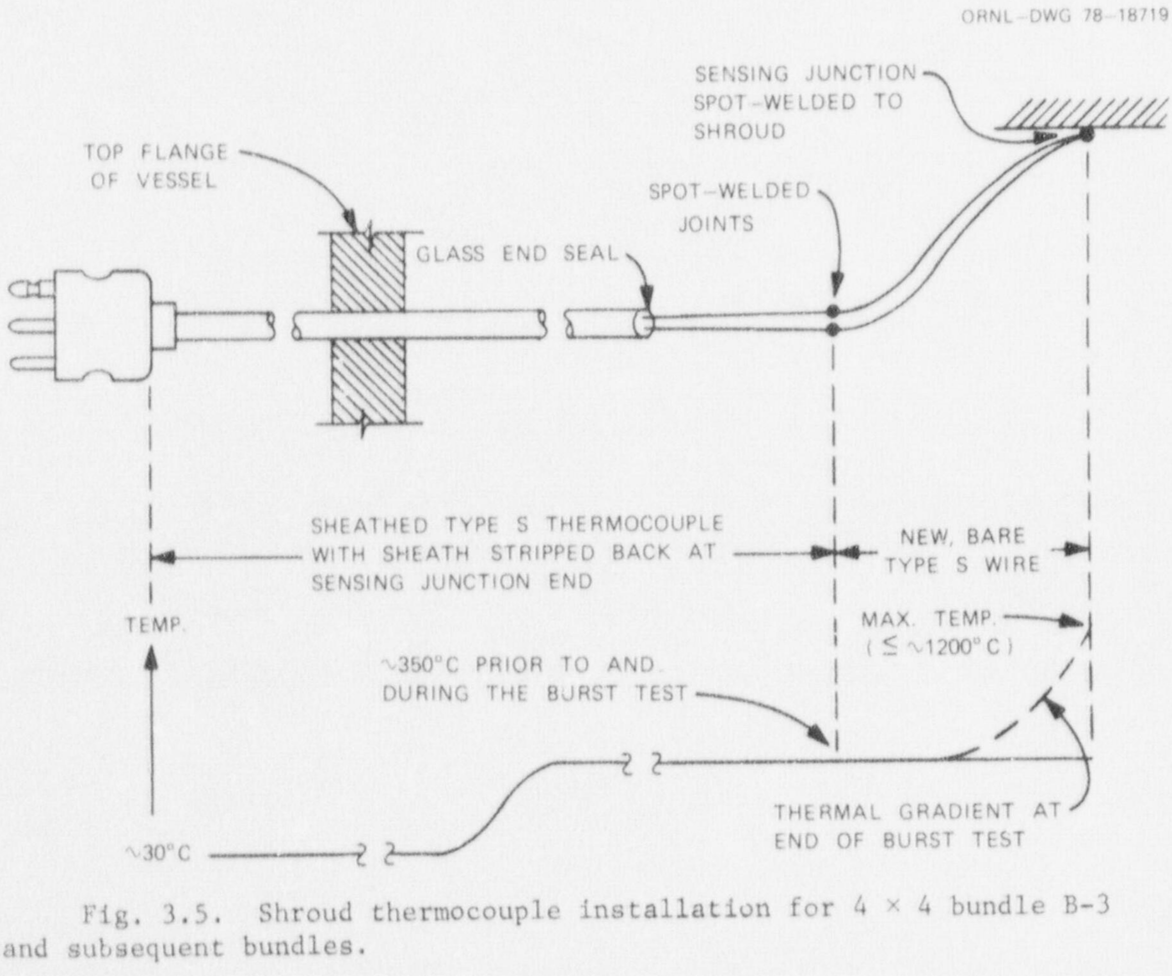

Fig. 3.5. Shroud thermocouple installation for 4 × 4 bundle B-3 and subsequent bundles.

the new, bare type S wire is in a virtually isothermal zone at ∿350°C and thus contributes very little, if any, to the total thermocouple output voltage. The thermal gradient along the sheathed thermocouple remains essentially constant during the temperature transient of the test bundle, which occurs in a time interval of <60 sec. The sheathed thermocouple, including its length of exposed wires up to the spot-welded joints shown in Fig. 3.5, is thermally shielded from the shroud and test bundle. The heated steam passes the spot-welded joints after passing through the bundle, but the flow rate is too low to cause appreciable heating of the sheathed thermocouple during the duration of the burst test. The thermocouple connector is at ∿30°C, the facility ambient temperature in the vicinity of the test bundle. A mating connector and thermocouple extension wire route the signal to a 65°C thermocouple reference box.

The data reduction method for the type S thermocouples involves the use of the National Bureau of Standards Monograph 125 mathematical relationship for electromotive force (emf) vs temperature, together with a correction emf derived from a calibration of the particular lot of thermocouples. The correction emf (μV) is calculated as $A + BT + CT^2 + DT^3$, where T is in degrees Centigrade and the coefficients A, B, C, and D are derived from the calibration data. To use two different lots of thermocouple material as shown in Fig. 3.5, it was necessary to derive a "composite" set of coefficients A, B, C, and D.

To derive the "composite" set of coefficients, the expressions $A + BT + CT^2 + DT^3$ for each of the two lots of material were used along with the basic expression relating thermocouple temperature to emf output, so that

$$e(t) = \int_{T_R}^{T_S} S_P \, dT + \int_{T_S}^{T_R} S_N \, dT \ , \qquad (3.1)$$

where

$e(t)$ = thermocouple output voltage,

S_P = Seebeck coefficient of position thermoelement,

S_N = Seebeck coefficient of negative thermoelement,

T_R = temperature of the reference junction,

T_S = temperature of the sensing junction.

The analysis showed that the proper "composite" coefficients are the same as those for the new, bare wire except for the A term, which is sized to account for the difference between the two lots of wire at 350°C. The derivation of these "composite" coefficients and their use in the data system programs help avoid a temperature measurement error of ∿5°C which would occur otherwise.

3.3.2 Type S shroud thermocouple end seals

We have previously reported[3] the two problems experienced with the glass end seals installed at the sensing junction end of the type S shroud thermocouples: (1) some of the end seals have apparently allowed moisture to pass and enter the thermocouple insulation over a period of time and (2) the thermoelectric wires are very fragile at the point where they exit the end seal, resulting in frequent breakage of the wires, even with the most careful handling.

A hermetic end seal on these sensors is desirable for these reasons:

1. During a burst test, the voltage between the thermoelectric wires and the sheaths of the shroud thermocouples is typically ∿100 V and could be as much as ∿200 V. The thermocouple insulation must be of sufficient quality to prevent any appreciable leakage currents or voltage breakdown.

2. Undesirable materials (in addition to moisture) admitted to the interior of the thermocouple through a faulty end seal over a period of time could cause decalibration of the thermoelectric wires. The thermoelectric wires outside the thermocouple sheath are exposed and therefore may be cleaned periodically or conveniently replaced with new wire.

3. A wire-to-wire insulation resistance of sufficiently low magnitude would shunt the thermocouple output signal and result in temperature measurement error, although the shunting resistance would have to be as low as a few kilohms to cause 1°C error, as shown in Fig. 3.6. One possible approach is to omit end seals on these thermocouples altogether, remove (bake out) moisture from the thermocouples just before installation in a test bundle, and verify the absence of moisture or other electrically

ORNL-DWG 78-18720

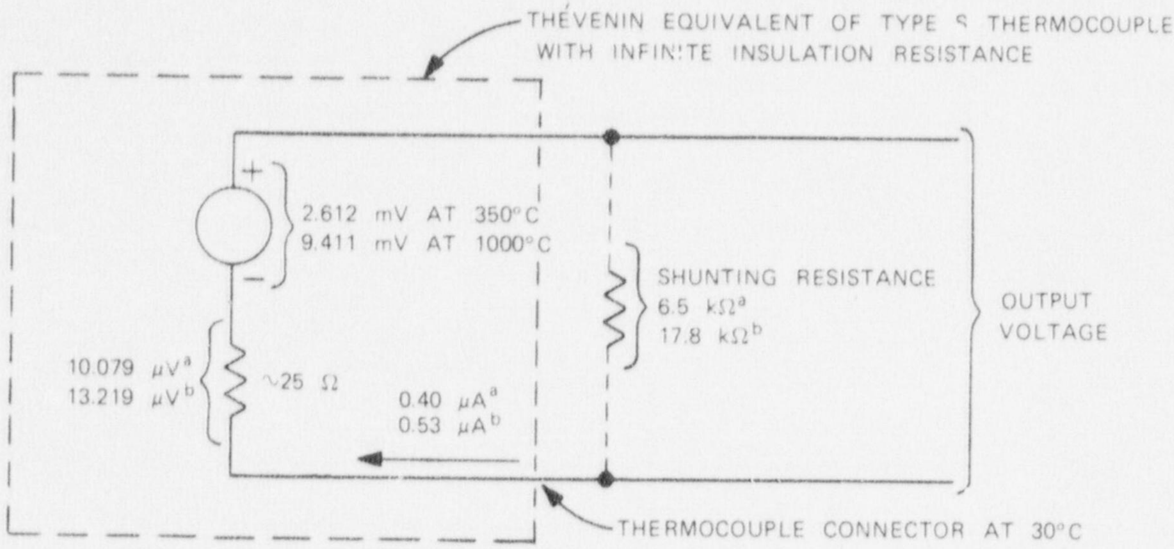

Fig. 3.6. Analysis of shunting resistance effects on temperature measurements with type S thermocouples.

shunting agents by insulation resistance measurements. The use of this method would leave only the question of whether a high-resistance material that would cause decalibration had entered the insulation of any of the thermocouples, which is probably unlikely.

Although we could continue to use the glass end seals by repairing defective end seals and broken wires, we ordered an alternate end seal material for evaluation, Epoxylite No. 6203 high-temperature epoxy made by the Epoxylite Corp.

Another possible end seal method is the use of premanufactured hermetic end seals made by Ceradyne, Inc. A disadvantage of these seals is that they have hollow-pin Kovar feedthroughs for the thermoelectric wires which would cause a small temperature measurement error if a thermal gradient should exist along the Kovar/thermoelectric wire system. Installation of these end seals on the thermocouples would involve brazing or welding the end seal to the sheath and possibly fusion welding to close the hollow-pin feedthroughs around the thermoelectric wires.

3.3.3 Tantalum-sheathed thermocouples

The order for 80 tantalum-sheathed thermocouples was cancelled by mutual agreement with the manufacturer in March 1978. These 0.71-mm-OD (0.28-in.) thermocouples were intended for use in the first high-temperature (>1000°C) test bundle to avoid eutectic formation with Zircaloy. The order was cancelled because of continuing difficulty in producing the tantalum-sheathed material in 0.71-mm-OD size without sheath breakage. The original scheduled delivery date on this order was November 1976.

A definite need for this type of sensor remains. An alternate approach to avoid eutectic formation in the high-temperature burst tests is to install 0.51-mm-OD (0.020-in.) stainless-steel-sheathed thermocouples with a tantalum oversheath installed to result in an overall OD of 0.71 mm (0.028 in.). No material melting would result with this type of sensor, even at up to ∿1400°C, well above the 1175°C maximum test temperature in the program. One manufacturer has demonstrated the ability to produce at least short lengths of this type material. However, a potential problem with this approach is that the 0.51-mm basic OD size requires thinner insulation between the wires and between each wire and the sheath, which might result in unacceptably low insulation resistance. Early in the next quarter we plan to determine the suitability of this type of thermocouple, as well as that of the chromium-plated thermocouples mentioned in an earlier report.[3] If these approaches are not successful, we will again invite bids from manufacturers for 0.71-mm-OD sensors with a sheath composed of tantalum only. One manufacturer successfully produced ∿50 thermocouples of this type for the MRBT Program about two years ago, although he, too, experienced production difficulties.

3.3.4 Thermocouples for 4 × 4 Bundle 4

Production has proceeded routinely on an order of 125 Inconel-sheathed 0.71-mm-OD (0.028-in.) Chromel-Alumel thermocouples for use in 4 × 4 Bundle 4, and delivery is expected by the first week in July. Type S thermocouple material for the shroud temperature measurement application in this bundle is already on hand.

3.4 Single-Rod Facility Temperature Control with Heated Shroud

K. R. Carr*

The temperature control requirements for the single-rod facility heated-shroud configuration were studied and the system design was initiated. The system will have proportional action with no rate or reset. A simplified preliminary block diagram is shown in Fig. 3.7. The temperature profile generator is an instrument which provides a voltage vs time profile in accordance with a preplotted program attached to a rotating drum. As shown in Fig. 3.7, preset fixed voltage demand signals

---

*Instrumentation and Controls Division.

ORNL-DWG 78-18721

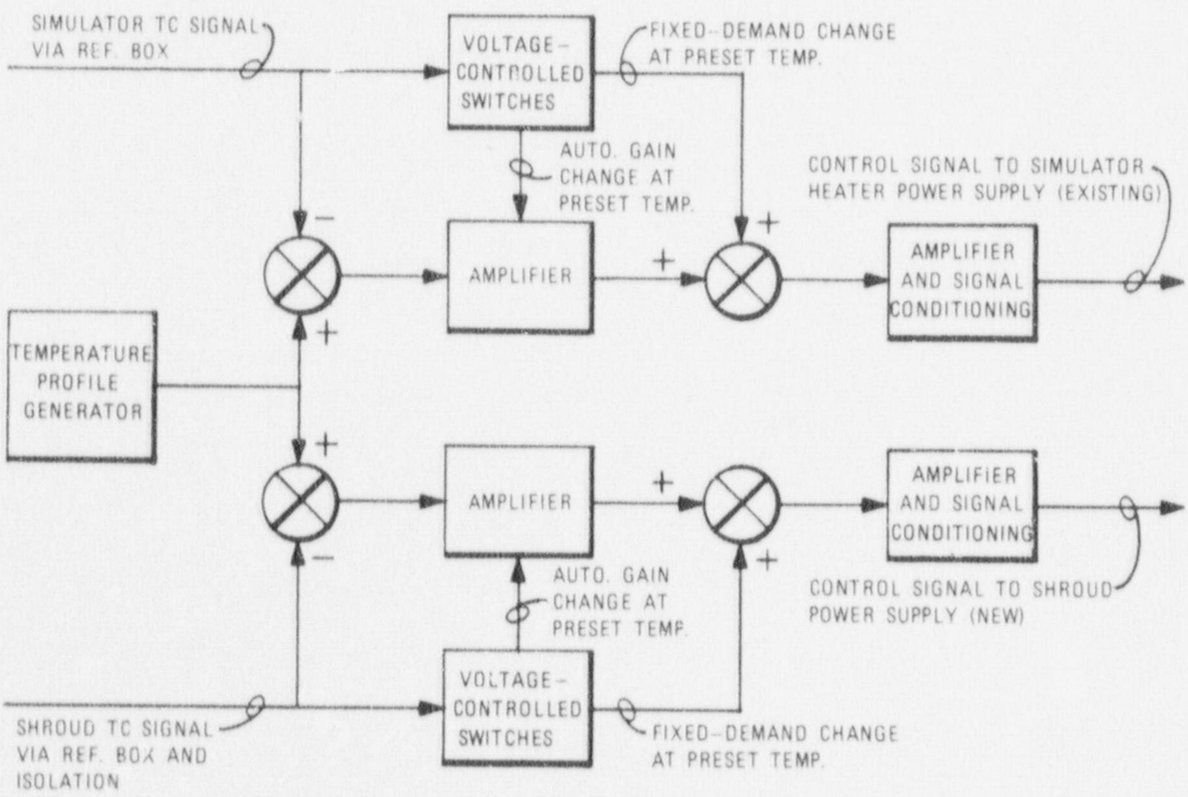

Fig. 3.7. Preliminary block diagram of single-rod temperature control with heated shroud.

are added to the amplified temperature error signals until preset temperatures are reached. This feature eliminates the need for very high amplifier gain on temperature ramps, which might cause instability in the control. The settings will be independently adjustable for each of the two power supplies. Also, the amplifier gains may be changed automatically when preset temperatures are reached, so that optimum amplifier gains may be used for both temperature ramps and steady-state temperatures. These automatic features have previously been performed manually by an operator observing a strip-chart trace of simulator temperature in creep-rupture experiments. The control approach shown in Fig. 3.7 incorporates the experience gained in previous single-rod testing and will provide maximum flexibility and performance as required in future burst tests as well as in creep-rupture tests. The installation and checkout of the temperature control equipment is planned for October 1978.

4. DESIGN, FABRICATION, AND CONSTRUCTION

4.1 Data Acquisition and Software

K. R. Carr* F. R. Gibson*

The present computer-based data-acquisition system (DAS) at the MBTF was purchased and installed as a part of the Thermal Hydraulic Test Facility (THTF). The THTF project work is continuing, and the two projects are sharing the DAS, the MBTF group being essentially a "guest" of the THTF group in the use of the DAS. This arrangement has worked well with no serious scheduling problems or other difficulties. However, the THTF requirements, particularly the necessary data sampling rate for an expanded number of channels (more than 500), have exceeded the capabilities of the present DAS, and a new system with significantly improved capabilities will be installed by the THTF project this fall. The present DAS will be removed from the test site and used to meet pressing data-acquisition needs in another building. Therefore, although the present DAS is adequate for the MBTF requirements (including 8 × 8 rod array bundles), both software and hardware changes must be made at the MBTF to conform to the new installation.

The software changes constitute the major portion of the effort needed for conversion to the new DAS, since the MRBT applications software must be extensively revised and rewritten. The present DAS, which uses a PDP-8/E minicomputer, is programmed in FOCAL interpretive language. The upgraded DAS uses a PDP-11/34 minicomputer with all applications software written in FORTRAN and operates in a multiuser, real-time executive environment. Most of the rewritten applications programs will operate in the same manner as before with respect to operator responses, listing formats, etc.; thus operational procedures will require only very minor changes. The greatest differences will be in the method of starting the programs and in the speed of producing calculations and printout. The MRBT software will be rewritten to use THTF subroutines and utility programs whenever possible. These routines, instrument data base utility,

*Instrumentation and Controls Division.

scan task, operator's display, and operator's periodic log will require minor changes, and the THTF engineering units conversion routines will be significantly modified. The MRBT software for the upgraded DAS is about 30% complete at this time.

The hardware changes needed for conversion to the new DAS consist mainly of rerouting signal and control cables. Therefore, the design effort will be minimal, but because of the number of cables involved (several hundred), the construction and checkout phase will require an appreciable investment of time. Coordination meetings with THTF project personnel were held this quarter to define locations of equipment, cable tray routing, etc., and to ensure that all of the MRBT project needs will be met in the installation of the new system.

The new DAS is based on a Digital Equipment Corporation PDP-11/34 minicomputer, using the vendor's real-time, multitask executive software, RSX-11M; all applications software will be written in FORTRAN. A block diagram of the upgraded DAS is shown in Fig. 4.1. This block diagram was adapted from a THTF project report describing the total system and includes some features that are not contained in the MRBT work. As shown in the figure, automated calibration and verification channels are not being installed for the MRBT, primarily because the mode of operation (a relatively small total number of experiments with an experiment run only every few months) does not justify the cost. The "T.S. Level" in the figure is associated with a test section level probe in the THTF. The "Safety Trips" are the end-of-experiment relay contacts ("X" thermocouples over-temperature or "Y" rods burst) in the MBTF configuration. Additional comments on Fig. 4.1 are as follows:

1. The RK05J and RK05F cartridge disks are Digital Equipment Corporation models with storage capabilities of 1.2 and 2.4 million words, respectively.
2. The magnetic tape units are Digital Equipment Corporation Model TU16, with 800 NRZI/1600 PE recording format.
3. The analog tape recorder and its digital input/output are not used in MBTF operations.
4. "1000" LPM" denotes the printer/plotter printing speed of 1000 lines/min.

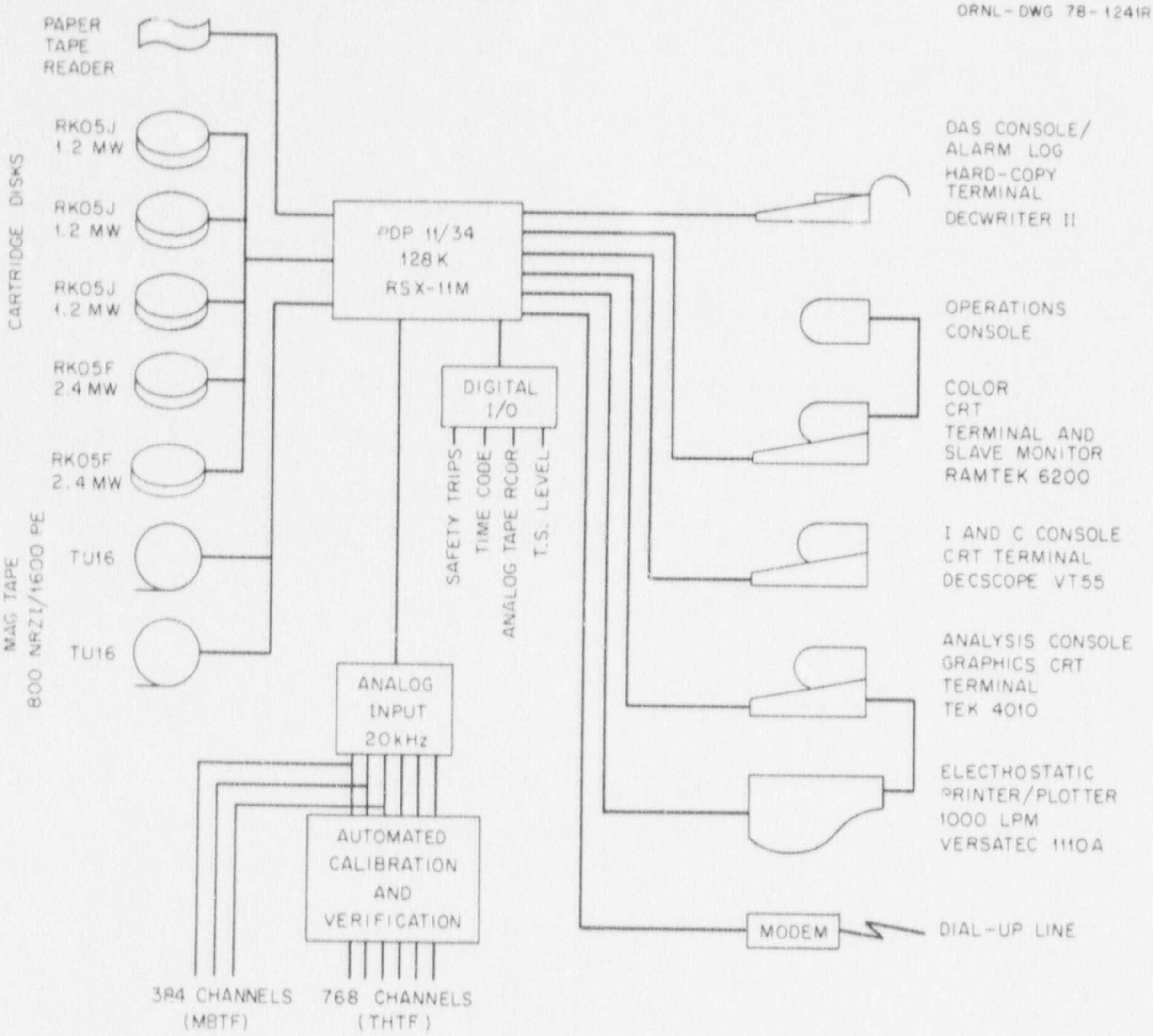

Fig. 4.1. Block diagram of upgraded data-acquisition system.

The RK05J removable cartridge disks are used as storage units for the operating system, application programs, instrumentation data base, plots, and short data scans. The magnetic tape units are primarily used to record and process data acquired from test instruments. Since they are industry compatible, the tapes can also be used to interchange data and programs with other computers. The high-speed analog input system is capable of acquiring data from 1024 high- or low-level inputs at a rate of 20,000 samples/sec. A custom computer interface for the analog input system was functionally designed at ORNL, with the detailed design and fabrication contract awarded to Datum, Inc.

Although the present DAS is adequate for the MRBT project needs, the upgraded system will provide several advantages over the present one:

1. Unlike the present system, the upgraded DAS will not be limited to one user at a time. During program development, three users can simultaneously edit, compile, or execute programs. At least three independent CRT consoles can be utilized during pretest and posttest operations to select real-time displays and periodic logs of any specified data set.

2. The improvement in computational power will allow more quick-look data analysis and instrument evaluation to be done immediately after a test. The 1000 lines/min electrostatic printer/plotter will provide both rapid printout of data and the capability of generating report quality plots. In addition, the graphic CRT terminal will be available for quickly viewing and editing plots of selected data.

3. Test data tapes can be reproduced onsite. With two magnetic tape units, a working copy of the test data tape can be made immediately after a test. This will make protecting the test data during posttest analysis more convenient. Previously, it was necessary to transport the test data tape to a computer facility located several miles from the MBTF to generate a duplicate tape.

4.2 Lower Seal Repair of B-3

J. L. Crowley A. W. Longest

High leak rates in B-3 lower seal glands occurred during burst test preparations and prevented test completion in April, as planned. The test attempt is described in Sect. 5, and the development of equipment and procedures for B-3 repair is described in Sect. 3.2. The actual B-3 repair and burst test are expected to take place in July and will be described in the next progress report.

4.3 Single-Rod Test Vessel Modifications for Heated Shroud

J. L. Crowley H. R. Payne

The initiation of procurement of a power supply to heat the shroud of the single-rod tests was described in the last progress report.[4] Delivery of the 500-kW power supply is expected in September. Meanwhile, the design has been completed for the test vessel, flange, and shroud assemblies, which incorporates a heated shroud for the single-rod burst tests. Materials and subassemblies necessary for two single-rod test assemblies have been ordered. The single-rod heated shroud will require up to 1500 A for some transient tests. The shroud is being fabricated of ∿0.8-mm-thick Inconel 600 in the shape of a cylinder of the same diameter as the present unheated shroud.

5. OPERATIONS

J. L. Crowley K. R. Carr* A. W. Longest

Operational activities of this report period consisted of an operational check of the revised MBTF steam system piping, the burst test attempt on B-3, and the development testing of lower gland seals in the single-rod facility.

After the completion of the B-3 assembly, the bundle was installed in the MBTF test vessel on March 29. By April 7, all electrical, instrument, and steam system connections had been made. The steam system had previously been revised to increase the flow of posttest cooling steam and to improve the access to the test vessel.[4] A pretest check of the revised steam piping was made April 7, during which the vessel and bundle were heated to $\sim$200°C. The pretest operation of the steam systems accomplished the intended objective — a qualitative indication of increased cooling steam flow and a steam leak test of the revised piping. However, the thermal cycle to which the bundle was subjected apparently caused the helium leaks which appeared later in the lower glands after the bundle was reheated for the attempted burst test on April 11. Room-temperature leak rates were satisfactory (from 0 to 3 kPa/min at 11,000 kPa) on April 10 before the second heatup. Heat was applied to the vessel the night before the test, and by the next afternoon, the leak rates had increased to as much as 6,000 kPa/min, making the completion of the burst test impossible.

Following system cooldown, the lower flange of the test vessel was removed and soap-bubble leak checks verified the location of leaks to be at the copper gasket between the lower Zircaloy adapter and the stainless steel portion of the insulator gland. Bundle B-3 was removed from the vessel and transported to the assembly area for further evaluation. It was decided that the bundle would not be otherwise disturbed until the leakage problem could be fully evaluated and a satisfactory solution demonstrated. The search for this solution is described in Sect. 3.2.

---

*Instrumentation and Controls Division.

REFERENCES

1. R. H. Chapman, *Multirod Burst Test Program Quarterly Progress Report for January—March 1976*, ORNL/NUREG/TM-36.

2. R. H. Chapman, *Multirod Burst Test Program Quarterly Progress Report for April—June 1977*, ORNL/NUREG/TM-135.

3. R. H. Chapman, *Multirod Burst Test Program Progress Report for July—December 1977*, ORNL/NUREG/TM-200.

4. R. H. Chapman, *Multirod Burst Test Program Progress Report for January—March 1978*, ORNL/NUREG/TM-217.

NUREG/CR-0398
ORNL/NUREG/TM-243
Dist. Category R3

Internal Distribution

1. R. E. Bohanan
2. K. R. Carr
3-17. R. H. Chapman
18. W. G. Craddick
19. J. L. Crowley
20. H. L. Falkenberry
21. D. O. Hobson
22. P. T. Jacobs
23. Milton Levenson
24. A. W. Longest
25. R. W. McCulloch
26. F. R. Mynatt
27. H. R. Payne
28-29. M. R. Sheldon
30. R. D. Stulting
31. J. R. Tallackson
32. H. E. Trammell
33. J. D. White
34. Patent Office
35. Nuclear Safety Information Center
36-37. Central Research Library
38. Document Reference Section
39-42. Laboratory Records Department
43. Laboratory Records (RC)

External Distribution

44. Director, Research and Technical Support Division, DOE, ORO
45. M. L. Picklesimer, Division of Reactor Safety Research, Office of Nuclear Regulatory Research, NRC, Washington, D.C. 20555
46-58. Special distribution by NRC
59-383. Distribution as shown in category R3 (TIC-2, NTIS-25)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1977-748-189/290