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# ELECTRICAL RESISTANCE HEATERS DEVELOPMENT STATUS REPORT

APPLIED TECHNOLOGY

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# ELECTRICAL RESISTANCE HEATERS DEVELOPMENT STATUS REPORT

By
J. A. Klea

***Energy Technology Engineering Center***

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by Energy Systems Group, Rockwell International

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## ABSTRACT

This report summarizes the results of a heater development program being conducted at the Energy Technology Engineering Center (ETEC) to provide reliable tubular heaters and mineral insulated (MI) cable for use in LMFBR liquid metal applications. The program started with the preparation of a composite procurement specification (RDT Standard P4-3T) prepared from the input of heater manufacturers, users, and the Department of Energy (DOE). This was followed by a test program designed to evaluate the effectiveness of the procurement specification requirements. Heaters were originally procured from three manufacturers - Chromalox, Rama, and Hesco. The heaters were tested in various configurations, sizes, grades, compaction density, and voltage ratings. Various means of limiting heater failure damage by the use of protective devices in the heater elecrical circuits, heater standoff designs, and resistance grounding were also accomplished as part of the technology involved in the safe use of electrical resistance heaters. In addition, a limited program evaluating MI cable for trace heating of small piping systems used for heat transport in LMFBR liquid metal applications was conducted.

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# I. SUMMARY


The tubular heater accelerated life test matrix shown in Table 1 indicates (on a small sampling) some interesting information on the life of tubular heaters with regard to the variables tested. Early in the testing, the maximum sheath temperature was adjusted to 1500 $\pm$ 25°F during an accelerated life cycle but the failure rate was not sufficiently accelerated. The maximum sheath temperature was then raised to 1700 $\pm$ 25°F. In spite of this attempt to accelerate the failure rate, many heaters were cycled at this rigorous rate for over a year before failure occurred. This caused the program to be lengthy.

Trends in the numbers of life cycles that the heaters accumulated before failure tend to indicate the superiority of one heater over another. The MgO compaction density has been shown to have a significant effect on heater life. The size or diameter of the heater has also been shown to have a primary effect on life. Bending of the heater in the heated area has been shown to decrease heater life. The rated voltage is also shown to have a substantial effect on heater life. Unfortunately, in addition to the expected trends, there are data which show very poor life from heaters in the same lot. This may indicate that quality assurance for given lots is not adequate to minimize the premature failures, or that still untested and unspecified parameters effect heater life.

The use of tubular heaters for sodium systems has been widespread and the use of MI cable generally has been limited to special cases, generally small components. Interest in the use of MI cable originated from favorable reports on its use in Europe and the expectation that it may be more easily installed on small components than tubular heaters. This interest has resulted in the establishment of a modest MI cable test program (Reference 1). The objectives were to evaluate the various methods of fabrication, installation, and reliability. The main engineering effort was concentrated on

providing a satisfactory junction between the hot element and the cold lead wire. Considerable effort was spent in this area as it appears to be the foremost weakness in the general use of MI cable. Three designs were selected for evaluation. One was provided by the cable manufacturer with the MI cable. A second consisted essentially of a commercial hermetic seal installed in the field, and the third was patterned after a design used at EBR-II involving sealing the end with a liquid sealant and brazing the lead directly to the protruding element wire (also a field installation). Subsequent testing included MI cable assemblies from French and German suppliers.

In addition to both tubular heater and MI cable evaluation testing, ETEC has completed studies dealing with electrical resistance heater failures and their potential damage to sodium piping systems. When the heater sheath is in contact with a grounded pipe or component with no failure protection except circuit breakers, failure can cause significant damage to the pipe or component due to arcing. Studies supported with experimental work were performed to evaluate three methods of solving this problem. These methods were: (1) the use of ground fault interrupters (GFI) which promptly stops the current flow when the leakage current exceeds a preselected value, (2) grounding the heater power circuit through a resistance to limit the fault current to an acceptable value, and (3) installing the heaters on standoffs.

It has been determined that the resistance grounding method will not prevent arcing damage to the sodium piping system. The most cost effective method to prevent arcing damage is to use GFI's on all heater circuits. Heaters can also be installed on standoffs where additional protective assurance is required. Test results indicate that primary GFI settings of 5 amperes leakage current maximum for 35 milliseconds maximum is reasonable and provides the protection desired.

Table 1. Heater Accelerated Life Test Matrix (1/2-in.-diameter heaters)
(Sheet 1 of 3)

| Diameter (in.) | Grade (1) | Rated Voltage (V) | MgO Density ($g/cm^3$) | Shape | Heater Manufacturer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Rama | | Hesco | | Chromalox | |
| | | | | | S/N | Cycles | S/N | Cycles | S/N | Cycles |
| 1/2 | I | 480 | >3.0 | Straight | 74-146 | 762 | 74-134 | 5,309 | 75-128 | 36,957 |
| | | | | | 74-147 | 3,071 | 74-135 | 5,315 | 75-129 | 31,159 |
| | | | | | 74-148 | 766 | 74-136 | 5,208 | 75-130 | 36,700 |
| 1/2 | I | 480 | >3.0 | S-Bend | 74-149 | 4,878 | 74-137 | 5,039 | 75-134 | 25,055 |
| | | | | | 78-143 | 3,745 | 74-138 | 7,387 | 75-132 | 8,497 |
| 1/2 | I | 480 | >3.0 | Hairpin Bend | 78-141 | 10,346 | 74-139 | 4,512 | 75-133 | 8,359 |
| | | | | | 78-142 | 15,886 | - | - | 75-131 | 15,029 |
| 1/2 | I | 480 | <3.0 | Hairpin Bend | 75-157 | 6,622 | 75-178 | 1,709 | 75-142 | 15,703 |
| | | | | | 75-158 | 1,776 | 75-179 | 1,654 | 75-143 | 6,618 |
| 1/2 | II | 480 | >3.0 | Straight | 75-164 | 8,371 | 75-171 | 9,627 | 75-135 | 6,980 |
| | | | | | 75-165 | 15,092(2) | 75-172 | 9,722 | 75-136 | 11,762 |
| | | | | | 75-166 | 15,092(3) | 75-173 | 9,609 | 75-137 | 12,826 |

Notes:

(1) Grades defined in RDT Standard P4-3T.
(2) Test terminated: 70% resistance change.
(3) Test terminated: 11% resistance change.

Test Conditions:

Cycle = 5 min "on" and 10 min "off".
Maximum sheath temperature: 1700°F.
Periodic parameter checks.

Table 1. Heater Accelerated Life Test Matrix (3/8-in.-diameter heaters)
(Sheet 2 of 3)

| Diameter (in.) | Grade (1) | Rated Voltage (V) | MgO Density (g/cm$^3$) | Shape | Heater Manufacturer Rama S/N | Rama Cycles | Hesco S/N | Hesco Cycles | Chromalox S/N | Chromalox Cycles |
|---|---|---|---|---|---|---|---|---|---|---|
| 3/8 | I | 480 | >3.0 | Straight | 76-17 | 15,980 | 76-59 | 3,925 | 76-101 | 13,160 |
| | | | | | 76-18 | 10,126 | 76-60 | 10,646 | 76-102 | 11,428 |
| | | | | | 76-19 | 16,649 | 76-61 | 6,956 | 76-103 | In test |
| 3/8 | I | 480 | >3.0 | Hairpin Bend | 76-20 | 9,547 | 76-63 | 12,836 | 76-105 | 13,350 |
| | | | | | 76-21 | 2,703 | 76-64 | 57 | 76-106 | 15,146 |
| | | | | | 76-22 | 2,487 | 76-65 | 1,017 | 76-107 | 27,638 |
| 3/8 | I | 240 | >3.0 | Straight | 76-24 | 4,548 | 76-66 | 3,143 | 76-108 | 35,145 |
| | | | | | 76-25 | 3,036 | 76-67 | 1,955 | 76-109 | 36,556 |
| | | | | | 76-26 | 4,436 | 76-68 | 1,795 | 76-110 | 36,317 |
| 3/8 | II | 480 | >3.0 | Straight | 76-38 | 13,746 | 76-80 | 7,076 | 76-122 | 77 |
| | | | | | 76-39 | 7,720 | 76-81 | 280 | 76-123 | 33,691 |
| | | | | | 76-40 | 2,802 | 76-82 | 13,140 | 76-124 | 380 |
| 3/8 | II | 240 | >3.0 | Straight | 76-45 | 10,210 | 76-87 | 11,897 | 76-129 | 32,310 |
| | | | | | 76-46 | 12,591 | 76-88 | 9,424 | 76-130 | 34,132 |
| | | | | | 76-47 | 12,494 | 76-89 | 13,152 | 76-131 | 36,991 |

Notes:

(1) Grades defined in RDT Standard P4-3T.

Test Conditions:

Cycle = 5 min "on" and 10 min "off".
Maximum sheath temperature: 1700$^{\circ}$F.
Periodic parameter checks.

Table 1. Heater Accelerated Life Test Matrix (1/4-in.-diameter heaters)
(Sheet 3 of 3)

| Diameter (in.) | Grade (1) | Rated Voltage (V) | MgO Density ($g/cm^3$) | Shape | Heater Manufacturer | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Rama | | Hesco | | Chromalox | |
| | | | | | S/N | Cycles | S/N | Cycles | S/N | Cycles |
| 1/4 | I | 240 | >3.0 | Straight | 76-52 | 3,989 | 76-94 | 8,315 | 76-136 | 6,636 |
| | | | | | 76-53 | 7,544 | 76-95 | 1,533 | 76-137 | 6,092 |
| | | | | | 76-54 | 10,074 | 76-96 | 755 | 76-138 | 10,747 |
| 1/4 | II | 240 | >3.0 | Straight | 76-31 | 9,625 | 76-73 | 5,563 | 76-115 | 20,399 |
| | | | | | 76-32 | 9,966 | 76-74 | 3,305 | 76-116 | 7,537 |
| | | | | | 76-33 | 8,241 | 76-75 | 3,344 | 76-117 | 1,551 |
| 1/4 | II | 240 | >3.0 | Hairpin Bend | 76-34 | 11,806 | 76-76 | In test | 76-118 | In test |
| | | | | | 76-35 | In test | 76-77 | 10,495 | 76-119 | In test |
| | | | | | 76-36 | In test | 76-78 | 8,888 | 76-120 | In test |

Notes:

(1) Grades defined in RDT Standard P4-3T.

Test Conditions:

Cycle = 5 min "on" and 10 min "off".
Maximum sheath temperature: 1700°F.
Periodic parameter checks.

## II. CONCLUSIONS AND RECOMMENDATIONS

### A. CONCLUSIONS

The following conclusions are based upon the evaluation tests completed to date:

1) Of the various manufacturers' tubular heaters tested, the Chromalox heaters have exhibited a significantly longer and more consistent accelerated life. However, Rama and Hesco also appear to be viable sources for tubular heaters.

2) In general, the larger-diameter heaters, when operated at the same voltage, exhibit a longer average life than the smaller-diameter heaters. The operating voltage (3/8-inch diameter heaters) and MgO density have a significant effect on heater life.

3) Bending of the heaters in the heated length, as anticipated, decreased the heater life when compared to heaters of the same lot tested in the straight configuration.

4) The accelerated life test results indicate that tubular heaters have significantly greater reliability than the MI cable, but MI cable reliability may be sufficient for selected LMFBR plant applications.

5) MI cable offers some advantages over tubular heaters such as flexibility and being able to be used for odd-shaped components such as valves or sodium pressure transducer seals. However, the voltage to individual heaters or heating systems must be tailored to not exceed predetermined current limits or premature failure will occur.

6) Termination technique, MgO purity and MgO compaction density are areas which require the greatest control for maintaining or improving the MI cable reliability.

7) ETEC personnel found the installation of tubular heaters to be easier and faster than the installation of MI cable.

8) Thermal-magnetic circuit breakers and fast-blow fuses are not sufficient to prevent damage to the surface the heater is mounted on in the event of a tubular heater failure. Ground fault interrupters have been shown to provide adequate protection from heater failure damage. The protection can be further enhanced by employing a heater standoff mounting arrangement.

9) Heater failure has not been a major problem at either ETEC or FFTF after construction and plant checkout is completed. Failure during service of heaters procured to RDT Standard P 4-3T are rare in spite of the large number of heaters utilized at each facility.

## B. RECOMMENDATIONS

Based on the results obtained during the evaluation tests performed, the following recommendations are made:

1) RDT Standard P 4-3T (Reference 2) should be replaced with a heater procurement specification which more closely controls heater details and provides qualification to LMFBR plant requirements.

2) The majority of electrical resistance heaters used for an LMFBR plant should be 1/2-in.-diameter tubular heaters with a 480-volt rating derated to 277 operating voltage, and with the heated length maintained in a straight configuration. The Grade I heater requirements should be used in all critical applications but the lower cost Grade II heaters may suffice for some applications.

3) If small odd-shaped components such as valves require heat, it is recommended that 3/8 or 1/4-in.-diameter heaters be considered in lieu of MI cable.

4) In order to minimize both design and installation problems, it is recommended that the Preferred Practices Manual (Reference 3) be followed to minimize premature heater failures due to improper design or installation practices.

5) To prevent or restrict damage to the sodium containment boundary caused by an electrical resistance heater failure, all heater circuits should be provided with redundant ground fault interrupters (GFI's) set to initiate power cutoff when ground current is 5 amps or greater within 35 milliseconds.

6) The heater evaluation program should be extended. Other variables such as higher purity MgO, improved quality element wire, and different sheath materials should be evaluated in an attempt to improve heater life.

## III. INTRODUCTION

In 1971, ETEC was requested to prepare an RDT Standard for electrical resistance heaters to support component testing at ETEC, to be utilized for procurement of the FFTF plant heaters, and to be utilized on commercial LMFBR plants. The procurement standard was prepared based upon input from a number of electrical resistance heater manufacturers and also from heater user experience.

During preparation of the standard, it became clear that little test data existed in the open literature to verify which design features contribute to reliable performance. Many companies contended that data had been generated but was company proprietory. Others suggested that data had been previously developed on various classified military programs; however, this could not be confirmed. Because of the lack of verifiable data, ETEC was asked to initiate a test program to evaluate the significance of various design features on heater life.

Since heater life in normal operation must be in excess of 30 years, it was necessary to establish an accelerated life test program to evaluate the relative effects of different features. Although it has not been possible to establish a correlation between performance in the accelerated life test and plant life, it is possible to determine if individual heater features significantly add to or reduce heater life from the accelerated life test data. Unfortunately, even the accelerated life test is time consuming since some heaters have survived in excess of one year in the test. Hence, only those features originally judged to be the most significant have been tested to date.

Early in the program, it became clear that heaters could not be treated solely as a component because both their performance and their life was imminently connected to their application both physically and electrically. ETEC was then requested to evaluate methods to prevent damage to components being heated in case the heater fails (see Reference 4) and to provide preferred methods of handling, installing, and testing heaters and their protective equipment.

This report was prepared to review the progress made on this program to date and recommend a future course of action.

# IV. PREHEAT REQUIREMENTS FOR SODIUM SYSTEMS

Electrical resistance heaters are used extensively in liquid metal cooled reactor plants to preheat the liquid metal and/or metal vapor containment systems prior to filling the system. In addition, electrical resistance heaters provide the heat required to maintain selected portions of the system - such as the purification loop - at their normal operating temperatures during plant operation. The electrical heating system also provides the makeup heat required to maintain the liquid metal coolant system during refueling and during extensive reactor shutdown periods. The following requirements were taken from Reference 4, which provides the latest known requirements for a loop-type liquid metal cooled plant and should, in general, be applicable to all loop-type plants and to portions of pool-type plants.

## A. FUNCTIONAL REQUIREMENTS

The piping and equipment electrical heating and control system performs the following heating functions for all the systems which contain sodium or sodium vapor during operation of the plant:

1) Preheating of components of sodium process systems from ambient temperature to 450°F (232°C), before filling them with liquid sodium. This heating function is accomplished at a controlled heatup rate to minimize temperature differentials within and among components of the process systems.

2) Heating of components of sodium processing systems from extended plant shutdown conditions to full reactor operating conditions, with components already filled with sodium. This function is achieved at prescribed heatup rates and specific starting and terminating temperatures.

3) Holding heat, or heat to maintain sodium-filled piping and components indefinitely at the required conditions. In this function, the heat provided by the system overcomes all heat losses from normal heat-leakage paths and on-going process functions and takes into account all available heat sources such as heat from operating pumps, reactor core decay heat, etc.

4) Sequential heating to melt sodium in sections of piping and components within a process system in which sodium is frozen due to a planned event or an unplanned casualty event. This melting function is achieved by controlled heating of sections of the system in a sequential mode, starting from a free surface to avoid damage to the equipment due to the sodium thermal expansion.

5) Standby heating of emergency drain lines.

## B. OPERATIONAL REQUIREMENTS

The piping and equipment electrical heating and control system shall meet the following operational and design requirements for all sodium process systems:

1) Preheating the outer surface of all components containing liquid sodium, for each liquid metal system, from ambient temperature to 450°F (232°C) at a nominal rate not to exceed 3°F/hr. After a soak at a 450°F (232°C) surface temperature (to preheat the internals to a nominal temperature of 400°F (204°C)), the surface temperature will be allowed to cool to 400°F (204°C). The heatup rate may vary from the 3°F/hr if temperature distribution does not exceed the allowable stresses of the components.

2) Heaters and controls shall be arranged so that it will be possible to melt frozen sodium in the piping and components of the liquid metal system. Melting shall begin at a free sodium surface and sequentially progress through the system to avoid damage due to sodium expansion.

3) Process system temperatures shall be held at the prescribed temperatures for that particular system, subsystem, piping, and/or component.

4) Heaters shall be automatically operated and controlled from local control panels.

5) Non-operating spare heaters and control thermocouples shall be installed in inaccessible areas.

6) All heater circuits shall be provided with ground fault protection.

7) Contiguous components, such as tanks and related nozzles, piping, and valves shall be heated at comparable heating rates to minimize temperature differentials.

8) Heaters shall be either tubular resistance type or mineral insulated (MI) cable.

9) Heaters shall be operated at derated power to ensure the required heater design life for each system. Heaters shall operate nominally at less than one-half of their rated power.

10) Heaters and control thermocouples shall be arranged on the equipment to ensure temperature distribution and rate of change of temperature within the required design limits.

11) The failure of the heating system shall not impair the safety function of associated systems and components.

12) On components and piping requiring standoff heaters, the heaters shall be supported a minimum of 1/4 in. from the surface of sodium-containing pipes and vessels. For equipment and piping where standoffs are not required, the heaters can be mounted directly on the metal.

## C. STRUCTURAL REQUIREMENTS

All equipment provided by the piping and equipment electrical heating and control system shall be designed to operate and remain functional within the structural requirements as described in the following paragraphs.

### 1. Environmental Condtiions

Environmental conditions for specific heater locations are tabulated in Table 2.

### 2. Design Thermal Transients

Heaters are subject to the thermal transients that cause their temperature to be higher or lower than the temperature of the components to which they are attached. The heater installation shall allow for this temperature difference between the heater and the component, without any resulting damage to the heater and without violating the minimum standoff clearance.

### 3. Seismic Design

The piping and vessels electrical heaters are classified as seismic category II equipment and shall be designed to withstand an SSE without damage to process components and piping. Heaters shall be seismically qualified by analysis and/or test.

### 4. Vibration

Heaters are subjected to continuous vibration forces originating in the components to which they are attached. Heaters shall be designed to withstand vibration forces equivalent to the displacement and the frequency of the components on which they are installed. Qualification of heaters shall be by analysis and/or testing for the peak acceleration resulting from the piping and vessels vibration, to ensure that they will withstand peak acceleration over the frequency range applied.

Table 2. Heater Environmental Requirements

| Function | Equipment Location A | B | C | D |
|---|---|---|---|---|
| Temperature | | | | |
| (Max.) | 1200°F | 135°F | 1200°F | 110°F |
| (Min.) | 40°F | 55°F | 40°F | 50°F |
| Pressure | | | | |
| (Max.) | 35 psig | 35 psig | Atmospheric | Atmospheric |
| (Min.) | -2.75 W.G. | -2.75 W.G. | -2.75 W.G. | -2.75 W.G. |
| Atmosphere | Air/nitrogen + 0.5% to 2.0% oxygen | Air/nitrogen + 0.5% to 2.0% oxygen | Air | Air |
| Relative Humidity (Water Vapor) | | | | |
| (inerted) | 1000 ppm | 1000 ppm | 5%-95% | 5%-95% |
| (de-inerted) | 5%-95% | 5%-95% | | |
| Radiation | Compatible with the plant criteria | | | |

Legend:

A = Within nitrogen cells and within outer insulation sheath.

B = Within nitrogen cells and outside outer insulation sheath.

C = Within SGB, RSG, and within outer insulation sheath.

D = Within SGB, RSG, and outside outer insulation sheath.

## 5. Heater Allowable Stresses

Heaters shall maintain their structural integrity when subjected to the long-term effects of continuous operation at less than 1000°F for 30 years, intermittent exposure of the heater sheath to an ambient temperature of up to 1200°F, and short-term effects from seismic events.

# V. HEATER DESCRIPTION

## A. TUBULAR HEATERS

A typical tubular heater is shown in Figure 1. The major parts are: (1) the heating element, (2) the cold end conductors, (3) the electrical insulation, (4) the sheath, (5) the seal, and (6) the electrical terminations.

The heating element is a helical wound metallic wire or ribbon strung between two cold end conductors. The element is usually a nickel-chromium alloy although nickel-chromium-iron and iron-chromium-aluminum alloys have also been extensively utilized. Multiple heating elements have also been utilized by some manufacturers. The RDT Standard limits the element to a single strand wire with a minimum diameter of 0.010 in.

The cold end conductors are low electrical resistance elements utilized to provide an electrical path through the thermal insulation. They are required to prevent over-temperature and early failure which would occur if the heating element was allowed to extend through or into the thermal insulation. These are usually larger diameter (0.125 in.) mild steel or nickel rods. The heating element is normally welded to the cold end conductor.

The electrical insulation surrounds the heating element and the cold end conductors and prevents electrical shorting to the sheath. The insulating material is usually magnesia (MgO) or alumina ($Al_2O_3$).

The sheath is the heater outer housing. Its purpose is to provide the mechanical strength to support the heater element, the cold ends, and the electrical insulation, maintain their configuration, and protect them from physical harm. The sheath is normally a stainless steel, Incoloy or Inconel tube which has been drawn or swaged to provide compaction of the electrical insulation.

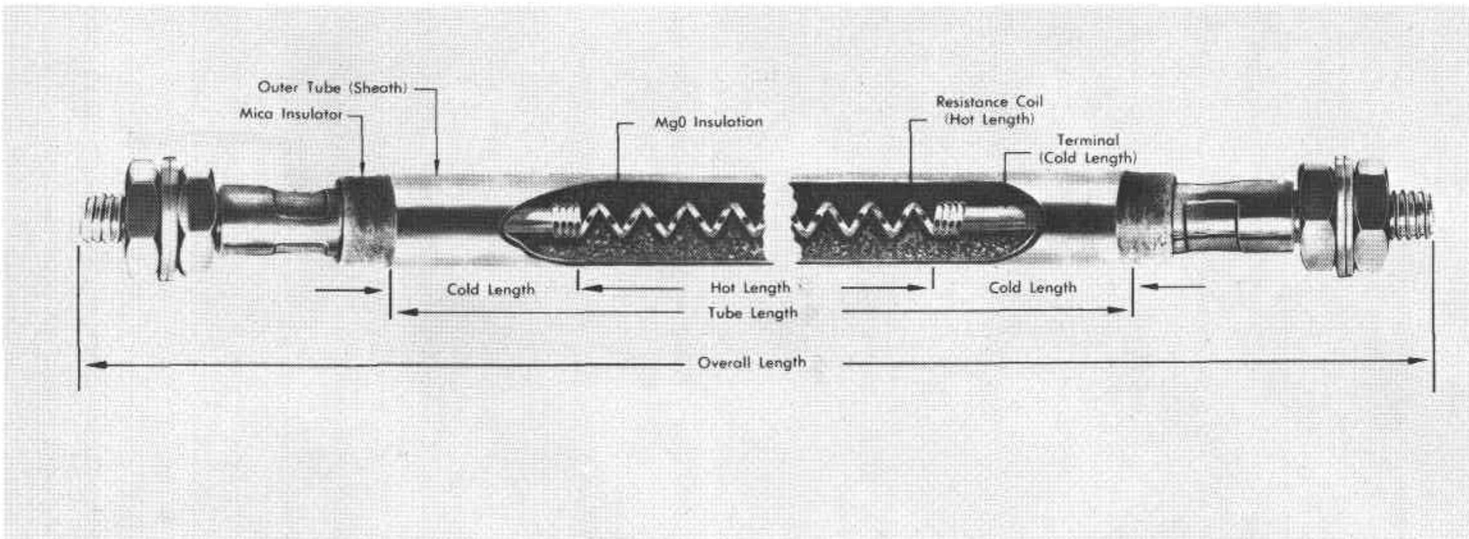


Figure 1. Cutaway View of Standard Tubular Heater (Typical)

The purpose of the seal is to retain the electrical insulation material at the point where the cold end conductor protrudes through the sheath and to prevent or minimize the amount of moisture passing into the electrical insulation when the heater is cold. The seal can either be non-hermetic or hermetic.

The purpose of the electrical termination is to allow field connections to the electrical distribution system. Threaded terminations are shown in Figure 1. This type of termination has been proven to be highly successful and efficient provided the terminal temperature does not exceed 150°F. If the temperature does exceed 150°F, then another method of connection must be made. This is one area where further development must be conducted to minimize the problems experienced at FFTF.

## B. MINERAL INSULATED CABLE

A typical section of MI cable is shown in Figure 2. The major parts are: (1) the heating element or center conductor, (2) the electrical insulation, and (3) the sheath. The cold end conductors, end seals, and electrical terminations were typically installed by ETEC in an attempt to evaluate these variables. However, several designs of MI cable with cold ends, seals, and electrical terminations are available from MI cable manufacturers.

The heating element is one of the major differences from tubular heater construction in that it is straight wire as opposed to the helical wound metallic wire or ribbon found in tubular heaters. Multiple heating elements as well as various diameter center conductors (ohms/ft) are available. Surrounding the heating element is an insulating material which is generally magnesa (MgO) or alumina ($Al_2O_3$). The insulation prevents shorting of the center element to the sheath as well as providing a heat transfer medium between the element wire and the sheath. The outermost surface of the cable is referred to as the heater sheath. The sheath provides the mechanical

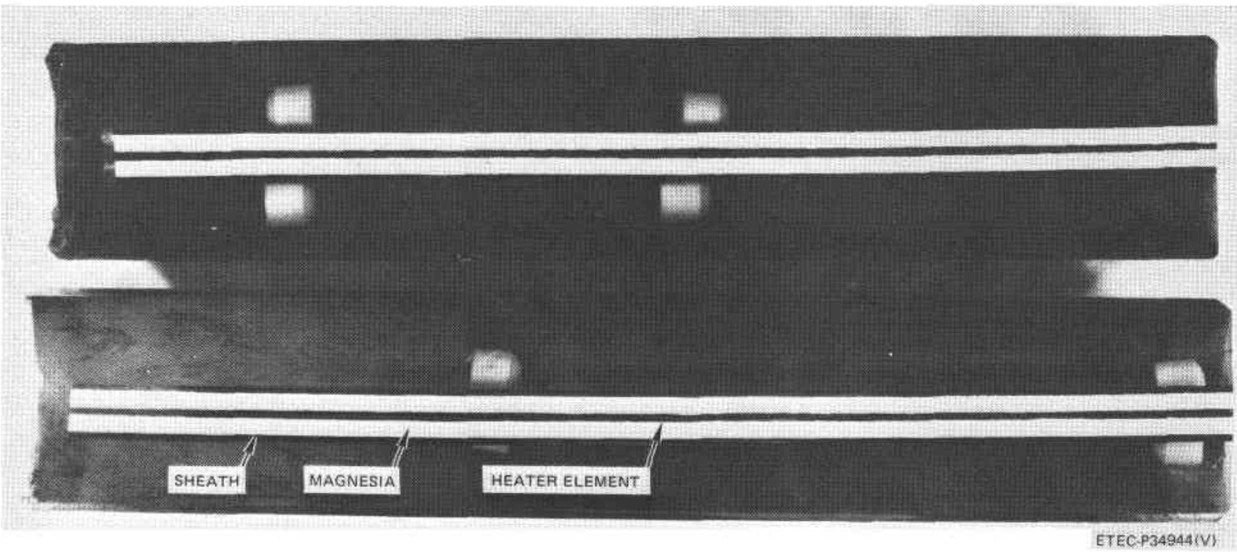


Figure 2. Sections of MI Heater Cable (Typical Construction)

strength to both support and protect the heating element wire, the insulation, and the cold end termination. This sheath material is normally a 300 series stainless steel, Inconel or Incoloy tube which is drawn or swaged to provide compaction of the electrical insulation. The compaction of the insulation material is necessary to improve the heat transfer between the center conductor and sheath.

When the MI cable is purchased in bulk (roll), the ends are sealed by the manufacturer. If the cable is cut to a specific length, the ends must be resealed as soon as possible to prevent or minimize moisture entering into the insulation which is hygroscopic. The sealing operation must be preceded by a drying operation. One drying technique is to heat the cable to 350°F (177°C) for at least 10 hours to ensure all moisture is driven out. One method of sealing is to place the ends into a liquid sealing material, such as "Aeroseal" (ARI P/N 61226-2), while the cable is still hot.

A variety of field-installed cold end terminations were evaluated. The purpose of the electrical termination is to allow connections to the electrical distribution system. It is this cold end electrical termination which has proved to be the greatest weakness in the reliability of the MI cable. Of course, the cold end termination can be purchased from the manufacturer, but this impacts the "field cut to length as needed" feature of the MI cable.

An RDT Standard or other similar standard for imposing material, fabrication, or quality control requirements onto the manufacturer does not exist at this time. Commercial quality MI cable was purchased for the evaluation test program.

# VI. PROCUREMENT, INSTALLATION, AND PROTECTIVE REQUIREMENTS

## A. TUBULAR HEATERS

### 1. Variables Which Affect Heater Life

In order to maximize the reliable operation of heaters, it is necessary to know which parameters affect heater lifetime. At the start of this development program, considerable effort was expended soliciting both heater manufacturers and heater users experience to identify those parameters which must be controlled in the procurement phase, and those parameters which must be controlled in the application (including storage and installation) phase. Parameters which must be controlled during the procurement phase were identified as:

1) Element wire material and cleanliness
2) Element wire diameter
3) Cold end conductor material
4) Method of connecting element wire to cold end conductor
5) Element helix aspect ratio
6) Uniformity of element wire pitch
7) Electrical insulation material and impurities
8) Insulation material particle size and/or particle size distribution
9) Electrical insulation material compaction density and compaction density uniformity
10) Electrical insulation material thermal conductivity
11) Insulation thickness
12) Sheath material and cleanliness
13) Sheath fabrication technique
14) Sheath diameter
15) Sheath metallurgical condition
16) Heater element centering within the sheath
17) Cold end to external electrical wire connection provision
18) Cold end seal technique
19) Voltage and power (watt density) rating
20) Length of heated and cold end sections
21) Quality control.

Parameters which must be controlled after procurement were identified as:

1) Cleanliness
2) Handling
3) Bending
4) Method of installation
5) Operating voltage and/or operating power
6) Operating temperature of element wire and sheath
7) Temperature control technique
8) Over-voltage / over-current protection
9) Fault detection technique and speed.

Radiographs of a random selection of commercial heaters, Figure 3, demonstrate the extent of manufacturing anomalies that can be anticipated and only be varified by extensive post-fabrication inspection.

## 2. RDT Standard P 4-3T

Many tubular heater manufacturers, a number of users of tubular heaters across the United States, and the RDT I&C Branch participated in the preparation of this consensus RDT Standard to be used as a basis for the procurement document for metal-sheathed, mineral-insulated electrical resistance heaters for FFTF and other LMFBR applications. Emphasis in preparing this standard was placed on controlling material and construction requirements which were important in extending heater life and performing acceptance tests to verify good construction.

Electrical resistance heaters cover a large variety of heaters such as strip, cartridge, band and tubular. The standard was restructed to single-wire, helical heater elements, metal-sheathed, double-ended heaters with compacted mineral-oxide insulation. The standard was prepared specifically for applicability to liquid metal heat transfer systems for both preheating or heating and maintaining component operating temperatures up to 1200°F (649°C). In addition, the heaters are classed in grades according to the application. Heaters for general application in which heater replacement is acceptable to the program are given a Grade II classification. These heaters

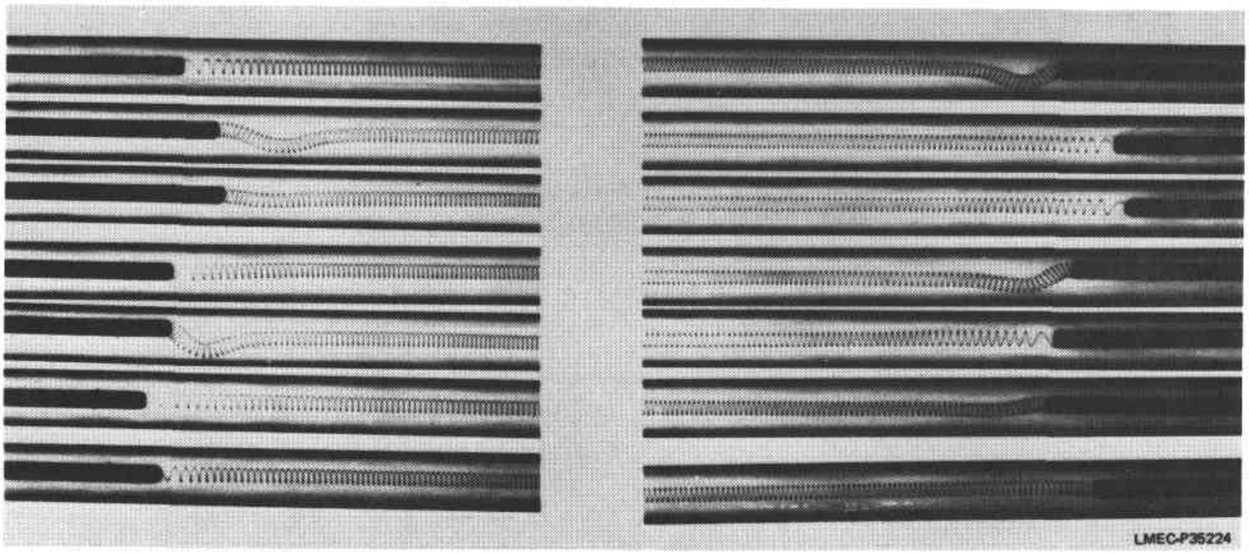


Figure 3. Radiographs - Heater Element Anomalies (Sheet 1 of 4)

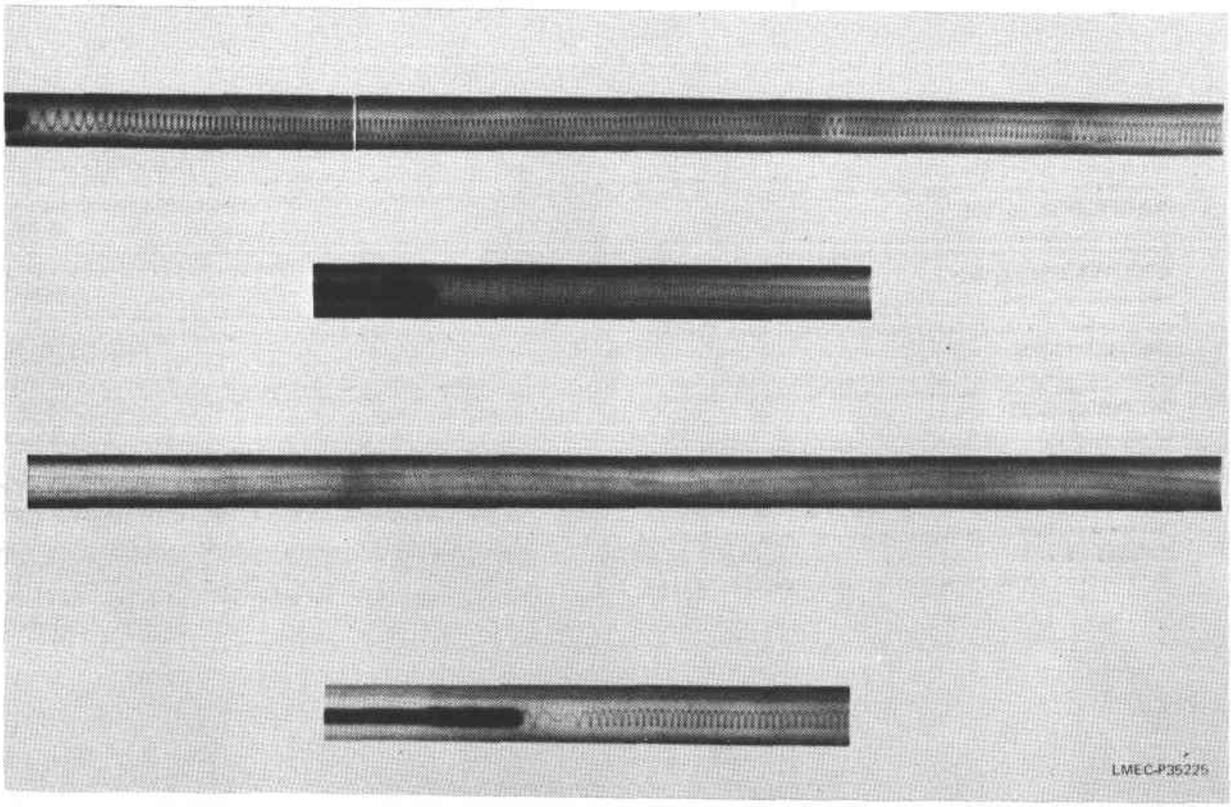


Figure 3. Radiographs - Heater Element Anomalies (Sheet 2 of 4)

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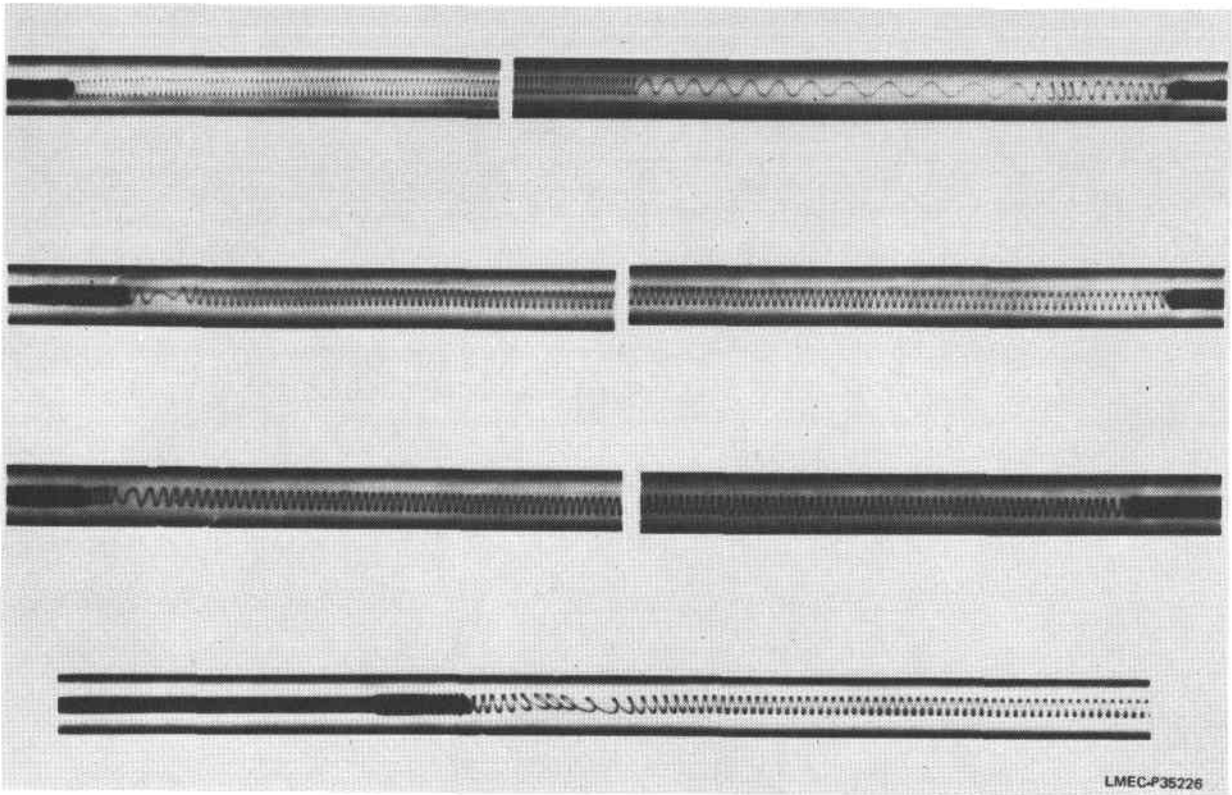


Figure 3. Radiographs - Heater Element Anomalies (Sheet 3 of 4)

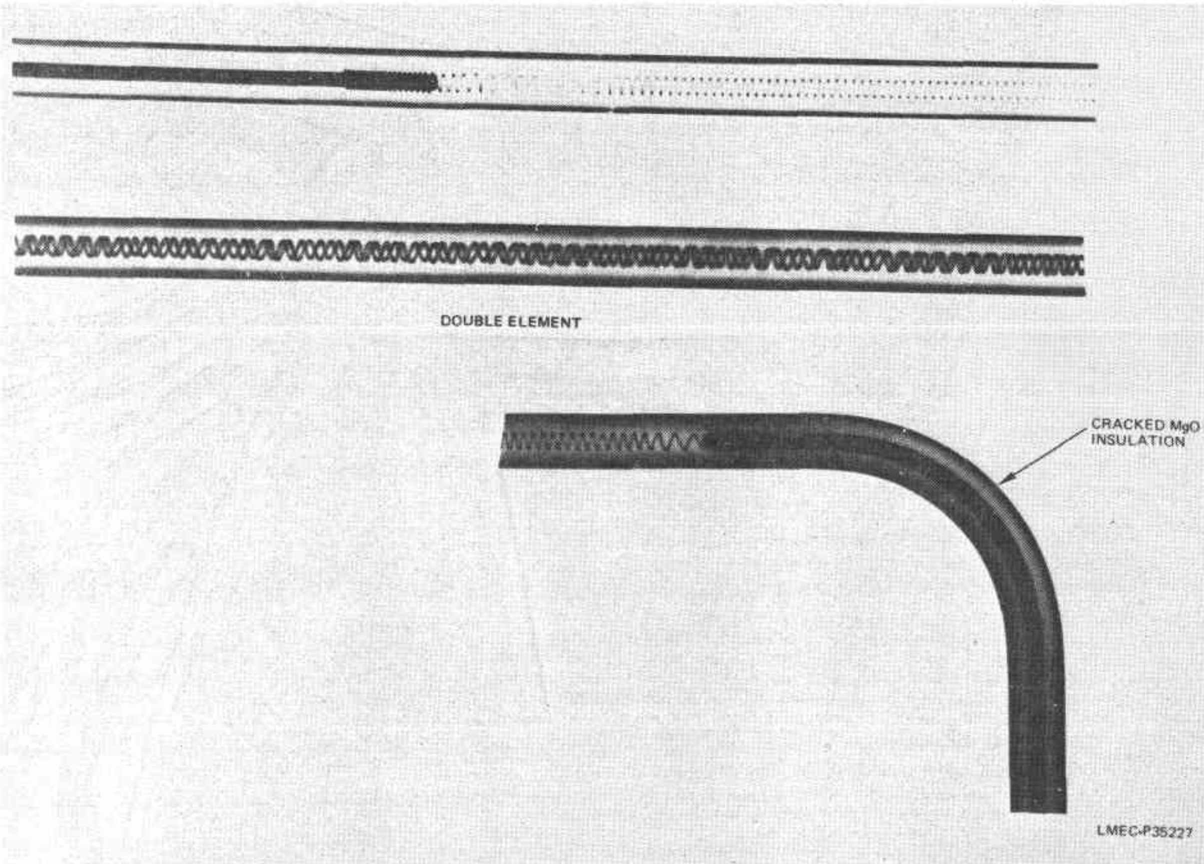


Figure 3. Radiographs - Heater Element Anomalies (Sheet 4 of 4)

are specified for nearly all applications at ETEC. Premium heaters are classed as Grade I and are subjected to extensive in-process and post-fabrication quality verification to reduce the probability of random failures in service. The Grade I heater would be specified in applications where a heater failure would be extremely difficult to replace and jeopardize critical operations.

To ensure quality materials and methods are used to fabricate the heaters, a series of additional RDT standards, American National Standards (ANSI), and American Society for Testing and Materials (ASTM) standards are included in the RDT P4-3T specification.

Within the RDT standard are performance, mechanical, electrical, materials, fabrication, quality assurance, preparation for delivery, and ordering data requirements. All of the requirements were delineated in an effort to improve the quality of the heater without instituting requirements that are not practical or achievable by the potential heater manufacturer. After review by both heater users and heater manufacturers, the standard was released.

Many of the United States tubular heater manufacturers were invited to bid on the tubular heater orders. Four manufacturers accepted. They were the Edwin L. Wiegand Division (Chromalox) of Emerson Electric of Pittsburgh, PA; the Rama Corp. of 39651 Esplanade Street, San Jacinto, CA; Heat Engineering and Supply Co. (Hesco) of 213 East Valley Blvd., San Gabriel, CA; and Sensor Dynamics, Inc., Chicago, IL.

3. Preferred Practices Manual

The method chosen by the RDT I&C Branch to control application of electrical trace heaters was to prepare a Preferred Practices Manual. ETEC was assigned the task of initiating this manual. The following sections were prepared to cover tubular-type electrical resistance heaters:

| | |
|---|---|
| PPM-II-A-1.2 | Temperature Control for Electrical Resistance Heaters Application and Design |
| PPM-II-A-1.3 | Electrical Resistance Heater Circuit Protection Systems - Application and Design |
| PPM-II-A-3.1 | Tubular Electrical Heater Receiving Inspection |
| PPM-II-A-3.2 | On-Off Relay-Type Temperature Controller Receiving Inspection |
| PPM-II-A-5.1 | Surface Mounted Tubular Electrical Heater Installation Procedure |
| PPM-II-A-5.1-1 | Standoff-Mounted Tubular Electrical Heater Installation Procedure |
| PPM-II-A-5.3 | Ground Fault Interrupter System Installation Procedure |
| PPM-II-A-6.1 | Heater Control System Post-Installation Checkout Procedure |
| PPM-II-A-6.3 | Ground Fault Interrupter Post-Installation Checkout Procedure |
| PPM-II-A-6.3-1 | Ground Fault Interrupter System, Emergency Checkout Procedure |
| PPM-II-A-6.4 | Heater Control System with Proportional Controller and External SCR Post-Installation Checkout Procedure |
| PPM-II-A-6.4-1 | Heater Control System with Proportional Controller and Internal Triac Post-Installation Checkout Procedure |
| PPM-II-A-7.3 | Ground Fault Interrupter System Maintenance. |

These PPM's are used routinely at ETEC to control electrical resistance heating systems. The PPM's are available to all LMFBR participants who request them. Revisions are made as necessary to refine the procedure based upon both internal and external feedback.

Preparation of PPM's for mineral-insulated cables has not been initiated because they have not been adopted for general use on LMFBR plants.

## B. MINERAL-INSULATED (MI) CABLE

### 1. Variables Which Affect Heater Life

It is generally regarded in the industry that many of the same variables which affect tubular heater life also affect MI cable life. The exceptions, of course, are element wire helix diameter, helix pitch, and aspect ratio. On the other hand, it is generally suspected the end termination method will have an even greater effect on heater life of MI cable than it does on tubular heaters. Because of the smaller external diameter, higher insulation compaction densities can be obtained during fabrication of MI cables than can be obtained when manufacturing tubular heaters. This provides the possibility of obtaining a lower element wire operating temperature.

### 2. Procurement Specification

An RDT STandard was not prepared for MI cables since it was not seriously considered for application on FFTF. However, because of the interest in using the MI cable on CRBR, GE prepared specification number 23A2655 (Reference 5) for the purchase of MI cable assemblies for use on CRBR.

# VII. HEATER TEST DESCRIPTION AND RESULTS

## A. TUBULAR HEATERS

### 1. Accelerated Life Test Description

In order to ascertain the effectiveness of this procurement document, heaters were procured in accordance with the RDT P4-3T standard and an accelerated life test program was initiated. The test is based upon the knowledge that heater life decreases with increased power cycling and increased operating temperature. Since cycling the heaters within normal operating temperature limits would take an excessive amount of test time, an accelerated life type program had to be initiated to evaluate the relative merits of different design features and different manufacturers. As shown in the heater accelerated life test matrix (Table 1), heaters were ordered in different lots and at different times to accommodate the variables listed. Heater size (length and diameter), grade, rated voltage, MgO density, total wattage or watts/in.$^2$, heated length, and cold end length are the typical variables which are specified for a given heater order. The individual heaters were serialized to provide traceability of materials and fabrication time period. The serial numbers shown in the heater accelerated life test matrix indicate the year purchased followed by a dash and a unique number assigned to an individual heater.

Heater accelerated life testing is conducted in a special heater test facility, which is a wire-screen-enclosed area 10 x 25 ft (3 by 7.5 m), located within Building 057. Within the enclosed area are nine oven-type test boxes on three tables in which the heaters are installed for accelerated life testing. A typical test heater installation, with the enclosure tops in place, is shown in Figure 4. Six oven-like boxes are shown which contain the tubular heaters under test are shown. The heater voltage control cabinet is shown in the background.


Figure 4. Accelerated Life Test Facility Showing Six Test Ovens

Figure 5, is a closeup view of two ovens with the tops removed. Two hairpin-shaped heaters are shown. Each heater is supported over its length by several small-diameter stainless steel wires to reduce "sag" at the elevated temperature while minimizing thermal loss and hot-spot or cold-spot formation. The attachment of monitoring thermocouples (three, type K) is also shown on each heater. Early in the heater evaluation test program, small thermocouples were spot-welded to the heater sheath, but during thermal cycling of the heater, oxidation of the sheath would occur and the thermocouple would fall off.

Another method of attachment was developed which percussion-welded individual thermocouple wires to the heater sheath. The uninsulated thermocouple wire attached by percussion welding can be seen in Figure 6. After the thermocouple wires are welded, small ceramic beads are strung onto the wires to provide insulation. As shown in Figure 7, these thermocouples are used to control the sheath temperature of the heaters during accelerated life cycle testing.

The tubular heaters shown in Figure 5 are being tested in the hairpin configuration, but straight and "S" bend heaters are tested as well. The program was conducted on 1/2, 3/8, and 1/4-in.-diameter heaters.

The accelerated thermal life test is the primary means being used to obtain relative heater quality and reliability data. All of the tubular heaters being evaluated and tested were procured and manufactured to RDT Standard P4-3T in one of two grades (Grade I or II). After the heaters are fully X-rayed, they are installed into the oven-type enclosures shown in Figure 4.

The tubular heaters are connected to a 3-phase, 480-volt, variable-voltage supply. The voltage is increased to each heater individually until its sheath temperature reaches 1700 $\pm$ 25$^{\circ}$F (920 $\pm$ 14$^{\circ}$C). Generally, the voltage must exceed (slightly) the rated voltage of the heater to achieve

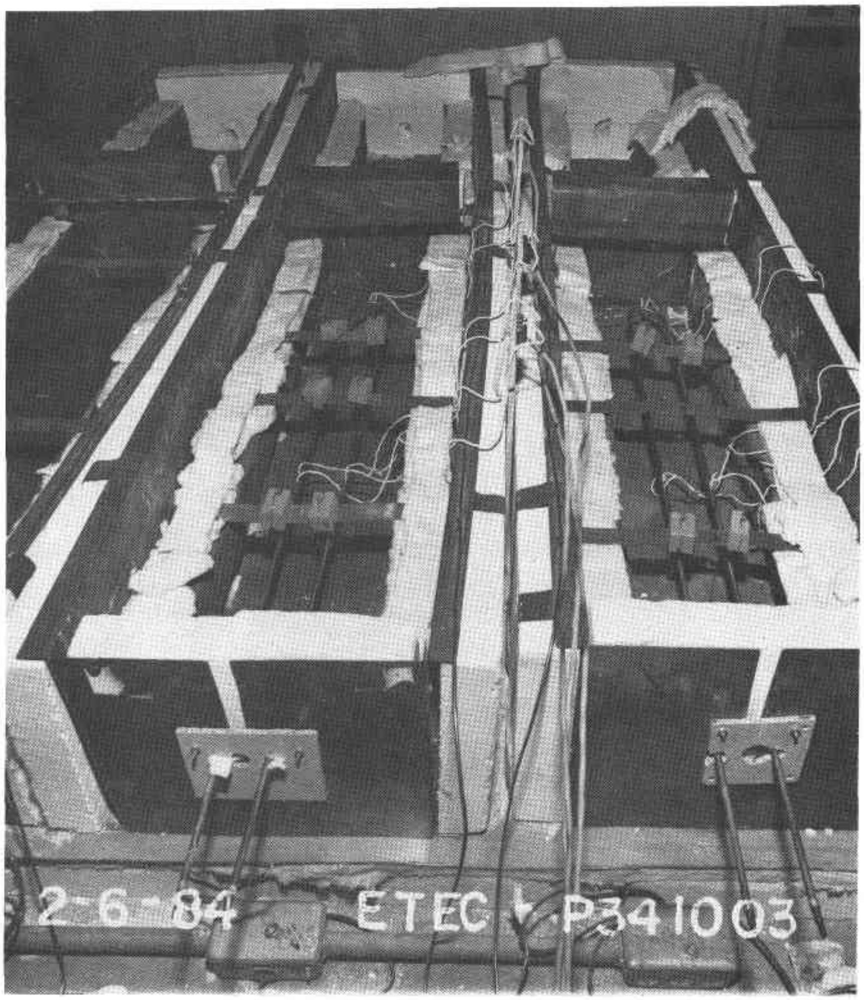


Figure 5. Two Test Ovens with Cover Removed Showing Two Hairpin-Type Heaters

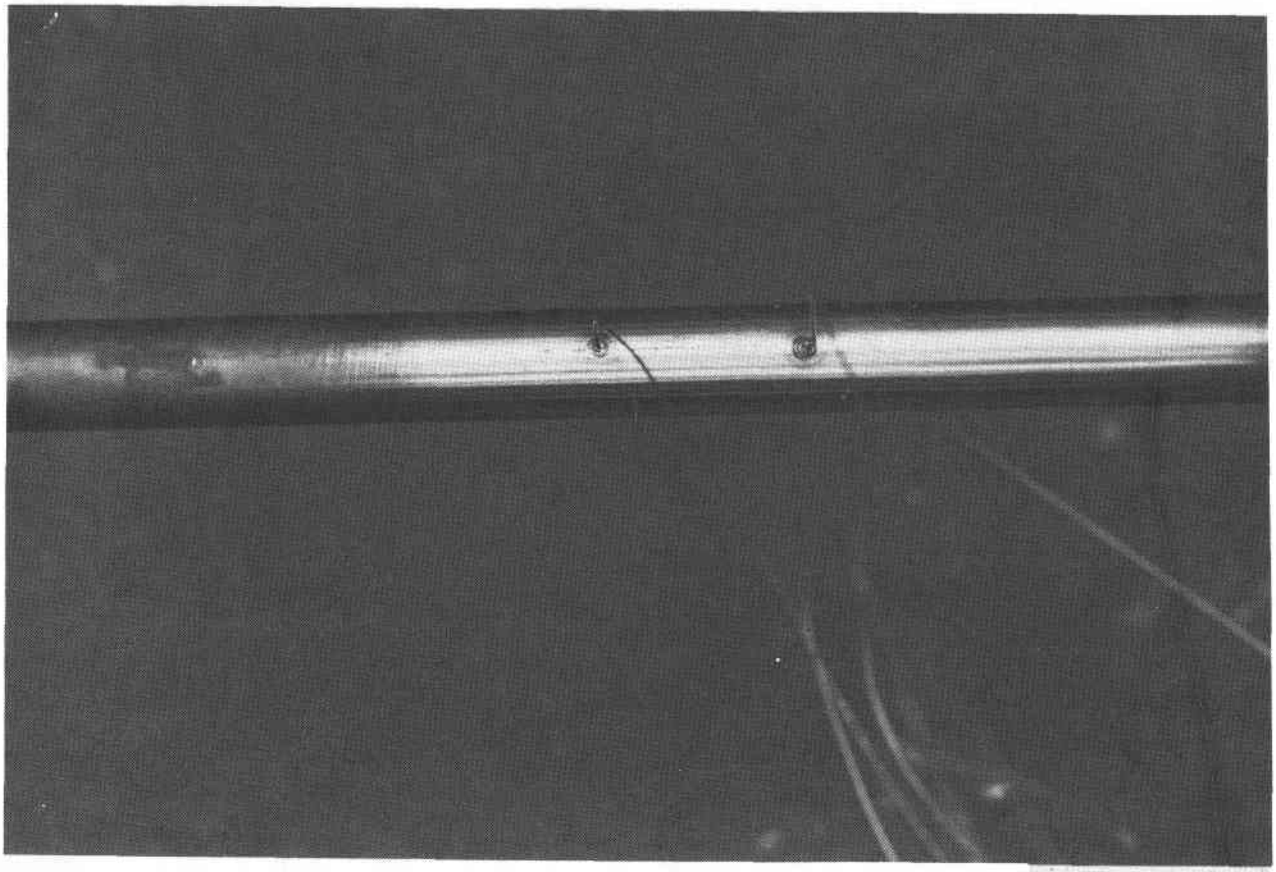


Figure 6. A Closeup View Showing Percussion-Welded Thermocouple Wires to a Heater Sheath

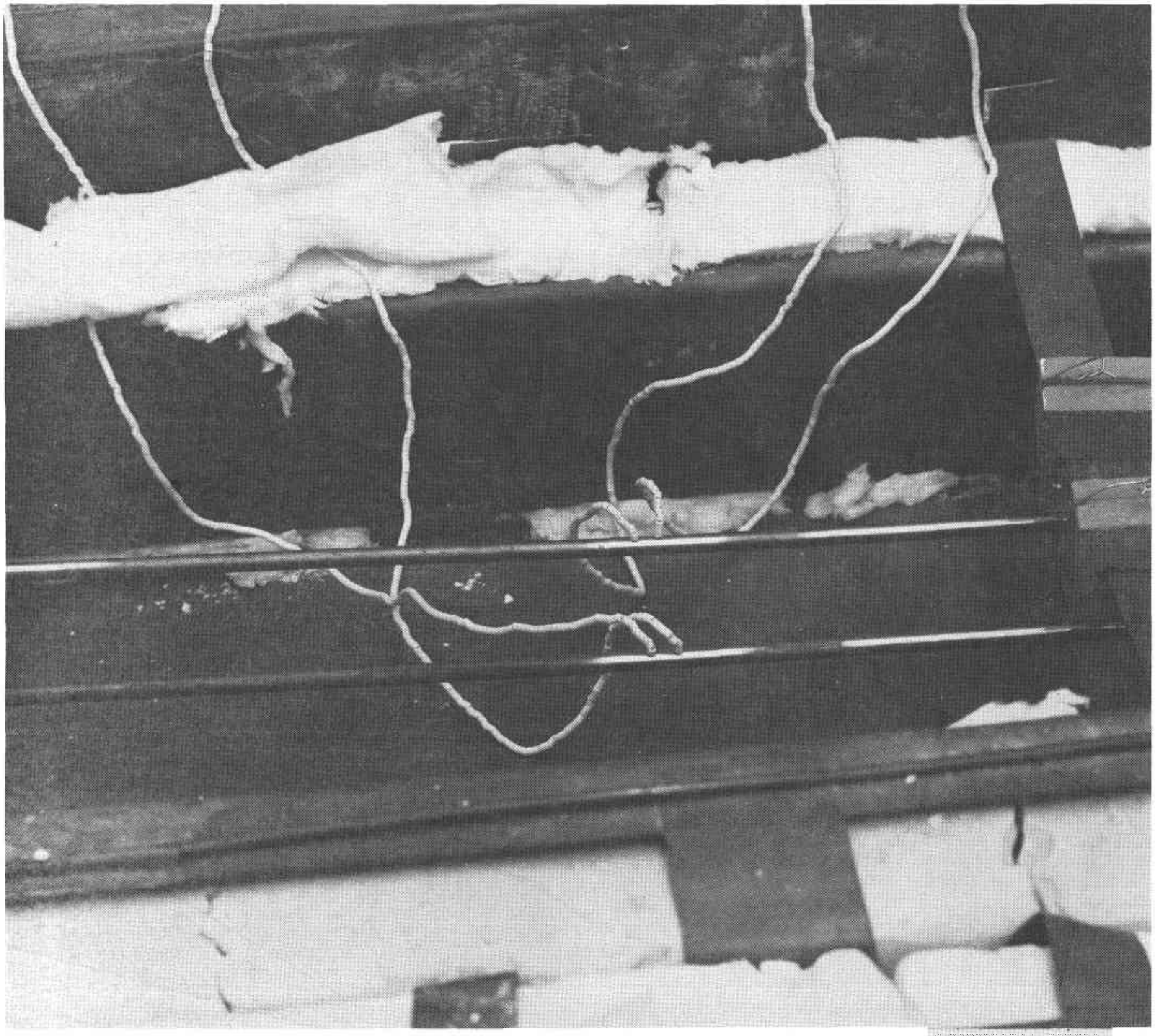


Figure 7. A Closeup View of Beaded Thermocouple Wires Attached to the Heater Sheath

this temperature. Originally, the sheath temperature was set to 1500 ± 25°F (816 ± 14°C), but the life cycle test was not accelerated sufficiently in time to provide a practical test. Once this temperature is reached, a rigorous on-off power cycle is started (see Figure 8). The cycle consists of 5 minutes at full power and 10 minutes with the power off.

During the "power on" cycle, the heater sheath temperature reaches 1700 ± 25°F (920 ± 14°C) before the power goes off. During the "off" cycle, the heater sheath typically cools to approximately 900 to 1000°F (482.2 to 593.3°C) before power is applied again. At convenient periods of 1000+ thermal cycles, the heaters are permitted to cool to ambient temperature. At this time, several parameters such as coil resistance, insulation resistance, and leakage current are measured in order to obtain indications of heater degradation.

The evaluation test heaters are continuously subjected to this thermal cycling until heater failure occurs. When a heater fails (either shorted to ground or open circuit), it is removed from the oven-like enclosure, X-rayed to determine the location of the failure if it is not readily apparent, and dissected for visual examination. The failed area is then photographed to show the condition of the wire, MgO, and sheath. A metallographic examination of the failed areas was also accomplished. Some of the failures may be found in Appendix B.

A complete summary of the accelerated life test program test results thus far, based on the number of accumulated thermal life test cycles, is presented in Table 1. Although the sample size is relatively small, a number of significant differences in average life expectancies between heater features and manufacturers is apparent.

The test program was designed to evaluate the relative merits of heaters of different manufacturers, different insulation densities, different voltage ratings, different diameters, and straight vs bent heaters. Although the testing is not labor intensive, the testing time to achieve heater failure is long, thereby prolonging the calendar time required to evaluate the relative merits of each design and fabrication element.

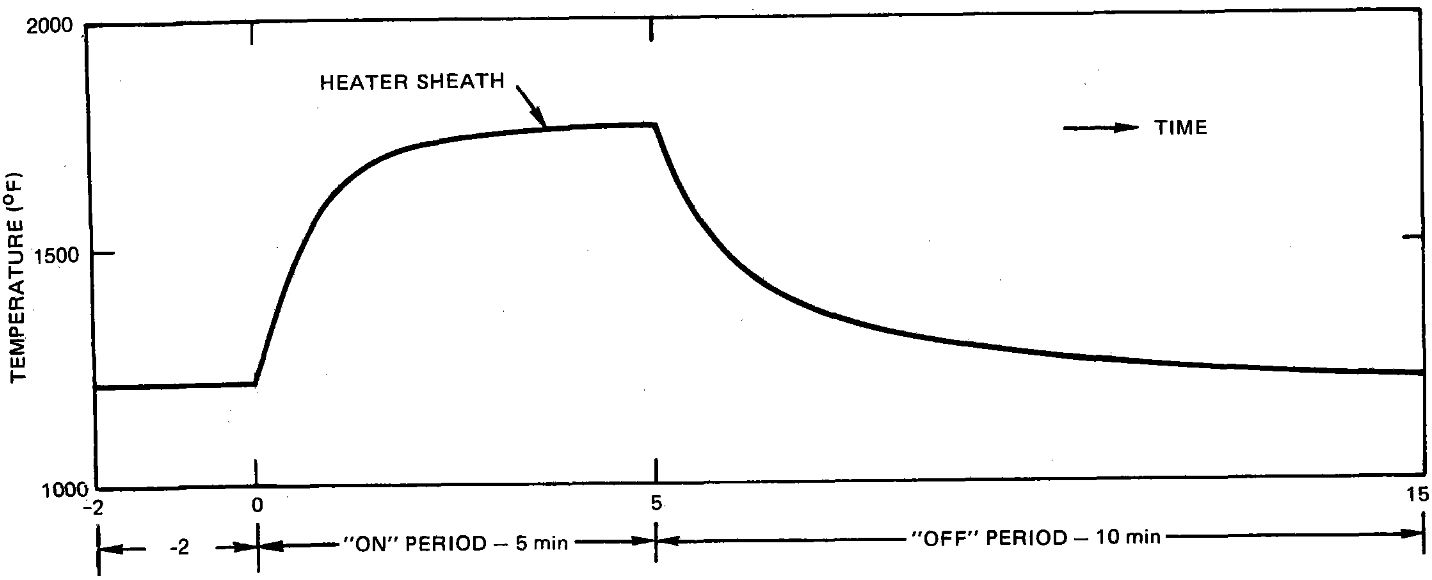


Figure 8. Typical Temperature Profiles - Heater Accelerated Life Test - Rama Corp. Heaters

## 2. Accelerated Life Test Results

A critical review of the test results presented in Table 1 shows that the best life can be expected from straight Chromalox Grade I heaters which have a 1/2-in.-diameter sheath and a 480-volt rating, or with straight Chromalox 3/8-in.-diameter heaters rated at 240 volts. There was no significant difference in life between the Chromalox straight, 240-volt, 3/8-in.-diameter Grade I and Grade II heaters. This is not totally unexpected since the Grade I and Grade II heater have the same general material, fabrication, and cleanliness requirements. The major difference is in the amount of in-process and post-fabrication inspection required. These heaters demonstrated very good consistancy in the grouping of specimens tested as well as better than 100% longer life expectancy (on the average) than any other types or manufacturers of heaters tested. The results show that in the 1/2-in.-diameter, Grade I category (rigorous quality assurance) heaters, the Chromalox heaters have well over 100% longer life expectancy than either Rama or Hesco heaters. Additionally, the Chromalox Grade I heaters (rigorous quality assurance) survived more than three times longer than Chromalox Grade II (less rigorous quality assurance) heaters. However, when a similar comparison is made of the Rama and Hesco heaters, the converse is true. The Grade II heaters outperformed the Grade I heaters. The interesting feature to be noted here is that both the Rama and Hesco Grade II heaters were manufactured at a later time (as indicated by the serial numbers which identifies the year of manufacture) than the Grade I heaters. In continuing the review of 1/2-in.-diameter heaters, both Rama and Hesco heaters were drastically affected by an MgO density of less than 3.0 grams/cc, while Chromalox heaters exhibited a smaller decrease in life. When the heaters with bends were compared to heaters without bends, the life of Chromalox heaters was more affected by the bend than the Rama and Hesco heaters.

In reviewing the 3/8-in.-diameter heaters accelerated life test data, additional anomalies are apparent. Since the 3/8-in.-diameter heaters are available in both 480-V and 240-V ratings, both were purchased to evaluate their relative merits. The test data on the 3/8-in.-diameter Chromalox heater clearly indicates that the operating voltage plays a significant part in potential heater life. In both Rama and Hesco Grade I heaters, the lower voltage (240-V) rated heaters did not exhibit as long a life as the higher voltage (480-V) heaters. However, for both manufacturers, the lower voltage (240-V) rated heater of the Grade II type outlasted the higher (480-V) rated heater. These types of unexpected data fail to be clearly understood and explainable at this time. The 3/8-in.-diameter heaters also do not exhibit a sharp decrease in life when tested in the hairpin configuration as was exhibited by the 1/2-in.-diameter heaters. This is not totally unexpected.

The 1/4-in.-diameter heaters are currently in test, but some data has been acquired thus far. In general, the 1/4-in.-diameter heaters do not exhibit the life expectancies of the larger diameter heaters. Only 240-V rated heaters are being tested as 480-V ratings for this diameter heater would be considered beyond good design limits. In both the Rama and Hesco heaters, the Grade II (less rigorous quality assurance) has, in general, outperformed the Grade I (rigorous quality assurance) heaters. In the Chromalox case, the Grade II data is very inconsistant and comparison is difficult. With the limited amount of data on the hairpin-bent heaters, it is apparent that the bent heaters have shorter life expectancy than straight heaters.

In summary, the review of the accelerated life test data in Table 1 reflects results which are as anticipated in some cases but have considerable inconsistency in other cases. The inconsistencies indicate that either the fabrication techniques are not being adequately controlled by the in-service and post-fabrication inspections or additional factors not presently being controlled are a significant factor in determining heater life.

## 3. Heater Installation Standoff Design Tests

In addition to the concern about heater failure from the standpoint of replacement difficulty and cost, there is a concern that the heater failure may cause damage to the sodium containment boundary. One means of accomplishing this is to electrically isolate the heater from the sodium containment boundary. Two ways of accomplishing this are available. One method is to use an ungrounded electrical power system. The second method is to mechanically isolate the heater from the sodium containment boundary by the use of standoffs.

The ungrounded or floating electrical power system raises some questions from the national and applicable local electrical codes standpoint. These concerns are moot, however, since it has been demonstrated that it is possible for a faulted heater to arc from the element to the sheath and back to the element. Hence, ungrounded electrical systems do not provide the arc suppression protection required.

Physically isolating the electrical heater from the sodium containment boundary does not in itself suppress the electrical arc but is effective in isolating the arcing from the boundary, thereby protecting it from damage.

References 6, 7, and 8 are reports on standoff electrical heater design, including thermal insulating tests conducted to support FFTF and SPTF heater installation.

The primary objective of Reference 6 was to determine the structural integrity of the heater mounting hardware when subjected to the thermal operating requirements of SPTF. To accomplish this, heaters and insulation were installed on a 42-in. section of a 16-in.-diameter pipe in accordance with the SPTF drawings, and the assembly was tested in the Out-of-Sodium Test Facility (Building 025) at ETEC.

The heater standoff design can be seen in Figure 9. Note how the heaters are installed into the strap material. A closeup view is shown in Figure 10. The thermocouple installation is shown in Figure 11. After the thermocouple and heater installation, the entire pipe section was insulated as shown in Figure 12. The assembly was subjected to: (1) 11 thermal cycles between 400 and 1050°F at a rate of 40°F/hr, (2) 2000 power cycles of 10 to 13 min "ON" and 2 to 5 min "OFF" at 1050°F, and (3) 677 hr of operation at 1050°F over a 50-day total test period. The testing was divided into 11 separate tests as various changes were made.

During the testing of the assembly, it was found that the temperature of the outer stainless steel jacket was exceeding the maximum design limit of 140°F (was 157°F). Calculations showed that this was due to: (1) the insulating material having a thermal conductivity higher than its specified value

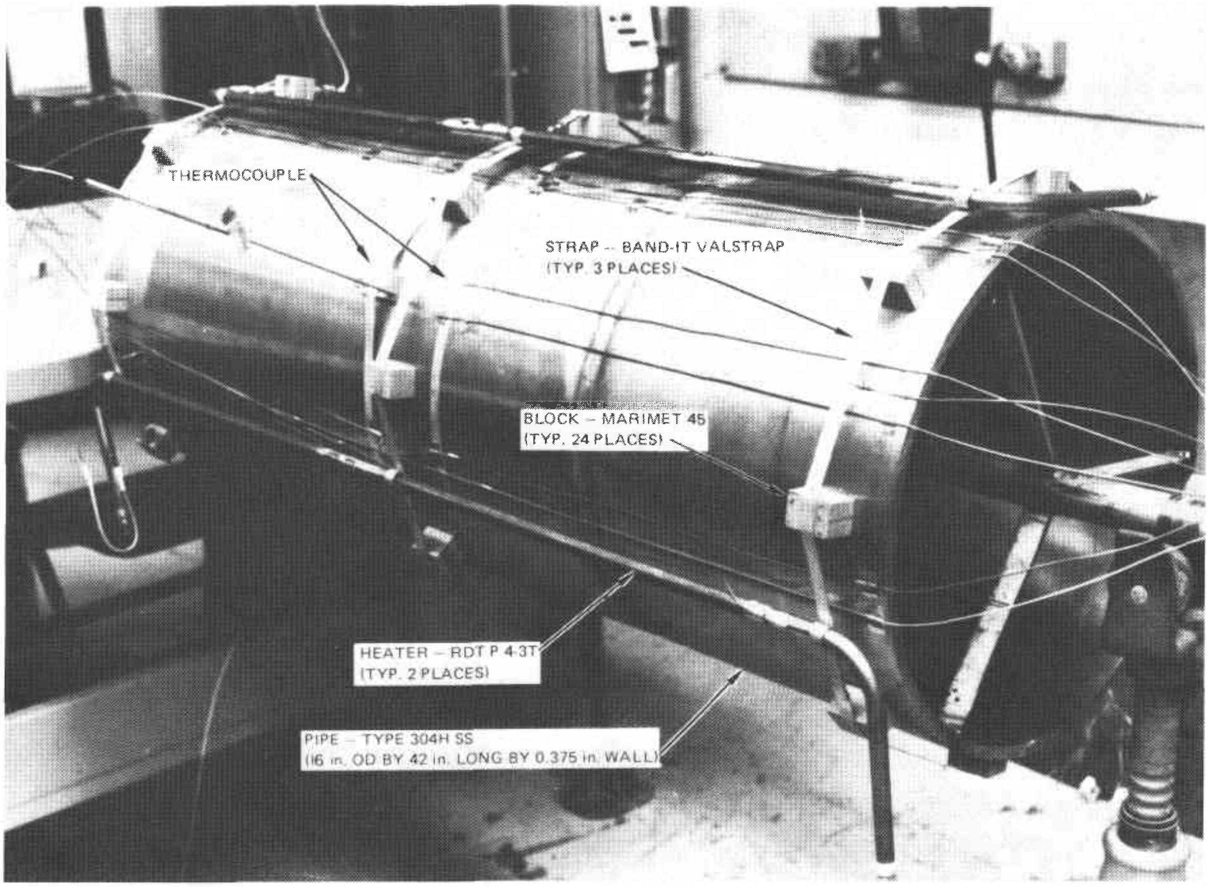


Figure 9. Standoff Heater Design

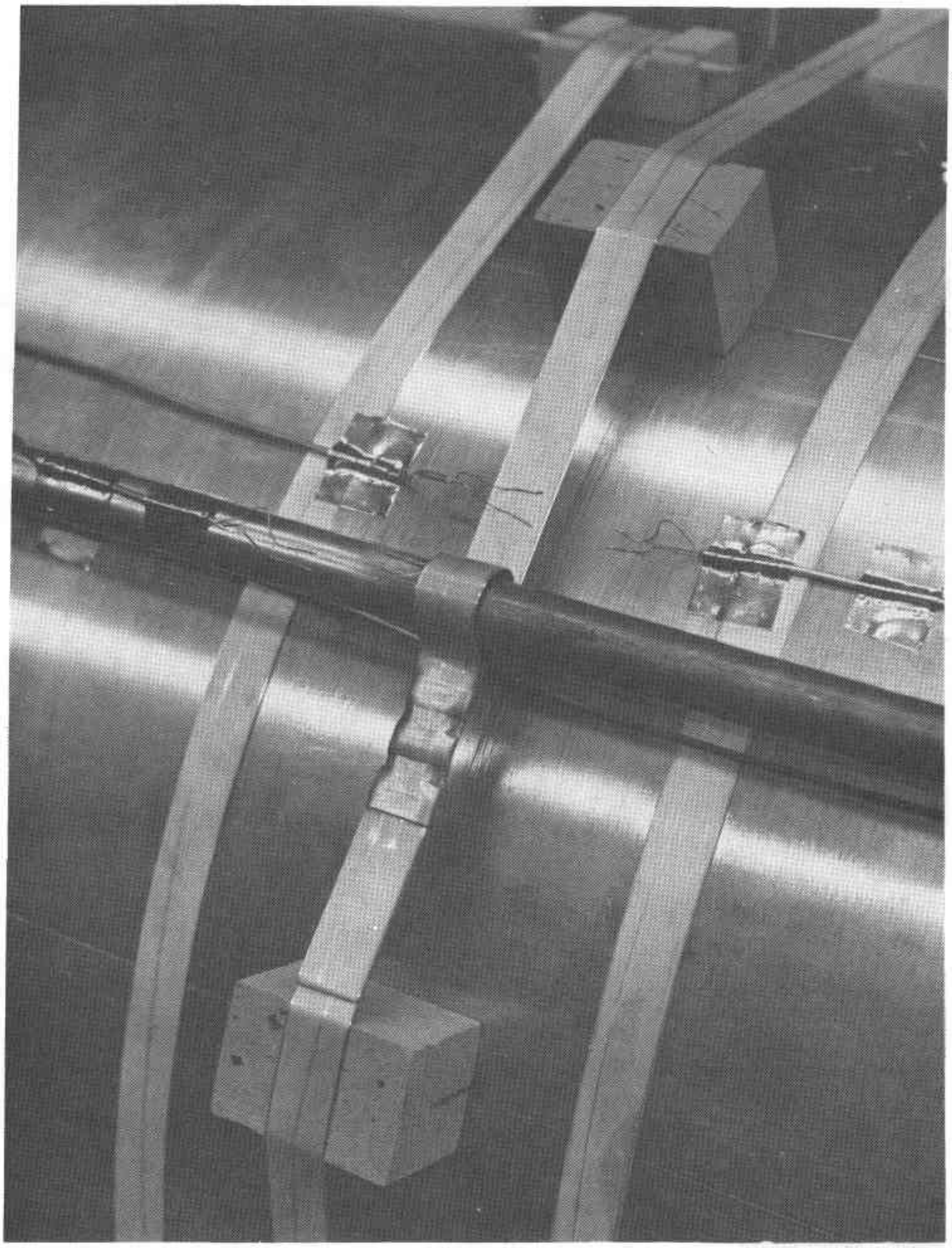

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Figure 10. Middle Strap Showing Heater Attachment

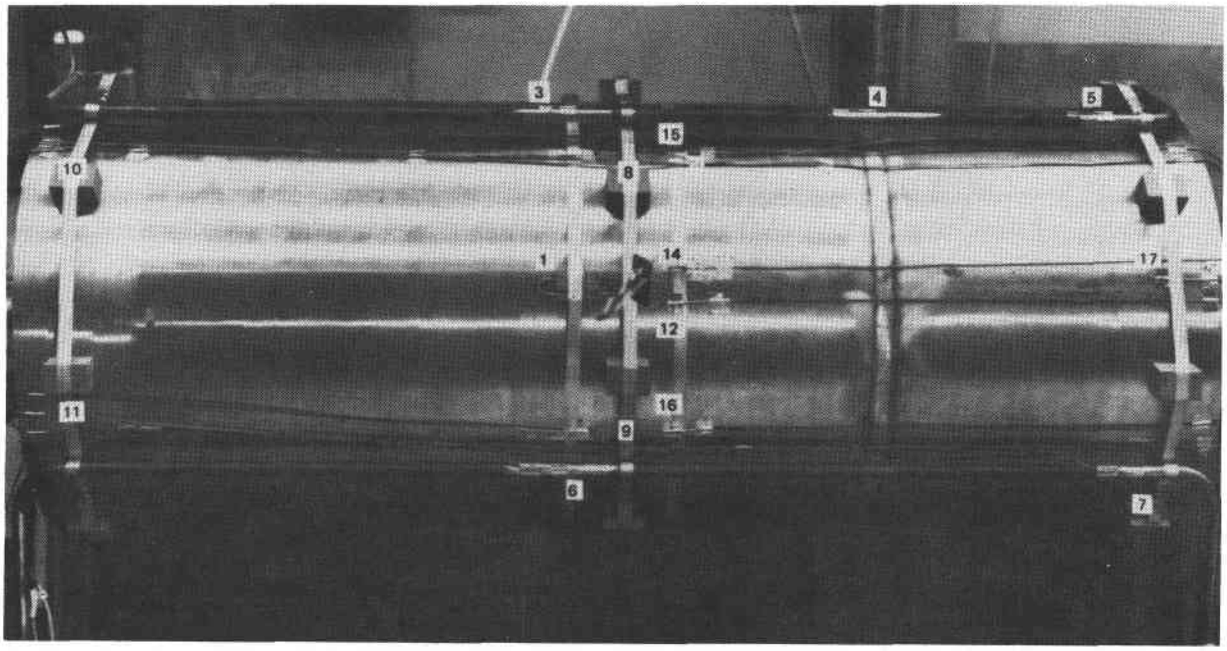



Figure 11. Thermocouple Installation (Front)

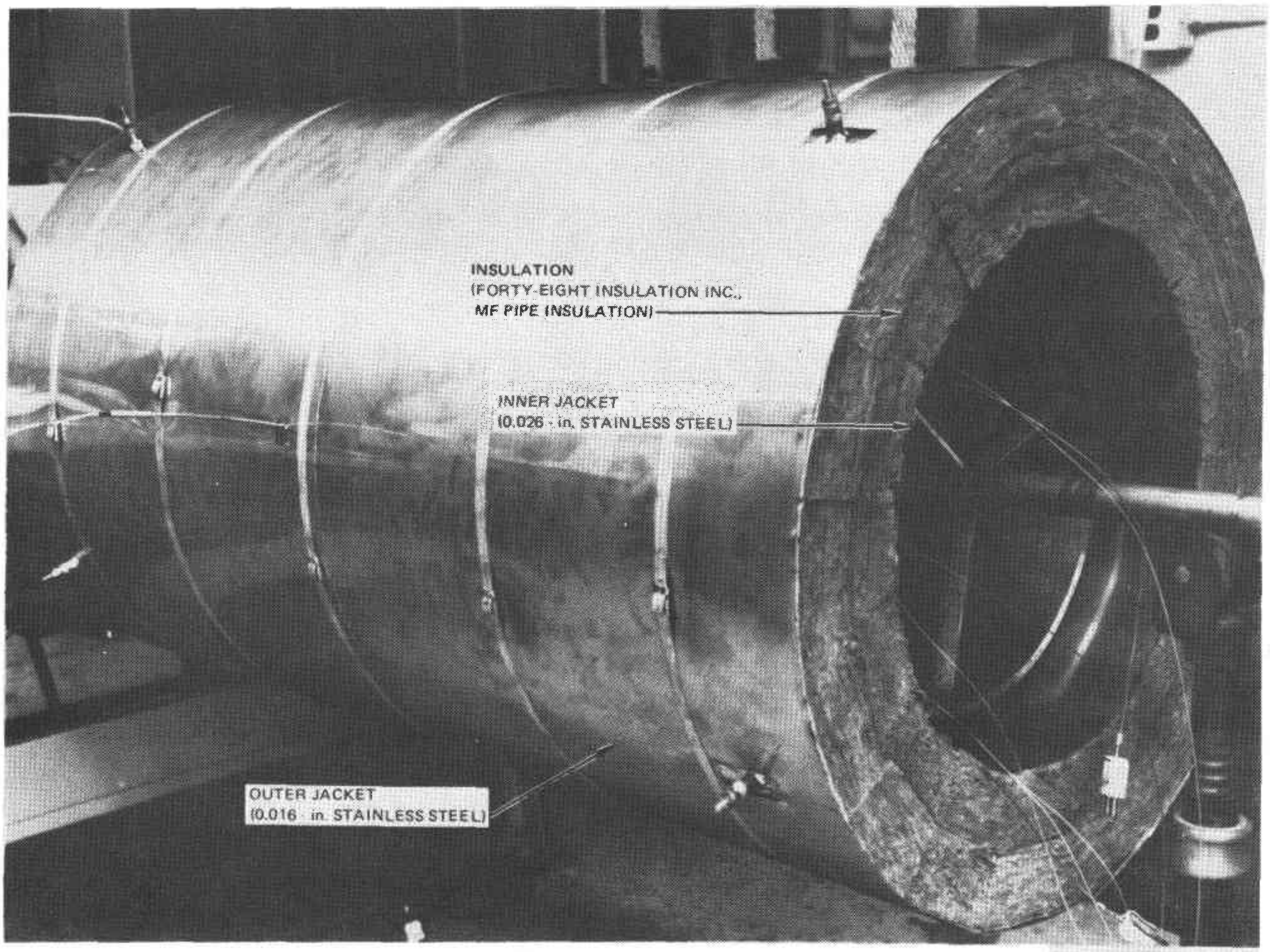



Figure 12. SPTF Heater Test Assembly

and (2) the emittance of the stainless steel outer jacket being too low. Various changes were made to the outer surface in an effort to lower its temperature, and the best results were obtained with a canvas and Arabol covering. Post-test visual inspection of the heater installation showed no structural degradation of the straps or blocks.

It was also determined that the heater annulus produced a chimney effect when the pipe was tested in the vertical position; hence, convective blocks in vertical annuli are required to provide a uniform temperature field.

The primary objectives of Reference 7 were to: (1) demonstrate assembly feasibility using pre-production pipe heater support hardware and (2) obtain functional verification of the heater support system at representative operating conditions. The test was set up using an 8-ft-long section of 28-in.-diameter pipe. The heater support hardware was slightly different but the mounting concept is very similar to that reported in Reference 6 and similar test results were obtained.

The primary objective of Reference 8 was to determine if the thermal insulation, MF48 blanket insulation, produced deleterious effects on the stainless steel pipe based upon the observation noted in Reference 7 during disassembly of the test section. Post-test examination, including extensive metallurgical sectioning of the inner sheath and the pipe, revealed no evidence of degradation of the microstructure.

### 4. Heater Circuit Protective Devices

In 1973, during normal operation of sodium test vessels in Building 032 at ETEC, four tubular heaters failed within a relatively short time interval. Inspection of the failed heater installation disclosed that three of the heaters experienced electrical arcs to the tank wall with resulting erosion of the tank wall in the area of the arc. The fourth heater which failed did not experienced arcing external to its sheath. Inspection of the damaged test vessels subsequent to the heater failure revealed penetrations into the tank wall of 0.085 to 0.210 in.

The circuit breakers used in the heater circuit (Square D, Type ML-1, 20 amp) were tested for trip time at overloads of approximately 180% and 300% of rated load and were found to operate within the limits specified by the manufacturer.

A series of tests (Reference 9) was conducted to determine the type of protection that should be installed in electrical heater circuits to prevent heater failures from damaging the components being heated. Three types of circuit protection devices were tested: (1) a molded-case, thermal-magnetic circuit breaker; (2) fast-blow fuses; and (3) a ground fault interrupter (GFI). All three types of devices were tested under similar conditions, with heaters installed on a pipe section and in contact with the pipe surface in a method prototypical of the installation practice followed at ETEC. Failure was induced by limiting the heat loss from the test section and allowing the heater temperature to rise to the point where heater lifetime was reduced to a few hours.

Since it was also desired to create the largest possible fault current, the heaters were overlapped at the cold conductor ends, thus producing a hotter region of heater operation at the heater element - cold conductor transitions. Failure in this region was desirable since: (1) this is the region in which heater failure occurred on the Building 032 tank heaters; and (2) by eliminating as much heater length as possible in the fault circuit, the maximum fault current can be obtained (i.e., failures occur at the heater ends). The extent of the damage to the heaters and their surroundings is a function of the total energy dissipated in the fault area.

A detailed summary of the comprehensive tests conducted and the protective circuit devices used in each test can be found in Reference 9.

Of the circuit protection devices tested, only the ground fault interrupter (GFI) system when used in conjunction with normal thermal-magnetic circuit breaker protection provided adequate protection to prevent damage to the component being heated. As a result of this investigation, ETEC employs GFI systems on all heater circuits throughout its facilities, prepared several preferred practice procedures on their correct use and maintenance, and recommends that they be used on all electrical resistance heater circuits which have heaters installed on liquid metal boundaries.

## 5. Resistance Grounding Study of Heater Protective Devices

As previously discussed, a method of protecting sodium piping from damage due to failure of an electrical resistance heater is necessary in a sodium piping system. Several methods to prevent this from occurring have previously been discussed. These include isolating the heater from the pipe, installing a ground fault interrupter in the electrical system as shown in Figure 13 and/or a combination of these two methods. (Note: Only one GFI is shown in Figure 13 for clarity. ETEC recommends dual GFI protection for heater circuits.) In addition to these methods a passive system using resistance grounding was proposed as an alternate method of protecting sodium piping systems from electrical resistance heater failure damage. ETEC conducted a number of resistance grounding tests to evaluate this method. In addition, an outside consultant was contracted to perform an independent analytical study on this concept.

The objective of ETEC tests was to determine the relationship between pipe damage and arc energy. The tests were initially conducted on a probe and plate arrangement. A schematic diagram of the setup is shown in Figure 14. The results proved to be inconclusive because the plate damage was minor and the arcing could not be sustained at the higher currents (amps).

In a second series of tests, actual tubular heaters were mounted on test plates (simulating piping surfaces) and operated until heater failure occurred. Figure 15 shows the actual test setup for the heaters and plates. The value of ground resistance was varied between zero (solid ground) and infinite (ungrounded). The results, as shown in Figures 16 through 21, reveal excessive damage to both the heater and test plates with various ground resistances. The tests indicated that the fault current was not limited by the ground resistance because a secondary electrical breakdown

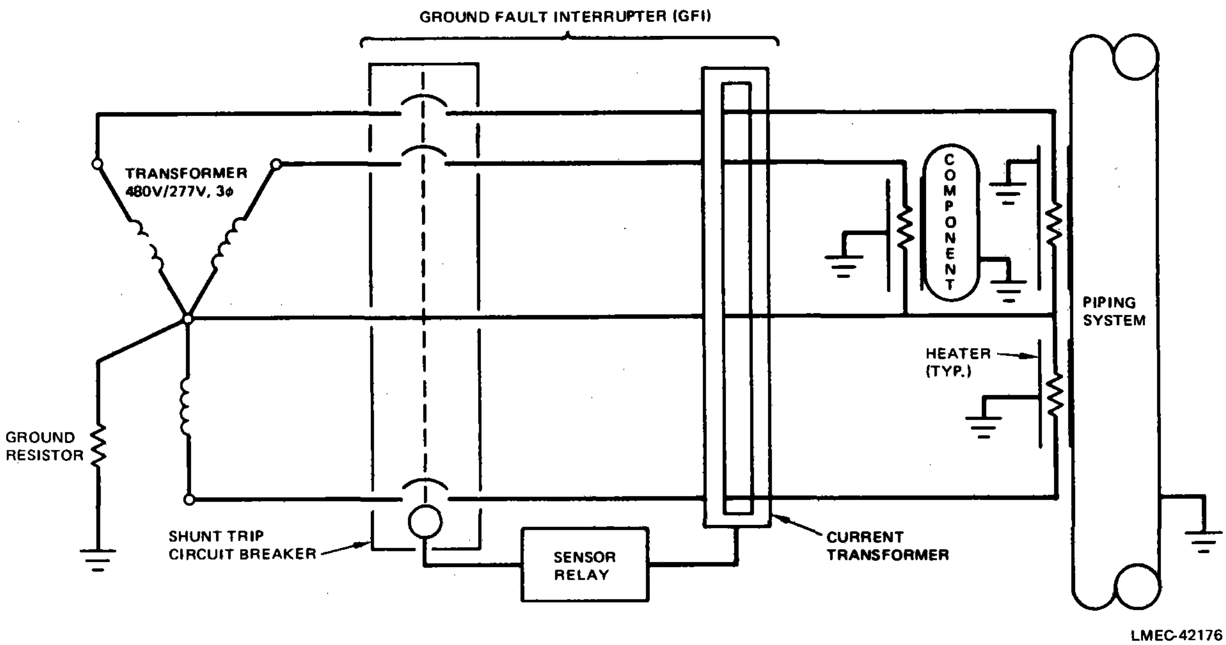



Figure 13. Typical Ground Fault Interrupter (GFI) Installation

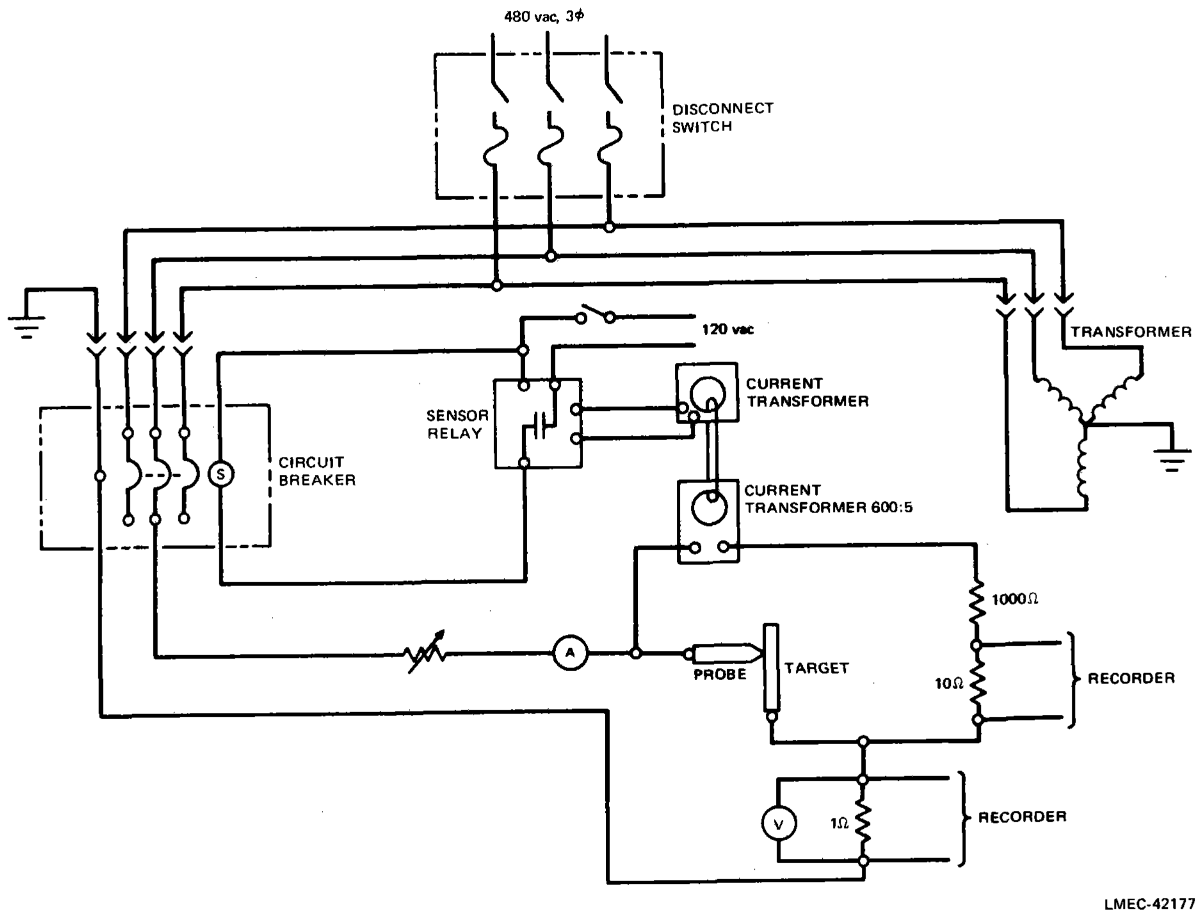
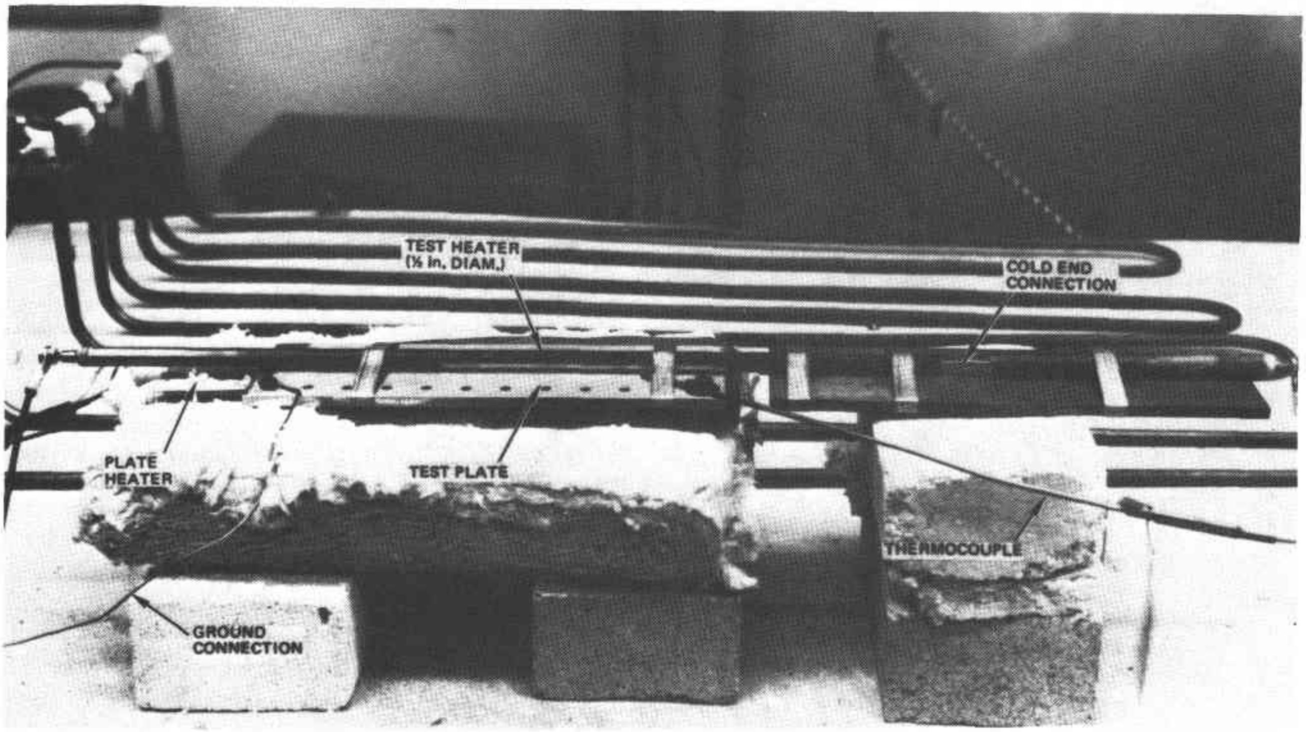
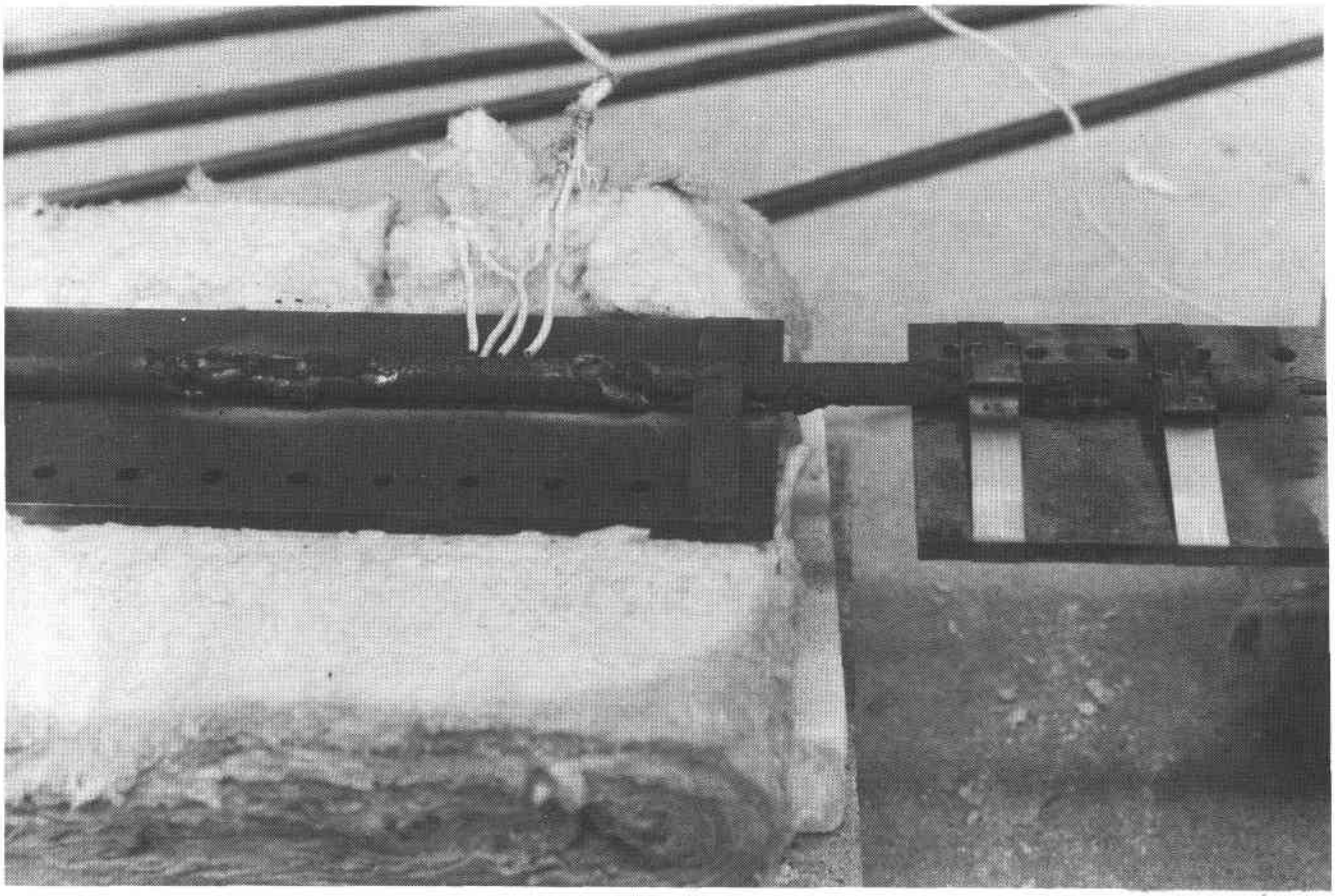



Figure 14. Schematic, Probe and Plate Tests




LMEC-P42162

Figure 15. Test Fixture, Heater and Plate Tests



LMEC-P60041

Figure 16. Post-Test Condition of Heater with 50 ohms of Ground Resistance

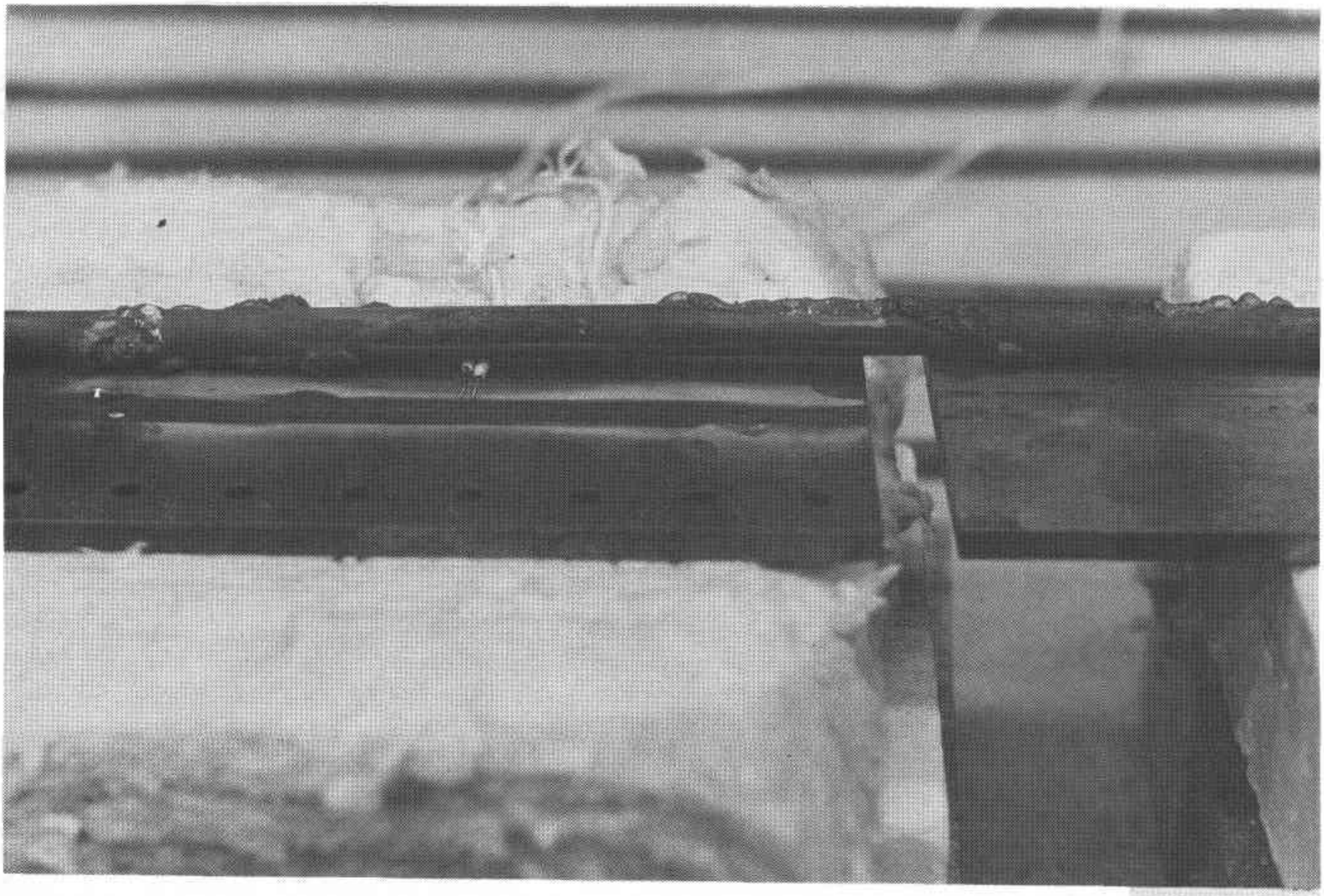


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Figure 17. Post-Test Condition of Plate with 50 ohms of Ground Resistance

LMEC-P42160

Figure 18. Post-Test Condition of Heater with Plate Heated and 50 ohms of Ground Resistance

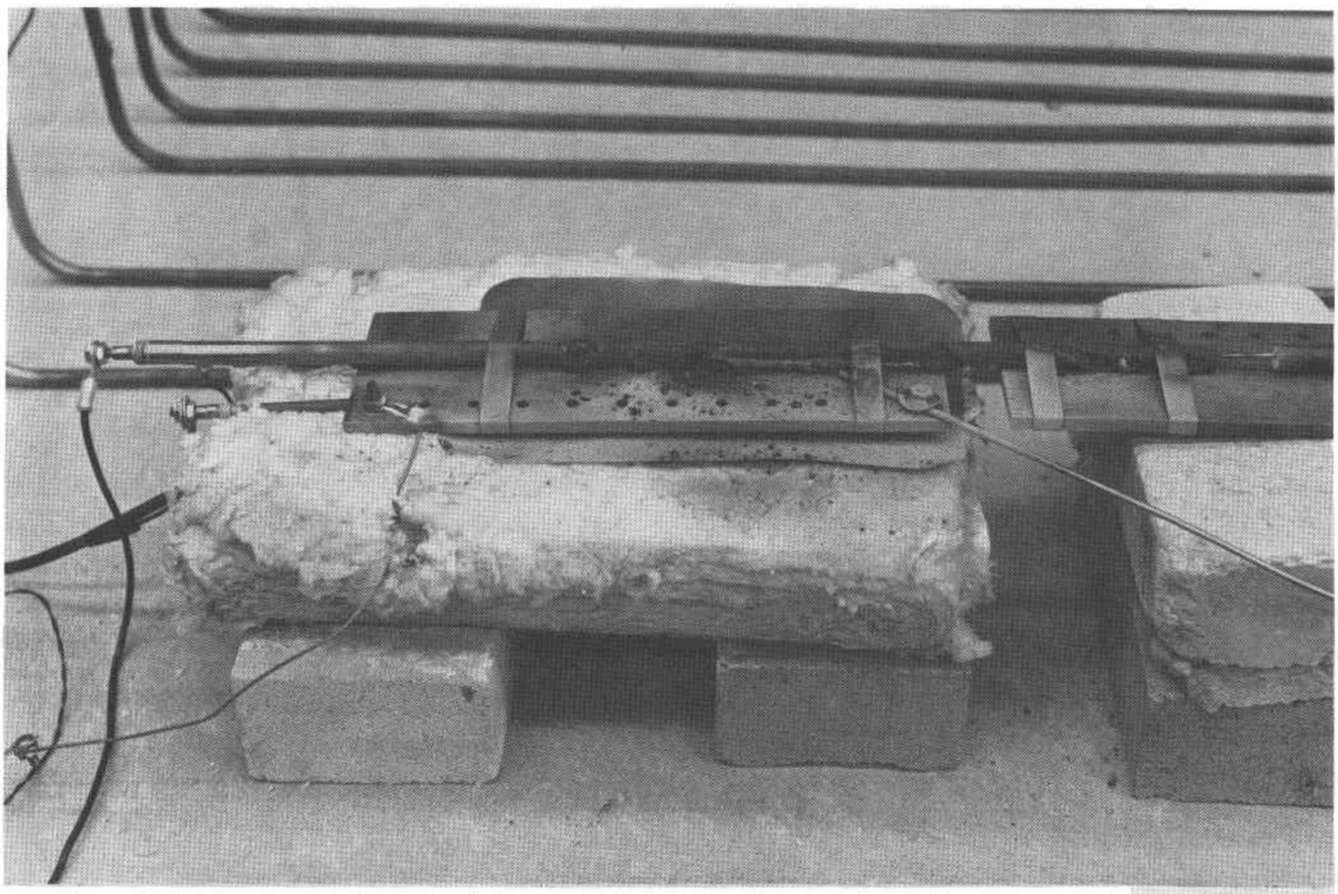

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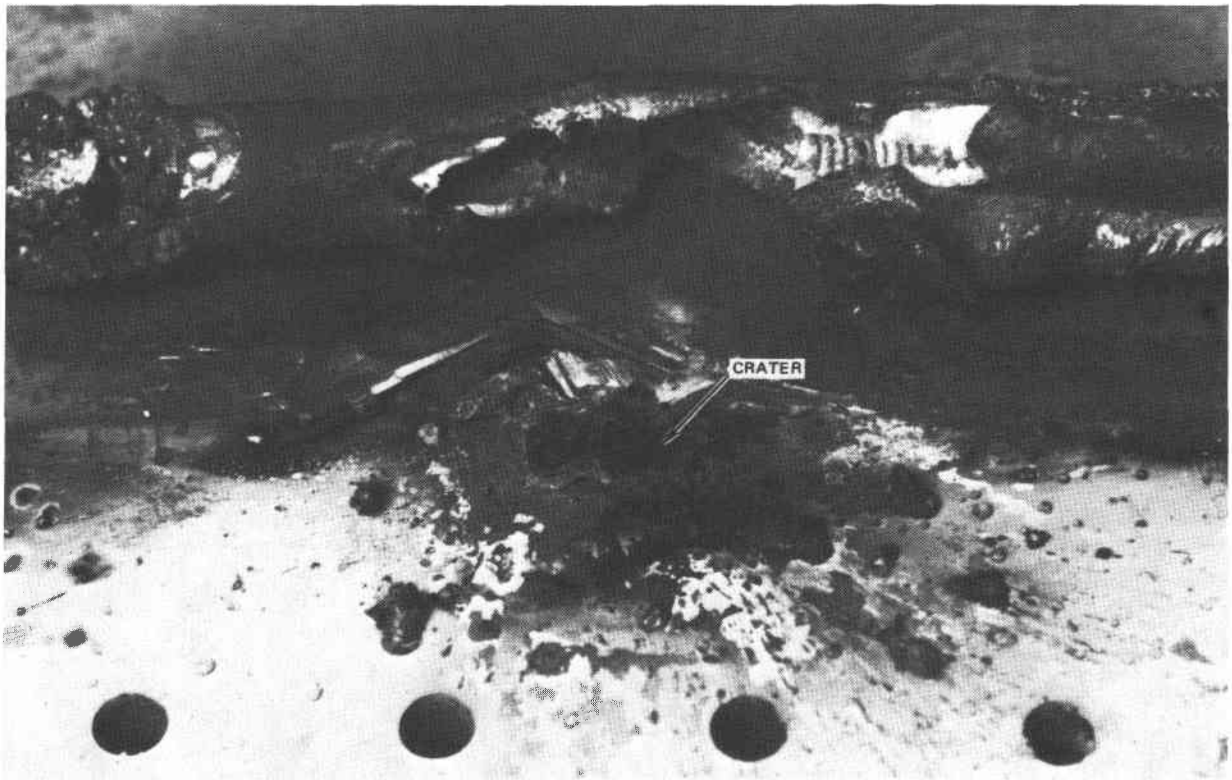
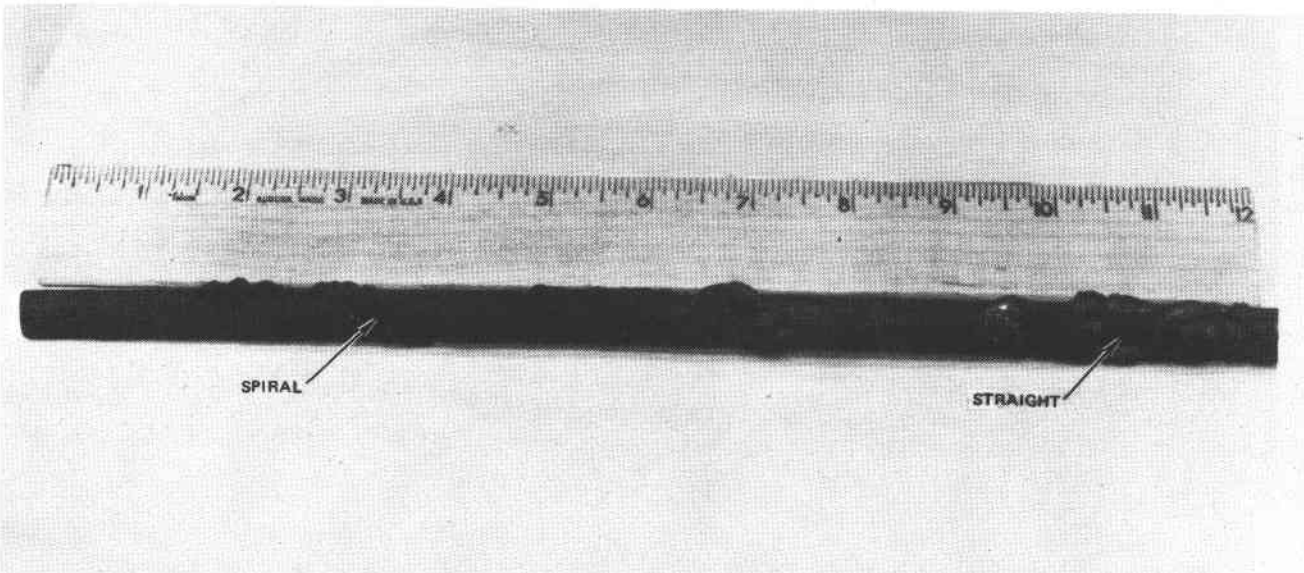
Figure 19. Post-Test Condition of Test Setup with Plate Heated and Solidly Grounded (Zero Resistance)




LMEC-P42167A

Figure 20. Post-Test Condition of Plate and Heater with Plate Heated and Solidly Grounded




LMEC-P42170A

Figure 21. Typical Heater Damage with Resistance Grounding

occurred between the sheath and heating element. As a result of this evidence, it was concluded that resistance grounding would not prevent damage by electrical resistance heaters to sodium piping systems, and that the continued use of ground fault interrupters was recommended.

The outside consultant study results also indicate that a grounding resistor cannot be used and there was no criteria to establish the value of the resistor and several aspects of the electrical code may prohibit its use.

A complete report on the resistance grounding study performed by ETEC as well as the outside ETEC consultants report may be found in Reference 10.

## B. MINERAL-INSULATED CABLE

In addition to the tubular heater evaluation test program, ETEC was asked to conduct extensive tests to ascertain the suitability and reliability of mineral-insulated (MI) cable for trace heating of small pipe systems used for heat transport in LMFBR plants. This request was based upon reports of widespread use of MI cable in some foreign countries (France and Germany) and in one installation in the U.S. (EBR-II in Idaho). It was thought that the material, installation cost, and the ease of application of MI cable on certain components or small piping systems might be more advantageous because of its smaller diameter than the more commonly used tubular heaters.

The initial program defined tests dealing with some of the unknowns about MI cable. These tests were identified as follows:

1) Bend (of cable) test
2) Terminations test
3) Prototype pipe application tests
4) Accelerated life tests at 1700°F.

In 1980, the Clinch River Project approved the use of MI cable for certain applications. As a result, the prototype pipe testing was expanded and the following two additional tests were added:

5) Accelerated life tests at 1500°F.
6) Prototypic pipe verification tests and methods.

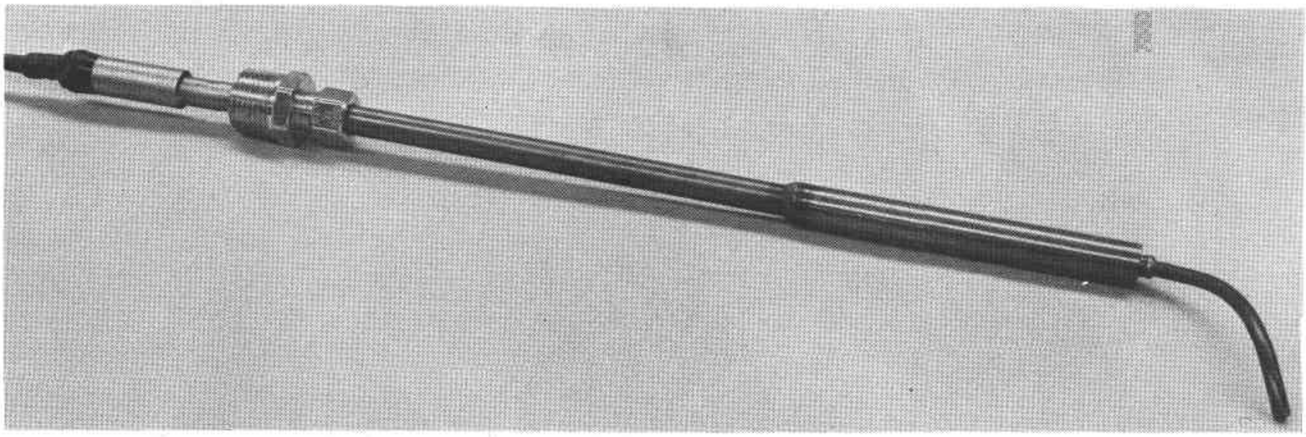
The purposes and methods of these six tests are briefly described in the following paragraphs, but a more detailed description of the test, test methods, and results may be found in Reference 1.

1. Bend Tests

The purpose of the bend test was to determine the fatigue resistance of samples of MI cable. The method was to alternately bend and straighten samples of the cable and to search for evidence of mechanical damage as the cycling operation progressed. In each failure case, the sheath separated as a result of fatigue. The test results indicate that the number of cycles before fatigue cracks were apparent was a function of bend radius as anticipated. The number of bends or cycles achieved before failure was considered adequate for most installations and testing was discontinued.

2. Termination Tests

The purpose of the termination tests was to determine the relative merits of several types of terminations, including those in common use and improved forms which might have been developed during the course of these tests. The method was to include the various termination designs in the heaters in accelerated life and prototype pipe life tests, and upon completion of these phases, select the optimum design for use in the final heater design verification test. The majority of the engineering effort was expended in the cold end termination fabrication area. Six different kinds of cables and cable terminations were tested and evaluated. As anticipated, the reliability of an MI cable is largely controlled by the reliability of the cold end termination. Figures 22 through 29 are examples of some of the terminations and their installation. The Pyrotenax factory-fabricated transition between the element wire and cold end of the heater was judged as the best design tested.



ETEC-P34754

Figure 22. Type A Termination - Photograph

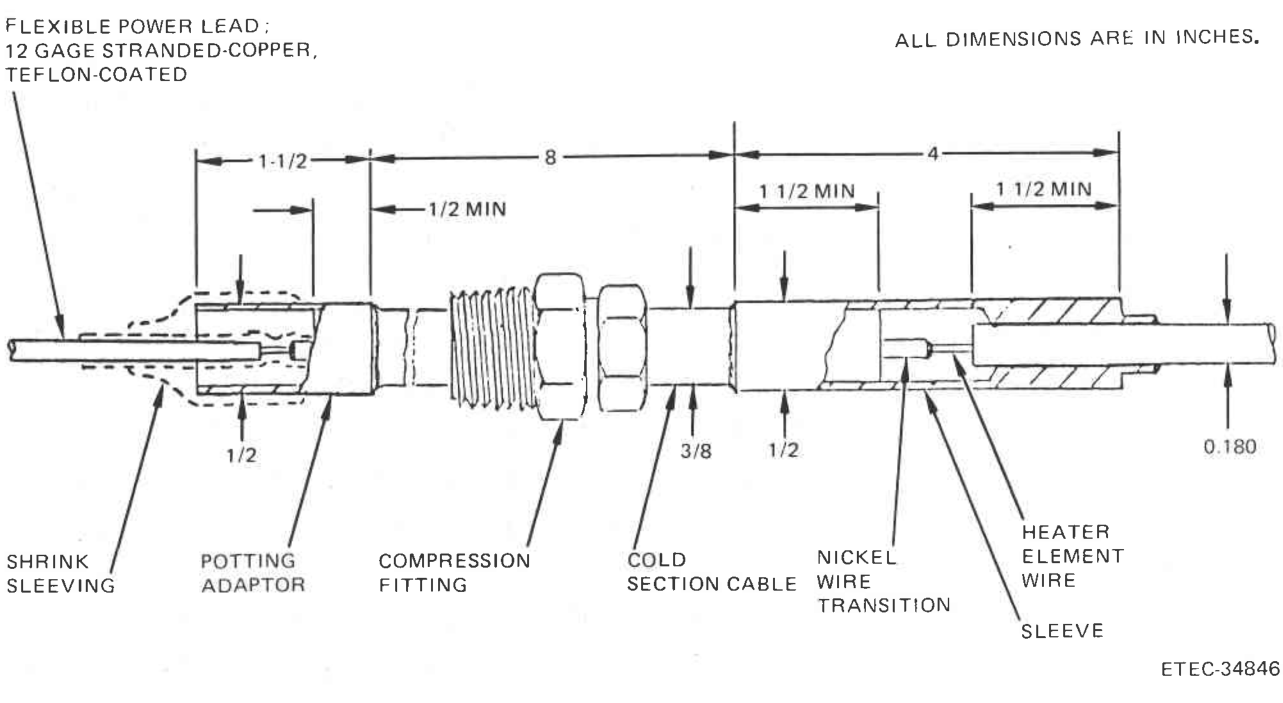



Figure 23. Type A Termination - Drawing

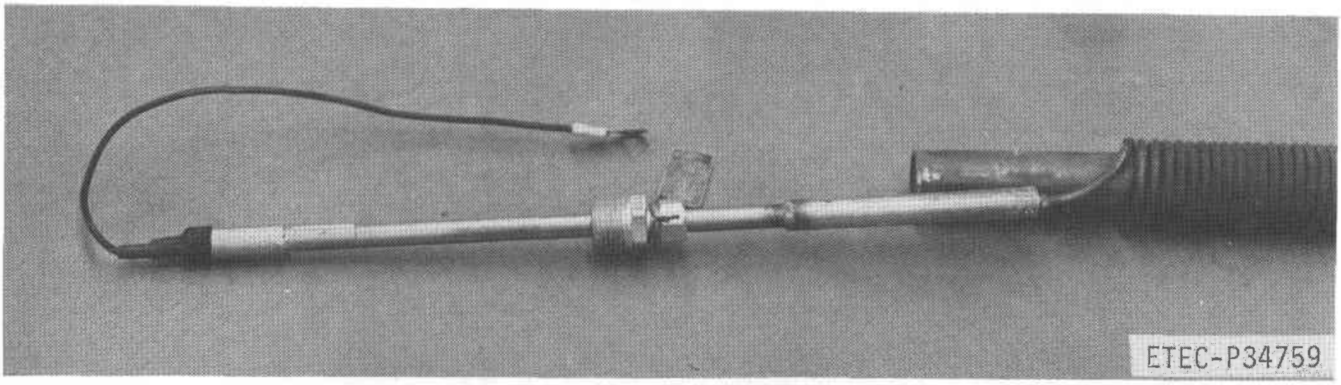



Figure 24. Type A Termination on Heater 006 Used in Accelerated Life Test, 1700°F


Figure 25. Typical Orientation of a
Typical Heater Mounting on a Prototype Pipe

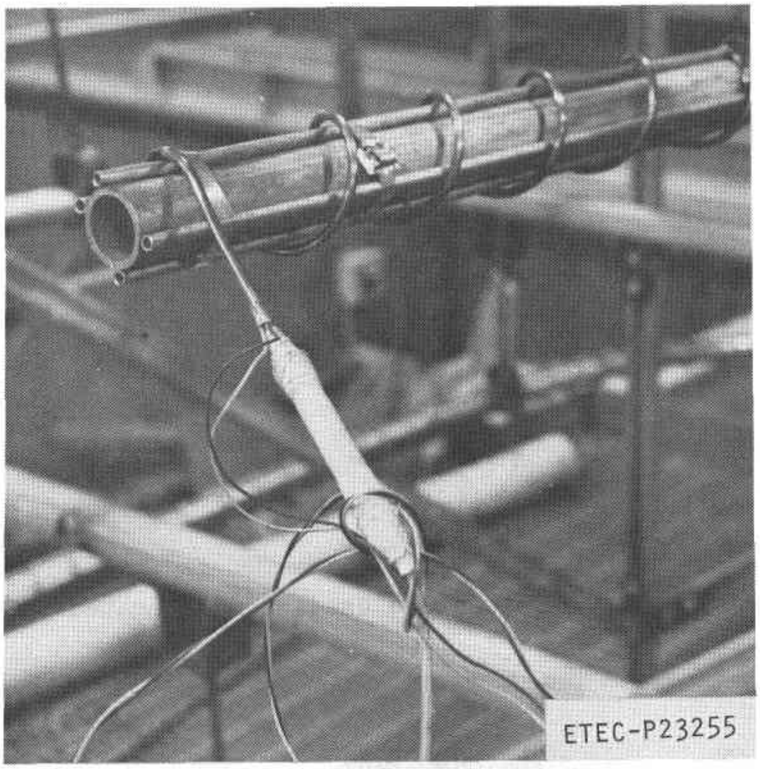


Figure 26. Type B Termination in Service

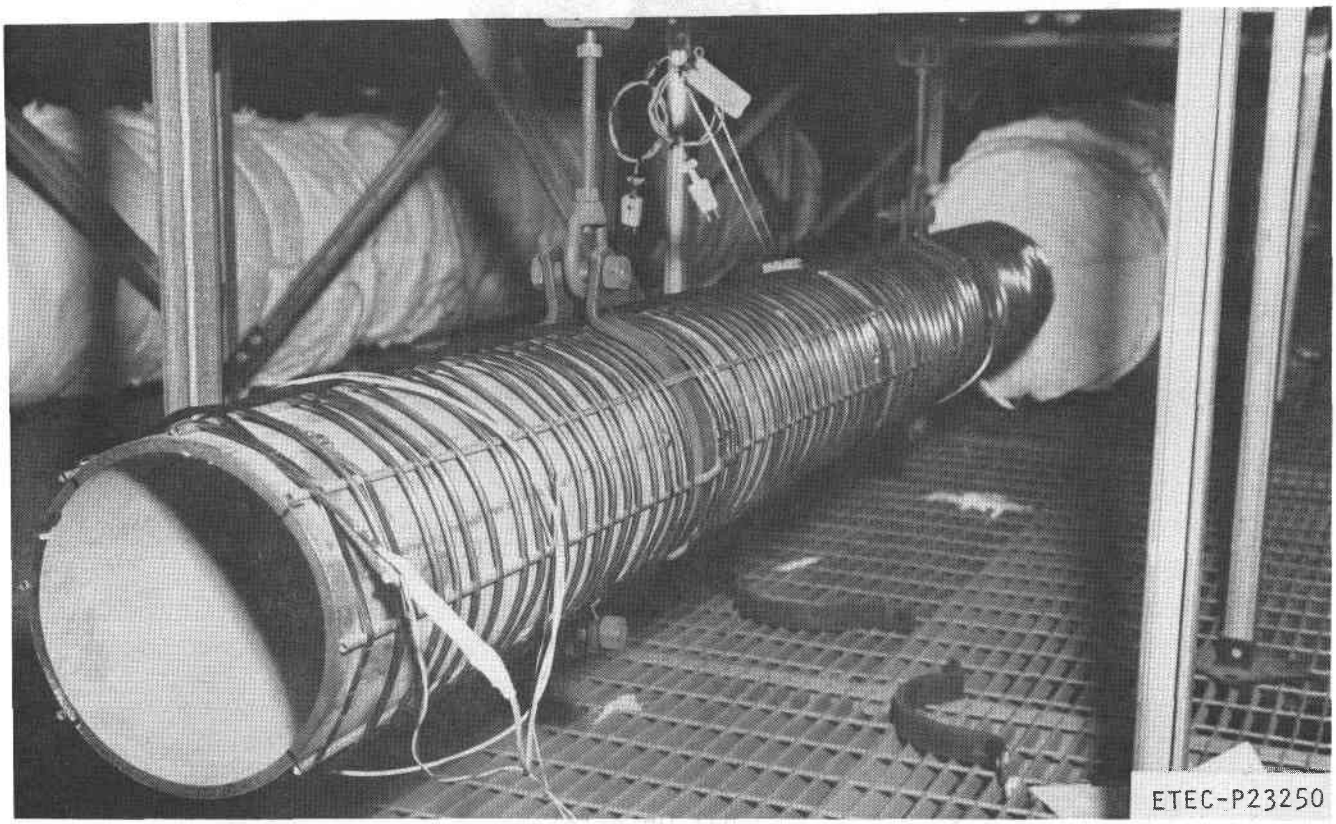


Figure 27. Type B Termination - Heater 014 Installed on Test Pipe

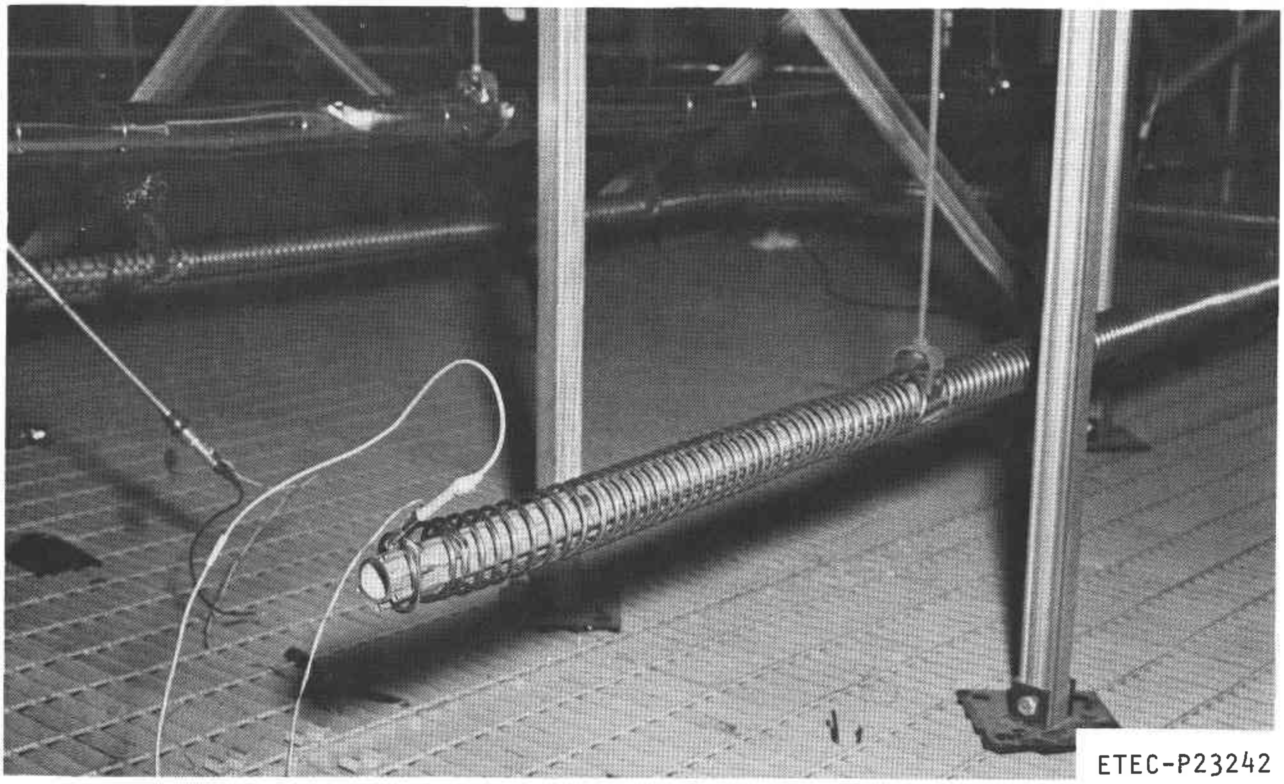



Figure 28. Type C Termination on Heater 20

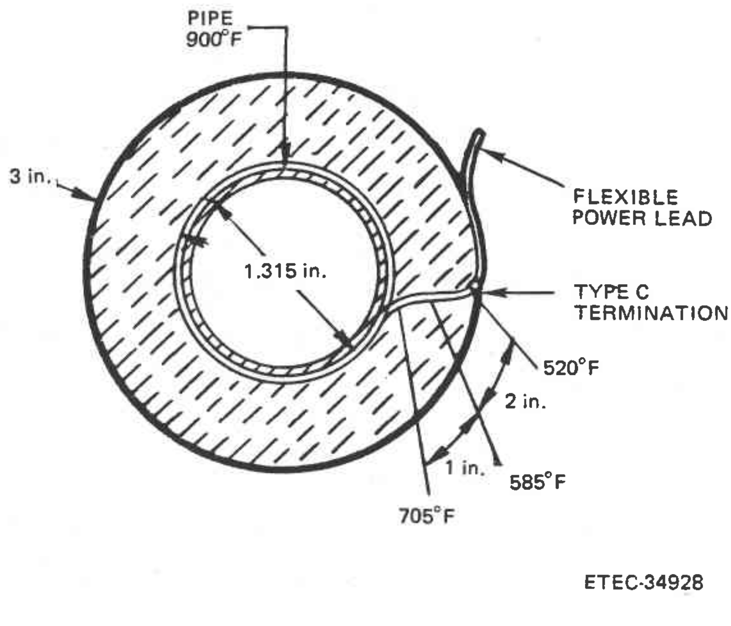



Figure 29. Type C Termination - Near Termination of Heater 020

## 3. Prototype Pipe Tests

The purpose of the prototype pipe tests was to determine the relative merits of several types of heater cables and methods of mounting them. The method was to mount several types of heaters on pipes using several mounting configurations, insulating the assembly per a CRBRP design, and operate under steady conditions at a temperature in the range of the highest expected in the CRBRP.

These prototype pipe tests were conducted on 1-inch and 8-inch pipe sections. These tests gave the first real information upon the difference in installation techniques required between installing tubular heaters and MI cable upon straight piping. Helical installation, recommended by EBR-II, was soon discarded in favor of serpentine installations to both reduce the amount of field effort and to reduce the amount of unnecessary handling (bending) of the MI cable. Figures 30 through 36 show the various installations of MI cable on different types of pipe sections. The MI cable prototype pipe test setup in SCTI is shown in Figure 37.

## 4. Accelerated Life Tests at 1700°F

The purpose of the MI cable accelerated life test was to provide information for making a life expectancy comparison between the MI cable and tubular heaters.

A heater accelerated life test is a test in which the heater is subjected to operating conditions much more severe than normal operating conditions. This kind of test is of value in obtaining relative life expectancies between two or more devices when the life under normal operating conditions is very long. In the case of tubular heaters, where the normal life expectancy is in the order of 30 years, accelerated life testing is mandatory to make any meaningful comparisons between heaters relative to life. Accelerated life testing, using power cycling and very high sheath temperatures as the severe operating conditions to induce early failure, has been in use for several years at ETEC for evaluating different kinds of tubular heaters and was used in these tests. Figure 38 shows MI cable being tested on a 1-in.-diameter pipe within the test ovens. Figure 39 shows the accelerated life test of MI cable around a much larger diameter heating surface.

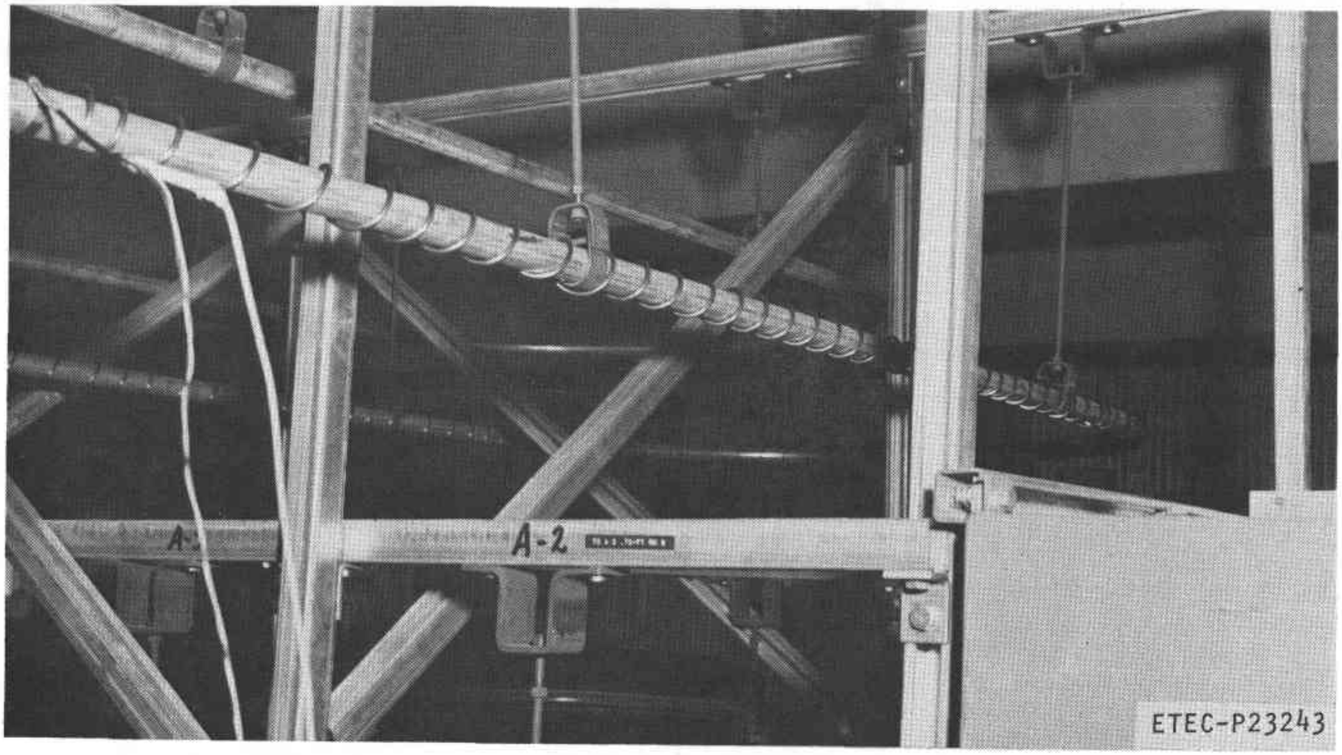



Figure 30. MI Cable Mounted Directly Onto a Straight Section of 1-in. Pipe

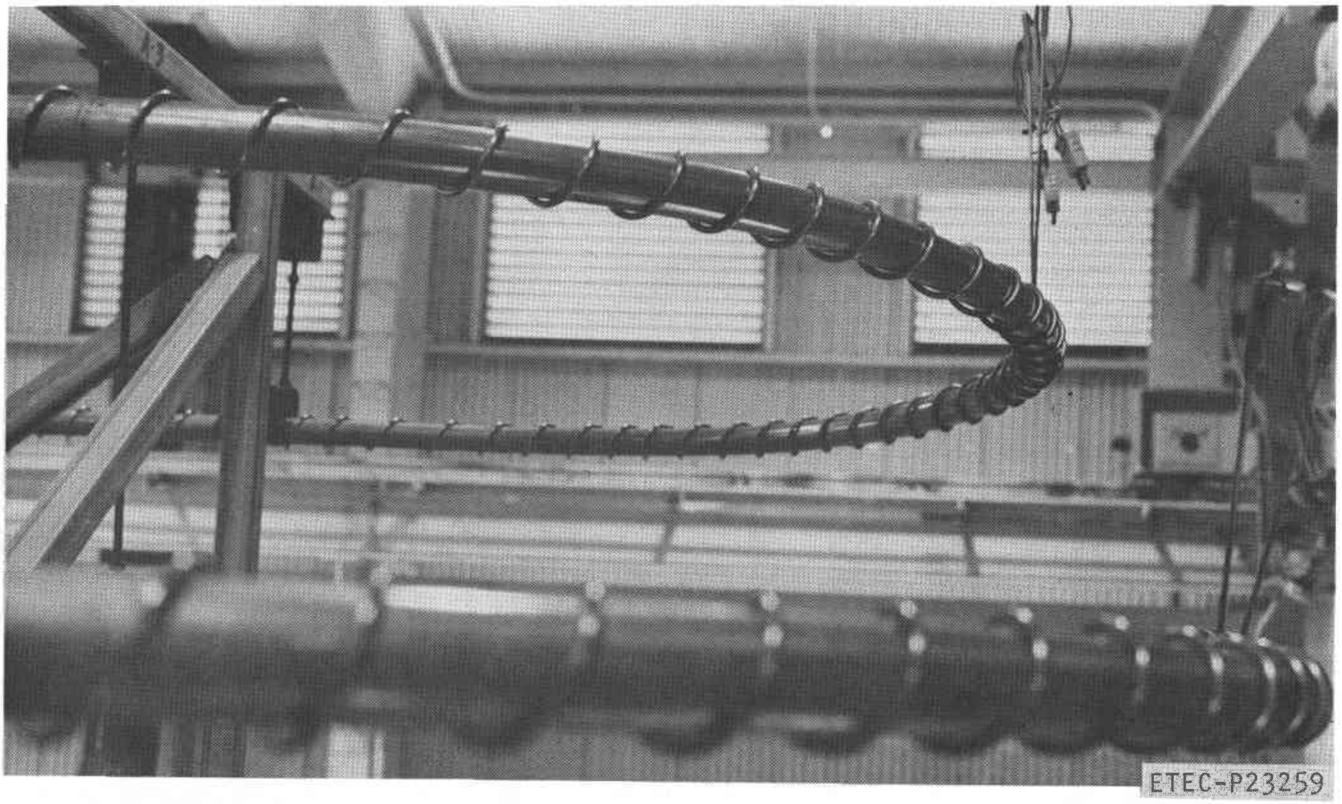



Figure 31. MI Cable Mounted Directly Onto a Curved Section of 1-in. Pipe

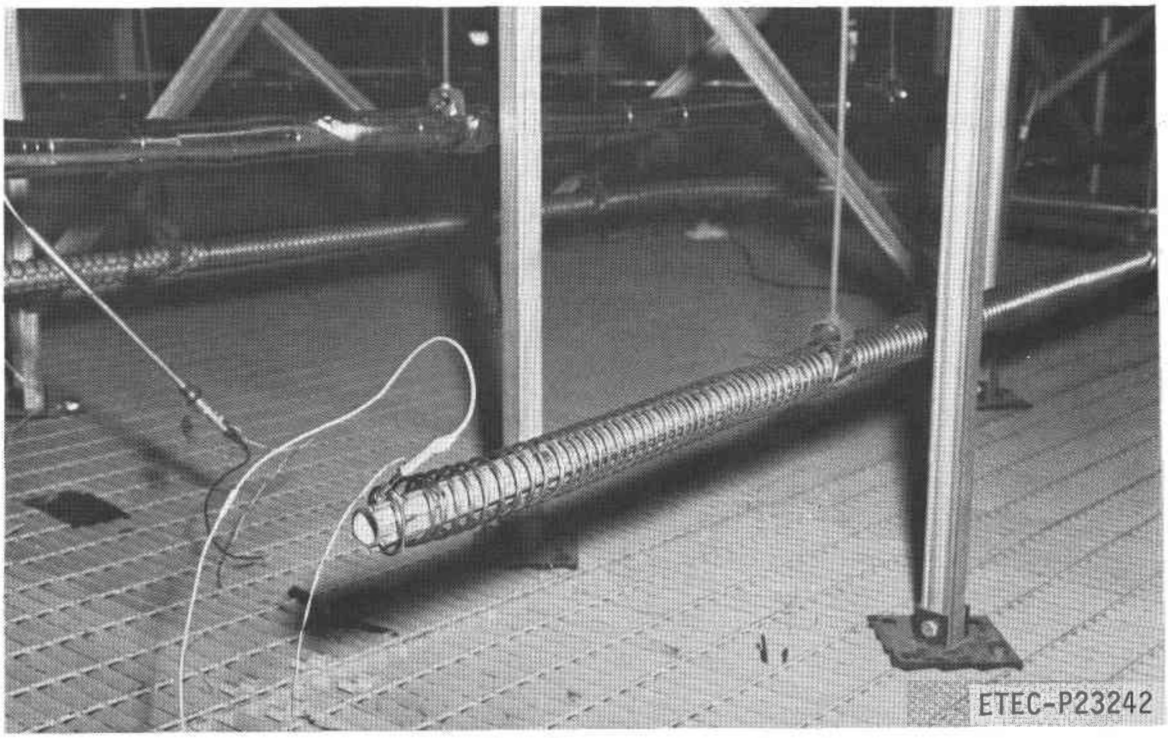



Figure 32. MI Cable Mounted on Spacers on a Straight Section of 1-in. Pipe

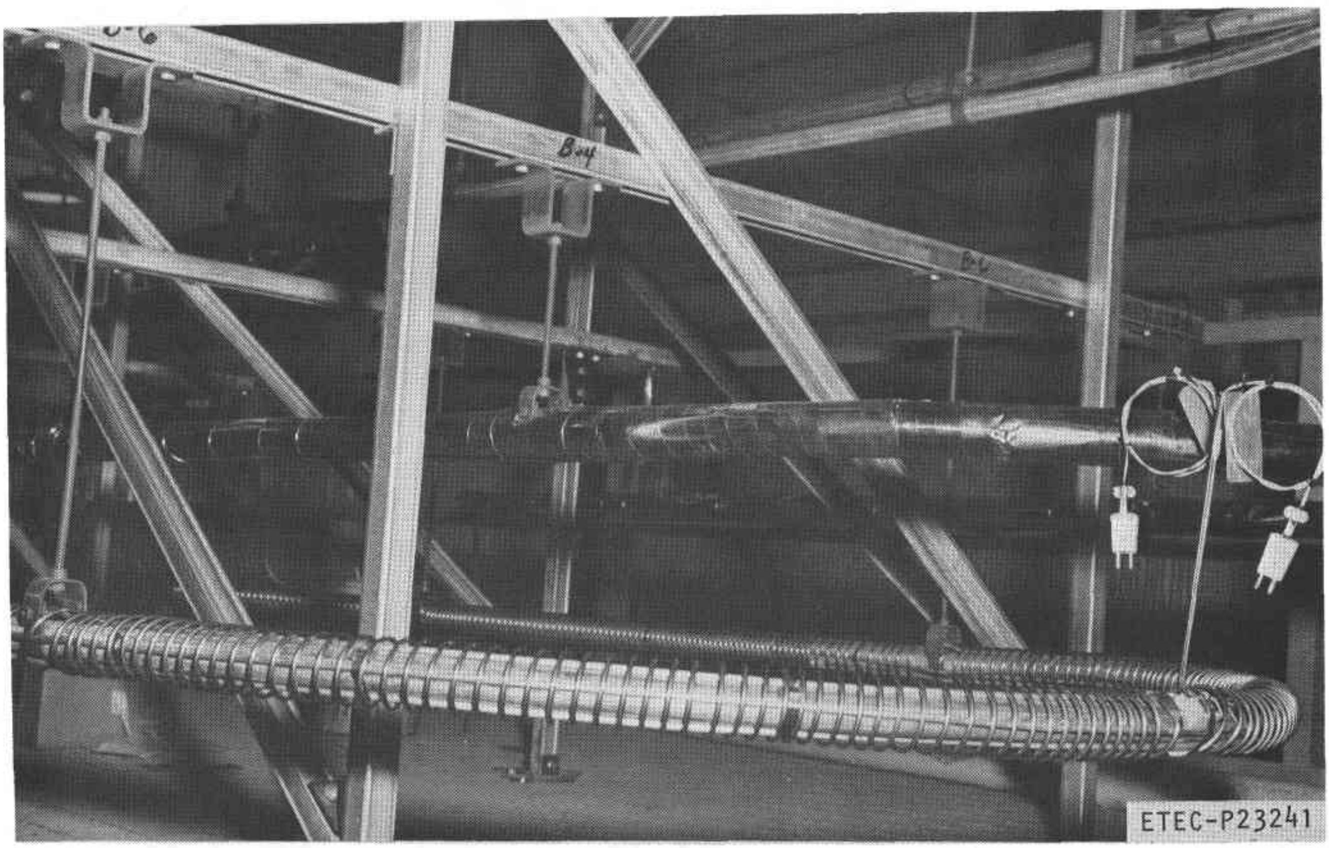



Figure 33. MI Cable Mounted on Spacers on a Curved Section of 1-in. Pipe

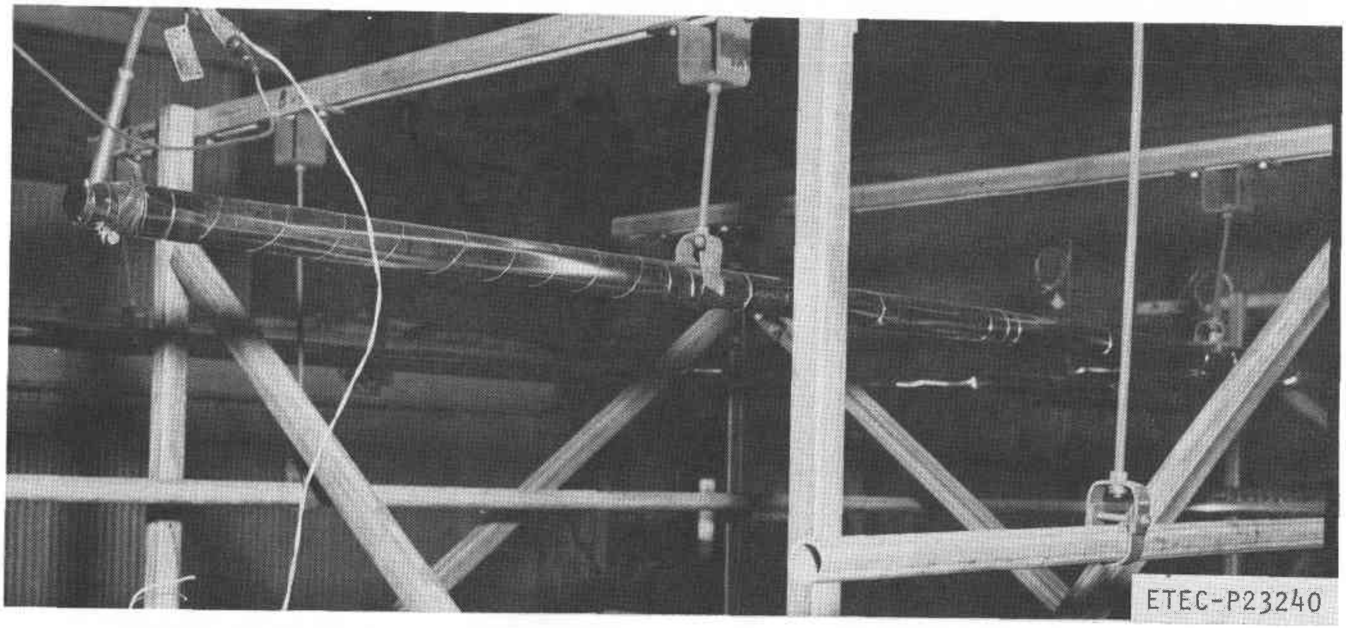



Figure 34. MI Cable Mounted on a 1-in. Test Pipe and Covered with Stainless Steel Foil Which Serves as a Support for Thermal Insulation

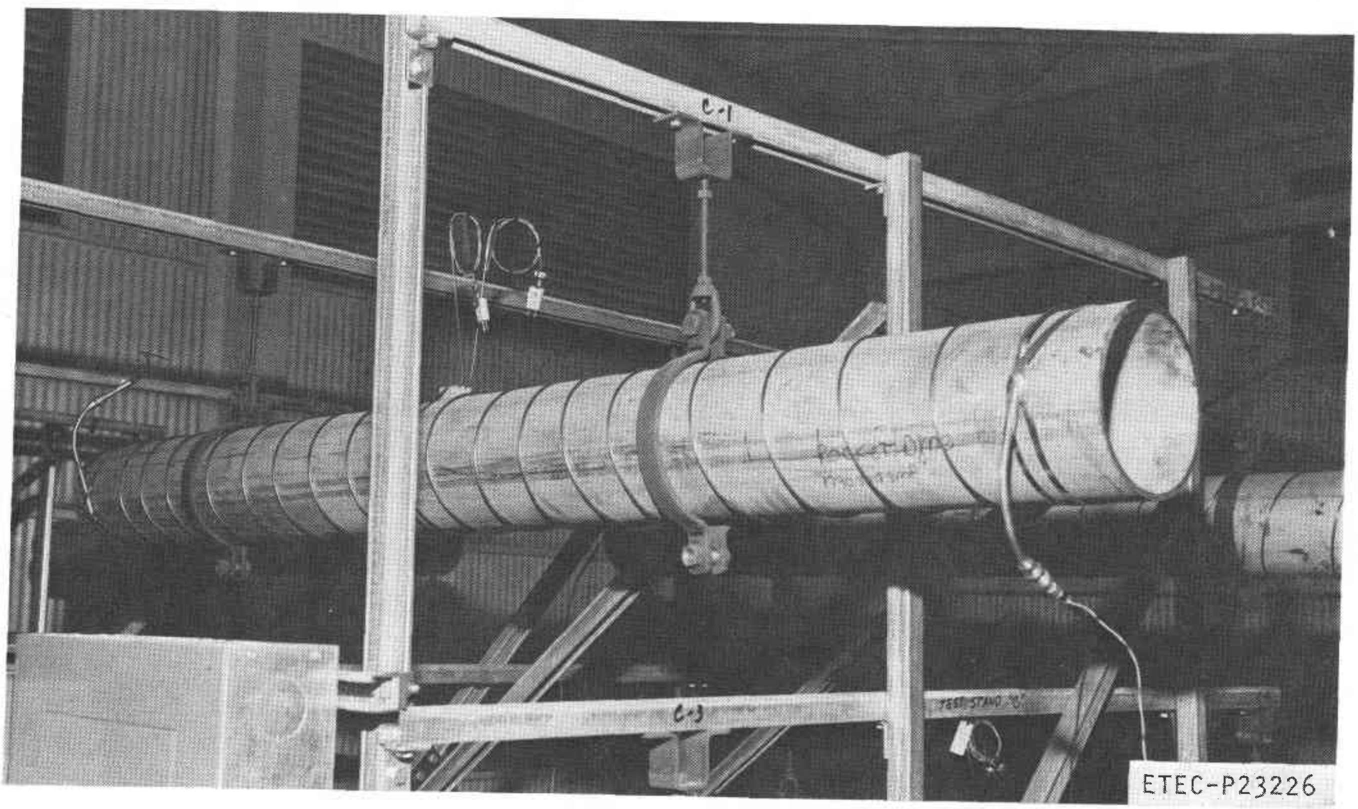



Figure 35. MI Cable Mounted Directly on an 8-in. Test Pipe

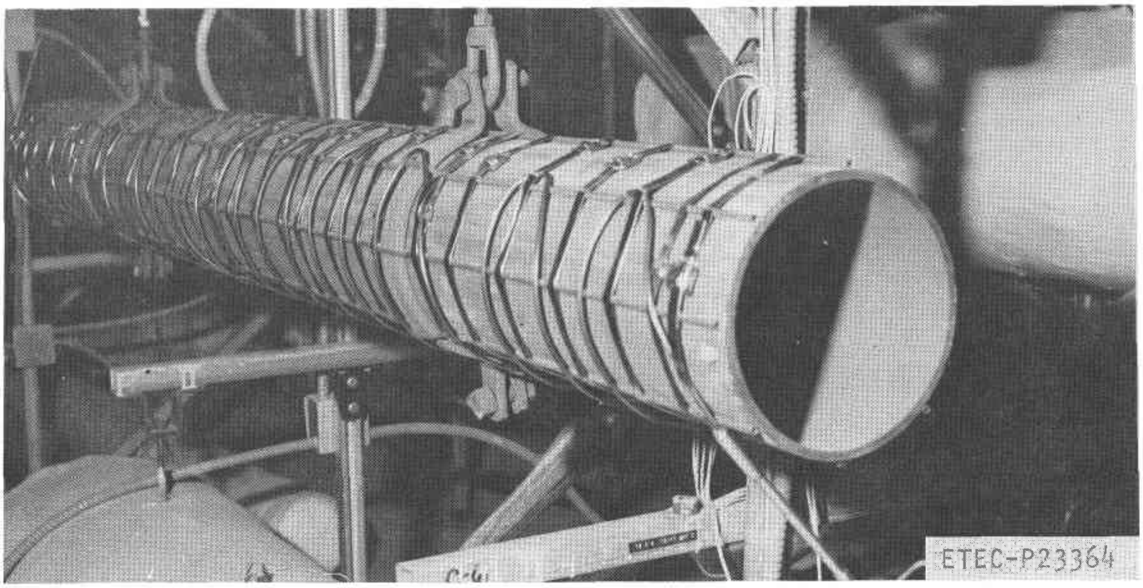
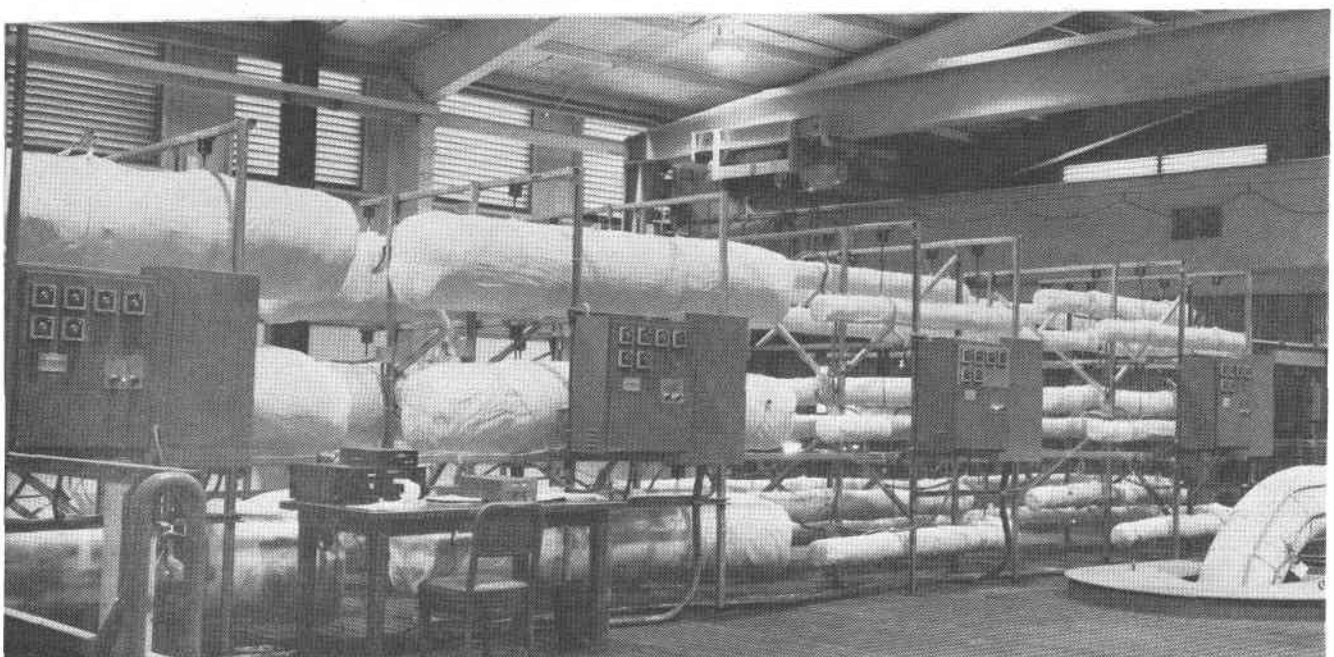



Figure 36. MI Cable Mounted on an 8-in. Test Pipe in a Serpentine Pattern

Figure 37. MI Heater Cable, Prototype Pipe Test Facility



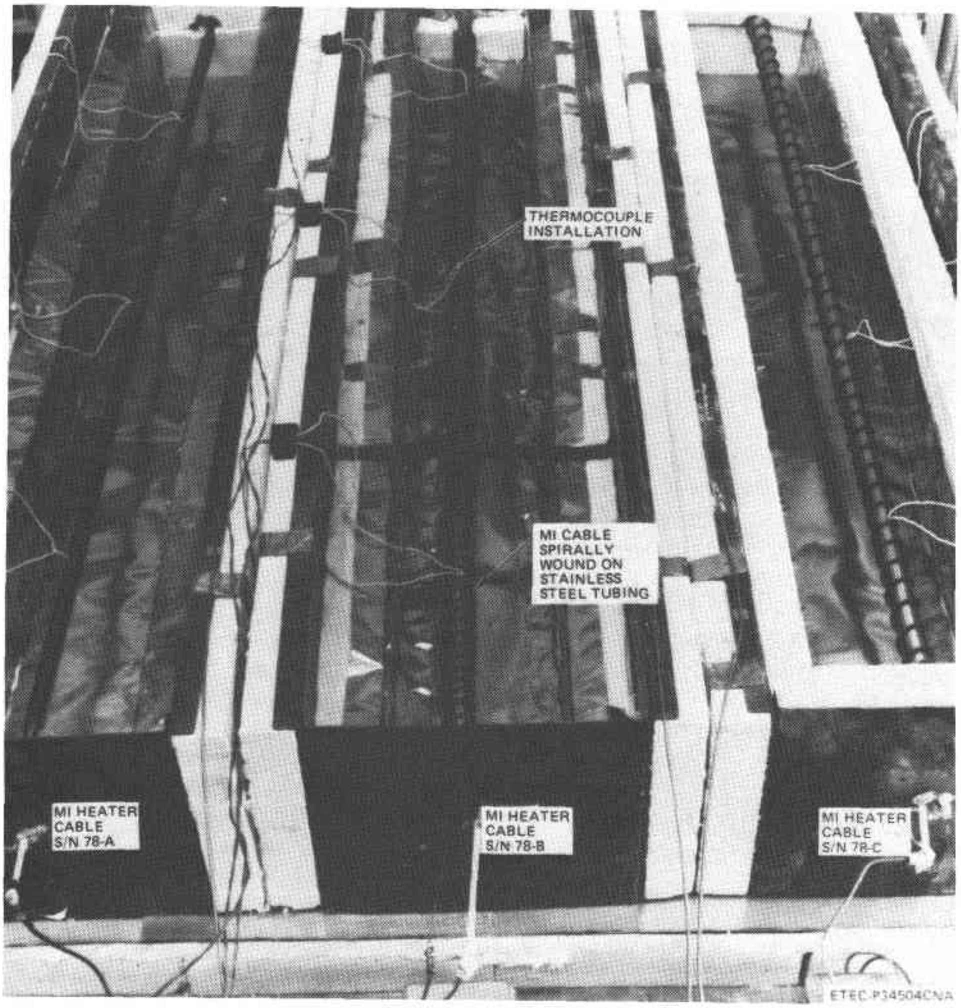



Figure 38. Three Ovens with Covers Removed to Show Interiors and MI Cable Heaters in Place

Figure 39. Accelerated Life Test Facility

The use of the accelerated life test as a means of comparative evaluation of heaters in terms of life expectancy is subject to criticism. The argument against the test is that the failure mechanism at severe operating conditions is not necessarily the same mechanism as under the milder intended service operating conditions. Although this argument may have technical merit, no other test has been proposed as a suitable alternative.

### 5. Accelerated Life Tests at 1500°F

The reason for testing at 1500°F was to determine if the "rule of thumb" regarding the effect of sheath temperature on life expectancy is applicable to accelerated life test. This "rule" states that for every 100°F increase in sheath temperature, the heater life expectancy is halved. The method of testing at 1500°F was the same as for 1700°F; i.e., power cycling at high temperature.

### 6. Prototypic Pipe Section Tests

In 1981, a test to demonstrate the adequacy of the MI cable designs was included in the ETEC testing program. The prototypic pipe section consisted of a length of 2-inch piping with horizontal and vertical sections including two elbows, one insulated pipe hanger, two MI cable heaters on the pipe (a primary heater and a secondary heater of 30% higher power capability to be used only if the primary heater could not provide the desired temperatures and heating rates), and thermal insulation.

The method of testing the prototypic pipe section was to apply power at a low level so as to raise the pipe temperature slowly, thus allowing all parts to reach steady temperatures of about 820°F. The pipe section was then allowed to cool back to room temperature. Finally, the section was to be heated at 50°F per hour to 820°F, at which temperature it was to be subjected to a 4000-hour endurance test. Testing on this pipe section was concluded in late 1982.

7. Prototype Pipe Section Test

The prototype pipe section consists of a length of 2-in. pipe with horizontal and vertical sections. Its major difference from the prototypic pipe section was the inclusion of a 2-in. bellows sealed valve. The pipe section was also extended in length. Four MI heater cables, procured to the Reference 5 specification, were installed on the pipe. Tubular heaters were installed on the valve to provide additional makeup heat. Testing on this section has not been completed.

The following conclusions and recommendations related to MI cable can be made based upon the testing which has been completed:

1) The overall reliability of tubular heaters tested at ETEC appears to be significantly greater than the reliability of the MI cable tested; however, the reliability of the MI cable may be sufficient for selected plant applications.

2) MI cable offers a distinct advantage over tubular heaters for odd-shaped components such as valve bodies and bonnets, small diameter piping typically found in sodium purification loops, or for small individual temperature-controlled components such as sodium pressure transducer seals or sodium valves because of the ease of installation. These types of installation require MI cable lengths to be tailored to the installation. Since the power dissipation per unit length of MI cable is limited to a narrow range by cable design parameters, the electrical power distribution system for MI cable systems must be more versatile than for tubular heaters and may require tailoring to individual heaters.

3) Termination technique, MgO purity, and MgO compaction density are the three areas which require the greatest control for maintaining or improving MI cable reliability. The Pyrotenax factory-fabricated transition between the element wire and the cold end of the heater was judged to be the best design, followed by the Vacuumschmelze factory-fabricated transition. The brazed joint between the element wire and the flexible power lead produced the next best results.

4) Installation techniques should consider the ease of field installation, the degree of cold working of the heater during installation, and the differential expansion between the heater and the article being heated. In general, ETEC mechanics preferred to install tubular heater rather than MI cable on straight sections of pipe. This may be due in part to their experience with tubular heater installation; however, because of the tubular heaters shorter length and greater rigidity, they are easier to handle. All heaters require freedom to expand at a different rate from the article they are mounted to; however, because of the greater length of the MI cable, the differential expansion is even larger and must be taken into account to prevent cyclic bending and subsequent sheath failure at one or more points.

5) Bending of the MI cable is acceptable; however, it should be kept to the minimum required to adequately form the cable to the component being tested.

6) Factory termination will allow the best transition design between the hot element and the cold end and should provide the best overall reliability; however, this does give up the advantage of field fabrication.

# VIII. PLANT EXPERIENCE

## A. FAST FLUX TEST FACILITY (FFTF)

FFTF has approximately 10,000 tubular heaters installed on various sodium tanks and piping systems throughout the facility. The primary purpose of most of the heaters is to preheat the sodium systems to approximately 400°F (204°C), although others are used to heat such areas as purification loops to 900 to 1000°F (482 to 538°C).

The tubular heaters (supplied by Rama Corp. of San Jacinto, CA) were purchased in various wattages, heater lengths, and cold end lengths. Many of the cold ends of the heaters were prebent at a 90-degree angle with a 1-in. bend radius which was repressed by the manufacturer. The majority of the tubular heaters used are 1/2-in. in diameter with the remainder 3/8-in. in diameter. Most of the heaters are used in the straight configuration, with the cold ends at right angles to the heated surface. Hairpin-shaped heaters with a minimum bend radius of 2 in. (5 cm) are used in a number of applications where it is more convenient to have the terminations at a single end. The cold end lengths vary according to insulation thickness. Most cold ends protrude from the insulation by approximately 2 in. (5 cm). The tubular heaters are strapped (using metallic "Band-it") onto the pipe, but a metallic spacer is used to keep the heater physically off the pipe or heated surface. The heater sheath is in electrical contact (via the spacers) but not in intimate contact with the pipe. The heaters are covered with a thin metallic sheet and then calcium silicate insulation in various thicknesses (depending on pipe size) is installed.

The original method of making the electrical connection to the heater was to crimp a copper sleeve to the mild steel cold end conductor and the 12-gage nickel-clad stranded-copper wire (Bostrad 19, with high temperature insulation). A number of problems occurred in this method of attachment. The crimping tools used during the early installation were not calibrated, which resulted in a number of improper crimp joints. The connecting wires were easily pulled off the steel cold end conductor. After these problems were identified, the crimping tools were calibrated to apply the proper pressure to the joint and personnel were trained to install the connecting wires properly. During heatup of the sodium system, the joints became hot enough to cause the crimp to relax and result in a poor electrical connection. Through testing, it was found that if a proper crimp joint achieved a temperature of 180°F or higher, the coefficient of expansion between the copper sleeve (used to make the crimp joint) and the cold end conductor would permit the relaxation of the mechanical connection.

After this problem was identified, a technique for brazing the existing crimp joint was developed. Heaters which were already installed were torch brazed by hand but heaters which could be brazed before installation were induction brazed. Pull tests were performed on a number of samples at heated conditions to ensure the termination problem was solved. All of the heater terminations are now brazed. The ground wire attached to each heater sheath is also brazed.

An additional problem regarding the heater terminations was uncovered as construction was progressing. Since the heater cold ends protrude from the insulation, they were vulnerable to being stepped on and/or physically abused from passing personnel who may be carrying tools and/or equipment into confined work areas. A number of terminations became broken in this manner as the crimp joint area is not strong enough to withstand loading. To remedy this problem, a ceramic sleeve was placed over the electrical termination to provide electrical as well as physical protection for the joint area. This modification has sufficed for the most part but occasionally the ceramic tubes have also been cracked or broken. In the fuel storage facility, heat shrink tubing is shrunk onto the braze/crimp joint to provide electrical insulation as well as additional stiffening.

Most of the tubular heaters are operated at 277 V, although rated at 480 V. This reduction between the rated and operating voltage effectively derates the heaters, thereby increasing their operational life. The heater rated power is designed not to exceed 40 watts/in.$^2$ (per the RDT P4-3T specification) but with the reduction of 480 V rated voltage to 277 V operating voltage, the rated power decreases to 13 watts/in.$^2$ operating power.

In a number of applications, heaters are connected in series. This was done to reduce the number of electrical circuits and wiring to the heaters. In order to provide additional trace heat reliability, many of the more critical piping systems have redundant heaters attached which are wired to convenient electrical panels but are not connected to a power source.

All of the tubular heater circuits at FFTF are protected by ground fault interrupters (GFI). In the event of a heater failure, which typically is a ground fault, the heater circuit will become open circuit very quickly. Although many of the heaters (approximately 5000) have been in operation since 1978, only one heater (hairpin) failure has occurred since the beginning of the construction phase. Two additional heater circuits have been reported to be grounded and the redundant heater string is being used. The exact nature or cause of the problem cannot be determined because of the inaccessible location.

Nearly all preheat systems at FFTF use tubular heaters and their reliability has been very good thus far. Mineral-insulated (MI) cable is not used at FFTF but flexible metallic GE heater cable is used for small, temporary heating projects.

## B. ENERGY TECHNOLOGY ENGINEERING CENTER (ETEC)

ETEC has a large number of tubular heaters installed on various sodium tank and piping systems throughout its facilities. At ETEC, most of the heaters are used to heat sodium systems from ambient temperature to as high as 1200°F (649°C). All new tubular heaters are purchased to the RDT P 4-3T specification, generally Grade II with the exception of sodium immersion heaters which are Grade I. Tubular heaters of various lengths, sizes, and wattages are maintained in an inventory at ETEC. Most of the heaters purchased are 1/2-in. in diameter with 8 or 12-in. cold ends, 240 or 480-V rating, 100 or 200 watts/ft of heater length and in the straight configuration.

Heaters are formed and installed by contractors or ETEC personnel in accordance with a Preferred Practices Manual (PPM) (Reference 3). In this procedure, the proper methods for heater installation are given. At ETEC, the heaters are banded directly to the pipe or tank wall without spacers in nearly all applications. The heaters and heated surface are then covered with a minimum 3 mil stainless steel sheeting material before an insulation blanket of calcium silicate or Cerablanket (flexible insulation) is placed over the entire heater installation. The insulation joints are staggered to minimize heat leaks and then the insulation surface is covered with a medium weight canvas and painted with a lagging adhesive (Arabol). The cold ends of the heaters typically protrude through the insulation surface by $1^1/_4$ in. minimum and they are then covered with a metallic junction box. Solid 12-gage copper wire is typically used to make the field connection to the heater. It is wrapped around the threaded end of the cold end conductor and locked into position using flat or cupped washers between the two nuts. A ground wire is clamped to the heater sheath by using a hose clamp. This ground wire is routed to the facility ground to assure compliance with the electrical code. Redundant ground fault interrupter (GFI) protection is provided for all heater circuits at ETEC.

Few heater failures have occurred at ETEC in recent years, in spite of the fact that many of the heaters have been installed in excess of 12 years or more. The failures which have been encountered involve improper installation. Tubular heaters are derated to operate at no more than 50% of rated power. Heaters are purchased with either a 480-V or 240-V rating but used at 277 V or 120 V. When the heater is operated in this manner, the operating power is only 1/3 or 1/4 of the rated power. This effective power rating is taken into account when designing the heat tracing system. The purpose of derating the heater is to extend its normal life and experience has shown that this is an excellent method for achieving this goal.

In critical applications, redundant heaters may be designed into the heating system, but as a general rule, they are not, as heater reliability has been very good. Tubular heaters are connected in parallel rather than in series to prevent loss of one heater effecting adjacent heaters. All of the trace heating systems at ETEC are protected by ground fault interrupters (GFI).

Each GFI is periodically checked by simulating a ground fault and verifying that the shunt trip breaker opens the circuit within the current and time limits specified.

Nearly all heat trace systems at ETEC employ tubular heaters, but a few applications require the source of heat to be fit into a small space. On this application, mineral-insulated (MI) cable has been used. This cable is purchased in a roll and can be cut to length for a specific task. The diameter of the cable used is either 0.125 or 0.180 inches. It has a solid exterior stainless steel sheath with a straight (non-coiled) center conductor. Magnesium oxide (MgO) is used as the insulator between the center conductor and the exterior sheath.

The MI cable has several distinct advantages over the tubular heater in some applications. It is more flexible and smaller in diameter which permits installation in areas where tubular heaters could not be used. If the MI cable is used in a relatively short length, the voltage to the cable must be reduced in order to limit the current through the cable, as well as the temperature of the heated surface. Another disadvantage of the MI cable is that a cold end type of junction must be made to the center conductor. If this joint is not made carefully and placed in a protected area, the probability of heater failure at this transition area is high. Since MI cable does have some limitations, it is only used where tubular heaters are not practical.

# IX. REFERENCES


1. K. A. Davis, "Mineral Insulated (MI) Heater Cable for CRBR Performance Tests," ETEC-TDR-83-14, 1984.

2. NE(RDT) Standard P4-3T, "Metal-Sheathed, Mineral-Insulated Electrical Resistance Heater," March 1975.

3. "Instrumentation and Control Preferred Practices Manual - Surface Mounted Tubular Electrical Heater Installation Procedure," PPM-II-A-5.1, Rev. D, 12/01/81.

4. Clinch River Breeder Reactor Plant System Design Description - Piping and Equipment Electrical Heating and Control System, SDD-68.

5. CRBR Equipment Specification 23A2655 "MI Cable."

6. G. R. Armstrong, "Evaluation fo SPTF Heater Standoff Design," LMEC-TDR-74-10, 12/16/74.

7. "First Article Test Report for FFTF Heater Supports," 71563-E-08, Westinghouse Astronuclear Laboratory, 12/23/74.

8. G. R. Armstrong, "SPTF Thermal Insulation Performance Test," LMEC-TDR-75-14, 11/14/75.

9. K. A. Davis, B. E. Fischer, and H. H. Schiowitz, "Evaluation of Heater Circuit Protective Devices as a Means of Limiting Heater Failure Damage," LMEC-TDR-73-9, 8/27/73.

10. M. I. Gould, G. R. Armstrong, "Heater Protective Devices Resistance Grounding Study," LMEC-TDR-76-2, 8/20/76.

## APPENDIX A

## HEATER TEST FACILITY DESCRIPTION

## APPENDIX A

## HEATER TEST FACILITY DESCRIPTION

ETEC's heater evaluation test program is being conducted in an accelerated life test facility, which is a wire-screen-enclosed, 10 by 25-ft (3 x 7.5 m) area located in Building 057. Within this enclosed area are three tables with three insulated oven-type boxes (12 by 10 by 68 in.) in which the heaters are installed for accelerated life testing. The typical test heater installation with the insulated tops in place is shown in Figure 4. The six oven-like boxes which contain the tubular heaters under test are shown. The heater voltage control cabinet is shown in the background. An internal view of the oven with the heater installed is shown in Figure 5. The heater is supported over its length by several small diameter stainless steel wires to reduce "sag" at elevated temperature while minimizing thermal loss and hot-spot/cold-spot formation. The tubular heaters shown are being tested in the hairpin or "U" shape configuration, but straight and "S" bend heaters are tested as well.

The sheath temperature is controlled by the thermocouples (beaded wires) attached to the heater sheath. Individual voltage controls permit the voltage and sheath temperature to each test heater to be individually controlled. In order to keep the control voltage near the heater rated voltage and still acquire a sheath temperature of 1700 $\pm$ 25°F during the power "ON" cycle, the amount of insulation covering the oven is adjusted to minimize the heat loss.

Each of three tables contain three test ovens for a total of nine heater test positions. Each oven can be modified to accept straight, hairpin type, or "S" bend shape heaters. Each power "ON" cycle is recorded by an electrical impulse counter and the sheath temperature is recorded (on a periodic basis) with a strip chart recorder. Each table or group of three heaters is fully protected with a ground fault interrupter which trips the power circuit breaker in the event of a heater failure. Most test heater failures create a ground fault and trip the circuit breaker. The life cycle test is monitored by

ETEC personnel a minimum of three times daily. Typically, when a failure occurs, the failed heater is electrically disconnected and power is returned to the other heaters under test. When another heater is prepared to replace the failed heater, it is reconnected to the power source.

# APPENDIX B

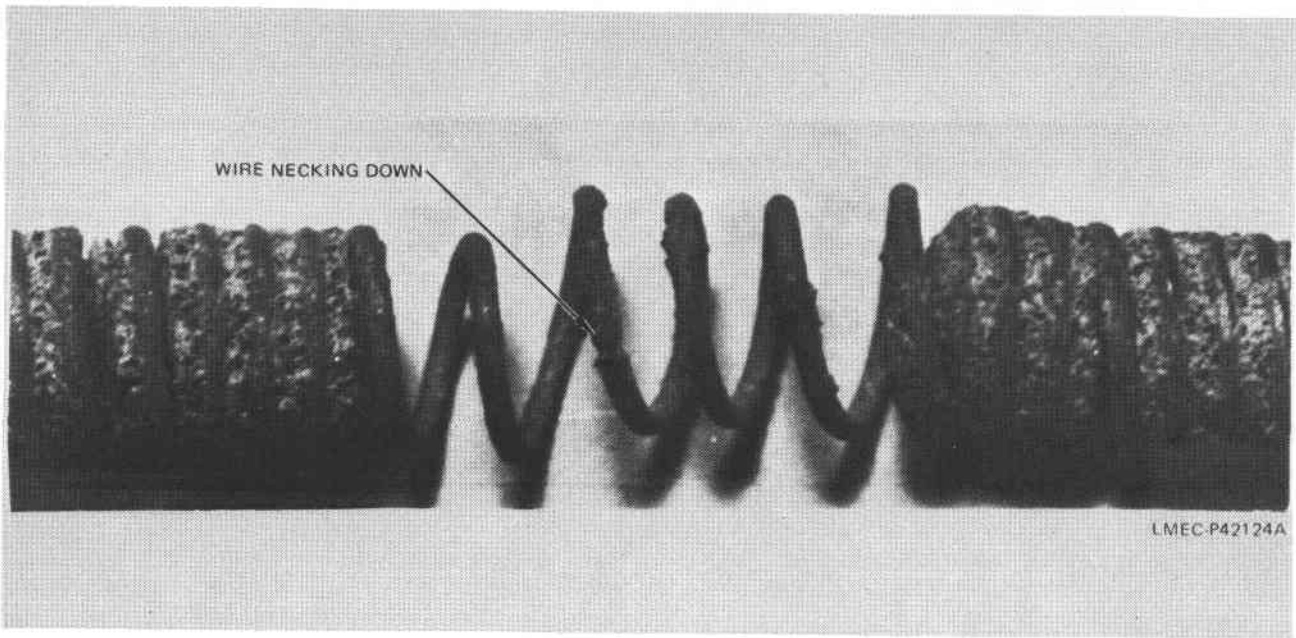
# EXAMPLES OF HEATER FAILURES

Manufacturer: Sensor Dynamics Inc. S/N: 73-310 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 4688 Sheath Composition: Unknown

Remarks: MgO adjacent to the element wire in necked down area was green in color. Necked down area is assumed to be element hot spot preceeding open element spot if test had continued..



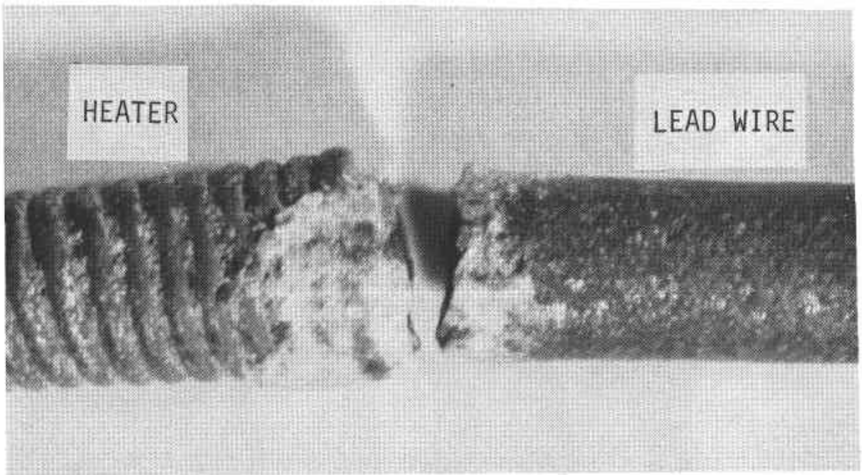
Manufacturer: Rama S/N: 74-147 Grade: I

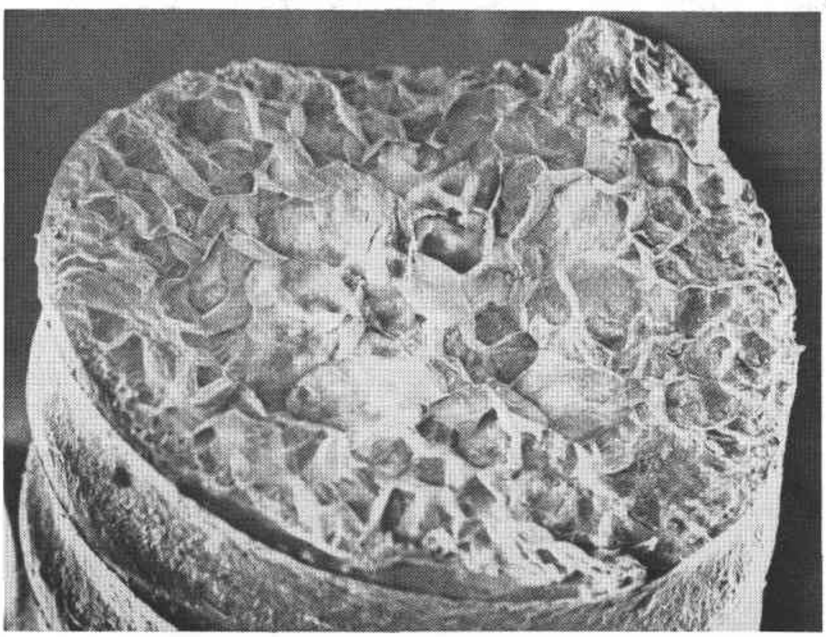
Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 3071 Sheath Composition: 321SS

Element Wire Size: 0.020 in. MgO Grain Size: 5

Remarks: Probably failed by gross oxidation (bulk and intergranular) of the nickel lead wire.



Face of Fracture
37.5 magnification

Manufacturer: HESCO S/N: 74-134 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 5309 Sheath Composition: Incoloy 800

Element Wire Size: 0.026 in. MgO Grain Size: 5

Remarks: Several arc spots on sheath wall. Element wire melted. Probable recrystallization in element.

Sheath

Heater Wire

MgO Insulation

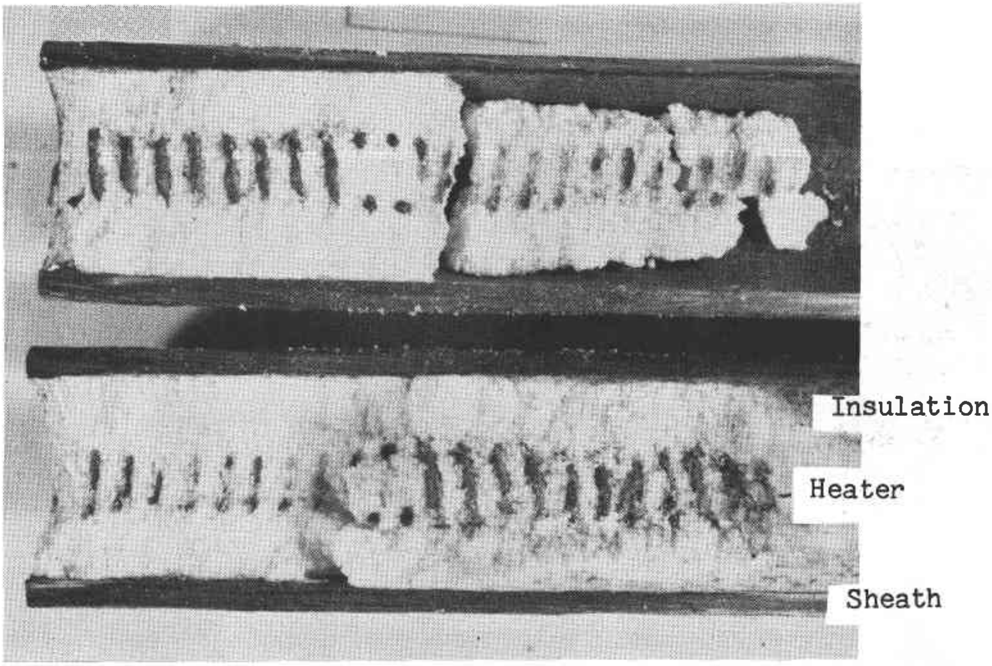
Manufacturer: Chromalox S/N: 75-128 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 36,957 Sheath Composition: Incoloy 800

Element Wire Size: 0.024 in. MgO Grain Size: 4

Remarks: Electrical arc from element to sheath. Gross oxidation of element.



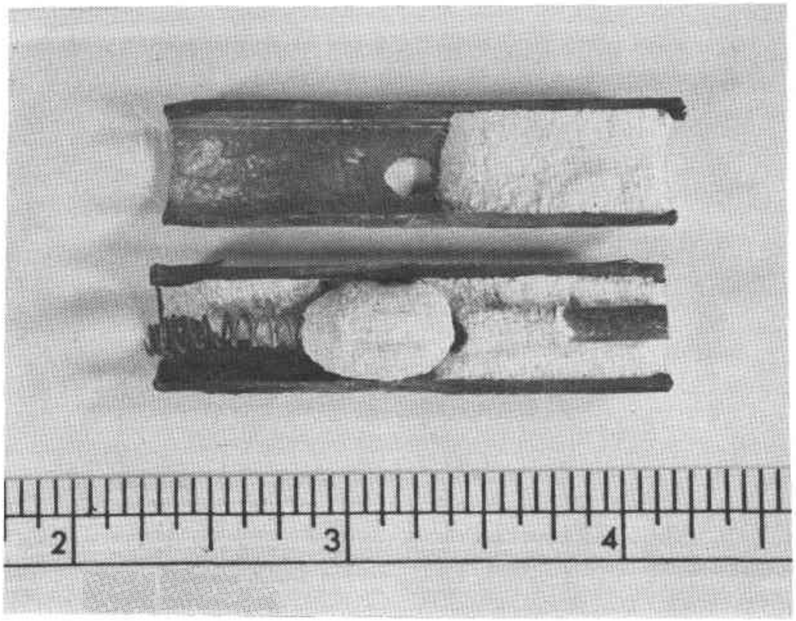
Manufacturer: Rama S/N: 75-165 Grade: II

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 15,092 Sheath Composition: Incoloy

Element Wire Size: 0.018 in. MgO Grain Size: 5

Remarks: Failed by electrical arc from element to sheath at cold end junction.



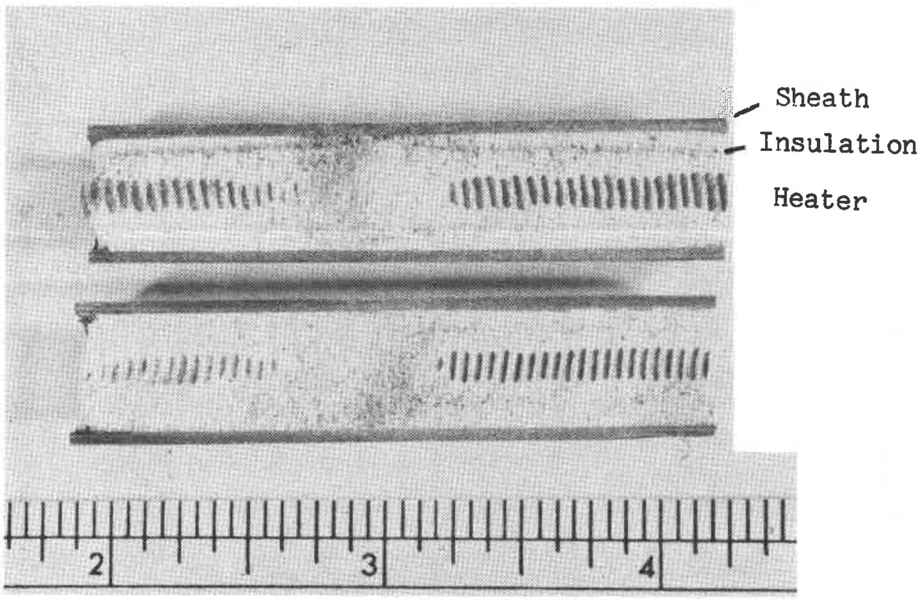
Manufacturer: HESCO S/N: 75-173 Grade: II

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 9,609 Sheath Composition: 321SS

Element Wire Size: 0.022 in. MgO Grain Size: 2-4

Remarks: Failed by electrical arc from element to sheath. Element wire melted.



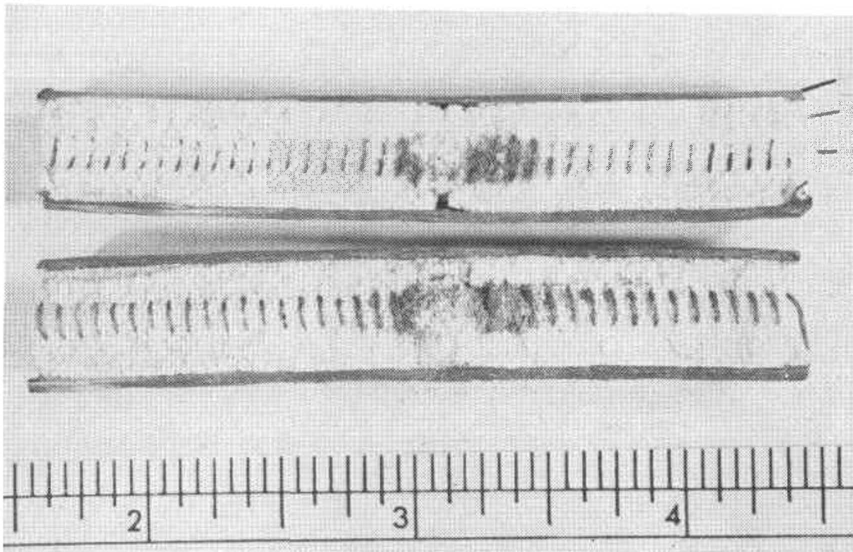
Manufacturer: Chromalox S/N: 75-135 Grade: II

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

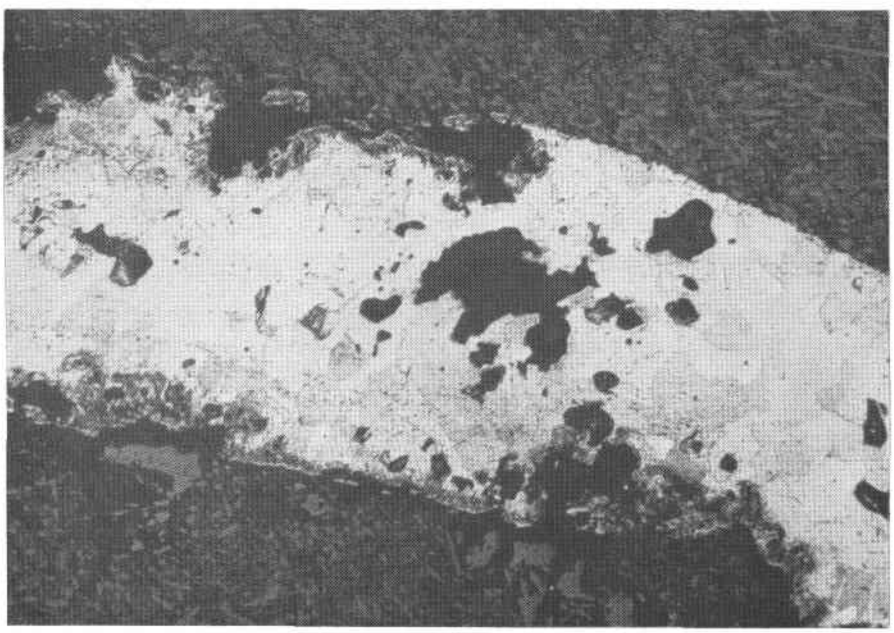
Accelerated Life Cycles: 6980 Sheath Composition: Incoloy 800

Element Wire Size: 0.024 in. MgO Grain Size: 5

Remarks: Failed by electrical arc from element to sheath.
Element wire deteriorated.




Sheath
Insulation
Element



Element wire
100X Mag

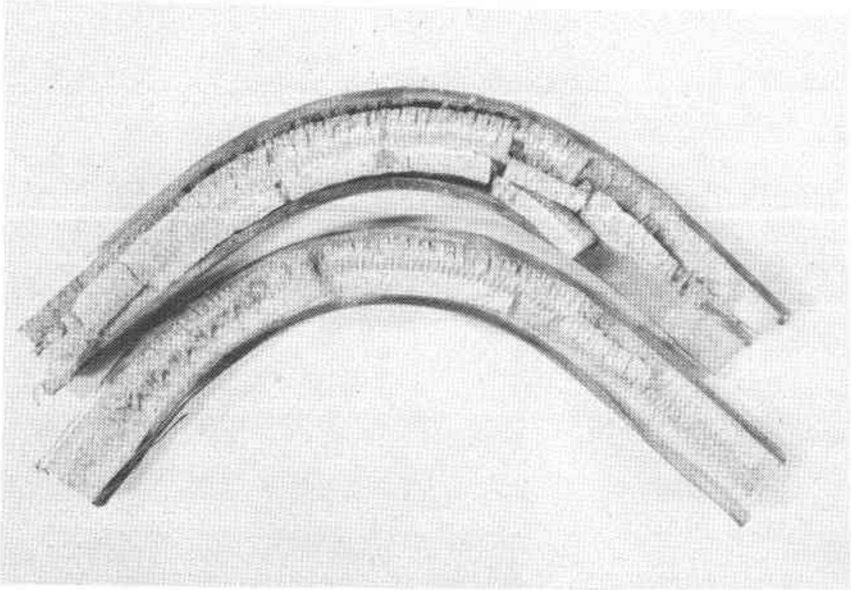
Manufacturer: Rama S/N: 78-143 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: "S" Bend

Accelerated Life Cycles: 3745 Sheath Composition: High Nickel Alloy

Element Wire Size: 0.022 in. MgO Grain Size: 5

Remarks: Failed at elbow where MgO segmented.



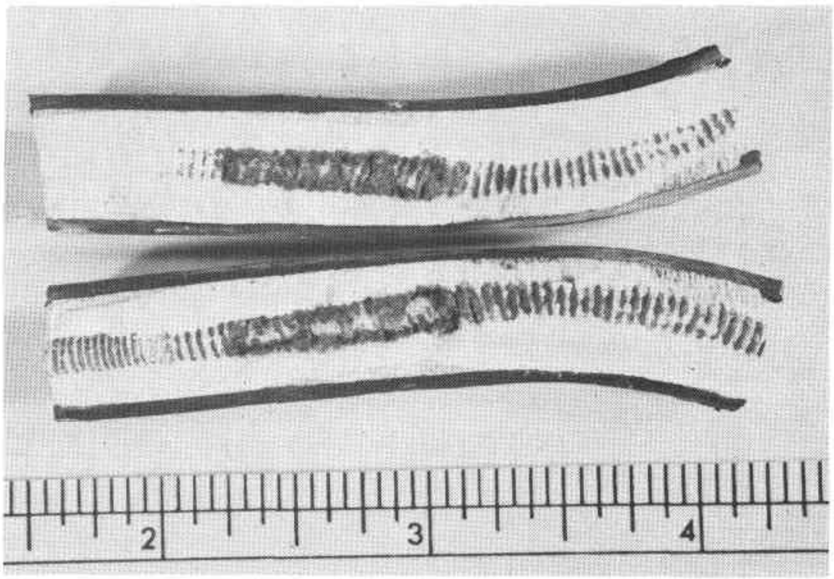
Manufacturer: HESCO S/N: 74-138 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: "S" Bend

Accelerated Life Cycles: 7387 Sheath Composition: 321SS

Element Wire Size: 0.024 in. MgO Grain Size: 5

Remarks: Failed by arcing from lead element junction to sheath. Lead wire identified as iron. The element wire melted.



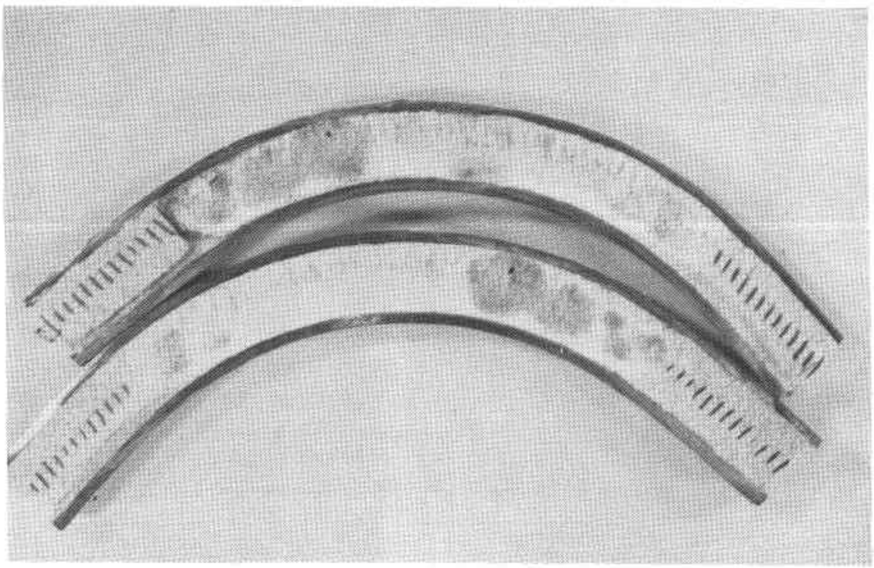
Manufacturer: Chromalox S/N: 75-132 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: "S" Bend

Accelerated Life Cycles: 8497 Sheath Composition: Incoloy 800

Element Wire Size: 0.019 in. MgO Grain Size: 4

Remarks: Element wire melted in elbow from an electrical arc from element to sheath.



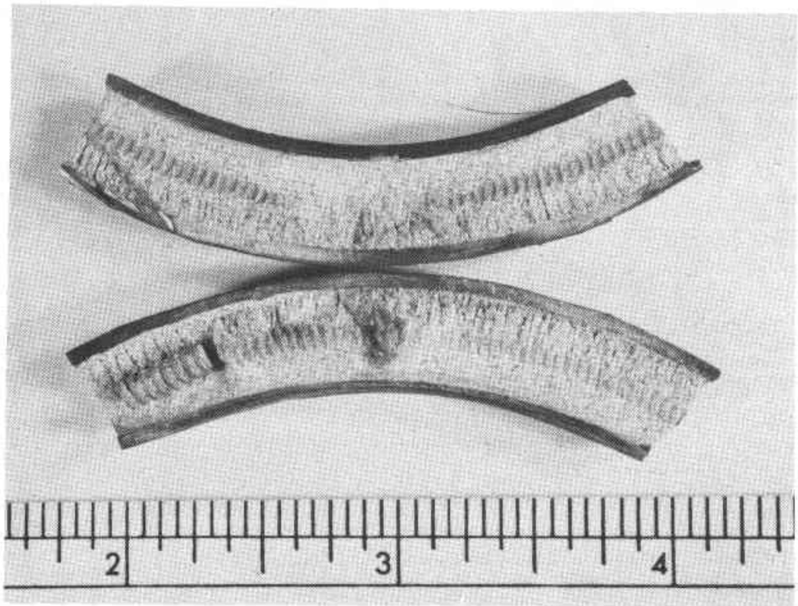
Manufacturer: Rama S/N: 75-158 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 1776 Sheath Composition: 321SS

Element Wire Size: 0.022 in. MgO Grain Size: Totally melted

Remarks: Failed by arcing from element to sheath at the elbow.



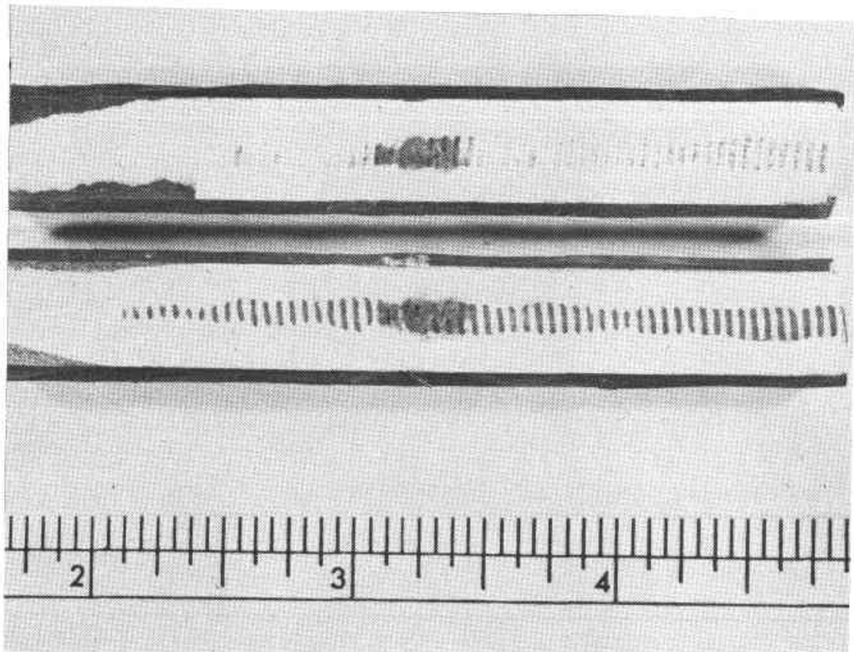
Manufacturer: HESCO S/N: 75-178 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 1709 Sheath Composition: 321SS

Element Wire Size: 0.022 in. MgO Grain Size: -

Remarks: No obvious failure path of arc from element to sheath. Localized discoloration of MgO at arc location.



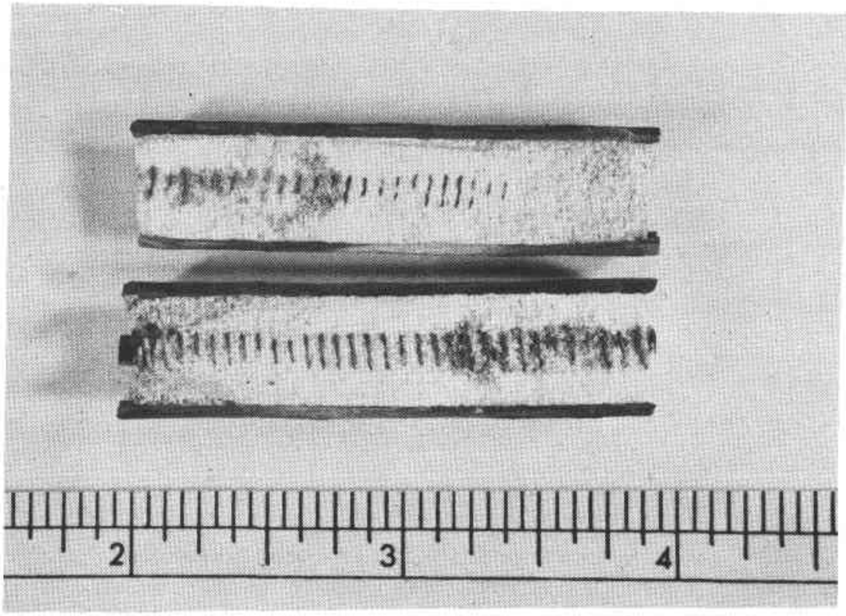
Manufacturer: Chromalox S/N: 75-143 Grade: I

Size: 1/2-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 6618 Sheath Composition: Incoloy 800

Element Wire Size: 0.022 in. MgO Grain Size: 1 or larger

Remarks: Very large grain size. Element wire deterioration.
Probably arced to sheath.



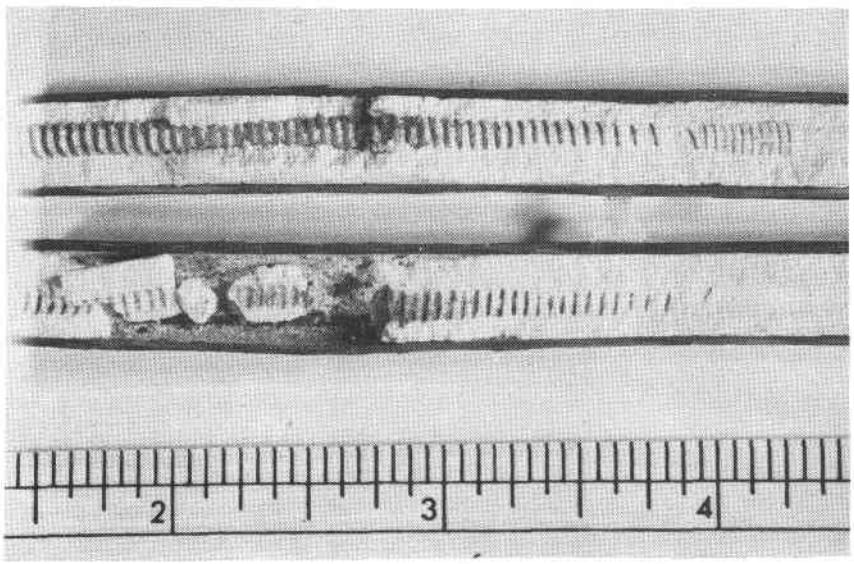
Manufacturer: Rama S/N: 76-17 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 15,980 Sheath Composition: Incoloy 800

Element Wire Size: 0.022 in. MgO Grain Size: 4

Remarks: Failed by electrical arc from element to sheath.
Element wire deteriorated.



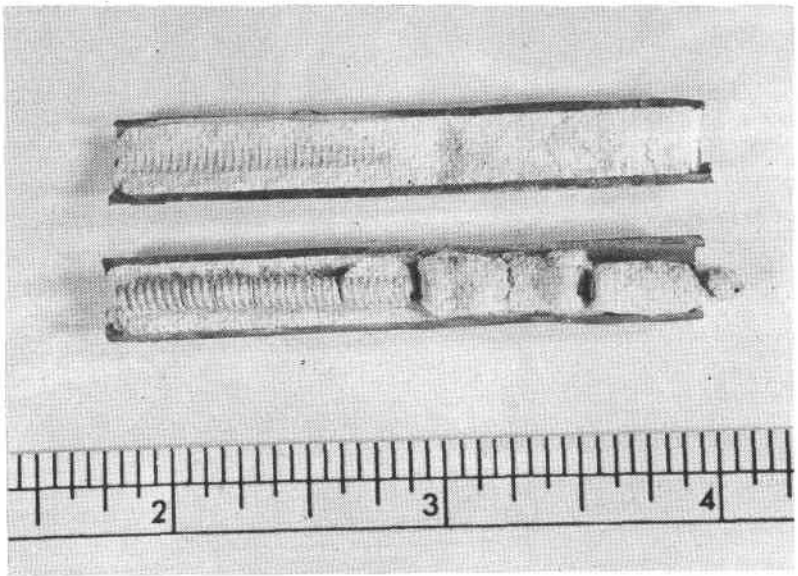
Manufacturer: HESCO S/N: 76-61 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 6956 Sheath Composition: 321SS

Element Wire Size: 0.020 in. MgO Grain Size: 3-4

Remarks: Failed by electrical arc from element to sheath.
MgO fused and element wire deteriorated.



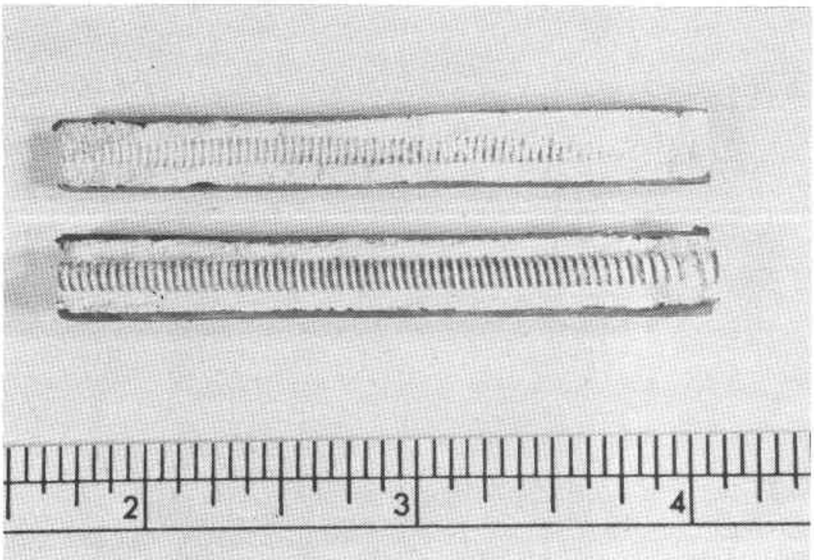
Manufacturer: Chromalox S/N: 76-102 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 11,428 Sheath Composition: 321SS

Element Wire Size: 0.020 in. MgO Grain Size: 4

Remarks: Apparently arced between element and sheath.



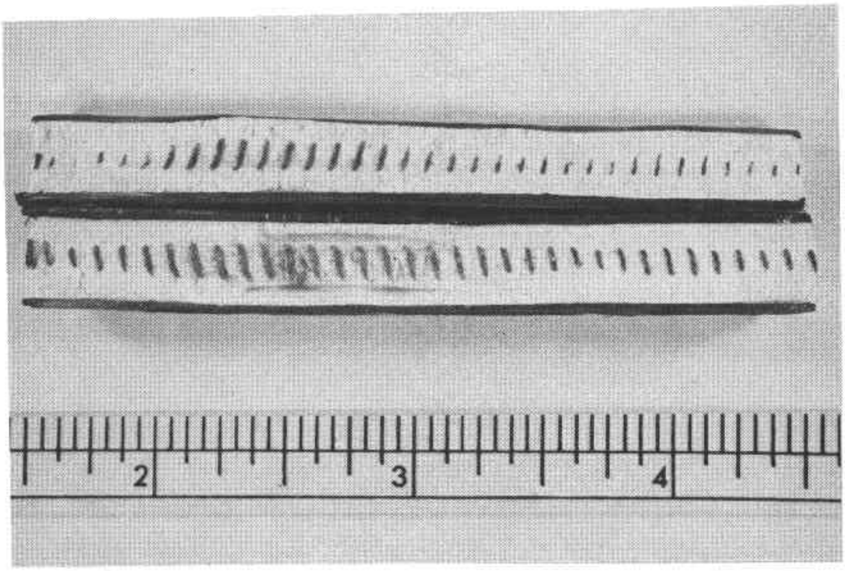
Manufacturer: Rama S/N: 76-25 Grade: I

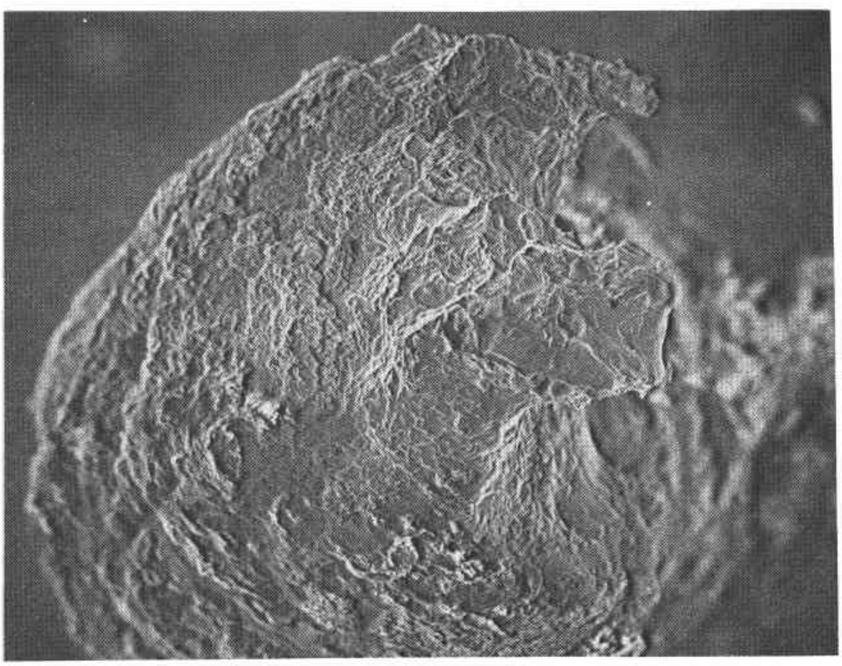
Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 3036 Sheath Composition: Incoloy 800

Element Wire Size: 0.027 in. MgO Grain Size: 5-6

Remarks: No apparent arcing at break. Heavy green oxide present.



Face of Fracture
100X Mag

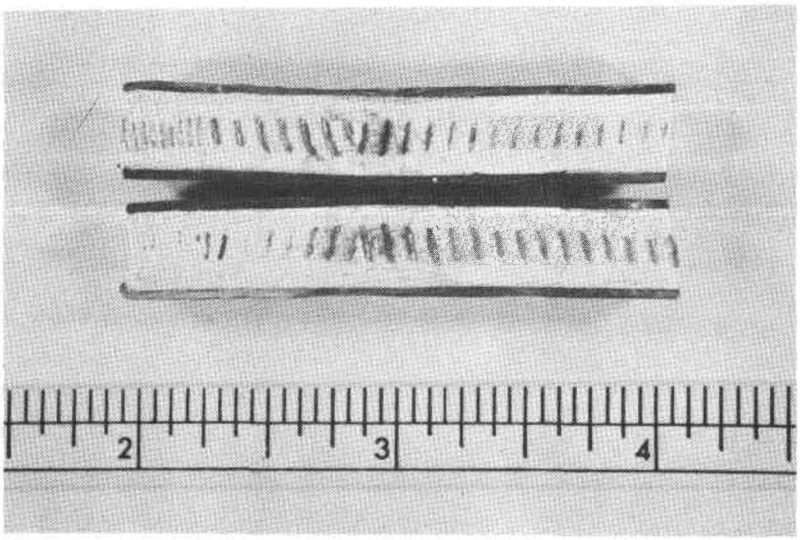
Manufacturer: HESCO S/N: 76-67 Grade: I

Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 1955 Sheath Composition: Incoloy 800

Element Wire Size: 0.018 in. MgO Grain Size: -

Remarks: Green oxidation of element with no apparent arc to sheath.



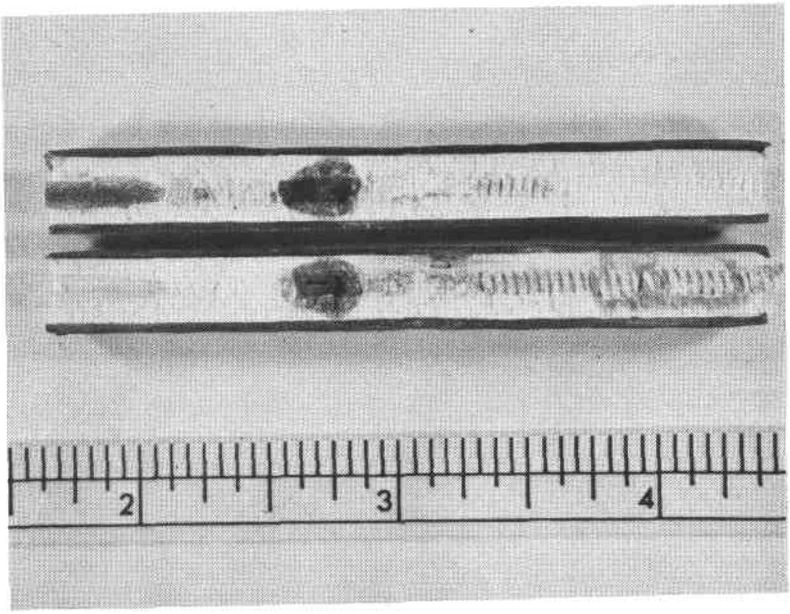
Manufacturer: Chromalox S/N: 76-108 Grade: I

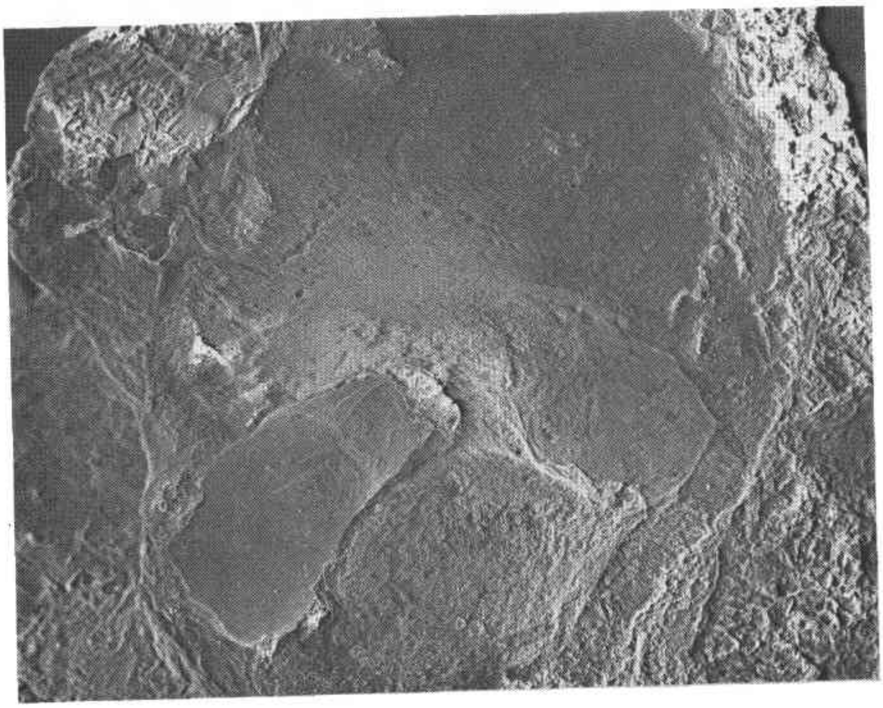
Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 35,145 Sheath Composition: Incoloy 800

Element Wire Size: 0.018 in. MgO Grain Size: -

Remarks: Failed by electrically arcing from totally oxidized iron lead wire element junction to sheath (hole).



Face of Fracture
50X Mag

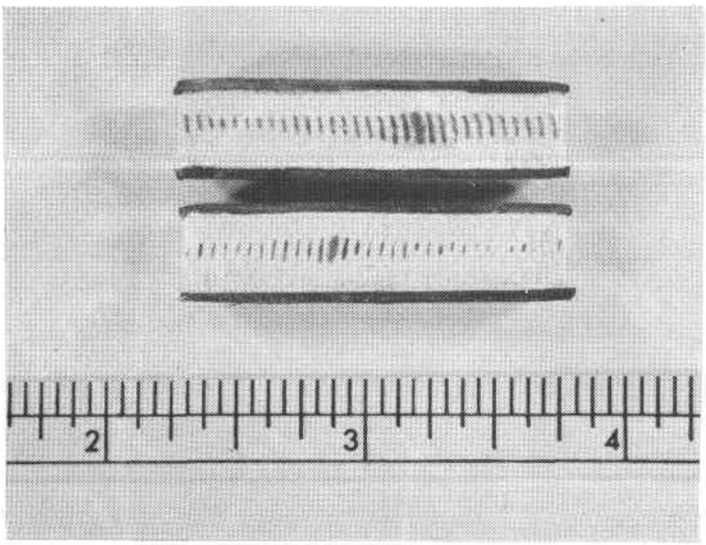
Manufacturer: Rama S/N: 76-40 Grade: II

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 2802 Sheath Composition: Incoloy 800

Element Wire Size: 0.019 MgO Grain Size: -

Remarks: Element very brittle (gross green oxidation) and broken into several pieces.



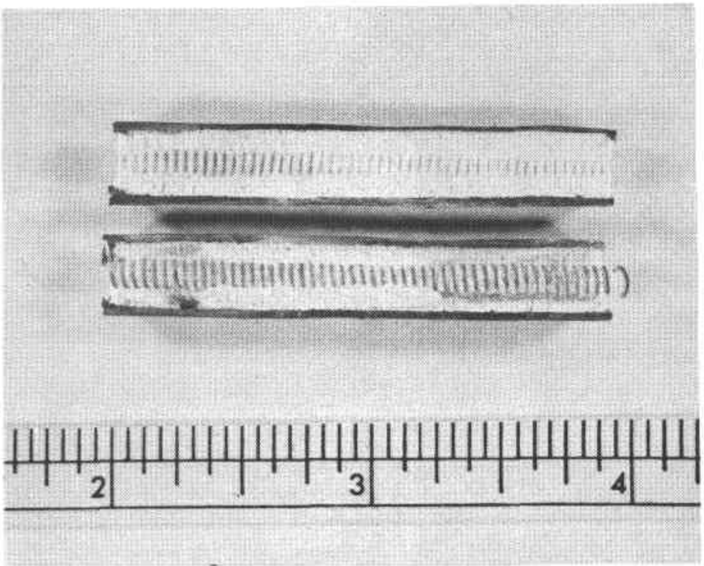
Manufacturer: HESCO S/N: 76-81 Grade: II

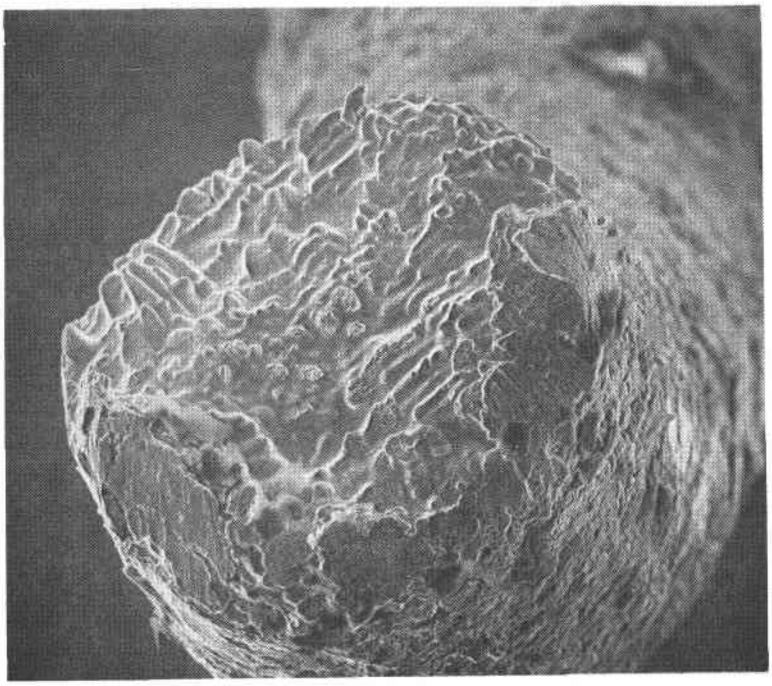
Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 280 Sheath Composition: 321SS

Element Wire Size: - MgO Grain Size: -

Remarks: No apparent electrical arcing; however, melting found at failure. Element wire very soft.



Face of Fracture

200X Mag

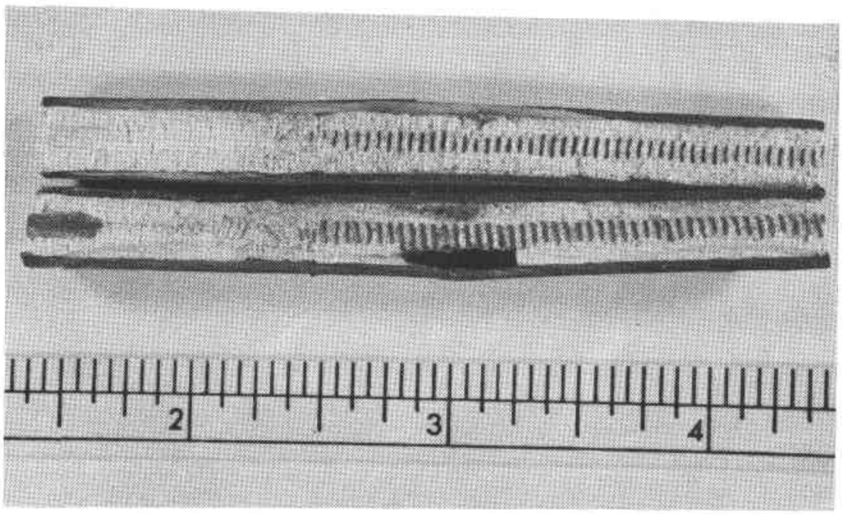
Manufacturer: Chromalox S/N: 76-124 Grade: II

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 380 Sheath Composition: Incoloy 800

Element Wire Size: 0.016 in. MgO Grain Size: 5-6

Remarks: Bulge in sheath where element electrically arced to neighboring coil element. Element is very brittle. Lead wire identified as iron.



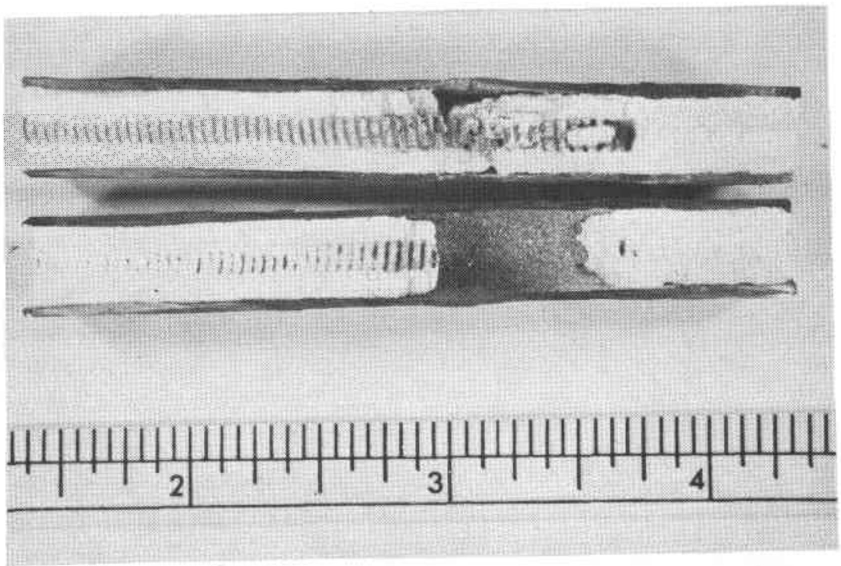
Manufacturer: Rama S/N: 76-45 Grade: II

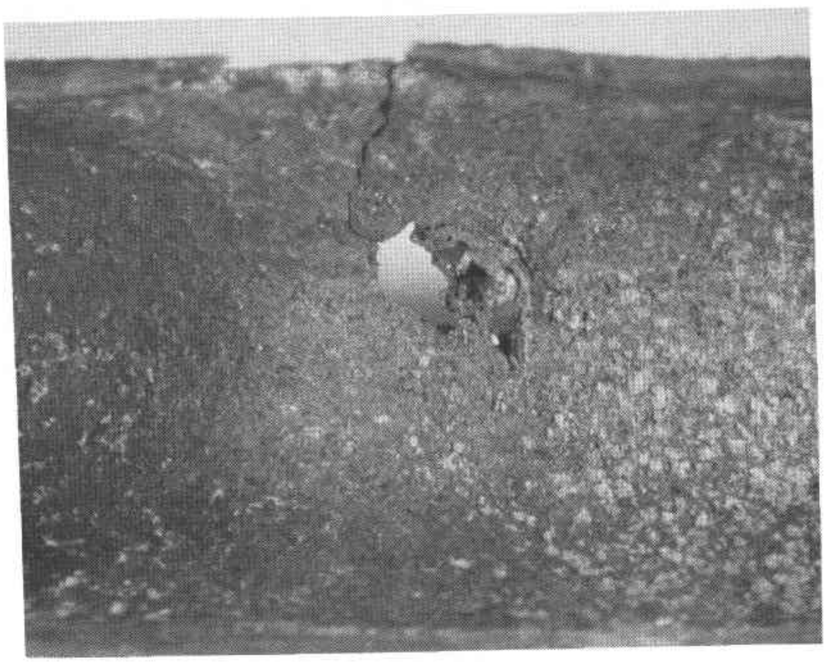
Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 10,210 Sheath Composition: Incoloy 800

Element Wire Size: 0.018 in. MgO Grain Size: 7

Remarks: Bulge in sheath at failure. Gross overheating of element. Element very brittle.



Sheath

$7^1/_2$X Mag

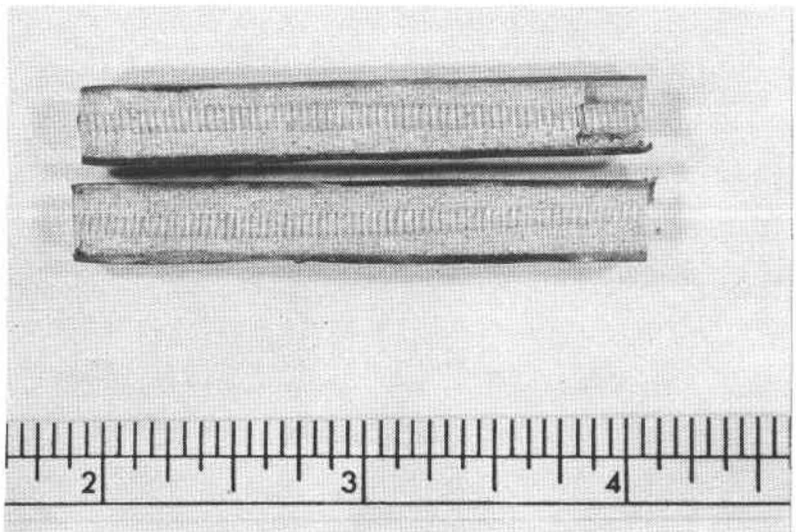
Manufacturer: HESCO S/N: 76-88 Grade: II

Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 9424 Sheath Composition: 321SS

Element Wire Size: 0.018 in. MgO Grain Size: -

Remarks: MgO exhibits grayish cast.



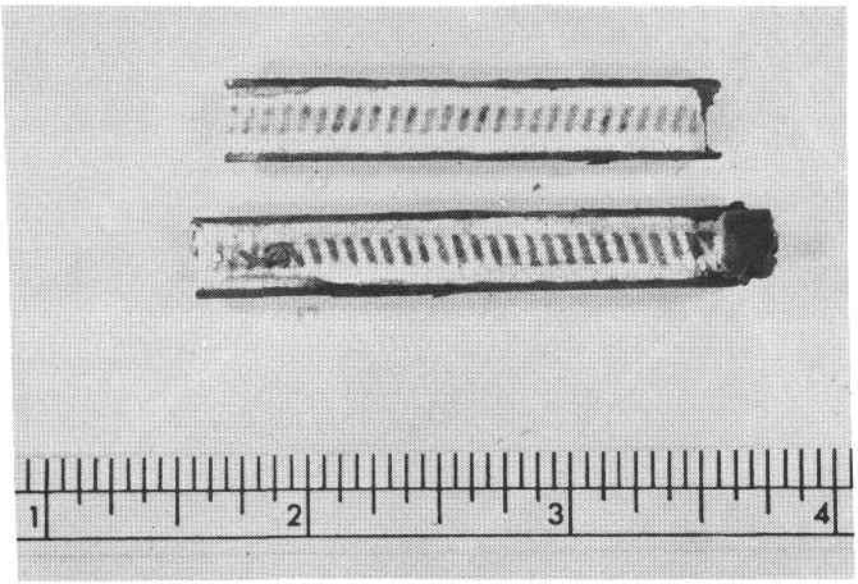
Manufacturer: Chromalox S/N: 76-129 Grade: II

Size: 3/8-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 32,310 Sheath Composition: Incoloy 800

Element Wire Size: 0.024 in. MgO Grain Size: -

Remarks: Element wire brittle at failure point.



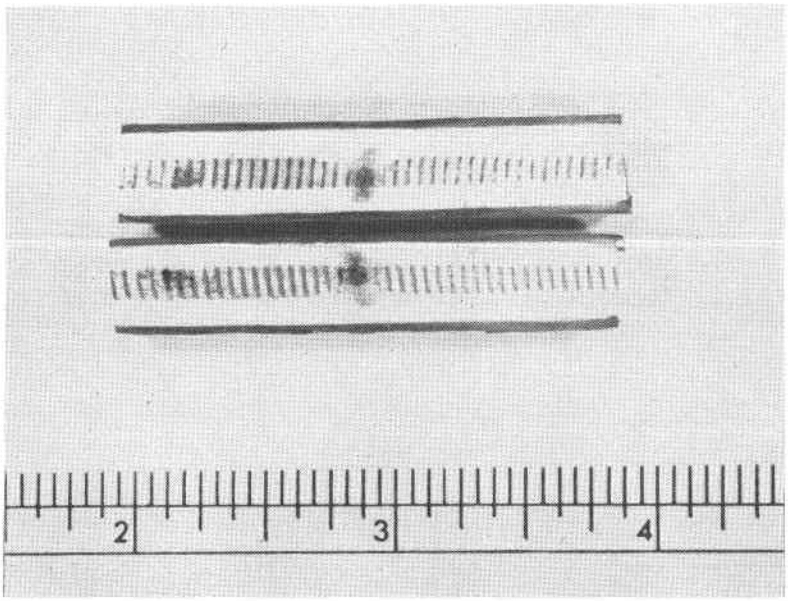
Manufacturer: Rama S/N: 76-22 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 3487 Sheath Composition: Incoloy 800

Element Wire Size: 0.018 in. MgO Grain Size: -

Remarks: Localized discoloration of MgO at failure point.
Element wire ductile.



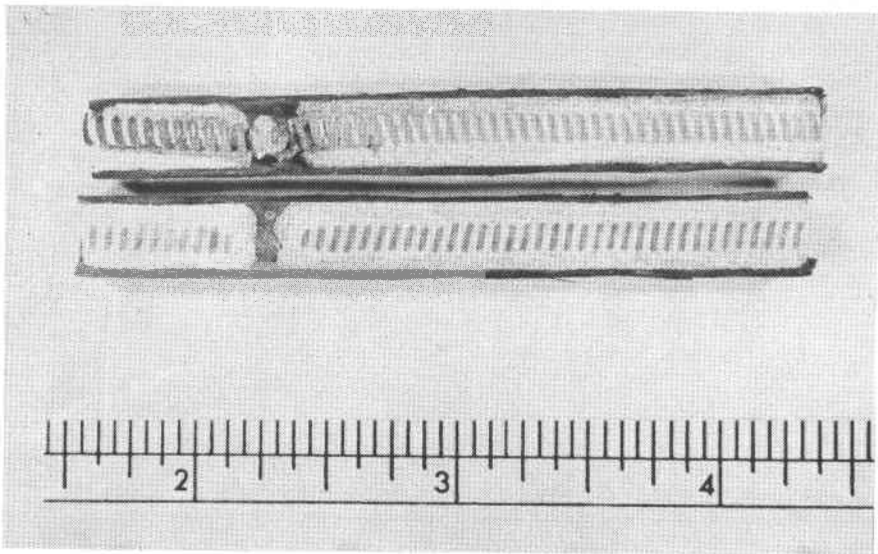
Manufacturer: HESCO S/N: 76-63 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 12,876 Sheath Composition: 321SS

Element Wire Size: 0.027 in. MgO Grain Size: -

Remarks: None.



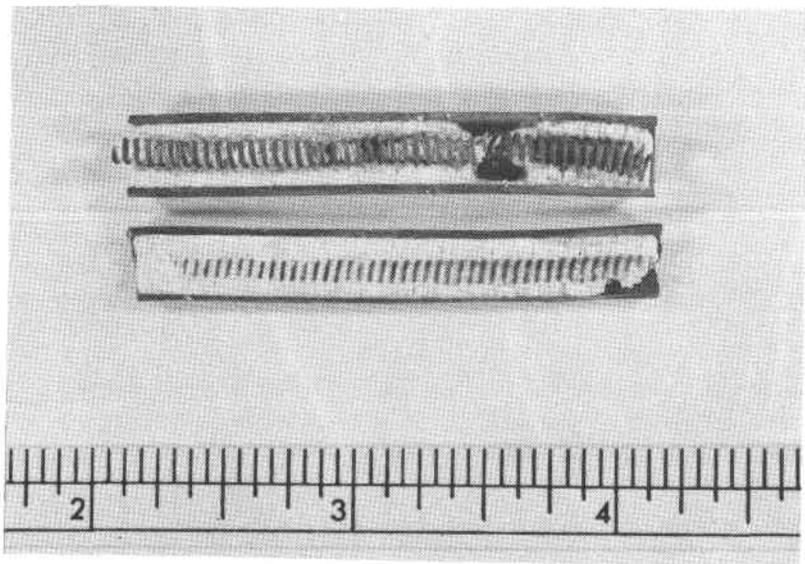
Manufacturer: Chromalox S/N: 76-105 Grade: I

Size: 3/8-in.-dia Rated Voltage: 480 MgO Density: 3.0 Shape: Hairpin

Accelerated Life Cycles: 13,350 Sheath Composition: Incoloy 800

Element Wire Size: 0.024 in. MgO Grain Size: 4-5

Remarks: Failed by electrical arcing from element to sheath.
Element wire very ductile.



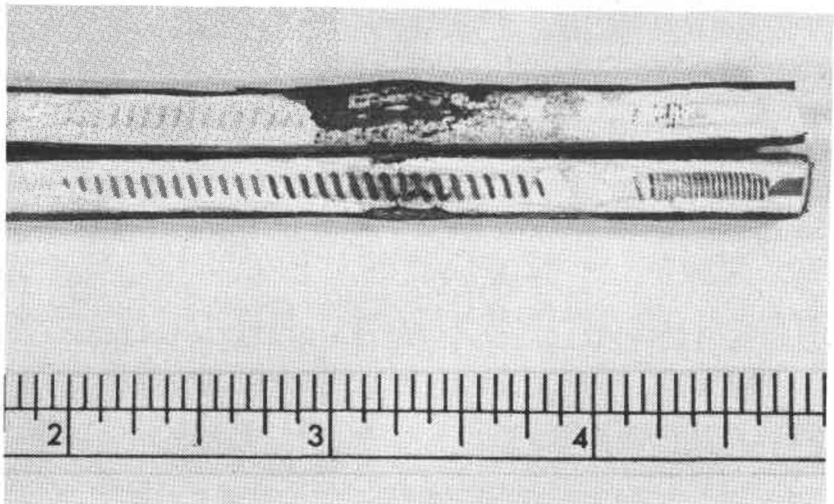
Manufacturer: Rama S/N: 76-53 Grade: I

Size: 1/4-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 7544 Sheath Composition: Incoloy 800

Element Wire Size: 0.026 in. MgO Grain Size: 4-5

Remarks: Bulge in sheath at failure where element arced electrically to sheath. Element wire brittle with considerable grain boundary oxidation.



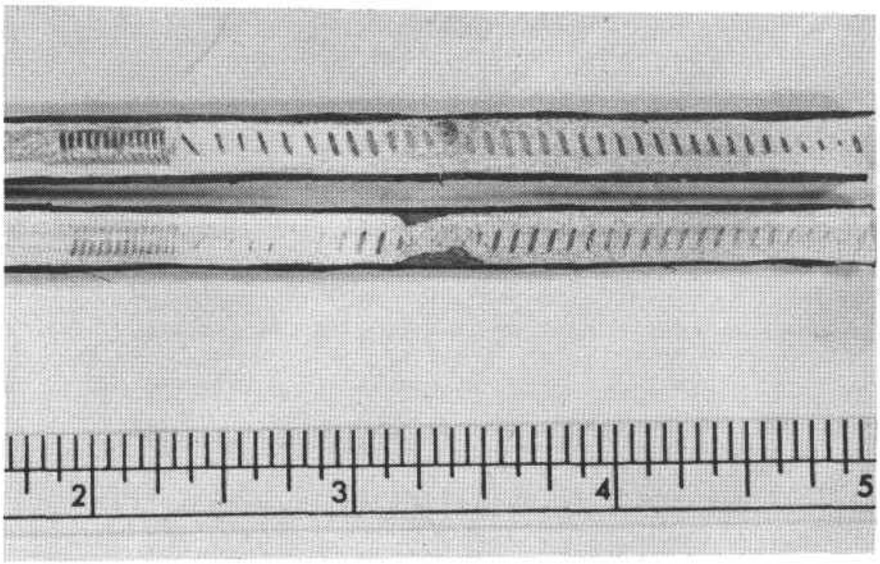
Manufacturer: HESCO S/N: 76-96 Grade: I

Size: 1/4-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 755 Sheath Composition: 304SS

Element Wire Size: 0.024 in. MgO Grain Size: 5-6

Remarks: Lead wire is iron. Did not fail in lead wire. Element wire is ductile.



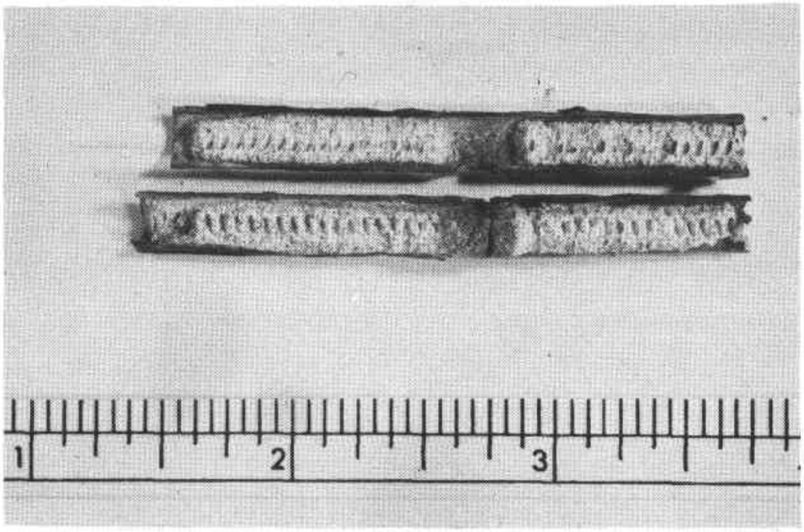
Manufacturer: Chromalox S/N: 76-136 Grade: I

Size: 1/4-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 6636 Sheath Composition: Incoloy 800

Element Wire Size: 0.022 in. MgO Grain Size: 4-5

Remarks: Element wire is brittle with considerable grain boundary oxidation at point of failure.



Manufacturer: HESCO S/N: 76-75 Grade: II

Size: 1/4-in.-dia Rated Voltage: 240 MgO Density: 3.0 Shape: Straight

Accelerated Life Cycles: 3344 Sheath Composition: 304SS

Element Wire Size: 0.024 in. MgO Grain Size: -

Remarks: Failed by electrical arc from element to sheath. Element wire ductile. Did not fail in lead wire.