99 up
7-17-73
Deets in C-92

UC 80

Dr. 228

AI-AEC-13089

SPACE NUCLEAR SYSTEM
"SHEATHED" ELECTRICAL CABLES
SUMMARY REPORT

AEC Research and Development Report

Atomics International Division
Rockwell International

P.O. Box 309
Canoga Park, California 91304

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

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

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

SPACE NUCLEAR SYSTEM
"SHEATHED" ELECTRICAL CABLES
SUMMARY REPORT

L. E. DONELAN

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Atoms International Division
Rockwell International

P.O. Box 309
Canoga Park, California 91304

CONTRACT: AT(04-3)-701
ISSUED: JUNE 30, 1973

RECEIVED
JUL 1 1973
fey

DISTRIBUTION

This report has been distributed according to the category "Systems for Nuclear Auxiliary Power (SNAP) Reactor – SNAP Program," as given in the Standard Distribution for Classified Scientific and Technical Reports, M-3679.

CONTENTS

	Page
Abstract	5
I. Introduction	7
A. Functions of Electrical Cables	7
B. Electrical Cable Designs	8
II. Performance and Environmental Requirements	10
III. Material Selection	12
A. Sheath Material	12
B. Insulating Material	12
C. Conductor Material	12
D. Cable Assembly	13
IV. Sheathed Cable Design	14
V. Cable Termination Design	17
VI. Cable Tests	19
VII. Test Results	21
A. Humidity Testing	21
B. Mechanical Testing	23
C. Mechanical Property Tests	23
D. Thermal Cycle — Vacuum-Life Testing	24
VIII. Conclusions and Recommendations	25

TABLES

	Page
1. Sheathed Cable Requirements	10
2. Test Cables	20

FIGURES

	Page
1. Cable Termination End	16
2. Typical Termination Design	16
3. Sheathed Cable Termination to Actuator	18
4. Sheathed Cable Termination to Limit Switch	18

ABSTRACT

A metallic-sheathed electrical cable is being developed for use with the zirconium hydride reactor power system. The positive protection to the conductor, and the insulation, provided by the metallic sheath is expected to increase the cable performance reliability from that of the previously utilized braided-wire-covered cables. Material and design studies were conducted to select the reference cable configuration. The reference design selected consisted of a single stainless steel clad 0.040-in. diameter conductor, encased within a 0.090-in. diameter stainless steel sheath, with compacted MgO insulation between the conductor and the sheath. Methods of terminating the cable to the actuator and the limit switch were also selected.

Preliminary tests have shown that this type of cable will maintain the insulation resistance well above the minimum acceptable level, under long-time exposure to the fabrication, system assembly, and operational environments and conditions. The mechanical properties of the cable, and the termination designs, require further testing and evaluation.

BLANK

I. INTRODUCTION

Series of compact nuclear reactors and electrical power systems were designed, developed, and tested for the Systems for Nuclear Auxiliary Power (SNAP) Program. The zirconium hydride reactors for these systems were fueled by hydrided zirconium-uranium elements, enclosed within high-temperature, corrosion-resistant tubes. Windows in the external beryllium neutron reflector were adjusted by rotating the drums or sliding the segments to regulate the neutron loss from the core, and thus the power output of the reactor. A direct radiating thermoelectric module powered Power Conversion System (PCS) produced over 500 w of electrical power on the flight-tested SNAP 10A system. A mercury Rankine cycle turbogenerator PCS of 3- and 30-kwe power range were demonstrated for the SNAP 2 and SNAP 8 systems respectively. The latest 5-kwe thermoelectric system was based on the compact tubular thermoelectric PCS. The NaK used to transfer the heat from the reactor to the PCS, and then from the PCS to the space radiator, was circulated by dc conduction electro-magnetic pumps on the thermoelectric systems, and by mechanical centrifugal pumps on the mercury Rankine systems.

A. FUNCTIONS OF ELECTRICAL CABLES

Electrical cables are required to transmit the necessary electrical power and signals to and from the reactor control and instrumentation components, such as drive actuators, limit switches, position sensors, etc. The cables must maintain the electrical isolation of each conductor, not only during power system operation under high-temperature, high-vacuum, nuclear radiation environment, but also during the pre-launch preparation and checkout phase. The cables must possess sufficient inherent flexibility to facilitate the installation, and to absorb differential thermal expansion induced movements. The cables must be easily terminated to the components, to provide highly reliable electrical circuitry. Further, the removal and retermination to replacement components should be possible with minimum physical and electrical effects.

B. ELECTRICAL CABLE DESIGNS

Relatively successful electrical cables had been developed for use on previous zirconium hydride reactor systems. The electrical conductor consisted of multiple strands of stainless steel clad copper wires, covered with one or more glass fiber sleeving for insulation. Commonly, two or more insulated conductors were bundled together, reinsulated with additional glass fiber insulation, and then covered with woven overbraid of fine stainless steel wires. For service requiring protection from electromagnetic interference (EMI), a second layer of glass fiber insulation and wire overbraid were added, with the initial overbraid being used as the grounding circuit.

Under normal conditions, the glass fiber provided adequate electrical insulation of the individual conductors, and the wire overbraid provided mechanical protection to both the insulation and the conductors, while maintaining the necessary flexibility. For use at high temperature in vacuum, it is necessary to remove the organic binders in the glass fiber, to eliminate carbonization which could result in short circuits. The air bake-out operation of the cable material, to remove most of the binder by oxidation, left the glass fiber insulation in a very friable condition. The fine wires of the overbraid were also subject to rupture during the fabrication process, installation and system check-outs. Once ruptured, the ends of the wire could penetrate through the glass fiber insulation to the conductor, resulting in short circuits. Thus, extreme care and constant inspections were required throughout the material fabrication and procurement, cable fabrication and installation, and system checkout phases. Because of the hygroscopic characteristics of the glass fiber insulation, the electrical isolation of individual conductors can become severely degraded under high humidity environment, such as may be encountered during system launch operations.

An alternate cable design, to overcome most of the preceding disadvantages, is an electrical conductor within a thin metallic sheath, and electrically insulated with compacted magnesium oxide, similar to sheathed thermocouple wires. This type of cable is fabricated by stringing MgO beads on the conductor, placing the combination within a thin hollow tube, and then swaging the total assembly by drawing it through dies. The swaging operation crushes the oxide

beads, and simultaneously reduces the diameter of both the sheath and the conductor and compacts the crushed oxide insulation. No organic binders are required to retain the insulation in place. The continuous metallic sheath provides complete retention of the oxide insulation, as well as mechanical protection. Thus, very high operational reliability can be achieved, with less precautionary efforts required during the fabrication, installation and system checkout phases.

This report summarizes the preliminary studies, cable component evaluation, cable and termination design studies, and tests conducted to develop the "sheathed" electrical cable for the 5-kwe thermoelectric System.

II. PERFORMANCE AND ENVIRONMENTAL REQUIREMENTS

The sheathed cable requirements are listed in Table 1.

TABLE 1
SHEATHED CABLE REQUIREMENTS

Storage	
Time (years)	2
Temperature (° F)	30 to 150
Humidity (max.) (% RH)	80
Pre-Launch Through Launch	
Shock	No requirement
Random Vibration (min.) (each axis)	3
Level (Hz)	
At 0.0025 g ² /Hz	20 to 42
At +10 db/octave	42 to 80
At 0.019125 g ² /Hz	80 to 160
At -6 db/octave	160 to 700
At 0.001125 g ² /Hz	700 to 2000
Acceleration	
Duration (each axis) (sec)	60
Level (g)	
Longitudinal	+6, -1.2
Lateral axis	±1.5
Pressure	Sea level to 10 ⁻¹³ torr
Temperature (° F)	50 to 200
Relative Humidity (%)	80
Operational	
Shock	No requirement
Gravity (g)	
Axial	0 to 0.6
Transverse	0 to 0.1
Vibration	1/100 of launch for 3 min

TABLE 1
SHEATHED CABLE REQUIREMENTS

Acceleration (for 3 min) (g)	
Transverse	0.005
Axial	0.100
Pressure	10^{-9} torr or less
Temperature	
Range ($^{\circ}$ F)	50 to 1125
Thermal cycles (max.)	100
Thermal rate (max.) ($^{\circ}$ F/min)	15
Irradiation	
Neutron (nvt) ($E > 0.1$ Mev)	2×10^{20}
Gamma (rad)	2×10^{11}
Breakdown Voltage (conductor to sheath) (v-dc)	500 (for 60 sec at ambient)
Current Capability (min.) (amp)	8
Voltage Rating (v-dc)	50

In addition to the cable being able to withstand these environmental and performance requirements, the cable must also withstand the various installation system checkout requirements. For example, the cable may be flexed many more times during the checkout of the reactor end-of-life shutdown system than during the actual operation.

III. MATERIAL SELECTION

A. SHEATH MATERIAL

Almost any metallic material could be used for the sheath, but the selection can be rapidly narrowed by several considerations. The high-temperature capabilities and compatibility with materials of the other cable components indicate stainless steel or nickel-based alloy. Type 304 stainless steel is the most common and the least expensive of the materials used for sheathed thermocouples. Its coefficient of thermal expansion is compatible with that of potential conductors. The threshold nuclear fluence for any significant change of mechanical properties is estimated at 10^{21} nvt, considerably higher than the 10^{19} nvt expected during the system lifetime. Therefore, Type 304 stainless steel was selected for the cable sheath.

B. INSULATING MATERIAL

The two commonly used insulating materials are alumina (Al_2O_3) and magnesia (MgO) powder. The alumina is a harder material than MgO , and is less hygroscopic than magnesia. Suppliers indicated alumina tends to become embedded in the conductor and sheath during the swaging operations used in the fabrication of sheathed cable, causing thinning or establishing future fracture points. This is especially true for thin sheath walls. Since the cable is to be as small as possible, for flexibility and weight savings, it was evaluated that mechanical integrity was more important than hygroscopic considerations. The more commonly used magnesia was selected as the preliminary insulating material for the cable.

C. CONDUCTOR MATERIAL

The conductor must have a reasonably high electrical conductivity at operating temperature, in order to minimize the power loss. It must also have adequate strength to withstand bending and termination loading, as well as being compatible with the sheath and insulation materials. Evaluation of materials indicated metals such as copper, silver, etc. for conductivity, and stainless steel, nickel alloys, etc. for strength and compatibility. Thus, a composite conductor appears the most desirable, as having the required conductivity,

compatibility, and strength. Based on prior evaluation of data of conductors for actuators, a stainless steel clad copper conductor was selected as the most desirable material for the cable conductor.

D. CABLE ASSEMBLY

The selected cable construction was a conductor of stainless steel clad copper, magnesia insulation, and a Type 304 stainless steel sheath. This combination was reviewed with the potential suppliers, and found to be very suitable, and requiring no additional fabrication development. Calculations indicated this cable would have suitable conductivity, and adequate strength for reliable termination.

IV. SHEATHED CABLE DESIGN

Once the basic materials were selected, the next significant cable design parameter to be determined was the size of the electrical conductor. The conductor was sized on the basis of the maximum power transmission requirement for operating the control reflector drive actuators. A single input cable supplies power to each actuator stator phase, consisting of two phase coils connected electrically in parallel for reliability. To maintain the equivalent current density (amp/cross-sectional area) as the 24 AWG (0.020 in. diameter, 0.000317 in.² cross-sectional area) coil conductor, the input power cable conductor should have an area of 0.000634 in.². On the return side of the actuator, power from two separate phases (2 sets of 2 coils) is routed through a common return cable. Because these phases are energized separately, the maximum current in the return cable is the same as that of the supply cable, but its maximum duty cycle is 50%, compared to 25%. To compensate for the higher duty cycle, the area of the return cable should be increased at least 50%, or to 0.00095 in.². The closest standard size to this area is 19 AWG (0.036 in. diameter, 0.0010 in.² cross-sectional area). To insure that the inherent reliability of the electrical cable would be higher than that of the individual stator coil, where a single failure can be tolerated, the next larger wire size, 18 AWG (0.040 in. diameter, 0.0016 in.² cross-sectional area), was selected as the conductor size.

The stiffness of the sheathed cable is determined primarily by the outside diameter of the outer sheath. This, in turn, is determined by the conductor diameter and the thickness of the sheath wall and of the oxide insulation. The minimum wall and insulation thicknesses are determined by fabrication limitations. Consultation with manufacturers of sheathed electrical cables indicated that 0.090 in. was the minimum practical outside diameter of a cable with a 0.040 in. diameter conductor. Analysis showed that the 0.090 in. diameter cable should be approximately 3.7 times more flexible than a 0.125 in. diameter cable. Based on preliminary bending tests conducted on 0.125 in. diameter cable samples, the expected flexibility of the 0.090 in. diameter cable was considered adequate.

The final cable design is configured as a single conductor, insulated from the sheath by compacted MgO material as follows:

- 1) Conductor — 0.040 ± 0.002 -in. diameter of stainless steel clad copper
- 2) Sheath — 0.091 ± 0.003 -in. OD of stainless steel, 300 Series,
 $0.014 \begin{smallmatrix} +0.002 \\ -0.003 \end{smallmatrix}$ in. thick
- 3) Insulation — Compacted MgO material.

The cable for the reactor instrumentation can be of a smaller size, limited only by termination difficulties. A minimum size cable was designed, in conjunction with potential suppliers, based on maintaining a nominal 0.009-in. insulation thickness. This is considered a minimum, from a preview of termination problems. This cable would be as follows:

- 1) Conductor — 0.025 ± 0.002 in. diameter of stainless steel clad copper
- 2) Sheath — 0.060 ± 0.002 in. OD of stainless steel, 300 Series,
 $0.008 \begin{smallmatrix} +0.004 \\ -0.002 \end{smallmatrix}$ in. thick
- 3) Insulation — Compacted MgO material.

Since the cable usage for instrumentation is limited, and the weight savings would not justify the extra effort to test two cable sizes, it was concluded the 0.090-in. diameter cable would be used for all cable applications. The 0.060-in. diameter cable design would be retained as backup, in case increased flexibility became a requirement.

6531 5542

Figure 1. Cable Termination End

6531 5543

Figure 2. Typical Termination Design

V. CABLE TERMINATION DESIGN

Factors to be considered in a successful termination of the electrical cables to the reactor components include the end preparation of the cable, maintaining the electrical isolation of each conductor, establishing and maintaining the electrical continuity, and the mechanical retention of the cable to the component. In a typical sheathed cable termination,* the cable is prepared by cutting back the sheath and insulation, exposing the conductor. The exposed end of the oxide insulation is sealed with epoxy or other organic cement, to prevent hygroscopic pickup of moisture by the insulation, and the attendant insulation resistance reduction. The electrical termination is accomplished mechanically to the terminal stud or lug, with the outer sheath attached to the component by a cushioned clamp. The exposed conductor is protected with additional glass fiber or organic insulation materials.

The high-temperature, vacuum, and nuclear environment of the reactor cable precludes the use of organic cements, binders, or insulation. Welded connections between the components and cables are required, to achieve the high operational reliability. The initial cable end preparation design is shown in Figure 1. The stainless steel sleeve, when welded to the cable sheath, not only retains the ceramic insulation seal, but also reinforces the cable end mechanically. A typical termination of this cable to the electrical component is shown on Figure 2. The cable end is mechanically secured to the component by the cable clamp. The electrical connection scheme allows temporary mechanical attachment followed by final welded attachment. The positive isolation of the bare conductors is assured by separation from each other and short lengths. A cover over the termination area provides mechanical protection.

Subsequent tests have shown that the insulation seal and the reinforcing sleeving are not necessary, simplifying the cable end preparation to the stripping of the sheath and the insulation. The proposed termination designs with the simplified cable end for the actuator and the limit switch are depicted on Figures 3 and 4.

*Non-nuclear, low-temperature applications

Figure 3. Sheathed Cable Termination to Actuator

Figure 4. Sheathed Cable Termination to Limit Switch

VI. CABLE TESTS

Cable testing was performed in two phases. The first was a series of tests to determine the effect of humidity on the cable insulating material, and the capability of the end sealing method to reduce deleterious effects expected from the humidity. Both engineering evaluation tests (in a humidity chamber) and practical tests (in the areas of expected assembly and storage) were performed. It was expected that humidity would decrease the cable insulation resistance below an acceptable value. It had previously been determined, on the S8DR system, that a 1% cable leakage loss could be accepted; and, as such, insulation resistances as low as 1000Ω were acceptable. Assuming an installed cable length of ~ 30 ft, the minimum insulation resistance/ft would be $30k\Omega/\text{ft}$, or $10k\Omega$ for a 3 ft test sample.

The second phase of testing was to determine the mechanical characteristics of the cable (i. e. , the ability of the cable to be bent into its final shape and withstand the repeated bending associated with the proposed end-of-life device testing). Although finite limits on the cable stiffness had not been established, maximum flexibility was desirable.

Since it had been established that the radiation effects should be negligible, the suitability of room-temperature or high-temperature testing of the cable was evaluated. It was determined that ambient testing was the more severe condition, for both humidity and mechanical testing, than elevated temperatures; and, if the cable could withstand the ambient conditions, it should have less damage at elevated temperatures. Therefore, all testing was conducted at ambient temperature, except for thermal cycling.

For the purpose of testing, a conductor material substitution of nickel clad copper for stainless clad copper was made. This facilitated delivery, as nickel clad copper was a stock item. This substitution was not expected to have any effect on the tested properties of the cable, or in termination development. The initial cable order was for catalog cables of 1, 2, 3, and 4 conductors in a single sheath. These cables are listed in Table 2. This table also lists the reference and backup design cable.

TABLE 2
TEST CABLES

Art Industries Inc. Catalog No.	Sheath Material	Insulation Material	Configuration	Sheath OD (in.)	Conductor Size (in.)	Wall Thickness (in.)
<u>Preliminary Cable Design</u>						
125-1A-A(304)18	Type 304 SS	MgO	1-Conductor	0.125	0.043	0.019
0.188-2M-A(304)20	Type 304 SS	MgO	2-Conductor	0.188	0.032	ND*
0.188-3M-A(304)20	Type 304 SS	MgO	3-Conductor	0.188	0.032	ND
0.188-4M-A(304)20	Type 304 SS	MgO	4-Conductor	0.188	0.032	ND
<u>Final Cable Design</u>						
0.093-1M-A(NiCu 27)18	Type 304 SS	MgO	1-Conductor	0.093	0.037	0.015
0.060-1M-A(NiCu 27)22	Type 304 SS	MgO	1-Conductor	0.060	0.025	ND

*Not determined

VII. TEST RESULTS

The preliminary sheathed cable, when delivered, was found to contain a conductor of solid Type 304 stainless steel, rather than clad copper. The first evaluation was on the multi-conductor cables (0.188 in. OD), which were determined to be too rigid for the application by a considerable amount, and were discarded immediately. The single-conductor cable (0.125 in. OD) was also too rigid for application to the 5-kwe Thermoelectric System, but the construction and configuration was suitable for the first set of tests (i. e., tests for sealing and moisture effects).

The cable described as 0.093-IM-A(NiCu 27)18 was used for the second set of tests (i. e., tests for mechanical characteristics). This cable is expected to have mechanical characteristics nearly identical with the reference cable.

A. HUMIDITY TESTING

Humidity tests were performed on 3-ft samples of cables in three configurations. The first configuration, for the purpose of this report, known as Type A, had the end sealed as in Figure 1, using AI's ceramic cement. The second configuration, Type B, used a commercial cement. The third configuration, control, had the ends exposed without any end preparation. The following are the results of this testing.

1. Engineering Testing

- 1) Nine samples were tested at 90°F and 40% RH, then thermal cycled from 50 to 190°F ten times. The minimum insulation resistances were:

Type A 177 k Ω

Type B 107 k Ω

Control 192 k Ω

- 2) Nine samples were tested at 90°F and 70% RH, then thermal cycled from 50 to 170°F ten times. The minimum insulation resistances were:

Type A 94k Ω

Type B 185k Ω

Control 166k Ω

- 3) Nine samples were tested at 90° F and 95% RH, without thermal cycling. The minimum resistances were:

Type A 58k Ω

Type B 111k Ω

Control 111k Ω

- 4) A control type, 10 ft long, was thermal cycled ten times between 50 and 170° F in 95% RH, and then the test environment pressure was reduced to 1×10^{-3} torr. Post test examination showed no evidence of damage. The minimum insulation during testing was 312 k Ω

The conclusion from these engineering tests was that sealing of the cable ends is not required to maintain insulation resistance in the acceptable range and the ceramic-type seals were not effective in limiting the moisture absorption by the MgO insulation.

2. Practical Testing

Practical testing consisted of samples (Type A, Type B, and Control) located in the normal fabrication, assembly, and worse-case storage area. This test was conducted to verify the results of the engineering tests.

- 1) Six samples in the fabrication area (air conditioned) for 1 year produced the following minimum insulation resistances:

Type A 227 k Ω

Type B 166 k Ω

Control 227 k Ω

- 2) Six samples in the assembly area (heated, indoors) for 1 year showed the following minimum insulation resistances:

Type A 125 k Ω

Type B 166 k Ω

Control 138 k Ω

- 3) Six samples in a worse-case storage area (outdoor shelter, under a roof) for 1 year produced the following minimum insulation resistances:

Type A 6.2 k Ω

Type B 790 Ω

Control 83 k Ω

The results from the first two test areas confirmed the conclusions from the engineering tests. It also demonstrated that long-term exposure of the cables to uncontrolled environment may result in insulation resistance degradation below the acceptable level.

B. MECHANICAL TESTING

Three 18-in. long samples of 0.090-in. diameter cable were tested as follows, to determine mechanical handling effects on the insulation resistance:

- 1) 180° bend test for 10 cycles. Minimum insulation resistance for all tests was 7.5 k Ω
- 2) 15° flexure test for 100 cycles. Minimum insulation resistance for all tests was 35 M Ω
- 3) 15° torsional test for 100 cycles. Minimum insulation resistance for all tests was 2.7 M Ω

No mechanical failures were experienced. In all cases the insulation resistance decreased slightly during the test. The conclusion from this testing is that the cable will withstand the necessary handling and flexing required for the 5-kwe Thermoelectric Reactor application; but the cable is sensitive to mechanical damage, and care in installation is required.

C. MECHANICAL PROPERTY TESTS

Preliminary mechanical tests were conducted on a single sample of 0.090-in. diameter cable, and the following was observed:

- 1) The yielding of the sheath material occurs at minimal bending. The calculated bending moment at the yield point was ~ 2.0 in. -lb. Further bending yielded the sheath material, but additional force was required, probably to physically relocate the MgO insulation. Approximately the same force was required to straighten the cable.
- 2) The endurance limit of reversed bending over a 15° arc was 2500 cycles. The sheath failed by fatigue cracking, although the insulation resistance was not affected.

D. THERMAL CYCLE - VACUUM-LIFE TESTING

Nine samples of 0.125-in. diameter cable (three of each Type A, Type B, and Control) were made up as for the humidity testing. After conditioning the cables in sets at relative humidities of 40, 80, and 95%, the cables were installed in vacuum systems and tested for 7 to 8 months at 1150°F . During this test period they experienced 100 thermal cycles from 300 to 1150°F . The minimum insulation resistance recorded for these tests is as follows:

Type A $76\text{ k}\Omega$

Type B $54\text{ k}\Omega$

Control $59\text{ k}\Omega$

No damage from thermal vacuum testing could be determined. Again, the control sample performed as well as the terminated samples.

Thermal cycle vacuum testing was performed on three control type samples of the 0.090-in. diameter cable for 45 days. The cable samples were thermal cycled 20 times from ambient to 1100°F . The minimum insulation resistance during testing was $20\text{ kM}\Omega$.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Although testing of the sheathed cable is incomplete, some tentative conclusions can be drawn from the results to date:

- 1) A satisfactory sheathed cable for the 5-kwe Thermoelectric Reactor is available.
- 2) This cable contains a conductor of stainless clad copper of a nominal 0.040-in. diameter, and is nominally 0.090-in. in outside diameter.
- 3) Smaller cables are available, at a reduced conductor size. The minimum practical cable diameter appears to be 0.060-in. OD, due to construction and termination problems.
- 4) Sealing of the end of sheathed cable, to eliminate humidity effects is not required, as sealing cements do not increase cable termination resistance to humidity.
- 5) Multiconductor cable, due to the greater OD, is not practical for this application, as it is too rigid.
- 6) Evidence does not support any conclusion in regard to the requirement of sealing the cable ends to prevent flaking of the insulation during shock and vibration, but handling effects indicate sealing will not be required.