MAY 20 1966

for off

RE-10-0320

SAF-C

7 APRIL 1966

REON TECHNICAL MEMORANDUM

EVALUATION AND TESTING OF ENGINE-MOUNTED
METAL-SHEATHED CABLE ASSEMBLIES

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.

Author:

Approved:

REON Technical Staff

R. A. Fox

R. A. Fox
Development Section
Instrumentation Dept
Engineering Division
REON

I. L. Odgers

I. L. Odgers, Manager
Engineering Division
REON

J. D. Peterson

J. D. Peterson
REON Technical Staff

Release Approval:

E. A. Sheridan

E. A. Sheridan, Manager
Control Systems Department
Systems Division
REON

DISTRIBUTION OF

Sc

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.

I. INTRODUCTION

This report is the first of a series describing the evaluation and testing of engine-mounted, metal-sheathed cable assemblies. This program is a joint effort of Sub-subtask 1.5.4 and Sub-subtask 2.4.6, the purpose of which is to provide information to those people responsible for engine diagnostic instrumentation and control systems. The efforts during this period were divided into two categories; cable seals and high temperature evaluation of sheathed cable dielectrics.

II. CONCLUSIONS AND RECOMMENDATIONS

Except for its hygroscopic nature, high purity magnesium oxide (MgO) offers the best dielectric qualities in sheathed cables for use in temperatures to 1800°F. Aluminum oxide (Al_2O_3) or beryllium oxide (BeO) is recommended for use in temperatures from 1900°F and up.

Because a localized oxide contamination was discovered in two test specimens, an additional acceptance test has been included on all sheathed cable assemblies procured for this program.

Either a radiation resistant or a non-radiation resistant seal is required on the ends of MgO insulated cable. A weldable metalized-ceramic-insulated seal is recommended for nuclear applications. For low radiation environments General Electric's #1201 Glyptol is recommended, especially when used in the field because mixing, heating, etc., are not necessary for curing.

Engine-mounted sheathed cables, heated by gamma energy, undergo changes in insulation resistance and cable capacitance. These changes will not affect transducer operation if the heating is controlled by routing and installation design to a maximum of 1200°F.

III. DISCUSSION

The sheathed cable assembly is constructed by threading refractory oxide insulators onto wires, drawing the assembly into a metal tube, and reducing the diameter of the tube to compact the insulation to produce a tough integral assembly of wire, tube, and insulation. This process is performed by drawing or rotary swaging. Magnesium oxide has been selected as the insulation for diagnostic instrumentation cables. Although it has the best dielectric properties to 1800°F, MgO is very hygroscopic and requires

special consideration. The insulation must be protected at each end of the cable by a seal, otherwise it will take on moisture which will cause low values of shunt resistance and affect the operation of associated instrumentation or control circuits.

To avoid confusion regarding which seal and which end of the cable are being discussed, the letter "E" will signify exposure to the environments, either test, or engine. The letter "N" will signify non-exposure, meaning ambient test conditions or low radiation areas.

Unless otherwise specified, all insulation resistance measurements were made with a Weston Model 799 Megohm Meter with an applied potential of 50 vdc.

A. CABLE SEALS "N" TYPE

Before the tests described in this section were made, letters of inquiry were sent to sheath cable manufacturers requesting sealant recommendations and problem areas based on their experience. The items submitted ranged from various forms of room temperature vulcanizers (RTV), epoxies, and cements to enamels, silicones, and urethanes. Since the criterion for the "N" type seal is that the sealant must have moderate radiation tolerance with no curing agents, the field was reduced to the RTV's and enamels. The reason for eliminating curing agents is that the viscosity of resin, catalyst base sealants cannot be easily controlled. This leaves an uncertainty regarding the wetting of the sheath cable components which would tend to make sealing unreliable.

The RTV's were examined and were found to contain acetic anhydrides which form acetic acids when exposed to moisture or water vapor. There is a controversy regarding the possible corrosive effects of this material on copper. This problem is being investigated. All of the one part RTV's that were lab tested were found to have excellent dielectric characteristics but were too viscous to wet the materials and as a result produced an unreliable seal. Other RTV's, such as General Electric RTV-11, or the RTV's designed to meet MIL-S-23586 (WEP), will be investigated as soon as the acetic acid controversy is resolved.

Information submitted by two cable manufacturers pertained to shipping seals. In many cases when sheathed cables are shipped by air, the seals "breathe" or are lost because of the pressure differential. Both Aero Research Instruments and Continental Sensing Inc., recommend the use of "Stycast," which is an epoxy casting resin supplied by Emerson & Cummings, Inc., Canton, Massachusetts. Another recommendation is "Aeroseal" which is the trademark of Aero Research Instruments. This material is an inorganic moisture barrier. It is not a mechanical hermetic seal but allows "breathing" of inert gases while preventing the penetration of water vapor through molecular action.

The use of General Electric's #1201 Glyptol is recommended for field application based on the following information. Using ten cables with Glyptol as the sealant, a test was performed at elevated temperatures to determine if there would be any carburization or shunting effects on the cable dielectric. With a potential of 50 vdc, measurements were made with the results shown in Table I. After exposure to these temperatures, the specimens were allowed to return to room ambient temperature (74°F at 45% humidity). The insulation resistance was then measured and found to be 100 megohms or better in each case.

TABLE I

<u>Temp °F</u>	<u>Average Insulation Resistance</u>
Ambient	>9K Meg (Liquid)
200	9K Meg
400	1K Meg
600	600 Meg
800	20 Meg
1000	1 Meg
Post Ambient	100 Meg

The ten specimens were stripped of the original Glyptol, baked at 200°F, and then resealed at both ends. Three humidity tests were then performed at intervals of approximately 17 days. The average room humidity between tests was 40% at 74°F. Following is a tabulation of the cable types used. Tables II, III, and IV show a record of the test observations.

<u>SPECIMEN NO.</u>	<u>MANUFACTURER</u>	<u>PART NO.</u>	<u>AGC AS NO.</u>
1 and 2	Aero Research	125-2M-F-Cu-24	AS9702-E-A-A-14
3 and 4	Temptron Div. CCC	347-125-Cu-24	AS9702-E-A-A-14
5 and 6	Cont. Sensing	187-4Cu-Al ₂ O ₃ -304	AS9702-E-A-?-48
7 and 8	Cont. Sensing	125-TRIAX-Al ₂ O ₃ -304	TRIAX, All 304 SS
12 and 13	Aero Research	156-3M-H-Cu-22	AS9702-E-D-A-34

NOTE: Items 5 and 6 show a question mark in the AS Part
No. because AS9702 does not presently call out
Al₂O₃ as a dielectric.

TABLE II
HUMIDITY TEST NO. 1
CONDUCTED 12-20-65

SPECIMEN NO.	A		B		C		D	
	CC	CS	CC	CS	CC	CS	CC	CS
1	>10KM	>10KM	20M	60M	7KM	7KM	>10KM	>10KM
2	>10KM	>10KM	90M	90M	10KM	10KM	>10KM	>10KM
3	>10KM	>10KM	20M	60M	9KM	9KM	>10KM	>10KM
4	>10KM	>10KM	60M	60M	10KM	10KM	>10KM	>10KM
5	>10KM	>10KM	9M	40M	1KM	4KM	>10KM	>10KM
6	>10KM	>10KM	50M	50M	10KM	10KM	>10KM	>10KM
7	>10KM	>10KM	100M	90M	10KM	9KM	>10KM	>10KM
8	>10KM	>10KM	100M	100M	8KM	10KM	>10KM	>10KM
12	>10KM	>10KM	30M	100M	10KM	10KM	>10KM	>10KM
13	>10KM	>10KM	50M	80M	10KM	9KM	>10KM	>10KM

CC = Conductor to Conductor

CS = Conductor to Sheath

M = Meg ohms

KM = Thousand meg ohms

A = Ambient conditions 74°F at 40% humidity (pre-test)

B = Exposed two hours, 180°F at 85% humidity

C = Exposure 115°F at 10% humidity

D = Ambient conditions 74°F at 40% humidity (post-test)

Insulation resistance using
a potential of 50 vdc

TABLE III

HUMIDITY TEST NO. 2

SPECIMEN NO.	A		B		C		D	
	<u>CC</u>	<u>CS</u>	<u>CC</u>	<u>CS</u>	<u>CC</u>	<u>CS</u>	<u>CC</u>	<u>CS</u>
1	>10KM	>10KM	80M	500M	2KM	8KM	No measurement available	
2	>10KM	>10KM	2KM	1KM	10KM	10KM	>10KM	>10KM
3	900M	6KM	80M	300M	200M	3KM	6KM	8KM
4	>10KM	10KM	300M	400M	10KM	8KM	>10KM	>10KM
5	2KM	9KM	100M	200M	400M	1KM	4KM	10KM
6	9KM	9KM	20M	200M	2KM	2KM	>10KM	>10KM
7	>10KM	>10KM	8KM	2KM	10KM	10KM	>10KM	10KM
8	>10KM	>10KM	7KM	1KM	10KM	8KM	>10KM	>10KM
12	9KM	>10KM	200M	800M	1KM	2KM	>10KM	>10KM
13	7KM	>10KM	300M	700M	2KM	6KM	7KM	>10KM

- A = Ambient conditions 74°F at 40% humidity (pre-test)
 B = Exposure of 122°F at 93% humidity
 C = Exposure of 77°F at 58% humidity
 D = Ambient conditions 74°F at 40% humidity (post-test)

TABLE IV

HUMIDITY TEST NO. 3
CONDUCTED 1-24-66

SPECIMEN NO.	A		B		C	
	CC	CS	CC	CS	CC	CS
1	10KM	10KM	30M	20M	100M	100M
2	8KM	8KM	90M	80M	600M	130M
3	8KM	8KM	10M	10M	9KM	8KM
4	>10KM	>10KM	10KM	10KM	8KM	6KM
5	10KM	10KM	40M	40M	>10KM	> 10KM
6	>10KM	>10KM	70M	90M	1KM	800M
7	>10KM	>10KM	100M	100M	10KM	9KM
8	>10KM	>10KM	30M	30M	>10KM	>10KM
12	>10KM	>10KM	80M	70M	>10KM	>10KM
13	>10KM	>10KM	30M	20M	>10KM	>10KM

A = Ambient condition 74°F at 40% humidity (pre-test)

B = Exposed environment 193°F at 96% humidity

C = Post tests conducted 2-11-66

NOTE: These specimens were moved about for a 3 week period by outside contractors during laboratory remodeling. Consequently, the specimens as well as the conductors and seals were badly distorted and damaged. Therefore the figures under Column "C" are not necessarily relevant. The insulation measurements are still remarkably high considering this fact. The 100 Meg on Specimen No. 1 is the lowest measurement made which was attributed to a broken seal.

Glyptol is sold and controlled under MIL-E-22118A (WEP), and is classified as an electrical insulating enamel. It is non-toxic and consists essentially of a red iron oxide pigment with phthalic-alkyd type vehicles. It may be applied by any method convenient to the user. Glyptol has a storage stability of six months at 70 to 90°F. Although reducers are available, they are not recommended for this program because the viscosity cannot be controlled and contamination may occur during mixing.

Although Glyptol is tacky free after one-half hour and is dry at two hours, heating is permissible to accelerate this time. A second application is recommended after 24 hours in extreme environments. The material has a wet dielectric strength of 300 volts/mil and a dry dielectric strength of 1200 volts/mil. Although detailed radiation compatibility information is not available at this time, the following information was taken from REIC Report 21, page 47 (Reference 1):

"The approximate radiation resistance of alkyd enamels containing 30% phthalic anhydride is from 6.1×10^{10} to 8.8×10^{10} Ergs/Gm(C) and 7 to 10×10^8 roentgens."

In accordance with AGC 90016-A, the maximum expected gamma dose (above station 137 XE-1 upper thrust structure region), plus or minus a factor of two, is 4×10^6 Ergs/Gm(C)/hr.

Glyptol is therefore being considered for use in the UTS portion of XE-1 because temperatures are not expected to exceed 400°F where the shunt resistance of <1K meg becomes a factor to consider.

B. CABLE SEALS "E" TYPE

The "E" type seals are necessary because the cable will be engine mounted and exposed to environments far in excess of the capabilities of the "N" type seals. The following "E" type sealant materials are being considered for use with diagnostic instrumentation in the NERVA XE-1 engine environments.

1. Aero seal, registered trade-mark for Aero Research Division of American Standard, Chicago, Illinois.
2. A-508 glass pre-forms, produced for WANL by Glass Beads Co., Latrobe, Penn.
3. 58-W Glass Frit, produced by T. C. Thompson, Highland Park, Illinois.
4. PRX Cement, by Robert G. Allen, supplied by Baldwin Strain Gage Co.

5. CA9R cement, Engelhard Industries, Inc., East Newark, New Jersey.

6. Braze on metalized ceramics, Physical Sciences Corp., Western Gold, Consolidated Electrodynamics Corp., and others (capabilities to be determined).

Of the "E" type seals mentioned, only the Aeroseal and Glass Beads have had significant environmental testing. No additional test information is available at this time for the other "E" type seals.

a. Aeroseal

Aeroseal has been tested at the Ground Test Reactor Facilities at Fort Worth, Texas (References 2 and 3). Test 23/R701 was a combined radiation and temperature test with a vibration test performed after termination of irradiation. Three test specimens, made up of Aero Research P/N 125-4M-F(Cu)24, were irradiated to integrated exposures of 4.33×10^{16} neutrons/cm² ($E > 0.9$ Mev) and 1.44×10^{11} Ergs/Gm(C) gamma. The specimens were temperature cycled from -320 to +450°F. Measurements were made of insulation resistance and capacitance during all test cycles. No changes in capacity were noted that could be correlated with radiation. However, some decrease in insulation resistance was noted with accumulated dose, but showed a marked recovery during post radiation measurements.

An additional post-irradiation test was performed at Aerojet six months later which confirmed the compatibility of Aeroseal with this environment. Insulation tests were performed again and found to be greater than 10K meg ohms for all three specimens.

A second laboratory test was performed to confirm the manufacturer's claim of the seals capability at +1000°F. Two additional specimens were prepared using Aeroseal and temperature cycled at 1000, 1100, 1200, 1300, and 1400°F. After each temperature cycle the specimens were returned to ambient room conditions for one hour when a measurement was made. A reading of greater than 10K megs was recorded, even after being exposed to 1400°F. A post measurement was made after 30 hours of elapsed time, where the ambient conditions were 74°F and 40% humidity. The insulation resistances are recorded in Figure 1. A comparison of Figure 1 to Figures 8 and 9 (where no sealant was used) indicates there is no detectable degradation in insulation resistance.

FIGURE 1

b. Glass Beads

WANL has developed a glass pre-form that provides a temporary moisture seal when integrated to a terminated sheath cable (References 4 and 5). Some testing has been performed on these seals but there is not sufficient evidence to consider them as a fully qualified "E" type seal. Some non-nuclear testing (Reference 6) and nuclear testing (Reference 7) has been performed but it did not cover the entire environmental spectrum expected on the XE engine.

c. Problem Areas

Aeroseal and the glass sealing techniques have been found to be suitable for most engine environments, but maintaining the seal is further complicated by the integration of a sealed cable with a transducer during the manufacturing process. For example, even though Aeroseal has been found to be effective over the temperature range of -320 to +1400°F, at exposures above 1000°F the seal starts to deteriorate into gaseous matter. This does not cause a drop in insulation resistance. However, if the Aerosealed cable is to be integrated by welding or brazing into a gas tight assembly, the elevated temperatures will cause out gassing to occur and prevent positive sealing of the assembly. Figure 2 shows the considerations necessary when selecting an "E" type seal. It should be noted that the seal must maintain three important functions: a sealant, a dielectric, and when severe vibration is expected, conductor support. The loss of any one will affect the function of the cable. Aeroseal, as previously mentioned, is not a mechanical seal and does not provide conductor support. Glass Beads, on the other hand, do provide mechanical support. However, if excessive heat is applied when integrating a glass sealed cable to a transducer, fractures may take place which will destroy the seal. Even though the seal is compatible with the operational environments, without due consideration it may not survive the manufacturing process to which it must be exposed.

A possible solution to these problems is a metalized ceramic termination which can be brazed or welded into place. An example of how this can be done is presented in Figure 3. Once the cable has been terminated it becomes completely impervious to both engine and handling environments. There are no voids that will permit ionization or material fatigue. It may be easily integrated into a transducer, splice, or connector assembly. The Figure 3 geometry is such that it may be inserted into any standard, four-conductor, number eight shell size connector, by simply extending the length of the hypodermic tubing.

FIGURE 2

Fabrication is accomplished by removing 0.7-in. of the cable sheath to expose the conductors. The adapter housing is slid back over the remaining cable. The wire pilot ceramic is inserted over the conductors and pushed firmly against the sheath termination. The pilot ceramic is retained at this point by the conductors. The header ceramic is slid over the conductors until it is firmly against the pilot ceramic. This assembly is aligned parallel to the sheath and all but one of the conductors are brazed to the hypodermic tubing (Tig welded if thermocouple materials). The adapter housing is slid forward until it bottoms against the pilot ceramic and then brazed or seal welded closed as shown. Note that no sealant is specified or required at the sheath termination. In the event that moisture is absorbed, it becomes a simple matter to remove it through heating. By heating, the contaminating gases exit through the unsealed tube. When the desired level of insulation resistance is obtained, the remaining conductor is then brazed to form a hermetic seal. Upon cooling a negative pressure is generated and thus offers an excellent means to determine the sealing integrity of the assembly. With the proper materials and fabrication, this sealed sheath termination is usable in temperatures in excess of 1500°F.

C. HIGH TEMPERATURE EVALUATION OF SHEATHED CABLE

Although the properties of oxide insulation materials are well known, there is still uncertainty regarding the insulation and capacity effects when these materials are integrated into cable assemblies and exposed to high temperature. For example, the insulation and capacity varies as a function of cable length and temperature. The tests described were made to determine if any limitations would be imposed on the associated transducers by the heating effects of the gamma fields of XE-1. A high temperature furnace was used to simulate the effects of gamma heating. Fourteen specimens were subjected to temperatures ranging from ambient to 1500°F. The "E" exposed end of the cable was stripped of its shipping seal, while the "N" unexposed end retained its original shipping seal. Two tests were made to determine the relative insulation resistance of 10-foot and 1-foot lengths. Of the 14 specimens tested, there were 5 cable configurations. These configurations with their identification are presented in Table V.

TABLE V

CABLE CONFIGURATIONS OF SPECIMENS TESTED

<u>SPECIMEN NUMBER</u>	<u>MANUFACTURER*</u>	<u>PART NUMBER</u>	<u>AGC AS9702 EQUIVALENT</u>	<u>DIELECTRIC</u>
AR 1	Aero Research	125-2M-F-Cu-24	AS9702-E-A-A-14	MgO
AR 2	Aero Research	"	"	"
TEMP 3	Temptron	"	"	"
TEMP 4	Temptron	"	"	"
CONT 5	Continental	187-4Cu-Al ₂ O ₃ -304	AS9702-E-A-?-48	Al ₂ O ₃
CONT 6	Continental	"	"	"
CONT 7	Continental	125-TRIAX-Al ₂ O ₃ -304	AS9702-?-?-?-18	"
CONT 8	Continental	"	"	"
AR 9	Aero Research	125-4M-F-Cu-24	AS9702-E-A-A-16	MgO
AR 10	Aero Research	"	"	"
AR 11	Aero Research	"	"	"
AR 12	Aero Research	156-3M-H-Cu-22	AS9702-E-D-A-34	"
AR 12A	Aero Research	"	"	"
AR 13	Aero Research	"	"	"

* Aero Research, Division of American Standard Products,
315 North Aberdeen Street, Chicago, Illinois

Temptron, Division of Consolidated Controls Corp.,
2338 Alaska Avenue, El Segundo, California

Continental Sensing Inc., 1960 North Ruby Street,
Melrose Park, Illinois

NOTES:

1. Specimen No's 7 and 8 are special, all steel, Al₂O₃ insulated, and are not covered by AS9702.
2. All measurements shown in the following figures that indicate 10¹⁰ ohms are in reality 10¹⁰ ohms or greater.

Prior to the tests, it was determined that the maximum heating effects caused by the XE-1 gamma fields would be 1000°F (Reference 8). The specimens, however, were taken to 1500°F in an attempt to determine if any copper migration, or permanent effects would result from this temperature. A second reason was to determine the practical level to which future cable assemblies can be exposed without degradation of the associated transducer's performance.

In the tables that follow, CC stands for the measurement made between conductor and conductor, and CS stands for the measurement between the conductor and sheath. Figures 4 and 5 represent the measurements made with 10-foot lengths exposed, comparing identical parts procured under AGC Specification 90052 manufactured by separate companies. There was no difference noted between manufacturers. The low readings of AR 2 and TEMP 4, in the low temperature range, were shunt resistances which were attributed to shipping seal leakage. It was decided to continue using the seals "as is" to determine the overall insulation resistance effects with defective seals.

Four additional specimens were tested at this time. They contained Al_2O_3 instead of MgO as a dielectric. As evidenced by Figures 6 and 7 the shipping seals were in good condition (they were styccast). By comparing these tables with any other, it can also be proved that the resistivity of Al_2O_3 falls from 2 to 3 orders of magnitude lower than MgO .

FIGURE 4

FIGURE 51

Based on the test data provided in Figures 6, 7, and 8, it is strongly recommended that Al_2O_3 not be used for engine mounted cables in the NERVA program. Figure 13, at the end of the text, is provided as a guide for the selection of insulation materials.

No further testing was performed on these specimens except for capacitance measurements (See Table VI).

Test specimens 1 through 4 were retested to determine the insulation temperature relationship of 12-in. compared to 120-inches. As expected, a one order of magnitude difference was observed (see Figures 4, 5, 8, and 9). This information supports the fact that the finished cable has uniform geometry throughout its full length. As observed in Figure 8, the "N" shipping seal on specimen #2 was completely gone during this test. This specimen was baked at 200°F until the measurement was $>10\text{K}$ megs, at which time it was sealed and retested to 1000°F . An interesting discovery was made at this time. As specimen #2 was curing, a heat gun was being applied to the "N" portion of specimen #3 to bake out the moisture that was taken in as a result of a damaged seal. This applied temperature was approximately 500°F . As the heat gun was being moved toward the end of the cable, a sharp decrease in resistance was noted (<0.1 meg ohm) as it passed a given portion of the cable. This process was repeated several times with the same phenomenon occurring. It was decided to test all the cables in this manner and the same effect was observed on a portion of specimen #4. This discovery was alarming since all the cables being considered for engine use could conceivably reach this temperature or higher. These portions of the cables were removed and X-rayed where a small particle of dense material was observed on one specimen.

FIGURE 6

FIGURE 7

FIGURE 9

However, these specimens were accidentally destroyed before a spectrum analysis could be made. The question then arose whether the specimens were contaminated or whether there was a possibility that a portion of the cable was touching a furnace element during one of the baking cycles. If the cable had touched an element it could have been exposed to temperatures in excess of 2000°F, where the copper could have become gaseous and penetrated the insulation. As a result of these findings, AGC Specification 90052 is being upgraded to incorporate an insulation uniformity clause, as an acceptance test, to prevent a recurrence of this phenomenon. This clause will appear as follows:

Insulation Uniformity - The entire finished cable shall be raised to a temperature of 1000°F in an inert atmosphere for a minimum of 30 minutes. When the cable has been stabilized at this temperature, an insulation resistance measurement (with an applied potential of 50 vdc) shall be made from conductor to conductor, and between conductor and sheath. The measurements thus made shall be recorded.

The normal volume resistivity shall be computed using equations 1 and 2. The measured values shall be compared with the computed values and shall not be less than 10% of the computed values.

$$R_1 = \frac{P}{2\pi L} \ln \left\{ \frac{D_2^2 - S^2}{D_1 \cdot D_2} \right\} \quad \text{Equation No. 1} \quad \begin{array}{l} \text{(Conductor} \\ \text{to Sheath} \\ \text{Resistance)} \end{array}$$

$$R_2 = \frac{P}{\pi L} \ln \left\{ \frac{2S}{D_1} \times \frac{D_2^2 - S^2}{D_2^2 + S^2} \right\} \quad \text{Equation No. 2} \quad \begin{array}{l} \text{(Conductor to} \\ \text{Conductor} \\ \text{Resistance)} \end{array}$$

where:

- P = Specific resistivity in ohm centimeters at temp.
(MgO = 10¹² ohms at 1000°F and 500 vdc)
- L = Cable length in centimeters
- S = Center line distance between conductors in cm
- D₂ = Inside diameter of sheath in cm
- D₁ = Conductor diameter in cm

The data shown in Figure 10 represent the relative insulation of a 4-conductor, 1/8-in. stainless steel sheathed cable (AS9702-E-A-A-16) to a 3-conductor, 5/32-in. copper sheathed cable (AS9702-E-D-A-34). It is interesting to note that specimen #12 had leakage at both ends of the cable. A slight increase in resistance was measured at 400°F because of the baking effects of the test. After the test both specimens were removed and the "E" ends of the cables were resealed. After 5 days exposure to 40% humidity at 74°F, a measurement was made with no change in resistivity noted. However, an approximate one order of magnitude difference in insulation resistance was noted between specimens. Had the "N" seal been adequate, the measurements of specimen No. 12 would have been comparable to specimen #11 as evidenced by Figure 11.

A destructive test was performed on specimens 9 and 10 to determine the maximum temperature that Aero-seal can withstand. By comparing Figure 12 with Figure 1 it can be seen that the damage threshold is between 1400 - 1500°F. The post-test measurements of Figure 12 show that leakage occurred after being exposed to 1500°F.

A test was performed to determine the relative capacity of MgO and Al_2O_3 with temperature. Ten foot lengths of cable were exposed to the temperatures shown in Table VI.

46 6212

SEMI-LOGARITHMIC
5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

RESISTANCE IN OHMS

FIGURE 10

FIGURE 11

FIGURE 12

RESISTANCE IN OHM - CENTIMETERS

TEST VOLTAGE 500 VDC

FIGURE 13

TABLE VI
RELATIVE CAPACITY OF MgO AND
 Al_2O_3 WITH TEMPERATURE

SPECIMEN NO.	CAPACITY IN NANOFARADS AT 200°F		CAPACITY IN NANOFARADS AT 1300°F	
	CC	CS	CC	CS
1	3.12	4.4	3.25	4.65
3	1.5	2.4	1.78	2.8
5	0.8	1.4	9.5	12.3
7	3.7	7.0	13.0	17.4
8	3.7	7.0	11.0	13.5

Note the marked increase in capacitance of items 5, 7, and 8 relative to items 1 and 3. Items 5, 7, and 8 contained Al_2O_3 whereas items 1 and 3 contained MgO as the dielectric.

D. RECOMMENDATIONS FOR SELECTING AND HANDLING SHEATHED CABLES

The following information is provided to aid the engineer when making a decision regarding sheathed cable assemblies. Figure 13, with Equations 1 and 2, is very useful in determining the overall insulation resistance of a specific cable or insulator.

1. Always remove storage seals before processing cables. When exposing conductors, a lathe or conventional sheath stripper may be used. Do not use solvents to remove seal. Take extra precaution to see that burrs, chips, and filings are removed.
2. If conductors require cleaning or de-oxidizing, use a SS White or equivalent oxide abrasive unit. The grit for this operation should be approximately 30 microns.
3. Repeated flexing at one point will result in work hardening and the eventual fracture of the sheath. Bending can be accomplished with ordinary tube benders but bend radius should not be less than two sheath diameters. It is advisable to make sure that the region to be bent is annealed.
4. Most forms of welding, brazing, or soldering may be performed on the sheath without destroying the insulation. However, all forms of flux materials must be kept away from the exposed ends as those fluxes will be absorbed by the dielectric and cause insulation degradation.
5. Always remove moisture before making the end seal pressure tight. If moisture is not removed and the cable is subsequently subjected to high temperature, rupture of the sheath may occur.
6. To remove moisture, bake material at 400°F in an oven or furnace until the desired minimum insulation is obtained. Seal the exposed ends immediately as they will absorb moisture in a matter of minutes in humid atmospheres. Always seal the ends when not in use.
7. If cables are Aerosealed, welding or brazing is permissible. However, the sealing qualities of the material may be permanently lost if exposed to temperatures in excess of 1000°F. Out gassing also occurs at this temperature and a pressure tight seal cannot be made unless a relief hole is provided.
8. Always avoid temperatures in excess of the softening point of the conductor material. Migration may occur and remain undetected until the cable is exposed to engine environments.

REFERENCES

1. REIC Report No. 21, THE EFFECT OF NUCLEAR RADIATION ON ELASTOMERIC AND PLASTIC COMPONENTS AND MATERIALS, Radiation Effects Information Center, Battelle Memorial Institute, September 1, 1961.
2. REON Report RN-S-0236, FINAL TEST REPORT FOR RADIATION EFFECTS TESTS ON INSTRUMENTATION CABLES 23/R601 AND 23/R701.
3. NARF Report FXK-184-6, NERVA COMPONENTS IRRADIATION PROGRAM, General Dynamics/Fort Worth, Volume 6: GTR Test 15, 19 March 1965.
4. WANL Process Specification 294624, SEALING, MOISTURE, TEMPORARY CABLES, February 1965.
5. WANL Procurement Specification 30173, GLASS PRE-FORMS, February 1965.
6. WANL 65-8B3-CCONS-R2, AN EVALUATION OF GLASS SEALS FOR ELECTRICAL CABLE, July 16, 1965.
7. LASL Progress Reports for periods September 10, 1965 through January 1966.
8. Memorandum 7461:M4185, G. L. Fluke to D. E. Swartz, Subject; Swaged Cable Temperatures in XE-1 Environments, dated 19 November 1965.