AD 698 617

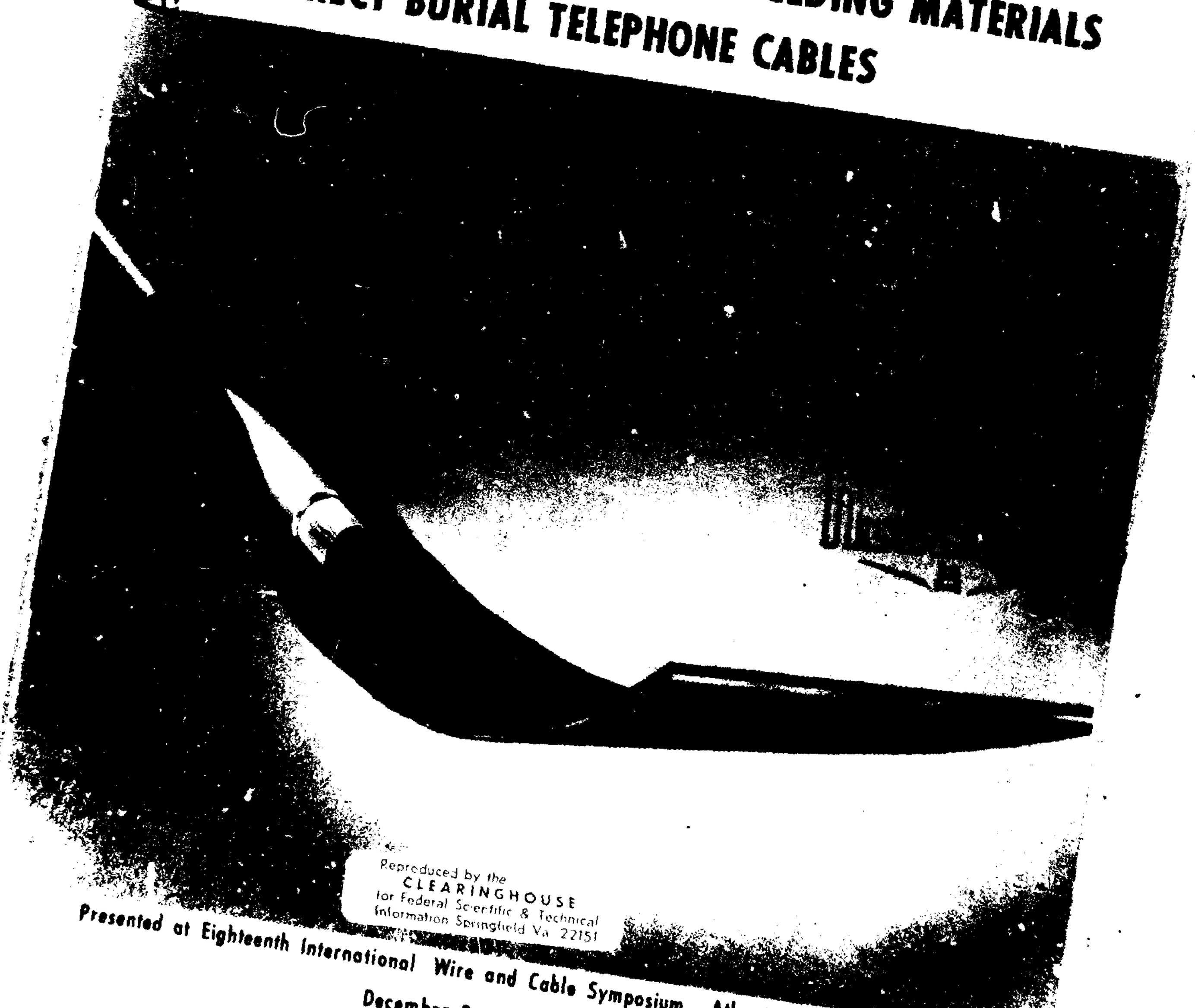
# PROGRESS REPORT ON CORROSION EVALUATION OF SHIELDING MATERIALS FOR DIRECT BURIAL TELEPHONE CABLES


Gerald A. Lohsl, et al

National Bureau of Standards
Washington, D. C.


1969

# PROGRESS REPORT ON CORROSION EVALUATION OF SHIELDING MATERIALS FOR DIRECT BURIAL TELEPHONE CABLES





Presented at Eighteenth International Wire and Cable Symposium, Atlantic City, New Jersey

December 3, 4, and 5, 1969



38

# PROGRESS REPORT ON CORROSION EVALUATION OF SHIELDING MATERIALS FOR DIRECT BURIAL TELEPHONE CABLES*

by

Gerald A. Lohsl

and

Melvin Romanoff

## ABSTRACT

Corrosion data on the performance of bare and plastic coated metals intended for use as cable shields in direct burial telephone cable is presented. The metals were placed in buried cable specimens which had their outer jackets damaged to simulate actual usage in the field. These cable specimens were then exposed for one year in six different underground environments which are representative of practically all soils within the United States.

*A paper to be presented on December 3, 1969, at the Eighteenth International Wire and Cable Symposium, Atlantic City, New Jersey, by Gerald A. Lohsl, Outside Plant Branch, Telephone Operations and Standards Division, Rural Electrification Administration, Washington, D. C. 20250 and Melvin Romanoff, Corrosion Section, Institute for Materials Research, National Bureau of Standards, Washington, D. C. 20234.

* * * * *

# PROGRESS REPORT ON CORROSION EVALUATION OF SHIELDING MATERIALS FOR DIRECT BURIAL TELEPHONE CABLES[1]


by

Gerald A. Lohsl

and

Melvin Romanoff


## INTRODUCTION

This progress report consists of the results of the first retrieval of the buried cable specimens, the burial of which was reported in a paper presented at the Seventeenth International Wire and Cable Symposium (1)[2]. This program was initiated by the Rural Electrification Administration (REA) in cooperation with the National Bureau of Standards (NBS) to develop and investigate metals or combination of metals and materials suitable for use as a substitute for copper in buried telephone cables. Historically, 5-mil copper has been used in the REA Program as a shield in nongopher infested areas with 10-mil copper being used in areas requiring gopher protection for the cables. Bimetallic shields containing copper and stainless steel have also been used in lieu of 10-mil copper.

---

[1]A paper to be presented on December 3, 1969, at the Eighteenth International Wire and Cable Symposium, Atlantic City, New Jersey, by Gerald A. Lohsl, Outside Plant Branch, Telephone Operations and Standards Division, Rural Electrification Administration, Washington, D. C. 20250 and Melvin Romanoff, Corrosion Section, Institute for Materials Research, National Bureau of Standards, Washington, D. C. 20234.

[2]Figures in parentheses indicate literature references at the end of this paper.

* * * * *

Even though our experience has been excellent with these materials, the ever increasing cost of copper and its fluctuating availability have prompted REA to investigate the possibility of the complete elimination of copper as a shielding material.

New developments in the cable industry, such as grease-filled cables, have also encouraged this program in order to offset the increased cost of materials associated with the filled cable design. The continued use of a copper shield in this type cable could inhibit its broad acceptance.

REA's prime concern in these tests, as in all of its tests, is to find ways to reduce construction costs and help the rural systems it finances to provide quality service.

Since it is desirable to develop a shielding material which would be suitable for all applications in all soils, the specimens were buried in several soils known to be very corrosive and many specimens were coupled to a cathodic metal (copper) to further accelerate the corrosion. It is realized that cathodic metals will not always be in the vicinity of the exposed shield; but it is also realized that this possibility certainly does exist. The thought is often expressed that, since buried cables have a polyethylene jacket covering the shield, the shield will not usually be exposed to the soil. However, cable damage during installation caused by construction personnel, equipment, rocks, sand abrasion, and rough handling are to be reasonably expected and does occur. Lightning and rodent damage will frequently occur and the possibility of a manufacturing flaw also exists. In some areas holes in the cable's outer jacket may exist in many buried cable sections (between terminal housings) with a greater incidence to be expected in gopher areas. Improved cable designs and construction practices could substantially reduce this incidence of damage, but is not likely to eliminate it completely. Since it is not practicable for detailed soil tests to be made or for different shielding materials to be specified for each individual application, a universal shield for use in all soil environments is desirable. The manufacturing and inventory problems will also be minimized by standardizing on one universal shielding material.

## Preliminary Soil Exposure Tests

Preliminary tests were conducted on plastic-coated metals commonly used as cable shields in buried telephone cable. These specimens were buried for 13 months in a tidal marsh soil and included homogeneous, plastic-bonded laminates, and metallurgically-bonded laminates. The results of these tests were given in a paper presented at the Seventeenth International Wire and Cable Symposium (1). These results indicated a need for a more extensive evaluation of cable shielding material in actual cable specimens. The cable specimens comprising 31 different systems and four hardware items used in connection with buried telephone cables were prepared and installed, during the spring and summer of 1968, at six NBS corrosion test sites. The soils at the test sites are representative, with respect to corrosion of metals, of practically all soil environments within the United States, and may be correlated with the corrosion rates observed at 128 test sites at which corrosion investigations were previously conducted by NBS (2).

## Materials Under Test

Each cable specimen is a 6-pair,19-gauge direct burial cable unless otherwise indicated. The different shield materials included in the test program are listed in Table 1. The hardware items included in the test program are described in a following section of this paper.

Other considerations for the shielding material selected, in addition to being corrosion resistant, are that it should be economical, abundant, resistant to gopher penetration, flexible, easily corrugated and formed, and should have good shielding characteristics. The results of lightning shield effectiveness tests conducted on various shielding materials and configurations were given in a paper presented at the Seventeenth International Wire and Cable Symposium (3). The noise induction shielding characteristics will be evaluated for those materials observed to perform best in other areas under consideration. This report is concerned only with the corrosion aspect.

## Specimen Preparation

The proposed shielding materials were inserted in the double jacketed cables which were supplied by various cable manufacturers in accordance with REA specifications. The cable was shipped on reels to the National Bureau of Standards, where it was cut into 14-in. lengths.[3] The specimens were prepared by REA outside plant personnel, as shown in Figure 1.

[3]Following are the conversion factors for the measurements employed in this manuscript to the corresponding SI equivalents:

inches x 25.4 = millimeters (mm)
feet x 0.3048 = meters (m)

Two configurations of specimens were prepared which are designated as Type 1 and Type 2. Each Type 1 specimen has a window approximately 2 by 0.5 in. removed as well as a 0.5 in. ring removed from the circumference of each cable specimen's outer jacket. This is intended to simulate possible construction, lightning, or rodent damage to the cable's outer jacket. The ends of each cable were sealed to prevent the entrance of moisture. Each Type 2 specimen was prepared similar to the Type 1 except that a bonding harness was applied to both ends of the Type 2 specimens for attaching a copper strip to simulate a dissimilar metal couple which may possibly be experienced in an actual field installation. No special care was taken in the removal of the windows to prevent damaging any coatings which may be present on the shielding materials. The window is expected to give some indication of the tendency of any spot damage to cable to permit complete corrosion of the shield around the circumference. This type specimen will permit a comparison of the amount of corrosion at the window to that occurring where the complete cable circumference is exposed.

## Test Procedure

The specimens were buried in the six different soil environments during 1968. Six specimens of each system were buried approximately two to three feet below the ground line, with the exception of system 12, for which only two cable specimens were buried in sites B, D, and E, and systems 27 and 28, for which only three specimens were buried in sites B and D. Specimens of systems 9, 10, 13, and 14, were only buried at three test sites (sites A, B, and G).

---

[3]The United States of America, as a signatory to the Treaty of the Meter, is under an obligation to support the actions of the General Conference of Weights and Measures, which include promotion of the International System of Units (Le Systeme International d'Unites, or SI for short), the modern "metric system." The position of the NBS as the official standards agency of the U. S. Government does require that the NBS be the leader of the nation's measurement system. As a major step in this direction, it is the official policy of the NBS to participate actively in the education of the U. S. scientific and technological communities with respect to the SI units and to lead the way within the United States in placing the SI units in a central position in the international language of science and technology. The AIP, the ASTM, the IEEE, and various other scientific and technical organizations are partners with the Bureau in this campaign to broaden the use of SI units as the language of technology within the United States.

With respect to the hardware items (systems 33, 35, 36, and 37), only one, two, or three specimens were buried at each test site, depending on the number of specimens that were made available.

One set of each system was removed, after exposure for one year, from each test site during 1969 (Table 3). The cable specimens (system 1-32) were returned to the laboratory for cleaning and detailed examination. Because of the limited number of hardware items (systems 33-37) exposed, the specimens were cleaned, examined, and photographed at the test sites, and returned to exposure for at least another year.

A second set of specimens will be removed, after exposure for two years, from the test sites during 1970. Based on the condition of the specimens at that time, a decision will be made regarding future inspection dates. The investigation was initially intended to last a minimum of six years and a maximum of 12. Additional specimens of newly-developed shielding systems will be included in the test program at the time of the periodic inspections.

## Soils at the Test Sites

The physical and chemical properties of the soils at the six test sites are given in Table 4. The pH of the soils varies from an acidity of 4.0 to an alkalinity of 8.8. Electrical resistivity ranges from 55 ohm-cm, which is approximately that of seawater, to 30,000 ohm-cm, indicating the absence of soluble salts. Chemical properties listed show that the soils differ widely in the nature and concentrations of soluble salts. Physical conditions of the soils range from well-aerated to very poorly aerated.

Descriptions of the soils at the six test sites follows:

Site A — Sagemoor sandy loam is a well-drained alkaline soil with a resistivity of 400 ohm-cm and a pH of 8.8. It is typical of soils found in vast areas of eastern Washington and Oregon. The site is located on the Yakima Indian Reservation near Toppenish, Washington. The soil is consistent in composition to a depth of at least 7 ft. and supports an abundant growth of sage brush.

Site B — Hagerstown loam is a well drained soil representative of the well-developed soils found in the eastern United States. The site is located at the Loch Raven Reservoir of the

Baltimore water department. The soil consists of a brown loam about 1 ft. deep, underlain by a reddish-brown clay extending down 5 ft. or more to a rock base. The soil has a resistivity of 5,200 ohm-cm and a pH of 5.8. Almost all the materials investigated since 1922 in NBS soil corrosion tests have been exposed at this site. Therefore, it can serve usefully as a reference site for correlating data obtained during the present program with that of earlier tests.

Site C Clay soil is located in a large clay pit on level land at Cape May, N. J. The soil consists of plastic gray clay to a depth of 6 in. This is underlain by gray clay mixed with patches of brown clay to a depth of 12 in. Underneath this is a poorly drained, very heavy plastic clay in which the specimens are exposed. The soil has a resistivity of 300 ohm-cm and a pH of 4.0.

Site D Lakewood sand is a white, loose sand with black streaks in some places. The site is located in a well drained, rolling area at Wildwood, N. J., which is not subject to overflow from the ocean except under unusual flood conditions. The sand, which supports the growth of beach grasses abundantly, has a pH of 7.3 and a resistivity of 30,000 ohm-cm.

Site E Coastal sand is a typical white beach sand with a high content of black sand streaks. It is similar to the Lakewood sand, except that at this site, on the Two-Mile Beach at Wildwood, N. J., the sand is saturated continuously with salt water. It has a pH of 7.1 and a resistivity of 55 ohm-cm.

Site G Tidal marsh is typical of the poorly drained soils found along the Atlantic and Gulf coasts. The site is located along a creek that empties into the Chesapeake Bay at Patuxent, Maryland. The soil is charged with hydrogen sulfide and has a resistivity of 300 ohm-cm and a pH of 7.1.

Data on the performance of carbon steel after exposure for eight years in the soils at the six test sites have recently been published (4,5). Extensive data on the corrosion performance of ferrous, copper, and other metals and alloys for exposures up to 17 years in Hagerstown loam, and a wide variety of other soils, are given in NBS Circular 579 (2).

## RESULTS

Following is a brief description of each system and its performance in the six soil environments in which the specimens were exposed for one year.

Table 1 summarizes the performance of each system by a numerical rating which indicates the corrosion performance of the metal shields in the specimens. The rating code is described in Table 2. A rating of 10 indicates that the shield was unaffected by corrosion. On the other extreme, a rating of 0 indicates severe corrosion, the amount of metal dissipated causing electrical discontinuity (ELD) of the shield. Hereafter the term ELD will be used to indicate longitudinal electrical discontinuity of the shield as a result of corrosion in the soil environment to which the specimen was exposed.

### System 1

This system consisted of an 8-mil corrugated bare aluminum shield.

The specimens exposed at sites A, D, and E were unaffected by corrosion. At site B only superficial etching was observed in the exposed window and ring areas.

The aluminum shield of the specimen exposed in the acid clay (site C) was severely corroded at the seam edges and had perforations due to pitting in the window and ring.

In the tidal marsh soil (site G) the aluminum shield was totally dissipated by corrosion, causing electrical discontinuity (ELD) of the shield at the window and ring. Corrosion was also apparent over most of both surfaces under the cable's polyethylene jacket.

### System 2

This system is the same as System No. 1 except that the shield was coupled to copper.

Complete ELD occurred on the specimens exposed at sites C and G. In the alkaline soil (site A) severe corrosion with many perforations by pitting, occurred on the shield in the areas of the window and ring, the ring being close to ELD.

At sites B, D, and E, metal attack was observed under the jackets of the specimens with some pitting, in addition to severe corrosion causing perforations in the exposed window and ring areas.

The galvanic couple which was formed by coupling the aluminum shield to the copper strip resulted in an appreciable increase in the corrosion of the shield because the copper was cathodic to the aluminum shield, which behaved as a sacrifical anode in the galvanic cell.

The copper strips, except for discoloration over practically the entire surface, were unaffected by corrosion in all the soils.

System 3

This system consisted of a 5-mil corrugated bare copper shield.

Except for surface discoloration and the presence of some green patina at several of the sites, the shields were unaffected by corrosion after exposure in five of the six soils. In the acid clay (site C), the exposed copper in the ring area was uniformly corroded and perforated in several isolated places and along the edge seam. The window in the same specimen was unaffected by corrosion.

System 4

This system consisted of a 5-mil bare copper alloy shield. The copper alloy contained 97.5% copper, 2.5% iron, and 0.02% phosphorous.

The specimens were unaffected by corrosion in the six soils. The surfaces exposed in the windows and rings were discolored, and localized patches of green patina were present in soils B, C, D, and G.

System 5

This system consisted of a 50-pair, 22-gauge cable with an 8-mil corrugated aluminum shield, with a plastic film coating on the core side of the shield. An adhesive outer jacket was then applied. The aluminum edges were also protected at the shield overlap by an experimental process.

The plastic film on the core side of the shield was unaffected in all soils.

The specimens were unaffected by corrosion at sites A, B, and D, and only superficial etching was present in the area of the exposed ring at site E. There was no evidence of moisture between the outer jacket and the shield in all specimens at these sites.

The specimens exposed in site C had metal attack and slight pitting in the exposed areas and in the areas under the jacket adjacent to the window and ring. At the ring, the metal was completely dissipated about 1/2-in. inward from the edge of the shield across the width of the ring.

At site G, the aluminum in the exposed window and ring was completely dissipated by corrosion, leaving the plastic film on the core side of the shield intact. ELD occurred at the ring.

System 6

This system is the same as System No. 5, except that the shield was coupled to copper.

The plastic film coating on the core side of the shield was unaffected, but corrosion of the aluminum shield was accelerated by the copper cathode in all soils.

In sites A, C, E and G, the aluminum shield was dissipated over large areas, or completely dissipated, leaving the plastic film intact. ELD occurred at both the window and ring in sites C and G, and only at the ring at site A. The ring on the specimen in site E was close to ELD.

The specimen exposed in site B had a uniform metal attack in the exposed ring and in an area under the jacket adjacent to the ring.

At site D, the window in the specimen was unaffected by corrosion, but there were many perforations due to pitting in the aluminum shield at the ring, and under the jacket in areas adjacent to the window and ring.

## System 7

This system consisted of a 50-pair,22-gauge cable with an 11-mil corrugated metallurgically bonded shield which consisted of aluminum-low carbon steel-aluminum (6-3-2 mils). This was an experimental aluminum alloy.

In five of the six soils, the aluminum exposed in the windows and rings was either unaffected by corrosion, or had some superficial metal attack or etching. The shields under the jackets on the specimens exposed at sites A, B and D were unaffected, but in sites C and E, the aluminum had appreciable metal attack over most of the surface on both sides of the shield.

The aluminum on both sides of the shield on the specimen exposed in tidal marsh (site G) was practically entirely dissipated, leaving the carbon steel in a rust-covered and very brittle condition. The steel residue had no perforation indicating that the aluminum provided cathodic protection up to this stage.

## System 8

This system is the same as System No. 7, except that the shield was coupled to copper.

The condition of the specimen exposed in tidal marsh (site G) was about the same as that observed on the similar specimen not coupled to copper (System 7), except that the steel residue was perforated in many places.

In the remaining five soils, the aluminum was practically entirely dissipated in the exposed windows and rings. In the alkaline soil (site A), the aluminum was dissipated over practically the entire outer and core surfaces of the shield, and the steel was perforated in many places. The specimens were close to ELD at the ring.

About 60% of the metallurgically bonded shield was dissipated at the window, and about 25% at the ring in the shield of the specimen exposed in the acid clay (site C). Under the jacket, the aluminum was almost entirely sacrificed on the core side, leaving a rusted steel surface.

In Hagerstown loam (site B), the steel was perforated by corrosion in several places in the ring area. Appreciable metal attack occurred in the window area and on both sides of the shield at the surfaces under the jacket.

In the dry sand (site D), the steel was pitted, but not perforated, at the window and ring. The shield under the jacket was unaffected. Only slight metal attack was observed on the specimen buried in the wet sand (site E) on the exposed and unexposed surfaces of the shield, with some pitting confined to the ring.

System 9

This system consisted of an 8-mil uncorrugated aluminum shield with a plastic coating on both sides.

Specimens of this system were only exposed to the soils at sites A, B, and G because the cable was not available in time to prepare specimens for burial at all the sites.

The plastic coating on both sides of the shield was unaffected by the soils at the three sites, as were the aluminum shields in soils A and B.

In the aggressive tidal marsh (site G) the aluminum was dissipated by corrosion up to 3/8-in. inward at the overlap edge of the window and ring. Many perforations due to corrosion were present in the exposed areas adjacent to the jacket where the plastic coating was disturbed in removing the adhering jacket at the window and ring area during preparation of the specimens.

System 10

This system is the same as System No. 9, except that the shield was coupled to copper.

Connecting the copper galvanically to the plastic coated aluminum shield accelerated the corrosion of the anodic aluminum in the three soils. The plastic on both sides of the shield was unaffected, even in the areas where the aluminum was corroded.

In the alkaline soil (site A) more than 50% of the aluminum was dissipated at the window, and about 10% at the ring; the corrosion was predominant from the overlap seam to about 1/2-in. inward. The aluminum was also dissipated about 1.5 in. under the jacket adjacent to the window and ring.

At site B, the aluminum was dissipated in two isolated places in the window, and three places in the ring between the plastic coating. The plastic was ruptured at one area in the ring. The rest of the shield under the jacket was unaffected by corrosion.

In tidal marsh (site G), the aluminum was dissipated by corrosion more than 50% at the window, and almost completely at the ring. The aluminum was also dissipated about 3/4-in. under the jacket adjacent to the window and ring. The shield was ELD at the ring.

<u>System 12</u>

This system consisted of a 6-mil corrugated tin-plated steel shield with a plastic coating on the outer side. The shield was galvanically coupled to copper.

Because of the poor bond between the plastic and metal shield, moisture or water got under the coating. The coating was blistered over most of the surfaces of the shield in all soils, and peeled readily. This system performed poorly in all six soil environments. In the acid clay (site C) and tidal marsh (site G) the metal in the exposed windows and rings were almost dissipated by corrosion, leaving only the plastic coating in place. The ring at site C was ELD, and very close to ELD at site G.

In the other four soils, many perforations were present in the window and ring areas of the shield. At sites A, B, and C, moisture got under the overlap seam and caused rust formations on the core side of the shield along the entire seam edge of the cable, with considerable pitting and localized perforations in the shield.

<u>System 13</u>

This system consisted of a 6-mil corrugated tin-plated steel with a black flooding compound coating on the outer side of the shield. The seam along the cable length was soldered. Specimens of this system were exposed at sites A, B, and G only, because cable was not available in time to prepare specimens for exposure at all six test sites.

The flooding compound in the exposed areas on the outer side of the shield was dry, but intact after exposure at site A, tacky and intact over 60% of the surface at site B, and practically entirely gone at site G. Under the jacket, the flooding compound appeared tacky and intact over the entire surface except on the peaks of some of the corrugations.

The specimen exposed in the alkaline soil at site A was unaffected except for one perforation through the shield in the ring area. The specimen exposed in the moderately corrosive Hagerstown Loam (site B) was perforated by pitting in isolated areas in the window and ring. In the tidal marsh soil (site G), the exposed shield in the window and ring areas was completely dissipated by corrosion, except for the soldered seam which remained intact. The ring was close to ELD. Generally, the corrosion appeared to be more severe 180$^{o}$ away from the soldered seam.

At least 1/3 of the core sides of the shields exposed in sites B and G were rusted, because of water seepage at the perforated areas. The core side of the shield was unaffected in site A.

System 14

This system is the same as System No. 13 except that the shield was coupled to copper. Specimens of this system were exposed at sites A, B, and G only.

The condition of flooding compound on the specimens was similar to that observed for System No. 13. Corrosion of the specimens was appreciably accelerated by coupling the shields to copper in the three soils.

At sites A and G, the shield exposed in both the window and ring was completely dissipated by corrosion, except for the soldered seam which remained intact. At site B, the metal in the window was about 40% dissipated by corrosion, and several isolated perforations by pitting were present in the ring area. Considerable rust was present over more than 1/3 of the surface on the core side of the shields at the three sites.

System 15

This system consisted of a 6-mil corrugated tin-plated steel shield with a clear flooding compound on both sides of the shield.

The flooding compound was gone from all specimens at the exposed windows and rings. Under the jacket, the flooding compound was moist and intact on both sides of the shield in all areas unaffected by corrosion. The flooding compound prevented moisture from entering under the core side of the shield, except in the areas where the metal was perforated by corrosion.

Appreciable corrosion to severe corrosion occurred on the exposed parts of the shields in the six soils. Localized pitting on the specimens was mainly confined to the peaks in the corrugations.

Site A: Slight pitting and one pinpoint perforation occurred in the ring. The window was unaffected by corrosion.

Site D: The ring was unaffected, but several isolated perforations by pitting occurred at the window, in addition to severe corrosion at the edge seam.

Site E: Many small pits were present in the window and one perforation in the ring.

Sites B and C: Many pits to perforation occurred in the windows and rings, at the seam edges and remote from the seam.

Site G: About 90% of the shield in the window and about 50% in the ring was dissipated by corrosion. The ring was close to ELD.

System 16

This system is the same as System No. 15, except that the shield was coupled to copper.

The clear flooding compound was in about the same condition as that described for the specimens in System No. 15.

The copper cathodes accelerated the corrosion of the specimen shield in all soils.

Sites C and G: The shield in the windows and rings was completely dissipated by corrosion and ELD occurred at the rings.

Sites A, B, and D: From 15 to 30% of the metal was dissipated in the exposed windows and rings. The rings of the specimens in sites A and D were close to ELD.

In the wet sand (site E), there were numerous perforations in the window and ring areas. This is the only specimen of this system which was not affected by corrosion under the jacket. In the other five soils, considerable rust extending along the entire length of the specimen was present on the edge seams of the outer and sometimes the core side of the shield.

System 17

This system consisted of a 5-mil corrugated type 304 stainless steel shield.

The specimens of this system were unaffected by corrosion in the six soils.

System 18

This system is the same as System No. 17, except that the shield was coupled to copper.

The specimens of this system were also unaffected by corrosion in the six soils.

The copper strips coupled to the specimens were not affected by corrosion in five of the six soils, except for discoloration of the surface. In the acid clay soil at site C, the copper strip was about 90% dissipated by corrosion.

System 19

This system consisted of a 6-mil corrugated tin-plated steel shield.

In the alkaline soil (site A), the shield in the window area was unaffected, but corrosion caused considerable rusting and one perforation through the shield in the ring area.

The windows and shields in the specimens exposed at sites B and D were perforated in several places, in addition to severe corrosion along the seam edges.

In the wet sand (site E) there was severe pitting over the entire window surface and numerous perforations through the shield, but none of the pits perforated the shield in the ring.

The windows and rings in the specimens exposed at sites C and G were completely dissipated by corrosion causing ELD at the rings in the cable specimens at both sites, and also in the window at site G.

System 20

This system is the same as System No. 19, except that the system is coupled to copper.

The specimen exposed in the wet sand (site E) contained numerous perforations through the shield in the window and ring.

In the other five sites the shields were almost entirely dissipated by corrosion in the exposed areas. The specimens in these five soils were ELD or close to ELD at the ring, and the specimens in sites C and G were also ELD at the window. At site C, the entire cable specimen was about 70% dissipated by corrosion, and the specimen exposed in site G was about 40% dissipated.

System 21

This system consisted of a 5-mil corrugated type 430 stainless steel shield.

The exposed windows and rings of the specimens were unaffected by corrosion in five of the six soils. In tidal marsh (site G) one pit on the peak of a corrugation perforated the shield in the ring.

The shields contained localized pits under the jackets in soils C and G. In soil C, there were several slight pits on the core side of the shield, in site G, pitting was present along the edges under the jacket adjacent to the window and ring. Two of the pits (pinhole size) perforated the shield.

The shields under the jackets in the other soils were unaffected.

System 22

This system is the same as System No. 21, except that the system is coupled to copper.

The specimens exposed in sites A, B, D, and E were unaffected.

About 50% of the shield in the window, and 75% of the shield in the ring were dissipated by corrosion in tidal marsh (site G). Under the jacket, considerable rust and numerous localized pits were present on both sides of the shield. The ring was ELD.

In the acid clay (site C), the window was unaffected by corrosion, but there was one pinhole perforation adjacent to the jacket in the ring. The copper strip coupled to this specimen was about 75% dissipated by corrosion. The remaining portion of the copper strip was corroded uniformly over the surface and severely at the edges.

System 23

This system consisted of a 6-mil corrugated metallurgically bonded copper-430 stainless steel-copper (2-2-2) shield.

In five of the six soils in which the specimens were exposed, the shields were unaffected by corrosion. There was no evidence of delamination of the metallurgically bonded shield at the edges.

In the acid clay (site C), the copper cladding was dissipated over about 50% of the shield in the window and ring areas. The underlying stainless steel was unaffected, except for two pinhole pits which perforated the shield in the ring.

Copper appears to behave as a sacrificial anode when coupled to stainless steel in the highly acid clay soil. This has also been noted in other specimens in which the copper strip was coupled to specimens with stainless steel shields (see System Nos. 18 and 22).

System 24

This system consisted of a [illegible] mil corrugated metallurgically bonded copper-low carbon steel-copper (2-2-2) shield.

The specimens exposed in the sand soils (sites D and E) were unaffected, except for superficial delamination in one small area at the edge seam in the ring on the shield of the specimen exposed in site E.

In the alkaline soil (site A) the window was unaffected, but the steel was dissipated, causing delamination of the copper about 1/8-in. inward from the edge seam.

In Hagerstown loam (site B), delamination of the copper shield occurred about 1/4-in. inward along the edges of the shield in the window and ring, because of dissipation of the steel. There were several pinpoint perforations through both layers of the remaining copper in the window.

The shields under the jackets of the specimens exposed in the above-mentioned soils (site A, B, D, and E) were unaffected by corrosion.

In the acid clay (site C) the steel was dissipated between the copper about 1/2-in. inward along the edges of the window, and entirely dissipated between the copper around the entire circumference of the ring. This condition extended about 3/4-in. under the jacket edges adjacent to the window and ring. The copper in the delaminated areas was unaffected by corrosion.

In tidal marsh (site G), delamination of the copper occurred, due to corrosion of the steel, along the entire length of the overlap cable edge up to 1/4-in. inward. Delamination of lesser extent occurred on the inner edge of the cable shield.

System 25

This system consisted of a 50-pair, 22-gauge corrugated 6-mil tin-plated steel shield. The edge seam was soldered and a black flooding compound coating was on only the outer side of the shield. There was also an inner shield which consisted of 8-mil bare uncorrugated aluminum.

The black flooding compound on the outer side of the shield was tacky on the specimens exposed at sites A and B, and semi-hard on the specimens at the other sites. The compound was intact over the exposed and unexposed surfaces of the shield, except on some of the peaks of the corrugated metal and in the areas affected by corrosion.

The shields were unaffected by corrosion in the specimens exposed in the soils at sites A, D, and E. The interior aluminum shields were also unaffected in these soils.

In site B, the outer shield was perforated by corrosion in one small area in the window and ring. The inner surface of the steel shield was rusted due to water entering the perforations. The aluminum was unaffected.

The outer shield of the specimen exposed in the clay soil (site C) was perforated in three places in the window, and in numerous places in the ring. There was metal attack over 50% of the surface on both sides of the inner aluminum shield, in addition to many perforations under the ring.

The outer shield of the specimen exposed in tidal marsh (site G) had numerous perforations in the window, and about 20% of the metal was dissipated in the ring, mostly 180$^{o}$ away from the soldered seam. The inner aluminum shield had numerous perforations due to localized pitting under the window and ring areas, and in other remote areas.

The soldered seam on the outer shield of the specimens was intact in all soils.

Following is the condition of the metal shields in the different soils:

Site A: The outer shield was corroded between the plastic coating along the edge up to 1/16-in. inward in the ring. The rest of the specimen was unaffected.

Site B: There were a few localized pits to perforation in the ring area of the outer shield. The rest of the specimen was unaffected.

Site C: Severe corrosion occurred along the edges (up to 1/8-in. inward) of the window and ring. There was one perforation in the corner of the window adjacent to the jacket, and four isolated perforations in the ring.

Site D: The specimen was unaffected by corrosion except for metal attack in a 1/8-in. diameter area in the ring of the outer shield.

Site E: The metal was dissipated up to 1/8-in. inward at the seam edge in the window and ring of the outer shield, and one perforation was present in the corner of the window.

Site G: The window was about 65% and the ring about 30% dissipated by corrosion on the outer shield. The aluminum inner shield was completely corroded in a 1/2-in.$^2$ area between the plastic coating which was unaffected.

<u>System 28</u>

This system is the same as System No. 27, except that the system is coupled to copper.

Considerably more corrosion occurred on the shields in the specimens of this system because of the galvanic couple effect.

Site A: Outer shield - There were four localized perforations and severe corrosion up to 1/4-in. inward from the edge seam. The ring was perforated in two places (1/2-in. in diameter). The edges along the entire length of the cable specimen were rusted and localized pitting was present in the shield under the jacket; Inner shield - Unaffected by corrosion.

Site B: Outer shield - Both the window and ring were pitted to perforation present in many places and severe corrosion occurred along the seam edges; Inner shield - Unaffected.

System 26

This system is the same as System No. 25, except that the system is coupled to copper.

Coupling the specimens to the copper strips accelerated the corrosion of both the outer tin-plated and inner aluminum shields of the specimens in practically all soils.

In the tidal marsh soil (site G), the ring in the outer shield was ELD, because about 75% of the metal was dissipated. There were also numerous perforations in the window. The inner shield was also ELD under the ring, and about 40% of the aluminum shield in the specimen was dissipated.

In site C, the outer shield was dissipated in 60% of the ring area, and about 20% in the window. The inner aluminum shield was attacked over the entire surface with numerous perforations. Both the outer (except for the solder) and inner shields were ELD in the area of the ring.

The specimens exposed at sites A, D, and E had many or numerous perforations in the window and rings of the outer shield. Localized perforations occurred in the aluminum shield under many places where the outer shield was perforated by corrosion in sites A and E. The aluminum was unaffected in site E.

At site B, only one or two perforations were present in the window and ring of the outer shield, with slight etching on the inner shield.

System 27

This system consisted of an outer and inner shield. The outer shield was a 6-mil corrugated tin-plated metal with a plastic coating on both sides. The inner shield was an 8-mil aluminum, coated helically on both sides with a black adherent plastic.

The plastic coating on both sides of the outer shield peeled readily and showed evidence of moisture under the coating along the entire length of the specimens exposed in all soils.

The black plastic coating was intact and unaffected on the inner aluminum shield on the specimens in all soils, even where the aluminum was dissipated by corrosion between the coating at site G.

Site C: Outer shield - The window was 50% dissipated by corrosion and the ring was completely dissipated by corrosion resulting in ELD. The plastic coating was still in place. Metal attack and pitting to perforation occurred in many places under the jacket along the length of the shield; Inner shield - The aluminum was dissipated in small areas under the window area. The plastic coating was unaffected.

Site D: Outer shield - Severe corrosion occurred along the entire seam edge and there were also numerous perforations along the score in the plastic coating at the window and ring. Considerable rust was present under the plastic coating along most of the length of the cable; Inner shield - Unaffected.

Site E: Outer shield - Severe corrosion occurred along the seam edges of the window and ring, and the shield was also perforated in several isolated places in these areas. The rest of the specimen, including the inner shield, was unaffected.

Site G: Outer shield - The metal in both the window and ring were completely dissipated by corrosion. The ring was ELD; Inner shield - The aluminum was dissipated between the plastic coating under 40% of the window area and in other localized small areas at the ring.

System 29

This system consisted of a corrugated bimetallic shield consisting of 3-mils of type 211 stainless steel on the outer surface, bonded with plastic to 8-mils of aluminum on the core side of the shield. A clear polyethylene grease (flooding compound) was applied on the core side of the shield.

The clear flooding compound was moist and intact on all the specimens. There was no evidence of moisture on the core side of the shield.

The stainless steel on the outer surface and core surface (when exposed by dissipation of the aluminum) of the shields was unaffected by corrosion in the six soils. In the sand soils (sites D and E), the aluminum laminate on the core side of the shield was also unaffected by corrosion. In the other four soils, the aluminum was dissipated under the overlap edge at the windows and rings to various degrees. The maximum dissipation of aluminum occurred in tidal marsh (site G), where the aluminum was sacrificed up to 3/4-in. inward from the edge seam in the window.

In soils A, B, and C, the aluminum was sacrificed from 1/8 to 1/4-in. from the seam edges on the core side of the shield.

System 30

This system is the same as System No. 29, except that the system is coupled to copper.

This system performed essentially the same as System No. 29, except for the greater dissipation of aluminum on the core side of the shield noted below.

The aluminum on the shields in the specimens exposed at sites A, B, C, and G was dissipated from 1/8- to 1-in. inward along the seam edges of the windows and rings, the maximum corrosion occurring on the specimens exposed at sites C and G.

The increase in the corrosion of aluminum in this system could be attributed to the galvanic effect of coupling copper to the shield. Obviously, the aluminum is anodic to both copper and stainless steel. However, it should be noted that the amount of aluminum sacrificed by any specimen on the shields in Systems 29 and 30 is not appreciable.

System 31

This system consisted of an outer corrugated 8-mil type 304 stainless steel shield, and an inner 8-mil uncorrugated aluminum shield. The two shields were separated by a polyethylene jacket.

The outer and inner shields of the specimens were unaffected by corrosion in the six soils, except in the acid clay (site C). In this soil, the 304 stainless steel shield had one small pit in the window and three small pits to perforation in the ring. The pits were at the jacket edges, or just under the jacket edges of the window and ring.

The inner aluminum shield was unaffected in all soils.

System 32

This system is the same as System No. 31, except that the system is coupled to copper.

Coupling the specimens to copper had little effect on the outer shields in this system, and no effect on the inner aluminum shields.

The inner aluminum shields were unaffected by corrosion in all soils, as were the outer shields on the specimens exposed in the soils at sites A, B, D, and E.

In tidal marsh (site G), the outer shield was perforated by small localized pits in five places in the window. All pits occurred along the jacket edges. The rest of the specimen was unaffected.

In the acid clay (site C), there were several perforations from small isolated pits adjacent to or just under the jacket edge at the ring. The rest of the specimen was unaffected. However, the copper sheet coupled to the specimen in this acid clay soil had thinned over the entire surface due to uniform corrosion. Although the copper was anodic to the stainless steel in this soil, it did not provide complete protection to the shield.

System 33

This system consisted of an aluminum splice case coated with coal-tar epoxy paint over the entire exterior surface. A cast aluminum anode was attached to the splice case with two austenitic stainless steel bolts. Two specimens were exposed at each site, one of which was scored through the paint coating to the aluminum.

Because of the limited number of hardware specimens at the test sites, the specimens were inspected in the field at the time of removal, photographed and returned to exposure. This procedure was also followed with the other hardware specimens (Systems Nos. 35, 36, and 37).

The coating was blistered to some extent in all the soils except in the dry sand (site D). The blisters which varied in size from minute to about 1/8-in. in diameter were intact and water-filled in the poorly drained soils (sites C, E, and G). The coating was peeled in several small areas on the specimen exposed in site B, and the paint was chipped in one small area on the specimen exposed in site C.

During the inspection, some of the blisters were broken in the epoxy coating to determine the condition of the underlying aluminum.

The aluminum specimens were unaffected by corrosion in all soils, except for superficial metal attack which was present on the specimen in site C where the paint was chipped. There was no evidence of corrosion in the scored areas. The austenitic stainless steel bolts were also unaffected by corrosion in the six soils.

The cast aluminum anodes showed varying amounts of metal sacrificed in protecting the wrought aluminum splice cases in the different soils.

Following are the approximate amount of anode sacrificed and the type of corrosion that occurred on the anode:

Site A: Anode sacrificed - 3%; Pitting over 10% of the anode

Site B: Anode sacrificed - Nil; Superficial metal attack

Site C: Anode sacrificed - 2%; Localized pitting

Site D: Anode sacrificed - 1%; Localized pitting

Site E: Anode sacrificed - 1%; Shallow metal attack

Site G: Anode sacrificed - 35%; Severe pitting over entire surface

System 35

This system consisted of a fiberglass terminal housing cover.

Specimens of this system were exposed in the soils at sites A, C, D, and E only.

The specimens showed no evidence of deterioration in the four soils to which they were exposed.

System 36

This system consisted of a 14-gauge galvanized steel sheet which was coated with a wash primer and a baked alkyd finish.

The metal beneath the coating was unaffected by corrosion after exposure in the soils at the six test sites. The coating was unaffected by the soil at sites B and E. The coatings on the specimens exposed in sites A, C, and D had small unbroken blisters over the entire surface. The specimen exposed in tidal marsh (site G) had unbroken water-filled blisters up to 3/8-in. in diameter over about 15% of the surface.

System 37

This system consisted of a coaxial buried splice housing assembly made of die cast aluminum. The housing was coated with a 7-mil aluminum alloy by the flame spray process, and top coated with a vinyl sealer. The splice case had seven austenitic stainless steel bolts exposed to hold the housing together and for connection purposes.

Specimens of this system were exposed in the alkaline (site A) and tidal marsh (site G) soils.

The coating on the specimen exposed in the soil at site A peeled and flaked off over about 75% of the housing surface. The bond between the die cast aluminum and coating was obviously very poor. White corrosion products were present over the entire surface of the housing, even under the remaining coating. Localized deep pits were present in at least six places on the housing.

The housing of the specimen exposed in tidal marsh was unaffected by corrosion, although the coating was blistered over most of the surface. The blisters were brittle and many were broken.

The stainless steel bolts on the specimens in both soils were unaffected by corrosion.

## DISCUSSION OF RESULTS

In reviewing the data on the performance of the bare and plastic coated metals intended for use in direct burial telephone cable, it should be emphasized that the tests have been conducted under some very adverse conditions.

The metals were placed in buried cable specimens which had their outer jackets damaged to simulate that which may possibly occur in the field.

The six different soil environments in which the specimens were buried are representative of as wide a range of soil as can be found in the United States, from moderately corrosive to extremely corrosive toward ferrous and other metals. Each of the soils at the six test sites are representative of the properties of groups of soils that are found in abundance in various parts of the United States and other countries.

In addition, the cable specimens with the simulated damages in the outer jacket, were electrically coupled to copper strips that created a galvanic cell between the shield metals which were other than copper, and the copper strip. This represents an electrical connection (possibly for protection purposes) between the metallic shield and a copper pipe, conductor, or ground rod which often occurs in a buried cable system.

Probably, had the cable specimens been installed at the test sites without damages in the outer jackets and without connection to the copper strip, the specimens would not be appreciably affected by corrosion in the soils at any of the sites. This is evident, for example, in a comparison between the performance of the aluminum shields in Systems 1 and 2 vs. Systems 31 and 32. In System 2, corrosion of the aluminum shield was appreciably increased by coupling to copper, in comparison with the performance of the aluminum shield in System 1. Whereas, in System 32, in which the aluminum shield was isolated from the soil elements by an inner polyethylene jacket, coupling the specimen to copper did not have any effect on the aluminum inner shield.

These facts are brought out to indicate that this investigation has been planned to be conducted under adverse conditions with respect to both the specimen preparation and soil exposure conditions.

Because REA is primarily concerned with small individual rural independent telephone systems to which shield failures in their buried cable plant could be extremely costly, it is necessary for REA to specify materials for use in direct burial telephone cables, which will provide adequate long-term performance under a wide variety of corrosive soil conditions.

The data presented in the previous section gives the performance of various specimens after exposure in different soil environments for one year. An overall summary of the performance of the shields in the cable specimens is given in Table 1. The ratings used in evaluating the performance of the shield materials are described in Table 2. The degree of corrosion is rated from 0 to 10. A rating of 10 indicates that the shield has been unaffected by corrosion, and a rating of 0 indicates complete failure of the shield as indicated by electrical discontinuity (ELD) of the shield in one or more places.

As for REA requirements, it is felt that even under the severe conditions of this test program and considering that the data presented in this report pertains to only one-year exposures, any cable system which shows a performance rating of six or less with regard to the corrosion performance of the shield should be used with caution.

The data for the one-year exposures show that the following systems provided excellent protection in all of the soil environments to which the specimens were exposed: System No. 4 (5-mil bare copper alloy); No. 17 (5-mil type 304 stainless steel); No. 18 (same as System No. 17, but coupled to copper); System No. 29 (3-mil type 211 stainless steel with an 8-mil aluminum plastic bonded laminate on the core side of the shield); and No. 30 (same as System No. 29, but coupled to copper). The 5-mil corrugated plain bare copper shield (System No. 3) fell just short of qualifying in the excellent category because it contained several perforations in the exposed ring area in the highly acid clay soil (site C). However, this system can be considered to have performed very good.

The other systems which showed good performance as indicated by a performance rating of six or better after the one-year exposure in the six soils, are: System No. 21 (5-mil type 430 stainless steel); System No. 23 (6-mil copper - 430 stainless steel - copper); System No. 31 (8-mil 304 stainless steel outer shield with an 8-mil aluminum inner shield separated by a polyethylene jacket); System No. 32 (same as System 31, but coupled to copper).

In accordance with the rating system used, the other systems have performed too poorly for consideration for use in one or more of the six soil environments. However, by eliminating the two most corrosive soils, the highly acid clay soil (site C) and tidal marsh (site G), the following systems show good performance in the four less aggressive environments (site A, B, D, and E): System Nos. 1, 5, 7, 9, 22, and 25.

As shown by the performance ratings, the following systems performed too poorly for consideration in soils in general: System Nos. 2, 6, 8, 10, 12, 13, 14, 15, 16, 19, 20, 26, 27, and 28.

The data show that with few exceptions, the copper strip coupled to the shield caused an appreciable acceleration in corrosion over that observed on the same system which was not coupled to copper. The copper behaved as the cathode in the galvanic cell and the dissimilar metal shield was the anode. The latter was dissipated by sacrificial corrosion in addition to the normal corrosion in the particular soil environment.

The exceptions noted are in the specimens with stainless steel shields (Systems 17, 22, and 32) galvanically coupled to copper in the highly acid clay soil (site C). Under these conditions the copper appeared to be anodic to the stainless steel, and only under these conditions did corrosion of the copper strips occur in the galvanic couples.

In the five other soils, the copper was cathodic to all shield materials, the copper showing no evidence of corrosion, except for a discoloration over practically the entire surface. In many cases, the presence of a green patina was observed on parts of the copper surface, but did not penetrate into the copper.

The hardware items included in the test program consisted of a coal-tar epoxy coated aluminum splice case with a cast aluminum anode (System 33), a fiberglass terminal housing cover (System 35, an alkyd-coated mill galvanized sheet (System 36), and a flame spray coated cast aluminum coaxial buried splice housing assembly (System 37). All of these specimens were practically unaffected by corrosion after exposure for one year in the soils at the test sites, with one exception. The cast aluminum splice housing (System 37) was appreciably pitted by corrosion in many localized areas.

References:

(1) G. A. Lohsl and M. Romanoff, Corrosion Evaluation of Shielding Materials for Direct Burial Telephone Cables. A paper presented at the Seventeenth International Wire and Cable Symposium, Atlantic City, New Jersey, December 5, 1968.

(2) M. Romanoff, Underground Corrosion, National Bureau of Standards Circular 579. U. S. Government Printing Office, Washington, D. C. (1957). NBS Circular 579 is out of print. A reproduction can be purchased at a cost of $3.00 per copy from Clearinghouse, U. S. Department of Commerce, Springfield, Virginia 22151. Order as PB-168350 UNDERGROUND CORROSION.

(3) E. L. Fisher, E. A. Robinson, and W. F. Bishop, Lightning Shielding of Plastic Telephone Cable, U. S. Department of Agriculture, Rural Electrification Administration. A paper presented at the Seventeenth International Wire and Cable Symposium, Atlantic City, New Jersey, December 5, 1968.

(4) M. Romanoff, Performance of Ductile-Iron Pipe in Soils. J. Am. Water Works Assn. 60, No. 6, 645 (June 1968).

(5) B. T. Sanderson and M. Romanoff, Performance of Commercially Pure Titanium in Corrosive Soils, Materials Protection, 8, No. 4, 29, (April 1969).

Acknowledgements:

The assistance of B. T. Sanderson (NBS), W. E. Williamson (REA), and James Fink (NBS) in various capacities during the investigation is acknowledged. The authors gratefully acknowledge the contributions of test materials and supplies which have gone into these investigations from the following:

Ansonia Wire and Cable Company
Anaconda Wire and Cable Company
Brand-Rex Division - American Enka Corporation
Chase Brass and Copper Company
Cook Electric Company
E. I. DuPont de Nemours and Company
Essex International, Incorporated
General Cable Corporation
Independent Cable, Incorporated

Jerrold Electronics Corporation
Laconia Metal Products, Incorporated
Olin Brass
Phelps Dodge Communications Company
Plastic Wire and Cable Corporation
Superior Continental Corporation
Texas Instruments, Incorporated
The Dow Chemical Company
The Okonite Company
Utility Products Company
Whitney Blake Company

Acknowledgement is made also to the following organizations which provided test sites and assistance during the burial and removal of specimens:

Bonneville Power Administration
U. S. Department of Interior

Baltimore Bureau of Water Supply
Baltimore, Maryland

U. S. Coast Guard Electronics
Engineering Station
Wildwood, New Jersey

U. S. Coast Guard Receiving Center
Cape May, New Jersey

Patuxent Naval Air Station
Lexington Park, Maryland

Table 1. Performance Ratings[a] of Shields in Cable Specimens Exposed Underground

| System No. | System Description | Soil Site[b] | Shield: Exposed Window | Shield: Exposed Ring | Shield: Area Under Jacket[c] | Copper Cathode |
|---|---|---|---|---|---|---|
| 1 | 0.008" corrugated bare aluminum. | A | 10 | 10 | 10 | N/A |
| | | B | 9 | 9 | 9 | N/A |
| | | C | 5 | 5 | 8 | N/A |
| | | D | 10 | 10 | 9 | N/A |
| | | E | 10 | 10 | 9 | N/A |
| | | G | 0 | 0 | 3 | N/A |
| 2 | Same as No. 1 except that system is coupled to copper. | A | 2 | 1 | 6 | 10 |
| | | B | 6 | 6 | 9(8) | 10 |
| | | C | 0 | 0 | 0 | 10 |
| | | D | 5 | 5 | 6+ | 10 |
| | | E | 6 | 6 | 8 | 10 |
| | | G | 0 | 0 | 0 | 10 |
| 3 | 0.005" corrugated bare copper. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 10 | 5 | 10 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10 | N/A |
| 4 | 0.005" corrugated bare copper alloy. (97.5% copper, 2.5% iron, 0.02% phosphorus). | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 10 | 10 | 10 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10 | N/A |
| 5 | 50 pair-22 gauge cable with 0.008" corrugated aluminum with plastic film coating on the core side of the shield. An adhesive outer jacket is then applied. The aluminum edges are also protected at the shield overlap by an experimental process. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 8 | 5 | 8 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 9 | 10 | N/A |
| | | G | 2 | 0 | 5 | N/A |
| 6 | Same as No. 5 except that system is coupled to copper. | A | 2 | 0 | 1 | 10 |
| | | B | 10 | 8 | 8 | 10 |
| | | C | 0 | 0 | 0 | 10 |
| | | D | 10 | 5 | 5 | 10 |
| | | E | 3 | 1 | 10 | 10 |
| | | G | 0 | 0 | 4 | 10 |
| 7 | 50 pair-22 gauge cable with 0.011" corrugated metallurgically bonded aluminum-low carbon steel-aluminum (6-3-2 mils) (Experimental aluminum alloy). | A | 10 | 9 | 10 | N/A |
| | | B | 9 | 8 | 10 | N/A |
| | | C | 8 | 8 | 8 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 8 | N/A |
| | | G | 4 | 4 | 4 | N/A |
| 8 | Same as No. 7 except that system is coupled to copper. | A | 3 | 1 | 4 | 10 |
| | | B | 8 | 6 | 8 | 10 |
| | | C | 2 | 3 | 4 | 10 |
| | | D | 7 | 7 | 10 | 10 |
| | | E | 8 | 7 | 8 | 10 |
| | | G | 4 | 4 | 4 | 10 |
| 9 | 0.008" uncorrugated aluminum with plastic coating both sides. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | G | 5 | 5 | 10 | N/A |
| 10 | Same as No. 9 except that system is coupled to copper | A | 2 | 4 | 4 | 10 |
| | | B | 6 | 6 | 10 | 10 |
| | | G | 2 | 0 | 5 | 10 |
| 12 | 0.006" corrugated tin plated steel with plastic coating on outer side. Coupled to copper. | A | 4 | 5 | 10(5) | 10 |
| | | B | 2 | 2 | 6 | 10 |
| | | C | 2 | 0 | 5 | 10 |
| | | D | 5 | 5 | 10(7) | 10 |
| | | E | 5 | 6 | 8 | 10 |
| | | G | 2 | 1 | 8 | 10 |

See footnotes at end of table

Table 1. Continued

| System No. | System Description | Soil Site[b] | Shield: Exposed Window | Shield: Exposed Ring | Shield: Area Under Jacket[c] | Copper Cathode |
|---|---|---|---|---|---|---|
| 13 | 0.006" corrugated tin plated steel plus black flooding compound coating on outer side of shield. Seam soldered. | A | 10 | 8 | 10 | N/A |
| | | B | 6 | 5 | 10(8) | N/A |
| | | G | 2 | 1 | 5(8) | N/A |
| 14 | Same as No. 13 except that system is coupled to copper. | A | 2 | 0 | 10(8) | 10 |
| | | B | 2 | 6 | 10(8) | 10 |
| | | G | 2 | 0 | 5(8) | 10 |
| 15 | 0.006" corrugated tin plated steel with clear flooding compound on both sides. | A | 10 | 6+ | 10 | N/A |
| | | B | 5 | 6 | 10 | N/A |
| | | C | 4 | 5 | 8 | N/A |
| | | D | 5 | 10 | 10 | N/A |
| | | E | 8 | 6+ | 10 | N/A |
| | | G | 2 | 1 | 8 | N/A |
| 16 | Same as No. 15 except that system is coupled to copper. | A | 2 | 1 | 8 | 10 |
| | | B | 2 | 3 | 9(10) | 10 |
| | | C | 2 | 0 | 4 | 10 |
| | | D | 5 | 1 | 8(10) | 10 |
| | | E | 5 | 4 | 10 | 10 |
| | | G | 2 | 0 | 8 | 10 |
| 17 | 0.005" corrugated type 304 stainless steel. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 10 | 10 | 10 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10 | N/A |
| 18 | Same as No. 17 except that system is coupled to copper. | A | 10 | 10 | 10 | 10 |
| | | B | 10 | 10 | 10 | 10 |
| | | C | 10 | 10 | 10 | 2 |
| | | D | 10 | 10 | 10 | 10 |
| | | E | 10 | 10 | 10 | 10 |
| | | G | 10 | 10 | 10 | 10 |
| 19 | 0.006" corrugated tin plated steel. | A | 10 | 6+ | 10 | N/A |
| | | B | 5 | 6 | 10 | N/A |
| | | C | 2 | 0 | 8 | N/A |
| | | D | 6 | 6 | 8(7) | N/A |
| | | E | 5 | 7 | 8 | N/A |
| | | G | 0 | 0 | 3 | N/A |
| 20 | Same as No. 19 except that system is coupled to copper. | A | 2 | 0 | 5 | 10 |
| | | B | 2 | 0 | 8 | 10 |
| | | C | 0 | 0 | 0 | 10 |
| | | D | 2 | 1 | 8 | 10 |
| | | E | 4 | 1 | 8 | 10 |
| | | G | 0 | 0 | 0 | 10 |
| 21 | 0.005" corrugated type 430 stainless steel. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 10 | 10 | 10(8) | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 6+ | 6 | N/A |
| 22 | Same as No. 21 except that system is coupled to copper. | A | 10 | 10 | 10 | 10 |
| | | B | 10 | 10 | 10 | 10 |
| | | C | 10 | 6+ | 10(9) | 2 |
| | | D | 10 | 10 | 10 | 10 |
| | | E | 10 | 10 | 10 | 10 |
| | | G | 2 | 0 | 5 | 10 |
| 23 | 0.006" corrugated copper-430 stainless steel-copper (2-2-2). | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 7 | 6 | 10 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10 | N/A |

See footnotes at end of table.

Table 1. Continued

| System No. | System Description | Soil Site[b] | Shield: Exposed Window | Shield: Exposed Ring | Shield: Area Under Jacket[c] | Copper Cathode |
|---|---|---|---|---|---|---|
| 24 | 0.006" corrugated copper-low carbon steel-copper (2-2-2). | A | 10 | 7 | 10 | N/A |
| | | B | 5 | 7 | 10 | N/A |
| | | C | 4 | 4 | 5 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 9 | 10 | N/A |
| | | G | 7 | 5 | 5 | N/A |
| 25 | 50 pair-22 gauge corrugated bare tin plated steel (0.006") plus bare aluminum (0.008") with black flooding compound coating on outer side of steel. The 6-mil steel is on the outside and seam soldered. | A | 10 | 10 | 10 | N/A |
| | | B | 6+ | 6+ | 10(8) | N/A |
| | | C | 6 | 5 | 9(5) | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 5 | 3 | 7(5) | N/A |
| 26 | Same as No. 25 except that system is coupled to copper. | A | 5 | 6 | 6 | 10 |
| | | B | 6+ | 6 | 8 | 10 |
| | | C | 3 | 1[d] | 5 | 10 |
| | | D | 5 | 5 | 10 | 10 |
| | | E | 5 | 5 | 10(8) | 10 |
| | | G | 5 | 0[d] | 8(2) | 10 |
| 27 | Corrugated tin plated 0.006" shield with plastic coating on both sides, and a 0.008" aluminum shield coated on both sides. | A | 10 | 5 | 10 | N/A |
| | | B | 10 | 6 | 10 | N/A |
| | | C | 5 | 5 | 8(10) | N/A |
| | | D | 10 | 9 | 10 | N/A |
| | | E | 5 | 5 | 10 | N/A |
| | | G | 2[e] | 2 | 8(10) | N/A |
| 28 | Same as No. 27 except that system is coupled to copper. | A | 4 | 6 | 9(10) | 10 |
| | | B | 4 | 4 | 10 | 10 |
| | | C | 2[e] | 0 | 4(10) | 10 |
| | | D | 4 | 4 | 9(10) | 10 |
| | | E | 5 | 5 | 10 | 10 |
| | | G | 2[e] | 0[e] | 8(10) | 10 |
| 29 | Corrugated aluminum (0.008") type 211 stainless steel (0.003") plastic bonded laminate with clear flooding compound on aluminum side facing cable core. | A | 10 | 10 | 10(7) | N/A |
| | | B | 10 | 10 | 10(7) | N/A |
| | | C | 10 | 10 | 10(7) | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10(7) | N/A |
| 30 | Same as No. 29 except that system is coupled to copper. | A | 10 | 10 | 10(7) | 10 |
| | | B | 10 | 10 | 10(7) | 10 |
| | | C | 10 | 10 | 10(7) | 10 |
| | | D | 10 | 10 | 10 | 10 |
| | | E | 10 | 10 | 10 | 10 |
| | | G | 10 | 10 | 10(7) | 10 |
| 31 | 0.008" uncorrugated plastic coated aluminum, inner jacket of polyethylene, outer 0.008" type 304 corrugated stainless steel. | A | 10 | 10 | 10 | N/A |
| | | B | 10 | 10 | 10 | N/A |
| | | C | 6+ | 6 | 10 | N/A |
| | | D | 10 | 10 | 10 | N/A |
| | | E | 10 | 10 | 10 | N/A |
| | | G | 10 | 10 | 10 | N/A |
| 32 | Same as No. 31 except that system is coupled to copper. | A | 10 | 10 | 10 | 10 |
| | | B | 10 | 10 | 10 | 10 |
| | | C | 10 | 6 | 10 | 8 |
| | | D | 10 | 10 | 10 | 10 |
| | | E | 10 | 10 | 10 | 10 |
| | | G | 6 | 10 | 10 | 10 |

[a]See Table 2 for description of code indicated by numerical rating.

[b]See Table 4 for properties of the soils at the test sites.

[c]When one number is given, the rating pertains to both the outerside and core side of the shields. A number in parentheses pertains to the core side of the shield or to the inner shield, and the other number to the outerside of the shield.

[d]Inner aluminum shield completely dissipated at ring, ELD.

[e]Some dissipation of inner aluminum shield, not ELD.

Table 2. Rating Code for The Corrosion Evaluation of Shields in Cable Specimens

| Rating | Performance | Degree of Corrosion |
|---|---|---|
| 10 | Excellent | Unaffected - No indication of corrosion. |
| 9 | Excellent | Superficial rust or etching on surface |
| 8 | Very Good | Uniform metal attack, rust, and/or slight localized pitting. |
| 7 | Good | Appreciable pitting over the surface, but no perforations through metal shield. Some minor delamination or dissipation of metallurgically or plastic-bonded metals leaving cathodic metal intact. |
| 6+ | Good | Localized pitting: Only one perforation in shield by pitting. |
| 6 | Good | Localized pitting: 2 to 5 perforations in shield by pitting. |
| 5 | Fair | Many localized pits causing perforation of shield; <5% of shield dissipated by corrosion; Extensive delamination of metallurgically bonded metals. |
| 4 | Poor | Severe corrosion: Pitting to perforation of shield; 5 to 10% of shield dissipated by corrosion; severe corrosion of anodic part of metallurgically bonded metals. |
| 3 | Poor | Severe corrosion: Pitting to perforation of shield; 10 to 25% of shield dissipated by corrosion. |
| 2 | Very Poor | Severe corrosion: More than 25% of shield dissipated by corrosion; shield still has electrical continuity along the cable. |
| 1 | Very Poor | Severe corrosion: Shield is close to electrical discontinuity (ELD) due to perforation in shield and dissipation of metal by corrosion. |
| 0 | Very Poor | Severe corrosion: Shield is electrically discontinous (ELD) due to dissipation of metal by corrosion. |

Table 3. Dates of Exposures and Inspections of Specimens at the Test Sites

| Test Site | Date Buried | Date Removed | Exposure Time (Years) |
|---|---|---|---|
| A | 6/25/68 | 6/24/69 | 1.00 |
| B | 9/5/68 | 9/4/69 | 1.00 |
| C | 6/6/68 | 6/19/69 | 1.03 |
| D | 6/5/68 | 6/18/69 | 1.03 |
| E | 6/5/68 | 6/18/69 | 1.03 |
| G | 6/18/68 | 6/2/69 | 0.96 |

TABLE 4. Properties of Soils at Test Sites

| Site Ident. | Soil | Location | Internal drainage of test site | Resistivity[a] (ohm - cm) | pH | TDS[b] | Composition of water extract (parts per million) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Ca | Mg | Na + K as Na | $CO_3$ | $HCO_3$ | $So_4$ | Cl | $NO_3$ |
| A | Sagemoor sandy loam | Toppenish, Wash. | Good | 400 | 8.8 | 7,080 | 108 | 23 | 1,960 | 0.0 | 5,002 | 216 | 330 | 6 |
| B | Hagerstown loam | Loch Raven, Md. | Good | 5,200 | 5.8 | (c) | --- | --- | --- | --- | --- | --- | --- | --- |
| C | Clay | Cape May, N.J. | Poor | 300 | 4.0 | 14,640 | 540 | 754 | 2,242 | 0.0 | 0.0 | 6,768 | 3,529 | 118 |
| D | Lakewood sand | Wildwood, N.J. | Good | 30,000 | 7.3 | (c) | --- | --- | --- | --- | --- | --- | --- | --- |
| E | Coastal sand | Wildwood, N.J. | Poor | 55 | 7.1 | 11,020 | 302 | 329 | 3,230 | 0.0 | 55 | 1,133 | 5,765 | 31 |
| G | Tidal marsh | Patuxent, Md. | Poor | 300 | 7.1 | 11,580 | 140 | 165 | 2,392 | 0.0 | 0.0 | 1,709 | 3,259 | 37 |
| | | | | | | (Milligram equivalents per 100 grams of soil) | | | | | | | | |
| A | --- | --- | --- | --- | --- | --- | 0.54 | 0.19 | 8.50 | 0.0 | 8.20 | 0.45 | 0.93 | 0.01 |
| B | --- | --- | --- | --- | --- | (c) | --- | --- | --- | --- | --- | --- | --- | --- |
| C | --- | --- | --- | --- | --- | --- | 2.70 | 6.18 | 9.51 | 0.0 | 0.0 | 14.0 | 9.94 | 0.19 |
| D | --- | --- | --- | --- | --- | (c) | --- | --- | --- | --- | --- | --- | --- | --- |
| E | --- | --- | --- | --- | --- | --- | 1.51 | 2.70 | 13.9 | 0.0 | 0.09 | 2.36 | 16.2 | 0.05 |
| G | --- | --- | --- | --- | --- | --- | 0.70 | 1.35 | 10.2 | 0.0 | 0.0 | 3.56 | 9.18 | 0.06 |

(a) Resistivity determinations made at the test site with Shepard Canes.

(b) TDS, total dissolved solids--residue dried at 105°C.

(c) Analyses not made for soils at sites B and D because of the very low concentrations of soluble salts in these soils.

## PREPARATION OF SPECIMENS FOR CABLE EXPOSURE TESTS

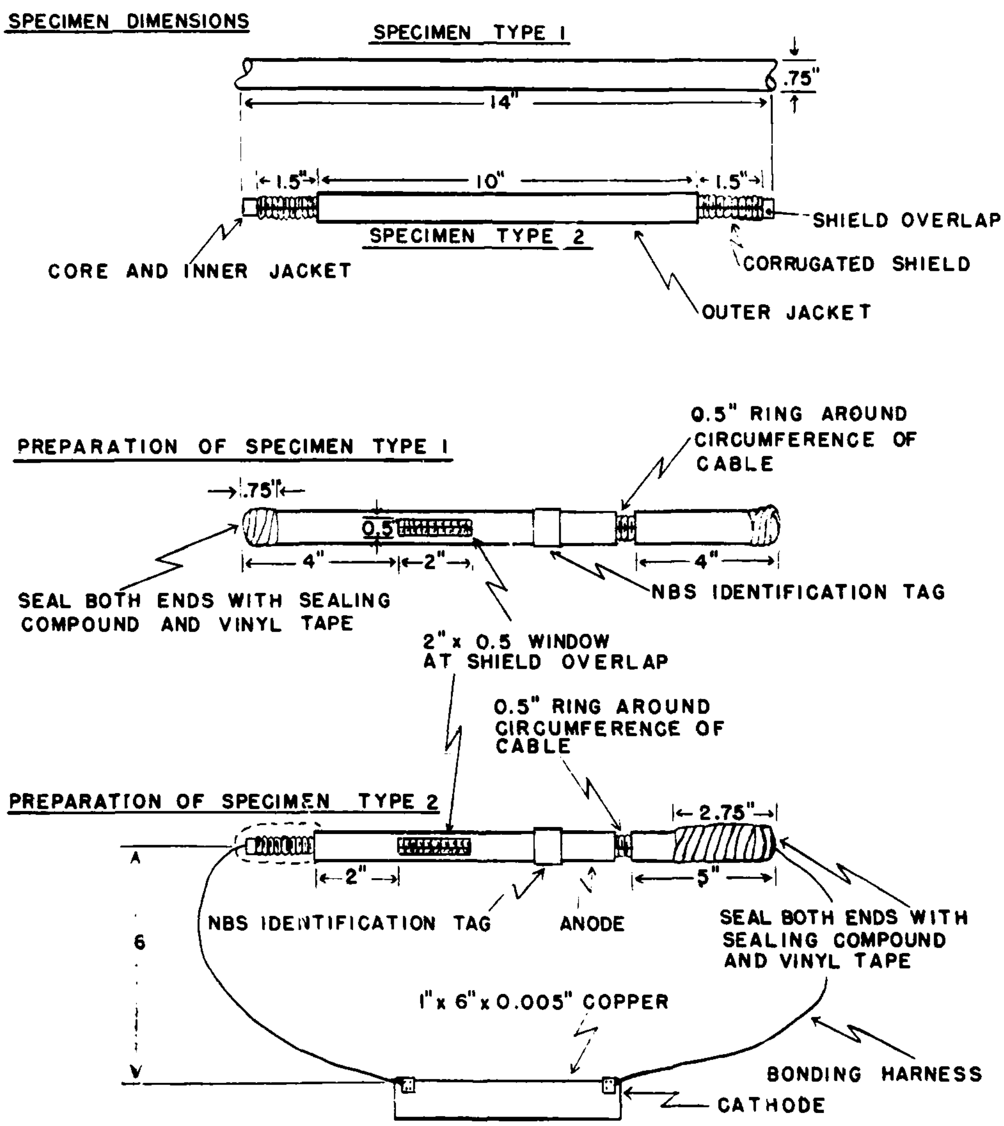



FIGURE 1