DESIGN, TESTING, AND APPLICATION OF MOISTURE IMPERVIOUS CABLE

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Abstract - Moisture barriers can effectively protect the insulation of medium voltage cables from water treeing. Activities to study and qualify the performance of moisture barrier cable have progressed on a global scale. Design concepts for three types of moisture barrier cable are presented. One design includes wire neutrals with a separate moisture barrier over the neutrals and under the jacket. In the second design, the moisture barrier acts as both a radial water block as well as a shield. Materials for the sheath, such as plastic coated metals, water-blocking tapes, cushion layers for thermal expansion, and adhesives for sealing are discussed. The third design utilizes a thin lead/plastic laminate placed directly over the insulation semi-conducting screen. This is called an "on-core design." Standardization activities for watertight cable are proceeding on an international scale. Application of watertight cables in several power systems indicate reduced fault rates and lack of failures associated with treeing.

INTRODUCTION

A research project sponsored by the Canadian Electrical Association (CEA) evaluated the performance of an XLPE insulated cable with a plastic coated aluminum foil as a moisture barrier.[1] The work showed that "Moisture barriers can be very effective in reducing the ingress of moisture into the cable to the extent that water treeing is not a problem."

A research project sponsored by the Electrical Power Research Institute (EPRI) examined both materials for moisture barriers and the preparation of cable models to test these materials.[2] In the final phase of the project, prototype cables were evaluated with coated copper or coated aluminum under-jacket moisture barriers. The tests run were: 1) 60 cable loading cycles of four hours up to 90°C, four hours at 90°C, and sixteen hours of cooling; 2) bending around a 14 inch (356mm) mandrel for three cycles; and 3) moisture penetration using weight loss. There was no failure in any of the tests. The conclusion was that "the moisture barrier metal foil/polyolefin laminates essentially protect the cable from moisture ingress without any adverse effect on the mechanical properties of the cable."

Activities such as these to study and quantify the performance of moisture barrier cable are progressing on a global basis. The data continue to indicate that the common sense approach to prevent water treeing is to keep moisture out of the cable. Along these lines the concept of moisture impervious cable is emerging. Moisture impervious cable can be defined as a cable that is designed to block both the longitudinal and radial ingress of moisture to the cable. The objective is to prevent moisture from reaching either the inner or outer surface of the insulation. Radial moisture transmission is blocked by a layer of metal between the outer surface of the insulation and the inner surface of the protective jacket. Longitudinal moisture transmission is blocked by strand filling of the conductor and by the use of swellable powders or tapes within the air spaces or interfaces between the insulation system, the metallic shield or neutral and the protective jacket.

There are other related terms that have also come into use in defining cables that include some form of protection against the effects of moisture. A moisture barrier cable can be defined as a cable with a metallic layer over the core to block radial ingress of moisture. A moisture resistant cable can be defined as a cable designed to accept moisture ingress, but incorporating design measures and/or materials to reduce susceptibility to moisture.

This paper will review the design concepts for under-jacket and on-core moisture impervious cable, discuss the material requirements for such cable, cover standardization activities for moisture impervious cable, including test development, and provide application data.

DESIGN CONCEPTS FOR MOISTURE BARRIER CABLE

Under-Jacket Moisture Barrier With Wire Neutral

Coated aluminum moisture barriers, bonded to the jacket, are recommended for use with wire neutrals. Table I describes the construction of a cable design utilizing coated aluminum. The aluminum is not acting as a shield, but should be grounded to the neutrals at their ground points to insure that there is no build-up of voltage on the moisture barrier. For this reason, a one-side coated tape is recommended. The uncoated side is in contact with the semi-conductive water-blocking tape and the neutrals. The moisture barrier should be at ground potential over its entire length.

By bonding the moisture barrier to the cable jacket, the coated aluminum or copper can be applied smooth rather than corrugated. A significant advantage of bonding the aluminum to the jacket is improved mechanical properties, such as bend and crush resistance. The bond between the jacket and the moisture

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barrier forms a longitudinal water block. The seal in the overlap blocks moisture in this interface. The moisture barrier forms a radial moisture block. The water swellable tapes form a longitudinal water block at the moisture barrier - core interface. If a strand filled conductor is used, then the cable can be described as moisture impervious. The strand filling or solid conductor forms a longitudinal conductor water block.

Use of semi-conductive water-swellable tapes, longitudinally folded, will usually reduce costs and increase line speeds versus the use of helically wrapped tapes. There are several choices for the waterblocking tape. Combinations of higher or lower swelling ratio tape can be used.

Charge transfer through the semi-conductive tape to the bare side of the moisture barrier will bring the barrier to the electrical potential of the neutral. This eliminates grounding concerns over the cable length. Corrosion should not be a problem in case of sheath puncture or exposed ends. Water flow is limited by the swelling of the water blocking tape.

Under-Jacket Using Combination Moisture Barrier And Shield

A cable construction using coated copper as both a radial moisture barrier and shield is described in Table II. This type of cable may be used in industrial applications and as substation feeder cable by power companies. The coated copper can function as both the shield or neutral as well as the moisture barrier. The use of a longitudinally folded coated copper 0.15 mm (0.006 in) is recommended to replace spirally wrapped shields of copper tapes. Economics are improved with the combination shield/moisture barrier as compared to constructions with separate components.

The copper tape can be applied smooth or corrugated. However, the use of corrugated copper shields for power cable is increasing due to a number of factors. First, the longitudinally applied corrugated shield has many electrical and mechanical advantages over helically applied copper tape shields or copper wire shields. Second, the forming equipment and operation for applying corrugated shields has advanced significantly in recent years, allowing the use of longitudinally folded shields on large diameter power cables. Generally use of smooth tape on the larger cables is a difficult manufacturing operation. Third, the experience history of cables with longitudinally corrugated and folded shields is approaching 20 years. This experience has been excellent which is now leading to increased utilization of this type of shield.

On-Core Moisture Barrier

In this construction, a laminate of lead coated on both sides with a semi-conducting adhesive copolymer is utilized. The lead is quite thin, usually 2 mils, and the laminate is designed to expand and contract with the cable core. The moisture barrier laminate is placed directly over the semi-conducting screen and under the concentric neutral or shield. A semi-conducting bedding tape is normally used to protect the moisture barrier from the cutting effect of the neutral wires. Any jacket material may be utilized.

The principle advantage of the "On-Core" type of moisture barrier is that it directly protects the outer surface of the insulation screen and thus guards against longitudinal water migration around the neutral wires as well as radial permeation through the jacket. Thus, a water blocking tape at the neutral jacket interface is not a necessity. However, a semi-conducting bedding tape over the moisture barrier is required to prevent damage to the moisture barrier by the neutral wires when the insulation is expanded by load cycling. The moisture barrier must also be able to expand and contract with the insulation under such conditions.

The material considerations and testing of on-core moisture barrier cable has been extensively covered elsewhere.[3, 4, 5]

Material considerations for under-jacket cable will be covered in the following section. Standardization activities and applications include both types of constructions.

MATERIALS FOR MOISTURE IMPERVIOUS SHEATHS

Plastic Coated Metallic Tapes

For many years, a plastic coated aluminum product has been in widespread use as a moisture barrier in telecommunication cables and low voltage power, control and instrument cables.[6, 7] The aluminum is coated with a copolymer of polyethylene which forms a highly moisture resistant bond to the aluminum.[8]

The copolymer is adhesively compatible with low, linear low, medium and high density polyethylene jacketing materials as well as chlorinated polyethylene (CPE) and the zero-halogen jacketing materials. These latter two materials are used when ignition suppression is required. As noted in the previous section, coated aluminum is the laminate of choice in combination with neutral wires or wire shields. The use of coated aluminum tapes minimizes the added cost for moisture barrier protection.

Plastic coated copper is the material of choice when the moisture barrier serves a dual role of both shield and moisture barrier. Coated copper offers several benefits as a moisture barrier. First it forms terminations having excellent electrical stability. Second, it offers corrosion resistance. Third, because of its conductivity, it allows the moisture barrier to be used as the neutral in many instances. The modified copolymer used on the copper forms a long term moisture resistant bond.[9] This copolymer is also compatible with the wide variety of polyethylene jackets in use by the industry as well as chlorinated polyethylene and the zero-halogen materials.

A new family of coated aluminum, steel, or copper products has been developed which are adhesively compatible with PVC.[10]

Cushion Layer

A cushion layer is used between the core and moisture barrier sheath to absorb the thermal expansion of the core during load cycling. One type of material is a non-woven textile tape which incorporates a swellable powder to achieve water blocking.[11] A swellable powder is applied to a non-woven substrate and a very thin, porous, non-woven cover is laminated on top. Upon contact with water, the powder absorbs up to 500 times its weight and swells. The swelling produces a jelly that exudes through the porous cover. This jelly forms a dam in the cable interstices that eliminates the longitudinal water flow under the moisture barrier. The intrinsic porosity of the non-woven textile allows immediate wetting of the powder and allows migration of the jellied powder to fill all interstices of the cable. If heat generated within the cable drives the water out, the jelly returns to powder form. It is reactivated when contacted again with water.

The non-woven aspect of the tape also allows it to act as a cushion layer to protect the moisture barrier sheath from expansion and contraction of the insulation that occurs during electrical loading of the cable. These tapes are rated 90°C for continuous use and can withstand 150°C during short term emergency use. They can also withstand the 230°C or so exposure that can occur during cable manufacture. Non-woven tapes can be impregnated with carbon black to provide good semi-conducting properties.

More recently, another type of cushion layer has been developed based on a semi-conductive cross-linked polyethylene foam.

Adhesives For Sealing

A hot melt adhesive is inserted into the overlap of the metallic moisture barrier to aid in the sealing of the overlap. The use of hot melt adhesives provides a reliable method of sealing the overlap during continuous cable production. The desirable characteristics of hot melts for use in moisture barrier cable include (1) adhesive compatibility with the coated metal laminate used as the moisture barrier; (2) compatibility with any lubricating oils used to facilitate forming of the laminate; (3) moisture resistant bonds; (4) bond stability; and (5) low viscosity to allow uniform spreading within the overlap. Adhesion and cable performance studies have indicated that a hot melt based on a blend of polyamide and ethylene vinyl acetate are suitable for application in power cable [12].

Strand Filling Material

A recent technological advance in materials for power cable has been the development of filling materials for the conductors. These materials are applied by an extrusion process or pumped into place during the stranding operation. The fillers block the longitudinal migration of moisture in the conductors. They prevent accumulation of moisture in the strand during cable manufacture, storage, installation and use. These materials have no adverse effect on splicing and termination procedures.[13]

Jackets

As noted in the section describing the coated metal laminates, it is most important that jackets for use on moisture barrier cable have adhesive compatibility with the coatings on the laminate. Another key requirement is the degree of ignition suppressance required for the cable. Polyethylene jackets in a variety of densities and types are chosen when flame resistance is not a consideration. Chlorinated polyethylene is selected when flame resistance and chemical resistance are required. Zero-halogen jackets are selected when there is a need to minimize the emission of smoke and corrosive fumes. Polyvinyl chloride jackets are chosen for general purpose applications where ignition suppression and lower cost are the main considerations.

STANDARDIZATION ACTIVITIES WITH MOISTURE IMPERVIOUS CABLE

Background

There are several industry groups working on standardization of moisture impervious cable. These activities are taking place during the introductory and developmental stages of moisture impervious cable, before widespread commercialization. The standards-making process is helping to shape the moisture impervious cable technology, rather than just reacting to the developing technology. The process is dynamic, coming from the top-down.

IEC Activities

IEC 840, "Tests for Power Cables with Extruded Insulation for Rated Voltages above 30 kV up to 150 kV" was published in 1988. At that time, the "Water Penetration Test" (Paragraph 5.6.16) was under consideration. An International Electrotechnical Commission (IEC) working group is defining this test. A draft document 20A(CO)99, under the six months rule, was published as a secretariat document under 20A(Secretariat)164. This document describes a water penetration test for those cables where barriers to longitudinal penetration have been included. The test is applicable to barriers applied over the core and within the conductor. The water penetration test is applied after a length of cable has been subjected to the bending test. A 50 mm wide ring is removed from the center of the length including layers external to the insulation screen or, alternatively, the conductor. A tube at least 10 mm in diameter is placed vertically over the exposed ring and sealed to the surface of the oversheath. Normally tap water is used to fill the tube. A period of five minutes is allowed for filling. The height of the water in the tube is 1000 mm above the center of the cable. The water is allowed to stand for 24 hours. The sample is then subjected to 10 heating cycles. The conductor is heated until it reaches a temperature not less than 5° C or more than 15° C above the maximum rated temperature of the insulation in normal operation. The heating cycle is 8 hours on and 16 hours off.

A working group of CIGRE Study Committee 21 is preparing recommendations on tests for high voltage cables with synthetic insulation and laminated protective coverings as moisture barriers. These tests will supplement those of IEC 840, First Edition, 1988. The recommendations are to be published in the *Electra* journal in 1991 after amendments are made.

IEEE/ICC Task Group 6-23 Activities

Task Group 6-23 of the Insulated Conductors Committee (ICC) of the IEEE has undertaken, and is nearing completion, the preparation of an IEEE standard entitled "Guide on the Design, Testing and Application of Moisture Impervious, Solid Dielectric, 5 - 35 kV, Power Cable Using Metal/Plastic Laminates". The IEEE Standards Board has established Project No. P-1142 as the official identification for this endeavor. The task group is composed of representatives from utilities, industries, cable manufacturers, distributors and material suppliers. This task group was originally established to develop a guide on the use of metal/plastic laminates as moisture barriers in all types of cable. The scope was subsequently narrowed to encompass only medium voltage power cables.

As presently constituted, the guide includes sections on moisture barrier cable designs, metal/plastic laminates used for moisture barriers, cable performance and testing criteria and installation guidelines. Also included is a complete bibliography of technical papers, patents and specifications applicable to cables designed to preclude the effects of moisture.

Presently, the task group has under consideration such matters as testing for the effects of moisture on insulation materials both by direct and indirect means. Direct means involve techniques for measuring the moisture content of the insulation. Indirect means involve electrical tests, such as dielectric strength and impulse, in order to determine if there has been a deterioration in insulation performance. Likewise, further consideration is being given to means for measuring the integrity of the moisture barrier. Another task is to resolve differences between proposed test methods for determining the overall performance of the cable in blocking the longitudinal movement of moisture. Draft No. 6 of this guide will soon be balloted by the voting members of the ICC.

ICEA Activities on Strand Filling

A more recent technological advance in the development of water impervious power cables has been the use of strand filling materials to block the longitudinal flow of moisture in the conductors. Working Group 610 of the Insulated Cable Engineers Association (ICEA) was established in June 1985 with three priorities for developing tests for cable with filled conductors. The first was to prepare a guide on testing for resistance to water penetration. The second was to develop tests for compatibility of the filler compound with adjacent cable materials (conductor screen). The third was to consider requirements for connectability testing of sealed conductors.

The "Guide for Conducting a Longitudinal Water Penetration Resistance Test for Sealed Conductors" was published in September 1989.[14] The test procedure for qualification calls for two cable samples, 2 m long (7.5ft). One is heated to 90C for one hour and the other is cooled to 0C for an hour. After conditioning, the samples are bent around a mandrel for three reverse bends. A 1 m (3ft.) sample is attached to a pressurized water system and subjected to 35 kPa (5 psi) for one hour. For a production test one sample is subjected to pressure for 15 minutes without conditioning, but after being subjected to three reverse bends. Thus, the guide consists of both a qualification test and a production test.

The second priority of the ICEA working group was to develop a guide for establishing the compatibility of the filler compound used to seal the conductor.[15] The criteria for compatibility is the effect the filler has on the volume resistivity stability of the semiconducting compound used as the conductor screen. The working group has reviewed six test procedures and two have been completely tested and evaluated. A third procedure is presently under test. Variation in testing methodologies are being defined.

The work on the third priority, connectability, has been discontinued. The ICEA charter does not permit it to deal with accessories. However, extensive work by several organizations has indicated that connectability of strand filled conductors will not be changed versus unsealed conductors. Connectability is considered feasible with standard commercial connectors.[16,17]

De-Facto Standards - French Specifications

Watertight, medium voltage, synthetic insulated cable has been in use by Electricite de France (EdF) since 1978. Longitudinal water tightness is provided by a hygroscopic powder laid inside longitudinal grooves of the semiconducting insulation screen. Radial water tightness is obtained via an aluminum screen which is adhesively bonded to a polyvinyl chloride (PVC) oversheath. The cable meets EdF Standard HN 33-S-23. A complete body of standards has been developed to cover accessories (HN 33-M-03), 24 kV plug-in terminations (HN 52-S-61) single core terminations (HN 68-S-06), joints (HN 68-S-07 and HN 68-S-08), and connectors (HN 68-S-04). The connectors developed for the aluminum screen do not require stripping of the sheath. Thus, a complete technology package has been developed for the watertight cable design.

Specific tests for water tightness are included in the HN 33-S-23 specification. The longitudinal water tightness test is carried out after three bending cycles. A 10 mm wide ring is cut out of the oversheath in the middle of a 3 m long sample. The area around the ring is enclosed in a small tank that is sealed to the oversheath. The tank is filled with water and a water head of 800 mm is maintained over the sealed area. The sample is subjected to a 24 hour period at ambient temperature without current. Then 10 thermal cycles are applied bringing the conductor to 100° C for 4 hours, followed by a 4 hour cooling period. No water leakage is permitted from the sample ends.

For radial water tightness an immersion withstand test is used. A sample at least 10 m long is immersed in water with the ends exposed. A voltage at twice the operating voltage of the cable is applied. A current is applied to bring the temperature of the conductor to 100° C in parts of the cable not immersed in water. Thermal cycling of 8 hours on and 16 hours off for 200 thermal cycles or 5,000 hours is required without electrical breakdown of the insulation.

The cable standard also contains tests for checking the compatibility of the cable components and a metallic shield corrosion test is under consideration.

APPLICATIONS OF MOISTURE IMPERVIOUS CABLE

The need for a compact and low cost single conductor medium voltage cable for underground distribution led to a moisture barrier construction in Sweden. The cable consists of an aluminum conductor, a triple extruded XLPE insulation system, a semi-conductive paper tape to provide a thermal expansion layer, a longitudinally formed copolymer coated aluminum that acts as both moisture barrier and shield, and a jacket of cross-linked polyethylene. The aluminum is 0.30 mm (0.012 in) thick. The coating on the aluminum is bonded to the cable jacket. It has been reported that more than 3000 km of this cable has been in use since 1974 with no failures attributed to water treeing [18].

A medium voltage cable with synthetic insulation and an aluminum moisture barrier was developed by EdF and introduced into their power system in 1978.[19] The cable meets EdF standard HN 33-S-23. It has an oversheath of relatively thick 2mm (0.12 in) polyvinyl chloride jacket (PVC) to facilitate direct burial. Radial water tightness is achieved via an aluminum screen which is bonded to the PVC oversheath. The sealing of the overlap is facilitated with a hot melt adhesive. Longitudinal water tightness is provided by hydroscopic powder. Thermal expansion is handled by grooves in the strippable extruded semiconducting screen. The field experience with this cable has been excellent. At the end of 1986 a total of 31,000 km of HN 33-S-23 cable had been installed. As shown in Table III the mean national fault rate for all causes and all cables types combined has steadily decreased as more and more moisture barrier cable has been installed. The technology is fully developed and includes connectors for the moisture barrier (which do not require the jacket to be stripped), accessories, terminations, joints and installation practices.[20]

The use of aluminum as a radial moisture barrier on high voltage able is increasing. Recently a cable of this type was installed in Bavaria.[21] The construction has been altered due to the fact that water ingress can impair the dielectric strength of the cross-linked polyethylene insulation. The screen still consists of copper wires. A material capable of swelling is included in the zone of the screen to limit the axial penetration of water. The sheath is a laminated construction. A relatively thin aluminum tape is used as a barrier to the radial diffusion of water. The aluminum tape is adhered to a polyethylene jacket. Polyethylene was chosen because of its better mechanical properties over PVC.

Over 4000 km (2500 miles) of on-core moisture barrier cable has been installed in the United State by a large, east coast utility. Much of this cable is 1000 kcmil aluminum, 35 kV with XLPE insulation. Recently, a test program was initiated to check the condition and performance of this cable. Cable manufactured near the start of the program was obtained and its AC breakdown and lighting impulse breakdown strength was compared to field aged samples and newly manufactured cable samples. The data indicate that there was no significant deterioration of the cable electrical properties after seven years of service. A thorough microscopic wafer examination of the field samples showed no electrochemical treeing.[22]

CONCLUSIONS

The common sense approach to treeing is to keep moisture away from the cable dielectric. Moisture impervious cable is designed to do this. The use of such cable makes good economic sense as well. Cables are capital goods and their value as an investment must be optimized. The use of moisture impervious designs is justified when the life cycle costs associated with installation, outages, repairs, and premature replacement of cable are considered.

The concept of moisture impervious cable is emerging. Moisture impervious cable is defined as cable designed to block both the longitudinal and radial ingress of moisture into the cable. A plastic coated metallic tape provides the radial moisture barrier. In the case of under-jacket designs, the longitudinal transmission of moisture is blocked by 1) bonding the tape to the jacket and sealing the overlap, 2) using water swellable tape or powders in the interface between the moisture barrier and core, and 3) strand filling the conductor.

A variety of materials have become available to facilitate development and commercialization of under-jacket moisture barrier sheaths for medium voltage power cables. Water-swellable, non-woven tapes are functional as cushion (thermal expansion) layers and longitudinal water blocks. Plastic coated aluminum and copper tapes meet the needs for a radial metallic moisture barrier having excellent adhesion to polyethylene, chlorinated polyethylene or polyvinyl chloride jackets and excellent bond stability during thermal loading, temperature cycling, water aging, and exposure to elevated temperatures. Hot melt adhesives have been developed which are effective in sealing the overlap of the metallic moisture barrier and which meet all needs for adhesion and bond stability.

Two designs for under-jacket moisture impervious cable are in use or under development. One under-jacket design retains the wire neutrals while the other design uses the moisture barrier as both a radial water block and shield. Plastic coated aluminum is recommended when wire neutrals are required. The coated aluminum can be applied smooth and is longitudinally folded over the neutrals.

It is then bonded to the cable jacket and sealed at the overlap to form the moisture barrier. A plastic coated copper is recommended for the combination moisture barrier and shield. The copper can be applied smooth or corrugated. The use of corrugated shields is on the increase especially for larger diameter cable.

Standardization activities for moisture impervious cable are in progress globally. The International Electrotechnical Commission is defining water blocking tests. CIGRE is preparing recommendations for high voltage cables with laminated coverings. The Insulated Conductors Committee of the IEEE is preparing a guide on medium voltage cable using metal/plastic laminates as moisture barriers. The Insulated Conductors Engineers Association (ICEA) has issued a guide for testing water penetration for sealed conductors and is currently developing a guide for compatibility of the sealing compound with adjacent cable materials. A full complement of standards and tests have been developed by Electricite De France for use in their system. Those standardization activities are taking place during development of the technology for moisture impervious cable. The users are able to participate in the development of this technology and use the guides and standards to prepare their own specifications. The most widespread use of medium voltage watertight cable has been by Electricite De France with over 31,000 km (21,000 miles) of three phase network installed between 1976 and 1986. Experience has been excellent. The mean national fault rate has steadily decreased as more and more watertight cable is placed in service.

TABLE I

DESIGN CONCEPT FOR MEDIUM OR HIGH VOLTAGE, MOISTURE BARRIER, UNDERGROUND POWER CABLE WITH WIRE NEUTRALS

COMPONENT	DESIGN CONCEPT
Conductor:	Solid or Strand Sealed
Insulation:	XLPE, Triple Extruded
Waterblock/Cushion Layer:	Non-woven Semi-conductive Water Swellable Tape
Neutrals	Wire Neutral Sized to Specific Needs of the User
Waterblock/Cushion Layer:	Non-woven, Semi-conductive Water Swellable Tape
Moisture Barrier:	7.5 Mil (0.19 mm) One-Side Coated Aluminum (Smooth, Longitudinally Folded)
Seam Seal	Hot Melt Adhesive
Jacket:	Low Density Polyethylene or Linear Low Density Poly-ethylene Bonded to the Moisture Barrier

TABLE II

DESIGN CONCEPT FOR MEDIUM VOLTAGE MOISTURE BARRIER INDUSTRIAL OR UTILITY, POWER DISTRIBUTION CABLE

COMPONENT	DESIGN CONCEPT
Conductor:	Solid Sealed or Strand Sealed
Insulation:	XLPE, Triple Extruded
Waterblock/Cushion Layer:	Non-woven Semi-conductive Water Swellable Tape
Shield/Moisture Barrier:	Smooth or Corrugated 6 Mil (0.15 mm) One-Sided Coated Copper Longitudinally Folded
Seam Seal:	Hot Melt Adhesive
Jacket:	Chlorinated Polyethylene bonded to the moisture barrier (Industrial) or polyethylene, if Ignition Suppressance is not a consideration (utility). PVC compatible tapes are also available for use with PVC jackets.

TABLE III

USE OF WATERTIGHT CABLE BY ELECTRICITE DE FRANCE

YEAR	INSTALLED, KM[1]	CUMULATIVE, KM[2]	FAILURE RATE
1977	175	175	-
1978	1600	1275	-
1979	3200	4475	7.30
1980	4400	8875	6.75
1981	3900	12775	5.95
1982	3900	16675	5.00
1983	3700	20375	3.75
1984	3500	23875	3.30
1985	4600	28475	3.25
1986	5300	33775	-

1) Lengths of cable installed annually (Km of three phase network).

2) Failure rate per 100 Km of circuit/year (all causes and cable types combined).

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