



# IEEE Guide for Accelerated Aging Tests for 5 kV to 46 kV Extruded Electric Power Cables Using Water-Filled Tanks

**STANDARDS**

IEEE Power and Energy Society

Developed by the  
Insulated Conductors Committee

**IEEE Std 1407™-2021**  
(Revision of IEEE Std 1407-2007)



# **IEEE Guide for Accelerated Aging Tests for 5 kV to 46 kV Extruded Electric Power Cables Using Water-Filled Tanks**

Developed by the

**Insulated Conductors Committee**  
of the  
**IEEE Power and Energy Society**

Approved 9 November 2021

**IEEE SA Standards Board**

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**Abstract:** Provided in this guide are information and recommendations on the equipment, cable specimens, test conditions, test control methodologies, measurements, data analysis, and interpretation in performing accelerated aging tests for 5 kV to 46 kV rated cables using water-filled tanks. The accelerated aging tests may be time-to-failure tests and/or tests in which the samples are aged for fixed times followed by diagnostic testing.

**Keywords:** accelerated aging test, accelerated cable life test, ACLT, cross-linked polyethylene, EPR, ethylene propylene rubber, IEEE 1407, measurement and profile, medium-voltage cable, tank structure, temperature, test conditions, water-filled tanks, XLPE

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## Introduction

This introduction is not part of IEEE Std 1407-2021, IEEE Guide for Accelerated Aging Tests for 5 kV to 46 kV Extruded Electric Power Cables Using Water-Filled Tanks.

This guide provides information and recommendations on the equipment, cable specimens, test conditions, test control methodologies, measurements, data analysis, and interpretation in performing accelerated aging tests for 5 kV to 46 kV rated electric power cables using water-filled tanks. The accelerated aging tests may be time-to-failure tests and/or tests in which the samples are aged for fixed times followed by diagnostic testing.

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# IEEE Guide for Accelerated Aging Tests for ~~Medium-Voltage~~ (5 kV to 46–35 kV) Extruded Electric Power Cables Using Water-Filled Tanks

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# 1. Overview

The insulations commonly used in extruded medium voltage power cables are cross linked polyethylene (XLPE), tree retardant XLPE (TRXLPE), and ethylene propylene rubber (EPR). These materials are known to gradually deteriorate with time due to the synergistic action of moisture and electrical stress. This degradation, often referred to as water treeing, causes a reduction in the breakdown voltage and an increase in the dielectric loss. The degradation can be so severe that failures can occur in service at operating stresses. The mechanisms of moisture-induced degradation have been studied extensively and it is known that several mechanisms are occurring. Several accelerated aging tests have been developed to evaluate the long term performance of cables (Banks, Faremo, Steennis [B4],<sup>1</sup> Bartnikas, Densley, Eichhorn [B5], Bartnikas et al. [B6], Mashikian et al., [B20], Schroth, Kalkner, Fredrich [B25], Steennis and Faremo [B27]). The tests may be either fixed time, where the cables are aged for a fixed time and then subjected to one or more diagnostic tests to assess the cable condition, or a time to failure test. A problem inherent in all accelerated aging tests is the choice of test parameters in the test itself. These should contain the deterioration factors causing service aging and not introduce aging mechanisms that do not occur in service. The diagnostic test must measure a property representative of service aging. Research has shown that the most important parameters in tests to evaluate moisture induced degradation are electrical stress, temperature, water characteristics, and time.

Two accelerated aging tests have evolved in North America. One, a qualification test, is the accelerated water treeing test (AWTT) in which lengths of cables are aged in water filled pipes for 4, 6, and 12 months and then subjected to a step ac breakdown (ACBD) test, the diagnostic test (ANSI/ICEA S-94-649 and ANSI/ICEA S-97-682<sup>2</sup>). The other is a test where cables are aged in water filled tanks, either for a fixed time or to failure, i.e., an accelerated cable life test (ACLT) (Lyle [B18], Walton, Smith, Thue [B32]). The time to failure test has the advantage of involving the whole aging process, initiation, growth, and final failure. The main disadvantage is that the test duration is unknown and there can be considerable time

<sup>1</sup>The numbers in brackets correspond to those of the bibliography in Annex E.

<sup>2</sup>Information on references can be found in Clause 2.

between the first and the last failure. Several laboratories have performed and are now performing accelerated aging tests in tanks (both time to failure tests in which the samples are aged to failure and aging tests in which the samples are aged for fixed time periods followed by a diagnostic test such as a step ACBD test) using different aging conditions of voltage, temperature, water characteristics, etc. This makes a direct comparison of the data between laboratories very difficult. The situation is further complicated because the methods of measuring some of the critical parameters differ significantly. As a result, apparently similar test conditions can, in fact, be entirely different in two separate test arrangements. An example of this ambiguity is the temperature measurement. Although a nominal temperature of 90 °C is sometimes used as the maximum temperature during temperature cycling, the precise location where this temperature is measured may vary. It may be measured in the length of the cable outside the water or in the length of cable immersed in the water. If the water temperature is not controlled, however, the temperature of the immersed cable will depend upon the following:

- Tank size
- Tank shape and material
- Volume of water
- Number of cables in the tank
- Whether the tank is thermally insulated, etc.

This guide directly addresses tank type accelerated aging tests. Accelerated aging test parameters are presented that, if reported, will allow test data obtained by different laboratories at different times to be better compared.

This guide will:

- Identify the critical test parameters and techniques for their measurement and control.
- Review the levels of the test parameters, such as voltage (V), temperature (T), etc. It is not the intention of this guide to recommend specific test values.

—— Identify the test parameters to be included in reports, etc.

—— The following will be discussed:

—— Test specimens

—— Prior tests and preconditioning of specimens

—— Test structure

—— Temperature

—— Water

—— Voltage

—— Failures

—— Abnormalities

—— Diagnostics

—— Data analysis

—— Final report

It must be pointed out that some parameters are interrelated so that a change in one will have an effect on others (i.e., as already mentioned, the size of the tank could influence the temperature of the cable immersed in a tank without water temperature control).

## 1.1 Scope

This guide provides information and recommendations on the equipment, cable specimens, test conditions, test control methodologies, ~~and~~ measurements, data analysis and interpretation in performing-to-perform accelerated aging tests for 5 kV to 46 kV rated electric power ~~on medium-voltage~~ cables using water-filled tanks. The accelerated aging tests may ~~whether the test~~ be a time-to-failure tests and/ test-or tests ~~a test~~ in which the samples are aged for fixed times followed by a diagnostic testing ~~test such as a step ACBD test. The guide identifies the critical test parameters and describes techniques for their measurement and control. The implementation of the techniques will facilitate a comparison of data obtained by different laboratories.~~

## 1.2 Purpose

The purpose of this guide is to provide users of accelerated aging tests and the resultant data with detailed insight into important test parameters and their influence, enumerate reporting requirements, and recommend data analysis techniques to facilitate comparison of data within and between laboratories.

## 1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).<sup>1,2</sup>

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

<sup>1</sup>The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

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The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

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AEIC CS8-~~07~~, Specification for Extruded Dielectric Shielded Power Cables Rated 5 through 46 kV.<sup>3</sup>

ANSI/ICEA S-94-649, Standard for Concentric Neutral Cables Rated 5 through 46 kV.<sup>4,5</sup>

ANSI/ICEA S-97-682, Standard for Utility Shielded Power Cables Rated 5 through 46 kV.

ANSI/ICEA T-24-380, ~~Standard~~Guide for Partial-Discharge Test Procedure.<sup>6</sup>

## 3. Definitions, acronyms, and abbreviations

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<sup>6</sup>~~See Footnote 5.~~

### 3.1 Definitions

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**abnormality:** Any deviation from the ~~pre-established~~~~preestablished~~ test conditions, including the tolerance limits, that may affect the outcome of the test.

**air failure:** A failure in the cable above the waterline but below the termination.

**termination failure:** A failure in the portion of the cable that does not have a metallic shield covering.

**water failure:** A failure in the active, shielded cable length that is below the waterline and that did not occur as a result of mechanical damage.

**waterline failure:** A failure at the interface between air and the tank water to include the distance of the total waterline variation.

### 3.2 ~~Acronyms~~~~Abbreviations~~ and ~~abbreviations~~~~acronyms~~

ACBD              ac breakdown

ACLT              accelerated cable life test

RBS              retained breakdown strength

TTF              time-to-failure

~~AWTT              accelerated water treeing test~~

DSC              differential scanning calorimetry

<sup>5</sup>IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

|                |                                                              |
|----------------|--------------------------------------------------------------|
| EPR            | ethylene propylene rubber                                    |
| GMTF           | geometric mean time to failure                               |
| mle            | maximum likelihood estimators                                |
| PD             | partial discharge                                            |
| PL             | polymer or polymer-lined                                     |
| R              | conductor resistance                                         |
| SS             | stainless steel                                              |
| $\tan \delta$  | loss tangent (dissipation factor) of insulation              |
| <del>T/C</del> | <del>thermocouple</del>                                      |
| THD            | total harmonic distortion                                    |
| TRXLPE         | tree retardant cross-linked polyethylene                     |
| $V_{o\theta}$  | line to ground voltage                                       |
| VLf            | very low frequency                                           |
| $\omega$       | $2\pi f$ where $f$ is the frequency in Hz of applied voltage |
| XLPE           | cross-linked polyethylene                                    |
| <u>IT</u>      | <u>insulation thickness</u>                                  |
| <u>HS</u>      | <u>side spacing</u>                                          |
| <u>SCT</u>     | <u>surface covering thickness</u>                            |
| <u>TS</u>      | <u>end spacing</u>                                           |

VS bottom spacing

SS1 specimen spacing 1

SS2 specimen spacing 2

## 4. Cable materials and design considerations

An accelerated aging test in a water-filled tank, whether a time-to-failure test or a fixed aging time test (followed by diagnostic testing such as a step ACBD test), imposes a complex combination of electrical, thermal, and mechanical stresses on a cable during the aging test program. Since these stresses are applied to a manufactured cable that, at a minimum, must be a cable core composed of an unfilled conductor (conductor without strand-filling material that blocks ~~to block~~ the ingress of moisture or water), conductor shield, insulation, insulation shield (and metallic shield), the test inherently evaluates these individual materials and their combinations ~~as well as the overall cable structure~~. The synergistic effects between the various materials are important. Insulation/shield interface characteristics, differences in materials' ~~variable~~ thermal expansion characteristics, volatile materials' diffusion rates, ionic contamination, manufacturing process differences, and many other factors provide ~~for~~ a complex, dynamic test sample system ~~system~~ that is more than a simple sum of the individual parts.

The initial intent of the test is resistance to moisture for the insulation system [B24]. It should be kept in mind that thermal aging and other considerations could also limit the life of a cable. When extending to testing a complete cable, splices, terminations, factory repairs and field repairs would also factor into the design of the system to keep moisture out and should be tested. Thermal aging, thermal cycling, cold temperature, cold flow, wear from movement, corrosion, installation, chemicals in ground water, spills, etc. could all effect the ultimate performance of the system and should be considered, especially when the jacket, adhesives, and other materials may have much lower lifetimes in regard to keeping moisture out of a cable core. It should also be considered that moisture can penetrate into the core osmotically and the system may be limited by the weakest link.

An accelerated aging test in a water-filled tank, whether a time-to-failure test or a fixed aging time test followed by diagnostic testing, can also be used to evaluate more than just the cable core. Since utilities now commonly employ moisture-blocked conductors, overall jacket ~~jackets~~, and a variety of different radial and longitudinal moisture barriers, it is sometimes useful to test complete cable designs. Under these conditions the entire cable design structure is evaluated, including the cable core materials, all moisture barriers, jacket ~~jackets~~, etc. Once again, the many synergistic interactions between material and design ~~all-the-cable~~ components of the cable ultimately dictate the performance of the overall cable design.

In this respect, an accelerated aging test in a water-filled tank can be considered both a cable core performance test and a cable design performance test. For purposes of this discussion, when a cable core test is performed, the test cable sample design consists only of the minimum components required to make up a shielded cable design. When a cable design test is performed, the test cable sample design contains all of the components that the cable would have if placed in service on an electric distribution ~~utility~~ system.

## 4.1 Cable core test

To date, the cable core test ~~This~~ is by far the most common use of the accelerated aging test in a water-filled tank ~~to-date~~. When conducting the cable core performance test, four different aspects of the ~~a~~ cable design are addressed.

The ~~first~~ component considered to have the most important effect on cable performance ~~evaluated~~ is the insulation. It is the component that has to withstand the applied voltage. In- ~~and for~~ this test, the insulation ~~it~~ is not protected from moisture ingress which provides a way to assess the effect of moisture on extruded insulation materials. For extruded cables moisture can be; a key aspect of the aging process, though thermal aging may also be a factor ~~for many extruded dielectric insulation materials~~.

The ~~next~~ ~~second~~ component considered to have an important effect on cable performance is the conductor shield. The conductor shield primarily provides ~~controls~~ the smoothness of the conductor shield/insulation interface, a high stress region of the cable core design that is critical to achieving acceptable cable performance. Conductor shield cleanliness is also very important. Some chemical species, such as ionic and elemental contamination and formulation additives ~~contaminants, which come primarily from the carbon black used to make the conductor shield conductive,~~ can migrate into the insulation, providing stress enhancement ~~enhancing~~ sites for water tree initiation and growth. These chemical species may come from additives in the conductor shield, from the water used to conduct the test, and from water used in the manufacture of the conductor shield.

The next component considered to have an important effect on cable performance ~~third aspect~~ is the insulation shield. Like the conductor shield, the insulation shield provides ~~controls~~ the smoothness of the insulation/insulation shield interface. It also contains carbon black and other additives. Like the conductor shield, it is subject to all of the issues regarding cleanliness. However, because the voltage stress is lower at the insulation/insulation shield interface ~~is lower than that~~ at the conductor shield/insulation interface, the impact of the insulation shield on cable performance is considered to be less significant compared to ~~than~~ the conductor shield.

The ~~fourth factor in a cable core evaluation test is the~~ manufacturing process used to make the cable core is another factor which can have an effect on performance. This includes a multitude of factors including the curing process (for example dry cure versus steam cure versus moisture cure), extruder configuration (e.g., 3-in-1 true-triple extrusion versus 1 + 2 tandem triple extrusion), tooling and die design and its ~~their~~ condition, line speed, ~~and the~~ cable cooling process, and overall cable quality as quantified by standardized after extrusion factory production testing. Among other things, these process variables can ~~processes~~ affect void size and density, insulation morphological characteristics, residual cross-linking by-product levels, and residual mechanical stresses in the insulation.

In summary, a cable core material test is generally considered to be a test of the materials used to make up the core. However, it is also a test of the process used to manufacture the cable, [the cable quality](#), and an evaluation of the synergistic interplay between all of these items. Items evaluated in a cable core accelerated aging test in a water-filled tank are listed as follows:

- a) Insulation
- b) Conductor shield
- c) Insulation shield
- d) Manufacturing processes
- e) Synergistic effects between all preceding items

The relative ranking of the listed items [in significance or importance](#) is arguable, but the cable core performance test, by its very nature, evaluates all of these components [simultaneously](#).

## 4.2 Cable design test

While the accelerated aging test in a water-filled tank is primarily used to evaluate cable cores, it is occasionally used to evaluate complete cable designs. Since complete cable designs often employ some type of moisture-blocking component(s) [\(such as blocked conductors, water-swelling powders or yarns at the insulation shield/jacket interface, and extruded-to-fill jacket\)](#), they generally [wet](#)-age more slowly than cables in a cable core test. The accelerated aging test in a water-filled tank is [suitable](#) ~~ideally-suited~~ for evaluating these cables because the test generally runs for extended periods of time, often several years.

A complete cable design normally incorporates a cable core ~~with plus~~ a moisture-blocked conductor, metallic shielding, and a jacket. It may also employ the use of additional moisture barriers including water-swellaable tapes, hydrophilic or hygroscopic powders, and/or metal laminate sheathing laminates. How all of these design characteristics combine to influence performance is extraordinarily complex. The cable core continues to be the most important portion of the cable structure. However, once moisture ingress to the core structure is reduced or eliminated by one or more of the components that make up the cable design, then the dynamics of the aging process can change significantly. For example, if moisture is no longer present at the conductor, the role of the conductor shield material may not be as pronounced as it would be if moisture were present. The same is true for the insulation material. For cable designs that are utilized in ~~provide for~~ a complete hermetic sealed cable system (including splices and terminations), ~~the seal~~, insulation characteristics such as water-tree resistance may no longer be important.

Because it could take several years before specimens in a cable design test fail, it may be appropriate to remove specimens from the aging test periodically and conduct diagnostic tests such as ACBD and water tree counts. This is particularly useful for test programs conducted for the purpose of comparing different cable designs. Once a comparative performance trend is established, the test can be terminated without having to age the test specimens to failure.

Whether conducting a cable core test or a cable design test, it is important to know that the accelerated aging test in a water-filled tank does much more than evaluate the performance of one aspect of a cable construction. All of the cable components—from the conductor shield to the jacket—are inexorably linked. This means that performance data may ~~should~~ not be associated with one component, but rather with the entire cable construction.

This document does not make specific test protocol recommendations for a cable design test. However, test specimens in a cable design test are likely to incorporate components such as jacket ~~jackets~~ and blocked conductors that impede the ingress of moisture into the cable structure. As a result, specimens in a cable design test will likely age more slowly than designs in a cable core test. For this reason, it may be desirable to use more severe test conditions in a cable design test than for a cable core test.

## 5. Test specimens

Table 1 lists a format for documenting the cable under test and provides example information. The values listed in Table 1 are compatible with tanks shown in Figure 1, Figure 2, and Figure 3. The cable under test should conform to [the latest revision of applicable power cable standards](#) ~~AEIC CS8-07~~.

**Table 1 – Example of cable documentation**

|               |                                                                                   |
|---------------|-----------------------------------------------------------------------------------|
| Voltage class | 15 kV, <sup>a</sup> 4.4 mm (175 mil) insulation thickness <sup>b</sup>            |
| Conductor     | 53.5 mm <sup>2</sup> (1/0 AWG) 1350-H19 stranded compressed aluminum <sup>a</sup> |

(New)

|                                       |                                                                                                                                          |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Voltage class                         | 15 kV, <sup>a</sup> 4.4 mm (175 mil) insulation thickness <sup>b</sup>                                                                   |
| Conductor                             | 53.5 mm <sup>2</sup> (1/0 AWG) 1350-H19 stranded compressed aluminum <sup>a</sup>                                                        |
| Conductor shield                      | 0.38 mm (0.015 in) state grade and manufacturer, blend number, and date of manufacture                                                   |
| Insulation                            | 4.4 mm (0.175 in) state grade and manufacturer, blend number, and date of manufacture                                                    |
| Insulation shield                     | 0.76 mm (0.030 in) state grade and manufacturer, blend number, and date of manufacture                                                   |
| Metallic shield                       | ≥ 6 #14 bare copper wires <sup>a</sup>                                                                                                   |
| Jacket                                | None or identify material, thickness <sup>a</sup>                                                                                        |
| Cable extrusion                       | True triple                                                                                                                              |
| Cable extrusion date                  | To be included                                                                                                                           |
| Cure process                          | Dry cure                                                                                                                                 |
| Extrusion run identification          | Job number, reel number                                                                                                                  |
| Cable manufacturer                    | To be included                                                                                                                           |
| Cable quality control tests           | To latest relevant ICEA standard <sup>a</sup>                                                                                            |
| Number of specimens in population     | ≥ 10 <sup>a</sup>                                                                                                                        |
| Specimen total length                 | ≥ 5 m (16 ft) <sup>c</sup>                                                                                                               |
| Specimen length under water           | ≥ 3.7 m (12 ft)                                                                                                                          |
| Number of cable coils                 | ≥ 1                                                                                                                                      |
| Inner diameter cable coil             | 610 mm (24 in) <sup>a</sup>                                                                                                              |
| Date water added to tank              | To be included                                                                                                                           |
| Date initial water added to conductor | To be included                                                                                                                           |
| Start voltage/heat cycles date        | To be included                                                                                                                           |
| Replacement specimen                  | Same type and construction of cable as test specimen if cable heating is necessary to maintain consistent water temperature <sup>a</sup> |

(Deleted)

**Table 1—Example of cable documentation (*continued*)**

|                                       |                                                                                                                                          |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Conductor shield                      | 0.38 mm (0.015 in) Indicate grade and manufacturer, blend number, and date of manufacture                                                |
| Insulation                            | 4.4 mm (0.175 in) Indicate grade and manufacturer, blend number, and date of manufacture                                                 |
| Insulation shield                     | 0.76 mm (0.030 in) Indicate grade and manufacturer, blend number, and date of manufacture                                                |
| Metallic shield                       | ≥ 6 #14 bare copper wires <sup>a</sup>                                                                                                   |
| Jacket                                | None or identify material, thickness <sup>a</sup>                                                                                        |
| Cable extrusion                       | True triple                                                                                                                              |
| Cable extrusion date                  | To be included                                                                                                                           |
| Cure process                          | Dry cure                                                                                                                                 |
| Degree of cure                        | Hot set value                                                                                                                            |
| Extrusion run identification          | Job number, reel number                                                                                                                  |
| Cable manufacturer                    | To be included                                                                                                                           |
| Cable quality control tests           | To latest relevant ICEA standard <sup>a</sup>                                                                                            |
| Number of specimens in population     | ≥ 10 <sup>a</sup>                                                                                                                        |
| Specimen total length                 | ≥ 5 m (16 ft) <sup>c</sup>                                                                                                               |
| Specimen length under water           | ≥ 3.7 m (12 ft)                                                                                                                          |
| Number of cable coils                 | ≥ 1                                                                                                                                      |
| Inner diameter cable coil             | 610 mm (24 in) <sup>a</sup>                                                                                                              |
| Water type used                       | To be included                                                                                                                           |
| Date water added to tank              | To be included                                                                                                                           |
| Date initial water added to conductor | To be included                                                                                                                           |
| Start voltage/heat cycles date        | To be included                                                                                                                           |
| Replacement specimen                  | Same type and construction of cable as test specimen if cable heating is necessary to maintain consistent water temperature <sup>a</sup> |

(New)

<sup>a</sup>Values or tests in common use according to a survey conducted by the [original](#) task force [of A13W](#).

<sup>b</sup>Insulation thickness at point of failure is recommended for reporting in Clause 13, Clause 14, and Clause 15.

<sup>c</sup>Specimen total length needs to be increased to a minimum of 9.5 m (32 ft) if the residual breakdown strength will be measured after cable aging.

## 6. Prior electrical tests and thermal preconditioning ~~of specimens~~

### 6.1 Prior electrical tests

Prior electrical tests are carried out to help ensure the quality of the cable on the reel from which individual ACLT test specimens will be extracted. It is suggested that partial discharge and ac voltage withstand tests be performed on the reel of cable per the applicable sections of the latest revision of ANSI/ICEA S-94-649. After cutting and terminating the individual ACLT test specimens, each specimen can once again be subjected to a PD test to make sure the terminations were properly installed and are PD-free. The partial discharge test may be carried out according to ANSI/ICEA T-24-380 and the applicable section of the latest revision of ANSI/ICEA S-94-649.

If a fixed aging time accelerated aging test followed by diagnostic testing is the desired testing protocol rather than a time-to-failure test protocol, then initial diagnostic testing on each individual ACLT test specimen can be performed prior to the initiation of accelerated aging in the tanks. Consideration should be given to the severity of prior diagnostic testing and the possibility that this testing could influence future aging performance of individual specimens in the tanks. Examples of initial non-destructive diagnostic tests which have been employed prior to fixed time aging in water filled tanks include DF measurements (both at 60 Hz and at VLF),

isothermal relaxation current measurements, recovery voltage measurements, and dielectric spectroscopy measurements [B15]. Be aware that the maximum voltage level used for these diagnostic tests may impact the cable specimens. If the chosen diagnostic measurement is a destructive test such as an ac breakdown test, then the initial diagnostic testing must be performed on different individual specimens than those to be subjected to accelerated aging in the tanks. These unaged ac breakdown values can then be compared to the ac breakdown values on aged samples coming out of the tank following a fixed time aging period.

## 6.2 Thermal preconditioning of specimens

Once the quality of the cable on a reel is established and prior to any initial diagnostic measurements, thermal preconditioning is commonly ~~of cable specimens are~~ carried out ~~to assess whether the cable specimens have defects that cause partial discharges (PD) and~~ to limit the levels of ~~some~~ cross-linking by-products, which can occur in some cross-linking processes and ~~which~~ are known to affect the electrical properties of cables. Thermal preconditioning should not significantly alter the morphology of the polymeric materials of the cable core ~~XLPE.~~

~~PD tests should be performed on the entire reel of cable prior to cutting into test specimens. If there is any doubt as to whether or not the reel was subjected to a PD test or there is concern about the integrity of the terminations, it is suggested that PD testing be performed on individual test specimens. The PD test should be carried out according to ICEA T24-380.~~

It is well known that the most commonly used chemical cross-linking agent, dicumyl peroxide, produces a number of cross-linking agent by-products that include methane, acetophenone, cumyl alcohol,  $\alpha$ -methyl styrene, and smaller quantities of other by-products (Andrews et al., [B5]). Their formation cannot be avoided, but they are migratory and can diffuse out of ~~theoretically volatilize from~~ the cable. Residual cross-linking agent by-products may influence the electrical properties of polymeric insulating materials such as XLPE, TRXLPE, and EPR. The type and level of residuals will depend on the specific chemical reactions, which occur during manufacture, and the rate at which the by-products subsequently diffuse through the extruded layers. ~~Although the same cross-linking by-products occur in XLPE, TRXLPE and EPR, the rate of diffusion will differ for XLPE, TRXLPE, and EPR and may vary for different TRXLPE and EPR formulations.~~ There have been a number of studies of the effects of the by-products on the short- and long-term electrical behavior of XLPE, ~~TRXLPE insulation~~, and EPR insulations and these are summarized in Annex A. It is important to note that other peroxides besides dicumyl peroxide may produce different cross-linking by-products.

Silane-cured XLPE does not use dicumyl peroxide as the curing agent and thus contains different cross-linking by-products. ~~Little~~ ~~No~~ data are available at this time on the effects of the by-products for silane-cured insulation ([Ahlander et al., \[B3\]](#)), and the procedures in this clause may not be applicable to silane-cured XLPE. ~~Some~~ ~~Also no~~ data are available in the published literature on the effect of cross-linking by-products on EPR-insulated cables ([Srinivas \[B33\]](#)).

Although their effects on the performance of extruded cable insulation are not precisely known, there is sufficient published data, at least for steam-cured XLPE, to show that an increased concentration of by-products improves the resistance of the insulation system to water-treeing. [see Annex A. Furthermore](#), ~~and that~~ the concentration of by-products in XLPE [and TRXLPE](#) gradually decreases with time, ~~e.g., the concentration of cross-linking by-products in 15-kV XLPE cable may be less than 100 ppm after 10 years in service and, as a result,~~ may not contribute to the [water](#)-tree retardancy. However, in accelerated aging tests lasting a year or even longer, if the accelerated temperature does not drive off the cross-linking by-products, an apparent improved resistance of the insulation to water-treeing could result. Thus, the long-term behavior, for the insulation with a low concentration of by-products, may not be as good as that predicted by the results of the accelerated aging test. To reduce this possibility, the cables are preconditioned in order to reduce the amount of by-products in the insulation before being subjected to the aging test. The most common form of preconditioning is to subject the cables to elevated temperatures, either by conductor heating or oven heating, to increase the rate of diffusion of the by-products from the insulation.

In addition to removing the by-products, elevated-temperature preconditioning can:

- Cause chemical changes in the insulation depending on the temperature [and time](#) employed.
- Cause morphological changes in the insulation due to partial melting and recrystallization [of the polymeric components of the insulation](#).
- [Cause the insulation system to dry out.](#)