# Research Project

# "Aging Modelling of Nuclear Power Plant Cables"

Extending the lifetime of a Nuclear Power Plants (NPPs) to 60+ years is one of the most important concerns in the global nuclear industry. As electric cables are one of the long life items that have not been considered for replacement during the design life of NPPs (typically 40 years), assessing their degradation state and predicting their remaining lifetime are very critical issues. The polymers used for the insulation and jacket materials of electric cables are susceptible to ageing and degradation mechanisms caused by exposure to many of the stressors encountered in nuclear power plant service environments. Nuclear facilities rely on several hundreds of kilometres of low-voltage instrumentation, control, and power cables to perform a variety of functions for successful operation. Many of these functions directly support the safe operation of the facility; therefore, unanticipated or premature cable aging (especially for those cables with prolonged exposure to harsh environments) could lead to unavailability of equipment important to safety or could cause plant transients and shutdowns. The integrity and function of power and instrumentation and control (I&C) cables are monitored indirectly through the performance of in-service testing of safety-related systems and components. These tests can demonstrate the function of the cables under test conditions. However, they do not provide assurance that they will continue to perform successfully when they are called upon to operate fully loaded for extended periods as they would under normal service operating conditions or under accident conditions (design basis event (DBE) conditions). Therefore, methods of monitoring cables condition have long been researched in an attempt to identify an effective technique that can be used to determine the existing cables condition, as well as predict their future performance. Effective in situ condition monitoring (CM) techniques are considered an important aspect of managing cable aging. They also play an important role in the validation of the physical and chemical degradation models providing useful experimental data from the field. Related to the development of new CM techniques is the development of acceptance criteria that can be used to make decisions regarding the acceptability of the condition of cables currently installed in nuclear plants. While a CM parameter may provide an indication of cables aging degradation, specific acceptance criteria are needed to determine if the current condition, which may include degradation from "hot spots" and localized anomalies, is acceptable for continued service. In many cases, CM parameters provide a measure of cables physical condition, such as material hardness. However, these measurements must be correlated to the cable electrical performance in order to provide useful information on the cable acceptability for continued service. Therefore, correlation of the physical properties to electrical properties is very important. Since large I&C cable replacements could be prohibitively expensive in terms of plant unavailability, effective in-situ condition monitoring techniques together with the establishment of appropriate acceptance criteria will support utilities decision making in order to avoid unnecessary cables replacements.

This research project is included in a European EURATOM Project called TEAM-CABLES which aims at:

- Adapting, optimising and assessing promising electrical condition monitoring techniques for nuclear cables that are non-destructive and can be used in the field to determine the current condition of installed cables over the entire length;
- Using of condition monitoring techniques to predict remaining useful life, including the establishment of acceptance criteria and correlation of physical cables properties to electrical properties;
- Correlating condition indicators of cables near the end of life with accident (DBE) survivability;
- Investigating new cables design and formulation adapted to full-length electrical CM techniques to provide fundamental knowledge for the next generation of cables for future NPPs with improved diagnostic capability.

## Activity Plan

The training aims to impart theoretical knowledge and technology needed to investigate aging of insulating materials used in NPPs through electrical, mechanical and thermal property measurements. In particular, diagnostic properties obtained from measurement of partial discharges, space charge, dielectric spectroscopy will be analyzed and modeled aiming at predicting the remaining life of the NPP low voltage cables.

### Objectives of the Training Plan

The proposed training will focus on the study and the understanding of the impact of cable ageing on the electrical properties. The main objective is to understand and correlate the evolution of electrical properties with the dominant physical/chemical degradation mechanisms of polymers for different kinds of cable materials. This study will allow not only guide to the optimisation of existing diagnostic techniques, but also to interpret the results of the electrical measurements and to extend the validity of the results to other cables with similar formulations. The relevant deterioration mechanisms (e.g. chemical degradation, physical ageing, migration of additives) will be correlated with the evolution of

insulator electrical and mechanical properties. The electric properties of cables insulators will be mainly monitored by dielectric spectroscopy, polarization/depolarization current analysis, and by the assessment of space charge distribution.
Thermal stress and irradiation will both cause oxidation and chain scission in polymers. Both chain scission and oxidation will give rise to new chemical species and free radicals, affecting the dielectric response of the material. Furthermore, both physical and chemical trapping sites will be created at the surface and in the bulk of the insulation system. Whenever these phenomena are spread over a significant fraction of the cable, they will give rise to changes in the dielectric response of the complete cable as well as to the presence of space charge. At the latest stages of aging, cracks will likely start to appear.
First of all, the aged specimen will be investigated using (a) Dielectric Analyzers (b) the Pulsed Electro-Acoustic (PEA) technique. Analyses of type (a) are aimed at inferring changes in the dielectric response over a range of frequencies spanning from very low frequencies (say 0.01 Hz) up to 10 MHz. An investigation will be carried out to infer whether analyzing the dielectric in different frequency ranges could prove helpful to separate the effects of thermal aging from cumulative dose effects and, in case, how to combine the different evaluation techniques to achieve a global indication of the insulation system to withstand LOCA-related stresses.
The investigation above will provide a set of diagnostic markers, i.e., a set of quantities derived from electrical measurements that can signal changes associated with degradation processes. The correlation analysis of the selected diagnostic markers with the amount of aging of each specimen will provide a model connecting diagnostic markers with aging, thus enabling aging assessment for cables in the field. A connection between measurements of type (a) and (b) and polymer changes will be sought through chemical-physical analyses (e.g., TGA, DSC, SEM, EDAX,…) and (c) mechanical analyses. This part is very important in order to understand how diagnostic markers are influenced by the amount of internal degradation of the polymer. This will form the basis to define critical values of the diagnostic markers, beyond which operation of the cable is still possible but not advisable. Furthermore, it could help understanding the time behaviour of diagnostic markers as a function of the extent of degradation during time.

## Structure of the Training Plan

Among the various issues involved in research on diagnostic methods for NPP, the training plan will address in particular the following:
1. acquisition and / or deepening of knowledge base;
2. technological aspects in the implementation and adaptation of the experimental system test;
3. application of methodologies developed and the search for diagnostic indicators; in accordance with the following aspects:

**1. Theoretical basis:**

1.1 Literature survey on the effect of radiation and temperature on NPP cables
1.2 Literature survey on the main diagnostic techniques employed to diagnose cables in NPP

**2. Technonological and experimental systems**

2.1 Setup of the system for dielectric spectroscopy and conduction current measurements on NPP cables
2.2 Experiments on virgin cables and on aged cables
2.3 Processing of the results and electric quantity estimation (diagnostic markers)

**3. Modelling approach and diagnostic indicator research**

3.1 Creation of a database showing the diagnostic indicators for all tests performed;
3.2 Correlation of diagnostic markers with aging extent evaluation by means of chemical measurements
3.3 Modeling of the best diagnostic quantities to evaluate ageing due to radiation and temperature.
3.4 Residual life estimation

**4. Training and mobility**

4.1 Training visits in foreign research centers and industries involved in the European Project TEAMCABLES.