Effects of Temperature on Gamma Radiation Aging of Nuclear Cable Insulation

Muthu **ELEN**, Mychal P. **SPENCER**, Yelin **NI,** Donghui **LI**, Aishwarya **SRIRAMAN**, Anthony **GUZMAN**, Angel **ORTIZ**, Andy **ZWOSTER**, Mark **MURPHY,** Leonard S. **FIFIELD;** Pacific Northwest National Laboratory, (USA), leo.fifield@pnnl.gov

ABSTRACT

A concern related to accurate lifetime prediction of nuclear electrical cables is the potential for phenomena to occur during accelerated laboratory aging that is not representative of in-service aging. One such phenomenon is the case where polymer insulation materials exposed to gamma radiation age more rapidly at lower temperatures than at higher temperatures; the so-called "inverse temperature effect". To investigate this scenario, samples of cable insulation types commonly found in the United States commercial nuclear power plants were exposed to gamma radiation at a common dose rate and at contrasting temperatures of 26, 50, and 90°C. The effects of exposure temperature on the insulation materials were assessed using a range of methods including tensile elongation at break, color change, mass change, density, Fourier transform infrared spectroscopy-determined carbonyl index, indenter modulus, and indenter relaxation. This study determined that inverse temperature effects, in which degradation upon exposure to gamma radiation occur more rapidly at lower temperatures, are both material and metric-dependent. Degradation in elongation at break was observed to occur more rapidly at the lower temperature for cross-linked polyethylene, but not for ethylene-propylene-diene terpolymer insulation. Inverse temperature effects were not observed for any other properties measured in either material.

KEYWORDS

Nuclear Power Plants; Cable Insulation; Gamma Radiation Aging; Inverse Temperature Effects; Dose Rate Effects; Synergistic Effects; Thermal Aging; XLPE; EPDM; EPR

INTRODUCTION

Approximately 20% of electricity in the United States (U.S.) comes from nuclear power plants (NPP) [1], which were originally qualified for a 40-year operational lifetime [2; 3]. However, NPPs can apply for 20-year license extensions, and many are considering extending their licenses to 80 years. As a result, the Nuclear Regulatory Commission (NRC) has developed aging management program requirements to ensure the safe operation of NPPs during license extension periods, and the Expanded Materials Degradation Assessment (EMDA) Volume 5: Aging of Cables and Cable Systems report [4] identified issues that may affect subsequent license renewals. In response to this critical energy infrastructure need, researchers at Pacific Northwest National Laboratory (PNNL) identified 11 knowledge gaps related to cable aging, focusing on cable insulation degradation [4; 5]. Four knowledge gaps were selected for investigation based on issues raised in various reports including the EMDA Volume 5. These gaps include inverse temperature effects, diffusion-limited oxidation (DLO), dose-rate effects (DRE), and synergistic effects. This work focuses on the investigation of the inverse temperature effect phenomenon.

Manufacturers have traditionally qualified electrical cables for 40-year lifetimes using accelerated aging under conditions that exceed normal service temperatures and gamma radiation dose rates [6]. Previous studies have shown that some nuclear cable polymeric insulation degrades faster at lower temperatures under gamma radiation than at higher temperatures, known as the inverse temperature effect (ITE) [7]. ITE have only been observed to occur in semi-crystalline polymers such as cross-linked polyethylene and is caused by the combined or synergistic effects of thermal and gamma radiation exposure. However, relying solely on accelerated aging to predict cable lifetime under long-term, milder conditions may underestimate degradation if ITE is present. The impact of ITE on cable lifetime is still not fully understood, including which metrics are sensitive to ITE and its effect on the qualification of electrical cables for NPPs. To support the safe operation of NPPs for 80 years or more, additional information is desired regarding the impact of ITE on the historical qualification of electrical cables.

At least 75% of electrical cables in nuclear containments in the U.S. use XLPE and EPDM as the insulation material for and hence these materials were selected to evaluate ITE. This work aims to study ITE by evaluating the degradation of cross-linked polyethylene (XLPE) and ethylene propylene diene elastomer (EPDM), both of which are typically used as insulation material in nuclear electrical cables that are subjected to radiation aging at elevated temperatures.

MATERIALS

XLPE was extracted from a Brand-Rex cable (Ultrol 600V Sheilded PR #16 AWG), which was harvested from a decommissioned Crystal River Unit 3 plant and has a prior aging history [8]. EPDM was extracted from a Samuel Moore cable (Dekoron 2/C AWG 600V).

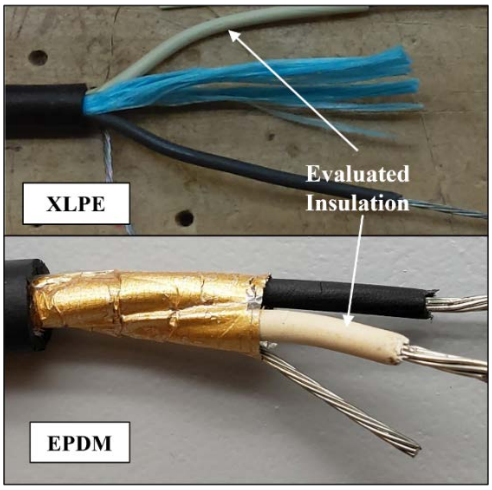

Figure 1: Evaluated insulation materials in selected nuclear electrical cables

Figure 1 displays the components of the low-voltage nuclear-grade instrumentation cables. Insulated conductor