Toward a Predictive Model for Cabling Failure: An interdisciplinary, collaborative effort between the University of Minnesota–Duluth and the Materials Research Pathway

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Medium- and low-voltage cables are used in nuclear power plants to deliver power to pumps and to control and power a variety of equipment. In many instances, the cables are unpowered and turned on only in backup/emergency scenarios. Having confidence that these power cables will operate when called upon is necessary for many applications, especially if they serve a safety function. The power cables are exposed to conditions that are known to degrade power cables, such as water immersion, cleaning chemicals, high temperatures, and other damaging stressors common to an industrial environment. Cable failures (see Figure 5) in submerged environments has been a growing problem, with an increasing number of reported failures for medium-voltage cables that have failed in the 20 to 40-year operational range [1].

A research team led by the University of Minnesota–Duluth (UMD), partnered with the LWRS Program, are in the second year of a three-year project supported by a U.S. Department of Energy (DOE) Nuclear Energy University Program (NEUP). The goal of the collaborative effort is to develop a mechanistic understanding of the degradation process to confidently predict functional properties and safety margins for dielectric breakdown in submerged

Figure 5. Water-related catastrophic failure of a power cable is important safety concern in various locations and applications for utilities (http://mydocs.epri.com/docs/PublicMeetingMaterials/1202/epri/05.pdf).

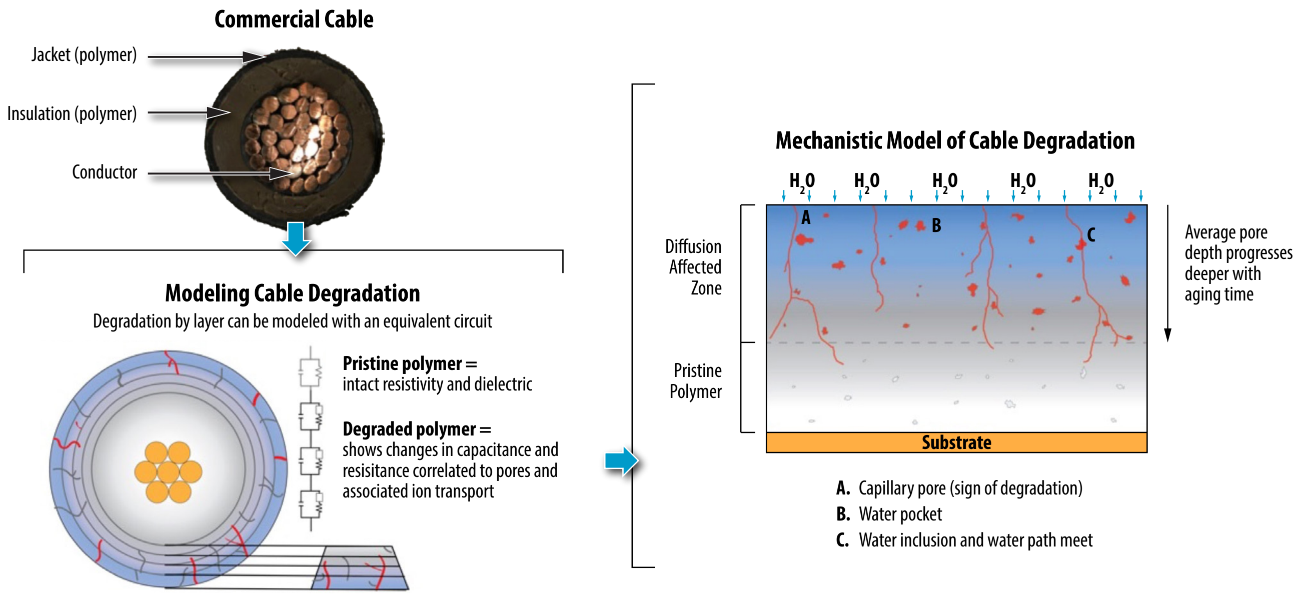

Figure 6. Mechanistic model to describe the degradation of the cables by water intrusion.

cables over extended nuclear power plant operational lifetimes. The research will result in an analytical, predictive aging model (see Figure 6) developed to estimate the accelerated rate of degradation of nuclear power plant electrical cables under various environmental stress conditions that include: temperature, cyclic aqueous immersion exposure, and oxygen concentration. As an example of recent work, electrochemical impedance spectroscopy was used to evaluate pore advancement, one mechanism leading to failures, into the cable insulation at various temperatures and with various electrolytes that are used to predict the time-to-failure at service environment temperature. Charged gold nanoparticle-based imaging methods are being used to help image the water pore structures of the degraded polymer samples.

This NEUP project has involved researchers and graduate and undergraduate students from three different departments at UMD and has offered a significant opportunity for student participation, through directly supported activities or providing a project opportunity through volunteering, the University of Minnesota Undergraduate Research Experience Program, graduate teaching assistantships, and as a project for a Senior Capstone Project. Furthermore, students from UMD have traveled to Oak Ridge National Laboratory during summer sessions, as shown in Figure 7, giving an opportunity to be involved in research at a national laboratory.

The mechanistic model of cable degradation rates in various locations in the nuclear power plant will help nuclear utilities make better informed decision on when expensive electrical cable replacements are needed. The value of this work also extends beyond the nuclear industry, as buried power cables from windmills have been found to be subjected to aqueous environments in underground conduits and fail in a similar fashion.

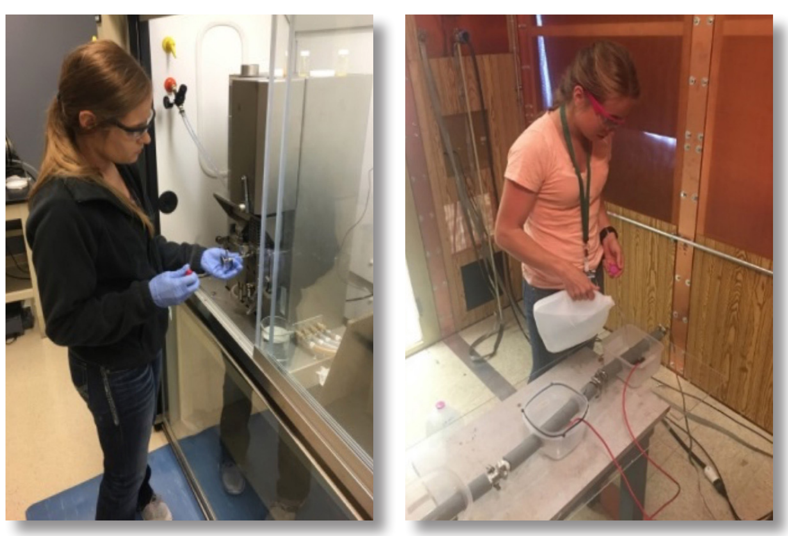

Figure 7. Tana O'Keefe (left) and Tayler Hebner (right) during their appointments at Oak Ridge National Laboratory in summer 2017.