

Light Water Reactor Sustainability Program

ACCELERATED THERMAL AGING OF HARVESTED ZION ELECTRICAL CABLE JACKET AND INSULATION (INTERIM REPORT)



July 2017

U.S. Department of Energy

Office of Nuclear Energy

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**Prepared for the
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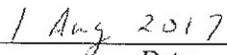
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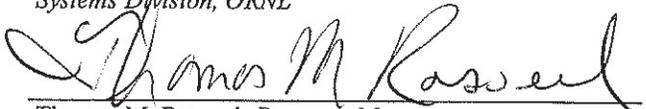
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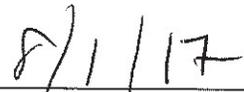
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SUMMARY

As part of the Cable Aging Task within the Material Aging and Degradation (MAaD) pathway of the DOE Light Water Reactor Sustainability (LWRS) program, ORNL is collaborating with Pacific Northwest National Laboratory (PNNL), the Electric Power Research Institute (EPRI), and the U.S. Nuclear Regulatory Commission (NRC) to study cable aging mechanisms. Understanding cable aging mechanisms in cable insulation and jacket material of power and instrument and controls (I&C) cables will provide existing nuclear power plants (NPPs) with needed information as they seek plant life extensions to 80 years of operations.

As part of this effort, the harvesting and assessment of I&C cables that are currently being used in the NPPs provides two main benefits. The first benefit is the determination of changes in the cable performance from their original qualification. This original qualification was based on expectations of accumulated dose and temperature for 40 years depending on cable installation location in the plant. The second benefit is the estimation of the remaining margin or remaining useful life of the I&C cables that are no longer being manufactured. For the original qualification, a level of conservatism was built into the cable qualification requirements that was based on the expected environments that the I&C cables would see in the NPPs. While the chemical nature for materials such as Chlorosulfonated polyethylene (CSPE) and ethylene propylene rubber (EPR) has not significantly changed in the last several decades, changes to fillers and suppliers over the course of this time has improved long-term performance. However, for those cables that were installed as the changes were made over the course of this time, some limited cases have shown the potential for negative impact on cable performance.

This report summarizes the technical progress on accelerated thermal aging of harvested I&C cables from the decommissioned Zion NPP. Harvested I&C cables considered here were fabricated by Boston-Insulated Wire (BIW) and Okonite. Accelerated aging in air at temperatures of 140°C and 150°C for BIW and Okonite insulations exhibited higher rates of degradation when compared to previous results, especially for Okonite EPR insulation. However, additional data at temperatures between 110°C and 130°C would clarify the significance and consistency of the observed degradation. While FTIR spectra indicated similarities to the CSPE utilized by BIW and Okonite, there are notable differences. As of this report, FTIR spectra have been collected on aged insulation and analysis is underway to quantify the differences between the two insulation types.

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ZION HARVESTING ACTIVITIES BACKGROUND

Characterization of materials harvested from US nuclear power plants (NPPs) provides an opportunity to improve the economics of their current and long-term operations and develop effective non-destructive evaluation tools to track component condition. Harvesting of concretes, structural components, and electrical cables from decommissioned plants provide vintage, relevant materials so their performance to date and their projected performance over twenty to forty years can be quantified. Harvesting activities at the decommissioned Zion Unit 1 and 2 NPP in Illinois, which operated from 1973 to 1998, provide a chance for DOE and the NRC to obtain materials that address current knowledge gaps and needs for their respective programs.

With respect to electrical cables from Zion, several thousand feet were removed from different locations in the NPP and sent to ORNL for further segregation and processing. Examples of removal locations at Zion are shown in Figure 1. These locations varied between containment, high thermal environments, and benign auxiliary areas so that the influence of thermal and radiation exposures could be separated. Additional information on the harvesting activities relevant to electrical cables and their location has been documented in a previous report (ORNL/TM-2016/263).

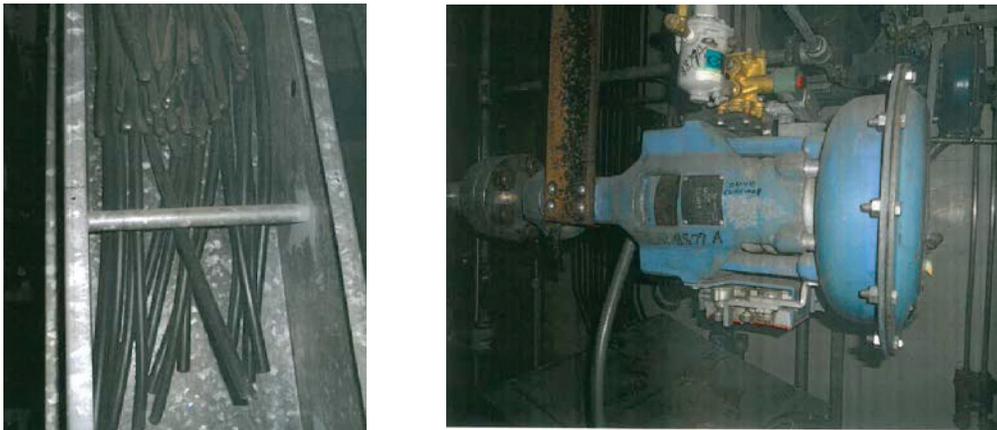


Figure 1. Examples of electrical cables and their installation locations at Zion NPP prior to harvesting.

Prior to the start of accelerated aging activities, the electrical cables were inspected, surveyed, and segregated. These activities were needed to quantify the nature of the mixed asbestos and radiation contamination for safe handling and to identify cables that meet highest priority needs. Of the approximately 4500 feet processed, 31% possessed asbestos contamination, 6% were rad contaminated, and only 26% had discernable manufacturer markings. Of this 26%, electrical cables from Boston Insulated Wire (BIW), Dekoron Elastoset, and Okonite were identified. Based on information within Expanded Material Degradation Assessment for NPP electrical cables (NUREG/CR-7153), BIW and Okonite represent two of the top ten commonly found cable manufacturers in NPPs. Identifying the remaining 74% of the harvested cables is planned as time and resources permit.

BIW AND OKONITE ELECTRICAL CABLES

Cross sections of the BIW and Okonite electrical cable that were studied are shown in Figure 2. The BIW cable is BIW Bostrad 7E with an outer diameter of 9.5 mm with a 1.85 mm thick Chlorosulfonated polyethylene (CSPE) jacket. Inside the jacket is a cotton fiber, a 12 AWG copper ground, and two 16 AWG insulated conductors. Each conductor had an outer diameter of 2.80 mm that consisted of copper wires and a 0.9 mm thick EPR insulation layer. On the exterior of the EPR insulation is a 0.08 mm thick CSPE coat. The Okonite is a slightly larger cable with a 11.7 mm outer diameter with an extruded CSPE

jacket with a thickness between 3 mm and 4.7 mm. Two 12 AWG conductors are inside the jacket with an outer diameter of 6.45 mm and EPR insulation thickness of 1.70 mm. Like the BIW cable, the EPR insulation on the Okonite cable has a CSPE jacket but its thickness is slightly larger at 0.3 mm. The information on the jacket and insulation materials was based on documentation obtained from the qualification library of the Zion NPP and from similar cables found from harvesting at other NPPs.

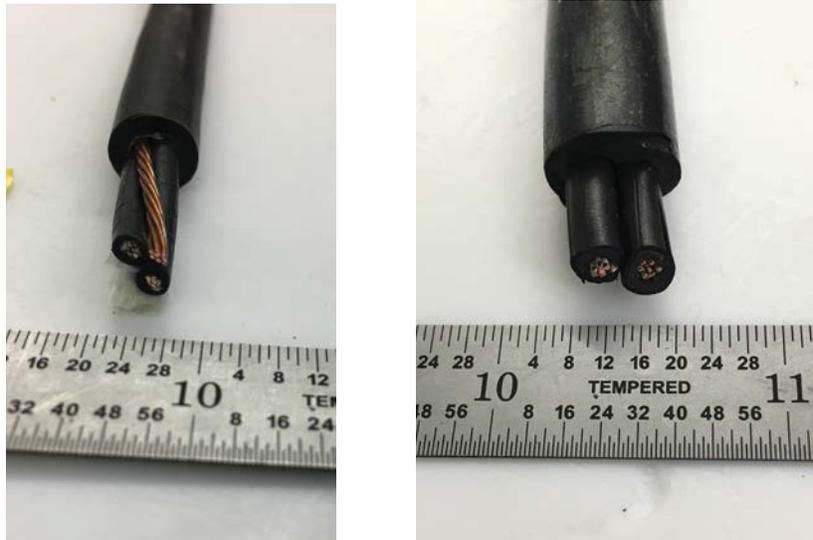


Figure 2. Cross sections of the BIW (left) and Okonite (right) electrical cables that were utilized in accelerated thermal aging in air at temperatures between 80°C and 150°C.

Accelerated thermal aging was carried out in air in laboratory ovens with temperatures between 80°C and 150°C on jacket and insulation samples that were removed from the harvested cables. Each sample was prepared to permit mechanical characterization via elongation at break (EAB) and indenter modulus (IM) per IEC/IEEE 62582-3 and IEC/IEEE 62582-2 respectively. After the mechanical properties were quantified, chemical characterization via Fourier transform infrared (FTIR) spectroscopy was performed to correlate mechanical changes with the changes in the chemical structure of the cable jacket or insulation. Comparison of the mechanical properties of the cable jacket and insulation to previous reported results and the original qualification documentation when possible was also performed to determine whether measurable changes in performance occurred since the original installation.

MECHANICAL DEGRADATION OF ZION HARVESTED CABLES

As a first step in the accelerated thermal degradation study, insulation from the BIW and Okonite manufactured cables was aged at 120°C to establish an initial performance profile. After a period of 45 days, no degradation was observed as the EAB for each insulation type was approximately 300%, which is the maximum value of the system with a total travel of 15.2 cm, and the IM was at 4 N/mm, which was the original value. To provide additional temperature performance points, exposures at higher temperatures were performed with the EAB and IM results for the BIW and Okonite insulation (Figures 3 and 4). It is clear that the EAB and IM for the Okonite insulation changes dramatically within a few days, while the BIW insulation only changes dramatically at 150°C.

There is currently insufficient data to predict a “remaining useful life” value at a given operating temperature. However, when the results are compared to Okonite EPR insulation data collected previously by Gillen (SAND2005-7331), as shown in Figure 5, there is a difference in expected performance. When compared to the EAB data in Figure 3, it is clear that the Okonite EPR insulation system that was measured previously and shown in Figure 5 lasted considerably longer. However, to

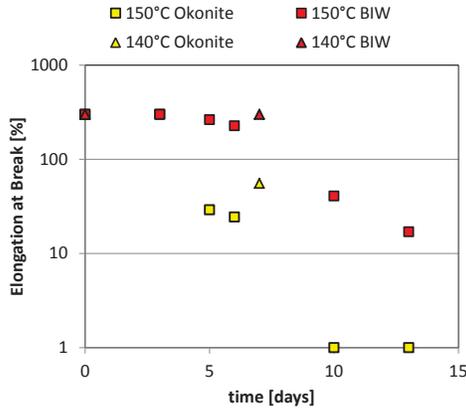


Figure 3. Elongation at break (EAB) as function of time and temperature for BIW and Okonite insulation. Each insulation sample consisted of a CSPE cover and EPR insulation.

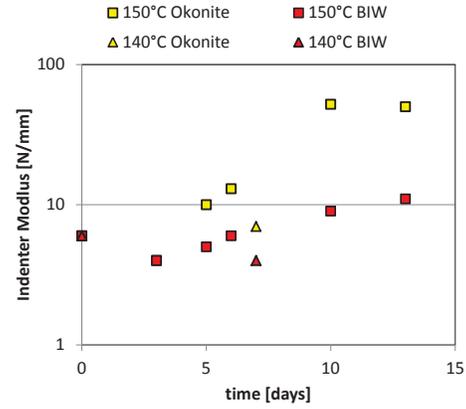


Figure 4. Indenter modulus (IM) as function of time and temperature for BIW and Okonite insulation. Each insulation sample consisted of a CSPE cover and EPR insulation.

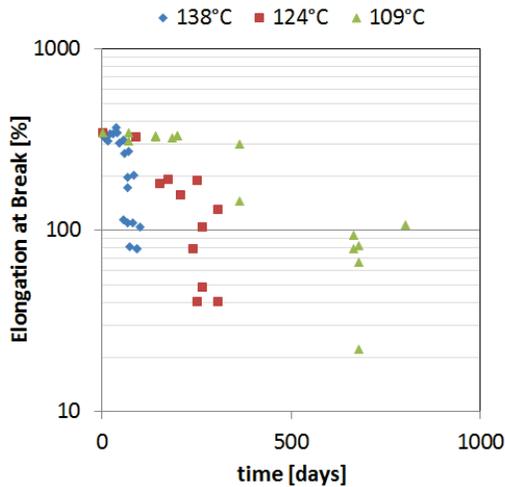


Figure 5. Elongation at break (EAB) as function of time and temperature for Okonite EPR insulation previously measured by Gillen (SAND2005-7331).

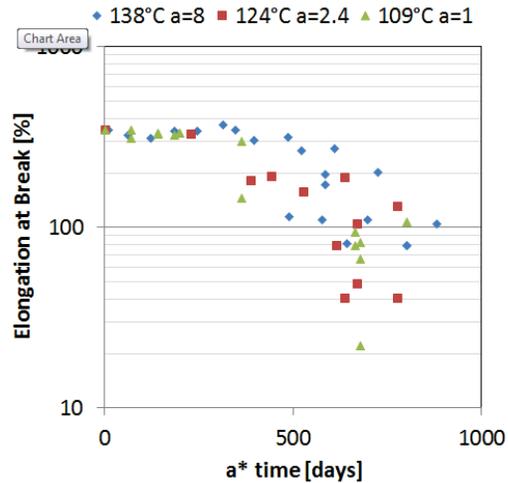


Figure 6. Elongation at break (EAB) as function of time multiplied by Arrhenius constant, a , and temperature for Okonite EPR insulation previously measured by Gillen (SAND2005-7331).

compare the effect of temperature an Arrhenius analysis, which is essentially picking a reference temperature and multiplying each other temperature by a constant, a , until the data overlaps, should be carried out. Figure 6 shows the resultant Arrhenius analysis for the Gillen Okonite EPR. Using an exponential curve fit for the Arrhenius constants with respect to inverse temperature, which assumes that the rate of degradation behaves as $e^{-k/T}$ and the time to 50% EAB of 625 days at the reference temperature of 109°C, the estimated time to 50% EAB for 140°C and 150°C is 67 days and 34 days respectively. While this is measurably different from the previous data, several factors need to be ruled

out before the value of this result is determined. The first is the amount of data to date that will allow for the performance of the BIW and Okonite insulation to be analyzed on its own. The second is the influence of CSPE individual jacket on each insulation on its mechanical performance. EAB measurements for the BIW and Okonite showed consistent failure across the insulation and cover. Finally, there could be non-linear temperature effects influencing this result. The approach required to resolve these factors not only includes additional measurements but also analyzing a select series of BIW and Okonite insulation samples at PNNL for a secondary confirmation that the results are not setup dependent.

CHEMICAL CHARACTERIZATION OF ZION HARVESTED CABLES

While FTIR spectra analyses are currently underway, comparison to the FTIR spectra for BIW and Okonite insulation as shown in Figures 7 and 8 could provide insight into the differences in similar materials across different manufacturers. For peaks shown at wavenumbers of 2848 cm^{-1} and 2916 cm^{-1} , the magnitudes would be indicative of the C-H bonds within each material with the Zion harvested materials showing a higher level of absorbance compared to previous BIW CSPE materials. For the CSPE

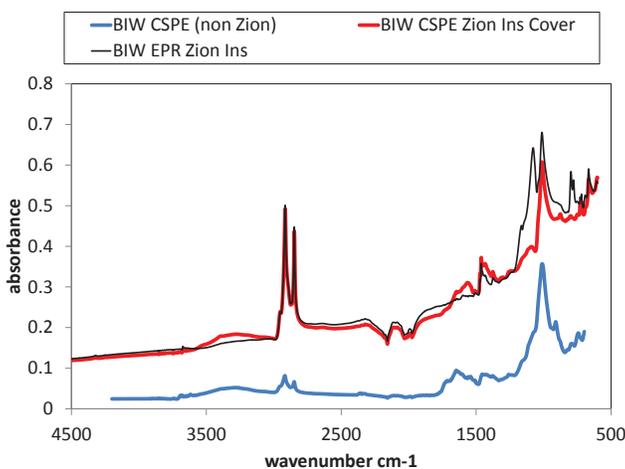


Figure 7. Comparison of FTIR spectra for BIW insulation and cover from Zion harvested electrical cables to a similar BIW CSPE material. The similar BIW CSPE material was obtained from a harvested electrical cable from a separate existing NPP still in operation.

based materials, increased absorbance near 1000 cm^{-1} and between 3200 cm^{-1} and 3600 cm^{-1} would suggest the level of oxidation within each material, but it should be noted that the Okonite CSPE peaks near 1000 cm^{-1} are much lower. The nature of these properties as well as other parts of the structure indicated by the spectra will be utilized to track changes from the accelerated aging as well as future comparisons to the 74% of cables that were unidentified from the Zion harvesting.

FUTURE PLANS FOR ZION HARVESTED CABLES

Given the results to date, additional measurements are needed to determine the nature of degradation in the BIW and Okonite and their relevance to long-term performance. As stated earlier, additional temperature degradation points at lower temperatures will provide significant clarity as additional aging data are obtained. Moreover, other activities that are being pursued include (in order of priority):

1. EAB measurements will be performed by PNNL to confirm the nature of degradation at 140°C and 150°C in these Zion BIW and Okonite insulation samples.

2. EAB measurements of insulation with and without a CSPE cover will be performed to determine its importance in the insulation failure and/or accelerated aging.
3. FTIR comparisons at multiple temperatures, in addition to differential scanning calorimetry, will be performed to determine the nature of the chemical change during accelerated aging.
4. Comparison of Zion BIW cables to other BIW harvested materials will be used to evaluate consistency of degradation across materials made by the same manufacturer.

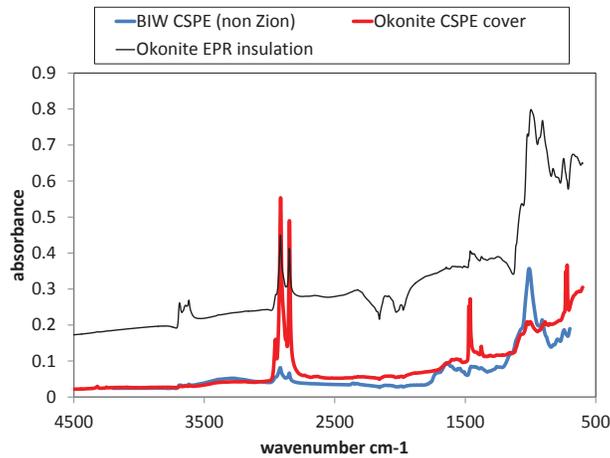


Figure 8. Comparison of FTIR spectra for Okonite insulation and cover from Zion harvested electrical cables to a similar BIW CSPE material. The similar BIW CSPE material was obtained from a harvested electrical cable from a separate existing NPP.