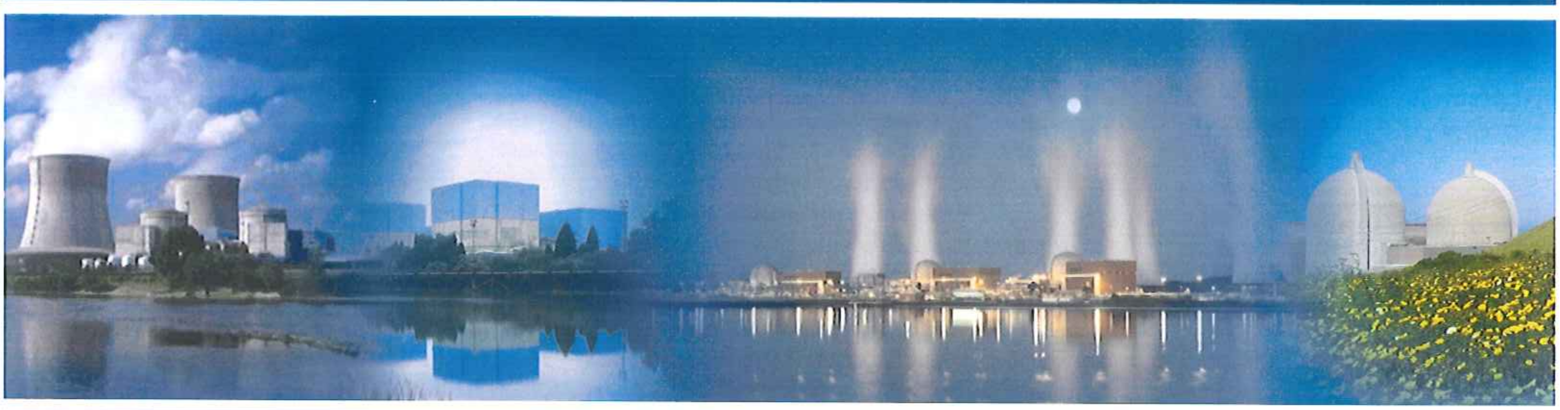
M3LW-15OR0404015
Revision 0

Light Water Reactor Sustainability Program

SCOPING/DESIGN STUDY ON OPTIMUM CONFIGURATION FOR COMBINED THERMAL/RADIATION AGING OF CABLE INSULATION SAMPLES AT ORNL



March 2015

U.S. Department of Energy

Office of Nuclear Energy

DISCLAIMER

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

M3LW-15OR0404015
Revision 0

SCOPING/DESIGN STUDY ON OPTIMUM CONFIGURATION FOR COMBINED THERMAL/RADIATION AGING OF CABLE INSULATION SAMPLES AT ORNL

Robert C. Duckworth

March 2015

Prepared for the
U.S. Department of Energy
Office of Nuclear Energy

Light Water Reactor Sustainability Program

SCOPING/DESIGN STUDY ON OPTIMUM CONFIGURATION FOR COMBINED THERMAL/RADIATION AGING OF CABLE INSULATION SAMPLES AT ORNL

Document Number M3LW-15OR0404015
Revision 0

March 2015

Approved by:

Gary L. Bell
Group Leader, Plasma Technology and Applications Group, Fusion & Materials for Nuclear Systems Division, ORNL

March 6, 2015
Date

Thomas M. Rosseel
Program Manager, Materials Science and Technology Division, ORNL

3/6/15
Date

SUMMARY

As part of the Cable Aging Task within 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. Facilities to perform combined thermal and radiation aging on the cable insulation and jackets harvested from decommissioned NPPs like Zion and Crystal River are needed to provide data to develop accurate models that will capture the contributions of factors like temperature and dose rate in cable aging.

An initial design study was carried out to determine the steps needed to perform combined thermal/radiation aging at ORNL. It was determine that there are two options for conducting the aging under relevant conditions. The primary option was the adaptation of existing hardware in order to irradiate cable samples at the High Flux Isotope Reactor Gamma Irradiation Facility (HFIR GIF). With some additional sample holders to accommodate the expected cable samples that are nominal 1" to 4" long and ½" wide, the ability to age samples at temperatures between 40°C and 100°C with dose rates between 250 Gy/hr and 100,000 Gy/hr are possible. Depending on the sample size, a set of 24 to 36 samples can be aged at separate temperatures and dose rates within the HFIR GIF in a single run. During the course of this design study, which involved comparing the HFIR GIF to other irradiation options, it was discovered that a secondary option for combined thermal/radiation aging existed at ORNL. A Co-60 irradiator with an available cylindrical volume of 226 cubic inches with a 6" diameter and an 8" height has an available, unshielded dose rate of 140 Gy/hr. While the amount of work to prepare a sample holder including lead shielding to lower the dose rate is slightly more than the HFIR GIF, there are advantages with respect to accessibility and availability that make the Co-60 irradiator a viable fallback option that could benefit with further exploration as cable aging in the HFIR GIF moves to the fabrication and test phase. While both of these sources are above the desired target dose rates between 0.01 Gy/hr and 10.0 Gy/hr, the information on cable aging mechanisms should be able to allow for models to be developed that can address this dose rate range.

This report provides a brief description of the high priority gaps in the LWRS MAaD Cable Aging Task along with an analysis of the two gamma irradiation facilities, (HFIR GIF & Co-60 Irradiator) that can provide the necessary conditions for exploring the effects of radiation on cable aging. The information in this report is submitted as objective evidence of completion of the milestone M3LW-15OR0404015 – COMPLETE REPORT DESCRIBING SCOPING/DESIGN STUDY ON OPTIMUM CONFIGURATION FOR COMBINED THERMAL/RADIATION OF CABLE SAMPLES AT HIGH FLUX ISOTOPE REACTOR GAMMA IRRADIATION FACILITY.

CONTENTS

SUMMARY iv

BACKGROUND 1

HFIR GIF FACILITY 2

CO-60 IRRADIATOR 4

FIGURES

Figure 1. Theoretical dose required to reach a specific level of degradation as measured by dose-equivalent damage (DED) as a function of dose rate at different temperatures for a representative polymeric cable material from NUREG-7153. 1

Figure 2. Susceptibility-Knowledge plot for cables at 45-55°C and 0.01 to 0.1 Gy/hr. 1

Figure 3. Overhead view of spent fuel pool at HFIR GIF (top) and canister (bottom) that is utilized for sample exposure in facility. 2

Figure 4. Flux profile with HFIR GIF for spent fuel elements with uniform gamma decay (left) and sample holder schematic (right) that has been used to successfully irradiate cable insulation samples from previous work. 3

Figure 5. Sample holder that was used previously for cable insulation sample irradiations (left) and the modified sample holder with respect to height and sample area to accommodate cable aging samples that are approximately 1" to 4" in length and 0.5" in width (right). 3

Figure 6. Co-60 irradiator with sample holder sitting above source (left) and the possible configuration for the cable aging sample insertion with multiple zones where the sample temperature or the dose rate could be varied through the usage of separate heaters or lead shielding, respectively. 4

SCOPING/DESIGN STUDY ON OPTIMUM CONFIGURATION FOR COMBINED THERMAL/RADIATION AGING OF CABLE INSULATION SAMPLES AT ORNL

BACKGROUND

The NRC in collaboration with EPRI and DOE among others recently released NUREG 7153 Volume 5 of the Expanded Materials Degradation Assessment (EMDA) that addresses aging in cable insulation and cable systems. This report summarized the current knowledge base of cable aging, the gaps in this knowledge, and methods that are currently used to quantify remaining useful life in cable insulation and cable systems. With respect to knowledge gaps, issues remain in the areas of inverse temperature effects (degradation near 45°C to 65°C) and synergistic effects (combined thermal/radiation aging). Figure 1 shows an example of the expected performance of cable insulation when synergistic effects are taken into account with respect to temperature and dose rate.

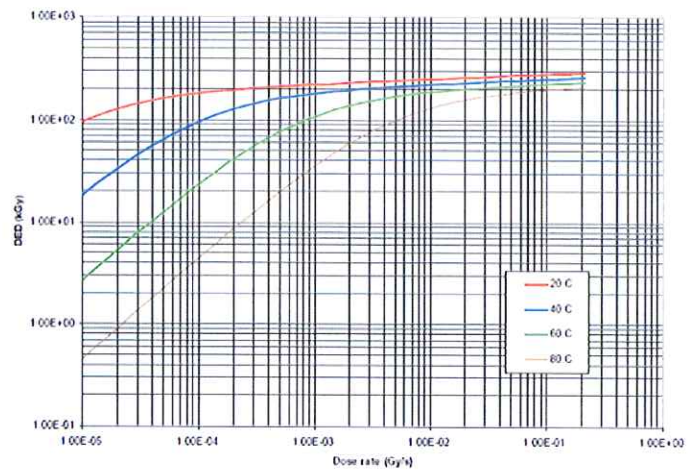


Figure 1. Theoretical dose required to reach a specific level of degradation as measured by dose-equivalent damage (DED) as a function of dose rate at different temperatures for a representative polymeric cable material from NUREG-7153.

As part of this EMDA, a phenomenon identification and ranking technique (PIRT) analysis was carried out across a broad spectrum of materials that ranked the knowledge of cable aging relative to the susceptibility to degradation. An example from NUREG-7153 is shown in Fig. 2. For example, if there is limited knowledge for cable insulation that is used in a control room where the accumulated dose is small and the increase in temperature when compared to ambient is also small, the need to study this material would not be as critical when compared to cable insulation that is near the containment vessel where the dose rate and change in temperature relative to ambient conditions is considerably higher and the consequence for replacement and damage is more significant. Based on the PIRT analysis and the EPRI-DOE-NRC Cable Aging Road Map, it is clear that thermal/radiation aging research with the dose rate between 0.01 Gy/hr and 10.0 Gy/hr and at temperatures between 45°C and 75°C for cross-linked polyethylene (XLPE), silicon rubber (SiR), and ethylene propylene rubber

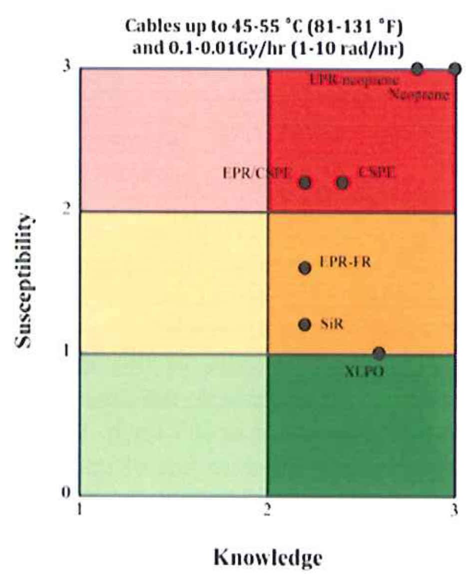


Figure 2. Susceptibility-Knowledge plot for cables at 45-55°C and 0.01 to 0.1 Gy/hr.

(EPR) is a critical need in developing a stronger understanding of cable aging in NPPs. These conditions serve as the initial target for this combined thermal/radiation aging design study.

HFIR GIF FACILITY

The Gamma Irradiation Facility (GIF) that is located at the High Flux Isotope Reactor (HFIR) was identified as the primary option at ORNL to provide the desired combined thermal/radiation aging for cable insulation and cable systems. The GIF consists of spent fuel elements that have been used during the operation of the HFIR over the past 30 years. The spent fuel elements are removed from HFIR and placed in the cadmium lined canisters shown in Fig. 3. After samples are inserted into a canister like the one shown in Fig. 3, they are placed into the central core or the effective flux trap of the fuel elements to obtain the desired gamma exposure and the canister is pressurized slightly above atmosphere (> 4psig) with either an inert gas or air to avoid water ingress from the pool during irradiation.

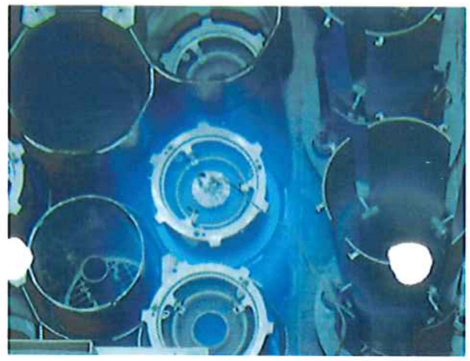


Figure 3. Overhead view of spent fuel pool at HFIR GIF (top) and canister (bottom) that is utilized for sample exposure in facility.

The age and nature of the spent fuel elemtns control the dose rate and dose rate profile. The dose rate along the length of the fuel element is surveyed prior to irradiation but for an "unmodified" fuel element, the dose rate profile can vary along the length as shown in Fig. 4. A "modified" fuel element refers to operations at HFIR when multiple, older spent fuel elements are combined to increase the dose rate. Given that the sample canister length is 24" long and the cable insulation/jacket sample under irradiation is between 1" to 4" long, multiple sample locations like the sample holder shown in Fig. 4 are possible and allow for different dose rates to be examined within the same sample run. The individual sample holder, which is shown in Fig. 5, was successfully used for a DOE Nuclear Energy Enabling Technology program radiation resistant dielectric project. The key aspects of the sample holder were the ability to load multiple samples and secure the sample holder to the wall of the canister to provide a thermal anchor to the pool temperature at 40°C. With the heater in the center of the sample holder, samples may be aged at temperatures between 40°C and 100°C. The absolute value of the dose rate is determined primarily by the age of the fuel element. For a 10 day old fuel element, the dose rate is 105 kGy/h (27 Gy/s). For the oldest fuel element available, the maximum dose rate is 405 Gy/h. With the variation of dose rate along the length, the dose rates are at the upper limit of the dose rate of interest (0.01 Gy/h to 10 Gy/h). However the data from this combined thermal/radiation can be used to develop models and determine cable aging mechanisms relevant to the lower dose rates.

In order to accommodate the longer and wider cable aging samples, the existing setup was modified as shown in Fig. 5. Essentially the length of the sample holders grows from 2" to 5" and the width for sample in the slots grows from 1/8" to 1/2". With respect to material cost using existing HFIR canisters and infrastructure, it will cost approximately $10,000 to fabricate new sample holders and procure the parts and instrumentation needed for the irradiation runs. If new infrastructure is needed, the cost for the canister and supporting material is between $5,000 to $10,000 depending on the amount of material needed. There are currently two canisters that are available for use but there are other interested parties that could be using these canisters and their use would impact the available time for irradiation at the HFIR GIF. This cost for the sample holders and canister is within the budget that was allocated for materials for this fiscal yeaer

With respect to time for the irradiation, each run will involve about 2-3 days to load the samples in the canister, 1 day to insert the canister in the HFIR GIF, and 1 day to remove and survey the cable insulation samples for activation. The irradiations will last between five to ten days depending on the temperature, dose rate, and accumulated dose. With a dose rate of 450 Gy/hr, a representative test run will be approximately 10 days to start populating a figure similar to the one that is shown for Fig. 1 for a given material.

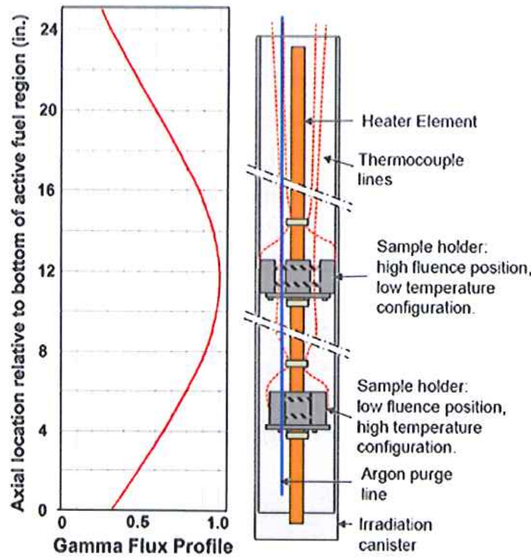


Figure 4. Flux profile with HFIR GIF for spent fuel element with uniform gamma decay (left) and sample holder schematic (right) that has been previously used to successfully irradiate cable insulation samples.

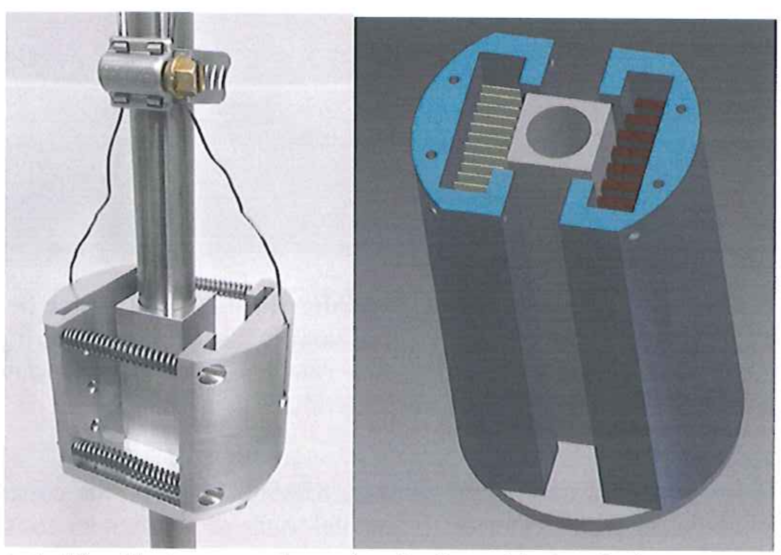


Figure 5. Sample holder that was used previously for cable insulation sample irradiations (left) and the modified sample holder with respect to height and sample area to accommodate cable aging samples that are approximately 1" to 4" in length and 0.5" in width (right).

CO-60 IRRADIATOR

During the course of the design study a comparison to other irradiation facilities across other national labs and universities was informally done and through this process it was learned that a second gamma irradiation source is available with dose rates closer closer to the dose rates of interest. In addition to the HFIR GIF design work, preliminary analysis was done on a Co-60 source located at ORNL and is in a separate location from HFIR. The Co-60 irradiator, which is shown in Fig. 6, is gamma source that is used to expose materials at lower dose rate for a longer period of time in support of other programs at ORNL, both NE and non-NE. It has a sample area with a 6" diameter and an 8" height that can accommodate more samples when compared to the HFIR GIF. The other performance parameter of interest is that dose rate is 140 Gy/hr and is uniform over the entire volume.

In order to prepare the Co-60 irradiator for use as an irradiation source for the cable aging samples, additional work and materials are needed to get it ready when compared to the HFIR GIF. Currently, irradiations can only be done at a single dose rate at ambient temperature in air. The modified HFIR GIF sample holders could be modified for the Co-60 irradiator with separate heaters to have two independently controlled areas. The dose rate could also be lowered by surrounding the sample holder with lead shielding, as shown in Fig. 6. Based on first order attenuation models, a ½" thick lead cylinder would decrease the dose rate by a factor of 40%. When compared to the HFIR GIF, using of the Co-60 irradiator for cable aging could be advantageous due to the lower dose rate, availability, and easier access to remove cable insulation/jacket samples periodically during irradiation.

Figure 6. Co-60 irradiator with sample holder sitting above source (left) and the possible configuration for the cable aging sample insertion with multiple zones where the sample temperature or the dose rate could be varied through the usage of separate heaters or lead shielding, respectively.

While the estimate for the hardware is approximately $20,000 based on the current state of the design, addition refinement could lower this estimate. In parallel to the sample holder construction for the HFIR, design work and some preliminary testing will be pursued over the next two months to determine the the temperature and dose rate options within the Co-60 irradiator. In addition to the material cost, an estimate of $60,000 was obtained for test run of 60 days with four sample removals for the Co-60 irradiator.