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Technical Assistance for Fuel Cycle Facilities, Transportation and Spent-Fuel Storage, Site Decommissioning, and Uranium Recovery

Final Report

Task Order Number 6

Technical Assistance on the Evaluation of Resin Polymers Used in Storage and Transportation Cask Shield Designs

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Summary Report
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1.0 Statement of the Problem

NAC International (NAC) and Holtec International (Holtec) each use a resin polymer to provide neutron shielding for spent nuclear fuel storage casks. ATL reviewed and evaluated performance data, studies, and procedures provided by each company to help determine whether NRC could continue to have reasonable assurance that both resin polymers would provide adequate shielding over a 20-year design life (10 CFR 72.236). Each resin polymer was to be evaluated based upon its own merits. The two resin polymers to be evaluated were (1) NS-4-FR, manufactured by NAC International, and (2) Holtite-A, manufactured by Holtec International.

2.0 Discussion and Analysis

To determine the ability of the resin polymers to provide adequate neutron shielding for a minimum of twenty years, ATL analyzed their performance and composition in three different areas: (1) material chemistry, (2) manufacturing process, and (3) performance testing. The following evaluation reviews both materials in these three areas.

2.1 Material Chemistry

NAC and Holtec provided the pertinent chemical formulas and Material Safety Data Sheets for the raw materials that comprise NS-4-FR and Holtite-A respectively. NS-4-FR and Holtite-A are both epoxy phenolic resins. These resins, which by their nature have highly interconnected networks in their structure, are relatively resistant to radiation-induced changes in properties. As with other polymers, phenolic resins give particularly favorable radiation tolerance. Ionizing radiation causes a negligible damage in epoxy resins of diglycidyl ether of bisphenol at dose levels on the order of 1×10^6 Gy. However, ionizing radiation can cause some damage and possibly severe damage to epoxy resins of diglycidyl ether of bisphenol at dose levels on the order of magnitude of 10×10^6 Gy and 100×10^6 Gy, respectively (Reference: Radiation Resistance of Polymers and Composites, Roger L. Clough, Kenneth T. Gillen, In "Irradiation effects on polymers", Edited by D. W. Clegg and A.A. C, Elsevier Applied Science, 1991). Based upon design requirements, the resin polymers in question should not be subjected to dose levels exceeding 10×10^6 Gy, which is several orders of magnitude above the design basis used for transportation/storage casks.

2.2 Manufacturing Process

In general, the manufacturing process for a resin polymer can be divided into three stages: (1) receipt, verification and preparation of the raw materials; (2) mixing of the raw materials based upon the relevant formulas and pouring the mixture into the casks; and (3) curing.

Receipt, verification and preparation of the raw materials: NAC and Holtec have provided the relevant procedures that govern the receipt and verification of raw materials that comprise their formula. ATL has determined that these procedures provide reasonable assurance that the raw materials meet required specifications.

Mixing and Pouring: In the mixing process, it is important to ensure that there is little to no variation in mixing ratios of the raw materials. Varying the composition of the final product can affect curing time and shielding properties because the specific gravity of the material is the major factor for shielding performance. NAC is constrained by the Japan Atomic Power Company (JAPCO) license to keep the composition of NS-4-FR within certain tolerances. BISCO has demonstrated the justification for the materials and the mixing ratios. Holtec also relies on documentation by BISCO to justify the limits set on mixing ratios. This includes ranges for B_4C content. B_4C content is important not only because of its neutron attenuation capabilities, but also because of its impact on fire retardation. When B_4C is added to the mixture, it is replacing an equal amount of fire retardant. If the B_4C content is too high, then a sufficient amount of fire retardant could be replaced that would negatively impact the safe performance of the material. As long as the B_4C content is maintained within the parameters specified by BISCO, the fire retardation performance should not be an issue. ATL has determined that the mixing and pouring operations for both Holtec and NAC appear to be sound manufacturing processes.

Curing: The specific gravity of the final cured product determines the shielding properties and thermal and radiation effects on the material. The specific gravity after curing specified by Holtec and NAC should provide the proper conditions for shielding. Neither NAC nor Holtec measure the degree of curing on a batch basis with a laboratory test, based upon information reviewed. Both NAC and Holtec rely upon a pre-determined time period as specified in their procedures to allow full curing.

2.3 Performance Testing

Temperature and radiation dose are two parameters that can impact the performance of resin polymers. Each of these parameters can, if large enough, break down the chemical composition of the resin polymers because the polymers are known to have high hydrogen content. Hydrogen atoms can be broken from the material matrix and become entrained in the material. As the chemical bonds are broken with the hydrogen atoms, interstitial sites can be introduced into the material matrix, reducing the specific gravity of the material. Introduction of these interstitial sites with the presence of free hydrogen provides an indication that the chemical structure is being degraded, thus influencing shielding performance.

NAC has relied on performance testing that has been earlier performed by BISCO. Thermal tests and radiation tests were performed at elevated temperatures and doses that exceeded expected operational conditions. ATL reviewed the procedures and test results to determine the impact of these variables on the creation of voids. Because these tests were conducted at elevated temperatures and radiation doses, the tests provide reasonable assurance that the resin polymer provides adequate shielding over the designed lifetime.

Holtec has conducted thermal and radiation tests at elevated temperatures and doses, respectively, thus bounding the expected operational conditions. Holtec has projected that the beginning temperature to which the shielding material will be exposed will be less than 200 °F during operations, assuming the spent fuel is at least five years old. The results of the thermal tests have shown that weight loss was approximately 3% after 238 days at 325 °F, an acceptable rate of degradation. Based upon the data available to date from Holtec thermal tests, and the data from the radiation tests, ATL projects that a reasonable assurance has been provided that Holtite-A will provide adequate shielding over the design lifetime.

3.0 Conclusions

ATL concludes that a reasonable assurance has been provided that NS-4-FR and Holtite-A resin polymers will safely provide proper shielding over the design life. This conclusion is supported by the following technical considerations:

- The raw materials used in NS-4-FR and Holtite-A are known to be materials that provide excellent resistance to ionizing radiation to at least 10×10^6Gy and elevated temperatures above the anticipated operational temperatures,
- The mixing, pouring and curing procedures are adequate to minimize the creation of voids,
- The results of the thermal and radiation performance tests adequately ensure that NS-4-FR and Holtite-A should perform because (the experimental) bounding conditions were set well above expected operational conditions.