Enhancing Fire Resiliency of Fixatives and Coatings for D&D Activities to Mitigate Potential Release of Radioisotopes during Fire and Extreme Heat Conditions-16393

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ABSTRACT

In discussions with officials from the Department of Energy's Office of Environmental Management and Savannah River National Laboratory (SRNL), the requirement for enhancing the operational performance of fixatives, coatings, and decontamination gels to better address the unique deactivation and decommissioning (D&D) challenges being faced by the SRS 235-F Project, and other high priority D&D efforts across the DOE Complex such as the Waste Isolation Pilot Plant (WIPP), has been identified as a priority focus area for research and development (R&D). Of particular interest is the immediate operational requirement to enhance a fixative's fire resiliency and survivability under fire and extreme heat conditions in order to mitigate the potential release of radioisotopes into the environment when subjected to these conditions.

In support of the DOE-FIU Cooperative Agreement, under the Waste and D&D Engineering and Technology Development Project, Task 2: D&D Support for Technology Innovation, Development, Evaluation and Deployment, the FIU Applied Research Center (ARC), in close collaboration with SRNL, is leading the development, implementation, and execution of a phased effort to improve the operational effectiveness of fixative technologies in the critical areas highlighted above, and specifically focusing on enhancing fire resiliency without degrading fixing capacity or decontamination factor (DF). The research area being explored involves the analysis, laboratory experimentation, and testing of existing products, which through layering/combining with an intumescent coating, could possibly produce a synergistic effect, resulting in a new and improved process / material with characteristics that significantly improve operational performance in this area.

INTRODUCTION

Few emergency situations are of greater concern during D&D and storage activities than fire. As evidenced by the incident at WIPP in February 2014, and others across the DOE and international nuclear complex, the potential for a release of radioactive contaminants when exposed to fire is ever present. This is particularly true in those cases where there is an extensive use of fixatives in the deactivation and decommissioning process, as many of these products are highly vulnerable to fire and extreme heat conditions, thereby increasing the risk of a release of the radioactive contaminants resulting in potential exposure by workers and the public. Conducting focused, targeted research to address this operational requirement is a high priority so that viable solutions can be identified and, most importantly, rapidly deployed to mitigate the risk.

Leveraging a basic layering concept put forth by research scientists at SRNL as they explore techniques to improve the radiation resiliency and hardening of fixatives, research scientists at the FIU Applied Research Center (ARC) identified the potential application of this approach to enhance the fire resiliency of those same fixatives. In that vein, ARC scientists also leveraged extensive knowledge and experience in the use of fire retardant technologies by the U.S. military, and hypothesized that layering intumescent coatings with fixatives used in D&D activities had the potential to significantly enhance the fire resiliency of those fixatives and mitigate the potential release of contaminants during a fire.

Intumescent coating technology has been around for some time, but since 9/11, there have been extensive developments in this area, and their potential application to a wide array of problem sets, to include the aforementioned, is evident. Initially developed to protect and insulate various substrates from extreme heat and fire conditions in order to maintain their structural integrity, our research revealed that in certain instances the fire protection was so effective that it actually protected the primer itself on the substrate. It was subsequently deduced that this same level of protection that was afforded the primer on the substrate could potentially do the same for a fixative designed to trap radioactive contaminants on a substrate. In other words, capitalizing on technological developments in one area designed for a specific purpose could have direct application to many of the pressing problem sets encountered in D&D activities.

Intumescent coatings can be in the form of thin or thick films. As exhibited in figures 1 and 2 below, when exposed to fire, the intumescent coatings react to heat by swelling in a controlled manner to many times their original thickness to produce a carbonaceous char which acts as an insulating layer to shield the substrate (e.g.; steel, wood, etc.) to which it is applied. The intumescent mechanism and subsequent char formation absorbs heat from the fire, helping to keep the temperature of the substrate below its limiting temperature and providing an extended period of fire-resistance.

Figure 1. Intumescent coating reacting to flame / heat source.

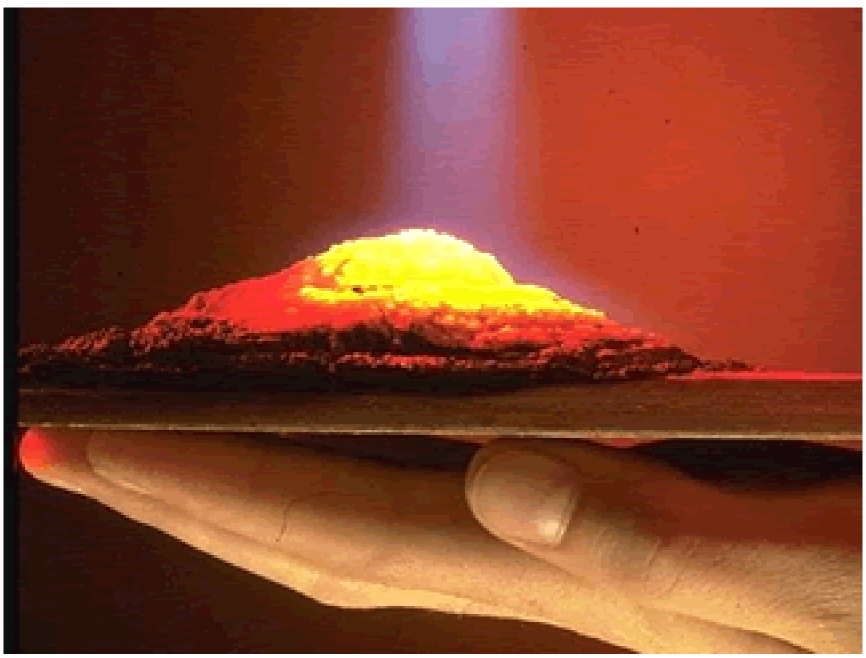

Figure 2. Protective shielding of intumescent coating.

With this as context and background, ARC research scientists moved forward and developed a comprehensive, phased approach to test the validity of the hypothesis. A 3-phased test plan was developed and approved by the various stakeholders (FIU ARC, SRNL, and DOE-EM) and initial implementation of that plan has yielded some positive results. To date, Phase I has been fully executed, culminating in a live demonstration to DOE-EM officials in November 2015. Based on the success of those findings, FIU ARC is moving forward with Phase II, and pending those results, will continue with Phase III with an anticipated completion date sometime in the Spring/Summer of 2016.

TECHNOLOGY DESCRIPTIONS

The fixatives, intumescent coatings, and decontamination gels selected and evaluated for this test plan were researched via: (1) FIU D&D technology databases (D&D KM-IT), (2) Peer-reviewed journal publications/literature searches, (3) Internet searches, (4) subject matter experts' consultations, (5) professional conferences and forums, and (6) vendor/manufacturers engagement and interface. Based on that research, the below list was comprised. In order to ensure confidentiality at this stage of the research, a very simplistic naming convention has been developed to identify the various products as outlined below.

1. Product A is a non-toxic, water-based fixative that forms a barrier between hazardous or contaminated materials and the environment. It advertises that it can be applied to any surface to lock down loose contamination and prevent leaching of contaminates after decontamination efforts. It is commonly used to stabilize large plant components, concrete, valves, and other problematic radioactive waste equipment prior to shipment.

2. Product B states it has the capacity to permanently stabilize radiological, beryllium, asbestos, and other hazardous contamination. It is used to permanently fix contamination on surfaces, and produces a hard coating that ensures stabilization of all dust and debris.

3. Product C is a high solids asbestos encapsulant/sealant, designed to encapsulate friable Asbestos Containing Material (ACM) such as fireproofing and insulation material. The high solids composition allows for dilution with water to provide maximum flexibility for specific asbestos abatement needs, including lockdown/removal, penetrating encapsulation and bridging encapsulation.

4 Product D is a self-leveling epoxy that produces a high gloss, seamless, durable surface in nuclear facilities subject to radiation, decontamination and loss of coolant accident.

5. Product E is recommended for decontamination of radioisotopes as well as particulates, heavy metals, water-soluble and insoluble organic compounds. It can be applied to horizontal, vertical and inverted surfaces of various

substrates including concrete, aluminum, steel, lead, rubber, Plexiglas, herculite, wood, porcelain, tile grout, and vinyl, ceramic and linoleum floor tiles. When dry, the product locks the contaminants into a polymer matrix.

6. Product F is an intumescent fire retardant and fire resistant coating that is advertised to withstand extreme temperatures (up to 2000° Fahrenheit) for an extended time (over two hours). It provides a fire barrier to a wide variety of materials including sheetrock, wood, plaster, concrete, sheet metal, tin, foam, foam composite panels as well as advanced materials such as fiberglass and carbon fiber.

EXPERIMENTATION

The test plan developed to support this research and experimentation has been divided into three distinct phases, with the findings and processes from each supporting the next. Though there are multiple test objectives embedded in each phase, the main ones are as follows: 1) Conduct analytical tests to baseline the selected fixative and coating technologies in accordance with ASTM E84 and ASTM D1360 standards to determine their fire resiliency qualities and characteristics as stand alones; 2) Conduct initial proof of concept experiments to determine if layering existing fixative technologies with an intumescent coating yields improved material properties and enhances the operational performance of these materials in the area of fire resiliency when exposed to direct flame / extreme heat conditions. A summary of each of the phases is contained below.

Phase I: Baseline Selected Products / Technologies in accordance with ASTM E84 / ASTM D3806 Equivalency and ASTM D1360 Test Standards, and Conduct Proof of Principle Experiments Through Exposure of Uncontaminated Coupons to Direct Flame

Stage I of Phase I was designed to baseline the fixatives, coatings, and decon gels as outlined above in accordance with ASTM E84 and ASTM D1360. These two test methods are uniformly accepted throughout the industry as being critical indicators that quantifiably characterize the fire resistant/fire retardant capabilities of paints, coatings, etc. The intent in establishing baselines for the respective fixative products is to facilitate future analysis and quantitative measures / improvements in operational performance.

ASTM E84 determines the comparative burning characteristics of coatings by evaluating the flame spread over the surface when ignited under controlled conditions in a small tunnel. This establishes a basis for comparing surface-burning characteristics of different coatings without specific consideration of all the end-use parameters that might affect surface-burning characteristics under actual fire conditions. The Flame Spread Index and Smoke Developed Index values obtained by the ASTM E84 / ASTM D3806 equivalency test are used by code officials and regulatory agencies in the acceptance of interior finish materials (e.g.; paints and coatings) for various applications. The most widely accepted classification system is described in the National Fire Protection Association publication NFPA 101, *Life Safety Code.* that states, “finishes shall be classified in accordance with ASTM E84, and such coating materials shall be grouped in the following classes in accordance with their flame spread and smoke-developed indexes.

i. Class A: Flame Spread 0-25’; smoke-developed 0-450
ii. Class B: Flame Spread 26-75’; smoke-developed 0-450
iii. Class C: Flame Spread 76-200’; smoke-developed 0-450”

ASTM D1360 (Standard Test Method for Fire Retardancy of Paints) determines quantitatively the fire retardant properties of a coating or coating system on a wood surface and the leaching effect of water on the fire retardancy of the coating or coating system. Specifically, this test method determines the weight loss and char index of coated panels subjected to a flame and the effect of leaching of the coating on these parameters.

Stage 2 of Phase I was developed as a proof of concept designed specifically to test the hypothesis by having each of the uncontaminated coupons exposed to a direct flame from a propane torch. FIU ARC constructed an apparatus specifically designed to support the experimental set-up, which allowed for the testing of three (3) 12”x12” red oak coupons simultaneously (see figure 3 below). From 19 Oct – 5 Nov, a set of “fixative-only” coupons was prepared with each of the products being applied to the red oak substrate in strict accordance with the manufacturer’s instructions, under ideal environmental conditions (47% humidity and 72 degrees F), and were allowed to cure. In parallel, a set of “fixative plus intumescent coating” coupons were also prepared, again in strict accordance with the vendor’s instructions, and allowed to cure. Once the application and curing components were completed, the coupons were placed into the apparatus at a distance of 4” from the propane torches and subjected to a direct flame for various time periods (see figure 4). This process was methodically conducted over the testing period and data collected.

Figure 3. Phase I, Stage II experimental set-up.

Figure 4. Phase I, Stage II direct flame exposure.

Phase II: Proof of Concept on Uncontaminated Coupons Through Exposure to Extreme Heat Conditions Using a Muffle Furnace

Phase II is intended to conduct controlled tests on “clean”, uncontaminated coupons using different substrates by incrementally increasing the temperatures in a muffle furnace. Similar to Phase I, Stage II above, ARC will apply each of the products to their own “fixatives-only” coupons, and then apply the various fixatives plus a layer of intumescent coating to a second series of coupons. Coupons in this particular instance will be 4”x4” red oak and sheet metal cuts in order to facilitate placement into the muffle furnace. The same application and curing procedures will be followed.

ARC will subject the cured “fixative-only” coupons to incrementally increasing temperatures (e.g.; 100 ^{0}F, 200 ^{0}F, 300 ^{0}F, 400 ^{0}F, and so forth) in a muffle furnace, for a time period of 2 hours per temperature, allow the coupon to cool for 1 hour, and then record the effect of the heat to the fixative. Effects observed and recorded will be the amount of weight lost, thickness degradation, and a visual inspection for evidence of failure, including peeling, cracking, blistering, abnormal discoloration, or loss of adhesion. The intent is to determine at what temperatures each of the designated fixatives begin to breakdown and display negative effects that could degrade its intended purpose, specifically fixing radioactive contaminants. Once the temperature threshold has been reached for a particular coupon, the incremental heating process will cease for that sample and the results / observations recorded.

ARC will follow the same procedures for the second series of coupons (fixative plus intumescent coating), and the results will be consolidated and analyzed as well. Again, the intent of this phase is to identify at what temperature each respective product begins to degrade, thus making it vulnerable to a potential release of a radioactive contaminant, and then observe whether that same fixative layered with an intumescent coating maintains its integrity longer and under more extreme heat conditions. FIU ARC anticipates completing Phase II by 8 Jan 2016.

Phase III: Proof of Concept on Contaminated (Uranium Oxide) Coupons Through Exposure to Extreme Heat Conditions Using a Muffle Furnace

Incorporating the data points obtained from Phase II, Phase III is designed to test the hypothesis on uranium oxide spiked coupons. These experiments will be conducted at FIU ARC's State of Florida Licensed Radiological Laboratory. The purpose is to simulate an operational radioactive environment while maintaining strict adherence to safety requirements.

The uranium oxide powder will be fixed to a set of 4"x4" steel and wood coupons by applying the selected fixative/coating/decon gel to the coupons in accordance with the vendor's application procedures. The coupons will then be measured for radiation and the results recorded. A basic swipe test will be conducted to ensure the powder is fixed to the coupon (verified by measuring potential radiation on the wipe after the swipe). This process will be repeated, if necessary, until all participants agree that the resin is sufficiently fixed to the coupon. The coupon will then be weighed.

ARC will subject the cured coupons (fixative only) to incrementally increasing temperatures (e.g.; 200 deg, 300 deg, 400 deg, and so forth) in a muffle furnace, for a time period of 2 hours per temperature, allow it to cool after each iteration for 1 hour, conduct a swipe test, measure for radiation (both coupon and wipe), and record the results. Effects recorded will also include weight loss and visual observations. The intent is to determine at what temperature the fixative begins to display negative effects that could degrade its intended purpose/fixing capacity. Once this point has been reached, the experiment will cease on that particular coupon. The same general process will occur for the other set of coupons (fixative plus intumescent coating), and the results recorded. In this particular Phase, we anticipate being able to identify at what temperature each fixative degrades to such a degree that there is a release of radioisotopes, and then to what extent those same fixatives, when layered with an intumescent coating, exhibit improved resiliency to extreme heat conditions, if any. Phase III is expected to be completed by 12 Feb 2016.

RESULTS AND ANALYSIS

At the submission deadline for this initial draft paper, the results from FIU ARC's R&D for this effort are not yet complete, with Phase I just concluding and Phases II and III projected to be executed in January and February 2016, respectively. However, it is fully anticipated that by the WM'16 Conference scheduled in March, analysis of the data will provide sufficient opportunity to present the findings during the professional oral presentation.

That said, some initial observations from Phase I can be highlighted as a precursor.

Figure 5. Fixative and intumescent coating coupons reacting to direct flame source.

Figure 6. Fixative continuing to burn after exposure to direct flame.

First, in each case during Phase I, every “fixative only” coupon exhibited signs of significant degradation when exposed to the direct flame, with several of the fixatives igniting upon contact. Vice versa, in every instance those same fixatives, when layered with the intumescent coating, displayed clear, outward signs of enhanced fire resiliency (see figures 5 and 6 above). Most of the fixative only coupons were significantly degraded after only 1-2 minutes of exposure, while all those same fixatives, when layered with the intumescent coating, continued to remain relatively intact for up to 35 minutes as the intumescent coating expanded and charred, creating an insulating effect. More importantly, when the intumescent coating was removed and the fixative underneath was exposed, the fixative coating displayed little to no visual damage.

Though much more research is required, the initial findings are promising, and seem to support, at least conceptually, that layering an intumescent coating on the designated fixatives improves fire resiliency and has the potential to mitigate the potential release of radioactive contaminants under fire / extreme heat conditions.

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