TECHNICAL PROGRESS REPORT

Incombustible Fixatives – Adapting Intumescent Coatings as Fire Retardant Fixatives to Support D&D Activities

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EXECUTIVE SUMMARY

In support of the DOE-FIU Cooperative Agreement under Project 3 (Waste and D&D Engineering and Technology Development), Task 2 (D&D Support for Technology Innovation, Development, Evaluation and Deployment), the Applied Research Center (ARC) at Florida International University (FIU), in close collaboration with Savannah River National Laboratory (SRNL), is leading the development and implementation of a phased approach to improve the operational effectiveness of fixative technologies in the critical area of fire resistance to better address the unique deactivation and decommissioning (D&D) challenges being faced by the Savannah River Site (SRS) 235-F Project and other high priority efforts across the DOE complex. Leveraging firsthand knowledge and experience of ARC research scientists in the use of intumescent coatings to harden facilities and improve fire protection in support of the U.S. military, and combining it with a basic layering concept put forth by research scientists at SRNL, it was hypothesized that commercial-off-the-shelf (COTS) intumescent materials could be adapted to enhance fire resiliency in fixatives and potentially mitigate the release of radioisotopes when exposed to fire and/or extreme heat.

In September 2015, ARC embarked on a series of proof-of-concept experiments to test the validity of the premise. The first component was to evaluate the state of industry fixatives currently in use and set the foundation for comparison to intumescent coatings. A baseline of five (5) commonly used fixatives and decontamination gels was conducted, and notable shortfalls and deficiencies were revealed, particularly in the critical area of fire resiliency. The key findings from that baseline activity are detailed in this report and Appendix A. In brief, all 5 fixatives demonstrated significant vulnerability to fire and extreme heat. Furthermore, parallel baselining of the 5 fixatives for radiation resiliency and environmental durability by SRNL have identified vulnerabilities in these functional areas as well.

Next, five (5) COTS intumescent coatings were investigated using the same methods, and then new protocols were developed to test and evaluate if layering the intumescent coatings over the fixatives would improve their operational performance in terms of fire resiliency. Initial test results have been promising, and validated the enhanced fire resiliency provided by intumescent coatings, to include: 1) improvement in fire resiliency of fixatives on various substrates (stainless steel, wood, glass, etc.); 2) minimization of flame spread and heat transfer; and 3) superb thermal insulation. Furthermore, though the testing is still underway and the initial results are being reviewed by SRNL, the intumescent coatings are also outperforming several of the fixatives in other key operational categories such as durability against less than ideal environmental conditions (temperature and humidity) and radiation resistance. These findings have prompted discussions about the possibility of adapting certain COTS intumescent coatings as standalone fixatives in and of themselves.

The results were presented to SRS 235-F site and safety personnel and DOE EM HQ in January, April and May 2016. The potential application to several of the most pressing D&D challenges was immediately evident, specifically improving the overall fire protection posture and decreasing the nuclear load within the safety basis of the facility, and an expedited R&D plan to adapt the technology to the radioactive environment encountered at SRS 235-F was requested.

DOE EM HQ further requested the ARC examine other potential fire protection applications of the technology across the DOE complex, with a particular emphasis on WIPP.

INTRODUCTION

Few situations are of greater concern during D&D and interim storage activities than the possibility of a fire. As evidenced by the incident at WIPP in February 2014, and others across the DOE and international nuclear complexes, the potential for a release of radioactive contaminants when exposed to fire is ever-present. In addition, many of the fixative products in common use during D&D of facilities are highly vulnerable to fire and extreme heat conditions, thereby increasing the risk of a release of the radioactive contaminants, resulting in potential exposure to workers and the public.

The Basis for Interim Operation (BIO) in support of SRS 235-F contains a postulated accident scenario where an earthquake causes a breach of the facility containment structure. This seismic event is also postulated to initiate a large room fire which could propagate and potentially evolve into a full facility fire which engulfs the material at risk (MAR) such as residual Pu-238 and Np-237, causing it to become airborne and released from the building. The responsible site contractor has determined that the unmitigated consequences of this event are greater than 10 rem offsite and 27,000 rem to the collocated worker at 100 meters. This contingency, and others related to fire across the various sites, has prompted a requirement for fire retardant / fire protection technologies that can enhance a facility's overall fire protection posture and mitigate the release of radioisotopes during these emergencies.

Since 9/11, there have been extensive developments in the area of intumescent coatings as a viable technology in fire and explosion protection. Initially developed to protect and insulate various substrates from extreme heat and fire conditions in order to maintain their structural integrity, research revealed that in certain instances the fire protection was so effective that it actually protected the primer itself on the substrate. ARC research scientists had firsthand knowledge and experience in the use of intumescent coatings to harden facilities and improve fire protection in support of the U.S. military, and through leveraging a basic layering concept put forth by research scientists at SRNL, explored the feasibility of using the technology to enhance fire resiliency in fixatives used in D&D. Additional research confirmed that agencies such as the National Aeronautics and Space Administration (NASA) and the Department of Homeland Security (DHS), as well as industries like oil and gas, have used this proven, cost effective technology with excellent results. In other words, capitalizing on technological developments in one area designed for a particular purpose could have direct application to many of the pressing problem sets encountered in enhancing fire resiliency during D&D activities.

Intumescent coatings are designed to swell between 10 to 100 times their original thickness into a robust, insulating char / foam upon exposure to heat, protecting the underlying material from fire by providing a physical barrier to heat and mass transfer (see Figures 1 and 2). Additionally, flame spread is inhibited through mechanisms common to other charring materials, and also reduces heat transfer to interior components. The closed foam / char structure that forms inhibits the transport of volatiles to the environment and the transport of oxygen to unburned regions beneath the char, and the retention of mass in the char limits further involvement of the underlying materials in the fire. Furthermore, many intumescent coatings are exceptionally cost effective (as low as 75 cents per square foot) and can be easily applied via brush, roller, or sprayer to a wide variety of substrates (stainless steel, wood, sheetrock, sheet metal, etc.). Lastly, depending on the substrate and specific requirement, as little as two coats (10-30 mils) meet or exceed fire protection regulatory ratings as measured by ASTM E119, ASTM E84, etc.

With this as context and background, ARC and SRNL moved forward and developed a comprehensive, phased approach to conduct a series of proof-of-concept tests and evaluations on the potential of adapting intumescent coatings to enhance the fire retardant qualities of fixatives. 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.

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

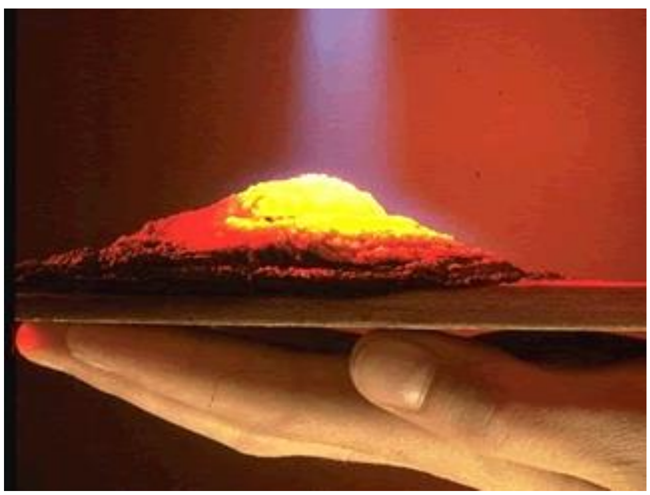


Figure 2. Protective shielding of intumescent coating.

EXPERIMENTAL DESIGN

The fixatives, intumescent coatings, and decontamination gels selected and evaluated were researched via: (1) FIU D&D technology databases (D&D KM-IT), (2) Peer-reviewed journal publications/literature searches, (3) Internet searches, (4) Consultation with subject matter experts, (5) Professional conferences and forums, and (6) Vendor/manufacturer engagement and interface. Based on that research, the product list below was developed. 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.

Industry Fixatives

The following industry fixatives were used:

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 accidents.
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.

Intumescent Coatings and Materials

The following intumescent coatings and materials were used:

1. Product FG is an intumescent fire retardant and fire resistant coating that is advertised to withstand extreme temperatures (up to 2000° Fahrenheit) for an extended period of 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.

2. Product FD is a sprayable, water-based material that dries to form a durable, elastomeric firestop coating. This material, when used as part of an assembly, will firestop building joints, perimeter joints (curtain wall), and through penetration seals. It is advertised to provide up to 4-hour fire protection in construction joints.
3. Product FF is a water-based, non-toxic, thin film intumescent fire retardant and resistant coating fully tested to provide fire ratings required by the International Building Code for wall assemblies, floor/ceilings assemblies, roof ceiling assemblies and individual structural members.
4. Product IM is a flame retardant / intumescent agent that advertises to be ideal for incorporation into thermoset coatings and foams, potting compounds, fiberglass reinforced structures, electrical laminates, thermal plastics, paints, films, resins and many other applications.
5. Product ICH is a single component, borate-free, high solids, low volatile organic compound (VOC) intumescent coating designed to provide fire protection to structural steelwork and has been independently tested at accredited laboratories.

ARC has also recently ordered a sixth COTS intumescent coating used by some of their research scientists in the military, but it has not yet been received or tested as of this Technical Progress Report. This intumescent coating will be called “FX” under the naming convention and has been previously tested extensively by the U.S. military. The coating has been utilized in numerous applications requiring fire and thermal protection, including ships, tanks, military vehicles, shelters, aircraft, and space vehicles.

Baseline and Proof-of-Concept Test Plan

The initial test plan developed to support this proof-of-concept was developed by the ARC and approved by the various stakeholders on July 9, 2015. The primary test objectives were as follows: 1) Baseline the five selected industry fixative technologies using tailored ASTM E84, ASTM E119, and ASTM D1360 protocols to determine their inherent, standalone fire retardant qualities and characteristics (modifications from the exact protocol were incorporated to better address specific conditions and requirements outlined by site personnel), and; 2) Conduct initial proof-of-concept experiments to determine if layering the selected fixative technologies with the selected COTS intumescent coatings would yield improved fire protection for the fixatives when exposed to a direct flame (propane torch) and extreme heat conditions (muffle furnace). Based on regular and extensive coordination with SRNL and SRS 235-F site personnel throughout the testing period, slight modifications to the test plan were made based on results obtained in order to remain responsive to operational requirements.

For the first test objective, baselining selected fixatives designed to support D&D activities in order to determine their inherent fire resiliency, it is important to highlight that there are no uniform testing protocols or standards specifically for D&D fixatives in this particular area. Therefore, ARC decided to develop a series of tests that incorporated various elements of certain ASTM International fire-related standards designed for paints, coatings, and construction materials. ASTM D1360 (Standard Test Method for Fire Retardancy of Paints), ASTM E119 (Standard Test Methods for Fire Tests of Building Construction and Materials), and ASTM E84

(Standard Test Method for Surface Burning Characteristics of Building Materials) were chosen to serve as the basis for these baseline experiments. In collaboration with the various stakeholders, those elements deemed most appropriate from the above mentioned ASTM standards were compiled and modified where necessary to form the basis of the baseline testing.

To test fire retardant characteristics when exposed to an open flame, ARC constructed an apparatus which allowed for the testing of three (3) test coupons simultaneously (see Figure 3). A set of fixative-only test coupons of various sizes and materials was prepared with each of the products being applied to the substrate of choice in strict accordance with the manufacturer's instructions, to the requisite thickness, under ideal environmental conditions (47% humidity and 72ºF), and were then allowed to cure. The substrate materials used included 12”x12”x1/2” red oak, 4”x4”x1/8” stainless steel, 4”x4”x1/2” sheetrock, and 4” diameter glass Petri dishes.

Figure 3. Open flame testing apparatus with 3 red oak test coupons.

Once the curing process was complete on the designated test coupons, relevant observations were made and documented in terms of visual observations, total mass, and fixative thickness, and they were then placed in the open flame testing apparatus and exposed to a flame generated by a propane torch approximately 4” from the center of the coupon for up to 5 minutes, depending on the resiliency of the fixative (see Figure 4). Observations were again taken and recorded in the various categories. This testing continues and is being repeated for each of the selected fixatives on each of the different substrates with a results matrix currently under development to capture and record the data.

Figure 4. Open flame testing of fixative-only test coupons on red oak substrate.

Under the first test objective, in order to baseline the 5 fixatives' resiliency against extreme heat, ARC applied each of the fixatives in accordance with the manufacturer's instructions to 4"x4"x1/8" stainless steel coupons as well as 4" diameter glass Petri dishes, and then exposed them to incremental temperature increases from 200°F - 800°F for a period of 15 minutes at each temperature setting (see Figure 5). Data points were observed and recorded (visual observations and mass measurements) at the onset as well as at the completion of each temperature setting with the intent of developing mass loss profiles for each fixative. Once again, there are no uniform testing protocols for determining the resiliency of fixatives used in D&D activities against extreme heat conditions, so a similar approach was pursued in developing the protocols to support the baselining experiments.

Figure 5. Fixative "A" on steel test coupon after exposure to 400ºF in muffle furnace.

For the second test objective, conducting proof-of-concept experiments to determine if layering fixatives with COTS intumescent coatings could enhance overall fire resiliency, a series of basic testing protocols were developed in close collaboration with SRNL. These protocols mirrored those outlined above, but with the addition of layering the designated fixative-covered coupon with a selected intumescent coating to the manufacturer's recommended thickness for the particular substrate.

For the open flame series of tests, once the application and curing components were completed, the fixative-plus-intumescent-coating test coupons were placed into the open flame apparatus at the same 4" distances from the propane torches to the center of the coupon. They were then subjected to a direct flame for 30 minutes. The extended time period, as compared to the fixative-only test coupons at 5 minutes, was pursued because it became immediately apparent that the fixatives-layered-with-intumescent-coating test coupons were significantly more fire retardant. This testing continues and is being repeated for each of the possible intumescent coating / fixative combinations on each of the different substrates with data being captured and recorded in a results matrix currently under development.

For the exposure to extreme heat series of proof-of-concept tests for the second objective, a similar testing protocol was pursued. ARC applied each of the fixatives in accordance with the manufacturer's instructions to 4"x4"x1/8" stainless steel coupons as well as 4" diameter glass Petri dishes, and then layered them with a selected intumescent coating to the recommended thickness for the substrate. Each fixative-plus-intumescent-coating test coupon was then exposed to incremental temperature increases from 200°F - 800°F for a period of 15 minutes at each temperature setting. Data points were observed and recorded (visual observations and mass measurements) at the onset as well as at the completion of each temperature setting with the intent of developing mass loss profiles for each fixative-plus-intumescent-coating test coupon. This testing continues and is being repeated for each of the possible intumescent coating / fixative combinations on each of the different substrates with data being captured and recorded in a results matrix currently under development.

It is interesting to note the utility of using the glass Petri dishes in this series of tests. Since the intumescent coating was layered over the fixative, and the Petri dish is transparent, ARC research scientists were able to make visual observations of the test coupons once the charred intumescent coating was removed from the bottom of the Petri Dish (see Figure 6).

Figure 6. Visual observation of fixative "E" (white) layered with intumescent coating "FD" (red) on glass Petri dish after the intumescent coating was removed.

PRELIMINARY RESULTS

It is important to re-emphasize that this is a completely novel approach to enhancing the fire resiliency of fixative technologies used to support D&D activities, and therefore the majority of the testing to date has been purposefully oriented towards basic proof-of-concept experiments to confirm whether the approach has merit. None of the intumescent coatings on the market today are designed for this specific purpose, and there is still significant research and development required to successfully adapt intumescent coatings to D&D activities to enhance the fire resiliency of fixatives and facilities. That said, the preliminary results to date from this particular effort are important in that: 1) they identified a potential vulnerability in fire resiliency (and possibly radiation resistance and environmental durability via testing at SRNL) of the current line of fixatives used in the industry today, and 2) they have been promising in identifying the adaptation of intumescent coatings as a potentially viable approach to enhancing fire resiliency of fixatives and facilities in support of D&D activities.

As highlighted in the Executive Summary, the series of baseline experiments implemented by ARC for industry fixatives currently in use today identified significant shortfalls and deficiencies in their fire retardant characteristics, and parallel testing efforts being conducted by SRNL for radiation resistance and environmental durability have yielded similar findings in those key functional areas. The below highlights some of the key findings from ARC's baseline testing:

1. At temperatures as low as 300-400°F, melting from the substrate occurred with every fixative in as little as 3-5 minutes of exposure, resulting in contaminant transport.
2. All 5 fixatives/decon gels began to exhibit mass loss at temperatures as low as 200°F, and the most significant degradation in terms of mass loss, desiccation, off-gassing, and chemical breakdown occurred between 600-800° F.
3. All 5 fixatives/decon gels lost between 70% to 90% mass when exposed to fifteen minute incremental temperature increases between 200-800°F. The chemical breakdown was so complete researchers assessed there would likely have been a release of radioisotopes if applied to a contaminated substrate.
4. All 5 fixatives/decon gels ignited / became flammable almost immediately when exposed to an open flame and burned completely off the various substrates within 1-5 minutes. A likely release of radioisotopes was deduced if applied to a contaminated substrate.

Though the presentation in Appendix A provides a detailed, comprehensive review of the impacts to each individual fixative when exposed to incremental temperatures, Figure 7 provides a good, general snapshot of the basic fixative profile exhibited by all the fixative materials tested.

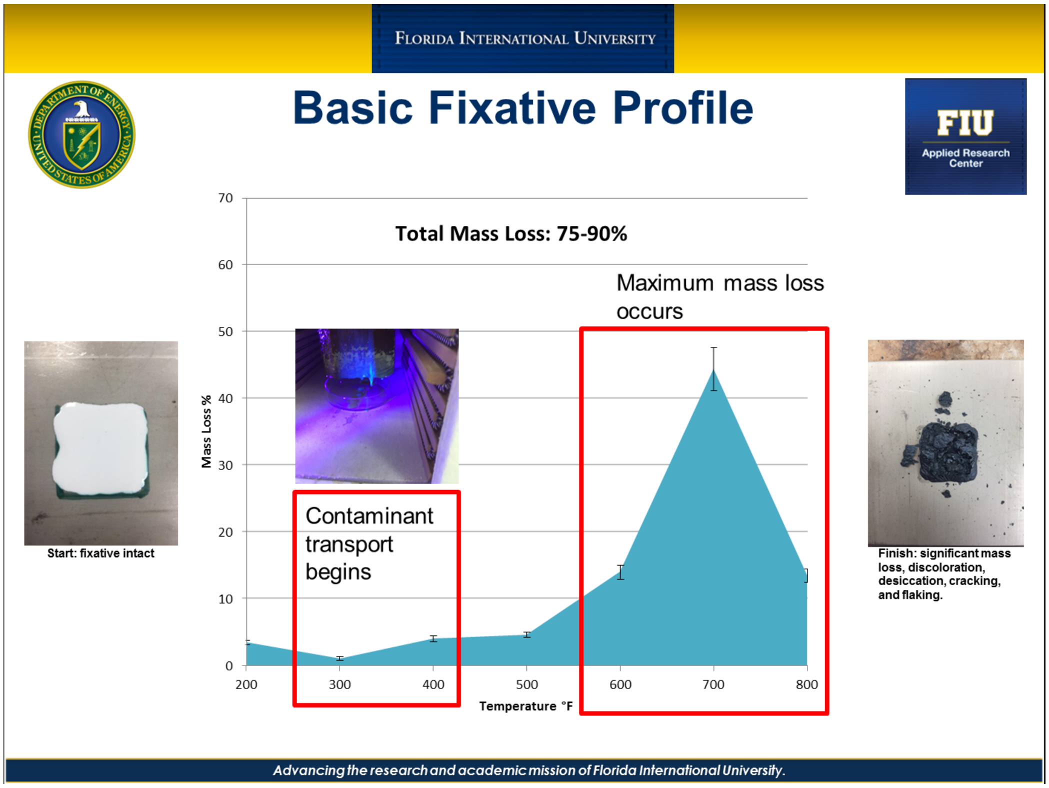


Figure 7. Basic fixative profile when exposed to extreme heat.

As depicted above, the use of GloGerm, a UV fluorescing compound, as a simulated contaminant allowed ARC researchers to identify the general impacts on contaminant flow when the fixatives were exposed to increasing temperatures. In every instance, for all 5 fixatives baselined, contaminant flow was observed between 250°F and 450°F. Furthermore, again in every instance, each fixative baselined displayed characteristics indicative of a near complete chemical breakdown at temperatures between 600°F and 800°F. Finally, during the open flame series of baseline tests, all 5 fixatives demonstrated notable deficiencies, with each one burning completely off the substrate within 1-5 minutes (see Figures 8 and 9).

Figure 8. Fixative "B" burning off a red oak substrate test coupon.

Figure 9. Fixative "A" continuing to burn after removal of flame source.

However, the preliminary results associated with the proof-of-concept on layering fixatives with an intumescent coating proved promising as highlighted by some of the key findings below. ARC and SRNL researchers are cautiously optimistic that fire resiliency of fixatives and facilities can be enhanced through the adaptation / integration of intumescent coatings, and the approach definitely warrants more extensive R&D. Again, the presentation in Appendix A provides more detailed documentation, but some of the more relevant findings include:

1. All 5 fixatives, when layered with any of the intumescent coatings, conclusively displayed enhanced fire resiliency when exposed to the propane torch / open flame on all substrates (see Figure 10).
2. Long term thermal insulation protection was recorded and documented.
3. Minimum flame spread and smoke was noted.
4. Mitigated damage, reduced off-gassing, and lessened mass loss of the fixatives occurred when fixatives were layered with an intumescent coating and subjected to extreme heat.

Figure 10. Demonstration of protection provided against flame when layered.

As shown in Figure 10, the middle panel demonstrates the effectiveness of layering a fixative with an intumescent coating. The left and right panels are covered in fixative only and burned completely off within 5 minutes of exposure to the flame source. The middle panel had a small area layered with intumescent coating “FG” over fixative “A”. Charring immediately occurred and protected both the substrate and the majority of the fixative for over 30 minutes. Flame spread / propagation was minimal, never extending more than 2-3 inches from the center.

These initial results and findings have prompted ARC researchers to recommend continued investigation into the concept of adapting intumescent coatings to enhance fire resiliency of fixatives used for D&D activities.

FUTURE WORK

Since the January 2016 brief to site personnel, ARC and SRNL have conducted extensive coordination with SRS 235-F personnel to facilitate planning in order to expedite the R&D related to this effort. An initial set of documents associated with the specific facility hot cells, including schematics, assessment of the manipulator arms, anticipated particulate sizes of the Pu-238 contamination, an approved tooling list, etc., were formally reviewed and approved for release by the site to ARC. Utilizing these as a foundation, pre-planning for further adaptation of the intumescent coatings and the application during a full-scale cold demo at a hot cell testbed at ARC has commenced in anticipation of funding.

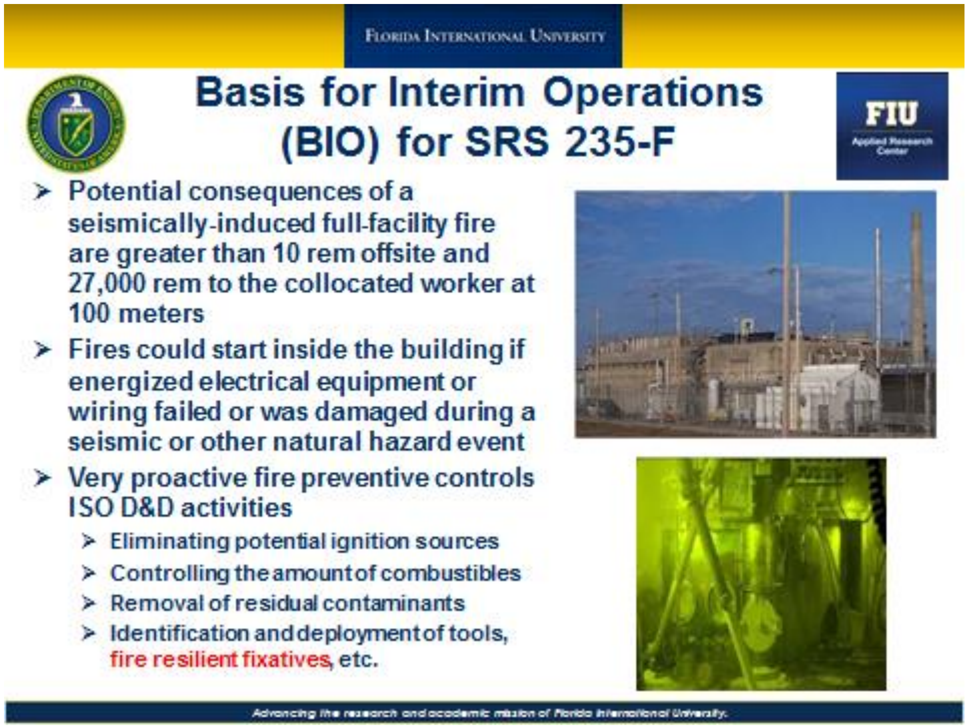
Based on initial discussions, future scope of work will have four main objectives: 1) confirm the specific operational, safety, and regulatory requirements that the intumescent coating fixative will need to satisfy; 2) continue the baseline testing of additional commercial-off-the-shelf intumescent coatings with the intent of identifying the one to two that best satisfy those specific requirements; 3) construct a full-scale mock-up of the SRS 235-F shielding cell to the greatest extent possible at the ARC testbed; and 4) conduct a full-scale cold test demo of the intumescent coating and its application in the testbed at ARC.

Additionally, some of the most recent discussions have highlighted the possibility of demonstrating the concept on a contaminated entry hood at the SRS 235-F facility. It is anticipated that contamination will remain after standard decontamination procedures. Consequently, the contaminants will be a primary focus, and ensuring that the intumescent coating is capable of fixing Pu-238 in particle sizes ranging from 10-300 um will be a focus area for testing. Secondly, heat generation from the Pu-238 will be another criterion the intumescent coating will need to address as this is a nontrivial parameter unique to Pu-238. Once decontamination operations on the selected apparatus are complete, tests will be performed by SRNL to quantify the remaining radioactive material, and this will provide a more precise data point from which to extrapolate the heat the intumescent material will need to withstand. Finally, for the fire resiliency baselining, an acceptable surrogate for Pu-238 will be identified (e.g., CeO2, WO4, UO2, TiO2, or other). Stainless steel coupons will be contaminated at ARC in a manner that closely matches the particle distribution expected to be encountered, then covered with the intumescent coatings, and burned at incremental temperatures to confirm its effectiveness in mitigating particulate release during fire / extreme heat conditions. These baselining tests will be conducted on the current line of industry fixatives as well to ensure a side-by-side comparison with the intumescent coatings can be made.

Though the primary area of focus will be working with SRNL to demonstrate the effectiveness of intumescent coatings in addressing high priority fire resiliency / protection and safety requirements in support of the SRS 235-F D&D project, it is envisioned this fire retardant technology will have much broader applications in mitigating the impacts of contingency scenarios outlined in Basis for Interim Operations documents at other sites. Consequently, ARC will also begin to investigate these potential linkages and make recommendations for future adaptations of intumescent coating technology to satisfy other problem sets and challenge areas related to fire / extreme heat conditions, with a particular emphasis on WIPP.

APPENDIX A

Incombustible Fixatives Technical Progress Presentation to DOE HQ



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Baseline of Fixatives ISO D&D Executive Highlights

Melting / expansion / transport of fixative and contaminant began, on average, at 300^{o}-400^{o} F within minutes of exposure

All 5 fixatives began to exhibit minor mass loss starting at temperatures as low as 200^{o} F, but most significant degradation in terms of mass loss, desiccation, chemical breakdown / change, etc. occurred between 600^{o}-800^{o} F (ref matrix and charts)

All fixatives lost anywhere from 70% to upwards of 90% mass when exposed to incremental temperature increases (200^{o}-800^{o} F). Again, greatest mass loss percentage occurred between 600^{o}-800^{o} F.

All 5 fixatives "ignited" / became flammable almost immediately when exposed to the propane torch / open flame and burned completely between 1-5 minutes.

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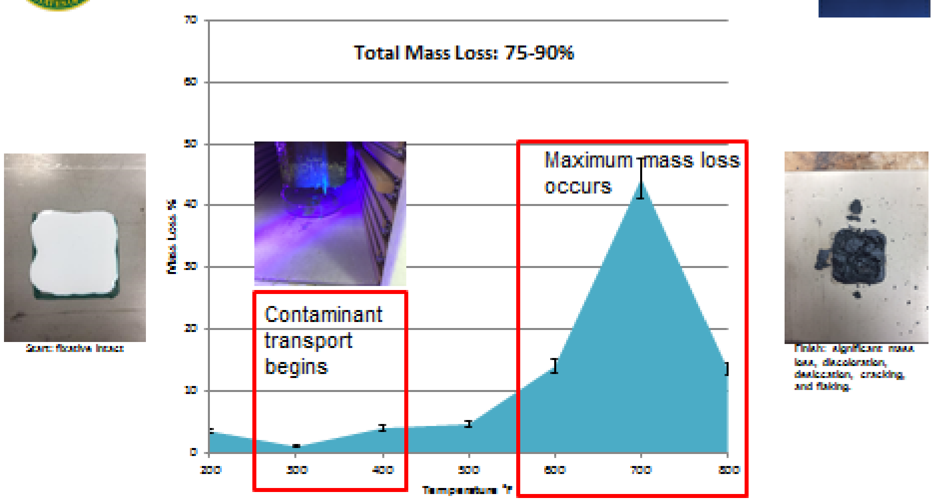
Basic Fixative Profile



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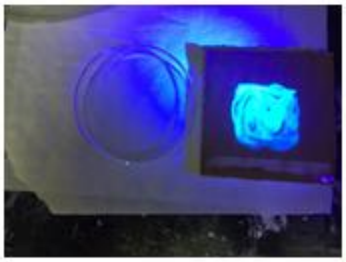
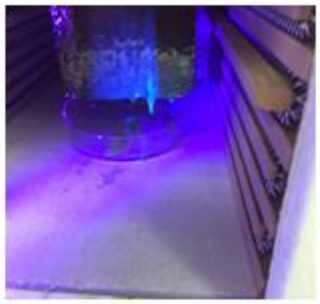
Contaminant Transport

All 5 x fixatives baselined demonstrated contaminant flow beginning at temperature ranges between 250-300 degrees in less than 5 minutes of exposure. At 500 degrees and above GloGerm particles could no longer be tracked due to extensive damage to fixative.

A product called GloGerm was used to simulate the contaminant and track particle flow during degradation. When exposed to a black light the GloGerm particles glow (note photos – Fixative A with GloGerm at 300 degrees).





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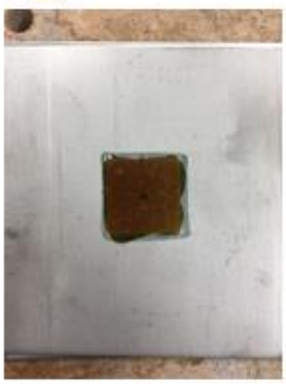
Observed Impacts to Fixative "A" at Incremental Temperatures



Discoloration, expansion, and minor mass loss (400° F)

Discoloration, bubbling, continued expansion, "off gassing", desiccation and mass loss (600° F)

Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking. (800° F)

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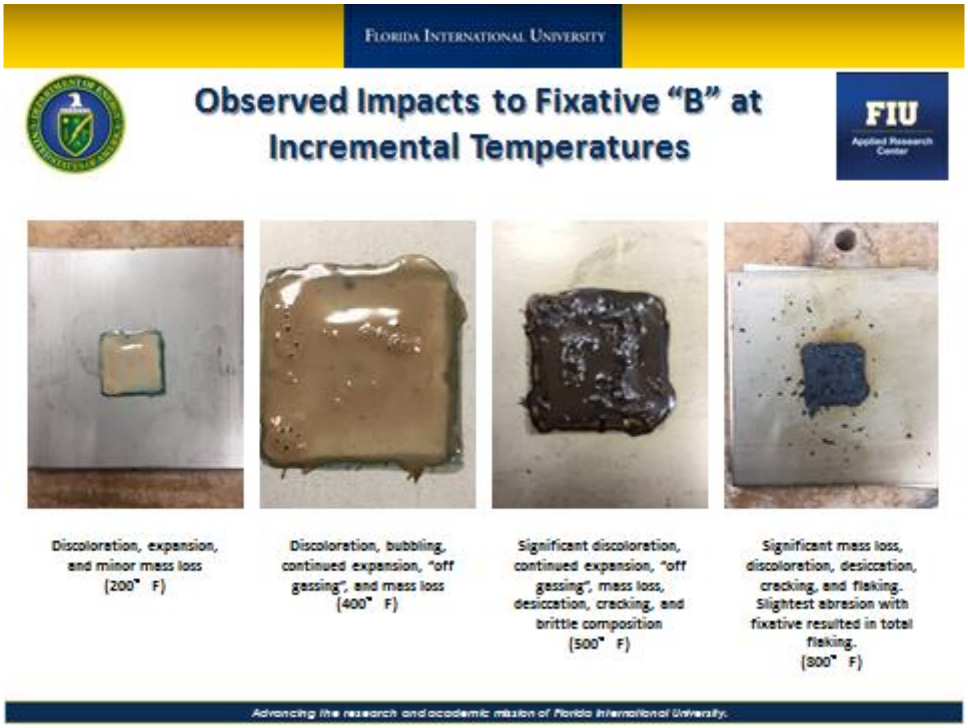
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Observed Impacts to Fixative "B" at Incremental Temperatures
FIU Applied Research Center
Discoloration, expansion, and minor mass loss (200° F)
Discoloration, bubbling, continued expansion, "off gassing", and mass loss (400° F)
Significant discoloration, continued expansion, "off gassing", mass loss, desiccation, cracking, and brittle composition (500° F)
Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking. (800° F)
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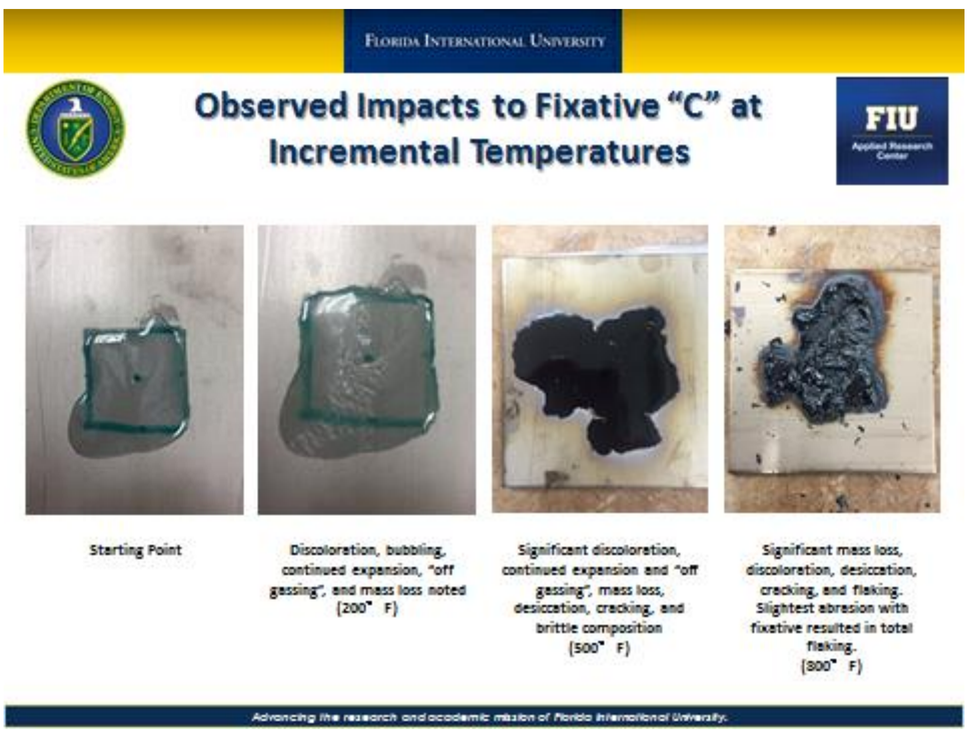
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Observed Impacts to Fixative "C" at Incremental Temperatures
FIU Applied Research Center
Starting Point
Discoloration, bubbling, continued expansion, "off gassing", and mass loss noted (200° F)
Significant discoloration, continued expansion and "off gassing", mass loss, desiccation, cracking, and brittle composition (500° F)
Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking. (800° F)
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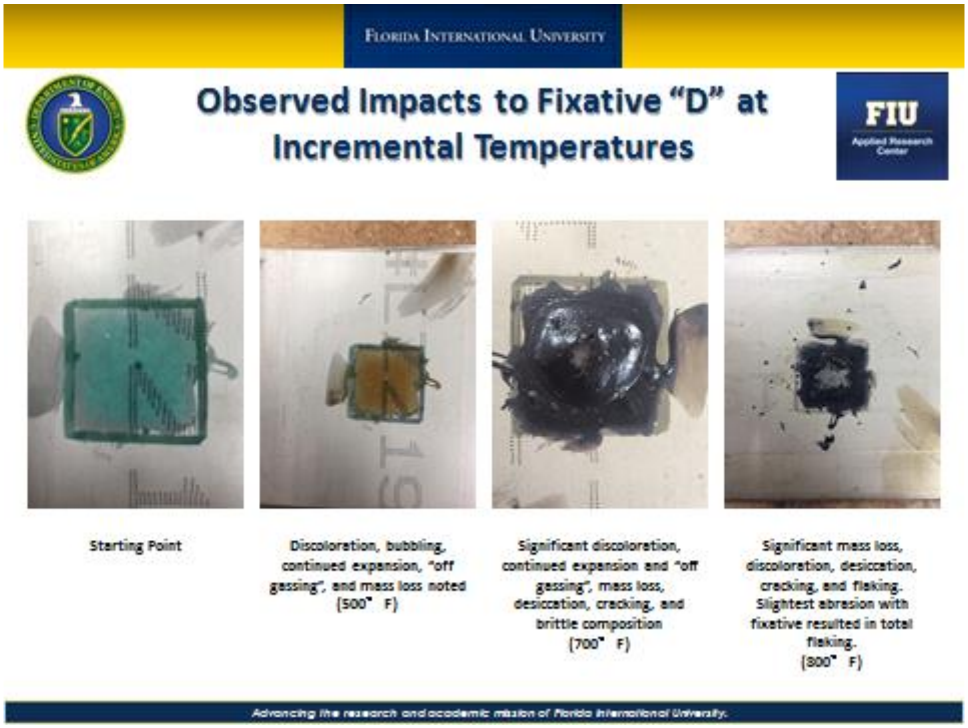
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Observed Impacts to Fixative "D" at Incremental Temperatures
FIU
Applied Research Center
Starting Point
Discoloration, bubbling, continued expansion, "off gassing", and mass loss noted (500˚ F)
Significant discoloration, continued expansion and "off gassing", mass loss, desiccation, cracking, and brittle composition (700˚ F)
Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking. (800˚ F)
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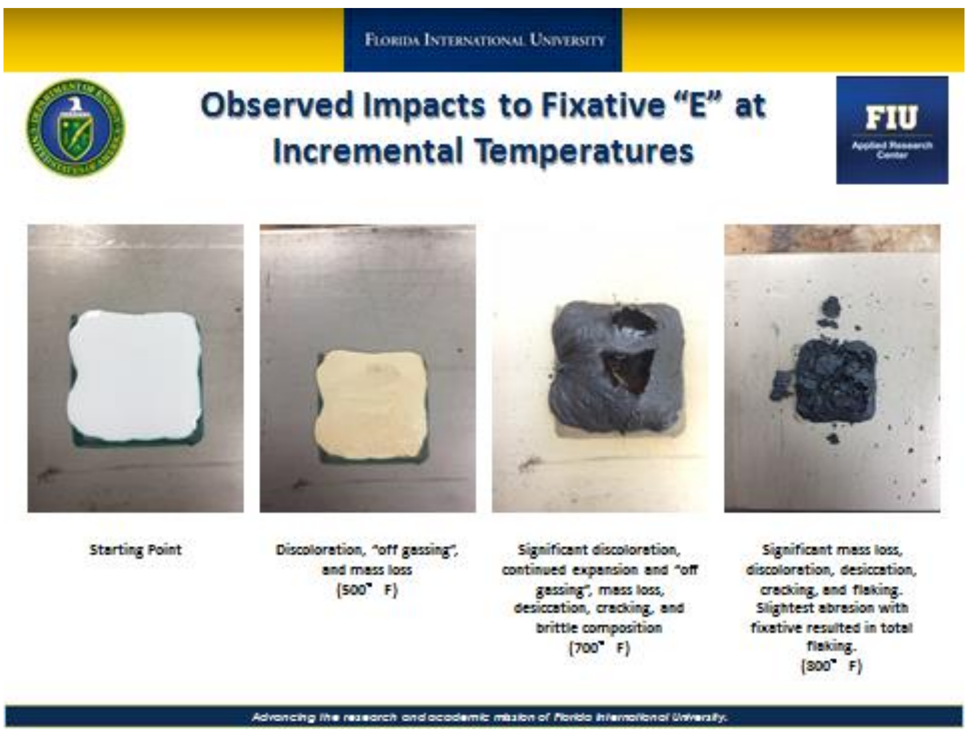
Florida International University
Observed Impacts to Fixative "E" at Incremental Temperatures
FIU
Applied Research Center
Starting Point
Discoloration, "off gassing", and mass loss (500˚ F)
Significant discoloration, continued expansion and "off gassing", mass loss, desiccation, cracking, and brittle composition (700˚ F)
Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking. (800˚ F)
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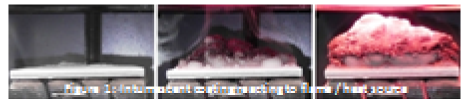
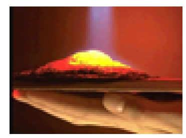
Enhancing Fire Resiliency of Fixatives

- **Problem Statement**: Mitigate / prevent release of radioisotopes during fire / extreme heat conditions. Most fixatives begin to see degradation between 200-400 degrees, at which time radioisotopes are potentially released into the environment.
- **Goal:** Improve operational performance of fixatives by enhancing their fire resiliency.
- **Potential Solution:** Layer/combine an intumescent coating with the fixative.
- **Explanation:** Since 9/11, there have been significant improvements in fire retardant / fire resistant technologies, with intumescent coatings being at the forefront of this development. Military and others use extensively to harden / protect facilities. Intumescent coatings develop a thick char to insulate the substrate and protect it from fire / extreme heat conditions. Applying that technology to fixatives through layering and combining should increase its fire resiliency and mitigate the risk of contamination under those extreme conditions.





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Adaptation of Intumescent Coatings as a Fire Resilient Fixative

- Designed to swell 50 to 100 times original thickness into an insulating char upon exposure to heat / fire
  - Provides physical barrier to heat and mass transfer
- Inhibits transport of volatiles to the environment and the transport of oxygen to unburned regions beneath char
  - Retention of mass in the char limits further involvement of the underlying materials in the fire
- Undergo rigorous ASTM, NFPA, UL, and UBC fire testing:
  - UL 263 / UL 723 / ASTM E-119 / ASTM E-84 / ASTM E-2768/ UL 10B
  - NFPA: 251 / NFPA: 255 / NFPA: 703 / NFPA: 252
  - As context, ASTM E119 test subjects a given wall / structure to 24 gas flames that reach temperatures between 1800-2000°F for periods between 1-2 hours
- Exceptionally cost effective (as low as $0.75 cents per square foot)
- Easily applied via brush, roller, or sprayer to a wide variety of substrates (stainless steel, wood, sheetrock, sheet metal, etc.)
- Very resilient to environmental conditions (heat, humidity, etc.)

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Proof of Concept Executive Highlights Intumescent Coatings (IC)

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- All 5 fixatives, when layered with the intumescent coating, conclusively displayed enhanced fire resiliency
  - Enhanced thermal insulation / protection
    - Fixative and substrate remained relatively intact
  - Mitigated flame spread and propagation
  - Limited to no smoke
- Some ICs have demonstrated potential as standalone fixative

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Flame Spread Test #2

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- 4”x4” steel coupon was coated with intumescent coating except for a 1 cm portion in the center which was coated with Fixative A only
- 2 propane torches were ignited and pointed towards outer edges (upper and lower, respectively) at a distance of ~1 ¾” from the exposed fixative (middle)
- Charring at both edges commenced immediately, and prevented flame spread and heat transfer to exposed fixative

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Thermal Insulation Reaction

- Each substrate (stainless steel, wood, glass, sheetrock) was layered to IC manufacturer's recommended thickness
- Charring commenced immediately when exposed to propane torch; it occurred at ~700° F in muffle furnace
- Dense charring ranged from 1"-2.5" depending on time, substrate, fixative-IC layering combination, etc.
- Provided enhanced thermal insulation to both substrate and fixative

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Thermal Insulation Test #2

- Used glass substrates to observe impact to fixative when covered with intumescent coating
- Charring commenced immediately when exposed to propane torch; it occurred at ~700° F in muffle furnace
- As long as charring is immediate, thermal insulation begins and provides improved protection to fixative

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Side-by-Side Comparison After 800° F for 15 Minutes

Fixative "E" **Without** Intumescent Coating

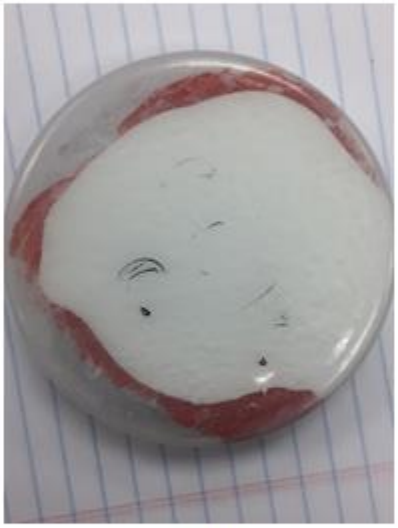
Fixative "E" **With** Intumescent Coating "FD"

Observed Impacts to Fixative "E" at 700° F and 800°F **Without** Layering Intumescent Coating

Significant discoloration, continued expansion and "off gassing", mass loss, desiccation, cracking, and brittle composition
(700 degrees)

Significant mass loss, discoloration, desiccation, cracking, and flaking. Slightest abrasion with fixative resulted in total flaking.
(800 degrees)

Observed Impacts to Fixative "E" at 800°F With Layer of Intumescent Coating "FD"

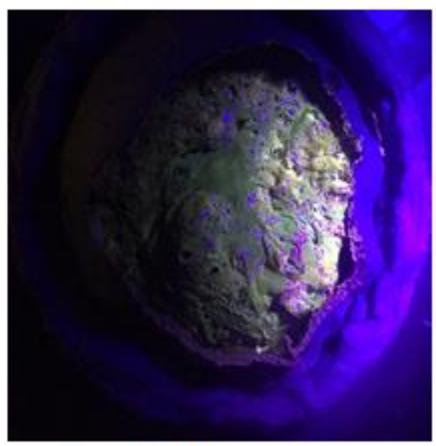


Starting Pont

Fixative "E" with protective layer of selected intumescent coating "FD" after being subjected to 800° F for 15 minutes

Observed Impacts to Fixative "A" at 800°F With Layer of Intumescent Coating "FD"

Starting Point



Fixative "A" with protective layer of selected intumescent coating "FD" after being subjected to 800° F for 15 minutes. GloGerm particulate still present.