FIU Applied Research Center

DOE-FIU Cooperative Agreement Annual Research Review – FIU Year 1

September 14, 2021		
9:00 - 9:05 am EDT	Kick-Off	Kurt Gerdes (Director, Technology Development) – DOE EM-3.2
9:05 - 9:10 am EDT	Welcoming Remarks (DOE-EM)	Nicole Nelson-Jean (Assoc. Principal Deputy Asst. Secretary for Field Ops) – DOE EM-3
9:10 - 9:15 am EDT	Welcoming Remarks (DOE-LM)	Carmelo Melendez (Director, Office of Legacy Management) – DOE LM-1
9:15 - 10:30 am EDT	Projects 4 & 5: STEM Workforce Development and Training	FIU, DOE HQ (EM & LM), SRNL, PNNL, WIPP, SRS, ORP, LBNL, WRPS, INL, Grand Junction
10:30 am - 12:00 pm EDT	Project 1: Chemical Process Alternatives for Radioactive Waste	FIU, DOE HQ, PNNL, WRPS, SRNL, SRS
1:30 - 3:00 pm EDT	Project 3: Waste and D&D Engineering & Technology Development	FIU, DOE HQ, SRNL, PNNL, LBNL, INL, ANL
3:00 - 4:30 pm EDT	Project 2: Environmental Remediation Science & Technology	FIU, DOE HQ, SRNL, PNNL, LANL, ORNL
September 15, 2021		
9:30 - 11:00 am EDT	Wrap Up (FIU Projects 1, 2, 3, 4 & 5)	FIU, DOE HQ (EM & LM)

PROJECT 3

Waste and D&D Engineering & Technology Development

FIU Personnel and Collaborators

Project Manager: Leonel Lagos

Faculty/Researcher: Himanshu Upadhyay, Joseph Sinicrope, Walter Quintero, Clint Miller, Santosh Joshi, Tushar Bhardwaj, Suresh Peddoju, John Dickson, Mellissa Komninakis, Kexin Jiao

DOE Fellows/Students: Roger Boza, David Mareno, Aurelien Meray, Adrian Muino Ayala, Christian Lopez, Christian Dau, *Derek Gabaldon, Philip Moore, Juana Perucina

DOE-EM: Dinesh Gupta, Genia McKinley, Jean Pabon, Jonathan Kang, Douglas Tonkay

SRNL: Jennifer Wohlwend, Justin Kidd, Emily Fabricatore, *Connor Nicholson, *Nick Groden, *Tristan Simoes-Ponce, Carol Eddy-Dilek

PNNL: Vicky Freedman, Rob Mackley

INL: *Rick Demmer

LBNL: Haruko Wainwright

*Former staff/student contributors

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Project Tasks and Scope

TASK 1: WASTE INFORMATION MANAGEMENT SYSTEM (WIMS) (HQ)	
Subtask 1.1	WIMS System Administration - Database Management, Application Maintenance & Performance Tuning
Subtask 1.2	Waste Stream Annual Data Integration
Subtask 1.3	Upgrade GIS module with Google Map API
Subtask 1.4	Deploy Power BI Reporting Server for Waste Stream Reports
Subtask 1.5	Cyber Security of WIMS Infrastructure
TASK 2: D&D SUPPORT TO DOE EM FOR TECHNOLOGY INNOVATION, DEVELOPMENT, EVALUATION AND DEPLOYMENT	
Subtask 2.1	Development of Uniform Testing Protocols and Standard Specifications for D&D Technologies
Subtask 2.2	Applications of Intumescent Foams and Other Fire-Retardant Materials to Mitigate Contaminate Release during Nuclear Pipe Dismantling and other D&D Activities
Subtask 2.3	Support to SRNL and SRS 235-F to Complete Final Data Collection and Technical Report for Onsite Hot Demonstration of Intumescent Fixative at SRS 235-F
Subtask 2.4	Certifying Fixative Technology Performance when Exposed to a Variety of Stressors Postulated in Contingency Scenarios Highlighted in Safety Basis Document
Subtask 2.5	Multi-functional 3D Polymer Framework for Mercury Abatement **(NEW)**

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Project Tasks and Scope

TASK 3: D&D KNOWLEDGE MANAGEMENT INFORMATION TOOL (KM-IT) (HQ, SRNL, INL, ANL)	
Subtask 3.1	D&D KM-IT Enhancements
Subtask 3.2	KM-IT Development – Enhance D&D Research Module for Multiple DOE EM Sites and National Laboratories
Subtask 3.3	Software Upgrades (Database and .NET Framework)
Subtask 3.4	Content Management
Subtask 3.5	Marketing and Outreach
Subtask 3.6	D&D KM-IT System Administration
Subtask 3.7	Cyber Security of D&D KM-IT Infrastructure
TASK 6: AI FOR EM PROBLEM SET (D&D): STRUCTURAL HEALTH MONITORING OF D&D FACILITY TO IDENTIFY CRACKS AND STRUCTURAL DEFECTS FOR SURVEILLANCE AND MAINTENANCE (SRNL)	
Subtask 6.1	Design & Development of Convolutional AutoEncoder Algorithm to Identify Cracks in D&D Mockup Facility
Subtask 6.2	Use LiDAR technology to scan the walls of the hot cell testbed to establish a baseline model using AI/deep learning technologies
Subtask 6.3	Object Detection (2D Space) (NEW)
Subtask 6.4	Object Detection (3D Space) (NEW)

Project Tasks and Scope

TASK 7: AI FOR EM PROBLEM SET (SOIL AND GROUNDWATER) - EXPLORATORY DATA ANALYSIS AND MACHINE LEARNING MODEL FOR HEXAVALENT CHROMIUM (CR [VI]) CONCENTRATION IN 100-H AREA (PNNL) (NEW)	
Subtask 7.1	Identification of Data Sources and Datasets from the Soil and Ground Water Repositories
Subtask 7.2	Data Pre-processing and Exploratory Data Analysis to Evaluate the Chromium Concentration in the Samples
Subtask 7.3	Machine-Learning and Deep-Learning Model Development for Anomaly Detection
TASK 8: AI FOR EM PROBLEM SET (SOIL AND GROUNDWATER) - DATA ANALYSIS AND VISUALIZATION OF SENSOR DATA FROM WELLS AT THE SRS F-AREA USING MACHINE LEARNING (LBNL, SRNL) (NEW)	
Subtask 8.1	Exploratory Data Analysis
Subtask 8.2	Identify the Master/Proxy Variables
Subtask 8.3	Machine Learning Model Development & Optimization for Sensor Placement in Groundwater Wells

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Task 2

D&D Support to DOE EM for Technology Innovation, Development, Evaluation and Deployment

Subtask 2.3: Support to SRNL and SRS 235-F to Complete Final Data Collection and Technical Report for Onsite Hot Demonstration of Intumescent Fixative at SRS 235-F PUFF Facility

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Site Needs:

- DOE EM complex-wide requirement for fire retardant / incombustible fixatives to immobilize residual contamination and mitigate risk of release when exposed to thermal stressors such as fire and extreme heat

Objectives:

- Investigate potential for down-selected COTS intumescent coating to function as a fire-retardant fixative to mitigate BIO contingency scenarios
- Validate technology development model designed to expedite lab to end user deployment
- Highlight and address critical enablers to facilitate adoption of technology solution

Table 1. Types of Accidents (and Frequencies) Summarized

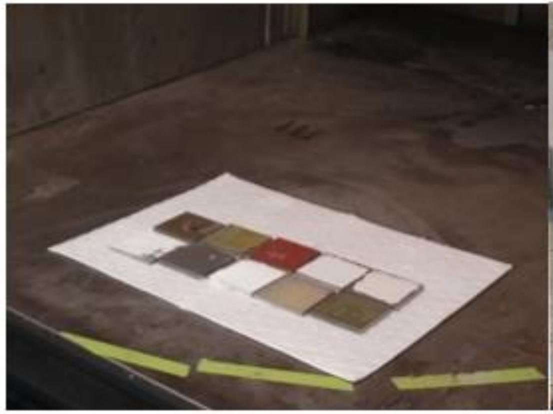
DOE Site/Facility	Fire Events	Explosion Events	Loss of Confinement (Spill) Events	Natural Phenomena Hazards	Other Events
RFETS Bldg 440	• ***1,200 Drum Fire (EU)*** • ***15 Crate Fire (U)*** • Truck Fire (EU)		• LLW Repack Spill (U) • Drum Spill (A)	• *Earthquake Collapse (U)*	• ***Aircraft Crash (EU)***
RFETS Bldg 664	• ***3 Drum Fire (U)*** • ***15 Crate Fire (U)*** • *336 Drums + 72 Crates Fire (EU)* • Truck Fire (EU)		• *Multi-Container Drop*	• *Earthquake Collapse (U)*	• ***Aircraft Crash (worst-case) (EU)*** • ***Aircraft Crash (realistic case) (EU)***
SRS APSF	• *Accountability Msmt. Room Fire (U)*	• *Explosion in Repackaging Area (A)*		• *Seismic Induced Full Facility Fire (U)*	
SRS HB-Line	• Full Facility Fire (EU) • Full Facility Fire & Secondary Events (EU) • ***Intermediate Fire (U)*** • ***Intermediate Facility Fire & Secondary Events (EU)***		• Spill (A)	• Earthquake with Secondary Events (EU)	
SRS Bldg 235-F	• Fire – Best Case (U) • Fire – Worst Case (U)			• Design Basis Earthquake (EU)	
SRS SWMF	• ***TRU Pads - Internal Culvert Drum Fire (U)***	• ***TRU Pads - Culvert Explosion (U)***	• TRU Pads - High Energy Vehicle Impact (EU) • ***TRU Pads - Dropped Steel Box (A)***	• TRU Pads -Tornado (EU)	• 634-7E Buried Waste Helicopter Crash (EU)
Hanford WRAP Facility	• *4 Drum Fire (U)* • *Single Drum Fire in Glovebox (U)*	• ***Drum Explosion with 4 Drum Fire (U)*** • *Single Drum Explosion in Glovebox (U)*	• Solid Waste Box Failure (A)	• ***Design Basis Earthquake (U)*** • Beyond DBE (EU)	
INEEL RWMC	• ***Vehicle Fire (U)***	• *Drum Explosion (A)*	• *Box Spill (A)*	• Design Basis Earthquake (U)	
LANL RAMROD Facility	• Small Fire (A) • Medium Fire (EU) • Large Fire (EU)	• Small Natural Gas Explosion (A) • Large Natural Gas Explosion (EU)	• Coring Glovebox Spill (A)	• Design Basis Earthquake (U)	• Aircraft Crash (EU)

Note: Scenarios in *Italics* are risk dominant events, based on Risk Class I or II for the collocated worker. ***Bold Italics*** denotes that it is also risk dominant for the public.

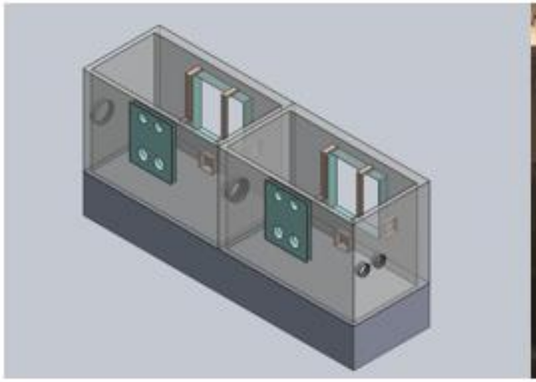
Subtask 2.3: Support to SRNL and SRS 235-F to Complete Final Data Collection and Technical Report for Onsite Hot Demonstration of Intumescent Fixative at SRS 235-F PUFF Facility

Research Highlights & Accomplishments:

- Proof-of-concept to onsite test and evaluation at SRS 235-F PUFF Facility in 3 years
    - Lab testing across major functional areas completed at FIU and SRNL (Oct 2015 - Nov 2016)
    - Cold demo (application procedures and tooling list) completed at FIU (Jan - Dec 2017)
    - SRNL incorporates FIU cold demo results and prepares Hot Test Plan (Jan 2017 - June 2018)
    - SRNL conducts Fixative Hot Test/Demo at SRS 235-F PuFF Facility (Fall 2018 – March 2021)



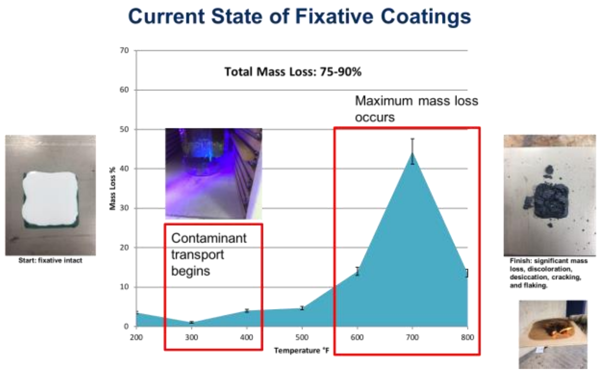
- Final results disseminated across DOE EM complex
    - FIU-SRNL Tech Talk presented on Jan 24, 2021
        - 556 views as of 8/23/2021
        - Top 5 countries include: US, United Kingdom, Canada, Germany, Italy
    - SRNL-STI-2021-00115, “A Novel Approach to Mitigating the Potential Release of Radioisotopes Under Fire Conditions - Enhancing Fire Resiliency of Radiological Contamination Fixatives During Deactivation & Decommissioning Activities” published on OSTI, Mar 2021

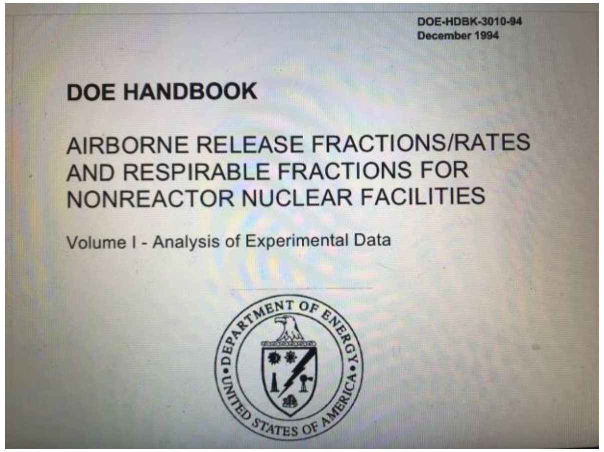


Subtask 2.3: Support to SRNL and SRS 235-F to Complete Final Data Collection and Technical Report for Onsite Hot Demonstration of Intumescent Fixative at SRS 235-F PUFF Facility

Executive Highlights and Lessons Learned:

- Current fixatives used to support D&D have vulnerabilities when exposed to thermal, impact and environmental stressors
- High potential for certain COTS intumescent coating technologies to function as fire retardant fixatives in support of D&D activities
- Need to address critical enablers
  - Development of uniform standard specifications and testing protocols through standards organizations such as ASTM International to methodically certify fixatives and mitigate risk
  - Update of DOE-HDBK-3010 to account for positive impacts of fixative technologies
- Validated holistic technology development, testing, and evaluation model





Subtask 2.3: Support to SRNL and SRS 235-F to Complete Final Data Collection and Technical Report for Onsite Hot Demonstration of Intumescent Fixative at SRS 235-F PUFF Facility

FIU Year 2 Projected Scope

- Closed Out

Subtask 2.1: Development of Uniform Testing Protocols and Standard Specifications for D&D Technologies

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Site Needs:

- A uniform, systematic, peer-reviewed, stakeholder endorsed test and evaluation process for fixative technologies
  - Define the operational requirement for the technology (What should it do and to what standard – characteristics and performance)
  - Develop uniform testing protocols so the D&D community can confirm it does, in fact, do it (also facilitates comparison)
- ***Operationalize knowledge***, not just archive it

Objectives:

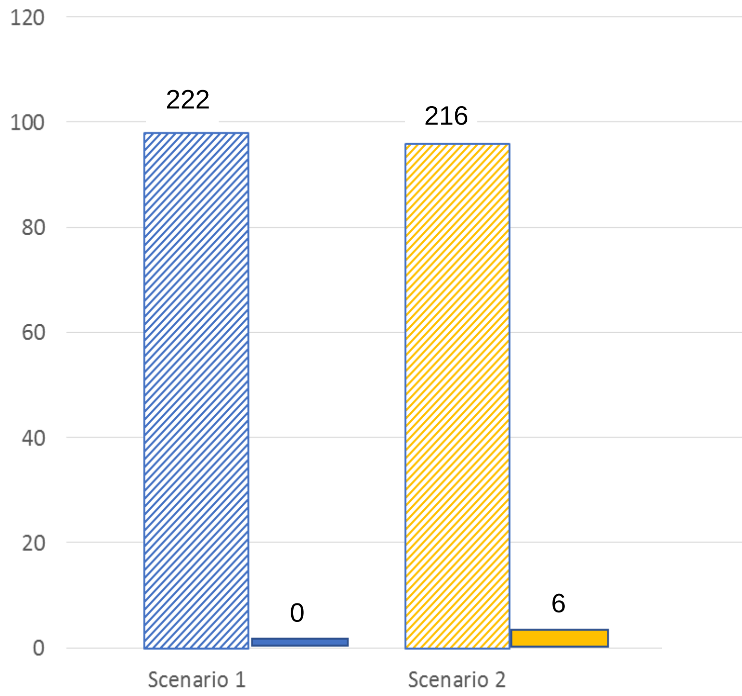
- Engage ASTM International's E10.03 Subcommittee on Radiological Protection for Decontamination and Decommissioning of Nuclear Facilities and Components to develop, ballot and promulgate standard specifications and uniform testing practices for fixative technologies intended to support D&D activities

Subtask 2.1: Development of Uniform Testing Protocols and Standard Specifications for D&D Technologies

Research Highlights & Accomplishments:

- 5 x ASTM Standard Specifications for fixative technologies ISO D&D activities formally published
  - E3104-17: Specification for Strippable & Removable Coatings to Mitigate Spread of Radioactive Contamination
  - E3105-17: Specification for Permanent Coatings Used to Mitigate Spread of Radioactive Contamination
    - Referenced in SRNL'S Incombustible Fixative and ACE 2.0 Test Plan: Radiological Hot Field Test of Intumescent Coating Fixatives and Electrostatic Precipitators (***operationalized knowledge***)
  - E3191-18: Specification for Permanent Foaming Fixatives Used to Mitigate the Spread of Radioactive Contamination
    - Referenced in FIU ARC and SRNL Test Plans of technology (***operationalized knowledge***)
  - E3190-19, Standard Practice for Preparation of Fixed Radiological/Surrogate Contamination on Porous Test Coupon Surfaces for Evaluation of Decontamination Techniques
  - E3283-21, Standard Practice for Preparation of Fixed Radiological/Surrogate Contamination on Non-Porous Test Coupon Surfaces for Evaluation of Decontamination Techniques
    - Being referenced in DOE-HDBK-3010 update activity (***operationalized knowledge***)
    - DOE EM News Release in July 2021

- First ever ASTM Student Chapter established at FIU
  - Formal designation in June 2021



Survey results demonstrating critical role of standards in facilitating technology acceptance

Subtask 2.1: Development of Uniform Testing Protocols and Standard Specifications for D&D Technologies

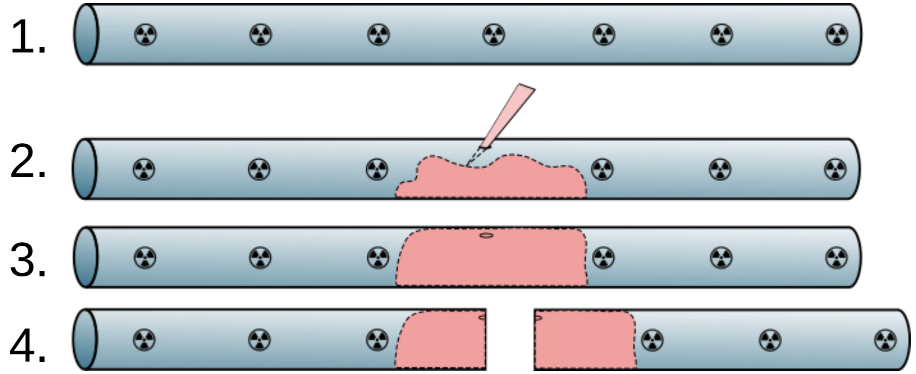
FIU Year 2 Projected Scope

- Press forward with development of WK77334 - New Specification for Dust Suppressant Technologies Designed to Support Nuclear Decommissioning and Open Air Demolition Activities
  - E10.03 members voted to proceed with work item
  - Working group formed
  - Targeting an initial E10.03 Subcommittee ballot in November 2021

Subtask 2.2: Applications of Intumescent Foams and Other Fire-Retardant Materials to Mitigate Contaminate Release during Nuclear Pipe Dismantling and other D&D Activities

Site Needs:

- A durable, lightweight foaming fixative capable of immobilizing residual contamination in 3D, irregularly-shaped void spaces such as hot cells, pipes, etc. when exposed to a variety of stressors (thermal, impact, environmental) to mitigate the risk of worker / environmental exposure during D&D activities



Objectives:

- Identify COTS technologies with potential to address operational requirement
- Down-select specific product after lab-scale testing against stressors
- Cold demo aligned with operational deployment and safety basis requirements
- Onsite demo in radioactive environment

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Subtask 2.2: Applications of Intumescent Foams and Other Fire-Retardant Materials to Mitigate Contaminate Release during Nuclear Pipe Dismantling and other D&D Activities

Research Highlights & Accomplishments:

Fire Testing

Conducting initial baseline test and evaluation of down-selected Hilti foam against a variety of stressors (thermal, impact, environmental, mechanical)

NRC 10 CFR 71.83
Model 9977 Safety Analysis (SRNL) / NRC 10 CFR 71.83
ASTM E 3191-18

Tensile Adhesion Testing

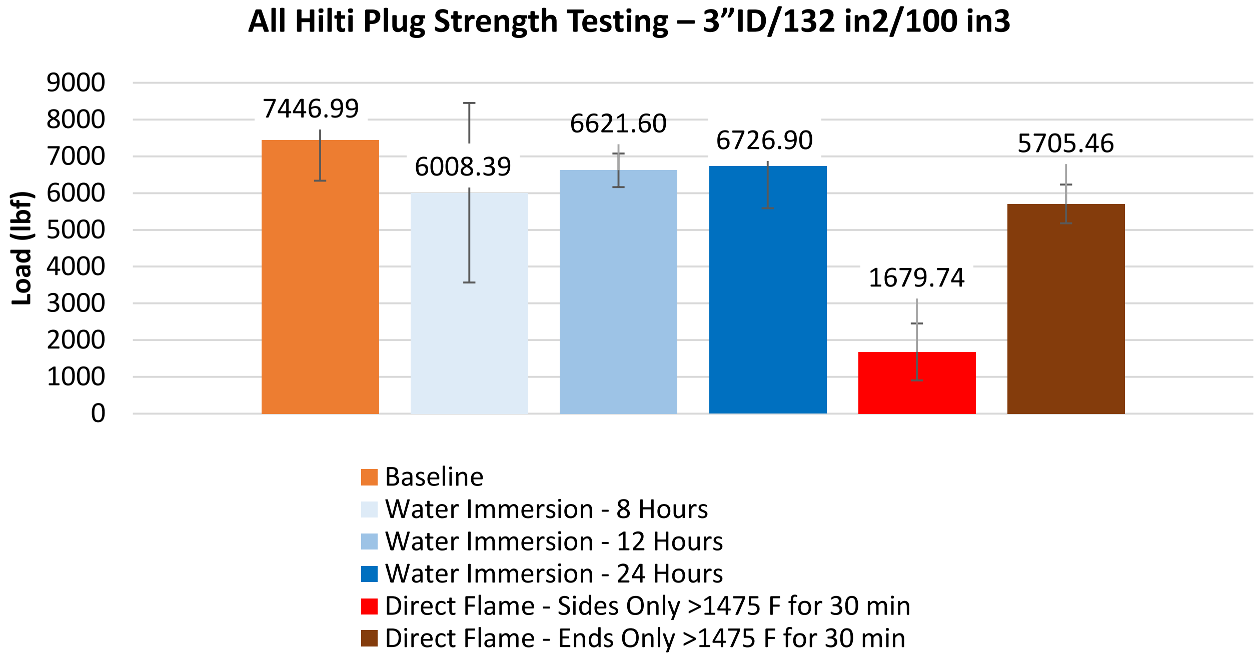
Water Immersion

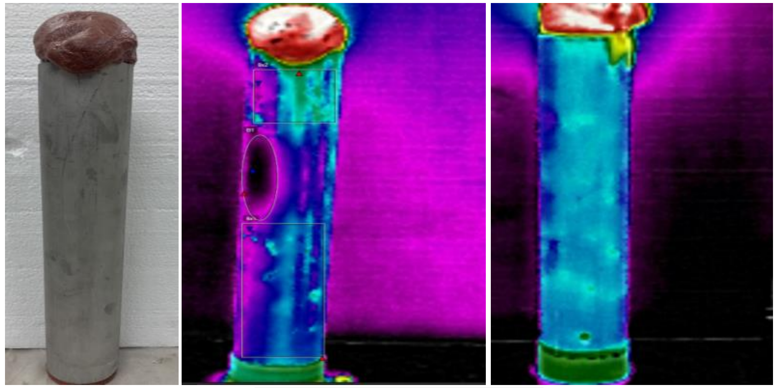
Drop Test

Plug Strength Testing

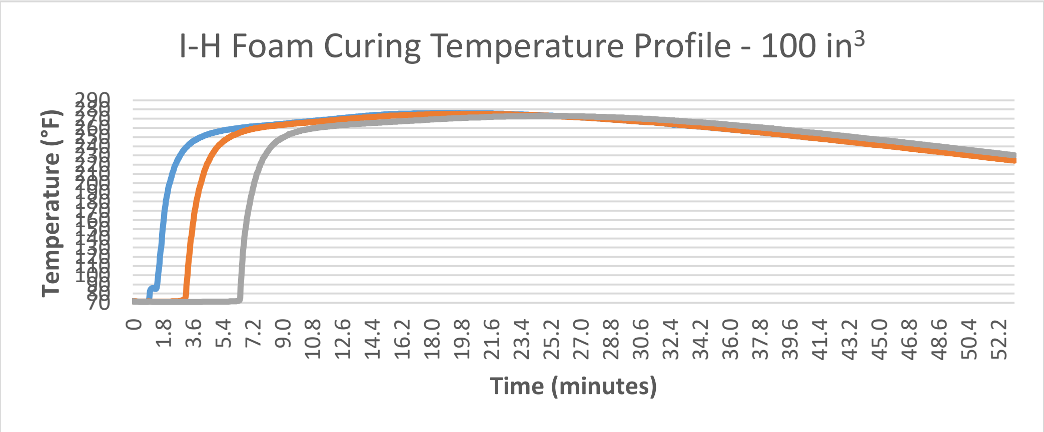
Subtask 2.2: Applications of Intumescent Foams and Other Fire-Retardant Materials to Mitigate Contaminate Release during Nuclear Pipe Dismantling and other D&D Activities

Research Highlights & Accomplishments:





- Developing baseline performance data when exposed to stressors
- Confirming curing temperature profile
- Exploring NDE technique to identify application anomalies by combining advancements in thermal imaging systems with understanding of foam curing temperature profiles



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FIU Year 2 Projected Scope (Incremental advancement towards Hot Demo in FY'23)

- Conduct basic lifecycle testing and evaluation of Hilti foam plugs when exposed to real-world environmental conditions
- Collaborate with SRNL and site personnel to develop Cold Demo Test Plan focusing on pipes at F/H Labs
- Continue baselining data of Hilti foam when exposed to various stressors
- Confirm curing profile
- Initiate execution of cold demo

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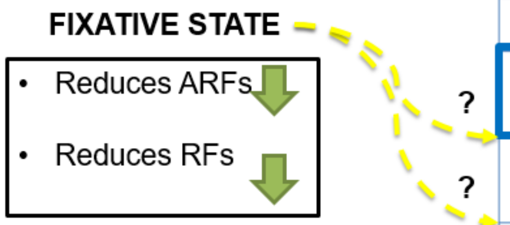
Subtask 2.4: Certifying Fixative Technology Performance when Exposed to a Variety of Stressors Postulated in Contingency Scenarios Highlighted in Safety Basis Document

Site Needs:

- Outdated regulations, such as the DOE-HDBK-3010, outline factors for dealing with residual contamination, but fail to account for the positive impacts provided by fixative technologies in reducing ARF coefficients.
    - Results in inconsistent certification methodology for fixative technologies.
    - Produces varying Source Term calculations.
    - Fails to provide sufficient credit for improvements in state-of-the-art fixative technologies.

Objectives:

- Develop an experimental design for the quantification of contamination release during impact stress.
- Reevaluate ARF coefficients for powder contaminants under impact.
- Determine ARF coefficients for fixative materials under impact.
    - Fixative/Polymer State
- Results can possibly be used to update DOE-HDBK-3010.



Contaminant Form	Impact ARF
Gas / Vapor	1.0
Powder	**3e-4**
Liquid	4e-5
Metal / Solid	No significant airborne release is postulated for this accident configuration.

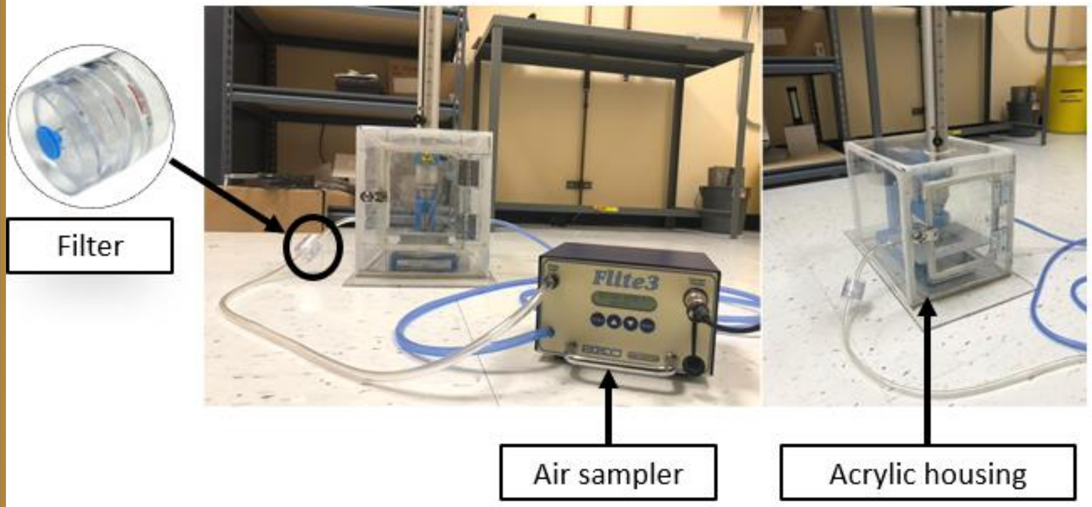
Subtask 2.4: Certifying Fixative Technology Performance when Exposed to a Variety of Stressors Postulated in Contingency Scenarios Highlighted in Safety Basis Document

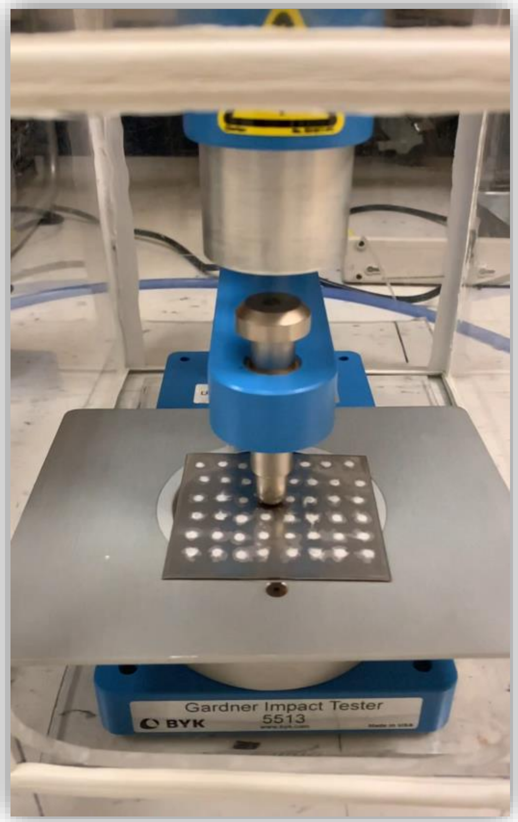
FIU Year 1 Research Highlights & Accomplishments:

- Validated the experimental design for evaluating ARFs for powder contamination under impact stress.
  - ASTM D2794

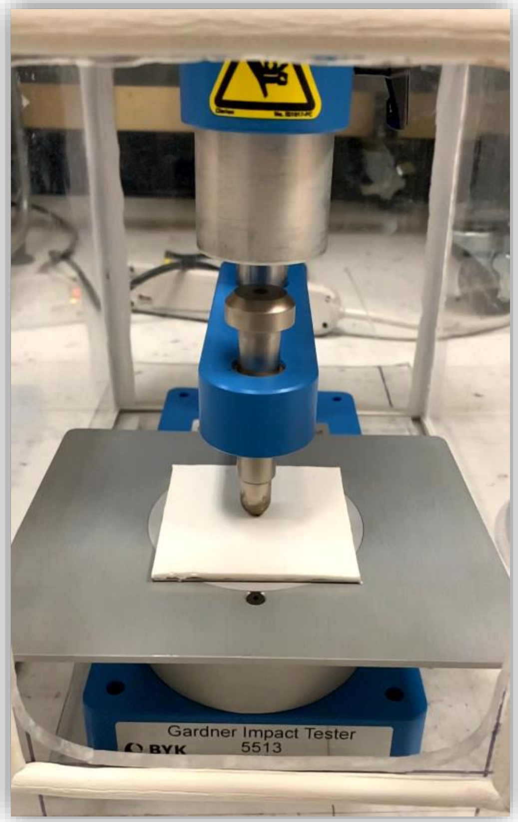
    Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
  - ASTM E3283

    Standard Practice for Preparation of Loose Radiological/Surrogate Contamination on Nonporous Test Coupon Surfaces
  - ICP-MS analysis for quantification.





Powder state



Fixative/Polymer state

Subtask 2.4: Certifying Fixative Technology Performance when Exposed to a Variety of Stressors Postulated in Contingency Scenarios Highlighted in Safety Basis Document

FIU Year 1 Research Highlights & Accomplishments:

- Initial baseline results (powder contamination only) is similar to the ARF presented in DOE-3010-HDBK.
- Initial results for fixatives, FD and PBS, showed a **significant reduction** in the ARFs.

FIXATIVE STATE

- Reduces ARFs
- Reduces RFs

Initial empirical data supports

Contaminant Form	Impact ARF
Gas / Vapor	1.0
Powder	**3e-4**
Liquid	4e-5
Metal / Solid	No significant airborne release is postulated for this accident configuration.

High Risk

Low Risk

BASELINE

	Impact (in-lb)	Average Airborne Release Fraction
Baseline	320	5.75E-04
	160	1.42E-04
Overall Average		3.59E-04

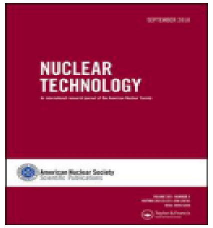
FIXATIVES

	Impact (in-lb)	Average Airborne Release Fraction
FD	320	5.55E-07
	160	3.33E-08
Overall Average		2.94E-07

	Impact (in-lb)	Average Airborne Release Fraction
PBS	320	6.00E-07
	160	3.18E-07
Overall Average		4.59E-07

FIU Year 2 Projected Scope

- Continue to quantify release and the performance of fixative technologies and reconfirm powder contaminant:
  - Other impact forces
  - Various substrate types and/or thicknesses
- Provide the data to substantiate a “Fixative/Polymer State”.
- Collaborate in future iterations for other contingency scenarios/stressors.
  - Sandia National Laboratory

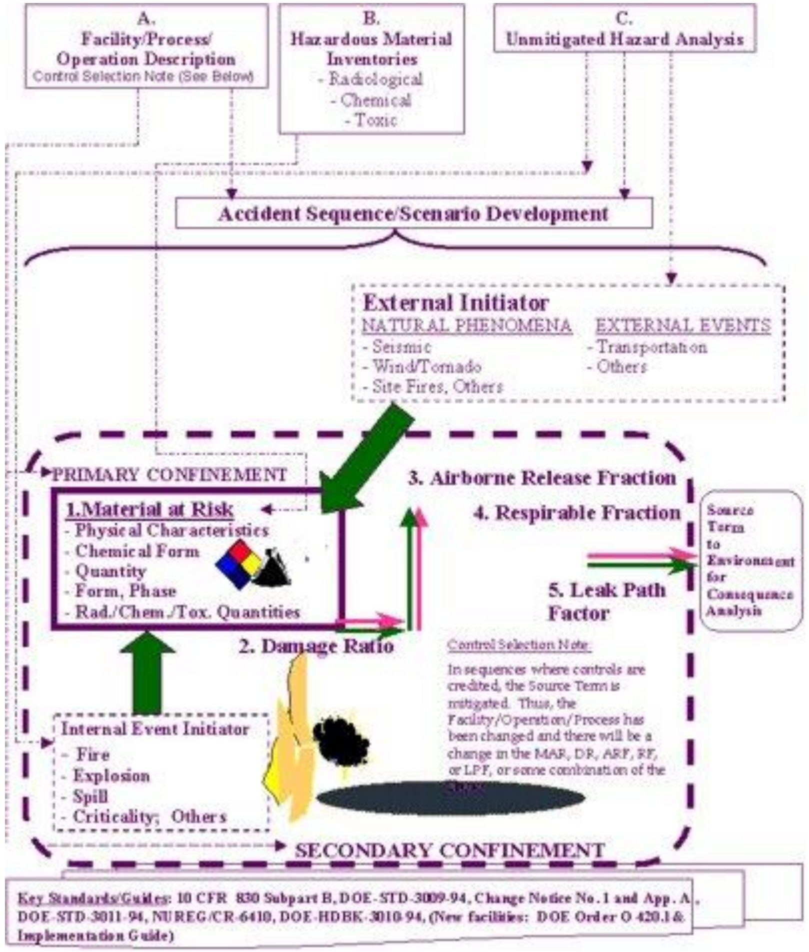


Nuclear Technology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/unct20

Determination of Airborne Release Fractions from Solid Surrogate Nuclear Waste Fires

Joshua A. Hubbard, Timothy J. Boyle, Ethan T. Zepper, Alexander Brown, Taylor Settecerri, Joshua L. Santarpia, Nelson Bell, Joseph A. Zigmond, Steven S. Storch, Brenda J. Maes, Nicole D. Zayas, Dora K. Wiemann, Marissa Ringgold, Fernando Guerrero, Xavier J. Robinson, Gabriel A. Lucero & Laura J. Lemieux



Subtask 2.5: Polydimethylsiloxane micro-ribbons for Mercury Abatement (NEW)

Site Needs:

- Developing novel technologies that support Hg abatement in water
- Studying the Hg absorbing kinetics
- Investigating the effects of environmental conditions

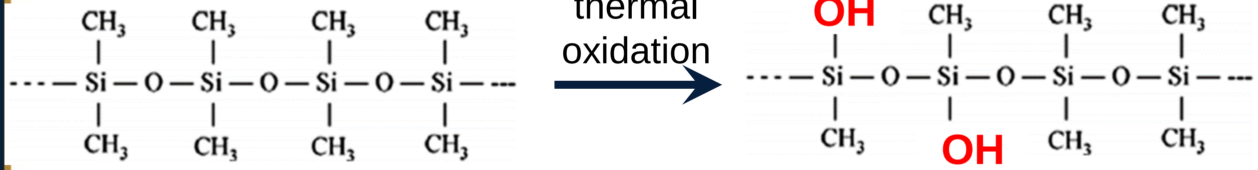
Objectives:

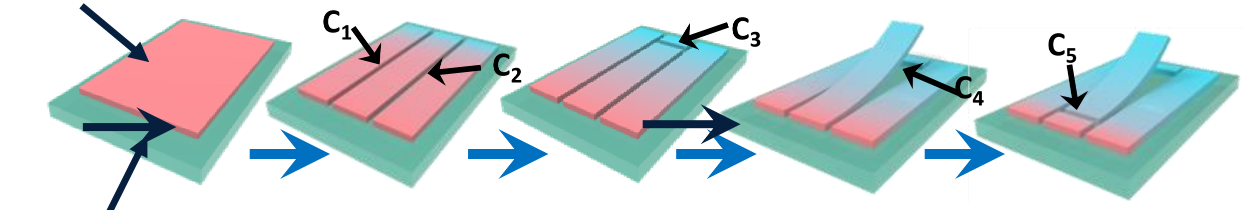
- Explore the potential of polydimethylsiloxane micro-ribbons (PDMS-MRs) to achieve Hg abatement and other pollutants.
  - PDMS-MRs design and synthesis
  - Characterization of PDMS-MRs
  - Lab-scale test of PDMS-MRs for Hg abatement in water
  - Optimizing PDMS-MRs for high performance Hg abatement

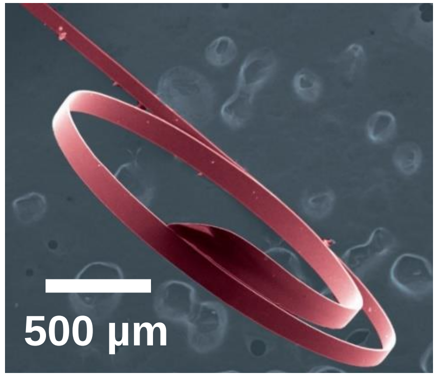
Subtask 2.5: Polydimethylsiloxane micro-ribbons for Mercury Abatement (NEW)

PDMS-MRs Concept and Synthesis

PDMS thin film on a glass slide → (ambient heating) → (ambient cooling) → PDMS-MRs







Average dimension of PDMS-MRs:

W: ~ 200 µm

H: ~ 10 µm

L: ~ 1 cm

Surface Area: ~ 350 m^2/g

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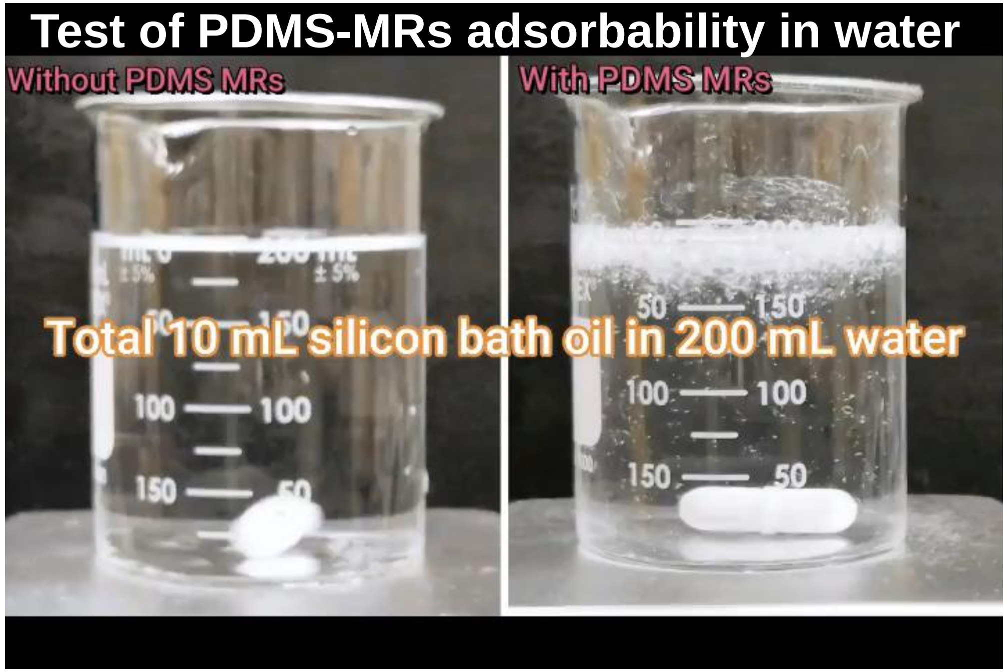
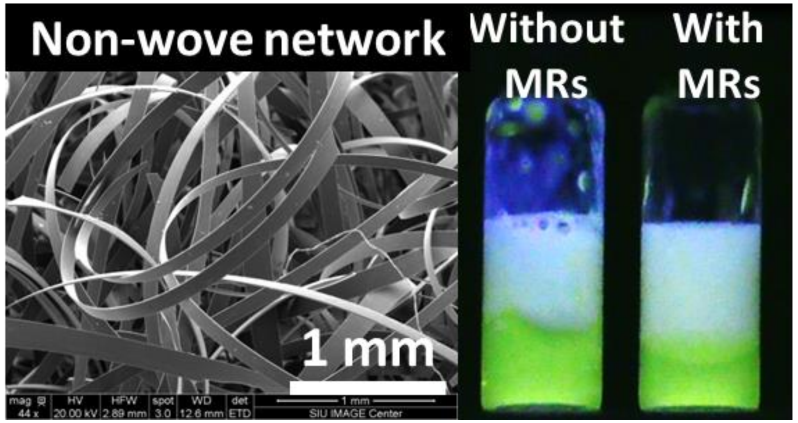
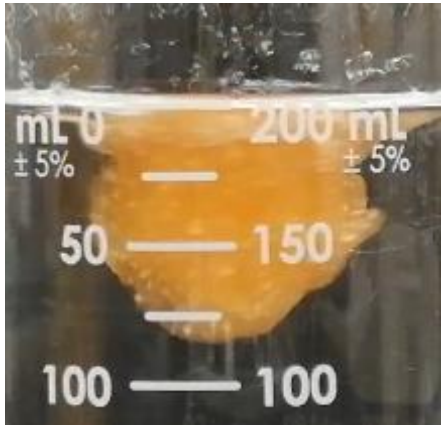
Subtask 2.5: Polydimethylsiloxane micro-ribbons for Mercury Abatement (NEW)

What makes PDMS-MRs a good candidate for an absorbent?



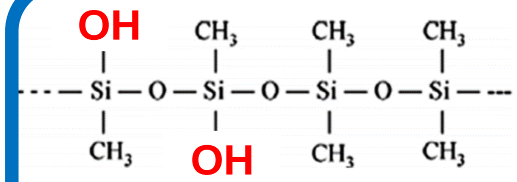




- Up to 1:40 oil absorbing capacity
  High surface area
- >95% oil recovery
  Intrinsic hydrophobicity
- Self-entangled network
  High aspect ratio
  Curly shape

Subtask 2.5: Polydimethylsiloxane micro-ribbons for Mercury Abatement (NEW)

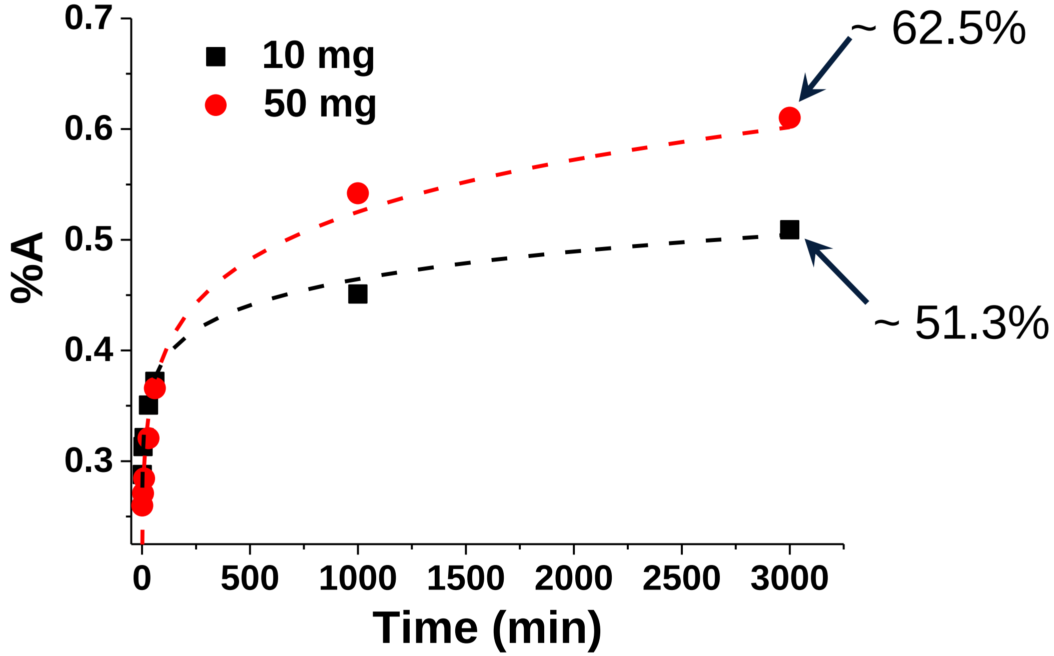
Proof of Concept – PDMS-MRs for Hg Abatement



PDMS-MRs

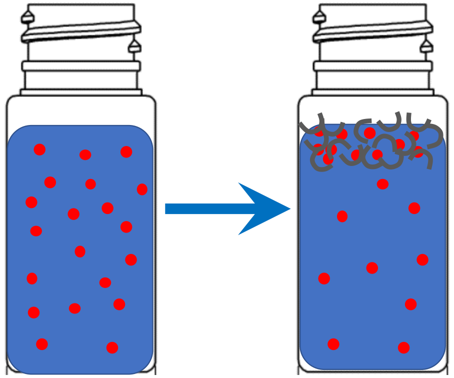
10 mg of PDMS-MRs
+10 mL of 0.5 ppm Hg^{2+} solution

shaking



Conclusion:

- PDMS-MRs can be used for Hg abatement
- The Hg abatement efficiency of the original PDMS-MRs is not high



Solution:

- Increase the hydrophilicity of PDMS-MRs
- Modify PDMS-MRs surfaces to make it fit Hg abatement

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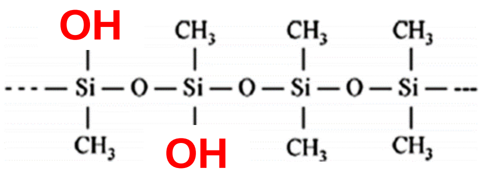
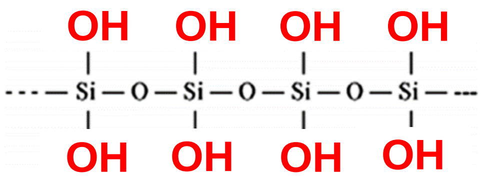
Optimized PDMS-MRs for Hg Abatement

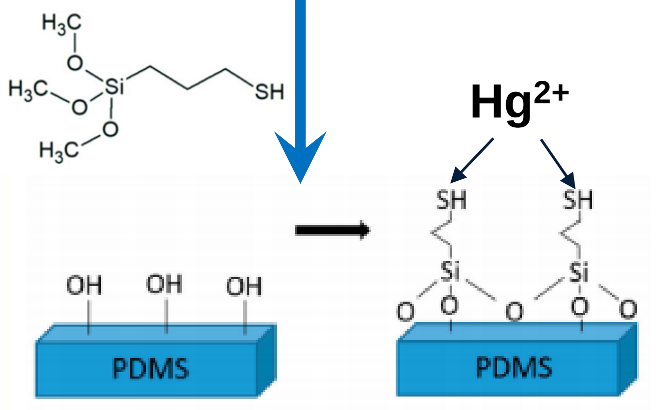


PDMS-MRs

ambient
350°C, 24h



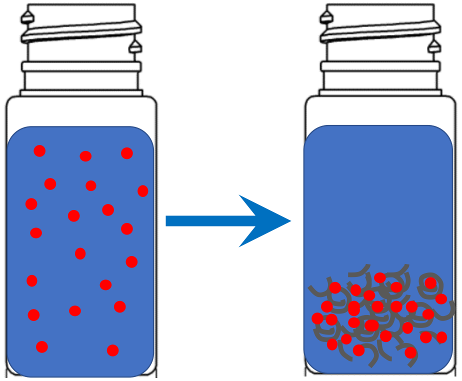
thermal oxidized PDMS-MRs



shaking

?

10 mg of PDMS-MRs
+10 mL of 0.5 ppm Hg^{2+} solution



Conclusion:

- Thermal oxidized PDMS-MRs are hydrophilic
- Was the surface modification at PDMS-MRs successful?

- Complete the Hg abatement tests
- Characterize the modified PDMS-MRs using FTIR and Raman spectroscopy

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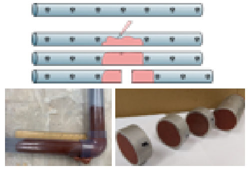
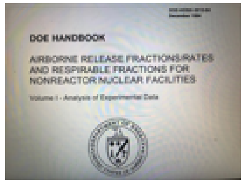
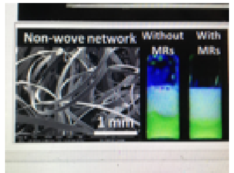
Projected Scope

- PDMS-MRs sorbent
  - Chemistry route: Material development
    - Pollution cleaning
      - Mercury abatement
        - Surface functionalization
        - Characterization
        - Mercury abatement
        - Lab-scale demo
      - waste oil, heavy metal, micro plastics, bacteria, virus…
    - Performance enhancement
      - Magnetization
      - environmental condition resistance, visualization, semi-quantification…
  - Engineering route: Manufacturing optimization
    - Large-scale fabrication
      - Substrate with proper thermal, physical, and chemical properties
      - Large-scale lamination, heating, and cooling
    - Cost-saving: practical application, reuse, recycle, maintenance…

Technology Development and Deployment Road Map

D&D Roadmap

	Activity	2018-2020	2021	2022	2023	2024
SRS 235-F PUFF Facility F/H Labs		On-site Test & Evaluation	Final Tech Report & Tech Talk			
		Down-select	Test & Evaluation	Cold Demo	Site Deployment	
DOE EM Complex-wide		ASTM E3104 ASTM E3105 ASTM E3191 ASTM E3190	ASTM E3283 ASTM Student Chapter established	WK77334 Development and Balloting	WK77334 Approval & Promulgation as Formal Standard	
			First Technical Progress Report		Final Technical Progress Report Initiate DOE-HDBK-3010 Update	PhD Dissertation Published
			Proof-of-Concept	Optimization and Bench-scale T&E	In-house Demonstration	Site Demonstration

Thank You. Questions?