



Glovebox Fire Suppression -  
Fire Foe™ Tubes  
Alternative Approach for  
Fire Suppression of Class A, B, and C  
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### Editors

Rodney B. Smith – [bsr@y12.doe.gov](mailto:bsr@y12.doe.gov)  
Scott Hinds  
[scott.hinds@merrick.com](mailto:scott.hinds@merrick.com)

**Advertising Manager**  
Crissy Willson

**Design and Production**  
Tony Monaco

**Publisher**  
American Glovebox Society

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526 So. E Street  
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**Tel.:** (800) 530-1022 or  
(707) 527-0444

**Fax:** (707) 578-4406

**E-mail:** [ags@gloveboxsociety.org](mailto:ags@gloveboxsociety.org)

**Website:** [www.gloveboxsociety.org](http://www.gloveboxsociety.org)

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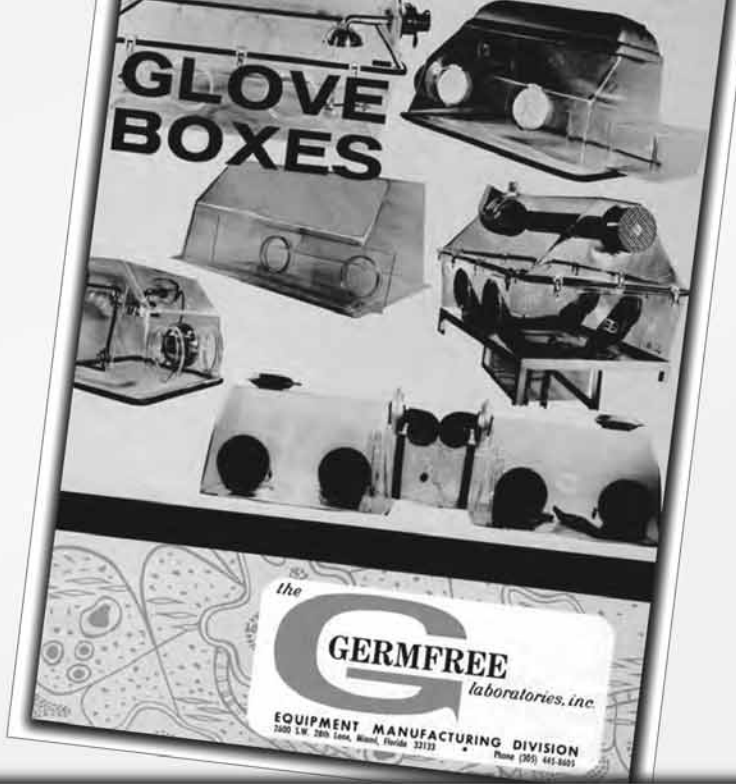
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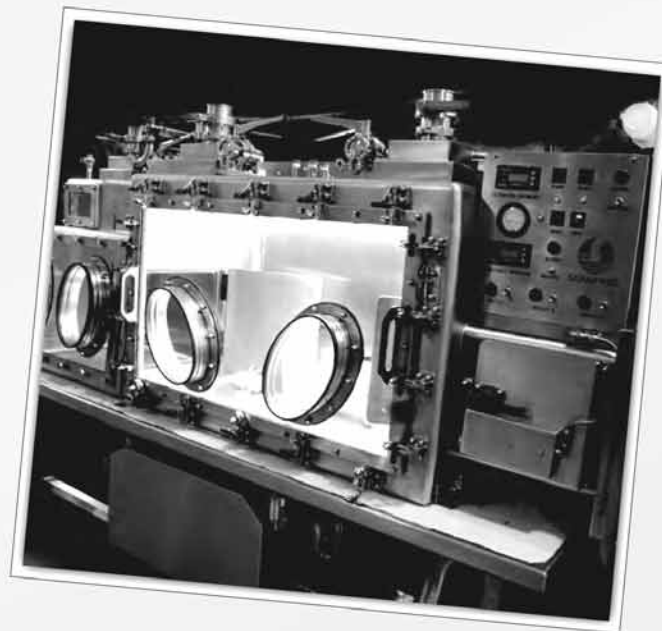
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# Glovebox Fire Suppression - Fire Foe™ Tubes

## Alternative Approach for Fire Suppression of Class A, B, and C Fires in Gloveboxes



By: Mark S. Rosenberger, ES-DE Fire Protection Services  
James A. Tsiagkouris, ES-DE Fire Protection Services



Mark R. and James T. of LANL

### ABSTRACT

Department of Energy (DOE) Orders and National Fire Protection Association (NFPA) Codes and Standards require fire suppression in gloveboxes. Several potential solutions have been and are currently being considered at Los Alamos National Laboratory (LANL). The objective is to provide reliable, minimally invasive, and seismically robust fire suppression capable of extinguishing Class A, B, and C fires; achieve compliance with DOE and NFPA requirements; and provide value-added improvements to fire safety in gloveboxes. This report provides a brief summary of current approaches and also documents the successful fire tests conducted to prove that one approach, specifically Fire Foe™ tubes, is capable of achieving the requirement to provide reliable fire protection in gloveboxes in a cost-effective manner.

### INTRODUCTION

DOE Standard 1066 and NFPA 801 require automatic fire suppression to be installed in gloveboxes and, potentially, fume hoods as well. These regulatory requirements stem from actual fire incidents. The need for some form of automatic fire suppression is

very real due to the nature of glovebox operations and the materials contained within gloveboxes and fume hoods. For the purpose of this report, we refer to gloveboxes and fume hoods as one category, called enclosures.

Significant resources are spent annually within the DOE Complex to analyze, evaluate, and develop engineered and administrative controls, develop surveillances, and audit the execution of Authorization Basis programs. These resources are expended in an effort to minimize the potential effects of an enclosure fire to workers and the public, facility and programmatic assets, and program mission delivery. Many of these controls rely on worker intervention to either extinguish the fire or to retard its growth, potentially exposing the worker to hazardous conditions. Additionally, this hands on approach does not address conditions in which a worker is not present. While a worker may be able to contain an enclosure fire and not be exposed to any detrimental effects, the resulting political fallout from such an event could significantly delay or prevent a program or even a facility from restarting operations.

The preceding discussion simply reinforces the need for some form of cost-effective automatic fire suppression to be installed in enclosures. The features of several existing and proposed fire suppression systems are described below.

Water-based suppression systems are capable of providing fire suppression and are inherently reliable. However, they require penetrations into the glovebox and present a potential dilemma in the event of sprinkler/nozzle activation with respect to volume of water discharged into the enclosure and the disposal mechanism for potentially contaminated water. Toppling of a glovebox during a seismic

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event would eliminate fire suppression in the enclosure with this type of system. Additionally, the volume of water flow from a broken pipe would far exceed the volume of water flow from multiple sprinklers, which would compromise the ability of the overhead sprinkler system to suppress a fire. A dedicated water mist system would be incapacitated, but not affect the overhead suppression system.

Inertion is another approach to minimize the potential for fire by providing an oxygen deficient atmosphere that does not support combustion in the enclosure. As such, inertion is not a “fire suppression” system. The inertion systems are installed to support process requirements typically involving pyrophoric metals. Inertion is the predominant approach throughout the DOE Complex to minimize the possibility of fire in enclosures. Fire mitigation is reliable up to the point at which the inert atmosphere can be maintained. Toppling of a glovebox during a seismic event or loss of electrical power to the vacuum equipment would compromise the inertion and the atmosphere intended to mitigate the possibility of a fire.



Glovebox Mockup

Dry chemical systems, similar to kitchen hood systems, have been proposed and mocked up, but not subject to actual fire tests to prove their viability. However, dry chemical systems would require penetrations into the enclosure and seismic modifications to the glovebox to support the agent cylinder, adding considerable expense to this unproven system. Toppling of a glovebox during a seismic event would potentially damage piping or the agent cylinder, compromising its ability to suppress fire. Additionally, the heat detector which is located in the ceiling, which acts as a means of activation for the dry chemical system, would now be located on the side of the glovebox, adversely affecting the response time for this suppression system if it were still functional after a seismic event.

Fire Foe™ is a self-contained fire extinguisher that would be mounted to the interior ceiling of the enclosure via four to six bolts. Fire Foe™ provides a reliable means of fire suppression. (See appendices for fire test data.) The tubes are seismically robust, and toppling of a glovebox during a seismic event would not affect the Fire Foe™ tube. Therefore, the tube would remain functional and provide an active means of fire suppression in the enclosure as opposed to the aforementioned systems.

### FIRE FOE™ TUBES

Fire Foe™ tubes are a self-contained, heat intelligent, fire extinguisher that is UL Listed for Class B (i.e., liquid pool fires) and Class C (i.e., energized electrical circuits) fires in enclosures of 15, 30, 60, 100, and 130 ft<sup>3</sup>. The manufacturer also produces a larger tube for 250-ft<sup>3</sup> enclosures. The 250-ft<sup>3</sup> tube was not subject to UL testing and does not carry the UL mark. The 250-ft<sup>3</sup> tube is manufactured to the same standards and with the same equipment used to produce the smaller UL-Listed tubes.



Fire Foe™ tubes do not carry a Class A (i.e., ordinary combustibles) listing because there is no nationally recognized test for Class A fires in enclosures less than 3,531- ft<sup>3</sup>.

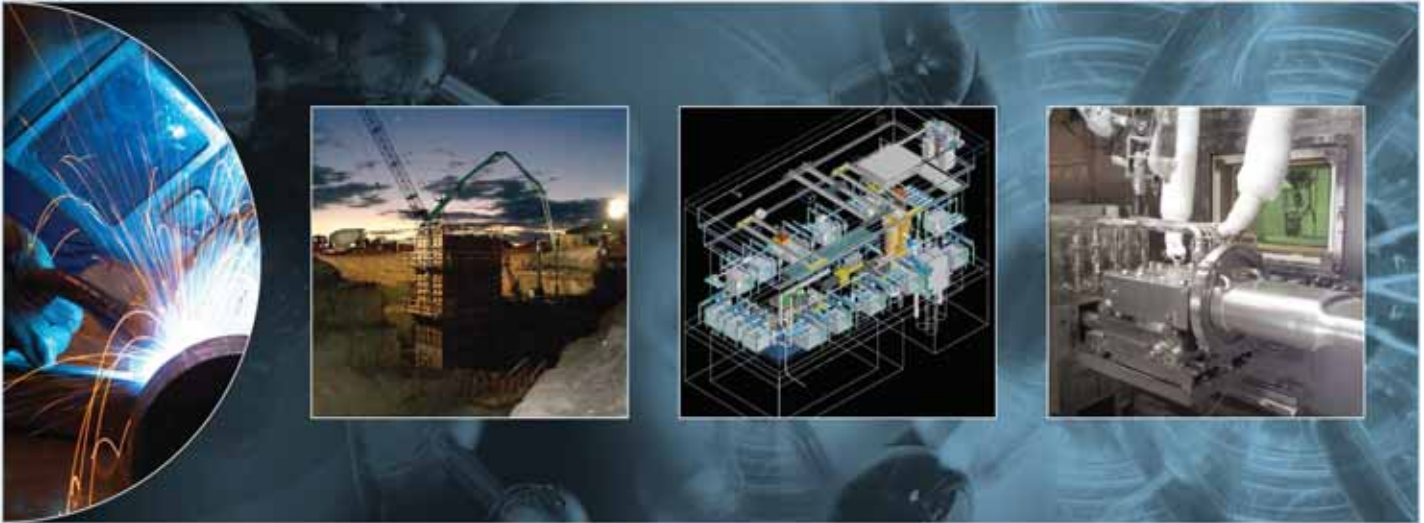
The Fire Foe™ tubes contain Envirogel®, which is a mixture of sodium bicarbonate powder (micro-ground) and two clean agent suppressants: FE-25™ and FE-36™. The sodium bicarbonate disperses with the clean agent suppressants and coats the contents of the enclosure to prevent re-ignition of combustibles.

Research into the clean agent suppressants revealed they are both listed for Class A, as well as Class B and C fires. According to the technical bulletins for each clean agent suppressant:

- FE-25™ “The accepted Minimum Extinguishing Concentration (MEC) for FE-25™ for Class-A fires is 6.7% based on the Class-A fire test requirements found in Underwriters Laboratories’ (UL) Standard 2166. For Class-B fires, the MEC is 7% based on cup-burner tests with n-heptane fuel... FE-25™ is an ideal replacement for Halon 1301 for the total flooding of enclosures. It can be used in applications where people are normally present (normally occupied spaces) for Class-A fire assets.”
- FE-36™ “DuPont™ FE-36™ is the most widely used zero ozone depleting replacement for Halon 1211 in portable fire extinguishers and is approved for use in Class-A, -B, and -C fires.”

The technical bulletins for FE-25™ and FE-36™ indicate extinguishing characteristics of the clean agent suppressants, which leads us to believe the tubes could be utilized to extinguish Class A fires. In addition, the manufacturer of the tube was confident Fire Foe™ tubes would prove successful for extinguishing Class A fires.

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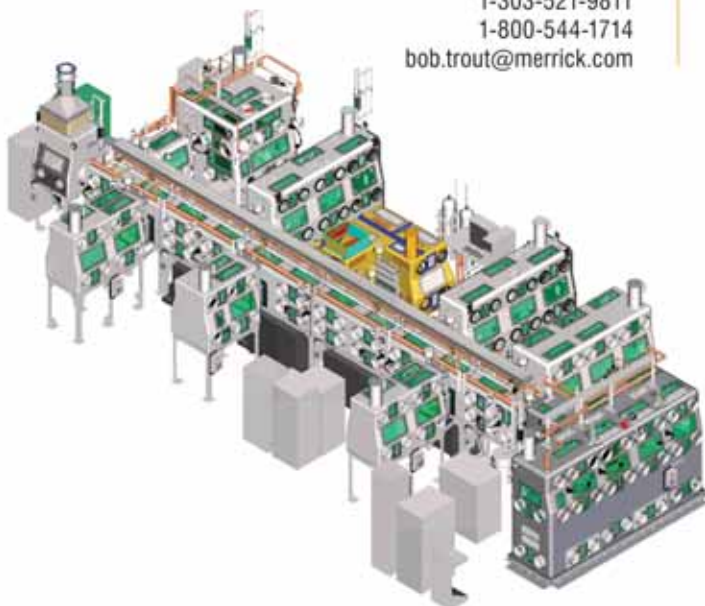
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The Fire Foe™ tube is constructed of Nylon 6,6 (PA66) that is 0.065" (1.65-mm) thick with a milled strip that is 0.055" (1.4-mm) thick for standard temperature tubes and 0.085-in. (2.16-mm) thick with a milled strip that is 0.075" (1.9-mm) thick. The thinner milled strip is intended to be the release/rupture point at tube activation. The milled portion is identified by a strip of black tape to facilitate alignment of the tube for optimal discharge during installation. Tubes are sealed at the ends with 12L14 carbon steel caps. One end of the tube is fitted with a fire extinguisher-type gauge, which provides an easy means to inspect the tube to ensure it is properly pressurized. The operating range of the gauge is 75 psi to 121 psi (i.e., the green band of the gauge). The other end of the tube is fitted with a threaded fitting and spring-loaded plunger assembly that is utilized to fill, pressurize, and seal the tube. Tubes can be manufactured with 304 stainless steel end caps instead of 12L14 carbon steel to suit glovebox working environments.

Fire Foe™ uses patented technology and specially formulated heat-intelligent nylon tubes, eliminating the need for additional heat detectors. There is no need for an initiating device to activate the tube or any type of power supply, making Fire Foe™ a cost-effective, automatic fire extinguishing system. The narrow tube profile and bolt-on simplicity save time and money when fitting or retro-fitting this fire suppression system, minimizing downtime and loss of productivity.

Standard tubes are effective in ambient operating temperatures up to 175°F (80°C) and are accredited by UL up to 130°F

(55°C). High-temperature tubes are suitable for use in ambient operating temperatures up to 220°F (105°C). The manufacturer can provide dummy tubes with heat recording labels to help determine maximum ambient operating temperature in the enclosure to determine which temperature tube should be installed if there is any uncertainty.

Fire Foe™ reacts to all fires, slow burning over time as well as flash fires. Tubes are normally pressurized to 100 psi at room temperature. Below 175°F (80°C), the Fire Foe™ tube is stable. When the heat from a fire climbs above 175°F (80°C), the Fire Foe™ triggers the heat-intelligent nylon tube, which begins to activate (i.e., soften). High-temperature tubes will begin to self-activate above 240°F (115°C). As the temperature rises, the internal pressure of Envirogel® increases, eventually rupturing the tube along a milled release strip, releasing the Envirogel®. At 316°F (150°C), standard temperature tubes discharge instantly. The Envirogel® undergoes a phase change from gel to gas, which instantly interrupts the combustion process, absorbing heat and chemically extinguishing the fire. The non-toxic and non-corrosive sodium bicarbonate powder travels with the gas, coating any combustible material to prevent re-ignition.

Tubes are vibration- and corrosion-resistant, unaffected by low temperatures, and will not activate before the pre-determined temperature has been reached (500 successful individual activations were performed sequentially, in accordance with UL 2166, to secure UL approval).

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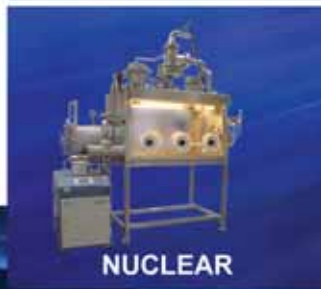
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## Glovebox Fire Suppression - Fire Foe™ Tubes

Fire Foe™ is provided with an integral pressure gauge for easy monitoring. Additionally, the tubes are available with an integral pressure switch that can be tied into the fire alarm system for monitoring.

Periodic maintenance for the tubes can be accomplished by a visual inspection of the gauge located on the end of the tube. A log should be maintained to confirm that the pressure is still within the acceptable range (i.e., green band on gauge).

### DEVELOPMENT OF TEST PROTOCOL

LANL's ES-DE Fire Protection Division developed a phased test plan to minimize financial exposure to LANL in the event proof-of-concept tests were not successful. The initial phase was comprised of proof-of-concept testing at the manufacturer's facility. Successful proof-of-concept testing would be followed up with subsequent phases that consisted of Nationally Recognized Testing Laboratory (NRTL) fire testing based on the developed test protocol.



Fire in Glovebox with Glove

As previously stated, there is not a nationally recognized test for Class A fires in enclosures. We used this to our advantage to develop a test protocol tailored to needs here at LANL. Specifically, the Class A combustibles would consist of a wood crib, boxes of Kim-wipes, and Tygon tubing. Class B combustibles would be comprised of acetone and cutting oil. Class C combustibles would consist of wire bundles comprised of #16 AWG, #18 AWG, and coaxial cables. The test protocol was prepared in conjunction with QuickFire, the manufacturer of Fire Foe™ tubes. Due to the lack of a Class A listing for any tubes, we developed the test protocol based on the largest tube (i.e., 250-ft<sup>3</sup>) tube manufactured by QuickFire to yield the greatest benefit to the Laboratory.

### PROOF-OF-CONCEPT TESTING

LANL provided sketches and details to QuickFire to permit them to fabricate a glovebox mock-up at their facility to perform fire tests. Dimensions of the mock-up were 8'L x 5'W x 6'H,

yielding a 250-ft<sup>3</sup> enclosure. LANL provided windows, window gaskets, gloves, and HEPA exhaust filters identical to equipment used on gloveboxes at LANL.

When the glovebox mock-up was completed, the manufacturer installed thermocouples to record the temperature profile in the enclosure, pressure transducers to record the pressure profile in the enclosure, and a blower and ducting to provide the airflow indicated in the test protocol. The thermocouples and pressure transducers were connected to a computer to record data for all proof-of-concept fire tests. Airflow was measured with an anemometer and set to 250 cfm (i.e., one air change per minute). The airflow used for the fire tests is greater than that used for gloveboxes, and more consistent with fume hoods, thus opening the door to the possibility that the tubes could be used in fume hoods—and providing a dual-use benefit of the tubes for LANL. The air intake opening was adjusted to provide negative pressure as indicated in the test protocol. Negative pressure is required in the enclosure, with respect to the room

in which it is located, to ensure the glovebox does not discharge its contained environment to the surrounding room in the event of a glove breach or other breach of the enclosure. The requirement to maintain negative pressure within the enclosure was a concern because of the fact that the internal pressure inside the Fire Foe™ tube is approximately 600 psi at rupture, which intuitively would generate a pressure surge. The concern was unfounded, as activation of the tube resulted in a negative pressure spike, actually pulling the gloves into the enclosure.

### Summary of Proof-of-Concept Test Results

QuickFire performed numerous fire tests at its facility in accordance with our co-established test protocol. Fire tests were performed utilizing Class A combustibles, Class B combustibles, and Class C<sup>1</sup>

combustibles fires and various combinations of combustibles to confirm the Fire Foe™ tube is capable of successfully extinguishing all three classes of fires in enclosures. Class A combustibles used for this series of fire tests consisted of wood cribs constructed of nominally 1"D x 2"W x 10"L pine into a 10" cube stuffed with crumpled newspaper to represent a deep-seated fire.

The individual proof-of-concept fire tests performed by QuickFire are referred to as "Test Protocol #" in its report, "Fire Foe™ in 250 CF Glovebox Proof-of-Concept Test Report". This report is available upon request.

QuickFire performed 10 proof-of-concept tests at -3/4" water column (i.e., glovebox negative pressure requirement) that were 100% successful. The proof-of-concept tests used various combustibles as defined in the test protocol. Successful testing led to an additional set of tests that were performed

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**ENCLOSURE**

## Glovebox Fire Suppression - Fire Foe™ Tubes

September 20, 2010, at QuickFire's facility in Fort Wayne, IN, and witnessed by LANL representatives Mark S. Rosenberger and James A. Tsiagkouris of ES-DE Fire Protection Division. The pressure was adjusted to -1/4" water column for this next series of fire tests to more closely reflect actual glovebox conditions found at LANL. An additional four proof-of-concept tests were performed that were also 100% successful.

The positive pressure surge envisioned at tube activation/rupture proved to be unfounded, as the pressure surge was negative due to the phase change and cooling effect of Envirogel®. The only positive pressure changes were the result of involvement of combustibles during the fire tests.

The Fire Foe™ tube was located along the longitudinal centerline of the glovebox mock-up for all 14 proof-of-concept tests performed at the manufacturers' facility. As we worked through proof-of-concept testing, we realized that even though the centerline of the glovebox was the optimal location for the tube, it was not the most accessible location for attachment of the tube. Additionally, equipment or processes used in the glovebox may preclude locating the tube in the centerline of the enclosure. We requested additional fire tests with the tube located closer to the side of the enclosure, which would have a two-fold benefit: allowing easy access to the tube from the glove ports and providing redundancy of suppression via installation of tubes on each side of the enclosure. QuickFire performed additional proof-of-concept tests with the tube located nominally 6" below the ceiling and 6" from the side wall; the tests were 100% successful.

All fire test conditions were maintained for a minimum of 5 minutes after activation of the Fire Foe™ tube to confirm there was not any re-ignition of combustibles or any remaining embers that would support continued combustion in accordance with UL guidelines. Table 1 shows a summary of the test results.

**Table 1. Summary of Proof-of-Concept Test Results**

At the end of this entire testing cycle, the gloves in the gloveboxes were still intact and pliable without any breaches, but they did have some discoloration because of their proximity to the fire. The windows did not suffer any damage or clouding, and the window gaskets showed no signs of fire damage.

### NRTL TESTING

Successful proof-of-concept testing permitted us to proceed with NRTL testing, which was to be witnessed by LANL representatives. Intertek, an NRTL, agreed that testing and set-up would be easier if the glovebox mock-up remained at QuickFire's facility. Follow-up NRTL testing was performed

October 19, 2010, and witnessed by LANL representatives Mark S. Rosenberger and James A. Tsiagkouris. The purpose of contracting with an NRTL was to provide independent verification of the test results. Additionally, the NRTL has the ability to provide long-term inspections at the manufacturer's facility to guarantee to LANL that tubes are manufactured to the same specifications as the tubes used for fire tests.

### Summary of NRTL Test Results

NRTL monitored and recorded the six tests that were performed. The Fire Foe™ tube successfully extinguished fire tests 1, 3, 4, 5, and 6. For this series of fire tests, we used a UL 1975 wood crib assembly. The UL 1975 wood crib has a smaller heat release rate than the wood crib used for the proof-of-concept fire tests. To initiate the fire test, the wood excelsior inside the base of the wood crib was ignited and allowed to burn for 1 minute prior to introduction of acetone. The pressure wave generated when the acetone became involved in the fire had an extinguishing effect on the wood crib fire. This effect is evident in fire test no. 2 as the fire burned out prior to reaching a temperature that was sufficient to activate the tube. To minimize the extinguishing effect experienced during introduction and involvement of acetone, we decided to allow the wood crib to burn for 2 minutes for fire tests 5 and 6. Table 2 summarizes the NRTL test results.

Table 1. Summary of Proof-of-Concept Test Results

| Fire Test No.  | Type of Combustibles                                  | Time from Ignition to Activation of Fire Foe™ Tube (minutes:seconds) | Approximate Ceiling Temperature at Tube Activation |
|--|---|--|--|
| 1  | Class B <sup>1</sup>                                  | 2:03   | 370°F  |
| 2  | Class B   | 0:56   | 465°F  |
| 3  | Class B   | 1:29   | 430°F  |
| 4  | Class A <sup>2</sup> and B                            | 1:25   | 340°F  |
| 5  | Class A and B   | 2:31   | 355°F  |
| 6  | Class A and B   | 1:16   | 255°F  |
| 7  | Class A, B and C <sup>3</sup>                         | 2:33   | 305°F  |
| 8  | Class A, B and C                                      | 1:07   | 390°F  |
| 9  | Class A, B and C                                      | 2:06   | 325°F  |
| 10   | Class A, B and C                                      | 2:18   | n/a  |
| 11   | Class A, B and C                                      | 1:58   | 315°F  |
| 12   | Class B and C   | 3:05   | 322°F  |
| 13   | Class B and C   | 5:59   | 270°F  |
| 14   | Class A, B and C                                      | 3:45   | 545°F <sup>4</sup>                                 |
| <sup>1</sup> Class B                                     | Liquid pool fires - Acetone and preheated cutting oil |  |  |
| <sup>2</sup> Class A                                     | Wood crib, and crumpled newspaper and Tygon tubing    |  |  |
| <sup>3</sup> Class C                                     | Coaxial cable, #16 THHN, and #18 THHN                 |  |  |
| <sup>4</sup> 130 ft. tube installed in 250 ft. enclosure |   |  |  |



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Table 2. Summary of NRTL Test Results

| Fire Test No.        | Type of Combustibles                                       | Time from Ignition to Activation of Fire Foe™ Tube (minutes:seconds) | Approximate Ceiling Temperature at Tube Activation | Approximate Pressure Change at Tube Activation |
|----------------------|--|--|--|--|
| 1                    | Class A <sup>1</sup> , B <sup>2</sup> , and C <sup>3</sup> | 4:21   | 311  | -9" WC   |
| 2                    | Class A, B and C   | Fire burned out  | -  | -  |
| 3                    | Class A, B and C   | 6:11   | 430°F  | -3.5" WC                                       |
| 4                    | Class A, B and C   | 2:52   | 340°F  | -6" WC   |
| 5                    | Class A, B and C   | 3:13   | 355°F  | -14.5" WC                                      |
| 6                    | Class A, B and C   | 3:42   | 255°F  | -12" WC  |
| <sup>1</sup> Class A | UL 1975 wood crib and Tygon tubing                         |  |  |  |
| <sup>2</sup> Class B | Liquid pool fires - Acetone and preheated cutting oil      |  |  |  |
| <sup>3</sup> Class C | Coaxial cable, #16 AWG, and #18 AG bundle of wires         |  |  |  |

in a glovebox or be at the face of a hood, then the products could be discharged into the adjacent air spaces. This smoke is fully anticipated to be processed by the secondary air handling systems supporting the affected facility. This type of scenario is normally addressed as part of the Authorization Basis for a facility but would have to be reviewed for any potential impact to the bounding design basis accidents that have been developed.

**ENVIRONMENTAL IMPACT**

Based on fire tests performed to validate this suppression system, Fire Foe™ tubes typically discharge within four minutes in the event of a fire in the enclosure. The resulting discharge will introduce the Envirogel® into the enclosure. At the time of discharge, the Envirogel® will consist of the components and forms listed in Table 3.

Table 3. Envirogel® Components and Forms

| Component          | Form   |
|--------------------|--------|
| Sodium Bicarbonate | Powder |
| Nitrogen           | Gas    |
| DuPont FE-25™      | Gas    |
| DuPont FE-36™      | Gas    |

Dupont, Inc., manufactures the fire extinguishing agents FE-25™ and FE-36™ as Halon 1301 replacements. Both agents have been Significant New Alternatives Policy (SNAP) program-approved by the Environmental Protection Agency (EPA) and are suitable for direct release to the atmosphere as ozone non-depleting agents.

The products of combustion that will be produced in a fire event cannot be fully anticipated because they are dependent on the contents of the enclosure and the materials involved in the fire. However, consistent with any industrial fire event, the agents will interact with the combustion process and will generate a number of compounds that are adverse to health safety and the environment.

In the event of a small fire, it would be fully anticipated, as long as the exhaust system remains functional, that the products of combustion would be contained by the primary exhaust system. This would provide filtering of the smoke prior to discharge to the environment. If the fire were to involve gloves

**Decommissioning**

Decommissioning of the tubes presents several challenges, listed below:

- Potential radiological surface contamination on the tube
- Relieving internal pressure of the tube
- Disposal of the tube contents
- Disposal of the tube

We have explored methods to decommission the tubes. We propose the following steps for disposal of tubes that are not provided with an integrated pressure switch:

1. Identify the tube for decommissioning.
2. Remove the identified tube from the mounting bracket.
3. Remove the screw end cap from the tube, exposing the spring-loaded valve.
4. Screw in the pressure relief tool and attach a capture bag to the discharge end of the relief tool.
5. Engage spring-loaded valve by rotating the tube and release internal pressure; any contents of the tube will be captured in the attached bag.
6. Empty the remaining contents of the tube into the bag.
7. Cut tube as required to accommodate removal of tube from the enclosure.

In the event of potential radiological surface contamination, the tubes will have to be disposed of as contaminated waste. Due to the nature of the tube's surface materials, it is not anticipated they could be adequately decontaminated to allow for a free release from the environments in which they are installed. Therefore, decommissioning will have to be performed inside the enclosure or transferred to a dedicated enclosure for decommissioning.

Once the pressure in the tube is relieved, and the contents of the tube (i.e., sodium bicarbonate powder) are removed, the body of the tube can easily be cut, by a hand or power saw, into shorter lengths as required to support removal from the

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enclosure by standard means. The cut sections of tube targeted for waste would simply be processed out of the enclosure as non-compactable waste.

The nitrogen gas used to charge the tube could be released in the enclosure itself and allowed to discharge with the exhaust air from the glovebox through the facility's filtered exhaust system. Additionally, at atmospheric pressure, the FE-25™ and FE-36™ clean agent suppressants that comprise the Envirogel® vaporize and are carried out with the nitrogen gas. This leaves only the sodium bicarbonate powder in the tube, which would be processed with the spent tube and disposed of as non-compactable waste.

## Accidental Discharge

There is always the possibility of an accidental discharge of the tube. One scenario would be premature failure of the tube. The most likely cause of this would be a standard temperature tube placed in an environment in which it sees higher than anticipated ambient temperatures, similar to the failure mechanism of a fire sprinkler in this type of environment. For a fire sprinkler, this type of failure would result in the fire suppression system activating and discharging water from the activated sprinkler into the protected area. In the event of a tube discharge, the result would be similar; the tube would rupture and the agent would be released into the protected enclosure.

Another scenario would be mechanical impact resulting in a puncture or breach of the tube. Once again, this scenario would be similar to a fire sprinkler placed in a physical location where the sprinkler could be damaged by physical impact. In the case of a sprinkler, physical damage could result in damage that causes it to leak or could result in the thermal element being dislodged, causing a full flow from the sprinkler. In either case, the result is the same: the fire suppression system would be impaired and water would be flowing in the facility. The tubes are more robust than a sprinkler but could be punctured, which would result in the agent being discharged from the tube into the protected enclosure. In this scenario, the tube would have to be replaced.

Following the battery of fire tests performed to prove Fire Foe™ extinguishes Class A, B, and C fires in enclosures, a puncture test was performed and recorded to help understand what would happen if a tube was accidentally physically damaged. The test results showed that the agent would discharge in powder form. If a glovebox technician was present at the time of damage, there would be positive visual indication of the agent discharging from the tube. Conversely, if a glovebox technician was not present at the time of the accidental discharge, there would be visible indications in the form of sodium bicarbonate powder coating the interior of the enclosure and its contents.

## SEISMIC CONSIDERATIONS

Seismic considerations for systems, structures, or components (SSCs) installed in several LANL facilities are of extreme importance. Seismic events present real and challenging problems in designing engineering controls, which must ensure that these facilities are safe after a design basis event. One of the most challenging accident scenarios considered as part of the Authorization Basis analysis is the post-seismic fire event. In accordance with DOE Standard 1066 requirements, automatic fire suppression is required to be installed in all

gloveboxes. The following is a listing of the best candidates to fulfill this requirement:

1. Water-based suppression (i.e., fire sprinklers, and water mist)
2. Dry chemical
3. Inertion
4. Fire Foe™ Tubes

Each of the above systems could be installed in an enclosure, but each one presents its own set of challenges in a post-seismic fire scenario.

### Water-Based Suppression

#### Fire Sprinkler

Fire sprinklers are arguably the most cost-effective means of automatic fire suppression available. Fire sprinklers have a history of effective fire suppression in many environments. Fire sprinklers can either be piped to the overhead fire suppression system or piped independently to each enclosure. These systems draw from water sources located outside of the facility they are protecting. However, the presence of water within the enclosures at LANL can present major problems for many processes, primarily the criticality of the materials present in the enclosures.

Given a seismic event, the water distribution system may not be intact and, therefore, no water would be available to the fire sprinkler system. Even if the outside water supply were to survive the seismic event, several issues remain with the seismic response of the facility and its contents. Facility interior walls could shear the suppression system piping, and equipment within the facility could shift and damage the piping, resulting in loss of water to the system. Another concern as a result of a seismic event is that of the enclosure itself. The enclosure could tip over if the support stand failed. This would result in the sprinkler piping breaking and water being discharged from the system, but not into the enclosure, which would also compromise the ability of the overhead system to suppress a fire.

### Water Mist

Water mist fire suppression systems use a limited-volume water supply and deliver the water at a high velocity through a nozzle designed to atomize the water stream into a fog. These systems are designed to use much smaller amounts of water than fire sprinkler systems—an advantage when considering criticality concerns. In another advantage, water mist systems are typically designed with limited independent water supplies. These systems are fully listed and recognized for distribution over time, which would allow for their application in environments that require active exhaust systems. System downtime would be minimal if the water mist system discharged as long as spare discharge nozzles, water, and gas cylinders were available.

However, water mist systems are still vulnerable to seismic response of the facility and its contents just as the standard fire suppression system is.

An additional concern is the life cycle cost of the system. Because water mist systems are limited supply systems, several

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of them would have to be installed to support a single facility. Additionally, water mist systems are more complex than traditional fire suppression systems and, therefore, require more rigorous periodic maintenance. The periodic ITM will increase the overall operational costs of the facility significantly.

## Dry Chemical

Dry chemical systems use dry powder fire suppression agents to suppress a fire. These systems have dedicated limited supplies similar to the water mist system. These systems avoid the criticality concerns that the water-based systems present.

However, they are also susceptible to the seismic response of the facility and its contents. These systems, due to their complexity, have the same reliability concerns as water mist systems. They also have the same life cycle costs that the water mist systems have because of the ITM requirements.

Dry chemical systems are not allowed for “discharge-over-time” applications when installed as listed by UL or Factory Mutual (FM). Additionally, NFPA 17, “Standard for Dry Chemical Extinguishing Systems,” does not permit them to be installed as discharge-over-time applications. Current systems being incorporated at LANL have installed flow restriction devices that prolong the duration of the agent discharge. Installation of these flow restriction devices places the overall system outside of its approved NRTL listing requirements. While they may use an ABC-listed extinguishing agent, dry chemical systems are only listed for BC enclosure fire applications since there is no nation-

ally recognized standard test for Class A enclosure fires. To satisfy these issues, an extensive testing plan will need to be developed and executed before installing a dry chemical system in an enclosure is possible.

## Inertion

Inertion, while not technically a fire suppression system, needs to be discussed at part of this report because it is currently the predominant method used to mitigate fires in enclosures. Typical inertion systems are installed in enclosures that perform processes or handle materials that may react in an environment containing oxygen. These systems typically dehumidify the atmosphere and displace oxygen with nitrogen or argon, lowering the oxygen content. The resultant oxygen concentration is less than 1% compared with the 21% present in the air we breathe. This controlled low level of oxygen does not support the combustion process. Inertion systems are typically package units that are sized, selected, and installed as part of the overall enclosure.

The systems are relatively complex with vacuum pumps, inert gas regulation, system controls, oxygen and humidity monitors, etc. The systems have good reliability as long as electrical power is maintained. Inertion within the enclosure would be lost in the event the system is de-energized or loses power. Additionally, inertion systems are vulnerable to the same seismic response issues of the facility and its contents as water-based fire suppression and dry chemical systems. However, inertion is more dependent on enclosure integrity than water-based fire suppression and dry chemical systems. Therefore, in a post-seismic fire event, inertion capabilities would be compromised by the loss of a window, glove, or gasket.

As previously stated, inertion systems are not fire suppression systems, but rather a means to create an atmosphere that does not support combustion. This complicates the fire alarm interface for monitoring and fire department response to alarms generated by the system. Engineering evaluations will have to be performed to determine which portions of these systems would have to be monitored and what the proper fire alarm response would be. This presents potential Authorization Basis impacts that would have to be evaluated.

## Fire Foe™ Tube

As described in previous sections of this report, the Fire Foe™ tube is a self-contained, self-actuating extinguisher. The tube contains a proprietary mixture of FE-25™, FE-36™ and micro ground sodium bicarbonate called Envirogel® as its extinguishing agent. The tubes, similar to the dry chemical system, do not use water, thus avoiding potential criticality concerns within the enclosures. The tubes are mounted entirely within the enclosure, eliminating the need for open or water-filled piping to be installed through the enclosure and, therefore, not expanding the enclosure envelope. This reduces potential issues that may increase the leak path factor associated with an enclosure. Leak path factors result from additional penetrations through the glovebox and subsequently affect the design basis calculations.

Issues associated with seismic events are greatly reduced because the tubes are a passive engineering control. They do not require any support SSC to be functioning in a post-seismic

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event for them to be able to function. Post-seismic event issues are further reduced if the installation is done in accordance with the proposed general design criteria, which would require redundant tubes be installed within an enclosure. If an enclosure were to fall over at any angle up to 90° degrees from the vertical, a tube would still be in the upper portion of the enclosure and exposed to heat generated by any fire within the enclosure. If the fire is of sufficient energy, the tube will activate to extinguish the fire.

Unlike the dry chemical system, the Fire Foe™ tubes are specifically listed and have been tested for environments that have up to one air change per minute. This provides a Listed and tested solution for discharge-over-time applications that are required for environments exhausting the enclosure to the atmosphere. This airflow rate exceeds typical exhaust flow rates for gloveboxes and is more in line with flow rate requirements for fume hoods.

The tubes are currently UL Listed for Class B and C fires in enclosures up to 130 ft<sup>3</sup>. As discussed in earlier sections of this report, the individual agents comprising the Envirogel® mixture are listed as Class A, B, and C extinguishing agents. This report documents the successful completion of fire testing that demonstrates, and has been verified by an independent NRTL, that the tubes are capable of extinguishing Class A, B, and C fires in enclosure up to 250 ft<sup>3</sup> under negative pressure with airflow equivalent to one air change per minute.

However, the Fire Foe™ tubes may not be suitable for installation in every glovebox at LANL because of the varying environments within the enclosures. High alpha radiation environments are a concern because these particles deposit all of their energy at the surface of the material they contact. Additionally, there may be aqueous chemical environments that attack the nylon tube in a manner that will result in an abbreviated unacceptable service life. Radiation exposure tests addressing the alpha contamination issues should be performed, and an evaluation of the aqueous chemical environment for each candidate enclosure will have to be evaluated prior to installation. These more aggressive environments will have to be reviewed to ensure they are compatible with the Fire Foe™ tube.

## RADIOLOGICAL AGE TESTING

Currently, the manufacturer does not list a recommended service life for the tube. The manufacturer does offer a five-year warranty on the tube. This warranty covers manufacturing and material defects for that period of time. In discussions of a service life for tubes installed at LANL, the driving concern is how the Nylon 6,6 will react over time in a radiological environment.

Alpha radiation presents the greatest challenge to the service life and integrity of the tube because alpha particles deposit their energy at the surface of the material. The average depth of penetration at the surface is 25 to 30 microns. This depth is nominally 2% of the wall thickness of the tube.

Initial literature reviews of Nylon 6,6 indicate that it will respond better in a radiological environment than Teflon. The issue with the published literature for Nylon 6,6 is that the literature does not present damage due specifically to alpha radiation; the nomographs typically present radiological damage information based on a combined radiation field. The most relevant information available are the results of the Teflon

testing performed by LANL.<sup>2</sup> Results of this testing showed that at 10<sup>9</sup> rad, the Teflon samples showed cracking, and at 10<sup>11</sup> rad, the Teflon evaporated. Due to the lack of specific data for Nylon 6,6, some type of testing and/or material monitoring should be established until a service life can be formally established for the tubes in radiological environments.

Accelerated age testing could be conducted by applying (i.e., painting) Uranium 238 (U238) to coupons of the Nylon 6,6, allowing the samples to age for specified periods, then cleaning the sample by removing the U238 from the coupon and analyzing the surface characteristics by comparing them to control sample of Nylon 6,6. A second approach would be to take coupons of the material and place them in various enclosures with varying environments and analyze the surface characteristics at specified intervals. A combination of these two approaches could be used to provide information to establish and formalize a service life for the tubes.

The accelerated age testing by applying U238 would present the most conservative results due to the high activity levels and heat generated by U238 particles relative to other materials. In the case of coupon monitoring, a methodology of monitoring the enclosure environment over the course of the testing period would have to be developed and executed to provide meaningful data for determining radiological service life effects. A formal experimental plan will need to be developed and executed to obtain definitive information.

## DESIGN CRITERIA

The following design criteria are considered the minimum guidance for manufacture and installation of the tubes within enclosures at LANL:

### Tube:

1. Tube body shall be constructed of Nylon 6,6.
2. Two activation temperatures shall be provided:
  - a. Standard Temperature: 175°F for installation in enclosures without heat-generating equipment.
  - b. High Temperature: 220°F for installation in enclosures with heat-generating equipment.
3. Tube end caps shall be constructed of 304 stainless steel (SS).
4. Pressure gauge assembly shall be 304 SS.
5. Nominal wall thickness of the tube body shall be
  - a. Standard temperature: 0.065" +/- 0.005"
  - b. High temperature: 0.085" +/- 0.005"
6. Wall thickness of machined activation strip:
  - a. Standard temperature: 0.055" +/- 0.005"
  - b. High temperature: 0.075" +/- 0.005"
7. Machined activation strip shall start along the tube body 1.75" +/- 0.25" from the end cap.
8. Machined activation strip shall be 0.875" +/- 0.125" wide, along the longitudinal axis of the tube.

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9. Tube shall be capable of being discharged within the enclosure.
10. Tube shall be capable of being fitted with a pressure switch capable of being monitored by a fire alarm system.
11. The pressure switch shall be a normally open dry contact type capable of being placed within the same environment as the tube.
12. Mounting bracket assembly shall be manufactured from 304 SS.

### Location

1. The tube shall be rigidly mounted within the enclosure.
2. The tube centerline shall be placed at 4" +/- 2" from the ceiling of the enclosure and a minimum of 6" +/- 0.5" from the wall of the enclosure.
3. The activation strip should be orientated in such a direction that it ensures coverage throughout the enclosure. Nominally, the discharge strip shall be orientated away from the nearest wall and at a 45° angle downward (i.e., 225° or 315°).

### Size and Number of Tubes

1. Tube sizing shall be based on gross volume, or net volume as determined by a registered professional engineer. Maximum volume that can be protected by the Fire Foe™ is 250 ft<sup>3</sup>. If the enclosure cannot support the tube length, then an engineering evaluation shall be performed for the enclosure and its contents. Tube size will then be based on the net volume of the enclosure.
2. As a means of redundancy, two tubes shall be installed in each enclosure. If the enclosure or process cannot support this configuration, then an engineering evaluation shall be performed.

### Service Life

As discussed in the previous section, the manufacturer does not publish a service life for the tubes. The following are the service life recommendations. Installation of the tubes in high alpha radiation and aqueous chemical environments is not recommended until material-aging studies can be completed.

1. Service life of tubes in non-U238 radiological environments is five years.
2. Service life of tubes in U238 radiological environments is unknown.
3. Service life in aqueous chemical environments is unknown.

### INSTALLATION METHODOLOGY

Specific instructions are required for each installation because each enclosure is unique with respect to layout and design to accommodate unique processes and hazards. The following set of generic installation instruction is provided as a baseline to initiate the development of specific installation instructions.

1. Identify the size of the tube to be installed. This is based on the gross or net volume of the enclosure up to 250 ft<sup>3</sup>. Net volume could be calculated to size the tube, but an engineering evaluation must be performed.
2. Determine support locations within the enclosure. Mounting brackets shall be located so that they attach to the tube 6" +/- 2" from each end, and not greater than 36" between brackets. For 250-ft<sup>3</sup> tubes, a bracket shall be required mid-span of the tube.
3. Prepare the enclosure to accept the brackets as required. For gloveboxes, the recommended process is to spot weld 0.25" threaded studs to the identified locations. For hoods, the recommended process is to through-bolt and seal the bracket to the hood wall at the identified locations.
4. In accordance with facility procedures, introduce the tube into the enclosure.
5. Clamp the tube in place according to the manufacturer's instructions.
6. Ensure the tube is properly orientated within the enclosure and that the pressure gauge is visible from a window of the enclosure to facilitate reading the pressure gauge.
7. If a pressure switch is provided with the tube, follow facility work control procedures to tie in the pressure switch to the facility fire alarm system. Activation of the pressure switch shall generate an alarm signal.
8. Perform an overall visual inspection of the installation.

### MONETARY CONSIDERATIONS

Cost comparisons between the fire suppression systems discussed in this report are difficult to evaluate because of the many factors that influence the final cost. For example, installation costs vary dramatically between LANL's different facilities. This also applies to ITM costs based on the level of training and access requirements. Wet-pipe sprinkler systems materials and installation costs are measured in the low tens of thousands of dollars. Fire sprinkler costs are typically the lowest if the facility is already protected with a sprinkler system. However, if the water supply cannot support the required expansion to provide suppression in enclosures, providing a dedicated fire sprinkler system becomes cost prohibitive for an existing facility.

Water mist and dry chemical systems materials and installation costs are measured in the high tens of thousands of dollars and possibly hundreds of thousands of dollars for retrofit applications. These systems are pre-engineered and require design and calculations to support the selection of equipment. They also require design of required facility SSCs to support the installation. Additionally, depending on the location of the system, seismic calculations and structural modifications may be required. The long-term ITM costs will add significantly to the Life Cycle Cost (LCC) of the systems. ITM costs will be measured in tens of thousands of dollars on an annual basis. These costs don't consider replacement of these systems as they age and become obsolete.

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Tel.: +49 (0) 6251 / 96340, Fax: +49 (0) 6251 / 54938  
E-Mail: [info@jung-gt.de](mailto:info@jung-gt.de)

# AGS CONFERENCE 2011 SUMMARY AND HIGHLIGHTS

During the week of July 18th 2011, the AGS's 25<sup>th</sup> Annual Conference took place in San Francisco, CA. This year's event was one of the top successful conferences of the AGS's existence drawing over 225 attendees. Under Jim Spolyar's leadership, over 30 vendors from 5 countries descended on the "city by the bay" to display the latest in glovebox and enclosure technology. Our theme of lessons learned and glovebox safety was highlighted by advanced training and technical presentations that were some of the best received in recent history. For leisure activities, San Francisco provided a backdrop of great restaurants and site seeing, as well as a Giants baseball game in which Brian "fear the beard" Wilson closed for a Giants' win. Special thanks to all the exhibitors and sponsors which added to the great success of this years event. Please make your plans for the **AGS Conference 2012 on August 6-9, in Arlington, VA.**



*I found the 2011 AGS Annual Conference and Trade Show in San Francisco to be a valuable and worthwhile experience.*

*This was my first AGS conference after six years of working in gloveboxes. I felt that the Monday training seminars helped confirm much of my glovebox knowledge and also added significantly to it especially in relation to glovebox ergonomics.*

*The speakers, discussions, and technical sessions on Tuesday and Wednesday stimulated my thoughts on glovebox materials and safety. They also gave me new approaches to various glovebox activities and challenges. I realized that although many miles may separate me from my glovebox colleagues, our common desire to improve the safety and efficiency of our work brings us together and keeps us coming back.*

*I was looking forward to meeting up with representatives in the Trade Show portion of the conference. I had specific questions to ask and ideas to pursue. I was pleasantly surprised to find that they also had tools, services, and knowledge beyond what I had anticipated.*

*The City of San Francisco is beautiful and the Parc 55 Wyndham was an excellent venue. The staff were helpful and responsive when I needed them and the food provided at the conference was delicious."*

*Chris MacCready (Technologist, AECL, Canada)*



*After years of attending the AGS conferences, I am finding it to be a useful place to exchange technology on gloveboxes with different organizations. The AGS conference is the only place that everyone that works with gloveboxes can come together and discuss ideas, experiences and challenges for a unique industry. It's great that different manufacturers and equipment suppliers can present useful solutions to address design requirements related to gloveboxes. Every year the location of the conference has improved and this year in the heart of San Francisco was no different. I look forward to next year's conference and expect to see the same results as what I experienced this year.*





Attending the AGS Conference provides me the opportunity to interface with glovebox users, fabricators and component vendors which comprises the majority of the interfaces that I need to support my customers. It also provides an excellent continuous learning process for both individual career enhancement and my company's benefit. As a Glovebox Design Authority Engineer in a National Laboratory, learning what others are doing and sharing what is working for us greatly helps me to perform my job and to bring due diligence to the work place. The establishment of face to face personal contacts at similar facilities has been "priceless" in trying to further resolve complex issues and initiate glovebox program improvements at my own facility.

Med Allen  
SRNL Glovebox Design Authority



I enjoyed the exhibitors and the ability to view new glovebox and containment technology being marketed. I was able to interact with vendors and make new business contacts. I gained insight on how professionals around the world can come together and share experiences of glovebox activities, design, setup, and equipment to safely and efficiently improve our own individual companies.

Angela W. Bowser  
Separations and Actinide Science Programs  
Savannah River National Laboratory



I gained a deeper understanding of the complexities inherent to glovebox systems, most notably, ergonomics. My co-workers and I have enjoyed learning better techniques and developing our own to accomplish work in a safer way. The advances in hardware for glovebox components and some new configuration ideas keep me constantly trying to develop newer safely efficient operations. The knowledge base that I have tapped into is concerned with helping, and I hope that in the years to come I will be able to provide help as well.

J. Ziska  
Materials Processing and Technology  
Savannah River National Laboratory

The AGS conference was thoroughly enjoyable and I appreciate the way I was treated. I'm a Senior Certified Fissile Material Handler (SCFMH) here at LLNL. I thought the lessons learned at the AGS conference were invaluable, in the type of work we are tasked to complete. I look forward to attending again, if my programmatic responsibilities will allow. Thank you again.

Kenneth E. Lema, Lawrence  
Livermore National Lab





Post- Fire Activation

Fire Foe™ tube material costs are measured in the low thousands of dollars. Installation costs are currently projected to be measured in hundreds of dollars for new work and thousands of dollars for retrofit applications. ITM requirements for the tubes are low and expected to be measured in thousands of dollars annually. Replacement and disposal of the tubes at the end of their service life are anticipated to be measured in tens of thousands of dollars. Replacement of the expended tube is expected to be measured in thousands of dollars.

Inertion systems acquisition and installation is currently measured in terms of hundreds of thousands of dollars.

All of these values are based on the authors' experience with costs associated with different projects at LANL.

## FUTURE ASPIRATIONS

The Fire Foe™ technology presents a fire suppression tool that is capable of meeting challenges that previously would have required more complex and costly solutions. Several possibilities that exist with this technology are very exciting. These possibilities result from the unique nature of the materials and applications that are present within the DOE Complex. One of the areas that is the most exciting and presents a potential solution to fires unique to the DOE Complex is determining if the delivery system can be used successfully with other types of extinguishing agents (e.g., MET-L-X, LITH-X) for other classes of fires. Additionally, this tool provides another solution to the fire suppression problem of providing protection to individual high-value or key pieces of equipment or apparatus in remote or hazardous environments, and thus also reduces the potential risk of program downtime caused by ineffective systems.

## CONCLUSION

Fire Foe™ tubes are a robust, reliable, and minimally invasive means of fire suppression for the majority of gloveboxes at LANL. The tubes are available for standard and high-temperature applications. Tubes are relatively easy to install and mounted/secured to the interior of the enclosure with four to six

bolts (depending on the size of the tube) and would not require penetrations through the glovebox shell. The tubes are easily monitored by a fire alarm system with an integrated pressure switch. Inclusion of a pressure switch would require a single glovebox feedthrough for one or two pairs of 16 AWG wires if the Fire Foe™ tube is connected to the fire alarm system for monitoring.

It is our intent to specify redundancy for this application by requiring two Fire Foe™ tubes to be installed, with one located on each side of the glovebox. This redundancy in the system would have an added benefit in a seismic event; if the glovebox toppled onto its side, there would still be an active Fire Foe™ tube located near the ceiling of the glovebox. If the tube located near the bottom of the glovebox is punctured or ruptured when the glovebox topples, it would potentially coat combustibles preventing ignition. The tube located near the top of the glovebox would remain intact and ready to extinguish a fire.

Proof-of-concept fire tests have been documented to prove Fire Foe™ tubes successfully extinguish Class A, B, and C fires in a glovebox enclosure when tested under conditions that are in line with an actual glovebox working environment at LANL. The successful proof-of-concept fire tests were followed by additional fire tests that were witnessed by Intertek, an NRTL. All fire test data and test reports are included in the appendices.

As mentioned earlier in the report, QuickFire manufactures a range of tubes targeted to specific volumes of enclosures. These tubes are scaled in their dimensions and contents for the volume of the enclosure that is to be protected. By selecting the 250-ft<sup>3</sup> Fire Foe™ tube for our fire tests and proving it is successful at extinguishing Class A, B, and C fires in enclosures, it affords us the scalability of the Fire Foe™ product line, permitting installation of the full range of tubes in enclosures with Class A, B, and C combustibles. ❖

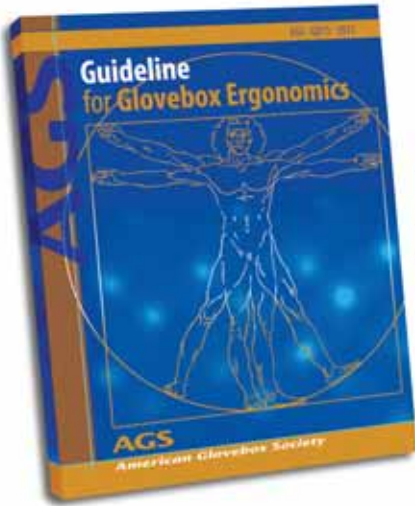
## References

\* Reference Los Alamos National Laboratory Report: LA-UR-11-00994 for Appendices containing Proof-of-Concept fire test report and NRTL fire test qualification report are available upon request from the authors.

<sup>1</sup> *Class C fires are energized electrical equipment, and the requirement is for the extinguishing agent to be electrically non-conductive. Envirogel® is already listed for Class C fires as a non-conductor. The intent of our fire test was to prove that the insulation for electrical equipment and wiring would be successfully extinguished (similar to Class A and Class B combustibles).*

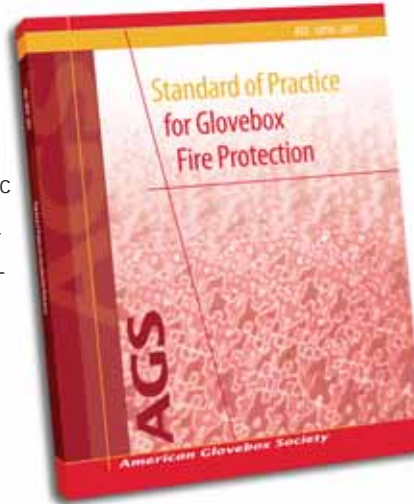
<sup>2</sup> *"Characterization of the Alpha-Radiation Effects on Polytetrafluoroethylene," Lakis, Rollin, et al., 2000.*

## NEW AGS PUBLICATIONS - ORDER TODAY



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