

Quantifying the Impact of Portable Fire Extinguisher Agents on Cultural Resource Materials: Fire and Non-Fire Exposure Tests

Fire Suppression and Detection Research and Applications – A Technical Working Conference (SUPDET 2016), March 1 – March 4, 2015, San Antonio, TX

Matthew E. Benfer, Joseph L. Scheffey, and Eric W. Forssell,
JENSEN HUGHES Inc.
3610 Commerce Dr., Ste. 816, Baltimore, MD 21227, 410-737-8677

Emily Williams,
Colonial Williamsburg Foundation
P.O. Box 1776, Williamsburg, VA 23187-1776, (757) 229-1000

Background

Portable fire extinguishers and their associated fire extinguishing agents play an important role in reducing the impact of fire on cultural resource collections. These may be valuable collections or the structure housing the resources which itself may be of cultural significance. A fire which can be suppressed with an extinguisher in its incipient stage will not grow to threaten adjacent materials. A range of extinguishing agents is commonly used in museums and libraries, including water, clean gaseous agents, dry chemicals, and foam. Their effectiveness in combating fires has been studied and is well-understood but their effects on collections materials have not been adequately studied. While conservators are well versed in the effects of moisture and water on collections, little data is available on the effects of other extinguishing agents. The potential collateral damage from agent overspray, potential misuse of extinguishers in spraying collection materials, and the byproducts of the agent when used to extinguish a fire is of interest. Particularly, short- or long-term exposure to extinguishing agents needs to be quantified.

In 2009, recognizing the need for further investigation, the National Fire Protection Association (NFPA) *Technical Committee on Cultural Resources* submitted a project proposal to the Fire Protection Research Foundation (FPRF). The proposal was to develop test specifications and procedures for measuring the impact of portable fire extinguisher agents on cultural resource collections. A scoping report was prepared which included a literature review. The theoretical parameters for testing the impact of extinguishing agents on collections materials were established. It was then vetted by a technical panel consisting of conservators, fire protection engineers and extinguisher manufacturers.

As part of this effort, an outline test plan was developed, in anticipation that interested parties would fund a follow on effort to develop a test method and conduct tests on the impact of agents on materials. The published report [1] provides the basis for these tests.

In late 2013, The Colonial Williamsburg Foundation (CWF) received a National Leadership Grant from the Institute of Museum and Library Services (IMLS). This funded a three-year research study of the effect of fire extinguishing agents on collections in cultural heritage environments. The project team consisted of CWF, JENSEN HUGHES, and the FPRF acting in the role as facilitator of a project oversight panel. The project oversight panel was appointed by the FPRF.

Objectives

This project was intended to quantify the impact of discharging portable fire extinguisher agents on cultural resource materials, and to establish a scientific method for this assessment. The research was also intended to validate and refine a cost-effective and repeatable test protocol. This can then be used by other organizations to continue to assess various materials and add to the database of known extinguisher effects.

Approach

Two primary types of tests were performed:

- Non-Fire (Neat Agent) Tests – This was an exposure of representative materials directly and indirectly exposed to the extinguisher spray. The intent was to assess the impact of an agent which is discharged accidentally or maliciously in the absence of a fire.
- Fire Tests – This was an exposure of representative materials within and outside of the extinguisher spray pattern while using the extinguisher to fight a fire. The intent was to assess the impact of agent byproducts resulting from the extinguishment process. The fire was sized to be easily extinguished and to limit the direct smoke/thermal impact from the fire itself.

Each test was conducted with each type of extinguisher. The following sections describe the test parameters and general approach of each type of test. Scoping tests were performed to refine the specific test parameters. The effect of a fire alone on the representative materials was not evaluated.

Materials Evaluated

The cultural resource materials were supplied by CWF. The choice of materials was based on commonality within the museum community and availability of repeatable samples.

Due to the large number of samples required for testing and the surface area required to test the cleaning techniques, the size of the sample materials was selected to be nominally 10 cm (4 in.) by 10 cm (4 in.). The small sample size also facilitated the use of direct mass measurement of the deposition on the exposed material. The thirteen materials that were exposed in this test program and their associated test designation include:

- Black iron sheet (1.57 mm [20 gauge] thick), Material #1;
- Copper sheet (1.08 mm [0.042 in.] thick), Material #2;
- Aluminum sheet (3.15 mm [0.12 in.] thick), Material #3;
- Vegetable tanned leather (Bovine leather with mimosa tan; 1.87 mm [0.073 in.] thick), Material #4;
- Tulip poplar wood, unvarnished (simulating secondary wood; 6.43 mm [0.25 in.] thick), Material #5;

- Cherry wood, varnished with a shellac (0.57 kg [1.25lb]) varnish (simulating primary wood; 6.43 mm [0.25 in.] thick), Material #6;
- Linen canvas, oil primed and painted with stripes of lead white paint, ivory black and red ochre with bare canvas between the stripes (0.46 mm [0.018 in.] thick), Material #7;
- Linen canvas, acrylic primed and painted with color stripes (0.46 mm [0.018 in.] thick), Material #8;
- Travertine tile, tumbled finish (9.75 mm [0.38 in.] thick), Material #9;
- Marble tile, tumbled finish (10.06 mm [0.41 in.] thick), Material #10;
- White-tailed deerskin (4.17 mm [0.16 in.] thick), Material #11;
- Unglazed terracotta tile (14.52 mm [0.57 in.] thick), Material #12; and
- Glazed ceramic tile (6.90 mm [0.27 in.] thick), Material #13.

Three arrays of samples were exposed during each test, with two samples of each material on each sample array. One array was exposed directly in the spray pattern of the portable extinguisher while the other two arrays were exposed indirectly outside of the spray pattern. The materials directly exposed and on one of the indirectly exposed arrays were cleaned using different techniques over a period of six months and assessed every six months for two years to document the effects of the extinguishing agents on the materials. For one of the indirectly exposed arrays, one sample was used as an uncleaned reference sample and the other was held for possible future chemical analysis using state-of-the-art material characterization techniques.

Two additional, identical sets of materials were prepared. These served as controls. Both of these sets were handled in the same manner as the test samples and travelled to the JENSEN HUGHES facility in Baltimore under the same conditions as the other samples but were not exposed to extinguisher agents. One of these sample sets was cleaned using the same techniques as used on the exposed samples to evaluate the effects of the cleaning methods. The remaining set will serve as an unexposed reference for relative measurements of the effects of the exposures.

The sample materials were mounted on plywood sample arrays using Velcro®. One sample of each material was located near the center of the sample array and one was located near the perimeter of the sample array. The test sample array included 26 samples (2 x 13 materials), with the center column containing six samples with reduced vertical spacing between samples. The total exposed area was approximately 56 cm (22 in.) wide by 67 cm (26.5 in.) tall. A photograph of a typical sample array is shown in Figure 1. The samples were placed in the same locations for each test.



Figure 1 – Typical sample array for exposure tests.

Extinguishers

The classification of fire extinguishers consists of a letter that indicates the class of fire on which a fire extinguisher has been found to be effective. The classes of fire relevant to collections are Class A, B, and C:

- **Class A fires** are fires in ordinary combustible materials, such as wood, cloth, paper, rubber, and many plastics.
- **Class B fires** are fires in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.
- **Class C fires** are fires that involve energized electrical equipment.

There are many types of extinguishers available to combat various fire hazards. The portable extinguishers evaluated were those applicable for use in a museum/cultural heritage type application. These extinguishers had a minimum UL 711 2A rating for A:B:C or A:C fires. The following five extinguisher agents were used:

- ABC Dry Chemical (monoammonium phosphate) [Amerex Model B456];
- Water Mist [Amerex Model B272NM];
- HCFC Blend B (Halotron I) [Amerex Model 398];
- HFC-236fa (FE-36) [Ansul Cleanguard Model FE13]; and
- ABC Dry Chemical [Amerex Model B456] and Water Mist [Amerex Model B272NM].

The combined ABC and water scenario was representative of water application from a sprinkler or water hose after unsuccessful application of an ABC powder extinguisher. The water mist extinguishers were filled with de-ionized water provided by the manufacturer. De-ionized water is typically used in the extinguishers. As CO₂ does not have a Class A rating it is generally not applicable to many museum/cultural heritage scenarios and was not included in the non-fire or fire tests.

With the exception of the HFC-236fa (FE-36) extinguisher, Amerex provided all of the extinguishers as in-kind support for the project. The FE-36 extinguishers, manufactured by Ansul, were purchased separately from a local distributor. The ABC unit specified had a monoammonium phosphate (MAP) content of 92–96%.

Test Enclosure

Cultural resource materials are commonly exhibited in rooms, display areas, and galleries. It was important to establish an appropriate fire size to room volume ratio. Keeping this ratio low is consistent with the typical application of portable extinguishers in museums and historic buildings, i.e., small fires in large spaces. The neat agent tests were conducted in a large test room at the JENSEN HUGHES' laboratory in Baltimore, Maryland. The internal dimensions of the room were 10 m (33 ft) wide by 10 m (33 ft) deep by 3 m (9.8 ft) high.

The fire exposure tests were performed at the Chesapeake Beach Detachment of the Naval Research Laboratory (NRL) located in Chesapeake Beach, MD. JENSEN HUGHES has a collaborative agreement with NRL to conduct fire tests. The enclosure at this facility was constructed in a similar fashion to the JENSEN HUGHES' test enclosure but was slightly smaller. The interior dimensions were 9.1 m (30 ft) wide by 9.1 m (30 ft) deep by 3 m (9.8 ft) high. This difference was not considered significant in terms of comparison between the two data sets.

Instrumentation

The instrumentation for the fire and non-fire tests was largely the same; Figure 2 is a schematic of the test enclosure with instrumentation for the non-fire tests. Figure 3 is a photograph of the test setup for the fire tests; the test setup for the non-fire tests was the same, except with the wood crib removed. The instrumentation employed during these tests included a scale to measure the deposition on the exposed objects. The scale was able to measure mass with a resolution of 0.001 g (2.2×10^{-6} lb). A scale with a larger resolution (0.1 g [0.0002 lb]) was used for samples weighing over 300 g (0.66 lb).

In the test enclosure, the temperature and relative humidity were monitored. Temperatures were recorded at two locations using vertical trees of five, evenly spaced type-K thermocouples at heights of 0.3, 0.9, 1.5, 2.1, and 2.7 m (1, 3, 5, 7, and 9 ft) above the floor. One was installed 0.45 m (1.5 ft) from the center of the indirectly exposed object array and 2.5 cm (1.0 in.) in front of the indirect array. The second was installed 0.45 m (1.5 ft) from the center of the directly-exposed object array and 2.5 cm (1.0 in.) in front of the direct array. In addition, a thermocouple was installed in the center of the directly-exposed object array so that the thermocouple bead was flush with the sample surface. This thermocouple was installed from behind the sample array.

A relative humidity and temperature sensor (Omega model HX92AV) was installed in a corner of the enclosure 1.5 m (5 ft) above the floor. All data was recorded at a rate of 1Hz using National Instruments data acquisition hardware and software.

Two video cameras were used to capture the extinguisher activation and spray during the test. One was located outside of the spray area behind the extinguisher, approximately 6.1 m (20 ft) away from the direct sample array, looking at the direct sample array. The second video camera was located outside of the test enclosure looking through a window perpendicular to the spray. The window was located near the indirect sample array mounted on the wall, approximately 4.3 m (14 ft) away from the direct sample array. An infrared camera (FLIR Model T440) was located inside of the test enclosure, behind the extinguisher approximately 6.1 m (20 ft) away. It was directed at the direct sample array to assess the extinguisher agent impact area. Photographs of the test setup, sample mounting, and extinguisher were taken.

For the fire tests, a Rhorback Cosasco Environmental Condition Monitoring System (ECM) was installed. This device measures the atmospheric corrosion by use of a sacrificial metal circuit which degrades as a result of corrosion. The ECM reader calculates the metal loss in Angstroms (\AA) based on the change in resistance of the circuit. Two thin film (2500 \AA) circuits were used for each test (Rhorback Cosasco model 610); the circuits were copper and silver. These devices were installed in the center of the direct sample array.

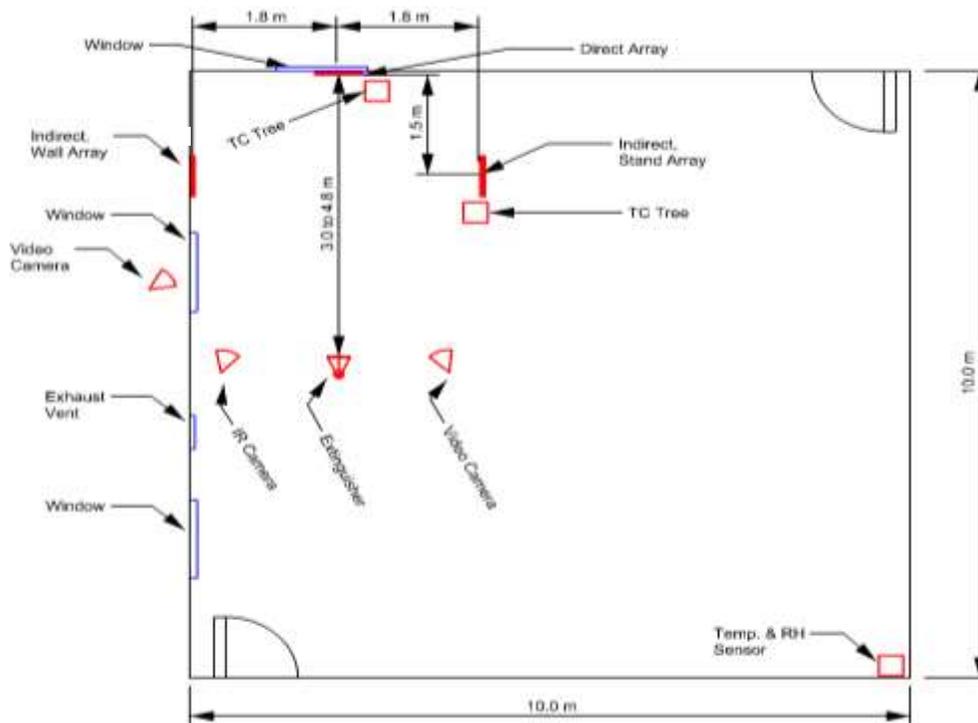


Figure 2 – Non-fire exposure apparatus, plan view.



Figure 3 – Fire exposure test setup.

Non-Fire Scoping Tests

Through scoping tests, the optimal extinguisher separation distances were determined to be between 75% and 90% of the maximum effective range identified in the manufacturer specifications. These distances were established such that the extinguisher would provide relatively full coverage of most of the direct sample array. For future tests, outside of this test program, the distance from the extinguisher to the target should be 90% or less of the published maximum effective range, reduced as appropriate to assure that the pattern is impacting the target. The following separation distances were established:

- ABC Dry Chemical (monoammonium phosphate): 4.3 m (14 ft);
- Water Mist: 3.0 m (10 ft);
- HCFC Blend B (Halotron I): 4.9 m (16 ft); and
- HFC-236fa (FE-36): 4.3 m (14 ft).

Through scoping tests, the locations of the indirect arrays were established. The indirect sample arrays were placed 1.5 m (5.0 ft) in front of the directly exposed array (and between the direct array and the extinguisher nozzle) and offset 1.8 m (6.0 ft) from the center of the direct array as shown in Figure 2. These locations provided some exposure to the indirect samples which was notably less than for the directly exposed sample array. It was decided to establish this criteria for both the non-fire and fire tests.

Fire Scoping Tests

The objective of the fire exposure tests was to evaluate the effects of the combination of the agents, decomposition products and fire effluent on representative materials. Fires in ordinary (Class A) combustibles appear to be the most common and representative fire threat as identified in the Phase I study.

The early stage magnitude of these threats could not be quantified directly from the loss history, but standardized tests and hazard techniques indicate a maximum threat limit on the order of 1

MW. A realistic scenario, approachable by an unprotected person using a portable fire extinguisher, is probably much lower than this. The use of standard extinguisher test methods (that is, the use of repeatable wood crib fires as the Class A source) was adopted, with the realization that a fire on the order of 200–500 kW would likely be used. Also, it was agreed that the fire should not be of sufficient magnitude to thermally damage exposed materials. This would allow for better assessment of agent effects. The Phase I report describes in detail the rationale for this approach.

Scoping tests were conducted to determine the sizes of the wood crib and associated ignition pan fire that could be readily extinguished by all of the extinguishers. Scoping tests were also conducted to establish the separation distance between the wood crib and the directly exposed sample array. All scoping tests were conducted in the open area of the NRL test facility, with limited ventilation from an overhead exhaust hood. The three criteria that were used to evaluate the scoping fires were: 1) the fire had to be easily extinguished, so that all flaming was extinguished well before the agent was totally expended; 2) agent exposing the direct sample array had to pass through and around the fire source; and 3) agent overspray and smoke/soot must be deposited on the directly exposed sample array without thermally damaging the sample array.

Two standard wood cribs were evaluated: a UL 1A crib (12 layers of 6 pieces per layer of 3.8 by 3.8 by 50.8 cm [1.5 by 1.5 by 20 in.] wood) [2] and a UL 1715 wood crib (10 layers of 5 pieces per layer of 3.8 by 3.8 by 38 cm [1.5 by 1.5 by 15 in.] wood) [3]. The wood cribs were ignited with a square pan 40 x 40 x 10 cm (16 x 16 x 4 in.) filled with 300 - 400 ml (0.08 - 0.1 gal) of commercial grade heptane. This produced a pan burn time of approximately 83 - 100 seconds. The pan was centered 38 cm (15 in.) below the cribs. The wood cribs were raised off the floor such that the bottom of the cribs were approximately 1.2 m (3.1 ft) above the floor. The cribs were allowed to burn for 4 minutes total. This was enough time for the fire to develop in the crib without causing the crib to collapse. UL crib firefighting procedures were then followed. The firefighter began extinguishment from approximately 1.8 m (6.0 ft.) away from the crib and was immediately allowed to approach the crib and aggressively attack the fire. Agent was applied to the front and side faces, from below, and from the top of the crib. Attack from the back face was prohibited.

The UL 1A crib was readily extinguished by all of the extinguishers tested. Only the FE-36 extinguisher was used on the UL 1715 crib and readily extinguished the fire. This crib produced a lower flame height and less smoke than the UL 1A crib and was deemed an appropriate incipient fire source for the fire tests.

The separation distance between the wood crib and the directly exposed sample array was also evaluated during this scoping test. A mock sample array with brown paper attached was moved towards the burning wood crib. The sample array was moved within a distance of 0.66 m (26 in.) of the burning crib without any discoloration of the paper. This met the criterion that the target should be close to the crib (to be exposed to the smoke and agent overspray), but not so close as to be thermally damaged. This distance was set as the separation distance between the sample array and the wood crib. In subsequent scoping tests, mock sample arrays were placed at this separation distance and the fire suppressed with an extinguisher. At this distance, all of the mock sample arrays had notable deposits after the tests. This indicated that the separation distance of 0.66 m (26 in.) allowed for fire products and agent deposition on the direct array.

It was determined visually from the firefighting procedures that the indirect target locations used in the neat tests were also appropriate for the fire tests. At these locations, it was determined that

the indirect arrays would be exposed to some fire products and agent deposition, but notably less than the direct array.

Test Matrix

A total of 5 non-fire and 6 fire tests were run during this test program. Each extinguisher type was evaluated for each type of test; the matrix of tests ran is shown in Table 1.

Table 1 – Test Matrix for Non-Fire and Fire Exposure Tests

Test Number	Exposure	Extinguisher
1A	Non-Fire	ABC Dry Chemical
2A	Non-Fire	Water Mist
3A	Non-Fire	HCFC Blend B (Halotron I)
4A	Non-Fire	HFC-236fa (FE-36)
5A	Non-Fire	ABC Dry Chemical and Water Mist
1B	Fire	ABC Dry Chemical
2B	Fire	Water Mist
3B	Fire	HCFC Blend B (Halotron I)
4B	Fire	HFC-236fa (FE-36)
5B	Fire	ABC Dry Chemical and Water Mist
6B	Fire	ABC Dry Chemical and Water Mist

General Pre-Test Procedures for Fire and Non-Fire Exposures

Except for the water mist extinguishers, all of the extinguishers came from the vendor in a charged and ready condition. The water mist extinguishers were charged in accordance with manufacturer’s instructions. All extinguishers were weighed prior to discharge.

Materials were conditioned to a temperature of $21 \pm 4^{\circ}\text{C}$ ($70 \pm 8^{\circ}\text{F}$) and a relative humidity of $50 \pm 10\%$ for a minimum of 5 days prior to the exposure tests. Velcro® was applied to the back of each sample. The representative materials were then labeled, weighed and mounted on either the directly exposed object array or the indirectly exposed object arrays. Where used, Velcro® was attached to the corrosion sensors, a baseline measurement was taken, and the sensors were mounted to the direct sample array.

Doors to the enclosure were shut during the all tests. For fire tests, natural ventilation was provided by a 0.45 by 0.45 m (18 in. by 18 in.) louvered vent in the ceiling. The louvered vent was located away from the fire in the opposite corner of the fire. No ventilation was provided for the non-fire tests.

The data acquisition systems in the test enclosure were activated and after one minute, the sample arrays were mounted in their appropriate locations. Both video cameras and the infrared camera were activated.

Non-Fire Exposure Procedures

For the non-fire tests, after 30 seconds of background video, the extinguisher was discharged at the center of the directly exposed object array from the desired separation distance. The fire extinguisher was discharged until it was completely empty. The end of discharge time was

recorded. For the ABC plus water mist test, the extinguishers were sequentially discharged, first the ABC unit, then the water mist unit.

Fire Exposure Procedures

The wood crib was placed in its stand above the ignition pan. Both video cameras were activated. The pan was then filled with 300 ml (0.08 gal) of commercial grade n-heptane. The firefighter was positioned in the enclosure near the extinguisher.

After 30 seconds of background, the ignition pan beneath the wood crib was lit and the doors to the enclosure were shut. The wood crib was allowed to burn for four minutes. The firefighter then began to suppress the fire with the portable extinguisher, starting from 1.8 m (6.0 ft), aligned with the directly exposed material array. The firefighter was allowed to advance on the crib and move toward either side of the crib, the top and bottom as necessary to cause extinguishment. The firefighter was not allowed to attack the crib from behind (nearest the directly exposed array). The firefighter fully discharged the fire extinguisher onto the wood crib; the end of discharge time was recorded. Where both the ABC and water mist extinguishers were used, the water mist extinguisher was fully discharged on to the wood crib after the ABC extinguisher was fully discharged. The end of water mist discharge time was recorded.

Post-exposure Procedures

For both test series, five minutes after the conclusion of the extinguisher discharge, the sample arrays were removed from the test enclosure by the firefighter and transported to the examination room. This five minute “soak period” allowed any agent dispersed throughout the test enclosure to settle onto the sample arrays.

The process of removing and transporting the sample arrays to the examination was accomplished within one minute. Once all sample arrays were removed, both doors to the test enclosure were opened and the test enclosure was purged using the ventilation system. Video recording was secured. The extinguisher was secured by inserting the pin and the weight was recorded. The data acquisition for the test enclosure was then secured. The enclosure floors, walls, and ceiling were vacuumed and/or cleaned as necessary to remove agent before conducting the following test.

Non-Fire Exposure Results

Extinguisher Spray Patterns

The spray patterns for the extinguishers were significantly different from each other. The ABC dry chemical extinguisher spray was a narrow stream as shown in Figure 4. After discharge, the agent rapidly formed a cloud as it impacted the enclosure wall. This cloud quickly filled and obscured the interior of the enclosure, reducing enclosure visibility. The firefighter had limited visibility. After the end of the 5 minute “soak period”, much of the agent had settled which allowed greater visibility. The ABC dry chemical spray pattern was consistent between Tests 1A and 5A. During Test 5A, the water mist extinguisher discharge tended to stir up the ABC dry chemical that had been discharged into the enclosure further reducing visibility.

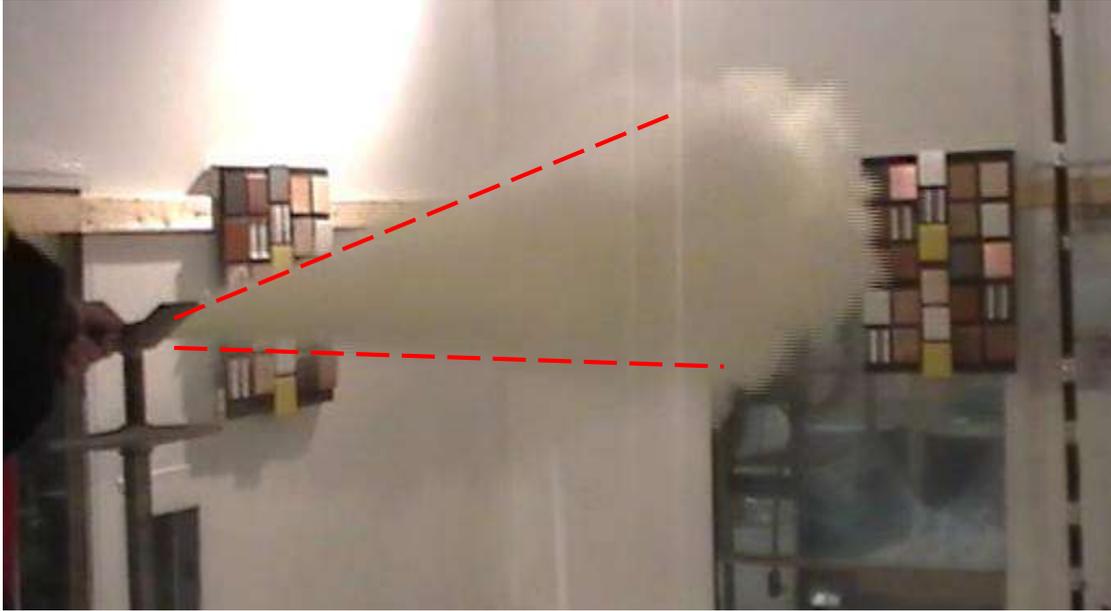


Figure 4 – Typical ABC dry chemical extinguisher spray pattern.

The water mist extinguisher produced a wide spray compared to the other extinguishers as shown in Figure 5 (left). The water mist spray was difficult to capture with photos or video footage; an outline of the spray pattern is shown for reference in Figure 5 (left). The droplets from the water mist extinguisher were relatively large compared to a high-pressure building water mist system. A significant amount of water was deposited on the floor of the enclosure in front of the extinguisher nozzle as outlined in Figure 5 (right). This was consistent between Tests 2A and 5A.



Figure 5 – Typical water mist extinguisher spray pattern (left) and water deposited on the floor (right).

The Halotron I extinguisher produced a narrow gas stream with a minimal amount of liquid agent present in the stream (see Figure 6). By the time the stream reached the direct sample array, most of the liquid had evaporated. The liquid agent quickly evaporated and the gaseous agent cloud quickly dissipated.

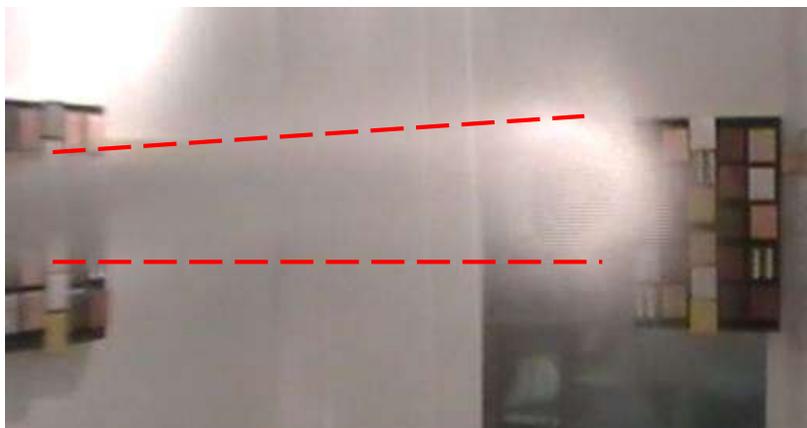


Figure 6 – Typical Halotron I extinguisher spray pattern.

The FE-36 extinguisher produced more of a narrow stream than the Halotron I extinguisher (see Figure 7). The agent stream was mostly liquid as it left the extinguisher; a notable amount of liquid agent remained as the stream impacted the direct array. The liquid agent quickly evaporated and the gaseous agent cloud quickly dissipated.

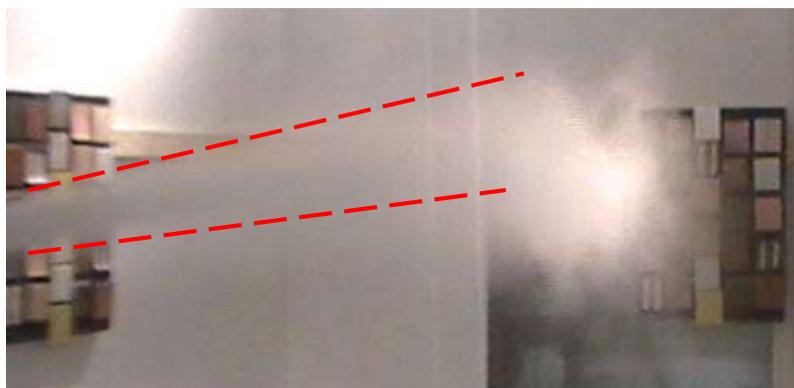


Figure 7 – Typical FE-36 extinguisher spray pattern.

A FLIR T440 infrared camera was used to capture the agent discharge and impact on the direct sample array. For the ABC dry chemical test (Test 1A), the agent quickly enveloped the direct array and obscured it from view. As the cloud of ABC dry chemical billowed and moved through the enclosure, the direct sample array came in and out of view. The infrared camera was unable to capture the agent impact area for this test. The temperatures measured using the IR camera are consistent with the observed lack of change in temperature of the thermocouple located at the center of the direct array.

For the test with the water mist extinguisher (Test 2A), the infrared camera was out of focus and did not produce a quality image. A temperature drop of nominally 3°C was observed over the area of the direct sample array for an extended period of time during the discharge. This was consistent

with the drop in temperature measured at the center of the direct sample array. Given the quality of the unfocused video, the agent coverage area was unclear.

The infrared footage of the Halotron I discharge (Test 3A) showed the only well-defined extinguisher spray pattern and agent impact area out of all of the tests. As shown in Figure 16, the Halotron I discharge is a narrow stream; this is confirmed by the visual image of the spray pattern shown in Figure 6. The extinguisher discharge covered the entire direct array with some overspray to the enclosure wall (based on temperature drop circled in Figure 8). The overspray area is only slightly larger than the size of the direct sample array.

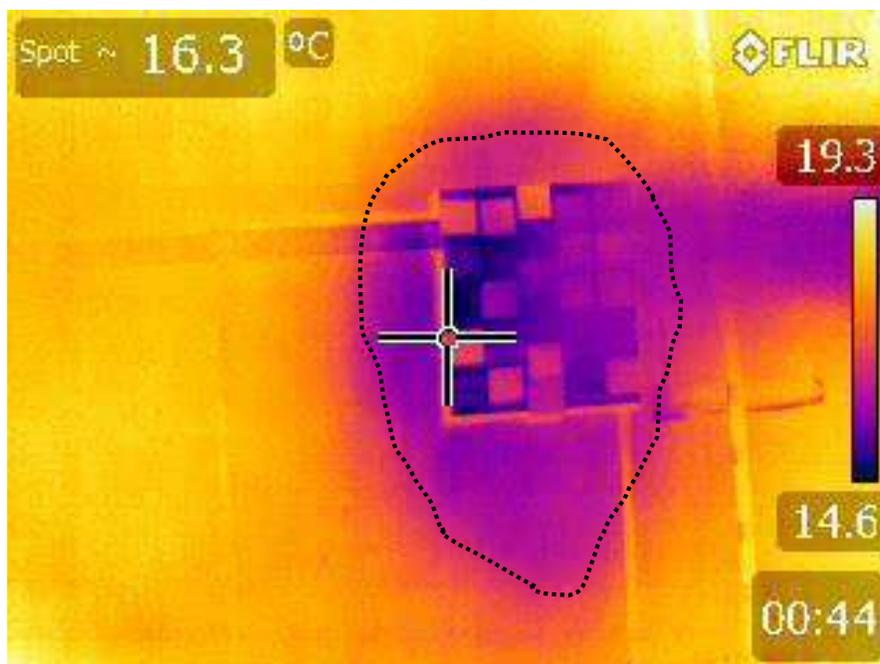


Figure 8 – Typical infrared image of Halotron I extinguisher coverage.

The infrared footage was not captured for the FE-36 extinguisher discharge (Test 4A). Based on the results from Test 3A (Halotron I), the infrared camera would have likely been effective for determining the coverage area for the FE-36 extinguisher also. This was due to the large temperature drops caused by the gaseous agent discharge.

For Test 5A with ABC and water mist, the direct sample array was generally obscured from the infrared camera as was seen for ABC dry chemical only (Test 1A). As the water mist extinguisher was discharged, there was a more uniform obscuration of the direct sample array and the temperature in the enclosure was observed to decrease slightly. It was not clear from footage whether the direct sample array temperature also decreased. No indication of coverage area was apparent from the infrared footage. Overall, the infrared camera was not effective for determining coverage area for the ABC dry chemical or water mist extinguishers.

Agent Deposition Results

In general, slight deposits of extinguishing agents were measured on all materials. However, deposit measurement was difficult due to the relatively small deposit mass versus the sample mass and the resolution of the scales used. The samples on the direct array had the largest deposits, with some of the fur samples gaining upwards of 1.0 to 2.0 g (0.0022 to 0.0044 lb). The samples on the indirect arrays generally had smaller deposits. In some cases, decreases in sample mass were measured. These ranged from small decreases of less than 0.1 g (0.00022 lb) to larger decreases up to 1.0 g (0.0022 lb). The decreases in mass could be due to damaged materials. During the water mist test, some of the heavier samples fell to the ground as the moisture impacted the Velcro tape residue. Typically, the samples which fell to the floor broke into several large pieces with some small chips. Although all of the large pieces of material were recovered, it is difficult to know that every small chip was recovered. This may account for some of the discrepancies in weight. In addition, when Velcro was removed, for some materials small bits of the sample were removed by the Velcro adhesive.

Direct Array Temperature Results

Prior to the agent discharge, the temperatures in the test enclosure were nominally 20°C. There was some minor variation (generally less than 1°C). A value of 20°C was used as the ambient temperature for further calculations. The temperature changes at the center of the direct array were calculated as the difference between ambient and the minimum temperature reached during the extinguisher discharge (see Table 2). For the ABC dry chemical test, the temperature at the center of the direct array did not change as a result of the discharge. For the tests with water mist extinguishers, including the combined ABC and water mist test, the temperature at the center of the direct array decreased by 6°C for Test 2A and 5°C for Test 5A.

The most significant temperature changes came from the gaseous agents. FE-36 had the largest temperature decrease at the center of the direct array (61°C). Halotron I had a notable, but slightly lower temperature decrease at the center of the direct array of 43°C. These large decreases in temperatures were expected for the gaseous agents because they are in a liquid state within the extinguisher, due to the high cylinder pressure. As Halotron I and FE-36 were discharged, the liquids rapidly evaporated and the temperature decreased dramatically. For the gaseous agents, the temperatures remained at the low values for approximately one minute after the end of discharge before returning to ambient. This was likely due to the presence of liquid agent or frost (from water in the air) that remained on the direct array after the end of discharge. Although the thermocouple temperatures returned to ambient levels within approximately 1 minute after discharge, there was visible frost remaining on some of the samples at least 6 minutes after discharge (i.e., when samples were photographed in the examination room).

Table 2 – Test Matrix for Non-Fire and Fire Exposure Tests

Test No.	Agent	Exting. Discharge Time (sec)	Min. Direct Sample Array Temp. During Discharge (°C)
1A	ABC Dry Chem.	29	20
2A	Water Mist	78	14
3A	Halotron I	15	-23
4A	FE-36	13	-41
5A	ABC & Water Mist	ABC: 33 Water: 85	15

Fire Exposure Results

Tables 3 and 4 are summaries of test data for the fire exposure tests. The extinguishing time was visually determined as the time after initial discharge at which all flaming of the wood crib was extinguished. There was good agreement between multiple observers for determination of extinguishing time. All of the extinguishing times were less than or equal to 6 seconds. The ABC dry chemical extinguishers had extinguishing times of 1 second in both tests.

Table 3 – Summary of Fire Exposure Test Data

Test Number	Agent	Extinguishing Time (sec)	Extinguisher Discharge Time (sec)	Agent Discharged (kg (lb))
1B	ABC Dry Chem.	3	33	4.5 (9.9)
2B	Water Mist	6	88	9.0 (19.8)
3B	Halotron I	3	13	7.0 (15.5)
4B	FE-36	4	14	6.0 (13.2)
5B	ABC Dry Chem & Water Mist	1	ABC: 34 Water: 83	ABC: 4.5 (9.9) Water: 8.8 (19.4)
6B	ABC Dry Chem & Water Mist	1	ABC: 32 Water: 93	ABC: 4.5 (9.9) Water: 9.0 (19.8)

Table 4 – Fire Test Environmental Conditions

Test No.	Agent	Pre-Test Enclosure RH (%)	Post-Discharge Direct Sample Array Temperature (°C)	Maximum Enclosure RH During Fire (%)	Maximum Enclosure RH Post-Discharge (%)
1B	ABC Dry Chemical	70	55	80	100
2B	Water Mist	51	31	72	93
3B	Halotron I	74	-3	88	98
4B	FE-36	78	18	79	98
5B	ABC & Water Mist	83	58	94	100
6B	ABC & Water Mist	84	61	88	98

During the fire there was a general increase in relative humidity in the test enclosure. The increase in relative humidity varied widely between tests; from 1% RH for Test 4B (FE-36) to 21% for Test 2B (water mist). After the extinguishers were discharged, the relative humidity spiked to nearly 100% RH for every test.

Prior to the agent discharge, the temperatures in the test enclosure were nominally 25°C; this was slightly higher than for the non-fire exposure tests but still in the range of what is considered normal indoor ambient temperatures.

The direct sample array temperatures were notably higher for the fire tests compared to the non-fire tests. In general, direct array temperatures from the fire exposure tests were between 17 and 59 °C higher than for non-fire exposure tests.

Agent Deposition Results

In general, the mass measurements exhibit the same trends as the non-fire exposure tests. There did not appear to be any effect of the fire on the change in sample mass.

Conservator Assessment of Materials – Preliminary Results

Each sample was examined directly after exposure and then again at 6, 12 and 18 month intervals. Some samples were cleaned immediately after exposure and others were stored for 6 months and then cleaned. The objective of this portion of the study was to examine the effects of the extinguishing agents on materials commonly used to create cultural heritage materials. A subsidiary goal is to examine which cleaning methods, commonly used by conservators and collections care specialists, are more or less effective at removing the extinguishing agents. The

delay time periods were designed to simulate the conditions in a smaller museum/institution where resources might not be available for immediate cleaning. This section discusses the preliminary results of the conservator assessment; analysis of the material effects and cleaning methods is ongoing.

Damage was generally within the expected parameters. There was cocking or surface distortion of some of the organic materials and corrosion of metal surfaces. Water mist, Halotron I and Fe-36 had a solubilizing effect on soot and tended to drive it into the organic samples (such as these leather samples) causing profound staining.

ABC Dry chemical powder coated nearly all of the samples. The extensive dispersal of the ABC dry chemical may complicate removal/ cleaning for items with multiple parts or with rough surfaces.

Halotron I had two effects that were unexpected. On the acrylic paint on canvas samples, the green pigment was lost from the canvas. This was only found on one sample and it is necessary to explore further whether the result is due to a flaw in the sample preparation or potentially a result of the cold temperatures causing damage to the sample. Of more concern was the degree of corrosion and tarnish seen on all the metal samples involved in the fire tests with Halotron I. In Figure 9, the front (right) and back (left) of a copper sample are shown. The brighter patches on the bottom image are where the Velcro masked the metal during exposure; the other areas show the notable tarnish of the copper.

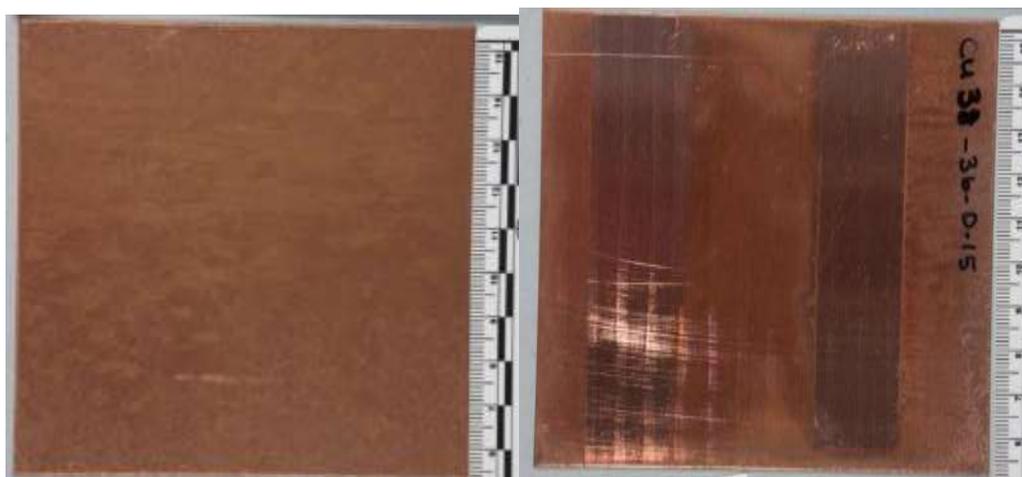


Figure 9 – Typical front (left) and back (right) of copper sample exposed to fire and Halotron I.

Cleaning Methods

Each sample was divided into 4 (2 by 2 inch) quadrants. Each quadrant was cleaned by a different method. All cleaning methods were chosen because they are commonly referenced in conservation literature for cleaning items that have been exposed to soot/and or fire. The four cleaning methods included swabbing with deionized water, rubbing with a soot eraser, brushing, and vacuuming. A standardized cleaning approach was used to ensure repeatability. For each cleaning method, the device was used in the sequence illustrated in Figure 10.

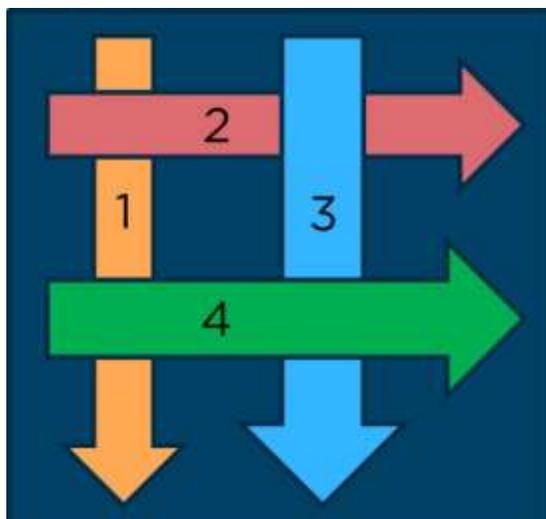


Figure 10 – Schematic of cleaning method.

Swabbing with deionized water and soot eraser were generally the most successful. However, swabbing tended to lead to surface darkening on organic samples (especially leather). The soot eraser appeared to leave residues on the surface of the metal samples which may lead to further corrosion/tarnish in the future. Preliminary recommendations are that the next phase of the project should look at additional cleaning technologies.

Summary

This test program has established a reproducible test method for fire and non-fire exposures of cultural resource materials by extinguishing agents. A wide range of cultural resource materials and extinguishing agents have been assessed which will form the foundation of an extinguisher selection matrix to be potentially included in NFPA standards. The conservator assessment and observation period has concluded; the final report will contain further analysis of the material effects and cleaning methods.

Acknowledgements

The authors would like to thank the NFPA Research Foundation personnel and project Technical Panel for their assistance in guiding the test planning and advising the test group. The authors would like to also thank Amerex for the donations of their extinguishers for testing.

References

- 1) Scheffey, J.L. and Forssell, E.W., “Measuring the Impact of Fire Extinguisher Agents on Cultural Resource Materials – Final Report,” Fire Protection Research Foundation, Quincy, MA, February 2010. <http://www.nfpa.org/research/fire-protection-research-foundation/reports-and-proceedings/suppression/clean-agents/measuring-the-impact-of-fire-extinguisher-agents-on-cultural-resource-materials>

- 2) UL 711, "Rating and Fire Testing of Fire Extinguishers," Underwriters Laboratories, Northbrook, IL, 2004.
- 3) UL 1715, "Standard for Fire Test of Interior Finish Material," Underwriters Laboratories, Northbrook, IL, 1997.