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Demonstration of a PFAS-Free Fire Suppression Alternative to Aqueous Film-Forming Foams

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A nontoxic alternative to traditional aqueous film-forming foams (AFFFs) for sprayable fire retardants offered by Paradise Environmental Group (Paradise, PA) was tested by U.S. Army Combat Capabilities Development Command Chemical Biological Center (Aberdeen Proving Ground, MD). Liquid solutions of this material, known as BlazeCheck, are easily mixed in either fresh or salt water. Their method of action is presumed to be emulsification of the fuel volume, which lowers the vapor pressure required to ignite and sustain combustion. This is in contrast to the action of AFFFs, which create an oxygen-depriving film over the surface and are considered to be toxic to the environment and to humans. Laboratory testing to verify the noncorrosive nature of BlazeCheck as well as its material and physical properties and lack of per- and polyfluoroalkyl substance (PFAS)-containing compounds was followed up with field testing to verify its performance against liquid fuel fires, metal fuel fires, and pyrotechnic fires.

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PREFACE

The work described in this report was authorized under project no. WP 20-5337. The work was started in December 2019 and completed in December 2021.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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Acknowledgments

The authors acknowledge the following individuals from the U.S. Army Combat Capabilities Development Command Chemical Biological Center (Aberdeen Proving Ground, MD) for their hard work and assistance with the execution of this technical program:

- Mr. Mark Hull for his field test support of this program; and
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EXECUTIVE SUMMARY

An environmentally low-impact alternative to traditional aqueous film-forming foams (AFFFs) for sprayable fire retardants offered by Paradise Environmental Group (Paradise, PA) was tested by the U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground, MD). Liquid solutions of this material, known as BlazeCheck, are easily mixed in either fresh or salt water. Their method of action is assumed to be an emulsification of the fuel volume, which decreases the vapor pressure required to ignite and sustain combustion. This is a different mechanism of action as compared to the AFFFs, which blanket the fuel surface with a film and cut off the oxygen supply. AFFFs are considered to be toxic to the environment and to humans. Laboratory testing to verify the noncorrosive nature of BlazeCheck, the material properties, and the lack of per- and polyfluoroalkyl substances (PFAS)-containing compounds was followed up with field testing to verify the performance of BlazeCheck against liquid fuel fires, metal fuel fires, and pyrotechnic fires.

Positive indicators for BlazeCheck include the noncorrosive nature of the solution (in fresh or salt water), the lack of any PFAS detected in the material, the nontoxic nature of the material, the relatively cheap cost of the solution, and the product's ability to extinguish class A and B fires relatively quickly in small fuel pools (diesel and gasoline) and some apparent effectiveness in extinguishing class D metal particle and pyrotechnic fires. Negative indicators for BlazeCheck include the necessity to add significant amounts of the solution and the time involved to extinguish the flames for large fuel pool class B fires, as was demonstrated in the 28 ft^2 pan test. Also, for a large fuel pool, even if the top layers are passivated, the fire can easily restart if the fuel below that level is disturbed and brought to the surface by mechanical action. This effect was demonstrated in the large fuel pool fire burnback tests.

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DEMONSTRATION OF A PFAS-FREE FIRE SUPPRESSION ALTERNATIVE TO AQUEOUS FILM-FORMING FOAMS

1. INTRODUCTION

An environmentally low-impact alternative to traditional aqueous film-forming foams (AFFFs) for sprayable fire retardants offered by Paradise Environmental Group (Paradise, PA) was tested by the U.S. Army Combat Capabilities Development Command Chemical Biological Center (DEVCOM CBC; Aberdeen Proving Ground, MD). Liquid solutions of this material, known as BlazeCheck, are easily mixed in either fresh or salt water. (The BlazeCheck safety data sheet is provided in the Appendix.) Their method of action is assumed to be an emulsification of the fuel volume, which decreases the vapor pressure required to ignite and sustain combustion. This is a different mechanism of action as compared to the AFFFs, which blanket the fuel surface with a film and cut off the oxygen supply. AFFFs are considered to be toxic to the environment and to humans.

Testing was divided into laboratory and full-scale performance testing. The objectives of the laboratory testing were to determine the corrosivity of the BlazeCheck solution, the presence of any per- and polyfluoroalkyl substance (PFAS)-containing compounds, and the general material properties. The objective of the performance testing was to determine the ability of the BlazeCheck solution to suppress the flame associated with liquid fuel fires, metal powder fires, and pyrotechnic fires.

2. LABORATORY AND PERFORMANCE TESTING

2.1 Test Plan: MIL-PRF-24385F

Testing was performed in accordance with MIL-PRF-24385F, *Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water* (2017) with modifications. This specification pertains to foam applications; however, it was applied with modifications where necessary to test the BlazeCheck solution. The objective of this work was to assess how the fire retardant solution application performed relative to the foam. The foam specification was followed as closely as possible, and modifications were made to accommodate use of the BlazeCheck solution where a direct application of the specification was either impossible or unnecessary. The specification and modifications are described in the following subsections.

2.1.1 Viscosity (Paragraph 4.7.2)

The viscosity shall be determined at temperatures of 5 ± 0.1 and 25 ± 0.1 °C in accordance with ASTM D445, using capillary viscosimeters in the appropriate size.

2.1.2 pH Value (Paragraph 4.7.3)

The pH value shall be determined potentiometrically, using a pH meter with a glass electrode and a reference electrode, at 25 ± 1.0 °C.

2.1.3 Corrosion (Paragraph 4.7.7)

The liquid for immersion of the metal specimens for general corrosion and localized corrosion tests shall consist of the concentrate diluted by 10% by volume with sea water.

Test specimens. The test specimens shall consist of the following metals, in accordance with Unified Numbering System (UNS) designations (see ASTM E527): G10100 steel, C70600 copper–nickel alloy, N04400 nickel–copper, and C90500 bronze. All specimens except the bronze shall be milled to finished dimensions of approximately 1⁄16 in. thick, 1/2 in. wide, and 3 in. long. The bronze shall have sand-cast faces and be approximately 3⁄16 in. thick, 1/2 in. wide, and 3 in. long. All specimens shall be degreased in acetone, rinsed with distilled water, and air-dried before exposure. (Prepared metal specimens were obtained from Metaspec; San Antonio, TX.)

Test procedures. Five weighted specimens of each metal shall be fully immersed in the test medium in a separate 600 mL beaker and held at room temperature for 60 days. A watch-glass cover shall be used to retard evaporation. At the end of the exposure period, the weight loss shall be determined and the corrosion rate calculated as required.

2.1.4 PFAS Content (Paragraph 4.7.8)

Mass spectrometry was used. A method for measuring PFAS content was not specified in MIL-PRF-24385F.

2.1.5 Fire Performance Tests

2.1.5.1 28 ft^2 Fire Test: MIL-PRF-24385F

Test equipment (paragraph 4.7.14.1.1). The fire test shall be conducted in a level, circular pan 6 ft in diameter, fabricated from 1/4 in. thick steel with a 4 in. high side. A shallow water layer shall be used to protect the pan bottom and to ensure complete coverage of the area with fuel. The nozzle used for foam application shall be the 2 gal/min device specified in MIL-PRF-24385F paragraph 4.7.5.

Test materials (paragraph 4.7.14.1.2). Retardant solutions shall be generated at 23 ± 5.0 °C from solutions made with fresh and sea water, as required, tested separately. The fuel shall be 10 gal of unleaded gasoline conforming to ASTM D4814.

Test procedure (paragraph 4.7.14.1.3). The fuel shall be dumped within a 30 s period. The fuel shall be ignited within 30 s of application and allowed to burn freely for 10 s. After the preburn period, the fire shall be attacked and extinguished as expeditiously as possible, and the fire extinguishing time shall be recorded at the exact cessation of all flame, but retardant solution application shall continue for a total of 90 s.

Burnback procedure (paragraph 4.7.14.1.4). Within 60 s of the completion of retardant solution application, a burning pan (1 ft diameter with 2 in. sides) containing 1 gal of unleaded gasoline shall be placed in the center of the 28 ft^2 pan and a timer started. When it appears that the fire has spread outside the pan so that the burning will continue after pan removal, the pan shall be removed. The burnback time is the time at which it is estimated that 7 ft^2 (25%) of the total area is involved in flames.

2.1.5.2 50 ft^2 Fire Test: MIL-PRF-24385F

Test site (paragraph 4.7.14.2.1). The fire test shall be conducted on a level, circular area 8 ft in diameter. The base and surrounding wall shall be suitable for containment of the fuel on a substrate of water. The water depth shall be the minimum required to ensure complete coverage area with the fuel.

Test equipment (paragraph 4.7.14.2.2). The nozzle used for retardant solution application shall be the 2 gal/min device specified in MIL-PRF-24385F, paragraph 4.7.5, operated at a gauge pressure of 100 lb/in^2.

Test materials (paragraph 4.7.14.2.3). The retardant solution shall be generated at 23 ± 5.0 °C from the most effective concentration solution seen in the 28 ft^2 test once using sea water and once with fresh water. The fuel shall be 15 gal of unleaded gasoline conforming to ASTM D4814.

Test procedure (paragraph 4.7.14.2.4). The fuel shall be poured into the area in less than 60 s and ignited in less than 30 s after fuel application is completed. After a preburn period of 10 s, the fire shall be attacked and extinguished in an expeditious manner. At 10 s intervals after the start of retardant solution application, observers shall estimate the percentage of fire area extinguished. The percentages at 10, 20, 30, and 40 s shall be totaled to give the "40 s summation" value. The exact extinguishing time shall also be recorded at the cessation of all flame, but retardant solution application shall continue for a total of 90 s.

Burnback procedure (paragraph 4.7.14.2.5). Within 60 s of the completion of retardant solution application, a burnback test shall be conducted as specified in paragraph 4.7.14.1.4, except that the burnback area shall be 12.5 ft^2 (25%).

2.2 Test Plans Other than MIL-PRF-24385F

2.2.1 Tests Against Class D-Type Metal Fires and Pyrotechnic Fires

Additional tests were conducted to determine whether a 10% concentration of BlazeCheck in a freshwater solution was capable of extinguishing or reducing fires associated with burning metal (magnesium) particles in air as well as pyrotechnic flare compositions, where internal oxygen sources make them more dangerous and difficult to extinguish. Results of tests against the metal particles are compared with those for a class D NaCl-based fire extinguisher.

2.2.2 Small Fire Pan Testing Against Class B (Paradise Environmental Group)

Paradise Environmental Group conducted numerous small-scale tests with BlazeCheck solution against gasoline and diesel fuel to determine the product's effectiveness in extinguishing class B fires.

3. LABORATORY-SCALE ANALYSIS

During the laboratory-scale analysis phase of the BlazeCheck fire retardant solution, the pH, viscosity, solubility, and corrosivity were measured, and the presence of PFAS was assessed.

3.1 pH Measurements

The analyst was Ms. Stephanie Padovani (DEVCOM CBC). The instrumentation included an Orion Dual Star pH/ion-selective electrode benchtop meter with an Orion Ross Ultra combination pH electrode (catalog no. 8102BNUWP; Thermo Scientific; Waltham, MA) and a magnetic stir plate.

Test method: pH meter measurements were conducted on an open bench top at an ambient temperature of 25 °C. (Temperature readings were taken from the pH meter.) The pH meter was calibrated using standard buffer solutions of pH 4, 7, and 10. Once calibration was complete, approximately 10 mL of sample was pipetted into three 20 mL glass vials, which were labeled 1–3. A magnetic stir bar (rice size) was placed in each vial. Starting with vial 1, the electrode was submerged in the sample vial on the magnetic stir plate. Stirring was turned on to ensure a uniform sample. Once the pH reading on the meter had stabilized, the number was recorded and the sample was removed. The electrode was rinsed with deionized water and wiped with a clean disposable laboratory wipe. pH measurements were repeated with sample vials 2 and 3. Table 1 lists the pH results for the three samples.

Table 1. BlazeCheck pH Test Results

Sample Vial No.	**pH**
1	8.07
2	8.07
3	8.05

3.2 Viscosity Measurements

The analyst was Ms. Patrice Abercrombie-Thomas (DEVCOM CBC). Testing was performed in accordance with ASTM D445, *Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)*. Instrumentation included a Cannon–Manning Semi-Micro viscometer, a Cannon CT-1000 temperature bath, and a

Cannon TE-1000 low-temperature bath (Cannon Instrument Company; State College, PA). Instruments were calibrated by the manufacturer.

Table 2 lists the viscosity results for the fire retardant sample at 25 and 5 °C. Each value represents the mean of multiple consecutive measurements conducted at the experimental temperatures.

Table 2. BlazeCheck Viscosity Results

Temperature (°C)	Viscosity ± SD (σ_{n-1}) (cSt)
25.0	36.05 ± 0.49
5.0	59.69 ± 0.65

SD, standard deviation.

3.3 Solubility Measurements

The analyst was Dr. Kevin J. Shefcheck (DEVCOM CBC).

Test method: An optical test method was used. Miscibility of two materials is often determined optically. When two miscible liquids are combined, the resulting liquid is clear. If the mixture is cloudy, the two materials are immiscible. Care must be taken with this determination: If the indices of refraction of the two materials are similar, an immiscible mixture may be clear and give an incorrect determination that the two liquids are miscible.

Results: BlazeCheck was tested for solubility in water. One milliliter of BlazeCheck was added to 1 mL of water. When BlazeCheck was initially added to the water, the mixture formed a bilayer with the denser BlazeCheck on the bottom (Figure 1, vial A). When the solution was gently shaken, the water and BlazeCheck appeared to mix completely (Figure 1, vial B). When the undisturbed bilayer was left at room temperature overnight, the BlazeCheck mixed completely with the water. The BlazeCheck was determined to be completely miscible in water.

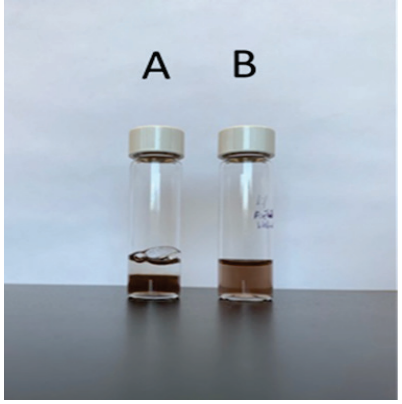


Figure 1. Miscibility of BlazeCheck in water. (A) Initial addition of BlazeCheck to water; (B) BlazeCheck–water solution after gentle shaking.

3.4 Corrosion Analysis

The analysts were Mr. Nino Bonavito and Dr. Erica Valdes (DEVCOM CBC).

Test method: Corrosion testing (general) was performed in accordance with MIL-PRF-24385F, paragraph 4.7.7.

Results: Testing was conducted between 19 November 2020 and 22 January 2021. Test coupons (as described in the specification) were ordered from MetaSpec. These included three specimens each in four configurations:

1. bronze cast alloy, C905 (UNS C90500), 3/16 in. thick, one side was the cast face and the other side was polished, 1/2 × 3 × 3/16 in.;
2. 90/10 cupro/nickel alloy (304-J), CDA-706 (UNS C70600), MIL-C-15726D, 1/2 × 3 × 1/16 in., polished;
3. Monel 400 nickel–copper alloy (Huntington Alloys Corporation; Huntington, WV), 304-H, QQ-N-281, class N4400, 1/2 × 3 × 1/16 in., polished; and
4. mild steel, 304-O; SAE-1010 (UNS G10100), cold-rolled, 1/2 × 3 × 1/16 in., polished.

As shown in Figure 2, each group of three specimens was added to a single 600 mL Pyrex glass beaker. Specimens were laid across thin cylindrical plastic strips so that the solution could get beneath the specimens and remain in contact with the entire surface of the specimen throughout the test. A brine solution of 3.6 g of sea salt per 100 mL of distilled water was developed (in accordance with ASTM D1141), and then the BlazeCheck fire retardant liquid was diluted 10% with the brine. The composite solution (200 mL) was added to the beaker to completely immerse the specimens. A watch glass cover was placed over the beaker to prevent evaporation of the solution that covered the specimens and thereby ensure continuous coverage throughout the test. Beakers were placed in a hood and kept at ambient conditions for the test period.

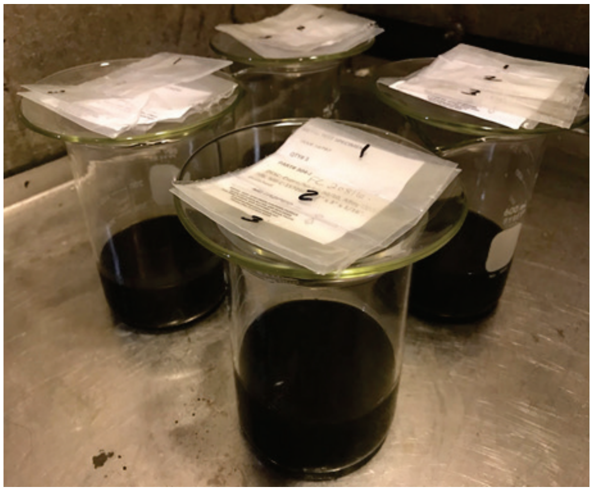


Figure 2. Corrosion test setup.

As shown in Table 3, except for a couple of outliers that may have been measured incorrectly before immersion, all of the mass changes were less than 0.13% by weight. The slight increase in weight for some specimens could be due in part to deposits observed on some of the samples that were originally assumed to be from the growth of oxidation products such as copper(I) chloride crystals. Samples of these deposits were scraped off of the specimens and submitted for elemental analysis to identify their composition. Elemental analysis was conducted, and it was determined that the deposits were not oxidation species (no Ni or Cu) but were rather unrelated materials such as Na, Mg, P, K, S, Cl (plus O and C) and were probably from the sea salt (see Table 4) or the BlazeCheck. The only Cu- and Ni-rich areas were particles that appeared to be residue from machining; these particles were very small and were not collocated with the other elements. Post-test specimens are shown in Figures 3–7.

No significant or measurable dimensional (cross-sectional) changes were found to have occurred; hence, a corrosion rate could not be calculated. The equation for this calculation is

$$\text{Corrosion rate} = \frac{87.6 \times \text{mass loss (g)}}{\text{density (g/cm}^3) \times \text{area change (cm}^2) \times \text{time (h)}}$$

Table 3. Corrosion Testing: Changes in Mass and Dimension

Sample No.	Mass			Thickness Dimension	
	Before (g)	After (g)	Mass Change (%)	Before (in.)	After
304-H/N4400 0.06 × 0.5 × 3 (thick × wide × long, nom)					
1	13.178	12.940	–1.8	0.06	No change
2	12.934	13.181	+1.9	0.06	No change
3	13.172	13.180	+0.06	0.06	No change
304-J/CDA-706 0.0625 × 0.5 × 3 (thick × wide × long, nom)					
1	12.250	12.193	–0.46	0.055	No change
2	12.297	12.284	–0.11	0.055	No change
3	12.226	12.213	–0.11	0.055	No change
304-O/SAE-1010 0.0625 × 0.5 × 3 (thick × wide × long, nom)					
1	11.477	11.468	–0.08	0.58	No change
2	11.423	11.408	–0.13	0.58	No change
3	11.418	11.414	–0.03	0.58	No change
305-MC/C905 0.1875 × 0.5 × 3 (thick × wide × long, nom)					
1	40.045	40.036	–0.02	0.194	No change
2	40.868	40.867	–0.002	0.2	No change
3	42.062	42.044	–0.04	0.198	No change

Figure 3. Post-test condition of the four test specimens.

Figure 4. Post-test condition of 304-H test specimens.

Figure 5. Post-test condition of 304-O test specimens.

Figure 6. Post-test condition of 305-MC test specimens.

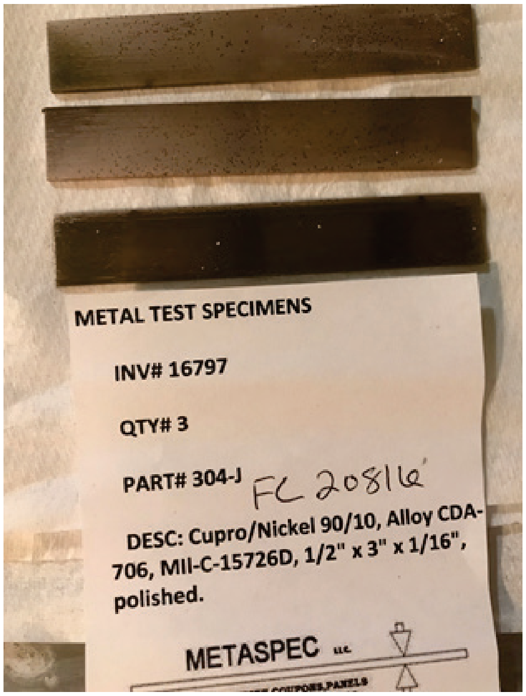


Figure 7. Post-test condition of 304-J test specimens.

Table 4. Artificial Sea Water Composition*

Chemical Name	Formula	Density (g/L)
Sodium chloride	NaCl	24.53
Magnesium chloride	$MgCl_2$	5.20
Sodium sulfate	Na_2SO_4	4.09
Calcium chloride	$CaCl_2$	1.16
Potassium chloride	KCl	0.695
Sodium bicarbonate	$NaHCO_3$	0.201
Potassium bromide	KBr	0.101
Boric acid	H_3BO_3	0.027
Strontium chloride	$SrCl_2$	0.0025
Sodium fluoride	NaF	0.003
Water	H_2O	988.968
	Total	1024.9775

*In accordance with ASTM D114-98. Values from Lake Products Company, https://www.lakeproductscompany.com/products/-artificial-seawater-astm-d-1141-98.

3.5 Trace Assessment of BlazeCheck for the Presence of PFAS-Containing Substances

The analyst was Dr. Erica Valdes (DEVCOM CBC). Mass spectrometry was used for this assessment.

Results: Trace analysis using mass spectrometry on samples of BlazeCheck (Figures 8–11) revealed that no perfluorooctane sulfonate (PFOS) or perfluorooctanoic acid (PFOA) was detected. Any fluorine compounds detected in the samples at trace levels were likely related to the fluoropolymers in the plastic container used to contain the solution prior to sampling. As shown in Figures 8–11, no detected trace compounds (defined as less than 100 ppm) were found to be above the 4 ppm level.

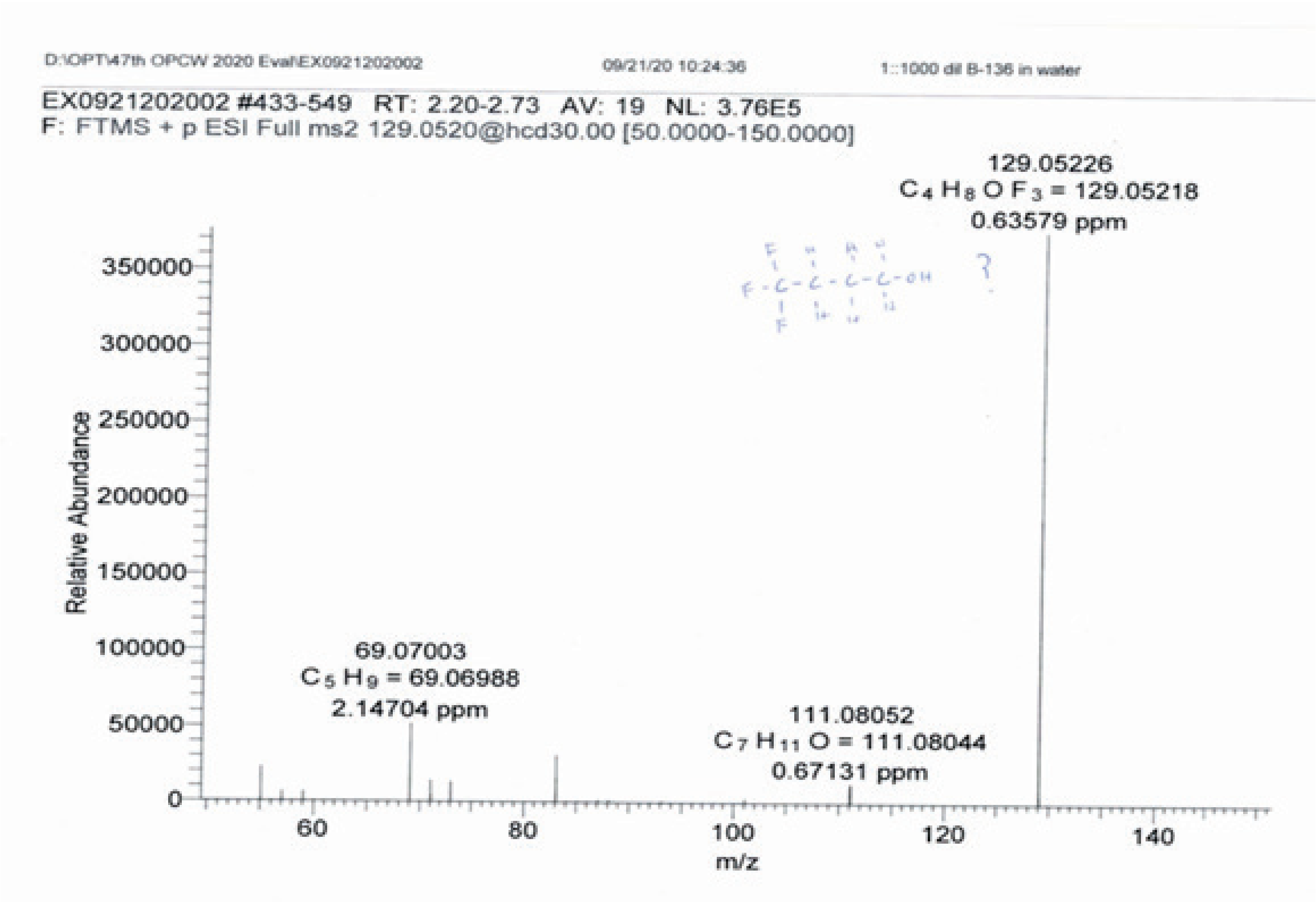


Figure 8. Mass spectrometry scans of BlazeCheck for presence of PFAS (normalization level [NL] = 3.76 × 10^5, retention time [RT] = 2.20–2.73 s, and number of averaged scans [AV] = 19).

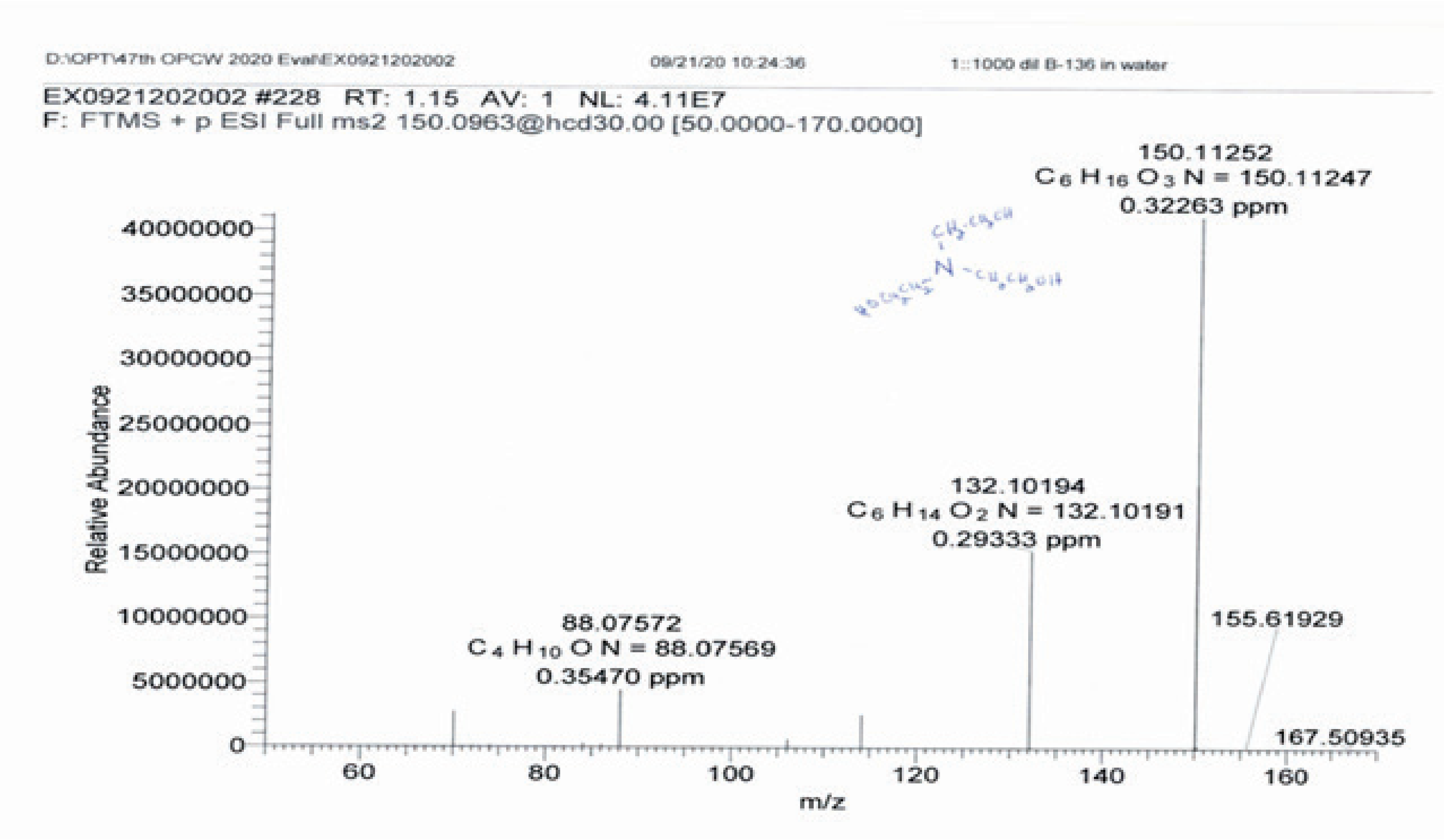


Figure 9. Mass spectrometry scans of BlazeCheck for presence of PFAS (NL= 4.11×10^7, RT = 1.15 s, and AV = 1.)

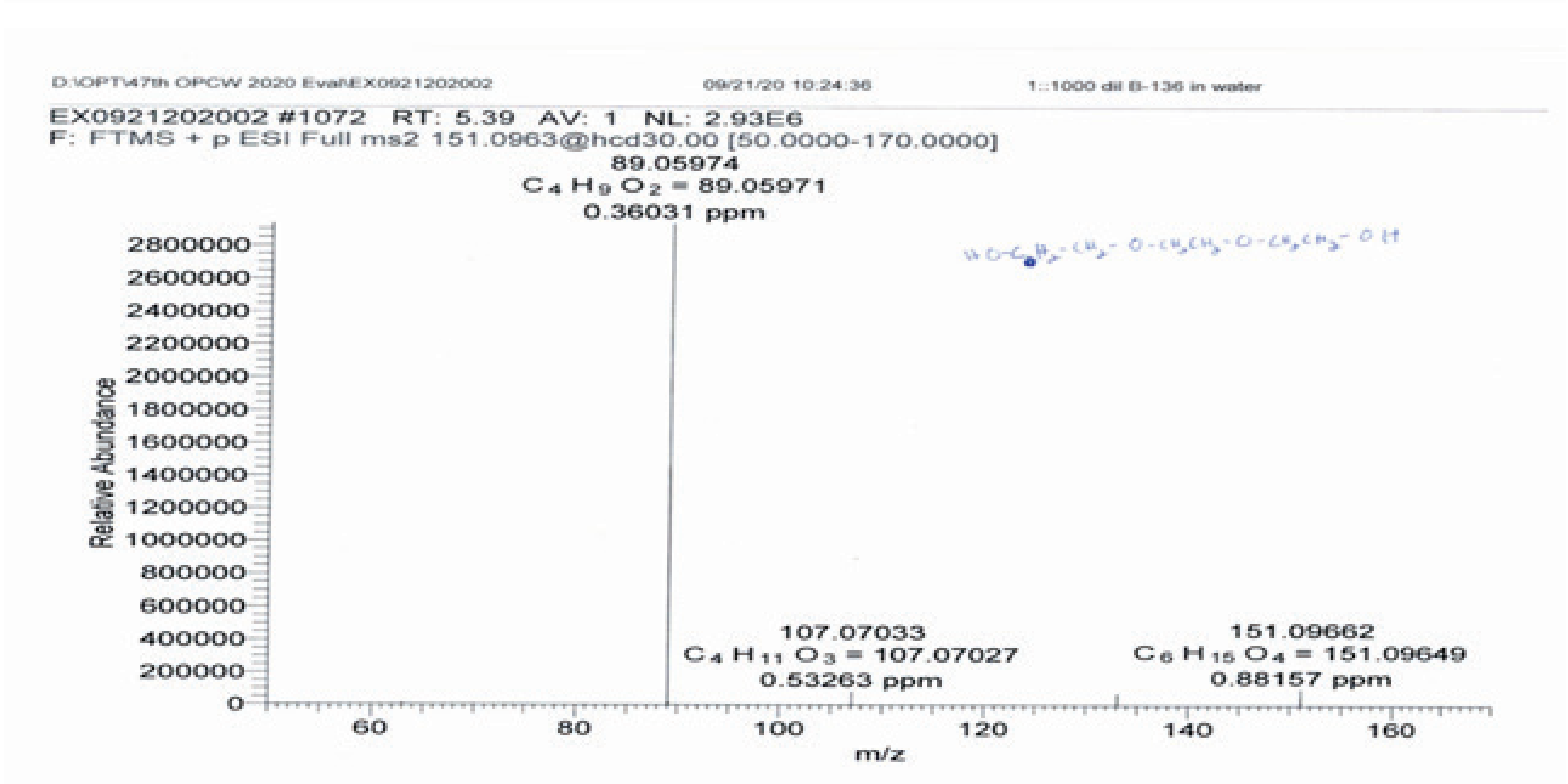


Figure 10. Mass spectrometry scans of BlazeCheck for presence of PFAS (NL = 2.93 × 10^6, RT = 5.39 s, and AV = 1).

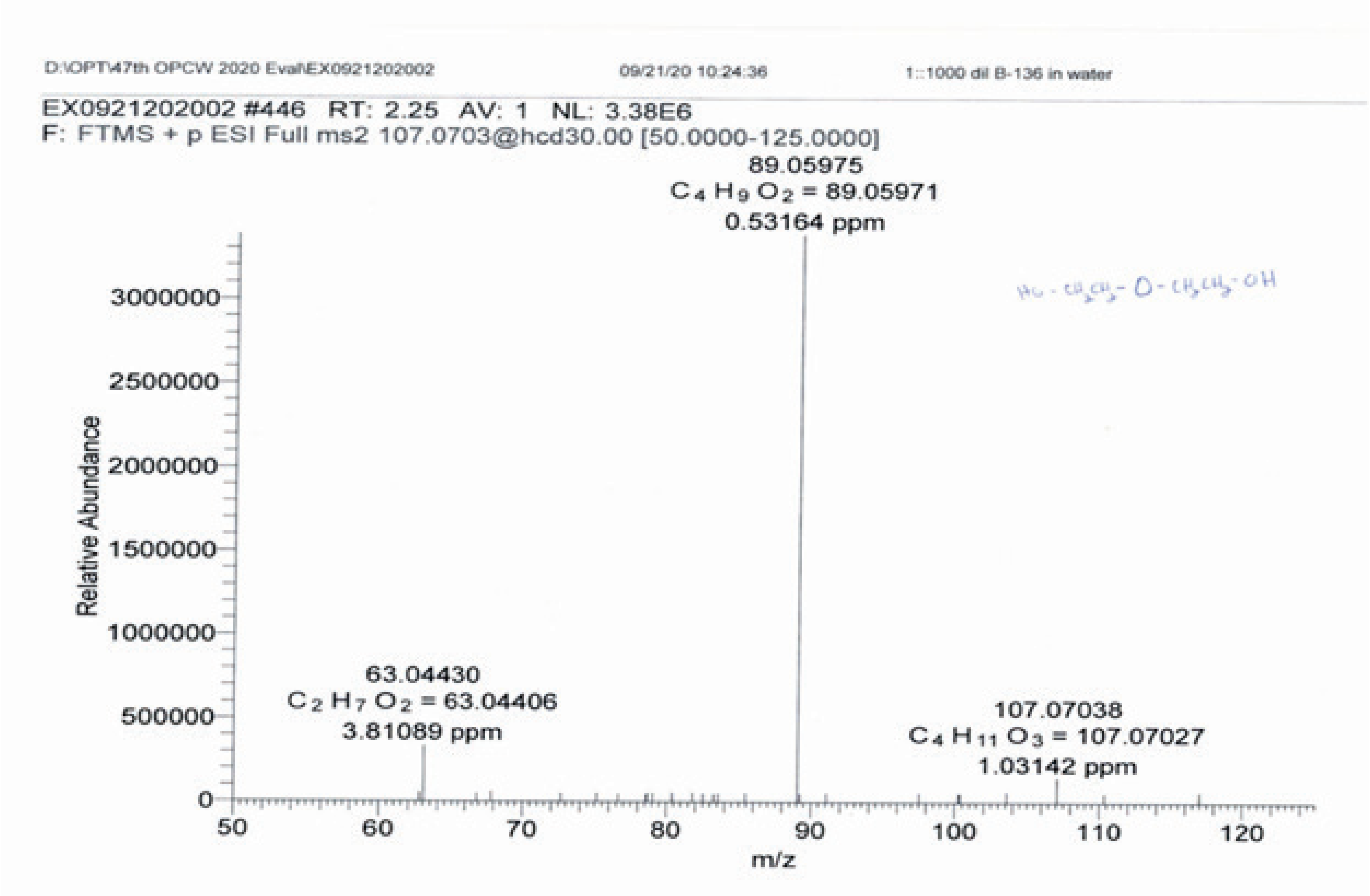


Figure 11. Mass spectrometry scans of BlazeCheck for presence of PFAS (NL = 3.38×10^6, RT = 2.25 s, and AV = 1).

4. PERFORMANCE TESTING

The objective of the performance testing was to determine the ability of the BlazeCheck solution to suppress the flames associated with liquid fuels, metal powder fuels, and pyrotechnic fuels.

4.1 Small Fire Pan Tests

For each trial, 800 mL of fuel was placed into a 1 ft^2 pan that was 2.5 in. deep. The extinguishing solution (either pure water, 10% BlazeCheck in water, or 20% BlazeCheck in water) was discharged from a 2.5 gal extinguisher at roughly 216 mL/s. Care was taken to ensure that there was minimal splashing of the burning fuel after the application of the extinguishing solution. As shown in Tables 5 (for burning gasoline) and 6 (for burning diesel), BlazeCheck solution was quicker than water alone at extinguishing and re-extinguishing fires.

Table 5. Extinguishment Time with BlazeCheck Solution on Gasoline Fire

BlazeCheck in Water (%)	Burning Gasoline: Extinguishment Time (s)	
	Initial	Relight
0	NR	NR
10	10	5
20	6	2

NR, no result.

Table 6. Extinguishment Time with BlazeCheck Solution on Diesel Fire

BlazeCheck in Water (%)	Burning Diesel: Extinguishment Time (s)	
	Initial	Relight
0	6	7
10	2	2
20	2	1

4.2 Pyrotechnic Fire Tests

To assess the effectiveness of BlazeCheck solution against pyrotechnic-generated flame, two underwater road flares (based on pyrotechnic flare formulation number 36 [Ellern, 1968]) were fabricated by the DEVCOM CBC Pyrotechnic Facility. Attempts were made to extinguish the flares with both pure water and 10% BlazeCheck in water. Pyrotechnics contain their own oxygen source, unlike standard fuel-based flames that obtain their oxygen from the air.

Standard Orion brand commercial road flares were tried first. Potassium perchlorate has been replaced by potassium nitrate in these types of road flare formulations, as environmentally approved for the state of California. The oxidizer substitution resulted in lower energy output and rendered the Orion flares more susceptible to water extinguishment. Both water and BlazeCheck in water were able to quickly extinguish the flares.

Therefore, the DEVCOM CBC Pyrotechnics and Explosives Team assembled a more energetic, classic, underwater road flare mixture and pressed it into fiberboard sleeves roughly 3 in. long (meant for wrapping commercial fireworks):

Underwater Flare Formulation Number 36 (Ellern, 1968)
16% magnesium
12% aluminum
40% barium sulfate
32% barium nitrate
binder (8 parts linseed oil, 1 part manganese dioxide)

When applied directly and repeatedly to the flame, the water-only stream was unable to smother the flare output until the flare had completely burned itself out (in roughly 30 s). Water alone was clearly ineffective in completely extinguishing the pyrotechnic flare (Figures 12–14). The flame was temporarily smothered when it was hit by a water stream; then, it would automatically relight. This relight happened four times over the 30 s. After the flare burned out, it was cut open to determine whether any unreacted flare composition was still present. None was found, which indicates that the water was not responsible for extinguishing the flare.

The stream containing 10% BlazeCheck in water was effective in smothering the flare flame with a single continuous application in roughly 3 s. The flare could not be relighted when a sustained flame was applied with the torch to the extinguished flare (Figures 15–17).

Figure 12. Pyrotechnic underwater flare, fully ignited.

Figure 13. Time 0, start of freshwater application against ignited pyrotechnic underwater flare.

Figure 14. Thirty seconds after water application to ignited pyrotechnic underwater flare. Flare appeared to burn out after 30 s without any assistance from the water application.

Figure 15. Pyrotechnic underwater flare, fully ignited.

Figure 16. Time 0, start of application of 10% BlazeCheck in water.

Figure 17. Three seconds after application of 10% BlazeCheck in water. Complete extinguishment without possible relight.

Although this demonstration was not definitive and should be repeated with various pyrotechnic formulations, it showed that BlazeCheck solution potentially has a retardant effect on pyrotechnic-based energetics as compared to the pure water solutions typically used in high-speed deluge systems for energetics-based facilities. The added safety potential of mixing high-speed deluge water with the BlazeCheck solution would likely outweigh any slight increase to the cost of deluge system operation.

Based on these limited findings, a more comprehensive test regime for use of this material in high-speed safety deluge systems might be warranted.

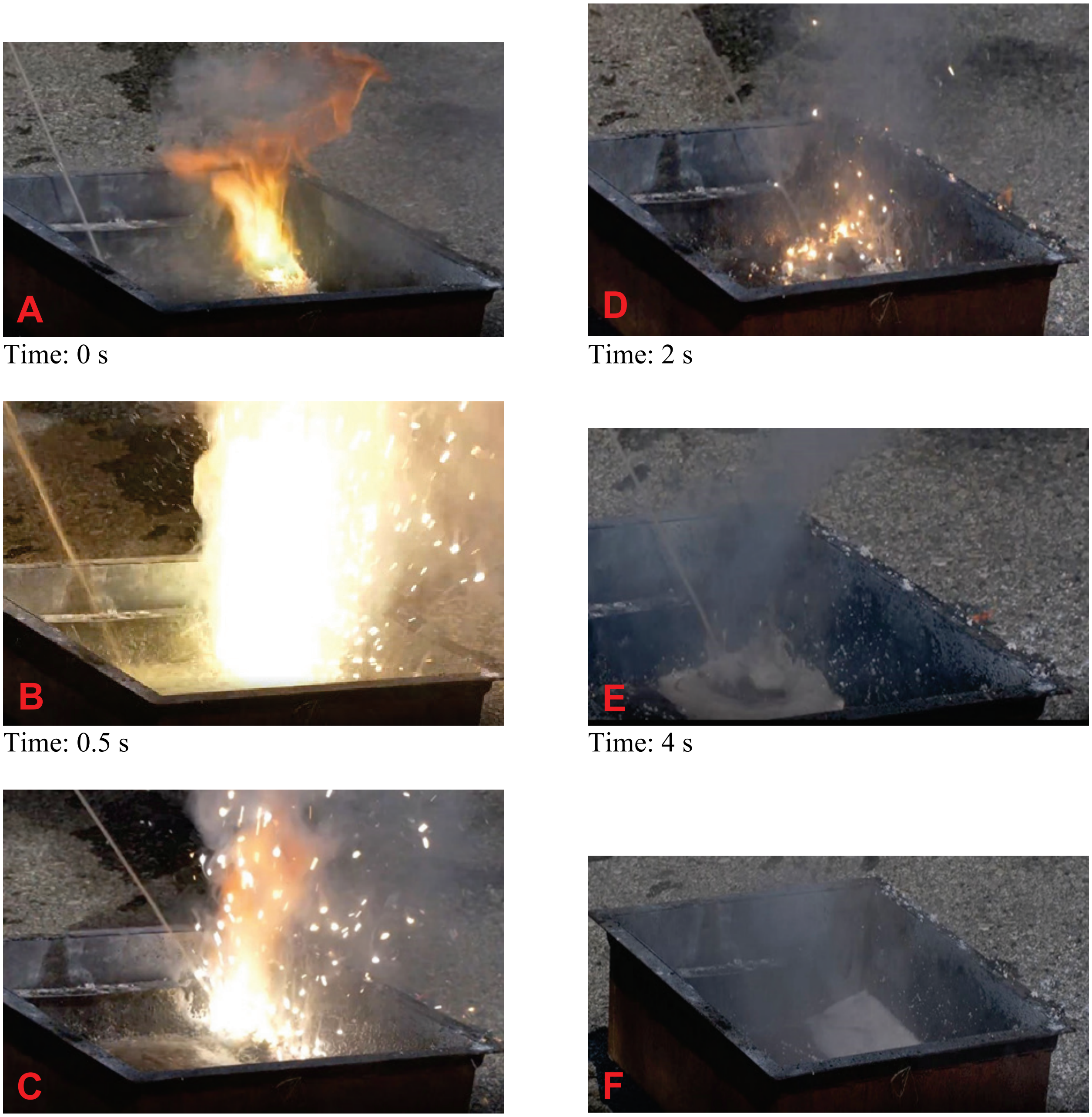
4.3 Metal Shavings Fire Tests

A 10% solution of BlazeCheck in water was compared to a class D (NaCl) extinguisher in tests against magnesium fires created using coarse magnesium shavings.

Water application: Once the magnesium was ignited (with a torch), any application of water caused the fire to flare violently without any extinguishment.

BlazeCheck application (Figure 18): Upon initial application of 10% BlazeCheck in water, the magnesium fire typically flared and then extinguished within a few seconds as the solution engulfed the firebrands. The wetted shavings would not relight when disturbed or uncovered. The application seemed to be effective at quickly quenching the burning magnesium shavings; however, the use of a water-based solution such as this for class D fires would require further study for safety before it could be recommended as a standard treatment. Video is available at BlazeCheck.net.

The class D extinguisher was successful at extinguishing the magnesium fire flames wherever the NaCl powder completely blanketed the material. However, any areas not completely covered continued to flame, and when the NaCl blanket was disturbed, the flames erupted anew in the presence of oxygen. The class D extinguisher material must completely cover the metal flakes and remain so to be effective.



Time: 0 s

Time: 0.5 s

Time: 1 s

Time: 2 s

Time: 4 s

Time 5: s

Figure 18. Metal shavings fire test: application of 10% BlazeCheck in water. Photographs taken at (A) 0 s, (B) 0.5 s, (C) 1 s, (D) 2 s, (E) 4 s, and (F) 5 s after BlazeCheck application.

4.4 28 ft^2 Fire Test Conducted in Accordance with MIL-PRF-24385F with Modifications

4.4.1 First Trial Results

During the first 28 ft^2 pan fire trial using the 2 gal/min discharger and a solution of 10% BlazeCheck in fresh water, the fire could not be completely extinguished in 90 s. This trial was considered a failure, and it was decided that a second trial would be attempted using a higher application rate.

4.4.2 Second Trial Results

During the second 28 ft^2 pan fire trial using a higher discharge rate (estimated at 15–20 gal/min) and a solution of 20% BlazeCheck in fresh water (Figure 19), the fire was extinguished in an estimated 75 s (Figure 20). The BlazeCheck solution failed to meet the burnback test objective, as the entire surface of the fuel in the pan reignited once the smaller burnback pan was lowered into the 28 ft^2 pan (Figure 21).

After the burnback fire reignited the fuel in the 28 ft^2 pan and the fire was allowed to burn for several minutes, a second extinguishment of the fire was attempted using the original 2 gal/min dissemination device prescribed in the specification (Figure 22). This time, the fire was extinguished in roughly 17 s. After this, the fire could not be reignited.

The BlazeCheck solution was clearly active in extinguishing the fire, as the rapid reignition of the fire after the introduction of the flaming small burnback pan showed there was still a substantial amount of fuel left in the 28 ft^2 pan after the first extinguishment. However, because the presumed mechanism of action requires the material to be mixed thoroughly with the top fuel layer to emulsify and reduce the fuel vapor pressure, it takes longer and requires a higher application rate for the BlazeCheck solution to extinguish the fire as compared with a typical AFFF application for such a large volume of fuel.

The second 28 ft^2 pan extinguishment trial is summarized in the rest of this section. Because the material could not meet the requirements of the 28 ft^2 test, it was decided that the 50 ft^2 fire pan test would not be performed. Nothing additional would be determined by conducting the scaled-up test.

The rest of Section 4.4 focuses only on the second 28 ft^2 pan extinguishment trial.

4.4.3 Test Procedures

Over a 30 s period, 10 gal of gasoline was added to the 28 ft^2 pan. The fire was allowed to burn freely for 10 s before extinguishment attempts were started. Spraying of the 20% BlazeCheck solution in fresh water began at the 20 s mark of the video (Figure 19). Because attempts to completely extinguish the flames in 90 s with the 2 gal/min device in the first test trial were unsuccessful, a higher volumetric rate disperser (estimated to be in the 15–20 gal/min range) was used to spray the solution in this trial.

Figure 19. Full ignition of the fuel and initiation of first extinguishment.

At the 1:35 min mark of the video (75 s after the extinguishment attempt began), the flames in the 28 ft^2 pan were completely extinguished (Figure 20). Some fuel and extinguishing solution overflowed into the lower catch pan.

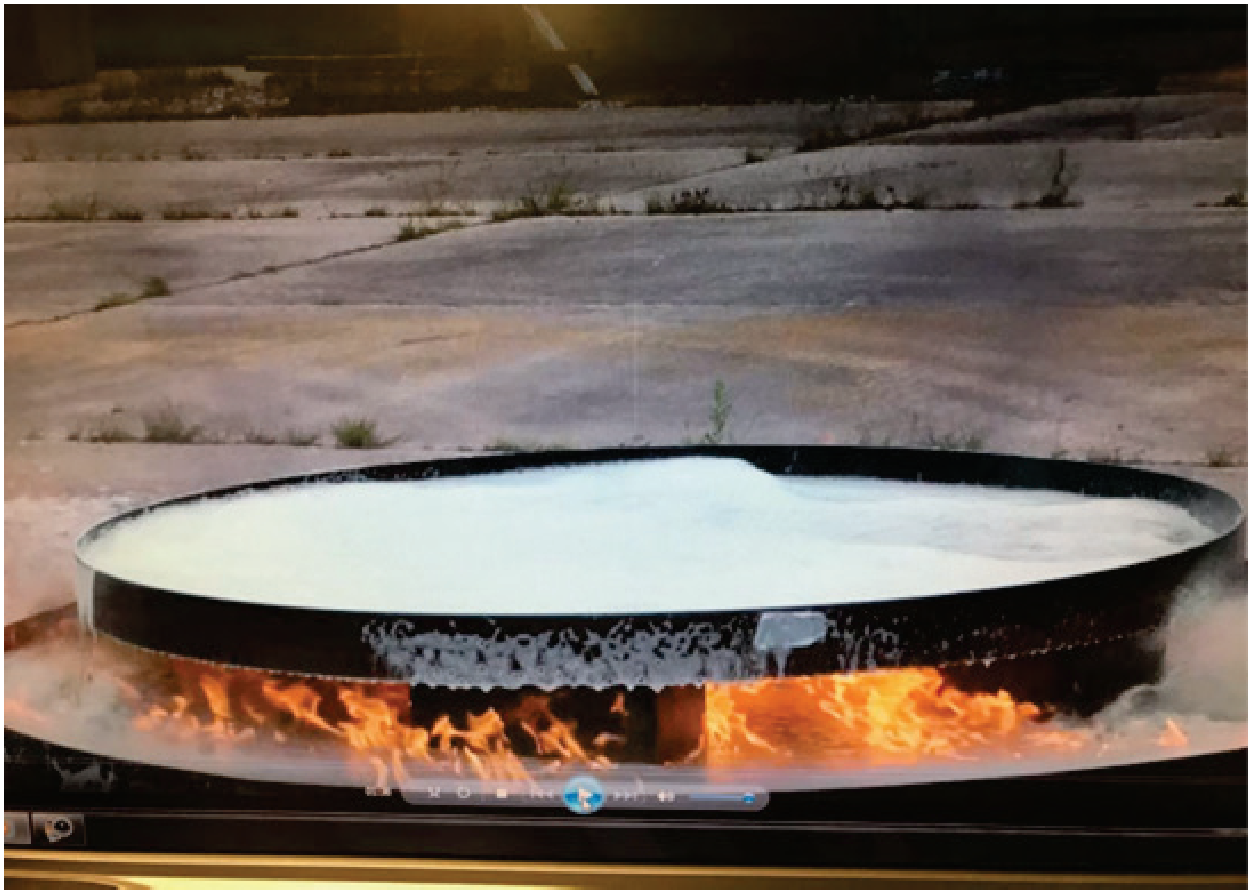


Figure 20. First extinguishment of the fuel in the 28 ft^2 pan.

4.4.4 Burnback Portion of Fire Pan Test

When the small burnback pan was introduced into the 28 ft^2 pan, it was able to rapidly reignite a fire throughout the entire pan (Figure 21); therefore, the burnback time requirement was not met. However, this shows that there was still a significant amount of unburnt fuel in the main pan, where the initial combustion had been extinguished by the BlazeCheck solution application. The amount of unburnt fuel in the pool below the surface was disturbed by the insertion of the burnback pan, and the fire in the burnback pan was able to reignite this fuel.

Figure 21. Burnback reignition of the fuel.

After the fire was allowed to burn for several minutes, another round of 20% BlazeCheck in fresh water was applied using the original 2 gal/min handheld extinguisher tank prescribed in the specification. Reapplication of the BlazeCheck solution using the standard 2 gal/min nozzle to the reignited fire from the burnback pan began at the 11:02 mark of the video.

Figure 22. Second extinguishment after burnback reignition began.

The extinguishment was complete at the 11:19 mark of the video. A total of 17 s had elapsed to complete the burnback fire extinguishment. Afterward, steam was noticed coming from the pool. It was not possible to reignite the fuel pool after this point.

After the test, the remaining fuel and BlazeCheck solution were pumped into a 55 gal drum and turned in to the Aberdeen Proving Ground hazardous waste handling facility to be disposed of in accordance with federal, state, and local environmental regulations. (Because the remaining solution was no longer ignitable, it could not be burned off; therefore, regulations required that it be turned in.) The hazardous waste component of the remaining pool was any benzene that would naturally be part of the gasoline. The BlazeCheck solution itself has no hazardous components.

5. DISCUSSION AND CONCLUSIONS

BlazeCheck was found to be readily miscible in water and to have a slightly basic pH and a kinematic viscosity similar to coconut oil. It was found to be noncorrosive against metal coupons in sea water solution, and no trace of PFAS was found after analysis with mass spectrometry.

Positive indicators for BlazeCheck performance include the noncorrosive nature of the solution (in fresh or salt water) in contact with metals, the lack of any PFAS detected in the material (the nontoxic nature of the material), the relatively cheap cost of the solution, the product's ability to extinguish class B fires relatively quickly in small fuel pools (both diesel and gasoline), and some apparent effectiveness in extinguishing metal particle class D and pyrotechnic fires.

Further studies for effectiveness against class A fires are recommended for BlazeCheck and other similar types of retardants, although that was not the focus of this study. Further studies for effectiveness against class D fires are recommended for BlazeCheck, especially regarding safety of use with a water-based solution as part of the evaluation. Study of the heat-sink effectiveness of BlazeCheck as compared to foams would be helpful in determining the ability of BlazeCheck to cool hot surfaces that contribute to continuation of fires.

Negative indicators for BlazeCheck include the necessity to add and mix significant amounts of the solution with the fuel and the time involved to extinguish the flames for large class B fuel pool fires, as was observed in the 28 ft^2 pan test. Also, for a large fuel pool, even when the top layers are passivated, if the fuel below that level is disturbed and brought to the surface by mechanical action, the fire can easily restart. This reactivation effect or lack of burnback resistance was demonstrated for large fuel pool fires in the 28 ft^2 pan burnback tests. It was deemed unnecessary to conduct the 50 ft^2 fire test, as nothing further could be learned about the performance of the material.

One source (Pelton, 2015) describes the positives and negatives of similar wetting agents and emulsifiers for firefighting: "wetting agents improve the efficiency of water in extinguishing class A fuel fires. Use on class B combustibles requires higher application rates than those requiring foam agents and is limited to non-water-soluble flammable liquids (hydrocarbons only). Little if any burnback resistance is present on class B fires extinguished with emulsifiers or wetting agents." This is similar to the results discovered in this study.

In summary, BlazeCheck solution appears to be an effective and safe general-purpose fire retardant for specific firefighting applications and is deserving of further study.

LITERATURE CITED

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Ellern, H. *Military and Civilian Pyrotechnics*; Rocket Science Institute, Chemical Publishing Company: Gloucester, MA, 1 December 1968 (digital reprint, 2015 edition).

Federal Specification: Nickel–Copper Alloy Bar, Rod, Plate, Sheet, Strip Wire, Forgings, and Structural and Special Shaped Sections; QQ-N-281D, Amendment 2 with Notice 1; Naval Sea Systems Command: Washington, DC, 2020; UNCLASSIFIED Specification.

Fire Extinguishing Agent, Aqueous Film-Forming Foam (AFFF) Liquid Concentrate, for Fresh and Sea Water; MIL-PRF-24385F(SH) with Amendment 2; Naval Sea Systems Command: Washington Navy Yard, DC, 2017; UNCLASSIFIED Specification.

Pelton, D. Firefighting Foam—Making Water Wetter. *International Fire Fighter,* 22 June 2015; https://iffmag.mdmpublishing.com/firefighting-foam-making-water-wetter (accessed 9 May 2022).

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Standard Specification for Automotive Spark-Ignition Engine Fuel; ASTM D4814; ASTM International: West Conshohocken, PA, 2021.

Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity); ASTM D445; ASTM International: West Conshohocken, PA, 2021.

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ACRONYMS AND ABBREVIATIONS

AFFF	aqueous film-forming foam
AV	averaged
DEVCOM CBC	U.S. Army Combat Capabilities Development Command Chemical Biological Center
NL	normalization level
PFAS	per- and polyfluoroalkyl substances
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
RT	retention time
SD	standard deviation
UNS	Unified Numbering System

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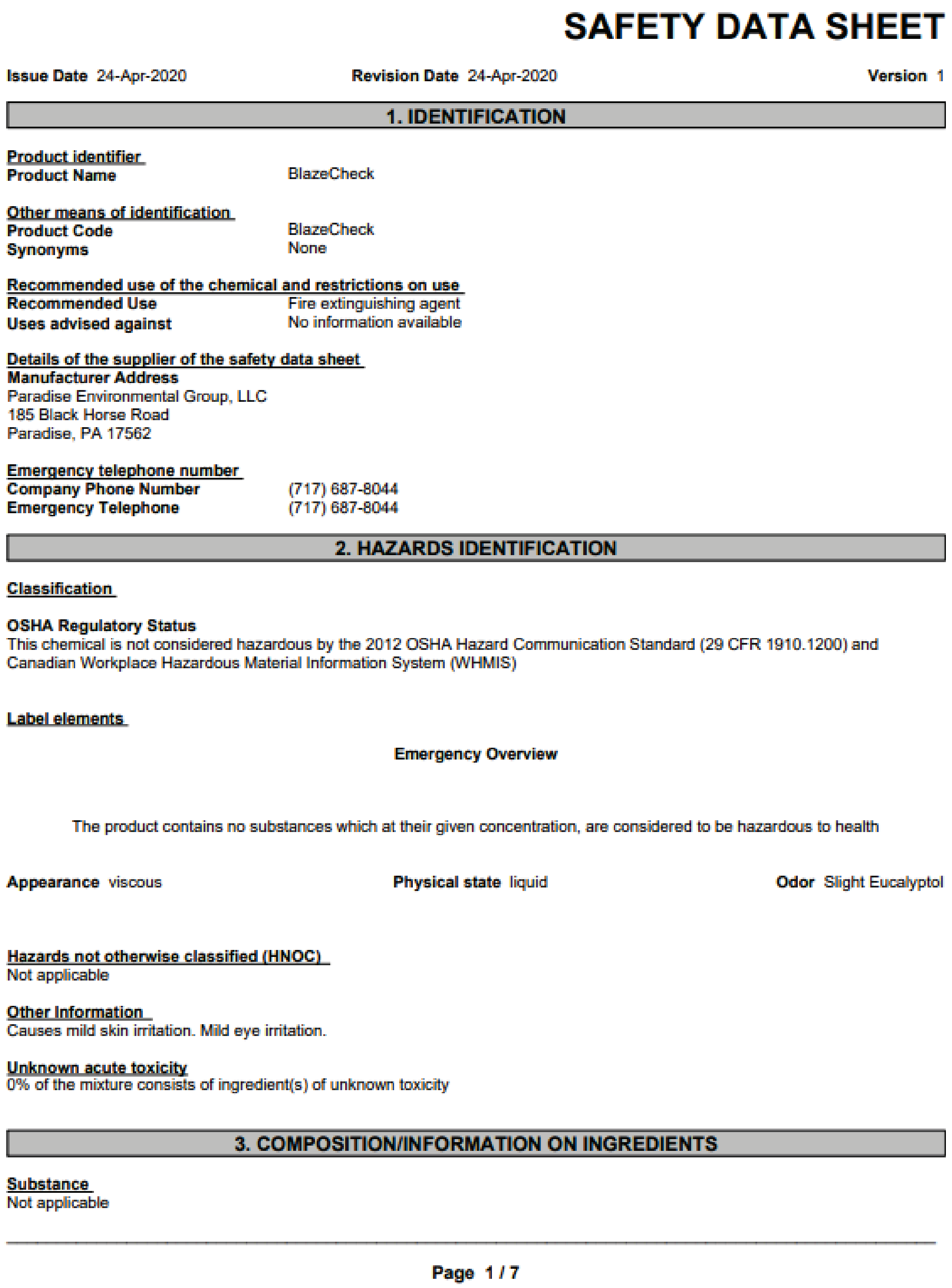
APPENDIX:
BLAZECHECK SAFETY DATA SHEET*



SAFETY DATA SHEET

Issue Date 24-Apr-2020 **Revision Date** 24-Apr-2020 **Version** 1

1. IDENTIFICATION

Product identifier

Product Name	BlazeCheck

Other means of identification

Product Code	BlazeCheck
Synonyms	None

Recommended use of the chemical and restrictions on use

Recommended Use	Fire extinguishing agent
Uses advised against	No information available

Details of the supplier of the safety data sheet

Manufacturer Address
Paradise Environmental Group, LLC
185 Black Horse Road
Paradise, PA 17562

Emergency telephone number

Company Phone Number	(717) 687-8044
Emergency Telephone	(717) 687-8044

2. HAZARDS IDENTIFICATION

Classification

OSHA Regulatory Status
This chemical is not considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200) and Canadian Workplace Hazardous Material Information System (WHMIS)

Label elements

Emergency Overview

The product contains no substances which at their given concentration, are considered to be hazardous to health

Appearance viscous **Physical state** liquid **Odor** Slight Eucalyptol

Hazards not otherwise classified (HNOC)
Not applicable

Other Information
Causes mild skin irritation. Mild eye irritation.

Unknown acute toxicity
0% of the mixture consists of ingredient(s) of unknown toxicity

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance
Not applicable

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*Available at https://irp.cdn-website.com/1226ab75/files/uploaded/English%20SDS.pdf (accessed 18 October 2022).

Mixture

Chemical Name	CAS No	Weight-%
Water *	7732-18-5	30 - 60
Liquid detergent *	Proprietary	15 - 40
Diethylene glycol *	111-46-6	10 - 30

*The exact percentage (concentration) of composition has been withheld as a trade secret. If CAS number is "proprietary", the specific chemical identity and percentage of composition has been withheld as a trade secret.

4. FIRST AID MEASURES

Description of first aid measures

General advice	In case of accident or unwellness, seek medical advice immediately (show directions for use or safety data sheet if possible). If symptoms persist, call a physician.
Eye contact	Keep eye wide open while rinsing. Immediately flush with plenty of water. After initial flushing, remove any contact lenses and continue flushing for at least 15 minutes. If symptoms persist, call a physician.
Skin contact	Wash off immediately with soap and plenty of water while removing all contaminated clothes and shoes. If symptoms persist, call a physician. Wash contaminated clothing before reuse.
Inhalation	Remove to fresh air. If breathing is irregular or stopped, administer artificial respiration. Avoid direct contact with skin. Use barrier to give mouth-to-mouth resuscitation. If symptoms persist, call a physician.
Ingestion	Call a physician or poison control center immediately. Do not induce vomiting without medical advice. Rinse mouth. Never give anything by mouth to an unconscious person.
Self-protection of the first aider	Use personal protective equipment as required.

Most important symptoms and effects, both acute and delayed

Symptoms None known.

Indication of any immediate medical attention and special treatment needed

Note to physicians Treat symptomatically.

5. FIRE-FIGHTING MEASURES

Suitable extinguishing media
Not applicable.

Unsuitable extinguishing media None.

Specific hazards arising from the chemical
None in particular.

Explosion data
Sensitivity to Mechanical Impact None.
Sensitivity to Static Discharge None.

Protective equipment and precautions for firefighters
Not applicable.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Personal precautions	Use personal protective equipment as required. Stop leak if you can do it without risk. Wash thoroughly after handling.

Environmental precautions

Environmental precautions	See Section 12 for additional ecological information.

Methods and material for containment and cleaning up

Methods for containment	Prevent further leakage or spillage if safe to do so.
Methods for cleaning up	Use personal protective equipment as required. Dam up. Cover liquid spill with sand, earth or other non-combustible absorbent material. Take up mechanically, placing in appropriate containers for disposal. Clean contaminated surface thoroughly.

7. HANDLING AND STORAGE

Precautions for safe handling

Advice on safe handling	Use with local exhaust ventilation. Use personal protective equipment as required. Handle in accordance with good industrial hygiene and safety practice. Wash contaminated clothing before reuse.

Conditions for safe storage, including any incompatibilities

Storage Conditions	Keep in a dry, cool and well-ventilated place. Keep from freezing. Keep at temperatures between -10 and 52 °C.
Packaging materials	Polyethylene. Steel. FRP.
Incompatible materials	Strong oxidizing agents. Strong acids. Strong bases. Magnesium.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Exposure Guidelines	This product, as supplied, does not contain any hazardous materials with occupational exposure limits established by the region specific regulatory bodies.

Appropriate engineering controls

Engineering Controls	Showers Eyewash stations Ventilation systems.

Individual protection measures, such as personal protective equipment

Eye/face protection	Wear safety glasses with side shields (or goggles).
Skin and body protection	Wear protective gloves and protective clothing.
Respiratory protection	If exposure limits are exceeded or irritation is experienced, NIOSH/MSHA approved respiratory protection should be worn. Positive-pressure supplied air respirators may be required for high airborne contaminant concentrations. Respiratory protection must be provided in accordance with current local regulations.
General Hygiene Considerations	Handle in accordance with good industrial hygiene and safety practice.

9. PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Physical state	liquid		
Appearance	viscous	**Odor**	Slight Eucalyptol
Color	dark green	**Odor threshold**	No information available

Property	**Values**	**Remarks • Method**
pH	7.65	
Melting point / freezing point	No information available	
Boiling point / boiling range	> 100 °C / 212 °F	
Flash point	Not applicable	
Evaporation rate	No information available	
Flammability (solid, gas)	No information available	
Flammability Limit in Air		
Upper flammability limit:	No information available	
Lower flammability limit:	No information available	
Vapor pressure	<1 mmHg	@ 20 °C
Vapor density	No information available	
Relative density	1.04	
Water solubility	dispersible	
Solubility in other solvents	No information available	
Partition coefficient	No information available	
Autoignition temperature	No information available	
Decomposition temperature	No information available	
Kinematic viscosity	No information available	
Dynamic viscosity	No information available	
Explosive properties	Not an explosive	
Oxidizing properties	Not applicable	

Other Information

Softening point	No information available
Molecular weight	No information available
VOC Content (%)	No information available
Density	No information available
Bulk density	No information available

10. STABILITY AND REACTIVITY

Reactivity
No data available

Chemical stability
Stable under recommended storage conditions.

Possibility of Hazardous Reactions
None under normal processing.

Conditions to avoid
Temperatures above 49 °C / 120 °F.

Incompatible materials
Strong oxidizing agents. Strong acids. Strong bases. Magnesium.

Hazardous Decomposition Products
None known based on information supplied.

11. TOXICOLOGICAL INFORMATION

Information on likely routes of exposure

Product Information

Inhalation	Based on available data, the classification criteria are not met.
Eye contact	Based on available data, the classification criteria are not met. Moderately irritating to the eyes.

Skin contact Based on available data, the classification criteria are not met. Substance may cause slight skin irritation.

Ingestion Based on available data, the classification criteria are not met.

Chemical Name	Oral LD50	Dermal LD50	Inhalation LC50
Water 7732-18-5	> 90 mL/kg (Rat)	-	-
Liquid detergent	= 13792 mg/kg (Rat)	-	-
Diethylene glycol 111-46-6	= 12565 mg/kg (Rat)	= 11890 mg/kg (Rabbit)	> 4600 mg/m^3 (Rat) 4 h

Information on toxicological effects

Symptoms No information available.

Delayed and immediate effects as well as chronic effects from short and long-term exposure

Sensitization	Based on available data, the classification criteria are not met.
Germ cell mutagenicity	Based on available data, the classification criteria are not met.
Carcinogenicity	Based on available data, the classification criteria are not met.
Reproductive toxicity	Based on available data, the classification criteria are not met.
STOT - single exposure	Based on available data, the classification criteria are not met.
STOT - repeated exposure	Based on available data, the classification criteria are not met.
Aspiration hazard	Based on available data, the classification criteria are not met.

Numerical measures of toxicity - Product Information

The following values are calculated based on chapter 3.1 of the GHS document .

ATEmix (oral)	>5000 mg/kg
ATEmix (dermal)	46,466.00 mg/kg
ATEmix (inhalation-dust/mist)	28.78 mg/l

12. ECOLOGICAL INFORMATION

Ecotoxicity

None known

84 % of the mixture consists of components(s) of unknown hazards to the aquatic environment

Chemical Name	Algae/aquatic plants	Fish	Crustacea
Diethylene glycol 111-46-6	-	75200: 96 h Pimephales promelas mg/L LC50 flow-through	84000: 48 h Daphnia magna mg/L EC50

Persistence and degradability

No information available.

Bioaccumulation

Not likely to bioaccumulate.

Chemical Name	Partition coefficient
Diethylene glycol 111-46-6	-1.98

Other adverse effects

No information available

13. DISPOSAL CONSIDERATIONS

Waste treatment methods

Disposal of wastes Disposal should be in accordance with applicable regional, national and local laws and regulations.

Contaminated packaging	Do not reuse container.

14. TRANSPORT INFORMATION

DOT	Not regulated
TDG	Not regulated
IATA	Not regulated
IMDG	Not regulated

15. REGULATORY INFORMATION

International Inventories

TSCA	Complies
DSL/NDSL	Complies
EINECS/ELINCS	Complies
IECSC	Complies
KECL	Complies
PICCS	Complies
AICS	Complies

Legend:

TSCA - United States Toxic Substances Control Act Section 8(b) Inventory
DSL/NDSL - Canadian Domestic Substances List/Non-Domestic Substances List
EINECS/ELINCS - European Inventory of Existing Chemical Substances/European List of Notified Chemical Substances
ENCS - Japan Existing and New Chemical Substances
IECSC - China Inventory of Existing Chemical Substances
KECL - Korean Existing and Evaluated Chemical Substances
PICCS - Philippines Inventory of Chemicals and Chemical Substances
AICS - Australian Inventory of Chemical Substances

US Federal Regulations

SARA 313
Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372

SARA 311/312 Hazard Categories

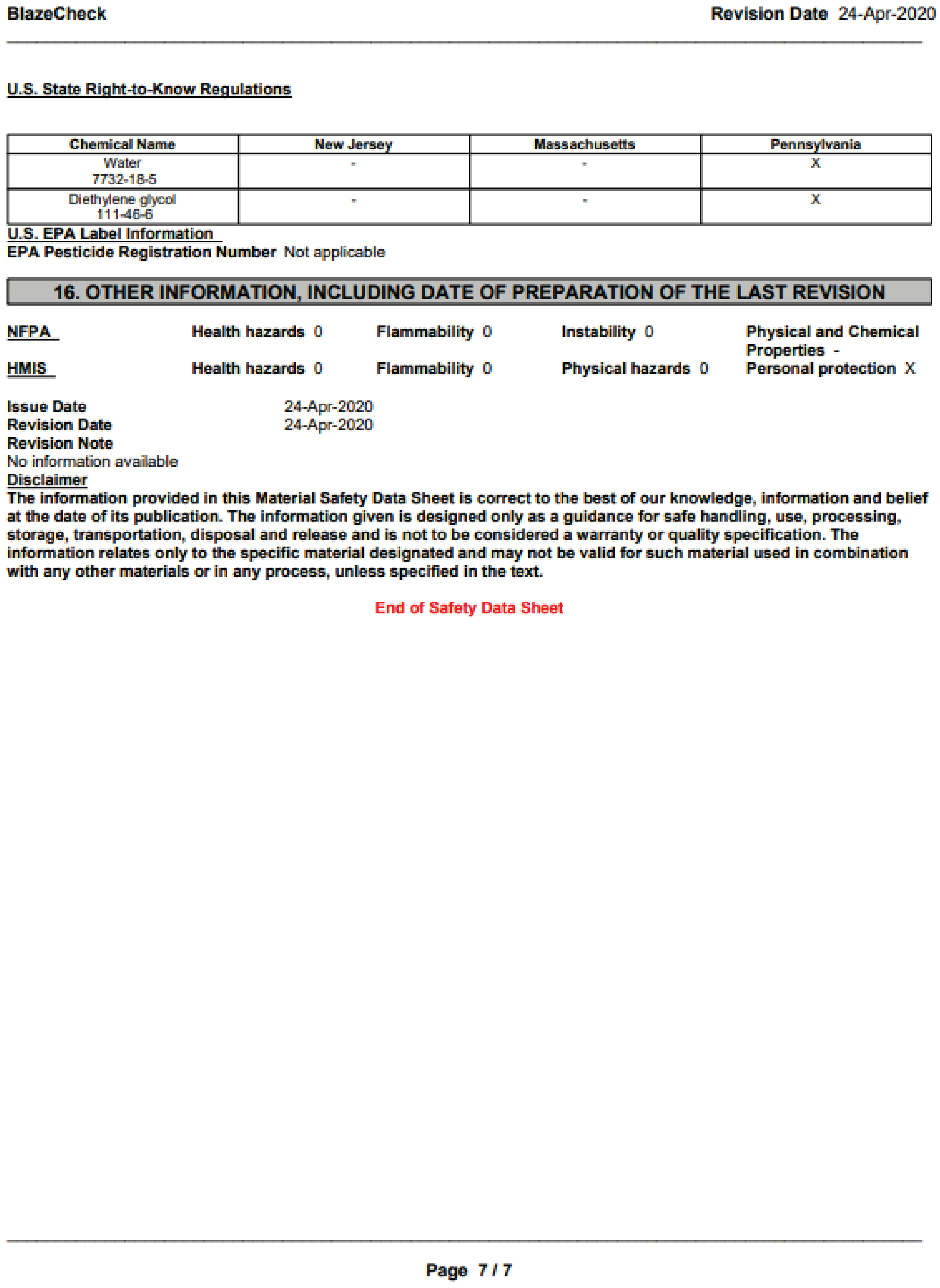
Acute health hazard	No
Chronic Health Hazard	No
Fire hazard	No
Sudden release of pressure hazard	No
Reactive Hazard	No

CWA (Clean Water Act)
This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40 CFR 122.42)

CERCLA
This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material

US State Regulations

California Proposition 65
This product does not contain any Proposition 65 chemicals



U.S. State Right-to-Know Regulations

Chemical Name	New Jersey	Massachusetts	Pennsylvania
Water 7732-18-5	-	-	X
Diethylene glycol 111-46-6	-	-	X

U.S. EPA Label Information
EPA Pesticide Registration Number Not applicable

16. OTHER INFORMATION, INCLUDING DATE OF PREPARATION OF THE LAST REVISION

NFPA	**Health hazards** 0	**Flammability** 0	**Instability** 0	**Physical and Chemical Properties** -
HMIS	**Health hazards** 0	**Flammability** 0	**Physical hazards** 0	**Personal protection** X

Issue Date 24-Apr-2020
Revision Date 24-Apr-2020
Revision Note
No information available

Disclaimer
The information provided in this Material Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

End of Safety Data Sheet

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