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Evaluation of a New Liquid Fire-Extinguishing Agent for Combustible Metal Fires

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Keith Bagot, Nicholas Subbotin*, and Jennifer Kalberer**	

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16. Abstract

A new liquid fire-extinguishing agent for combustible metal fires was evaluated. Aircraft rescue fire fighters may confront metal fires, such as magnesium and titanium, in aircraft brake assemblies, landing gear components, aircraft engines, and other structural components of aircraft. A combustible metal on fire could be a possible ignition source or a continuing source of ignition in an aircraft fire. The standard method for extinguishing combustible metal fires consists of using sodium chloride dry powder to smother the burning metal.

This evaluation determined the optimum chemical formulation and best extinguishing method using FEM-12 SC in hand-held extinguishers during the Federal Aviation Administration (FAA) Aircraft Rescue and Firefighting (ARFF) Research Program's combustible metal fire-testing protocol. A further evaluation included aquatic-toxicity testing of FEM-12 SC, and the extinguishing performance of FEM-12 SC compared to sodium chloride dry powder in accordance with the parameters set forth in the American National Standards Institute/Underwriters Laboratories Incorporated 711 "Rating and Testing of Fire Extinguishers," Section 10.2, Magnesium Fire Tests, Section 10.2.28, Magnesium Casting Fire Tests.

The tests conducted by the FAA ARFF Research Program determined optimum chemical formulation, FEM-12 SC, and the best extinguishing method using 240 pounds per square inch, high-pressure extinguishers in a straight-stream configuration. The aquatic-toxicity test results showed that FEM-12 SC was tested at 675 parts per million (ppm) median lethal concentration and was within the acceptable accuracy range of greater than 500 ppm. The extinguishing performance comparison results showed that sodium chloride extinguished a magnesium fire in an average of 102 seconds, twice as fast as FEM-12 SC. However, it created a potential long-term fire hazard due to its inability to cool the metal, which could redevelop into a fire if the sodium chloride-covered metal was disturbed. FEM-12 SC provided better cooling than sodium chloride so that the magnesium could be handled with bare hands within minutes of extinguishment. However, when FEM-12 SC came in direct contact with the burning magnesium, violent flare ups of the fire and flying magnesium sparks created potential fire hazards. Once the fire was extinguished, the fire hazards were eliminated.

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LIST OF ACRONYMS

AFFF	Aqueous film forming foam
AFRL	Air Force Research Laboratory
ANSI	American National Standards Institute
ARFF	Aircraft Rescue and Firefighting
ASTM	American Society for Testing and Materials
DO	Dissolved oxygen
FAA	Federal Aviation Administration
gpm	Gallons per minute
LC_{50}	Median lethal concentration
lb	Pounds
pH	Potential of hydrogen
ppm	Parts per million
psi	Pounds per square inch
UL	Underwriters Laboratories Incorporated

EXECUTIVE SUMMARY

A new liquid fire-extinguishing agent for combustible metal fires was evaluated. Aircraft rescue fire fighters may confront metal fires, such as magnesium and titanium, in aircraft brake assemblies, landing gear components, aircraft engines, and other structural components of aircraft. A combustible metal on fire could be a possible ignition source or a continuing source of ignition in an aircraft fire. The standard method for extinguishing combustible metal fires consists of using sodium chloride dry powder to smother the burning metal.

This evaluation determined the optimum chemical formulation and best extinguishing method using FEM-12 SC in hand-held extinguishers during the Federal Aviation Administration (FAA) Aircraft Rescue and Firefighting (ARFF) Research Program's combustible metal fire-testing protocol. A further evaluation included aquatic-toxicity testing of FEM-12 SC, and the extinguishing performance of FEM-12 SC compared to sodium chloride dry powder in accordance with the parameters set forth in the American National Standards Institute/Underwriters Laboratories Incorporated 711 "Rating and Testing of Fire Extinguishers," Section 10.2, Magnesium Fire Tests, Section 10.2.28, Magnesium Casting Fire Tests.

The test conducted by the FAA ARFF Research Program determined optimum chemical formulation, FEM-12 SC, and the best extinguishing method using 240 pounds per square inch, high-pressure extinguishers in a straight-stream configuration. The aquatic-toxicity test results showed that FEM-12 SC was tested at 675 parts per million (ppm) median lethal concentration and was within the acceptable accuracy range greater than 500 ppm. The extinguishing performance comparison results showed that sodium chloride extinguished a magnesium fire in an average of 102 seconds, twice as fast as FEM-12 SC. However, it created a potential long-term fire hazard due to its inability to cool the metal, which could redevelop into a fire if the sodium chloride-covered metal was disturbed. FEM-12 SC provided better cooling than sodium chloride so that the magnesium could be handled with bare hands within minutes of extinguishment. However, when FEM-12 SC came in direct contact with the burning magnesium, violent flare ups of the fire and flying magnesium sparks created potential fire hazards. Once the fire was extinguished, the fire hazards were eliminated.

INTRODUCTION

PURPOSE.

A new liquid fire-extinguishing agent for combustible metal (Class D) fires was tested and evaluated so it could be used by aircraft rescue fire fighters. The liquid fire-extinguishing agent, FEM-12 SC, was tested to compare its extinguishing time and characteristics to the standard method of using sodium chloride dry powder for extinguishing Class D fires, such as magnesium.

OBJECTIVE.

The objective of this evaluation was to

- conduct Federal Aviation Administration (FAA) Aircraft Rescue and Firefighting (ARFF) Research Program's protocol for combustible metal fire testing to determine the optimum chemical formulation and best extinguishing method for FEM-12 SC using hand-held extinguishers.

- test and evaluate the aquatic toxicity of FEM-12 SC.

- test and evaluate the FEM-12 SC extinguishing performance in comparison with sodium chloride dry powder (sodium chloride) in accordance with the parameters set forth in the American National Standards Institute (ANSI)/Underwriters Laboratories Incorporated (UL) 711 [1].

BACKGROUND.

Class D fires consist of the burning oxidation of certain combustible metals, such as magnesium, zirconium, titanium, and lithium. Characteristics of magnesium fires consist of a hot-burning white flame with temperatures reaching beyond 2500°F. Methods of extinguishment on metal fires include the use of sodium chloride dry powder on the source of the fire by crusting, smothering, or heat-transfer means, or to use large amounts of water at the source of the fire to cool the burning metal. However, when water-based products are used on metal fires, a violent, flaring explosion occurs. The water dissociates into hydrogen and hydrogen oxide; thus, the hydrogen ignites and increases the combustion and hydrogen explosive hazard.

The FAA is looking to evaluate the effectiveness of new and alternative firefighting agents for Class D fires, with emphasis on magnesium fires. Aircraft rescue fire fighters may see these types of metal fires in aircraft brake assemblies, landing gear components, aircraft engines, and other structural components of the aircraft. A combustible metal on fire could be a possible ignition source or a continuing source of ignition in an aircraft fire, especially when fuels are present. The standard and approved extinguishing agent used for Class D fires is a dry powder, a sodium chloride-based product for magnesium fires. Little industry research has been completed on the effectiveness and toxicity of new extinguishing agents appearing in the market.

In an effort to provide the most effective agents for aircraft firefighting, the FAA and the Air Force Research Laboratory (AFRL) conducted tests on a new fire-extinguishing agent called FEM-12 SC developed by TLI Group Ltd. The FAA ARFF Research Program conducted its own protocol fire tests and observation of the agent with the manufacturer to determine the optimum chemical formulation and best extinguishing method for FEM-12 SC using hand-held extinguishers. These tests were conducted by the FAA ARFF Research Program at the FAA William J. Hughes Technical Center's outdoor fire facility. Following the tests, AFRL was tasked by the FAA with evaluating FEM-12 SC for toxicity and extinguishment performance in comparison with sodium chloride dry powder in accordance with the parameters set forth in ANSI/UL 711 [1].

TEST PROCEDURES

FEDERAL AVIATION ADMINISTRATION FIRE TESTS.

The FAA ARFF Research Program conducted their own protocol Class D fire tests at the FAA William J. Hughes Technical Center's outdoor fire facility to observe and record data for Class D fire-extinguishing agents. The FAA ARFF Research Program Class D fire test protocol was based on its fire facility's capabilities and availability of magnesium material for testing. The testing process and procedure consisted of small magnesium fires that could be extinguished using hand-held, pressurized fire extinguishers. A Class D fire was created using magnesium turnings, from a machine shop coated with cutting oil and magnesium printing plates. Magnesium turnings, weighing approximately 5 pounds (lb), were piled on a fire brick testing surface to prevent heat and fire damage to the steel containment pan where the fire tests were being conducted. Several magnesium plates, weighing approximately 5 lb, were placed on edge in a circular pattern, shown in figure 1. The total weight of magnesium turnings and plates during the tests was approximately 10 lb.

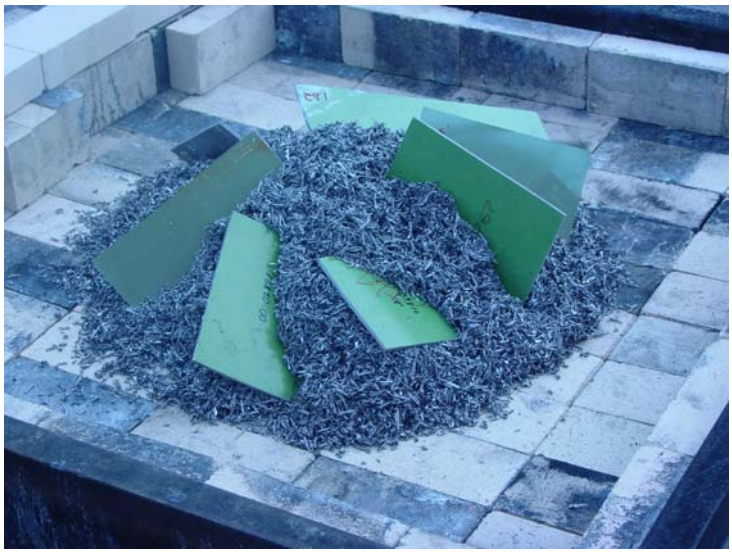

Figure 1. Magnesium Turnings and Plates Prior to Testing

A propane torch was then used to ignite the magnesium turnings that acted as an accelerant to ignite the magnesium plates. A preburn time was needed for each test until a consistent and steady burning of the magnesium plates had been established. The preburn time varied between each test due to outside causal factors such as wind, temperature, humidity, and metal inconsistencies. Once a consistent and steady fire was established, a fire fighter with hand-held extinguishers then attempted to extinguish the magnesium metal fire.

During the FAA fire test phase, several FEM formulations were tested on the procedure described. The evaluation also included different extinguishers, pressures, nozzles, and spray patterns for the optimum chemical formulation and best extinguishing method using the FEM-12 agent. For comparison, sodium chloride was also tested on the same described test process and procedure. The agents were evaluated for extinguishment time, quantity of agent used, and weight of unburned magnesium. Upon completion and analysis of the FAA fire test, the FEM-12 SC formulation and extinguishing method was chosen for aquatic-toxicity testing and a more extensive fire-testing protocol to be completed by AFRL.

AQUATIC-TOXICITY TESTS.

The aquatic toxicity of FEM-12 SC was conducted in accordance with American Society for Testing and Materials (ASTM) International E 729-96 [2]. Results were compared with Ansul aqueous film forming foam (AFFF) used as the baseline.

Toxicity tests were completed using the fathead minnow as the test organism. The ASTM E 729-96 Standard specifies that all organisms in a test should be as uniform as possible in age and size. To provide a consistent age class, at the beginning of each trial, Aquatic Research Organisms, Hampton, New Hampshire, provided 19-day-old, laboratory-reared fish. Dissolved oxygen (DO) levels were maintained between 60 and 100 percent of saturation, and the fish did not incur a temperature fluctuation of more than 3°C in any 12-hour period. The minnows were subjected to a 48-hour, acute, static, range-finding, toxicity test. A range-finding test, according to the Environmental Protection Agency, consists of a scaled-down, abbreviated, static, acute test in which groups of organisms are exposed to several widely spaced sample dilutions in a logarithmic series. Forty fish (twenty each, in duplicate chambers) were exposed to varying concentrations of AFFF.

Upon arrival, the shipping water was analyzed for dissolved oxygen (DO) concentration, potential of hydrogen (pH), and temperature to assure that no extreme changes in the water quality occurred during transport. The test water was also analyzed for DO, pH, and temperature. A deionized water filtration system was used as the source of purified water, which was oxygenated for 48 hours prior to the test.

Five concentrations of the test agents that ranged from 220,000 to 22 parts per million (ppm), were used during the trials. The test agents started at the manufacturer's suggested use and were successively diluted by factors of ten. Each concentration was one order of magnitude lower than the previous, starting with the recommended use concentration. Five concentrations (30,000 to 3 ppm) of Ansul AFFF were run simultaneously as a control and reference toxicant with each trial. Two chambers of fish with no agent added were used as a blank control. Duplicate samples at each concentration contained 1 liter of water and 20 fish. A total of 40 fish

were exposed at each concentration. Measurements, including pH, DO concentrations, and temperature were taken. The fish were not fed 24 hours prior to or during the experiment.

The median lethal concentration (LC_{50}) was calculated using the Tidepool Scientific ToxCalc™ Bioassay Calculator software. The data was calculated using the Trimmed Spearman-Karber Method and the results were shown in ppm.

AIR FORCE RESEARCH LABORATORY FIRE TESTS.

The AFRL fire test of FEM-12 SC was evaluated due to its performance during the FAA fire test and the results of its aquatic-toxicity test. The fire-extinguishing capabilities of FEM-12 SC were conducted in accordance with ANSI/UL 711 [1]. The results of these tests were compared with sodium chloride and used as the baseline.

The fire tests in this portion of the evaluation were conducted in an indoor fire-testing facility located at Tyndall Air Force Base, Panama City, Florida, by the staff of AFRL. The indoor facility eliminated the variables, such as wind, temperature, and humidity fluctuations, that were encountered during the FAA fire tests at the FAA William J. Hughes Technical Center's outdoor fire facility. Three fires were conducted for each agent to determine the fire suppression and extinguishment characteristics. These tests were conducted following the procedures and requirements set forth by ANSI/UL 711 [1]. This test simulated fires occurring in both horizontal and vertical surfaces of casting that would typically result in a pool of burning molten metal. Sodium chloride and FEM-12 SC were evaluated for extinguishment time, quantity of agent used, weight of unburned magnesium, scatter of burning material, and the depth of the agent used when applicable.

The materials used during the test consisted of 25 lb of magnesium castings and 1 lb of magnesium turnings. The magnesium castings and turnings were placed on a 3' by 3' by 1/4″ steel plate to prevent spalling of the concrete surface. Ansul 30-lb Class D extinguishers were used to discharge the sodium chloride dry-powder extinguishing agent. The FEM-12 SC agent manufacturer provided TLI Group Ltd. 2-gallon, high-pressure extinguishers and nozzles to deliver the liquid FEM-12 SC.

Twenty-five pounds of magnesium castings were weighed and placed on a steel plate prior to testing. One pound of magnesium turnings were placed on the magnesium casting to function as an accelerant for igniting the fire. A propane torch was then used to ignite the accelerant and, subsequently, the magnesium. The magnesium was allowed to burn until a steady flame and a molten pool of magnesium had been formed consisting of the bulk of the castings. Extinguishing agent was applied to the fire using techniques suggested by the manufacturer and the methods used during the FAA's fire test. Figure 2 shows fire technicians using a propane torch to ignite the magnesium test material.

Figure 2. Fire Technicians Using Propane Torch to Ignite Magnesium

DATA COLLECTION.

The following data collection methods were used during the Class D fire tests completed by the FAA and AFRL. The magnesium turnings, plates, and castings were weighed using a digital scale prior to and after each test. Extinguishment times referenced in the results are total flow extinguishment times. Total flow extinguishment time is the actual time of extinguishing agent being discharged during each test fire until the fire was completely extinguished, excluding the time for repositioning and changing extinguishers. Total flow extinguishment time is used for eliminating outside factors in order to evaluate the extinguishing agent's performance. Motion video and still photography were used to document and record all tests, and the time was verified using the video. For aquatic-toxicity tests, the LC_{50} was calculated using the Tidepool Scientific ToxCalc™ Bioassay Calculator software. The data were calculated using the Trimmed Spearman-Karber Method, and the results were shown in ppm.

RESULTS

FEDERAL AVIATION ADMINISTRATION FIRE TEST RESULTS.

The FAA fire test consisted of evaluating different FEM-12 formulations for the optimum chemical formulation used for extinguishing magnesium fires. Extinguishing methods were also evaluated during the FAA fire test. The FAA evaluated the different firefighting characteristics of the formulations, such as reaction to the fire, extinguishment time, and any other notable observations. Different extinguishers, pressures, nozzles, and spray patterns were also evaluated using the FEM-12 formulations. FEM-12 SC was chosen for its overall performance characteristics for extinguishing the magnesium fires as determined by the FAA ARFF Research Program. The FAA also evaluated sodium chloride, the standard extinguishing agent for Class D fires. The FAA ARFF Research Program personnel were confident in the findings and results of

the FEM-12 SC testing to move forward with a more extensive testing procedure to be completed by AFRL.

During FAA fire test, personnel used TLI Group Ltd. 2-gallon, high-pressure extinguishers with FEM-12 SC pressurized at 240 pounds per square inch (psi). A 240-psi extinguisher enhanced the distance needed to apply the agent (standoff distance) on the test fires compared to a lower-pressure extinguisher. Fire fighters were capable of discharging agent on the test fires from approximately 9 feet away. A straight-stream nozzle was also used instead of a variable-stream nozzle, which could alter the discharge of the agent in a spray pattern. A straight-stream application allowed the liquid agent to penetrate and break apart the pile of burning magnesium and make contact with the hot spots, which allowed for a more rapid extinguishment compared to a spray pattern application. The TLI Group Ltd. 2-gallon extinguishers in this configuration had approximately 30-35 seconds of agent discharge time at approximately 4 gallons per minute (gpm).

During the test, the initial contact of the liquid FEM-12 SC caused a violent flare-up and hot sparks to be propelled into the air. This was a result of the liquid agent reacting with the burning lightweight magnesium turnings and molten liquid magnesium. Figure 3 shows the consistent violent flare-ups and hot sparks seen during the test. The flare-ups of the fire continued until the fire was extinguished and the burning magnesium had sufficiently cooled. FEM-12 SC rapidly cooled the burning magnesium compared to using sodium chloride, and the magnesium plate remnants were unexpectedly cool enough to be picked up with bare hands immediately after extinguishment. A drawback to using a high-pressure extinguisher was the increase of hot sparks and magnesium ash remnants being scattered in a larger spread away from the fire surface compared to the low-pressure extinguishers.

Figure 3. Flare-Up and Hot Sparks

Ansul 30-lb Class D fire extinguishers charged by nitrogen gas were used to test the sodium chloride. The Ansul extinguishers discharge at approximately 1 lb of sodium chloride per

second for 30 seconds of total discharge time. Approximately 4 feet of standoff distance was needed to apply the agent on the test surface.

Sodium chloride was unable to extinguish the test fire and was canceled after 10 minutes. Initial contact of the sodium chloride on the magnesium fire did not cause a flare-up compared to FEM-12 SC. Some smoke and dry-powder dust was stirred in the air by the discharge pressure of the extinguisher, as shown in figure 4. Two extinguishers, a total of 58 lb of sodium chloride, were discharged during the test. The sodium chloride completely coated the magnesium fire and smothered the flames. However, small amounts of smoke continued to emerge from the pile. Approximately 2 minutes and 15 seconds after the start of extinguishment, the sodium chloride showed signs of turning black due to burning from underneath the sodium chloride pile, as shown in figure 5. Four minutes after the start of extinguishment, the top of the sodium chloride pile was agitated using a pole to break apart the surface. Once the sodium chloride pile was disturbed, flames appeared from the burning magnesium underneath the sodium chloride. The test was canceled after 10 minutes, and the remaining plates were weighed. It was determined that the sodium chloride smothered the immediate flame and fire, but showed no ability to cool and completely extinguish the metal fire.

Figure 4. Application of Sodium Chloride Dry Powder

Figure 5. Fire Continuing to Burn Underneath the Dry Sodium Chloride Powder

AQUATIC-TOXICITY TEST RESULTS.

The aquatic toxicity of FEM-12 SC was compared to Ansul AFFF. AFFF is the agent used as a baseline for evaluating the toxicity of other classes of liquid firefighting agents. Sodium chloride could not be evaluated for aquatic toxicity, since the agent is a powder and cannot be dissolved in water. The results from the toxicity tests are shown in table 1. The higher numbers indicate less toxicity.

Table 1. Aquatic-Toxicity Test Results

Agent	LC_{50} (ppm)
Ansul AFFF	949
FEM-12 SC	675

The LC_{50} for FEM-12 SC was 675 ppm, and for Ansul AFFF, it was 949 ppm. The LC_{50} of AFFF can range from 700 to 1000 ppm. Although the numerical value for FEM-12 SC was 274 ppm higher in toxicity than AFFF for this trial, the agent was within the accuracy of the range-finding test for Mil-Spec Type III Foam (>500 ppm).

AIR FORCE RESEARCH LABORATORY FIRE TEST RESULTS.

The AFRL fire test for Class D fire suppression and extinguishment characteristics of FEM-12 SC was compared to the baseline agent, sodium chloride dry powder. The test results are shown in table 2.

Table 2. Air Force Research Laboratory Fire Test Results

Test	Agent	Magnesium		Agent Used	Preburn (Min:Sec)	Extinguishment Time (Min:Sec)	Comments
		Preburn Weight (lb)	Postburn Weight (lb)				
1	Sodium Chloride	25.1	21.8	*60 lb	13:50	1:20	Practice
2	Sodium Chloride	25	23.6	90 lb	12:12	1:44	Extinguished
3	Sodium Chloride	25	23.8	90 lb	14:23	1:40	Extinguished
1	FEM-12 SC	25	21.6	6 gal	19:08	3:15	Extinguished
2	FEM-12 SC	24.9	19.3	6 gal	15:00	3:14	Extinguished
3	FEM-12 SC	24.7	22.3	6 gal	Not Available	Not Available	Extinguished

* Only two extinguishers were used; sand had to be applied to extinguish the remaining fire.

Three Ansul Class D fire extinguishers, containing 30 lb of sodium chloride each, were used to extinguish the fire during each test. The sodium chloride agent formed a hard crust over the burning magnesium that smothered the fire, as shown in figure 6. The depth of the sodium chloride on the steel plate after each test was approximately 0.5-inch deep. As long as the crust remained undisturbed, the magnesium would not reignite into a flame. The magnesium was slow to cool and remained extremely hot for 90 to 120 minutes after extinguishment. These test results were consistent for the second and third tests using sodium chloride.

Figure 6. Sodium Chloride-Formed Hard Crust

FEM-12 SC extinguished the magnesium fire tests using three fire extinguishers, each containing 2 gallons of premixed agent. Applying the water-based agent caused the magnesium to flare-up and scatter magnesium ash several feet from the center of the fire, as shown in figure 7. This was consistent for all three tests. FEM-12 SC took longer to extinguish the fires compared to sodium chloride, but provided better cooling so the magnesium would not reignite after extinguishment. The magnesium was cool to the touch within 5 to 10 minutes of extinguishment and did not show signs of reignition, even when disturbed. This behavior was observed for all three tests regardless of the application method. The depth of agent on the steel plate was undeterminable. The preburn and extinguishment times are not available for the third FEM-12 SC test due to a malfunction with the video camera that prevented reviewing the fire and determining the times.

Figure 7. Magnesium Fire Flare-Up From Application of FEM-12 SC

SUMMARY

FEM-12 SC was chosen for its overall performance characteristics for extinguishing magnesium fires, as determined by the FAA ARFF Research Program during its combustible metal protocol fire tests. The best extinguishing method evaluated using FEM-12 SC was with 240 psi, high-pressure extinguishers, flowing 4 gpm in a straight-stream configuration. The high-pressure discharge of the extinguishers enabled the fire fighters to stand approximately 9 feet away while applying the agent on the fire. The FEM-12 SC agent caused violent flare-ups and propelled hot sparks into the air, which were consistent with any reaction to liquid on a Class D fire. After the complete extinguishment of the magnesium fire, the magnesium remnants were substantially cooled enough to be picked up with a bare hand.

FEM-12 SC was tested for aquatic toxicity and compared to Ansul AFFF as the baseline. FEM-12 SC toxicity results were 675 ppm. The aquatic toxicity of the FEM-12 SC was comparable to the toxicity results of Ansul AFFF of 949 ppm, which can range from 700 to 1000 ppm.

FEM-12 SC was higher in toxicity by 274 ppm than Ansul AFFF during its trial; however, it was within the Mil-Spec Type III Foam toxicity range of greater than 500 ppm.

FEM-12 SC was tested and evaluated in extinguishing performance and compared to sodium chloride dry powder in accordance with the parameters set forth in ANSI UL 711 [1]. The results show that FEM-12 SC took approximately twice as long as sodium chloride to extinguish the magnesium fire tests. However, FEM-12 SC provided better cooling than sodium chloride, whereby the magnesium could be handled within minutes of extinguishment compared to hours with sodium chloride. FEM-12 SC created a potential fire hazard during the extinguishment process due to fire flare-ups and hot sparks, but once the fire was extinguished, the hazard was eliminated. Sodium chloride extinguished the fire flames immediately, but created a potential long-term fire hazard due to its inability to cool the metal. A fire could redevelop if the sodium chloride-covered metal was disturbed.

REFERENCES

1. ANSI/UL 711 Rating and Testing of Fire Extinguishers, Sections 10.2 and 10.2.28.

2. ASTM Standard Guide for Conducting Acute Toxicity Tests With Fishes, Macroinvertebrates and Amphibians, E 729-96, reapproved 2002.