SANDIA REPORT

SAND2005-5793
Unlimited Release
Printed September 2005

Equipment Compatibility and Logistics Assessment for Containment Foam Deployment

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SNL-200505

FY05 Operational Shortfall 35 b,c

Final Report

September 6, 2005

Joseph Jones
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Abstract

The deployment of the Joint Technical Operations Team (JTOT) is evolving toward a lean and mobile response team. As a result, opportunities to support more rapid mobilization are being investigated. This study investigates three specific opportunities including: 1) the potential of using standard firefighting equipment to support deployment of the aqueous foam concentrate (AFC-380); 2) determining the feasibility and needs for regional staging of equipment to reduce the inventory currently mobilized during a JTOT response; and 3) determining the feasibility and needs for development of the next generation AFC-380 to reduce the volume of foam concentrate required for a response. This study supports the need to ensure that requirements for alternative deployment schemes are understood and in place to support improved response activities.

ACRONYMS

AFC	Aqueous Foam Concentrate
AFFF	Aqueous Film Forming Foam
AR	Alcohol Resistant
CAFS	Compressed air foam system
ConOps	Concept of Operations
FFFP	Film forming fluoroprotein
FP	Fluoroprotein foam
gpm	Gallons per minute
HE	High Explosive
JTOT	Joint Technical Operations Team
NEST	Nuclear Emergency Search Team
NNSA	National Nuclear Security Administration
NST	National Standard Thread
P	Protein foam
RDD	Radiological dispersal device
SNL	Sandia National Laboratories
USA	United States of America

Executive Summary

This project has investigated three opportunities to support a faster and more mobile JTOT response to an RDD threat including: 1) the potential of using standard firefighting equipment to support deployment of the aqueous foam concentrate (AFC-380); 2) determining the feasibility and needs for regional staging of equipment to reduce the inventory currently mobilized during a JTOT response; and 3) determining the feasibility and needs for development of the next generation AFC-380 to reduce the volume of foam concentrate required for a response. The results of this study clearly demonstrate that the transportation logistics and transportation footprint can be significantly reduced through coordination with local fire departments on equipment use, strategic storage of select JTOT equipment, and development of the next generation blast suppression foam (Figure ES-1.).

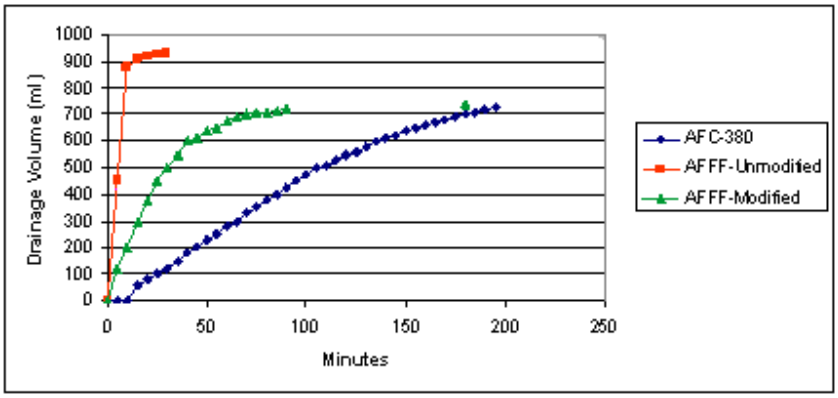

Figure ES-1. Initial additives for the Modified AFFF indicate that properties of the AFC- 380 Foam can be achieved to significantly reduce the foam transportation requirements.

The use of local fire department equipment to support response operations reduces the need to transport select equipment with each JTOT response, and the staging of select equipment at strategic locations, such as airports, is feasible based on facility interviews. The following results were generated from the fire department survey:

- 100% of fire departments surveyed have the capability and equipment to support aqueous foam;
- 97% of fire departments surveyed use fire fighting foam;
- 97% of fire departments surveyed use NST fittings or have adapters for their local fittings; and
- 95% of fire departments surveyed use in-line eductors (similar to those used with AFC-380).

Storage and operational considerations should be further investigated in a prototype staging demonstration. Finally, the largest transportation requirement in the current JTOT response to an RDD is the RDD suppression foam and support equipment. Proof-of-concept laboratory analysis has demonstrated the feasibility of developing an additive to AFFF having properties similar to the AFC-380 which would reduce the transportation footprint by up to 90%.

The current emergency response to an RDD, for which blast suppression and dispersion mitigation foam (AFC-380) is needed, requires transport of almost fifty, 5-gallon drums of foam concentrate along with support equipment. AFC-380 was specifically designed at Sandia National Laboratories to minimize drainage by holding water in a bubble matrix for extended periods of time (i.e. increased stability). This delay allows emergency response teams time to hold the HE device in a mitigating blanket of foam while render safe procedures are carried out and emergency management approval for forced detonation obtained. In order to support a faster, more mobile response team and reduce the transportation logistics requirements, it is possible to significantly reduce the volume (85 ft^3 weighing 2000 lb) of AFC-380 through the development of an additive to existing fire fighting foams. To support the faster, more mobile response of the JTOT, it is recommended that additional work in these areas be conducted as discussed in the Path Forward section of this report.

Table of Contents

ACRONYMS 3
Executive Summary 5
1.0 Introduction 9
1.1 Objective 9
1.2 Scope 10
2.0 Fire Department Logistics 10
3.0 Airport Logistics 12
4.0 Blast Suppression Foam Improvements 12
4.1 Foam Development 12
4.2 Foam Concentrates 13
4.3 Types of Foam Agents 13
4.3.1 Class A Foams 14
4.3.2 Class B Foams 14
5.0 Foam Production Systems 15
5.1 Proportioning Equipment 16
6.0 Laboratory Analysis 17
7.0 Path Forward 188
8.0 Conclusion 20
9.0 References 21

1.0 Introduction

The deployment of the Joint Technical Operations Team (JTOT) is evolving toward a lean and mobile response team. As a result, opportunities to support a more rapid mobilization direction are being investigated. This study investigates three specific opportunities including: 1) the potential of using standard firefighting equipment to support deployment of the aqueous foam concentrate (AFC-380); 2) determining the feasibility and needs for regional staging of equipment to reduce the inventory currently mobilized during a JTOT response; and 3) determining the feasibility and needs for development of the next generation AFC-380 to reduce the volume of foam concentrate required for a response. This study supports the need to ensure that requirements for alternative deployment schemes be understood and in place to support improved response activities.

AFC-380 has been developed by Sandia National Laboratories (SNL) to mitigate potential consequences resulting from the high explosive dispersal of an improvised nuclear device (IND) or a radiological dispersal device (RDD) event. The SNL developed aqueous foam is a particle capture and blast suppression foam that is mechanically produced by passing a large volume of air through a screen that is continuously wetted by an aqueous solution of a synthetic foam concentrate (AFC-380). The foam concentrates contain surfactants that are chemically similar to those used in hair shampoo and liquid soaps. Suppression is accomplished by forming an expanded foam which is maintained in position by a barrier element such as a tent or fillable bag (Figure 1).

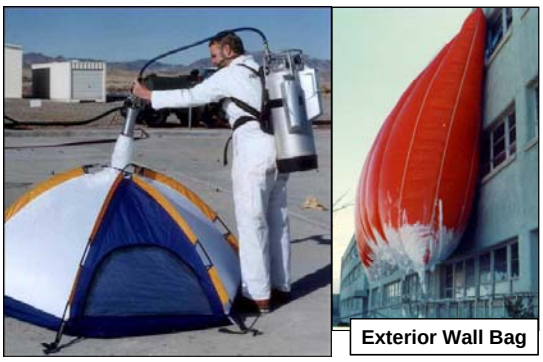

Figure 1. Small tent structure and wall bag for deployment of AFC-380

Deployment of the AFC-380 requires an equipment set including pumps, eductors, foam generators, foam concentrate, hoses, etc., to support a JTOT RDD response. The equipment requires a large transportation logistics footprint, and the operational logistics of loading and unloading the pallet deployed equipment to support mobilization requires time and resources to support mobilization. This study assesses various means to improve the transportation and mobilization logistics currently implemented to support an RDD response.

1.1 Objective

The objective of this project is to perform a system assessment to identify opportunities to improve JTOT response to an RDD threat. This includes determining whether there are interoperability issues with deployed foam equipment and fire department equipment, which could impact the ability to potentially leverage the use of fire department

equipment in a JTOT response. Pre-staging of select equipment was investigated and research was conducted to determine similarities between the Sandia foam and Aqueous Film Forming Foam (AFFF) to determine if there is a potential reduce the volume of foam concentrate currently transported by enhancing the characteristics of foam concentrates already being used for fire fighting to make them suitable for JTOT particle capture and blast suppression purposes (Figure 2).

1.2 Scope

In order to minimize the equipment deployed with JTOT, use of fire department equipment already present near a deployed response venue should be considered. This project investigated standard types of equipment used by fire departments at major metropolitan areas around the country and compared their foam-generating equipment to the type of equipment needed to deploy the JTOT mitigation foam. The project assessed the logistics of storing the foaming equipment at airports in metropolitan areas and maintaining it in a readiness state. The project also includes assessment of potential improvements to reduce the volume of AFC-380 currently deployed by JTOT. Detailed scope elements are identified below:

Equipment Interoperability and Logistics

- Identify the deployment characteristics of the Sandia foam;
- Research fire departments in various cities around the USA to establish equipment characteristics; and
- Research airport storage logistics and coordination of these activities with emergency response.

Foam Improvements

- Compare AFC-380 to AFFF to assess similarity of properties;
- Perform proof-of-concept laboratory testing of new foam additives; and
- Provide recommendations on the feasibility of improvements and path forward for the foam technology.

2.0 Fire Department Logistics

Currently, there are 442 certified bomb squads in the United States, and more than 10% of those squads are part of a fire department. More that 200 firefighters have been certified by the Federal Bureau of Investigations Hazardous Devices School at Redstone Arsenal in Huntsville, Alabama. Firefighters are trained in dealing with explosive devices and employing various types of equipment, and play an important and useful role in bomb-related activities.

Fire Departments

An assessment of fire departments in the largest cities in the Untied States was conducted to determine the types of foam generating equipment that is typically used and potentially available throughout the country. A list of the top 50 highest population cities was developed and the fire departments for all 50 cities were contacted. Sandia developed a questionnaire and completed the questionnaires for 37 of the 50 cities.

The following is a summary of the results found in the survey and a detailed table of the results may be found in Appendix A.

- 100% of fire departments surveyed have the capability and equipment to support aqueous foam deployment;
- 97% of fire departments surveyed use fire fighting foam;
- 95% of fire departments surveyed use Class B foams;
- 89% of fire departments surveyed use AFFF;
- 43% of fire departments surveyed use Class A foams;
- 97% of fire departments surveyed use NST fittings or have adapters for their local fittings; and
- 95% of fire departments surveyed use in-line eductors (such as are used with AFC-380).

As indicated above, all fire departments surveyed have the capability and equipment to support aqueous foam deployment. Typical fire truck foam generating connections using an external around-the-pump proportioner are shown in Figure 3.

Figure 3. Typical fire truck foam generating connections.

The approach to this task included development of a questionnaire that was used to conduct either telephone surveys or personal interviews. The questionnaire prompted the interviewee to ask follow on questions based on the results of the initial response. Sandia tested the questionnaire locally with the Kirtland Fire Department and the Albuquerque Fire Department prior to initiating the full scale survey. A list of fire departments and contacts for each department was then developed. Personal interviews were conducted at a total of seven fire departments as part of this survey.

For some cities, not all of the local fire houses have the same capabilities. In Albuquerque, foam capabilities are present for the fire department supporting airport runway operations while other fire houses do not use foam. NST fittings are common throughout the nation with some exceptions including Chicago, Cleveland, and Oklahoma City where local fittings are used. In most instances where local fittings are used, the departments are equipped with adapters to NST fittings; however, in Chicago, adapters are not available.

In summary, fire departments nationwide use fire fighting foam and are experienced in the use of foam generating equipment. There are no common interoperability issues with fire department equipment with the exception of Chicago where NST adaptors are not used.

3.0 Airport Logistics

Equipment Storage Logistics

Currently, when the JTOT responds to an RDD threat, the team must mobilize and transport a substantial equipment load including a pump, fittings, containment structures, foam concentrate, etc. The foam concentrate is one of the bulkiest items required in the RDD response in terms of transportation footprint (Figure 4). Any ability to reduce the transportation footprint provides for a potentially faster and leaner JTOT response. Sandia investigated the possibility of staging some of the larger equipment items at airports around the country to support reduction of the transportation footprint.

Figure 4. Foam Concentrate and Equipment for Transport

Interviews were conducted with six airports to determine if they were receptive to staging equipment for emergency response needs. The interviews included reviewing the airports' capabilities to stage the equipment, security concerns, and access ability. Capabilities varied among the airports with larger airports having room to store equipment in a secure manner. Access to the equipment, including off hours access and potential loading needs, such as use of forklifts, were reviewed.

In general, the larger airports were receptive to staging equipment and would typically stage it with the other onsite fire department equipment. Smaller airports, such as Albuquerque and Ronald Reagan, were not receptive to staging equipment indicating that they did not have adequate space to support these activities.

4.0 Blast Suppression Foam Improvements

The systems approach for review of foam alternatives included a review of existing foam technologies, foam production systems, and proof of concept laboratory analysis of foam additives.

4.1 Foam Development

The use of foam for fire extinguishment dates back to an English patent in 1877 for a method to produce chemical foam (Liebson, 1991). The British Navy experimented with agents foamed by means of compressed air foam systems (CAFS) in the 1940s for flammable liquid fires. In support of the Nuclear Emergency Search Team (NEST),

Sandia has considerable experience with the use of aqueous foam to mitigate high explosive detonations. Depending on the specific application, aqueous foam may be useful to limit: (1) the dispersal of respirable aerosols; (2) the strength of the shock propagated away from the explosion in unconfined detonations; (3) the quasistatic overpressure that occurs in confined detonations; and (4) cloud buoyancy following detonation.

4.2 Foam Concentrates

An assessment of AFC-380 and AFFF has been completed to determine the possibility of developing an additive for AFFF to enhance its particle capture and blast suppression characteristics. This task evaluated and compared the properties of AFFF with those of the Sandia containment foam (AFC-380). AFC-380 is chemically similar to AFFF as indicated in Table 1, but has been engineered to hold water in the bubble matrix for extended periods of time (several hours), whereas AFFF is designed to blanket an area with water that quickly drains from the foam. It would benefit the entire emergency response community if a firefighting product commonly found in major metropolitan areas could be enhanced with an additive in the field for use in RDD mitigation, thus eliminating the need to transport heavy aqueous RDD mitigating foam concentrate. Additional benefits would be achieved by using the same foam generation equipment, training, and maintenance procedures.

AFC-380	**AFFF**
Water	Water
Anionic Surfactant	Anionic Surfactant
Dodecanol	
Isobutanol	
Diethylene glycol butyl ether	Diethylene glycol butyl ether
Aqueous polymer	Aqueous polymer
	Fluorosurfactant

Table 1. Chemical similarities between AFC-380 and AFFF

4.3 Types of Foam Agents

A foam is a stable mass of small, air-filled bubbles with a lower density than oil, gasoline or water. In physical appearance, the fire-suppression foams resemble shaving cream. The foam is composed of three ingredients: water, foam concentrate, and air. The water is mixed with the concentrate to form a foam solution. This solution is then mixed with air to produce the foam. Fire retardant foams are generated by mechanical agitation of water with a specified concentration of foaming agent. Foam barriers retard heat transfer to a material by foam evaporation (Gopalnaryanan et al., 1999)

The following list of mechanical foam concentrates are the most common types currently used by firefighters today.

- Protein,
- Fluoroprotein,
- Film Forming Fluoroprotein (FFFP),
- Aqueous Film Forming Foam (AFFF),
- Synthetic-Medium/High Expansion Type (detergent),
- Alcohol Resistant (AR-AFFF),
- Wetting agent,
- Class A Foam Concentrate.

There are many different types of foams on the market as indicated above. These fire fighting foams can be put into two very broad categories, Class A and Class B. These categories correspond to the types of fuels for which the foams are designed to be used on. Class A foam is not designed to put out Class B fires because Class A foam does not have the ability to trap the explosive vapors. Class B fuels can be subdivided into two or more subclasses: hydrocarbons like gasoline, kerosene, and fuel oil that do not mix with water; and polar solvents like alcohols, ketones, and ethers which will mix with water.

4.3.1 Class A Foams

A Class A foam is a biodegradable mixture of foaming and wetting agents. They are usually formulated from a combination of specialty hydrocarbon surfactants, stabilizers, inhibitors, and solvents (ANSUL, 1999). Class A foam reduces the surface tension of water for improved wetting and penetration into Class A fuels. They also give water a foaming ability that allows water to remain and cling to vertical and horizontal surfaces. Class A foam concentrates are proportioned at rates between 0.1 percent and 1.0 percent. (By comparison, Class B foam concentrates are proportioned at 3 to 6 percent.) The survey results indicate that 43% of fire departments use Class A foams.

4.3.2 Class B Foams

Class B foams can be divided into two general categories: synthetic or protein based. The synthetic based foams include high expansion foam, aqueous film forming foam (AFFF), and Alcohol Resistant aqueous film forming foam (AR-AFFF). Protein based foams use natural protein foamers instead of synthetic soap. Protein type foams include regular protein foam (P), Fluoroprotein foam (FP), alcohol resistant fluoroprotein foam(AR-FP), film forming fluoroprotein (FFFP), and alcohol resistant film forming fluoroprotein (FFFP). In general, protein based foams spread slightly slower than synthetic, but produce a more heat resistant, longer lasting foam blanket. The survey results indicate that 95% of fire departments use Class B foams.

- **Aqueous Film Form Foam (AFFF)**

  Aqueous film forming foam (AFFF) is a highly efficient type of fire suppressant agent. All AFFF fire-fighting film agents, (standard and alcohol resistant) along with the fluoroprotein and film forming fluoroprotein (FFFP) foam concentrates contain fluorinated surfactants. These fluorinated surfactants provide AFFF with a low surface tension.

- **Protein Foams**

Protein foams are recommended for extinguishing of Class B fires involving hydrocarbons. This type of concentrate is based on hydrolyzed protein, stabilizers, and preservatives. Typically, these agents are used to protect flammable and combustible liquids where they are stored, transported and processed. They produce highly stabilized mechanical foam with good expansion properties and good reignition (burnback) resistance characteristics. Protein based foam concentrates are not totally synthetic and have a naturally occurring product in their formulations. If these products are stored within the manufactures' guidelines including temperature limits and in their original shipping container, a shelf life of 7-10 years or more can be expected.

- **Fluoroprotein Foam Concentrates (FFFP)**

FFFP is a derivative of AFFF and Fluoroprotein. These concentrates are based on fluoroprotein formulations that have an increased quantity of added fluorochemical surfactants added. In applications involving hydrocarbon bulk storage and handling- such as refineries and petrochemical operations- these agents offer several advantages over protein foams. They provide better control and extinguishing ability, greater fluidity and superior resistance to foam contamination. Fluoroprotein foams are useful for hydrocarbon vapor suppression and extinguishing fuel-in-depth fires.

- **High Expansion Foams**

High Expansion Foams are based on combinations of hydrocarbon surfactants and solvents and are used in both stationary and portable foam generators for applying foam to large areas in a total flooding or 3-dimensional applications such as warehouses, ship cargo holds and mine shafts. They are especially useful on fuels such as liquefied natural gas (cryogenic fuels) for vapor dispersion and control. In certain concentrations, high expansion foams are effective extinguishing agents for flammable liquid fires of most types in confined areas.

5.0 Foam Production Systems

Foam productions systems are similar in that they all include a liquid phase foam precursor, an expansion gas, and equipment designed to combine, mix, and discharge the foam product (Figure 5). In general, there are two types of foams, compressed gas foams and air aspirated foams. Foams produced from similar systems are not necessarily similar. The most obvious difference among gas foams is persistence, or lifetime, which is generally defined as drain time. Drain time is the time required for the foam to decompose into the original liquid and gas phases. Chemical composition affects the drain time.

Figure 5. Typical pumping equipment and connectors.

Commercial foam systems are optimized with respect to each of these criteria: liquid composition, expansion gas, persistence, delivery equipment, and foam performance.

5.1 Proportioning Equipment

Proportioning is the introduction of foam concentrate into a stream of water to produce a foam solution and is generally accomplished through the use of eductors, concentrate pumps, or nozzles.

Eductors- Eductors are simple devices with few or no moving parts, and do not require a power supply. Foam eductors use the Venturi effect to draw foam concentrate out of a container and into a hose stream. They are limited by specific water flow and water pressure requirements and usually must be within 150 feet of the nozzle to operate effectively. Eductors introduce a significant amount of friction loss into the hose line. Eductors are the least expensive introduction system, other than batch mixing the foam solution in the water tank. If the eductor is not pre-piped, firefighters may connect the eductor into the hose line and into the concentrate container when they arrive on the fire scene.

Concentrate Pumps- Mechanical or electric pumps can proportion foam concentrate into a water stream. Several manufactures produce packaged proportioning systems that mix water and foam concentrate at a rate set by the pump operator. This is accomplished through mechanical means (such as a venturi) or by electronic controls (flow meter), depending upon the type of unit. Concentrate pumps require an additional power supply and are more complex than other proportioning methods, but they allow the pump operator to select the percentage of the concentrate over a wide range (usually between 0.1 and 1 percent for Class A foams) to control the characteristics of the foam produced. These pumps are often more accurate over a wide range of flow rates than other proportioning devices.

Some of these systems can work with the two or more foam concentrate tanks, allowing the pump operator to choose between a Class A foam concentrate and Class B foam concentrate, depending upon the type of fire encountered.

Nozzles- Fire departments use a variety of hand-line nozzles and some high output monitor nozzles up to about 1,250 gpm. Nozzle-aspirated Class A foam can be used with standard firefighting nozzles. Combination nozzles help aerate the foam solution, forming a wet foam with little expansion. Combination nozzles can also be used with compressed air foam systems (CAFS); the combination nozzle will act to strip away the large bubbles formed in the foam, leaving a wet foam stream.

Smooth bore nozzles can be used with nozzle-aspirated Class A foam or CAFS. With CAFS, a large orifice smooth bore nozzle will help straighten and project the foam stream. A larger nozzle size is used because the hose is delivering finished foam, which expands rapidly when it leaves the nozzle. Some wild land fire fighting units apply CAFS with no nozzle on the hose lines. Specialized foam nozzles are available for Class A

foam, and these are often used in the wild land or wild land/urban interface setting, or for exposure protection.

6.0 Laboratory Analysis

Current aqueous foam technology requires the deployment of AFC-380 foam into a containment structure placed over an explosive device. When an explosion occurs, the resulting energy from the blast is dissipated by (1) mechanical break-up of the foam; (2) absorption of heat liberated from the HE; and (3) shock passage through the liquid-air-liquid interfaces. The particle capture and blast mitigation foam is highly stable. Small scale (50 gal) drainage tests show that 25% drainage occurs at 100 min, with larger foam columns having even longer drainage times AFFF is a specialized foam used for fire fighting. This foam has a very low surface tension that allows it to spread over a burning material forming a film that cuts off the oxygen supply to the fire. This foam is not stable and collapses very quickly (25% drainage in 10-15 min). AFFF was evaluated because it is routinely carried by firefighting units as verified in the fire department assessment discussed earlier.

Proof-of-concept laboratory analysis was conducted to determine if ingredients can be added to AFFF to increase its stability allowing it to be used in place of the existing mitigation foam. These additives would be introduced into AFFF in the field only when needed to perform mitigation functions (i.e., the ingredients would not be introduced into AFFF used only for fire suppression). This would eliminate the need for emergency response personnel to carry two types of foam since AFFF could be used for both fire suppression and blast mitigation (upon addition of the extra ingredients).

There are two critical parameters in the mitigation foam – the foam expansion ratio and the foam stability. The foam expansion ratio is defined as the volume of foam produced from a given volume of starting liquid. The foam expansion ratio will vary depending on the device (e.g., foam generator) used to generate the foam. In the field, the mitigation foam is typically deployed at an expansion ratio between 60:1 and 150:1. Foam stability can be determined by measuring the volume of liquid that drains out of the foam over time. For a more stable foam, the liquid drains out of the foam more slowly. As noted above, the blast mitigation foam will remain stable in the field for periods of one hour or longer.

A series of experiments were conducted to determine the feasibility of adding ingredients to AFFF to increase its foam expansion ratio and foam stability. The effectiveness of these added ingredients were determined by comparing the foam expansion ratio and the foam stability to AFC-380. Three ingredients were added – a foam stabilizer, a surfactant, and a polymeric viscosity enhancer. The total weight of the added ingredients was approximately 3% of the total AFFF formulation. Test results are shown in Figures 7 and 8 below.

As the results demonstrate, the addition of the three ingredients dramatically increased both the foam expansion ratio and the foam stability of AFFF. In the laboratory test setup (using a different foam nozzle than what is used in the field) the foam expansion ratio for AFC-380 was 19:1 while for the unmodified AFFF it was 6:1 (Table 2). With the modified AFFF, the foam expansion ratio was over 30:1. Likewise, as seen in Figure 6, the foam drainage rate for AFC-380 was very slow (i.e., it has a high stability) while the foam drainage for the unmodified AFFF was very fast (i.e., it has a low stability). The foam drainage rate for the modified AFFF fell in between that of the other two foams, demonstrating an increase in stability over unmodified AFFF (but not as high as AFC-380). The scope of this project included proof-of-concept; thus, no attempt was made to optimize the concentration of these ingredients or to test alternatives to these ingredients (e.g., other polymers, surfactants, etc.). However, based on these favorable results from this limited testing, we believe that the objective of adding ingredients to AFFF in the field for use as a mitigation foam (thereby resulting in weight and volume savings for JTOT response) appears achievable.

Foam	Expansion Ratio
Unmodified AFFF (fire fighting foam)	6:1
Modified AFFF	30:1
AFC-380 (mitigation foam)	19:1

Table 2: Expansion Ratios of the Unmodified AFFF, Modified AFFF, and AFC-380 Foams

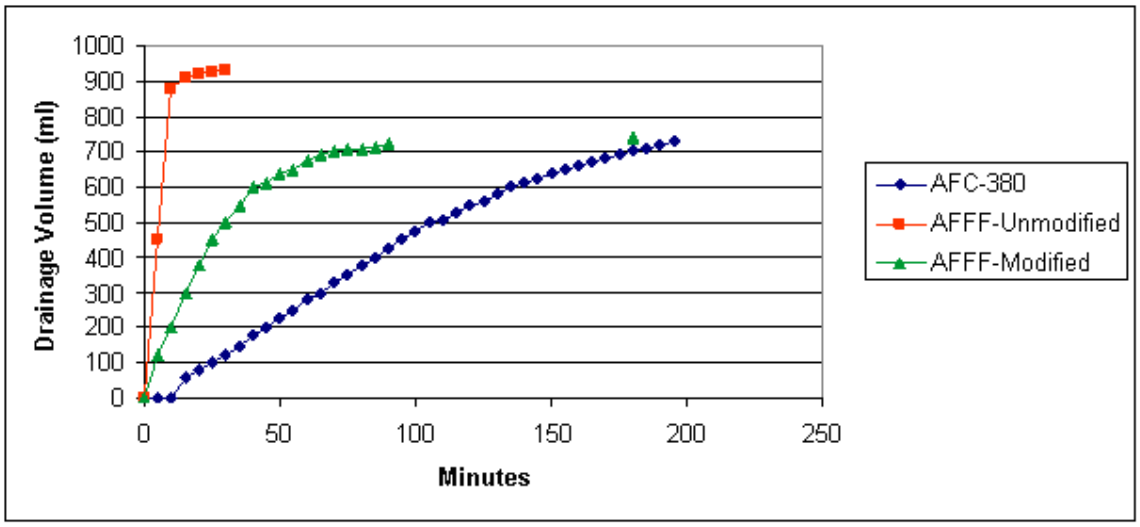

Figure 6: Drainage from Unmodified AFFF, Modified AFFF, and AFC-380 Foams

7.0 Path Forward

The current emergency response to an RDD, for which particle capture and blast suppression mitigation foam (AFC-380) is needed, requires transport of approximately 40 five gallon drums of foam concentrate along with support equipment. In order to support a faster, more mobile response team and reduce the transportation logistics requirements, it is possible to significantly reduce the weight and volume of foam generating equipment and foam concentrate (AFC-380) through the leveraging of fire department equipment and development of an additive to existing fire fighting foams.

Coordinated Equipment Logistics
The overwhelming response from fire departments was that they do use foam, and with few exceptions, use NST fittings. To implement coordinated equipment logistics with fire departments, a process is needed that identifies the necessary actions and activities required to pre-stage containment gear in strategic areas for NA-40 use. The approach to accomplishing this objective will be to build on the preliminary analysis performed in this project which investigated a select few locations and determined that pre-staging is feasible. The ability to minimize weight and bulk by pre-staging equipment at strategic locations fully supports a faster, more mobile response team.

The process should include criteria for selecting strategic storage areas, determining which equipment sets should be pre-staged, identifying potential storage locations, and establishing equipment access requirements. The need to prestage and the potential benefit warrant development of a process that must include a mission assessment, equipment specific assessment, and a reliability assessment.

First, the mission assessment should include a review of equipment deployed for types of events. This review should identify the equipment that the response team is 'required' to possess including those items that if not available, would severely compromise the success of the mission. Such items would likely not be pre-staged except to provide redundancy. Second, equipment that could be pre-staged should be reviewed to determine the most appropriate items for staging. This should include an assessment of the transportation logistics footprints, evaluation of any maintenance or calibration needs, and any shelf life issues. The assessment should also include an analysis of the access capabilities by NA for use when needed. Additional considerations include evaluation of security needs for storage, access control and retrieval needs, such as availability of a forklift, when necessary, to load. Thirdly, the process should be field tested by selecting a site, deploying equipment, and then evaluating the strategic value of pre-staging the equipment to determine whether full scale implementation should be considered.

Foam Development
It is recommended to pursue the development of an additive to fire fighting foam such that the quantity of foam concentrate deployed is reduced by approximately 90% to no more than five, 5 gallon drums of concentrate. The proof-of-concept research and testing identified multiple commercial fire fighting foams in use, including AFFF, Class A and Class B foams. The chemistry of these foams is similar enough that a single additive could be developed that would work with any of the major fire fighting foams. The study also concluded that fire departments overwhelmingly use AFFF in concentrations ranging from 1 to 6%. Furthermore, these fire departments in many cases have foam generating equipment and eductors used in foam deployment.

The approach to accomplishing the path forward work is based on the understanding of the chemistry of fire fighting foams and their use in the US. Firefighting foams are designed to hold water for a short period of time and release it quickly after it is applied. AFC-380 is designed to hold water for much longer time frames. Using a 55 gallon

container with 500:1 expansion ratio foams, even the best fire fighting foams give 50% liquid drainage in thirty minutes. In contrast the 50% drainage time for AFC-380 is three hours or more. Drainage time in larger volumes can be even longer. An additive could dramatically enhance the stability of fire fighting foams allowing for their use in mitigating the effects on an RDD. The goal for the stabilizing additive is 50% drainage times of two hours or more. The patented AFC-380 foam uses a water soluble polymer and a fatty alcohol to improve bubble structure and decrease drainage. Any number of water soluble polymers may be used for this purpose. Due to the potential deployment in seawater, AFC-380 foam uses xanthan gum as the polymer and dodecanol as the fatty alcohol. This combination is the key to success in blast suppression and provides the starting point for research and development of a foam additive. The degree to which currently deployed fire fighting foams vary in composition likely will make no difference to additive performance.

To accomplish this task, Sandia will: 1) determine the key characteristics of the fire fighting foam chemistry; 2) develop a laboratory test plan for assessing additive performance; 3) conduct laboratory tests with various additive 'cocktails' to determine effectiveness; 4) develop the concept of operations (ConOps) procedure to ensure all elements of the response are considered; 5) demonstrate the performance characteristics at the laboratory scale; 6) demonstrate the performance characteristics at a large scale; and 7) prepare a final report that includes the performance characteristics and path forward for production of the additive.

8.0 Conclusion

This project has investigated three opportunities to support a faster and more mobile JTOT response to an RDD threat. The use of local fire department equipment to support response operations reduces the need to transport select equipment with each JTOT response. The staging of select equipment at strategic locations, such as airports, is feasible based on facility interviews. There are storage and operational considerations that should be further investigated in a prototype staging demonstration. Finally, the largest transportation requirement in the current JTOT response to an RDD is the RDD mitigation foam and support equipment. Proof-of-concept laboratory analysis has demonstrated that it is feasible to develop an additive to AFFF having similar properties to the AFC-380 and would reduce the transportation footprint by up to 90%. It is recommended that additional work in these areas be conducted as discussed in the Path Forward section of this report to support the faster, more mobile response of the JTOT.

9.0 References

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Appendix A

CITY	Is Aqueous Foam Used?	Do All Stations Have the Same Foam Capabilites?	Type of Aqueous Foam Used?	All Stations Use Same Product?	Manufacturer Part/Order Number of Foam	Capability/Equipment to Support Aqueous Foam?	Type of foam generation equipment used?	Use of in-line eductors and/or around-the-pump proportioners?	Manufacturer and model of in-line eductors and/or around-the-pump proportioners	Size of hose Department carrys	Type of fittings utilized	Supply 6% concentrate water mix to foam generator?
New York, NY	Yes	No	Class B Fluoro protein	Yes	a. Ansul 3% Fluoroprotein, #73973 b. Ansul, Jet-X High Expansion, #420008	Yes	a. Nozzle, Akron Brass Co., JS-10 b. Nozzle, Spam Co., 120 gallon nozzle	In-line eductors	a. Spam Co 120 gallon & 60 gallon (High Expansion) b. FIMS (6 injectable & 14 portable)	1.75", 2.5", 3", 5"	New York City threads	Yes
Chicago, IL	Yes	No	Class A and Class B AFFF (3/6%)	Yes	3M Products 3/6%	Yes	a. Nozzle/foam pipe, Elkhart Brass Co., #241 (125 & 250 gpm) b. Nozzle, Total Foam Nozzle c. Nozzle, Hydro Foam, #350 d. Nozzle (Fog), Task Force Tip, Cross Fire	Both	a. Elkhart Brass Co. b. Williams Fire Hazard and Control	1.75", 2.5", 4", 5"	Chicago Fittings (No NST)	Yes
Houston, TX	Yes	No	Class B AFFF-AR and AFFF	No	a. Chemguard, AFFF-AR b. Chemguard AFFF	Yes	a. Nozzle, Akron Brass Co., fog nozzle b. Tube, Akron Brass Co., foam tube c. Tube, National Foam, JS-10 d. Tube, National Foam, JS 35	In-line eductors	Akron Brass Co., various	1.75", 2.5", 4", 6"	NST	Yes
San Antonio, TX	Yes	No	Class A and Class B (AFFF)	Yes	a. Chemguard Class A Plus b. Chemguard Class B	Yes	a. Nozzle, Task Force tip, Foam Pak b. Nozzle, Hired Gun c. Nozzle, Ferra Apparatus	Both	a. Elkart Brass Co., #241 b. Task Force Tips, Foam Paks c. Williams Fire and Hazard Control	1.75", 2.5", 5"	NST for all except for 5" (Storz Quick Connect)	Yes
Indianapolis, IN	Yes	Yes	Class B AFFF	Yes	Chemguard, AFFF, #C-333	Yes	a. Nozzle, Elkhart Brass Co., fog nozzle b. Nozzle, Akron Brass Co., fog nozzle	In-line eductors	a. Elkhart Brass Co., various b. Akron Brass Co., various	1.75", 3", 5"	NST, except for 5" (Storz Quick Connect)	Yes
Jacksonville, Fla.	Yes	Yes	Class A and Class B AFFF	Yes	a. 3M Corp., AFFF 3% b. Ansul, AFFF 3/6% c. National, Class A	Yes	a. Nozzle, Akron Brass Co., Fog Nozzle b. Aerator, Akron Brass Co., Aerator nozzle	In-line eductors	a. Akron Brass Co., #3125 b. Angus, Low Pressure	1.75", 2.5", 5"	NST, except for 5" (Storz Quick Connect)	Yes

CITY	Is Aqueous Foam Used?	Do All Stations Have the Same Foam Capabilites?	Type of Aqueous Foam Used?	All Stations Use Same Product?	Manufacturer Part/Order Number of Foam	Capability/Equipment to Support Aqueous Foam?	Type of foam generation equipment used?	Use of in-line eductors and/or around-the-pump proportioners?	Manufacturer and model of in-line eductors and/or around-the-pump proportioners	Size of hose Department carrys	Type of fittings utilized	Supply 6% concentrate water mix to foam generator?
Columbus, Ohio	Yes	No	Class B AFFF & AFF-ATC	No	a. National Foam, 3/6% Alcohol resistant b. Chemguard, Alcohol resistant, C-363 c. National Foam, Aero Water 3%	Yes	Nozzle, Elkhart Brass Co., HF-350	Both	a. Elkhart Brass Co., Cat 241 b. Task Force Tip, Pro-Pak c. Feecon, APH-1.5	1.75", 2", 3", 5"	a. 1.75" & 2" NST b. 3" & 5" Storz Quick Connect	Yes
Austin, Tex.	Yes	No	Class A and Class B AFFF (3.6%)	Yes	a. National Foam, Universal Gold (1-3%) b. National Foam, Universal Plus (3-6%)	Yes	a. Nozzle, Task Force Tip, Extendaguns b. Nozzle, Elkart Brass Co., Chief 4000-14 c. Nozzle, Elkart Brass Co., Chief 4000-24	In-line eductors	a. Foam Pro Foam System b. Husky 10 Foam System c. Husky 30 Foam System	2", 3", 5"	Storz Quick Connect (Do have adapters for NST)	Yes
Memphis, Tenn.	Yes	Yes	Class B AFFF (ATC)	Yes	Ansul #55797	Yes	Nozzle, Elkhart Brass Co., SFL-95	In-line eductors		1", 1.75", 2", 3", 5"	a. 1" - 3" NST b. 5" Storz Quick Connect	Yes
Baltimore, MD	No					Yes		In-line eductors	Akron Brass Co.	1.75", 2.5", 3", 5"	NST	Yes
Milwaukee, Wis.	Yes	No	Class B AFFF (3%) and AFFF (ATC)	Yes	a. Chemguard AFFF 3% b. Chemguard AFFF ATC	Yes	Nozzle, Akron Brass Co., Hydrofoam (500 gpm)	Both	a. Elkhart Brass Co. B. Spam Co. Foam Box	1.75", 2.5", 3"	NST for all	Yes
Fort Worth, Tex.	Yes	Yes	Class A and Class B AFFF (3-6%)	Yes	a. Chemguard AFFF 3-6% b. Chemguard Class A	Yes	a. Nozzle, Elkhart Brass Co., SM-20 b. Nozzle, Elkhart Brass Co., SM-30	In-line eductor for AFFF & Built in system for Class A		1.75", 2", 2.5", 4"	a. 1.75" - 2.5" NST b. 4" Storz Quick Connect	Yes
El Paso, Tex.	Yes	Yes	Class B AFFF (3%)	Yes	a. Chemguard, AFFF 1%, b. Chemguard, AFFF 3% c. Chemguard, Class A Plus d. Chemguard, High Expansion Foam	Yes	a. Nozzle, Williams Fire & Hazard Control, Blue 700 gpm b. Nozzle, Williams Fire & Hazard Control, 1000 gpm c. Nozzle, Williams Fire & Hazard Control, Hydro foam nozzle	Both	a. Williams Fire & Hazard Control, around-the-pump propotioner b. Akron Brass Co., 125 gpm eductors c. Chemguard 95/120 gpm eductors (Model 3000/6000)	1.5", 1.75", 2.5", 3", 5"	NST for all except for 5" (Storz Quick Connect)	Yes
Boston, Mass.	Yes	No	Class A and Class B AFFF (3/6%)	Yes	a. Chemguard 3/6% b. Chemguard Class A	Yes	a. Nozzle, Elkart Brass Co., Combination Nozzle b. Generator, Akron Brass Co., Direct Connect Foam Tube c. Nozzle, Angus, Foam Master	Both	a. Williams Fire & Hazard Control, around-the-pump propotioner b. Akron Brass Co., Model 3060 c. Hercules, CAFS d. Fecon, around-the-pump propotioner	1.75", 2.5", 4"	a. NST - 1.75", 2.5" b. Storz Quick Connect- 4"	Yes

CITY	Is Aqueous Foam Used?	Do All Stations Have the Same Foam Capabilites?	Type of Aqueous Foam Used?	All Stations Use Same Product?	Manufacturer Part/Order Number of Foam	Capability/Equipment to Support Aqueous Foam?	Type of foam generation equipment used?	Use of in-line eductors and/or around-the-pump proportioners?	Manufacturer and model of in-line eductors and/or around-the-pump proportioners	Size of hose Department carrys	Type of fittings utilized	Supply 6% concentrate water mix to foam generator?
Seattle, Wash.	Yes	Yes	Class B AFFF (3/6%)	Yes	a. 3M Corp., AFFF, Like Water, 3/6% b. Ansulite, AFFF, 3%	Yes	a. Nozzle, Task Force Tip, Hand Line b. Tube, McCron, Straight Tube c. Tube, Angus, Foam Pipe	a. In-line eductors b. Pro-Paks	a. Zumischer, Z-4R b. Task Force Tip, Pro-Paks	1.75", 2.5", 3.5", 4"	NST	Yes
Washington, DC	Yes	Yes	Class B AFFF (3%)	Yes	3M Corporation, 3% Concentrate, #98-0211-5617-3	Yes	a. Nozzle, Akron Brass Co., Penetrating Nozzle b. Nozzle, Akron Brass Co., #4811 c. Nozzle, Fecon Corp., Vehicle Mounted, #3233-7013-5	Both	a. Williams Fire & Hazard, around-the-pump propotioner b. Akron Brass Co., #3097, eductor	1.5", 3"	NST	Yes
Denver, Colo.	Yes	No	Class A and Class B AFFF (3-6%)	Yes	a. National Foam, Universal Gold (1-3%) b. National Foam, Universal Plus (3-6%)	Yes	Nozzle, Akron Brass Co., Fog Nozzle	a. In-line eductors b. Built in systems	unknown	1", 1.75", 2.5", 3", 5"	a. NST - 1", 2.5", 3" b. 1.75" Denver Threads c. 5" - Storz Quick Connect	Yes
Nashville-Davidson, Tenn.	Yes	Yes	Class A and Class B AFFF (6%)	Yes	National Foam (Kidd Fire) 6%	Yes	Nozzle, Task Force Tip, Fog Nozzle	Bi-pass eductor	Akron Brass Co., Bi-pass eductor	1.75", 2.5", 4", 5"	a. NST - 1.75", 2.5" b. Storz Quick Connect - 4", 5"	Yes
Oklahoma City, Okla.	Yes	Yes	Class B AFFF (3-6%) and High Expansion Foam	Yes (for AFFF)	AFFF - Chemguard, #C363 High Expansion - US Foam, #FC-SHX	Yes		Both		0.75", 1.75", 2", 2.5", 4"	Storz Quick Connect (4") and Oklahoma Thread	Yes
Las Vegas, Nev.	Yes	Yes	Class A and Class B AFFF (3%)	Yes	a. Chemguard, AFFF 3% b. Chemguard (Class A), CA&P	Yes	a. Nozzle, Task Force Tip, 2.5" MDJ-12A b. Nozzle, Task Force Tip, 1.75" HMD-VPGI	In-line eductors	Foam Pro 2002 Dual Agent	1.75", 2.5", 5"	a. NST - 1.75", 2.5" b. Storz - 5" Quick Connect	Yes
Tucson, Ariz.	Yes	Yes	Class B AFFF (3-6%)	Yes	U.S. Foam, US-FC3	Yes	a. Nozzle, Akron Brass Co., Turbojet b. Foam Tube, Akron Brass Co., Quick Attack (used with above nozzle)	External Eductors	Akron Brass Co., Model 3095 (95 g.p.m.).	1.75"	NST	Yes

CITY	Is Aqueous Foam Used?	Do All Stations Have the Same Foam Capabilities?	Type of Aqueous Foam Used?	All Stations Use Same Product?	Manufacturer Part/Order Number of Foam	Capability/Equipment to Support Aqueous Foam?	Type of foam generation equipment used?	Use of in-line eductors and/or around-the-pump proportioners?	Manufacturer and model of in-line eductors and/or around-the-pump proportioners	Size of hose Department carrys	Type of fittings utilized	Supply 6% concentrate water mix to foam generator?
Albuquerque, N.M.	Yes	Yes	Class A	Yes	Angus Class A Foam	Yes	Nozzle, Elkart Brass Co., Sm-20	Direct Injection System	a. Foam Pro 2000 b. Husky - 10	1.75", 2.5", 5"	1.75", 2.5" - NST 5" - Stortz Quick Connect	Yes
Cleveland, Ohio	Yes	Yes	Class B AFFF (1%)	Yes	National Foam, Model - Universal Plus	Yes	a. Nozzle, Elkhart Brass Co., SM-2000 b. Aeration Tube, Elkhart Brass Co., #246S c. Nozzle, Elkhart Brass Co., HF-500	In-line eductors	Elkart Brass Co., Model #241-125	1.75", 2", 2.5", 4"	1.75" - NH Remaining hoses - Cleveland FD thread	Yes
Fresno, Calif.	Yes	No	Class B AFFF	Yes	3M, FC600F	Yes	Nozzle, Akron Brass Co., #4820	Both	Foam Pro 2000 and In-line eductor: Akron Brass, #3125	0.75", 1",1.5", 1.75", 2.5", 5"	NST	Yes
Sacramento, Calif.	Yes	Yes	Class B AFFF, Class A	No	a. Williams, Class B, Thunderstorm 1x3 b. Fire-Trol, Class A, 103 c. Thermo-Gel, Class A retardant gel	Yes	a. Nozzle, Elkart Brass Co., 241-125 b. Foam Tube, Elkart Brass Co., 246S c. Nozzle, Williams Fire & Hazard Control, Ranger 1.0, 1.5, and Ranger Lightning	Both	a. Eductor, Elkart Brass Co., 241-125 b. Around-the-pump, Williams Fire & Hazard Control, WATP-1500	1", 1.5", 1.75", 2.5", 3", 5"	NH - 1.5", 1.75", 2.5", 3" Storz Quick Connect - 5"	Yes
Kansas City, Mo.	Yes	Yes	Class A and Class B AFFF (3-6%)	Yes	Ansulite, #55797	Yes	Nozzle, Akron Brass, #4820	In-line eductors	In-line eductor, Akron Brass, #3125	1.75", 4"	NST	Yes
Virginia Beach, Va.	Yes	Yes	Class B FFFP (3%)	Yes	Angus Petro Seal, FFFP (3%)	Yes	a. Nozzle, Elkart Brass Co., #SM 20, 5:1 to 15:1 b. Nozzle, Elkart Brass Co., #SM 30, 5:1 to 15:1	In-line eductors	Akron Brass Co., Model 3095 (95 g.p.m.).	5", 1.75", 2.5"	NST	Yes
Mesa, Ariz.	Yes	No	Class B AFFF	Yes	a. Selvex AFFF b. Selvex Class A	Yes	a. Nozzle, Elkart Brass Co. b. Akron Brass Co., Automatic (95 gpm)	Foam Injection	a. Foam Pro b. Husky	1.5", 5"	NST and Storz Quick Connect (5")	Yes
Atlanta (Fulton County), Ga.	Yes	Yes	Class B AFFF	Yes		Yes		In-line eductors		1.75", 3", 5"	NST	Yes
Omaha, Neb.	Yes	Yes	Class B AFFF	Yes	National Foam, Model - Universal Gold 1% 3%	Yes	a. Nozzle, Akron Brass Co., SabreJet, #1523 b. Nozzle, Akron Brass Co., Pistol Grip Quadrfo	Around-the-pump-proportioner	a. Waterous Compressed Air Foam System b. Foam Pro Electronic Direct Injection Proportioner (2001 & 2002)	1.75", 2.5", 5"	a. 1.75" - NST b. 2.5" - Omaha Thread 5" - Storz Quick Connect	Yes
Oakland, Calif.	Yes	Yes	Class A and Class B AFFF			Yes	a. Nozzle, RP-6 b. Generator, Kidde	In-line eductors	Akron Brass Co.	1.75", 2.5", 3", 5"	NST and Snap Fitting (5")	Yes

CITY	Is Aqueous Foam Used?	Do All Stations Have the Same Foam Capabilites?	Type of Aqueous Foam Used?	All Stations Use Same Product?	Manufacturer Part/Order Number of Foam	Capability/Equipment to Support Aqueous Foam?	Type of foam generation equipment used?	Use of in-line eductors and/or around-the-pump proportioners?	Manufacturer and model of in-line eductors and/or around-the-pump proportioners	Size of hose Department carrys	Type of fittings utilized	Supply 6% concentrate water mix to foam generator?
Tulsa, Okla.	Yes	No	Class A and Class B AFFF	No		Yes		In-line eductors		1.75", 2.5", 3", 5"	NST	Yes
Honolulu, Hi.	Yes	Yes	Class B AFFF	Yes	3M Products 3%	Yes	Nozzle, Elkart Brass Co., 1.5" SFL	In-line eductors	a. Elkhart Brass Co., #240 95 GPM b. Akron Brass Co., #240 95 GPM	1", 1.5", 2.5", 4"	a. 1" to 2.5" - NST b. Storz Quick Connect	No
Minneapolis, Minn.	Yes	No	Class A and Class B AFFF	Yes (AFFF)	AFFF - Selvex Class A - Chemguard	Yes	a. Nozzle, Task Force Tip b. Nozzle, Task Force Tip, Dual Force HD-V c. Nozzle, Pro Packs, UM 12-IF	Both	a. Elkart (95 gpm) b.Task Force Tip, #UE-125-NJ-NF	1.75", 2.5", 5"	a. NH/NST b. Storz Quick Connect (for 5" hose)	Yes
Colorado Springs, Colo.	Yes	No	Class A and Class B AFFF, High Expansion	Yes		Yes		In-line eductors		1", 1.75", 3"	NST	Yes
Wichita, Kans.	Yes	No	Class B AFFF (3%)	Yes	a. Pyrocap B136 (1% 3% 6%) b. 3M AFFF 3%	Yes	a. Nozzle, Akron Brass Co., Assault Nozzle b. Akron Brass Co., Foam Tube, #777 (used with above nozzle)	Both	Hypro, Foam Pro Foam	1.75", 3", 5"	NST and Storz Quick Connect (5")	Yes
St. Louis, Mo.	Yes	No	Class B AFFF (3%)	Yes	Chemguard, C-2/VEE	Yes	a. Nozzle, Akron Brass Co., #4820 b. Nozzle, Akron Brass Co., #4824 c. Nozzle, Task Force Tip, M-ER	In-line eductors	a. Elkart Brass Co., #241 b. Akron Brass Co., #2305 c. Elkart Brass Co., Stinger	1.75", 2.5", 4"	NST and Storz Quick Connect (4")	Yes

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