The Resistance by Firefighters to Utilize Compressed Air Foam Systems (CAFS) Fire Streams

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CERTIFICATION STATEMENT

I hereby certify this paper constitutes my own product. Where the language of others is set forth, quotation marks so indicate. Appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

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Abstract

This author examined why firefighters at Clallam County Fire District No 3 (CCFD3) are resistant to using Compressed Air Foam Systems (CAFS) fire streams. CCFD3 had experienced that despite placing four engines with CAFS capability in service, providing CAFS fire stream training, and occasional use of CAFS fire streams, most firefighters are still resistant to its use. The purpose of this research is to identify the concerns that are making firefighters resistant to using CAFS fire streams, and to recommend solutions that give firefighters the confidence in CAFS fire streams for use during fire suppression activities. The descriptive research methodology was utilized. Procedures utilized were literature review, knowledge and skills evaluations, interviews, and surveys. The procedures were intended to produce answers to the following research questions: Are firefighters not using CAFS fire streams because of a resistance to the change process when CAFS was implemented? Are firefighters not using CAFS fire streams because of a deficiency in training and education? Are firefighters not using CAFS fire streams because of a deficiency in apparatus or equipment? Are firefighters not using CAFS fire streams during because flow rate capability is less than that of water only fire streams? The results of the research indicated poor implementation and lack of comprehensive training led to competency problems. Uncorrected these problems developed into a perception of CAFS being problematic and unreliable. Recommendations included discussing results of the research with the shift officers, development of a standardized training plan that addresses fire behavior and foam theory in addition to skill requirements, modification of CCFD3 procedure to allow CAFS fire stream during interior fire attack when appropriate, and a CAFS program review in two years.

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Since the beginning of recorded time, man has used fire as a tool. In order to prevent fire from causing unwanted damage and destruction man has controlled or extinguished fire by removing one of the four required elements; fuel, heat, oxygen or a self-sustained chemical chain reaction (International Fire Service Training Association [IFSTA], 2009). Historically, fires inside of structures have been controlled and extinguished by applying water to the base of the fire. Water has been the most common extinguishing agent used because it is abundant, inexpensive, and safe to handle. Water can be used in three ways to extinguish a fire. It can cool the fuel below its ignition temperature, displace air as it converts to steam thus smothering the fire, and it can mechanically separate the fuel.

The key to the cooling and smothering capacity of water is the ability for the water to convert from the liquid state to the gaseous state. The more efficient and complete the conversion, the more heat energy is absorbed from the fire, and the more steam is produced to displace the oxygen near the fire (Davis & Colletti, 2002). There are three important factors in the effectiveness of water as a cooling agent. First, water applied in small water droplets has more heat absorbing capability than an equal amount of water applied in the form of a solid stream. Second, the rate of heat transfer is proportional to the amount of surface area exposed to the heat. And third, the droplets must have enough energy to overcome the forces preventing it from reaching the heat source (*Fire protection handbook*, 2008).

A new technology, compressed air foam systems (CAFS) was introduced in the 1940s and further refined in the early 1970s. The technological change that CAFS introduced was the injection of compressed air into a water and foam solution before reaching the nozzle of the fire stream. Colletti explains:

> The agitation used to create CAFS finished foam is provided by turbulence as the compressed air and foam solution rush to move from an area of high pressure (the pump system) to an area of low pressure (through the hoseline to the open nozzle) (Colletti, 2006, p. 43).

Previous foam streams were nozzle aspirated, meaning that ambient air was introduced into the foam and water solution through a special nozzle or appliance as it left the hose line. CAFS fire streams can improve water's fire suppression efficiency by up to five times (Colletti, 2006). Although primarily developed and marketed for the protection from and suppression of vegetation fires, the CAFS fire streams have been proven to leverage the similar efficiency improvements in the realm of structure fire suppression (Cavette, 2001; Colletti, 2006; Davis & Colletti, 2002).

Historically, the United States fire service has been suspicious of technological advancements that change the way firefighters do business. This resistance to change was illustrated in the Chicago fire house motto portrayed in the 1991 Universal Pictures movie "Backdraft": "150 years of tradition unimpeded by progress."

The problem this research will address is that after a significant financial investment by Clallam County Fire District No 3 in CAFS capable fire apparatus, firefighters are resistant to using CAFS fire streams.

The purpose of this research is to identify the concerns that are making firefighters resistant to using CAFS fire streams and to recommend solutions that give firefighters the confidence in CAFS fire streams to utilize them during fire suppression activities.

The descriptive research methodology was utilized in the form of literature review, knowledge and skill evaluations, interviews, and surveys to answer the following research questions: Are firefighters not using CAFS fire streams because of a resistance to the change process when CAFS was implemented? Are firefighters not using CAFS fire streams because of a deficiency in training and education? Are firefighters not using CAFS fire streams because of a deficiency in apparatus or equipment? Are firefighters not using CAFS fire streams because flow rate capability is less than that of water only fire streams?

Background and Significance

Clallam County Fire District No. 3 is a small combination fire protection district in the Sequim-Dungeness Valley (Sequim) of the Olympic Peninsula in Washington State. The fire district covers 145 square miles of urban, suburban, and rural lands and protecting a population of approximately 27,000. The fire district responded to 5,374 incidents in 2009 (Clallam County Fire District No.3, 2009, p. 67) from three combination and four volunteer staffed stations.

Sequim is a unique community within Washington State that has a wide variety of environments and geography. The Northern boundary is approximately 40 miles of coastline along the Strait of Juan De Fuca. The Southern boundary is the Northern foot hills of the Olympic Mountain range. Southwesterly flows from the Pacific Ocean divide around the Olympics which creates a rainshadow for the area, keeping rainfall to an average of less than 15 inches annually. The valley is bisected North-South by the Dungeness River, the second steepest river in the United State with an elevation drop of 7,300 feet in 32 miles. This variation in natural features results in an array of environments in a small geographic area. The spectrum includes ocean coastline, arid river valley, irrigated farmlands, to foothills of the densely forested Olympic National Forest and The Olympic National Park.

Sequim is also unique in its demographics. According to 2000 United States census data, of the 21,547 residents of the Sequim area, the median age is 53.6 years compared to the national average 35.3 years. Only 39.9% of the area residents are in the labor force, compared to the national average of 63.9% (United States Census Bureau, 2000). The population has grown approximately 34% from 2000 to 2007. This dramatic growth is due largely to retirees relocating from the Puget Sound region of Washington and the State of California ("Sequim, Washington", 2010).

During this same time, residential and commercial development increased proportionally to the influx of population. The commercial development was primarily “big box” warehouse sellers such as Wal-Mart, Home Depot and Costco. The residential development increased in two opposite configurations. High density and multi-family units were built close in to the City of Sequim, while large 4,000 square foot to 15,000 square foot and larger single family residences were built in the remote, timbered wildland-urban interface (WUI) areas of the foothills.

In 2004, when purchasing two new engines in, the district’s apparatus design committee looked at the various fire problems the district faced in protecting the residents and their property and how to best equip fire engines to address those fire problems. The committee determined that CAFS should be installed on the new engines in order to address the increasing fire problem of homes being built in the WUI.

While researching various CAFS systems, the committee recognized the advantages of CAFS fire streams over traditional plain old water (POW) fire streams in structural firefighting operations. Even though the WUI fire problem justified the increased expense of CAFS capability alone, the fire district intended to utilize CAFS during the suppression of structure fires to increase water supply efficiency and reduce water damage. The district’s desire to use CAFS in this manner is consistent with the United States Fire Administration operational objective of “improving the fire and emergency services’ capability for response to and recovery from all hazards” (United States Fire Administration, n.d., p. 14).

A study conducted in 2009 confirmed the decision to add CAFS to the district’s engines. Researchers at Peninsula College in nearby Port Angeles determined that Clallam County had the highest risk of loss due to wildfire in Washington State, as well as the fifth highest risk of the counties in the 11 western states. Clallam County also ranks second in the western states for potential of increased risk due to increasing development in the WUI (DeSisto, Barry, Nabors, & Drake, 2009, p. 1).

Currently, four of the district’s seven first line engines have CAFS. The district’s procedure for the use of “class A foam” prohibits the use of CAFS for interior fire attack at this time. This procedure was adopted September16th of 2006, and was based on the procedures of the Phoenix, Arizona Fire Department. The prohibition from using CAFS fire streams for interior fire attack at that time was based on a determination that members needed to become more familiar with the new technology and there was a concern that CAFS fire streams do not provide adequate protection from excessive heat. Currently, at CCFD3 CAFS fire stream are only used in wildland fire suppression, overhaul, and occasionally during exterior fire attack of structure fires.

When the first CAFS equipped engine was delivered in 2004, the sales representative provided training on the operation of the pump and related systems, including the CAFS. There was no education on the theory behind the tactical use of CAFS, only the steps required to produce a CAFS fire stream from that particular system. Personnel were then trained in the proper hose and nozzle handling procedures for operating a CAFS fire stream. According to C. Turner (personal communications, October 27th, 2010), this training was performed by a few in-house members who had obtained some knowledge from trade magazines and text books. Turner went on to state that as firefighters trained with the CAFS, they frequently experienced poor performance, inconsistent finished foam production, hose kinking and difficulty managing the nozzle reaction of the hose lines.

In February of 2007, Firefighter Kjel Skov was sent by the district to the Southwest Compressed Air Foam Symposium in Texas. He attended a total of twenty hours of instruction over three days. Firefighter K. Skov (personal communications, November 16, 2010) indicated that during this training he became aware that the training provided by the district to this point was inadequate and incorrect in several areas including flow rates, operations of the components, and tactical application of CAFS.

When two new engines were purchased in 2008, the bid documents required training be provided to district members by the manufacturer of the pump, foam, and compressor system. On August 14th and 15th, 2008 after the engines were delivered, Waterous factory training instructor Keith Klassen performed five hours of training which included both lecture and practical application. The lecture included discussion of the theory of fire suppression tactics. 20 members of the district representing administration, suppression, and the maintenance divisions attended the training. No knowledge or skills evaluations were performed after the training.

After Waterous dealer-provided training was complete, the question arose as to the possibility of using CAFS fire streams for structure fire suppression. The district Operations Chief conducted a literature review of CAFS comparative effectiveness, primarily the tests performed by the Los Angeles County Fire Department (LACFD) in Palmdale California in 1990. After completing the literature review and reviewing the information from the Southwest Compressed Air Foam Symposium, it was determined by the district's administration that structure fire suppression with CAFS fire streams was viable and appeared to be superior to POW fire streams and conventional fire stream with Class A foam additive.

After having the CAFS capability for more than six years, CCFD3 firefighters have rarely used CAFS fire streams during fire suppression operations of any type. During post incident critiques when CAFS has been utilized, the primary reasons given by firefighters for not using CAFS fire streams are the same as the problems experienced after the initial training; poor performance, inconsistent finished foam production, hose kinking and difficulty managing the nozzle reaction of the hose lines. One additional reason given has been that the CAFS fire streams utilized fewer gallons per minute of water, and there is a belief that they do not provide enough protection during a hostile fire event such as a flashover.

The resistance to utilizing CAFS is in part, if not completely, an issue of adaptive change as discussed in the National Fire Academy Course Executive Development (R123). On its face, the resistance is based on fire district members' perception and beliefs about deficiencies in the CAFS technology. Their lack of confidence in the technology will prevent them from utilizing it.

Literature Review

A literature review was conducted to obtain additional information in four areas: (a) implementing change and new technology in the workplace, (b) training for implementing CAFS fire stream use during structural firefighting, (c) common deficiencies in apparatus and equipment used for producing CAFS fire streams, (d) flow rates of CAFS fire streams compared to flow rates of POW fire streams.

Change

Since 1938, most organizational and management theorists have held that in order to achieve an organizational goal, you must not rely solely on member compliance, but also develop cooperation and consensus. Some believe this is only possible for routine and unambiguous tasks in a stable organization. An alternative theory is that organizations that do not embrace disagreement and focus on consensus create a blind spot for creativity and innovation (Pettigrew, Thomas, & Whittington, 2002).

In her book *Agents of change: Managing the Introduction of Automated Tools*, Bouldin (1989) found that in her industry of data processing, the most effective method to implement a new tool or technology was to follow a collaborative process that included eight phases. The first five phases dealt with selecting the correct product, and the last three involved planning, implementing, and evaluating the new product. The successful implementation relied on a project team that was composed of all of the stakeholders. To be successful this project team must address the needs of all the groups affected, with special consideration given to both the end user and those who will have to maintain the new tool or technology. The more people that the team can include as participants, the more people will feel responsible for a successful implementation. This approach supports the cooperation and consensus theory mentioned earlier by Pettigrew, Thomas, and Whittington for not only the routine and unambiguous, but also for complex, multi–year and multi-system changes.

The manual, *Chief officer* (IFSTA, 2004), notes that change management is an essential skill for a chief officer in the fire service. “Knowing the types of change, how to overcome resistance to change, how to implement the change process, and how to use a follow–up plan can lead to successful change management.” (IFSTA, 2004, p. 136).

Employee resistance alone can cause a change initiative to fail. As outlined in *Chief officer* (IFSTA, 2004), the following six basic steps can enable a fire department to overcome resistance to change; “create a climate for change, plan for change, communicate the advantages and effects of change, meet the needs of both organization and employees, involve employees in the change process, provide support for employees during the change. " (IFSTA, 2004, p. 137). It is also important to seek the input and support of 'opinion leaders' in the organization. These steps build on the importance of cooperation between the change agent and those affected by the change, pointing out the need for employees to be supported through communication and involvement in the process.

Another key element addressed by Bouldin (1989) is the pace at which changes are implemented. In order to overcome resistance, people must be given the opportunity to have a series of small successes. Using a series of incremental steps allows the concerns and fears of your personnel to be identified, the issues address, and allows them to get comfortable with the change. In the fire service we often sacrifice the time required to do this, in favor of having the changes completed as soon as possible. Consistent with the idea put forward in the Chief Officer text (IFSTA 2004), the insecurity created by the fear of the unknown, and the anxiety associated with learning are the most common reasons to resist change. Both Bouldin and IFSTA promoted the idea that monitoring the comfort or anxiety level of employees essential in successful implementation of change.

In his book, *The Compressed Air Foam Systems Handbook*, Colletti (2006), dedicates an entire chapter called "Starting a CAFS program". His approach is also incremental. He proposes starting with a 3-hour seminar followed up with a practical demonstration, preferably a live fire exercise. This demonstration is meant to begin the change process by showing the desired benefit in a non-threatening environment. Colletti places emphasis on regularly training users to understand how CAFS is to be integrated into existing strategy and tactics. He states, "When the rubber eventually hits the road, the success of fire combat using CAFS depends upon an attack team's understanding of how to tactically apply foam." (Colletti, 2006, p. 201).

Training

The fire service commonly uses the generic term "training" to identify what is actually three different means for a person to gain skills, abilities, and knowledge – namely training, education and experience. People participate in varying degrees of training, education, and experience in order to develop the knowledge and skills required to competently perform their job.

The Merriam-Webster online dictionary defines the verb *train* as: (a) to form by instruction, discipline, or drill. (b) to teach so as to make fit, qualified, or proficient. (*Merriam-Webster Online Dictionary* [MWOD], n.d.) Russell Strickland defines *training* as the "…'skills and performances' that are taught to an individual." (Barr & Eversole, 2003, p. 280). These definitions indicate that training is concerned with imparting a skill or ability so that skill will be be performed at a competent level.

Education is defined by Merriam-Webster as: "the knowledge and development resulting from and educational process" (MWOD, n.d.). Whereas education is defined by Strickland as "…the 'knowledge' or non-skilled (theory) necessary for our profession." Dave Purchase further defines education as "teaching the meaning behind the specific task." (Buckman, III, 2005, p. 197). These definitions agree that education is about knowledge and understanding, rather than a physical ability to perform a skill.

Experience is "practical knowledge, skill, or practice derived from direct observation of or participation in events or in a particular activity." (MWOD, n.d.). Strickland and Purchase both agree that training, education and experience all need to be present in order for a training program to be effective.

A training and education program for CAFS must include education on basic foam principles, clear up misinformation, remove myths, include hands on training in foam stream application and hose handling, as well as live fire evolutions to allow firefighters to experience what they have learned (Colletti, 2006).

The education (knowledge) component of training programs was the first area reviewed. Theoretical knowledge, specifically the scientific principles and nature of fire behavior, is not valued in today's fire service. Ed Hartin has explored what the required level of knowledge, specific to fire behavior, is required by today's firefighter to operate safely and effectively. In his 2009 article *How much science is necessary?* Hartin explains that historically the fire service has trained at the vocational education level as the discipline was viewed as a blue collar, manual labor job (Hartin, 2009). He includes two very powerful quotes which have completely opposite points of view. First was from a 1938 roundtable discussion in the trade magazine Fire Engineering.

> The college man is difficult to educate to our standards, because of his advanced education …I do not find that the man with a college or higher school education is necessarily better adapted to the fire service…My experience in the fire service has been that the best materials come from the ranks of the laboring class, with grammar school education ("The round table: For practical discussion of current fire department and fire management problems", 1938, p. 253-256).

The opposing opinion comes from Sir Eyre Massey Shaw, the first fire chief of the London, England Fire Brigade.

> In order to carry on your business properly, it is necessary for those who practice it to understand not only what they have to do, but why they have to do it…No fireman can ever be considered to have attained a real proficiency in his business until he has thoroughly mastered this combination of theory and practice (Shaw, 1876).

As recently as 2006, the decision over how much science to include in firefighter textbooks was debated during the revision IFSTA's *Essentials of Firefighting* text (Hartin, 2009). Being familiar with the science related to fire suppression is important in developing a complete understanding of foam properties and fire behavior. A complete understanding of foam properties and fire behavior is necessary to understand fire stream delivery rates and application methods (Colletti, 2006; Klassen, 2010). This understanding and familiarity with the subject matter improves the user's critical thinking ability (Watters, 2010). Klassen reasons that if firefighters have CAFS made available to them without proper knowledge, they will likely refuse to use it, or use it improperly leading to a poor experience that will quickly be communicated throughout the rest of the organization (Klassen, 2008).

The practical skills components of training programs for CAFS are very specific and consist of hose handling and foam application skills acquired through repetitive drills in realistic environments. This needs to be accomplished in training facilities or private buildings acquired for fire training (Colletti, 2006; Klassen, 2010). Evolutions in a parking lot will not provide the environment necessary for advancing lines down hallways, around corners, or up and down stairs. The skills identified consistently among the authors are, deployment and advancements of hose lines, proper operation of the nozzle, managing nozzle reaction, and targeting of the fire stream. Proper application of fire streams during overhaul operations was also identified by Klassen as a needed skill (Colletti, 2006; Klassen, 2008).

Experiencing or “doing” results in a higher level of both acquisition and retention of the new knowledge or skill. Learning is actually a change in behavior that is best accomplished through a cycle that begins and ends with experience, particularly for adults (Hansen, 2000; Richardson, 1994). Colletti believes that hands-on training under live fire conditions is necessary in order for students to observe and understand the difference between the effect of a CAFS fire stream and a POW fire streams on an ordinary fire. Application of POW fire streams is stopped when the flames darken down. With CAFS fire streams, the application has to continue after the flames are darkened or the heat will not be fully dissipated, and the fire will rekindle. (Colletti, 2006) This difference in the duration of application of the suppressing fire streams can only be learned by experiencing the timing and environment of the two different methods.

The organization must carefully plan all four phases of training. Those phases are administration, implementation, delivery, and evaluation (Bouldin, 1989; Buckman III, 2005; IFSTA, 2006). Conducting effective training of a new technology will be effected greatly by three factors; complexity of the product, experience, capability and interest of the user, and the time and financial resources the organization is making available for the implementation (Bouldin, 1989). In order for the implementation of a new technology to be successful, the organization must be committed to supporting comprehensive planning and training.

Deficiencies in apparatus and equipment

As identified in the United States Fire Administration technical report *Class A Foam for Structural Firefighting* (Stern & Routley, 1996), anytime you increase the amount of additional electrical or mechanical systems to an operation, you could possibly increase the likelihood that a failure will occur. Lyon (2009) found that repeated failures in apparatus and equipment lead to firefighters not trusting the system. During the review of equipment and apparatus deficiencies three components of the systems were examined; the pump/proportioner/compressor system, hose lines and nozzles, and finished fire streams.

The apparatus pump, foam proportioner and air compressor system is the most complex part of the CAFS system and includes electronic and mechanical components. Mechanical failure of the pump/proportioner/compressor system is consistently hinted at and described as a concern, even to the point of being assumed as a disadvantage to CAFS during The Boston Fire Department field tests (Routley, 1994). However, upon completion of the field tests of several major fire departments, very few failures of equipment were reported (Stern & Routley, 1996). The problems that were documented were typically associated with either a retrofit of apparatus not originally designed for CAFS or manufacturer defects in the design and construction of new systems. Once these design and construction defects were corrected, questions of reliability by firefighters seemed to remain (Lyon, 2009; Routley, 1994; Stern & Routley, 1996).

Hoseline management is another common concern for firefighters. The three areas examined were relative weight of hose lines filled with POW compared to CAFS, kinking and burn through of the fire hose. All of the literature available confirms the logic that a hose line filled with air bubbles is going to be significantly lighter than one filed entirely of water (Colletti, 2006; Davis & Colletti, 2002; IFSTA, 2009; Lyon, 2009; Routley, 1994; Stern & Routley, 1996; Taylor, 1997). Although not proven, this weight reduction is assumed to reduce firefighter fatigue and injury (Stern & Routley, 1996).

There is a perception out there by firefighters that problems with hoseline kinking are common (Brooks, 2008; Lyon, 2009; Taylor, 1997). The field tests reviewed contradicted this perception. In the Boston Fire Department test, during 146 fire attacks, crews experienced problems with hose kinking two times (Routley, 1994). In the four field tests included in the

1996 USFA Technical report, hose kinking was never mentioned as a problem (Stern & Routley, 1996). Both of the previously mentioned reports did highlight several times that those crews operating CAFS hand lines found them much easier to maneuver and advance than POW hose lines. Experts contend that instances of hose kinking with CAFS hoseline are usually a result of incorrect operating pressures or lack of care in deploying the hose lines (Brooks, 2008; Colletti, 2006).

Lastly, the concern related to CAFS hose lines burning through when exposed to heat was reviewed. This concern was brought to the forefront of the CAFS debate in 1995 when the German fire service experienced its first line of duty deaths when two firefighters perished in a structure fire. Holger de Vries (2007) explains that during interior fire suppression, two firefighters were trapped with fire below them. During their may-day call, they reported their CAFS hoseline had burned through and that their escape route was blocked. This led to the German crime lab examining the circumstances surrounding the burst hose line. They determined that hose lines filled with CAFS are prone to fail sooner than those filled with only water when exposed to radiant heat or embers. This determination was based on tests of the German fire hose which is single jacketed polyester fire hose rather than the double jacketed fire hose commonly used in the United States fire service (de Vries, 2007). No research was found evaluating the difference in burn-through time of double jacketed fire hose for CAFS versus POW filled hoses.

Once the foam, water and air solution has been transported from the apparatus through the hose line to the nozzle, the firefighter has to manipulate the nozzle to properly apply the extinguishing agent to the fire in the form of a finished fire stream. Two common problems experienced at this point of the system are slug flow and increased nozzle reaction. Slug flow is defined by Collietti as;

> …only plain water and air fill the hose. Since plain water and air do not mix, they "slug" and separate as they move through the hoseline toward the nozzle, causing a rapid forward and aft pulsation, constituting a dangerous hose-handling situation, a totally useless fire stream, chafing of the hose`s exterior, and increasing stress on hose couplings (Colletti, 2006, p. 162).

The lack of effective fire stream, blowing of embers, and violent pulsation of the nozzle that occur during slug flow are commonly expressed as safety concerns by firefighters (Colletti, 2006; Lyon, 2009; Stern & Routley, 1996; Taylor, 1997). Slug flow is not a characteristic of CAFS itself, but is caused by either operator error or foam proportioner malfunction. To prevent slug flow, Hale Products Inc. developed a CAFS system that senses foam solution flowing into the hose line, and stops the air injection when foam solution is absent. (Hale Products Inc., 2005). A second commonly reported problem was increased nozzle reaction. Nozzle reaction is an example of Newton's third law- that every action has an equal and opposite reaction. In 1990, Paul Grimwood, conducted a research project evaluating the hand line streams utilized by the London England Fire Brigade. He found;

> By evaluating maximum flow capability for a hose-line that could be effectively directed and safely handled whilst advancing and working inside a fire-involved structure it was observed that there was a maximum nozzle reaction force that could be handled by one, two and three firefighters as follows -

One firefighter - 266N (60 lbf)

Two firefighters - 333N (75 lbf)

Three firefighters - 422N (95 lbf)

(Grimwood, n.d., para. 2)

The amount of nozzle reaction is easily calculated for solid stream nozzles with mathematical equations. IFSTA (1989) and Fornell (1991) agree with the use of the following formula for solid stream nozzles;

$$NR = 1.57\, d^2 NP$$

Where:

NR = Nozzle reaction in pounds

1.57 = A constant

d = Nozzle diameter in inches

NP = Nozzle pressure

For fog stream nozzles the following formula is used;

$$NR = 0.0505\, Q \sqrt{NP}$$

Where:

NR = Nozzle reaction in pounds

0.0505 = A constant

Q = Flow in gallons per minute (GPM)

NP = Nozzle pressure

No literature was found that provided a standard formula for calculating nozzle reaction for a CAFS fire stream. However, in his applied research project of 1997, Taylor (1997) performed evaluations measuring the nozzle reaction of various hoseline configurations. He found a CAFS handline with a 15/16 inch solid tip with flowing 130 GPM and a CAFS handline with a 1 3/8" solid tip with flowing 150 GPM both generated the same nozzle reaction force of 70 pounds (Taylor, 1997).

Flow rates of CAFS fire streams compared to flow rates of POW fire streams

The required flow rates of fire streams depend on three factors; how much water is required to suppress or extinguish the fire, what nationally accepted standards require, and the capabilities and limitations of the water supply, apparatus, and equipment that produce the fire stream.

Several formulas have been developed to determine needed fire flow. These formulas estimate what volume of water should be applied to a fire at a certain rate for a specific duration. This literature review focused on the two most commonly used formulas, the National Fire Academy (NFA) formula and the Iowa State University fire flow formula (Iowa). The Insurance Service Office formula was excluded as it is designed only for the containment of a fully involved structure and preventing the spread to adjacent exposures (*Fire protection handbook*, 2008). This formula is useful in determining water supply requirements before an incident, but not tactically for hose line application rates.

In the early 1950s Keith Royer and Bill Nelson of Iowa State University developed the Iowa fire flow formula during their research into uncontrolled fire behavior in structures. Their work was based in the science of fire combustion, utilizing physical properties of the fuel and environment and behaviors of fire and water. Iowa developed the concept that water applied properly to the fire would convert to steam, which in turn would displace air (oxidizer) and smoke (fuel) thereby smothering and controlling the fire to the point where it could be completely extinguished with a direct application of water. Royer and Nelson developed a formula for determining the application rate of water as a fog required to control, but not extinguish, a fire in a single fully involved compartment. The finished formula, a volumetric approach, is calculated as the volume of the compartment, in cubic feet, divided by 100. The formula returned the result in gallons per minute of water applied as a fog stream applied for 30 seconds. This rate of flow is only for the line controlling the fire and does not include flow for back-up or exposure lines. The science supporting the formula included the heat absorption capability of water, the contribution to combustion and heat production of air available to the fire, the efficiency and quantity of steam required to displace air in the compartment necessary for fire control.

Royer (1995) and Hartin (n.d.) agree that there are several limitations to the Iowa formula that are often forgotten and lead to misapplication of the formula. First, Iowa only works in a ventilation controlled fire where heat production is driven by the amount of available oxygen. Secondly, the fire compartment needs to have reached 1,000 degrees fahrenheit at the ceiling in order to get the 1,700:1 expansion ratio for steam that is cited in Royer and Nelson’s work. Third, the water being applied to the compartment is applied throughout the entire space simultaneously in a fine fog, from outside the compartment, commonly called an indirect attack. Lastly, the formula is only effective up to 1,000 GPM, which translates to 100,000 cubic feet, or 10,000 square foot building with ten foot ceilings.

While the Iowa Royer/Nelson formula was based in the science of fire combustion, the NFA formula was based on the experience and reasoning of seasoned fire officers. *Redefining Needed Fire Flow for Structure Firefighting* (Burns & Phelps, 1994) and *Estimating Required Fire Flow: The National Fire Academy Formula* (Hartin, n.d.) explain that when the *Preparing for Incident Command (PIC)* course was rewritten, the course developers designed a number of fire scenarios and distributed them to students that were attending the academy. In the scenarios the students were asked to indicate placement and size of hose lines they would use to control the fires. The size and placement information was collected and analyzed by the course developers who were all experienced fire command officers. When the floor area was divided by the fire flow the student believed they needed, the average result was three square feet per gallon of fire flow. This is how the NFA formula was developed; Needed Fire Flow = (Length X Width) / 3 plus 25% of fire flow for each exposure. Under the NFA formula this flow rate is applied for one to two minutes to achieve control of the fire.

As with the Iowa formula, there are limitations for the NFA formula calculation. First, the NFA formula is for a free burning compartment fire, also known as a fuel controlled fire, with ventilation openings totaling at least 10% of the floor area, and where up to 50% of the compartment floor space is involved in fire. Second, the water is to be applied from an interior position where a direct attack is made to the seat of the fire. Third, the formula is only effective up to 1,000 GPM, which translates to 3,000 square feet of fire involved floor area in a 6,000 square foot compartment. Fourth, this formula is based on area, not volume, and therefore ceiling heights greater than 10 feet may theoretically require a higher flow rate. Fifth, since the fire conditions are fuel controlled as opposed to air/ventilation controlled, the heat release rate varies depending on the fuel, and calculated flow rates may be inadequate for the fuel.

One other major difference between the two above mentioned formulas that is commonly forgotten or not known, is that while the Iowa formula is the flow rate for a single line to control a fire in a confined compartment, the NFA flow rate is for all attack, back-up and exposure lines combined (Hartin, n.d.). The amount of water needed solely for suppressing the fire is definitive in the Iowa formula, were in the NFA formula it is not.

The National Fire Protection Association (NFPA) has published NFPA *1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments, 2010 Edition*. In chapter 5 of this standard, it identifies that the initial full alarm assignment shall provide for the "Establishment of an effective water flow application rate of 300 GPM (1140 L/min) from two handlines, each of which has a minimum flow rate of 100 GPM (380 L/min) with each handline operated by a minimum of two individuals to effectively and safely maintain the line." (section 5.2.4.2.2). This is based on a fire in a *typical* 2,000 square foot house. In this standard there is no requirement to provide an exposure line. NFPA 1710 is not a tool to determine required fire flow for a structure fire. It is a performance standard that dictates a certain minimum capability of the initial full alarm assignment, regardless of the actual fire scenario encountered.

The CAFS from Waterous Company have some limitations to their flow rate capacities. The publication *Typical CAFS Flows* indicates that with a 200 cubic foot per minute compressor, a 1 ¾ inch hoseline producing wet CAFS foam flows at 90 gallons per minute and a 2 ½" inch hoseline producing wet CAFS foam flows at 190 gallons per minute (Waterous Company, 2007). This limitation would preclude the use of CAFS in situations where the required fire flow is higher than the system capability.

In summary, the literature review provided insight into the change process and how important it is to involve those affected by the change in developing and carrying out an implementation plan that is incremental, deliberate, and supported by the organization.

The literature review also clarified the difference between training and education, and how important it is the members understand the science and theory behind the tools and techniques they utilize to perform their duties. The significance of experiencing what the student is learning was examined, and how it aids in retention of skills and modification of behaviors.

Deficiencies in apparatus and equipment were examined in order to determine the most common problems encountered. Retrofitted equipment was identified as a common source of failure in the agencies reviewed. Several other perceived apparatus and equipment problems were found to be operator error, or lack of understanding rather than a problem with the hardware itself.

Finally, fire flow rates were examined from the perspective of tactical requirements for suppressing ventilation-controlled and fuel-controlled fires, as well as national performance standards, and actual capabilities of CAFS.

Procedures

Research was conducted using literature review and four procedures. The literature review utilized materials from many sources. Peninsula College, City of Port Angeles and City of Sequim libraries provided books on organizational management and implementing change in corporate environments. The National Fire Academy Learning Resource Center provided magazine and journal articles relating to fire flow formulas, CAFS fire streams, water application rates, fire flow formulas, and fog fire streams. The Learning Resource Center also provided several applied research projects related to CAFS. The Clallam County Fire District No 3 library provided materials related to fire service leadership and management, CAFS fire streams, and rural fire fighting tactics. The Waterous Company provided a compact disc titled *Palmdale Structure Test; Extinguishing Agent Comparison February 2001* which included technical data on the tests conducted by Los Angeles County Fire Department as well as several case studies, magazine and journal articles, technical reports and audio/video presentations. A number of internet websites provided technical reports, magazine and journal articles and definitions.

The first procedure was to conduct CAFS knowledge evaluations. The population of the evaluations was all 29 of 32 line firefighters of Clallam County Fire District No 3 (Appendix A). Three current line firefighters were excluded from the population as they were hired after the research process had begun. The breakdown of the population included three Captains, six Lieutenants, and 20 firefighters. These evaluations were intended to determine if members had a basic understanding of the technical aspects of CAFS and CAFS fire streams with the Waterous system. A Compressed Air Foam Operational Quiz (Appendix B) was administered through the district's on-line training website. The quiz utilized the 32 questions provided from the compressed air foam division of the Waterous Company, the manufacturer of the CAFS systems on CCFD3 engines. This quiz is typically administered by Waterous trainers after conducting CAFS operations training to new apparatus purchasers. Greg Geske of Waterous Company provided the quiz questions as well as the answers. The quiz questions and answers were entered into the district's training website by this author. The quizzes were completed by members using personal computers from October 19th until October 31st. The software on the district training website automatically graded the quizzes, calculated scores and performed test item analysis. Questions #5, #7 and #13 failed a content validity assessment because they contained multiple correct answers when only a single answer was allowed, and were therefore removed from the results. The test scores were recalculated after excluding the three failed questions using a Microsoft Excel spreadsheet, and various comparisons were made with the results.

The second procedure was to conduct CAFS practical skills evaluations. The population of the evaluations was all 29 of 32 line firefighters of Clallam County Fire District No 3 (Appendix A). Three current line firefighters were excluded from the population as they were hired after the research process had begun. The breakdown of the population included three Captains, six Lieutenants, and 20 firefighters. The evaluations were conducted of 24 members of the population. Firefighter Kjel Skov, the district's lead CAFS instructor conducted the skills evaluations and was not himself evaluated. Four other members were not able to be evaluated due to scheduling conflicts, leaving a total population of 24 members. These evaluations were intended to determine if members had a basic understanding of how to produce CAFS fire streams with the Waterous systems. The evaluations were conducted while the members were on duty, but were uninterrupted. The evaluations were conducted either at Station 34 (323 N. 5th Ave, Sequim, Washington 98382) or at the district's training center (255 Carlsborg Road, Sequim, Washington 98382) using one of two identical 2008 Sutphen Shield engines, CCFD3 vehicle numbers F-49 and F-50. These engines have Waterous 1500 gallon per minute single stage centrifugal fire pumps, model Advantus 6 foam proportioners, and model 200-SP PTO driven air compressors rated at 200 cubic feet per minute at 125 pounds per square inch (psi). The hose line consisted of 100 feet of 1 ¾ inch Mercedes brand double jacketed polyester fire hose connected to a 1 ½ inch CAFS discharge port, with an Elkhart 1 3/8 inch ball valve nozzle and Elkhart Fire Chief 175 GPM at 50 psi fixed gallonage combination tip. The engines had a full 700 gallon booster tank and a water supply from a fire hydrant as water supply sources. Firefighter Skov evaluated the members using the Waterous Company Delivery Operational

Instruction Practical test (Appendix C) provided by Greg Geske of the Waterous Company. This test is typically administered by Waterous trainers after conducting CAFS operations training to new apparatus purchasers. The evaluations took place between October 26th and November 16th. The duration of each evaluation ranged from 15 to 40 minutes. The following events or conditions would constitute a failure of the evaluation:

- The evolution was stopped to prevent injury to personnel or damage to the apparatus.
- Water, air or foam was not present when desired stream required it.
- The flow rate difference between dry and wet attack foam was less than 30 GPM.
- Wet foam flow rate was less than 80 GPM.

The third procedure of the research process was a questionnaire (Appendix D) completed by the same population as the knowledge and skills evaluations. The questionnaire was created and distributed by the author on Tuesday, November 09, 2010 using the internet web based program Kwiksurveys.com (2008-2010). Kwiksurveys.com allows the creation, distribution, collection, and analysis of the survey questions. Responses were collected until Wednesday, November 17th, 2010. Three members of the 29 person population were unavailable and did not complete the survey. The title of the questionnaire was Compressed Air Foam Systems at Clallam County Fire District No 3.

The questionnaire consisted of 11 questions utilizing multiple answering formats. Questions one through four and question seven allowed respondents to select one of five responses on a rating scale. Respondents were also allowed to select “not applicable” if they were not able to provide an answer or were not a member during the specified time, except question two. Questions five, eight and ten allowed respondents to select one response for each rating scale for multiple aspects of the question, with question eight having a text box for additional detail if applicable. Question five mistakenly had 'none' listed as a situation and was not calculated in the final results. Question six allowed respondents to select yes, no, or not applicable for multiple aspects of the question. Question nine was simply a yes or no response. Question 11 provided a text box for the respondent to provide their name. On November 18th and 19th the results of the questionnaire were tabulated and evaluated by the author.

The fourth procedure involved interviews of individual from agencies that have implemented CAFS from the Puget Sound region (Appendix E). The Interview questions (Appendix F) addressed all four research questions identified in the introduction. Interview questions one and two were designed to confirm that CAFS fire streams had been implemented into the agencies fire suppression operations. Interview questions three and four were designed to answer research question one. Interview question five was designed to answer research question two. Interview questions six and seven were designed to answer research question three. Interview question eight was designed to answer research question four.

Deputy Chief of Operations John Burgess of Gig Harbor Fire and Medic One recommended (personal communication November 10, 2010) that I speak with his Training Division Chief, Tracy Lyon. The interview with T. Lyon was conducted by telephone with each of us in our respective offices on November 15th, 2010. The interview lasted 25 minutes and covered all eight questions.

Battalion Chief of Training Jim Gillard of Poulsbo Fire Department was interviewed by telephone with each of us in our respective offices on November 15th, 2010. The interview lasted ten minutes and covered all eight questions.

Assistant Chief of Operations Ken Weatherill of City of Kent Fire Department was interviewed by telephone with each of us in our respective offices on November 16th, 2010. Chief of Training John Willis was also in Chief Weatherill's office and assisted with answering questions six, seven, and eight. The interview lasted 16 minutes and covered all eight questions.

Four assumptions were made in the above procedures. First, it was assumed that during on-line knowledge examination the members answered the questions without assistance from other members or resource materials. Secondly, it was assumed that when responding to the questionnaire respondents understood the questions and available responses. Third, it was assumed that respondents to the questionnaire responded honestly. Lastly it was assumed that the evaluator of the practical skills evaluation performed his evaluations fairly and consistently.

Two limitations were experienced during the research. First, five of the 29 member population had joined the department after the 2004 implementation of CAFS, and seven members had joined since the second delivery of CAFS capable apparatus in 2008. This provided a limited base of experience from which these members used to respond to the questionnaire. Secondly, the interviews with individuals of regional agencies which had implemented CAFS were all conducted with chief officers, who answered from their perspective which may not represent the opinions of their line firefighters.

Results

The literature review, evaluations, surveys and interviews provided the information needed to answer the research questions listed in the final paragraph of the introduction. Questions 1, 3, and 4 were answered by literature review and the results of the survey questions (Appendix D) and interviews questions (Appendix F). Question 2 was answered by literature review, knowledge and skill evaluations (Appendix B and Appendix C), the results of the survey questions (Appendix D) and interviews questions (Appendix F). The results of survey questions one through ten were reviewed by examining the population as a whole and also by each of the three work shifts that members are assigned to. These three work shifts are identified as A-Shift, B-Shift, and C-Shift. Question 11 of the survey was for sorting purposes only, provided no quantitative or qualitative data and will not be reflected in the results. The results of the survey are presented from the most frequent response to the least.

Research Question 1. Are firefighters not using CAFS fire streams because of a resistance to the change process when CAFS was implemented?

Question one of the survey (Appendix G) asked firefighters about their level of involvement in the decision to add CAFS to district apparatus. Of all the respondents, 37.0% reported very insignificant; 33.0% reported they were not members at the time the decision was made; 15.0% reported insignificant; 11.0% reported a neutral response; 4.0% reported significant; 0.0% of the respondents reported very significant. The noteworthy finding in this question was that only one respondent reported any significant involvement in the decision. There was no significant difference between the results of the individual shifts.

Question two of the survey (Appendix H) asked firefighters if the advantages of CAFS had been clearly communicated. Of all the respondents, 41.0% reported a neutral response; 30.0% reported that they agreed; 26.0% reported they disagreed; 4.0% reported they strongly agreed; 0.0% reported they strongly disagreed. Almost as many firefighters disagreed as agreed and the majority was neutral in their response. There was no significant difference between the results of the individual shifts.

Question three of the survey (Appendix I) asked firefighters if the plan for implementation of CAFS had been clearly communicated. Of all the respondents, 26.0%

reported they were not a member of the district when CAFS was implemented; 22.0% reported they agreed; 22.0% reported a neutral response; 22.0% reported they disagreed; 4.0% reported they strongly agreed; 4.0% reported they strongly disagreed. There was no notable difference between the results of the individual shifts.

Questions three and four of the interview were answered by T. Lyon (personal communication, November 15, 2010) and J. Gillard (personal communication, November 15, 2010) by both stating that the determination to add CAFS capability to their apparatus was made by an apparatus committee of their respective agencies. K. Weatherill (personal communication, November 16, 2010) stated that when his agency made the determination to add CAFS capability to their apparatus, an apparatus committee recommendation was reviewed by the training division before final approval was given by the administration.

Research Question 2. Are firefighters not using CAFS fire streams because of a deficiency in training and education?

The Compressed Air Foam Operational Quiz results (Appendix Q) were reviewed as a whole, as well as broken down by work shift assignment. Of all the scores the mean was 78.48%. By district policy a passing score was 70.00%. 18 of 29 or 62.1% scored above the mean. 20 of 29 or 69.0% attained a passing score.

When the scores for members of A-Shift were reviewed, five of eight or 62.5% scored above the mean; five of eight or 62.5% attained a passing score. When the scores for members of B-Shift were reviewed, two of nine or 22.2% scored above the mean; three of nine or 33.3% attained a passing score. When the scores for members of C-Shift were reviewed, eight of nine or 88.9% scored above the mean; nine of nine or 100.0% attained a passing score. When the scores for members not assigned to a shift were reviewed, three of three or 100.0% scored above the mean; three of three or 100.0% attained a passing score.

Operational Instruction Practical Skills Evaluation results (Appendix R) were reviewed as a whole, as well as broken down by work shift assignment. Of the 24 members evaluated, 16 were able to demonstrate competency in producing the required water, foam, and CAFS fire streams. Seven members failed the evaluation for the following reasons;

1. Spread between different types of CAFS streams 24 GPM
2. Spread between different types of CAFS streams 2 GPM
3. To long duration of slug flow (no foam concentrate)
4. Spread between different types of CAFS streams 14 GPM
5. Attempted to engage PTO with motor above an idle (damage potential)
6. No air in system/ no change in GPM.
7. No air in system

When the results for the members A-Shift were reviewed, five of seven or 71.4% passed. When the results for the members B-Shift were reviewed, two of seven or 28.6% passed.

When the results for the members C-Shift were reviewed, eight of eight or 100.0% passed.

When the results for the members not assigned to a shift were reviewed, one of two or 50.0% passed.

Question four of the survey (Appendix J) asked firefighters if adequate training on how to produce a CAFS fire stream had been provided. Of all the respondents, 41.0% reported they agreed; 30.0% reported a neutral response; 26.0% reported they disagreed; 4.0% reported they strongly disagreed; and 0.0% reported they strongly agreed or the question was not applicable. Just over one in four firefighters didn’t agree that their training in CAFS had been adequate.

When reviewing the results for the members of B-Shift, the number that reported disagreement was twice that of A-Shift, and four times that of C-Shift.

Question five of the survey (Appendix K) asked firefighters if there had been adequate tactical training on how to apply CAFS fire streams in five different fire situations:

- For wildland fires, 37.0% reported they disagreed; 33.0% reported they agreed; 22.0% had a neutral response; 7.0% responded they strongly disagreed; and 0.0% responded they strongly agreed.
- For vehicle fires, 30.0% reported they agreed; 30.0% reported a neutral response; 22.2% reported they disagree; 15.0% reported they strongly disagree; 4.0% reported they strongly agree.
- For exposure protection, 63.0% reported they agreed; 15.0% reported a neutral response; 12.5% reported they disagreed; 7.0% reported they strongly agreed; 0.0% reported they strongly disagreed.
- For interior structure fire combat, 37.0% reported they disagreed; 26.0% reported a neutral response; 19.0% reported they agreed; 15.0% reported they strong disagreed; 4.0% reported they strongly agreed.
- For exterior structure fire combat, 48.0% reported they agreed; 26.0% reported a neutral response; 22.0% reported they disagreed; 4.0% reported they strongly agreed; 0.0% reported they strongly disagreed.

In all five of the situations, the majority was neutral or agreed that adequate training had been provided. Exposure protection and exterior structural fire attack had the strongest affirmative responses with 70.0% agreement and 52.0% agreement respectively. A-Shift was the only shift to have 50.0% or more of respondents report that they agree there have been adequate training in all five categories.

Question six of the survey (Appendix L) asked firefighters if they had participated in five different types of CAFS training:

- For dealer provided training in 2004, 63.0% reported no; 30.0% reported not applicable; 7.0% reported yes.
- For dealer provided training in 2008, 59.0% reported no; 30.0% reported yes; 11.0% reported not applicable.
- For on shift by co-worker, 70%.0 reported yes; 26.0% reported no; 4.0% reported not applicable.
- For self study, 78.0% reported yes; 22.0% reported no; 0.0% reported not applicable. For seminars, 85.0% reported no; 15.0% reported yes; 0.0% reported not applicable.

A majority of the training participation has been through co-workers training each other and self-study. Only one firefighter recalled attending the dealer provided training in 2004. There was no significant difference between the results of the individual shifts.

Question five of the interview was answered by T. Lyon (personal communication, November 15, 2010) and J. Gillard (personal communication, November 15, 2010) both stating that their firefighters received initial training from their apparatus manufacturer. One member from each of the three duty shifts was designated as the pump trainer for their shift. These members received additional training and were responsible for instructing the rest of the members of their shift. K. Weatherill (personal communication, November 16, 2010) stated that manufacturer training was conducted with the delivery of each of the CAFS equipped apparatus.

Live fire training was conducted in acquired structures, where the training division experimented with CAFS fire streams. Delivery of training to the rest of the department was conducted subsequently by members of the training division.

Research Question 3. Are firefighters not using CAFS fire streams because of a deficiency in apparatus or equipment?

Question seven of the survey (Appendix M) asked firefighters to rate the reliability of the CAFS on the district's apparatus. Of all the respondents, 67.0% reported usually reliable; 15.0% reported a neutral response; 11.0% reported rarely reliable; 7.0% reported always reliable; 0.0% reported never reliable or I have never operated a CAFS system. All of the "Rarely reliable" responses were from members of B-Shift. All of the responses from A-Shift were "Always reliable" or "Usually reliable".

Question eight of the survey (Appendix N) asked firefighters if they had experienced four different types of problems with CAFS hose lines:

- For hose line kinking, 48.0% reported occasionally; 15.0% reported frequently; 15.0% reported rarely; 11.0% reported very frequently; 7.0% reported never; 4.0% reported not having used a CAFS hose line.
- For hose line burn through, 85.0% reported never; 7.0% reported rarely; 4.0% reported occasionally; 0.0% reported very frequently and frequently. In the field that was available for additional comments if a respondent has firsthand experience of a hose rupture there were two responses. The first response was "none". The second response was "did not happen to me, but I know of one instance that it happened at JCFD1 a number of years ago, I believe it was wildland related and was a result of hot ash and coals that were not seen".

- For unmanageable nozzle reaction, 41.0% reported occasionally; 26.0% reported rarely; 19.0% reported frequently; 7.0% reported very frequently; 4.0% reported never; 4.0% reported not having used a CAFS hose line.
- For slug flow, 41.0% reported occasionally; 22.2% reported frequently; 22.2% reported rarely; 7.0% reports never; 4.0% reported very frequently; 4.0% reported not having used a CAFS hose line.

Hose line burn through was the least observed hose line problem with 85% reporting never having experienced it. Over half of the respondents reported experiencing kinking, unmanageable nozzle reaction and slug flow occasionally of more. In regards to unmanageable nozzle reaction, half or more of the members of A-shift and C-Shift reported it to be a problem rarely or never, where all of the members of B-Shift reported it to occur occasionally or more.

Questions one and six of the interview were answered by T. Lyon (personal communication, November 15, 2010) stating seven of his agencies nine front line engines are equipped with CAFS. The CAFS was installed as part of the initial construction of each of the CAFS equipped engines. Their first CAFS equipped engine experienced a series of mechanical problems that prevented training from being conducted effectively. A problem which was later resolved prevented the engines from operating if intake pressures were above that of the CAFS compressor. Subsequent CAFS equipped engines also experienced troubles reaching expected target flows. These on-going problems led to uncertainty about the reliability and effectiveness of their CAFS systems.

Questions one and six of the interview were answered by J. Gillard (personal communication, November 15, 2010) stating his agency has only one CAFS equipped engine. The CAFS was installed as part of the initial construction of the engine. That engine immediately had a problem with the flow meter that took five years to diagnose and correct. This defect resulted in unreliable and unpredictable CAFS performance. This inconsistent performance resulted in some firefighters becoming hesitant to utilize CAFS. Ever since the flow meter has been repaired, the CAFS has been reliable and approximately 50% of the firefighters now use CAFS fire streams consistently.

Questions one and six of the interview were answered by K. Weatherill (personal communication, November 16, 2010) stating that all eight front line engines in his agency are equipped with a CAFS. A CAFS was installed as part of the construction of each engine. They have had no design or mechanical problems with the CAFS installed on their apparatus.

Question seven of the interview was answered by T. Lyons (personal communication, November 15, 2010) stating that they have had problems with hoseline kinking, but he was not aware of hose line burn through, unmanageable nozzle reaction, or slug flow being an on-going problem.

Question seven of the interview was answered by J. Gillard (personal communication, November 15, 2010) and K. Weatherill (personal communication, November 16, 2010) both stating they do not believe there are any on-going problems with kinking, hoseline burn through, unmanageable nozzle reaction, or slug flow.

Research Question 4. Are firefighters not using CAFS fire streams because flow rate capability is less than that of water only fire streams?

Question nine of the survey (Appendix O) asked firefighters if they believed that if properly applied, CAFS fire stream provide adequate fire flow to protect them from thermal injury during an interior structure fire attack. Of all the respondents, 67.0% reported no; 33.0% reported yes; 0.0% reported no answer. Two out of three respondents did not believe that CAFS provides adequate fire flow. A-Shift and B-Shift had at least 75.0% of their members give a response of “No”, where C-Shift was at 37.5%.

Question ten of the survey (Appendix P) asked fire fighters to rate their likelihood of using CAFS as the primary fire stream for five different fire scenarios:

- For wildland fire, 33.0% reported unlikely; 30.0% reported likely; 19.0% reported very unlikely; 15.0% reported a neutral response; 4.0% reported will not use; 0.0% reported very likely.
- For car fire, 41.0% reported likely; 22.0% reported a neutral response; 22.0% reported unlikely; 7.0% reported very unlikely, 7.0% reported will not use; 0.0% reported very likely.
- For exposure protection, 52.0% reported likely; 26.0% reported very likely; 15.0% reported a neutral response; 4.0% reported unlikely; 4.0% reported very unlikely; 0.0% reported will not use.
- For interior structure fire combat, 30.0% reported unlikely; 26.0% reported very unlikely; 19.0% reported a neutral response; 19.0% reported will not use; 7.0% reported likely; 0.0% reported very likely.
- For exterior structure fire combat, 48.0% reported likely; 19.0% reported very likely; 15.0% reported a neutral response; 15.0% reported unlikely; 4.0% reported very unlikely; 0.0% reported will not use.

At least 65.0% of respondents stated they would be likely to use CAFS for either exposure protection or exterior structure fire attack. Of all the respondents, 93.0% reported that they we not likely to use CAFS for interior structure fire combat. All members of C-Shift reported they were likely or very likely to utilize CAFS for the exposure protection scenario. For exterior fire attack, 75.0% of A-Shift and C-shift indicated they were likely or very likely to utilize CAFS. For interior structure fire combat, 88.8% of B-Shift, and 62.5% of A-Shift and C-Shift reported they were unlikely, very unlikely, or would not use CAFS.

Question eight of the interview was answered by T. Lyon (personal communication, November 15, 2010) stating “that’s the big one”. He speculated that of his line firefighters approximately 50% have accepted the use of CAFS and 50% are still resistant to the use of CAFS as a primary fire stream for anything other than wildland fire suppression.

Question eight of the interview was answered by J. Gillard (personal communication, November 15, 2010) stating his agency has tried to overcome the misconceptions about the amount of CAFS flow required to suppress a fire. After training on the scientific concepts of how water and CAFS absorb heat differently he speculated that of his line firefighters 25% will still refuse to utilize CAFS, and 75% would utilize CAFS when it was appropriate for the fire conditions.

Question eight of the interview was answered by K. Weatherill (personal communication, November 16, 2010) stating he did not believe that there were any concerns about fire flow related to CAFS fire streams. The use of CAFS fire streams is still at the discretion of the company officer, and he believes they consider CAFS to be “effective”.

Discussion

When looking at the reasons firefighters at CCFD3 are resistant to utilizing CAFS fire streams, there were several aspects of the literature review, knowledge and skill evaluation, survey, and interviews that complemented and supported each other. There were also new questions raised that were not clearly answered by the research. The agencies contacted through the interviews had different levels of success in making CAFS fire streams part of their regular operations. The resistance experienced at CCFD3 appears to be a result of management not recognizing how drastic of a change this was for firefighters, which in turn led to poor planning, inadequate training, and an inconsistent implementation across the three duty shifts.

The result drawn from the first research question, are firefighters not using CAFS fire streams because of a resistance to the change process when CAFS was implemented, showed that agencies who invest in the planning and implantation of CAFS were more successful than those that didn't. In *Agents of Change: Managing the Introduction of Automated Tools,* Bouldin (1989) explains that for a new technology to be successfully implemented a well planned, incremental process need to be developed that address the concerns and needs expressed by those affected by the change. CCFD3 and all three agencies interviewed had used an apparatus committee that included stakeholders. These committees made the recommendation to add CAFS to their agencies new apparatus. K. Weatherill (personal communication, November 16, 2010) stated that in addition to the apparatus committee, his agency had review from the training division and administration as well before the final decision was made. Further, the firefighters and training division performed considerable first hand evaluation before making the recommendation to move forward. In comparing the four agencies success in implementing CAFS, it was clear that this was the most successful implementation process.

The survey of CCFD3 revealed that three quarters of the members felt like they had an insignificant role in the decision, and only a third could agree that the advantages of CAFS and implementation plan were clearly communicated. Like Pettigrew and Whittington found (Pettigrew et al., 2002), CCFD3 concluded that this lack of communication didn't develop the cooperation and consensus required to successfully implement this large of an organizational goal (Pettigrew et al., 2002).

With the second research question, are firefighters not using CAFS fire streams because of a deficiency in training and education, the results showed the lack of an incremental, consistent and comprehensive training program led members to rely on co-workers and self study to educate themselves about the use of CAFS fire streams. The end result of the identified deficiencies was varying degrees of understanding and competency across the department, and significant disparity between shifts.

Only 69.0% of the members passed the Compressed Air Foam Operational Quiz. When the scores were reviewed by shift, only one third of B-Shift members were able to pass the quiz while all C-Shift members passed. The Operational Instruction Practical Skills Evaluation resulted in 29.2% of the members failing the evaluation. The ability to properly produce CAFS fire streams is a basic job requirement. These failures demonstrated a lack of understanding of the differences in the types of CAFS fire streams in addition to unfamiliarity with the air compressor and how it fits into the overall CAFS pumping system. When the results were reviewed by shift, less than one third of B-Shift members were able to pass the evaluation while all C-Shift members passed. The practical skills evaluation result raises the question of why there is such a significant disparity in demonstrated proficiency between two shifts. If a mechanism had been in place as described by Bouldin (1989) and IFSTA (2004) to monitor the needs and comfort level of personnel during the change process, having almost an entire shift of personnel not attaining competency in the use of CAFS likely would have been avoided.

The training provided by CCFD3 was cursory in nature and focused on the steps required to produce a CAFS fire stream from the apparatus. During training, theory was only briefly addressed, and tactical considerations nearly overlooked entirely. I believe these results prove the point made by Chief Shaw (1876) over a century ago, that practical training without an underlying understanding of theory will result in a lack of proficiency.

T. Lyon (personal communication, November 15, 2010) and J. Gillard (personal communication, November 15, 2010) stated that each of their agencies utilized three members as pump instructors. These instructors had a primary responsibility of emergency response, and instructed as an additional duty. Both agencies also utilized manufacturer provided training. This training process resulted in a more successful implementation than CCFD3, but still didn’t reach the level of success as Weatherill’s (personal communication, November 16, 2010) agency. Weatherill’s addition of live fire training in acquired structures and experimentation by the training division followed Colletti’s recommendations in chapters nine and ten of his book The Compressed Air Foam Systems Handbook (Colletti, 2006), and likely keyed the organizational success of his agency with CAFS.

With the third research question, are firefighters not using CAFS fire streams because of a deficiency in apparatus or equipment, the results showed that CCFD3 has experiences that in some cases were consistent with and some experiences that were inconsistent with the literature review and interviews of other agencies.

When it came to the reliability of CAFS systems, the Boston Fire Department saw the lack of reliability of their systems as a key issue during their evaluations of 1992 and 1993 (Routley, 1994). Boston’s reliability problems were attributed largely to the fact that they had retrofitted systems to apparatus that were not designed for CAFS. The report written by J. Stern & G. Routley (1996) indicated that during their review of four separate departments they found system failures were few, and primarily suggested improvements to water proofing of the system electronics. Of the agencies interviewed for this research project, all three had CAFS installed as part of the original construction of their engines; none of the systems were retrofitted. T. Lyon (personal communication, November 15, 2010) and J. Gillard (personal communication, November 15, 2010) stated that both of their agencies experienced significant and continual problems with their first CAFS equipped engines. It is believed that this led to a hesitation by firefighters to trust the CAFS systems and prevented them from utilizing CAFS consistently. CCFD3 has had very little actual problem with the reliability of the CAFS systems over the six years they have been in service, and note that none of the systems were retrofit, and all of the perceived reliability concerns originated on B-Shift.

The literature review addressed the issue of hoseline management primarily as a deficiency in training. Improper CAFS system operations or poor hose handling techniques created most of the reported hoseline management problems. Under-pressurized hose lines and poorly-executed hose deployment led to increased occurrences of kinking (Fornell, 1991). Colletti (2006) explained clearly that slug flow is caused by water and air being discharged through the hoseline without the presence of foam solution. Slug flow can be prevented by introducing the water, foam and air in the proper sequence and proportions, or by disabling CAFS when the foam concentrate supply is exhausted.

Nozzle reaction is a result of the energy being discharged from the hoseline. Simple formulas calculate the nozzle reaction created in POW fire streams (Fornell, 1991). If one of these formulas is applied to a 1 ¾" handline with a fog stream nozzle flowing 136 GPM with a nozzle pressure of 100 psi, the fire stream would generate 69 pounds of nozzle reaction. Talyor (1997) measured and recorded the nozzle reaction for various a CAFS 1 ¾" handline and found that with a 15/16" solid tip with flowing 130 GPM the fire stream generated a nozzle reaction force of 70 pounds of nozzle reaction. The literature indicates that the nozzle reaction for POW fog fire streams and CAFS fire streams with a similar flow rates are the nearly the same. This is supported by the results of the interviews with T. Lyon (personal communication, November 15, 2010), J. Gillard (personal communication, November 15, 2010) and K. Weatherill (personal communication, November 16, 2010). The survey of CCFD3 members reported that two thirds indicated some issue with unmanageable nozzle reaction. Again a difference between shifts was recognized, namely more than half of the members of A-shift and C-Shift reported it to be a problem rarely or never, where all members of B-Shift reported it to occur occasionally or even more frequently.

The fourth hoseline management issue that was examined was hose line burn through due to direct heat exposure. The possibility of burn through was enough of a concern for Germany's Chief Fire Officer that he issued a nation-wide advisory to fire departments that they should not use CAFS if the hose lines could be exposed to heat or hot particles (de Vries, 2007). His advisory arose from the investigation of a double firefighter fatality that occurred where the deceased were operating a CAFS hand line. None of the interviewees expressed hose line burn through as a concern within their agency. The results of the survey showed this was not a concern with members of CCFD3 either.

The last research question, are firefighters not using CAFS fire streams because flow rate capability is less than that of water only fire streams, was identified as a concern in both the survey and interviews. This universal concern seems to be a result of firefighters incorrectly applying, or not having a basic understanding of, the recognized fire flow formulas and how they are properly applied. This view further supports research question two's finding that inadequate theoretical knowledge will result in reduced levels of competency. Royer (1995) and Hartin (n.d.) agree that key elements are commonly forgotten or not understood and lead to misapplication of the formulas. The Iowa fire flow formula and the NFA fire flow formula are the two formulas universally used in the U.S. to determine tactical fire flow. They are designed for drastically different fire situations, one for ventilation controlled fires; the other for fuel controlled fires. They use opposite methods of extinguishment; one displaces air thereby smothering the fire; the other cools the fuel below its ignition temperature. Iowa specifies flow rates required for fire attack of the single largest fire compartment, applied as a fog throughout the entire compartment simultaneously. The NFA flow rate is the total capacity for attack and back-up lines operating in support of all tactical objectives being conducted on the fire ground. The NFA formula is the most frequently one used in the field (Burns & Phelps, 1994). Though completely different, they are commonly used interchangeably, or one formula is applied to all fire environments regardless of appropriateness.

When answering question nine of the survey, over two thirds of respondents reported they did not believe CAFS had adequate fire flow to protect them from thermal injury. The results of survey question ten indicated that the respondents were comfortable using CAFS fire streams from outside the building, but three quarters were not comfortable using CAFS fire streams inside the building. T. Lyon (personal communication, November 15, 2010) stated that overcoming firefighter’s concern with reduce flow from CAFS fire streams was his biggest challenge. J. Gillard faced the same challenge (personal communication, November 15, 2010) and “tried to overcome the misconceptions” by explaining the science behind heat absorption.

Since CAFS is primarily made of water, it still retains the ability to absorb heat. A GPM of water in the form of CAFS foam will convert to steam and absorb the same amount of heat as a GPM of POW. It stands to reason that as long as enough GPM of CAFS is being applied properly, it would protect firefighters from thermal injury as well as the same GPM of POW.

Simple logic would likewise support the adequacy of CAFS fire stream capability to control the fire so long as the GPMs of the CAFS fire stream match the GPMs dictated by the appropriate fire flow formula. For example, under the NFA parameters, 100 GPM of CAFS fire stream would be able to control 300 square feet of area involved in fire in a 600 square foot room.

The limit to a CAFS fire suppression capability is its maximum GPM capacity of the CAFS being used. Most CAFS for structural firefighting engines are limited to about 400 GPM of “wet” foam. G. Geske (personal communications, August 10, 2010) explains that this is due to the need to maintain a water to air output ratio of two GPM of water to one CFM of air. Although modern fire pumps are generally capable of between 1250 GPM and 2000 GPM, the largest commonly used air compressor is rated at 200 cubic feet per minute. A CAFS capable of producing 400 GPM of CAFS would provide enough fire flow to control 1,200 square feet of fire involved in a 2,400 square foot building under NFA fire flow formula conditions. While it may not be enough for some of CCFD3’s bigger homes, this capacity would still be adequate for a majority of residential structure fires.

In closing, the results of the research as to why firefighters are resistant to using CAFS seem reminiscent of when Positive Pressure Ventilation (PPV) was introduced. The practice of using a high volume gas powered fans to pressurize the building in order to direct products of combustion out of the path of firefighters and introduce fresh air faster than natural ventilation could was billed as a huge technological leap in fire fighting. After sales representatives over-sold the capabilities of PPV and fire departments implemented the new practice hastily, without buy in from the rank and file, and without proper training and support, firefighters pushed back and resisted using PPV. Decades later, after more training and education have been invested, and the capabilities and limitations are better understood, the use of PPV is more common. Now firefighters understand that it is simply one more tool available to accomplish a tactical objective. When PPV is used within its capabilities and limitations, in the appropriate environment, by a crew that understands how to use it and is proficient in its use, it makes the fire easier and safer to extinguish resulting in less loss of life and property.

I believe the same to be true with CAFS. When CAFS is used within its capabilities and limitations, in the appropriate environment, by a crew that understands how to use it and is proficient in its use, it will make the fire easier and safer to extinguish resulting less loss of life and property. The research revealed that the resistance to the use of CAFS by the members of CCFD3 is due largely to a deficiency in comprehensive training, that addresses the concerns and perceptions of those expected to utilize it. The problems experienced as a result of the training deficiencies have cultivated a perception that the system is not reliable, difficult to use and doesn't provide effective fire suppression capability.

Recommendations

To attempt to overcome the resistance to utilize CAFS currently present within the organization, CCFD3 should implement the following recommendations beginning January 1, 2011:

1. The results of this research should be made available to all members of CCFD3
2. The Training Officer should meet with the shift officers to discuss the results, and explore why B-Shift's results were drastically different than the other two shifts.
3. The CCFD3 Training committee should assign a work group to develop a standardized training program for CAFS. This program should include the following elements:

a. The training should begin with compressive fire behavior education and how to apply fire streams using the NFA and Iowa fire flow formulas.

b. Education should be provided on the theory and characteristics of foam and CAFS, and also include tactical application philosophy and methods for fighting various types of fires.

c. Training should be provided on the operation of CCFD3 CAFS engines following manufacturer recommendations and CCFD3 policies to develop the ability to consistently produce effective foam fire streams and reduce the occurrence of slug flow.

d. Training should be provided on hose handling techniques to reduce the occurrence of kinking and managing nozzle reaction.

e. Training in CCFD3's live fire trainer should be conducted so that students can experience the performance of CAFS fire streams compared to POW fire streams in a controlled environment. The use of thermo couplers and a data logger are recommended to provide both objective and subjective information feedback on performance.

f. Training should be conducted in acquired structures so that students can experience the effectiveness of CAFS fire streams on a larger scale in a more complex and less controlled environment.

g. All live fire training needs to comply with NFPA 1403.

h. Delivery of training should be incremental in that competency is attained in each phase before progressing on to the next.

i. Student feedback should be monitored so needs can be addressed.

4. CCFD3 procedures should be modified to allow for the use of CAFS fire streams for various types of fires, including interior structure fire combat. Initially, interior structure fire combat should be limited to ventilated post-flashover fires. Pre-flashover fire attack with CAFS fire streams should be considered after more research into the effect of CAFS fire streams on pre-flashover conditions is conducted and members of CCFD3 have demonstrate proficiency in CAFS fire stream application.
5. A complete review and analysis of the CAFS program should be conducted two years after the implementation of the revised CAFS and procedures. This review should include at the minimum the following:
    a. The review should be completed by a workgroup of firefighters, company officers, chief officers and members of the maintenance division.
    b. Knowledge and skills evaluations including, but not limited to, those performed as part of this research.
    c. A review of apparatus and equipment maintenance records to provide an objective account of system reliability.
    d. A survey identical to and completed by the same population that was utilized for this research.

This author believes this applied research project has answered the problem statement and four research questions identified in the introduction. Future readers may find additional information available that more clearly addresses the issue of nozzle reaction for CAFS fire streams and comparative measures of water conversion efficiency of CAFS and POW fire streams. I believe further research should be conducted in three areas. First, the development of a scientifically based flow formula similar to the NFA formula that calculates amount of flow required by a CAFS fire stream or alternatively proving the existing formulas work adequately for CAFS fire streams. Second, determine how, if possible, to apply CAFS fire streams throughout the entire fire compartment simultaneously as required by the Iowa fire flow formula. And lastly, the effects of CAFS fire streams on fire gases and thermal layering in a pre-flashover environment.

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Appendix A

Clallam County Fire District No 3 Line Staff that served as the population for this research

Contact may be made with the below listed individuals through the district office at

323 N. 5th Ave, Sequim WA, 98382. The District business phone number is (360) 683-4242.

Office hours are 8:00 A.M. to 5:00 P.M., Monday through Friday.

Name	Rank	Call Sign	Pers. No.
Kettel, Dennis	Captain	305	803
Sharp, Derrell	Captain	305	819
Turner, Chris	Captain	305	828
Rynearson, Paul	Lt./PM	306	829
Upchurch, Jeff	Lt./PM	306	811
Cate, Chad	Lt./PM	306	825
VanDeWege, Kevin	Lt./PM	306	833
Bingham, Lawrence	Lt./EMT	306	823
Lawson, Marc	Lt./PM	306	831
Albers, Jeff	FF/PM		845
Anders, Steve	FF/EMT		837
Anderson, Travis	FF/EMT		850
Bower, Joel	FF/PM		855
Dickson, Scott	FF/EMT		835
Forderer, Lee	FF/EMT		854
Gates, Stefanie	FF/PM		846
Horst, Len	FF/PM		836
Johnson, Tyler	FF/PM		851
Konopaski, Kolby	FF/PM		852
McKeen, Joel	FF/PM		844
Newell, Matt	FF/PM		818
Parker, Larry	FF/EMT		824
Romberg, Jared	FF/EMT		848
Skov, Kjel	FF/EMT		842
Swanberg, Bryan	FF/PM		839
Tenneson, Troy	FF/PM		853
Tillman, Ryan	FF/PM		847
Whitaker, Jim	FF/EMT		834
Whitney, Ron	FF/PM		821

Appendix B

Delivery Operational Instruction Quiz

Name__________________________ Fire Dept_______________________ Date_______

1. Which of the following reduces waters efficiency as an extinguishing agent?
    a. surface tension
    b. weight
    c. evaporation rate
    d. affinity for carbon
2. Class A and Class B concentrates can be mixed
    a. true
    b. false
3. Finished Foam is agitation:
    a. of air and water
    b. of air and foam solution
    c. of water and foam solution
    d. none of the above
4. Which of the following is not a foam type?
    a. fluid
    b. wet
    c. dry
    d. surfactant
5. A clear soapy liquid with no bubble structure and immediately runs off vertical surfaces is a:
    a. foam solution
    b. wet foam
    c. fluid foam
    d. dry foam
6. A watery foam which does not hold peaks and flows easily is a:
    a. foam solution
    b. wet foam
    c. fluid foam
    d. dry foam
7. The idea of critical application rate suggests that:
    a. you should match the water flow to the fire situation
    b. if the fire is too big don't waste your foam
    c. if your water flow is adequate, larger flow rates will mean shorter knockdown time
    d. all of the above
    e. none of the above
8. Foam affects the critical application rate by enhancing the heat absorbing ability of water
    a. true
    b. false

9. Identify the correct device to prevent contamination of a water source;
    a. gate valve
    b. gated wye
    c. foot valve
    d. ball shut off valve
10. A positive environmental impact of foam is improved air quality.
    a. true
    b. false
11. As a air passes through a venturi the pressure in the center of the venturi:
    a. increases
    b. decreases
    c. remains constant
12. As the expansion ratio increases;
    a. drain time increases, foam becomes drier
    b. drain time increases, foam becomes wetter
    c. drain time decreases, foam becomes drier
    d. drain time decreases, foam becomes wetter
13. An aspirating nozzle generating a 50 to 1 expansion ratio is a:
    a. low x
    b. mid x
    c. high x
    d. CAFS

Questions 14-26 - Match the foam generating system number to the appropriate descriptor/feature.

14. high energy system	a. Aspirating nozzle	b. CAFS
15. mix ratio about 0.5%	a. Aspirating nozzle	b. CAFS
16. low energy system	a. Aspirating nozzle	b. CAFS
17. small uniform bubbles	a. Aspirating nozzle	b. CAFS
18. mix ratio 0.2%-0.3%	a. Aspirating nozzle	b. CAFS
19. multiple bubble size	a. Aspirating nozzle	b. CAFS
20. lighter hose weights	a. Aspirating nozzle	b. CAFS
21. foam formed at nozzle	a. Aspirating nozzle	b. CAFS
22. quarter turn ball valve used as nozzle	a. Aspirating nozzle	b. CAFS
23. foam formed in hose	a. Aspirating nozzle	b. CAFS
24. slug flow	a. Aspirating nozzle	b. CAFS
25. can create high x foam	a. Aspirating nozzle	b. CAFS
26. may require a mixing chamber	a. Aspirating nozzle	b. CAFS

27. Which of the following is not a component of a CAFS?
    a. air compressor
    b. Proportioner
    c. water pump
    d. Mid-X nozzle
28. The auto sync on a CAFS matches the water GPM and the air cfm
    a. true
    b. false

29. CAFS are capable of pumping:
    a. water
    b. CAF
    c. class a aspirated foam
    d. all of the above
30. An electronic direct injection proportioner with a digital display will provide information on:
    a. GPM flow
    b. water used
    c. percent concentrate injected
    d. all of the above
31. Which of the following is not a firefighter safety concern with CAFS.
    a. weight
    b. nozzle reaction
    c. charged hose line
    d. slug flow
32. Foam type produced by a CAFS can be changed by:
    a. changing the amount of air
    b. changing the amount of solution
    c. changing the foam percent
    d. changing the nozzle tip size
    e. a and d only
    f. all of the above

Ben,

You have completed your answer key. 7 wrong is not bad (78% B-), especially since the quiz is usually given right after our power point presentation. Let me know if you do not agree with my corrections or you need anything else.

Best regards,

Gregg Geske
CAFS/Foam Systems Sales Manager
WATEROUS SINCE 1886
125 Hardman Ave. S.
South St. Paul, MN 55075 USA
651-450-5036 Phone
612-963-5160 Cell
gageske@waterousco.com
www.waterousco.com

From: Ben Andrews [mailto:BAndrews@ClallamFire3.Org]
Sent: Wednesday, August 11, 2010 10:40 AM
To: Geske, Gregg
Subject: RE: Clallam County FD #3 fire test

Greg,
That's funny, your right, I can walk the talk

1. A
2. B
3. C
4. D
5. C The answer is A. The key is no bubble structure (not CAFS) and runs off (wet). Fluid foam is actually the dryer condition of CAFS.
6. B
7. C I believe the answer would be D. The fire does exist in which it is too big to put out and is not worth wasting foam. Flow plain water through the deck gun for the channel 4 news.
8. T
9. C
10. B It is actually true because of foams ability to attract carbon it takes carbon out of the air improving air quality.
11. A Answer is B. Speed increases but pressure decreases.
12. A
13. C
14. B
15. A
16. A
17. B
18. B
19. A
20. B
21. A

22. B
23. B
24. B
25. A
26. A The answer is B. A mixing chamber is used with CAFS when you are using in with a deck gun or a whip line in that you do not have an adequate length of hose to scrub the foam and produce a proper CAFS.
27. D
28. A This is kind of a trick question that most people get wrong it is B. The Auto Sync matches air pressure (psi) with water pressure (psi) .
29. D
30. D
31. C The answer is A. Weight of the hoseline is lighter. A charged hose line will flow for some time after it is opened even with the system shut down because of the compressed air in the hose.
32. F

From: Geske, Gregg [mailto:gageske@waterousco.com]
Sent: Tuesday, August 10, 2010 7:03 PM
To: Ben Andrews
Subject: RE: Clallam County FD #3 fire test

Ben,

There is but I have to make one for you. You do not expect me to let you off that easy. Take the quiz and I will give you the correct answers. Here is the practical.

Best regards,

Gregg Geske
CAFS/Foam Systems Sales Manager
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www.waterousco.com

Appendix C

Waterous Company
Delivery Operational Instruction
Practical test

Student name_______________________________ Date_____________
Fire Dept.______________________ Apparatus_____________________

Passing score—Minimum 80% of all tasks and 100% of critical tasks (*)

		pass	fail	verbal	practical
1. Engages pump/starts engine	*				
2. Engages compressor/starts engine	*				
3. Opens tank to pump valve	*				
4. Recirculates water to tank	*				
5. Turns on proportioner	*				
6. Switches auto sync to run	*				
7. Primes pump	*				
8. Explains operation of jet primer (optional)					
9. Switches auto sync to auto	*				
10. Explains operation of auto sync					
11. Adjusts pump pressure					
12. Flows water only	*				
13. Flows low x aspirated foam					
14. Flows mid x aspirated foam	*				
15. Flows wet CAFS	*				
16. Flows fluid CAFS	*				
17. Flows air only	*				
18. Demonstrates 4 ways to change CAFS foam type	*				
19. Demonstrates or explains use of static mixer					
20. Flushes system	*				

Evaluator ______________________________ Pass _____ Fail ______

Appendix D

Compressed Air Foam Systems at Clallam County Fire District No 3

As you know, I am working on an applied research project for the Executive Development course at the National Fire Academy.

By completing this questionnaire you are acknowledging that I have permission to use your responses for the purposes of this research project.

In the questionnaire Compressed Air Foam Systems is abbreviated to **CAFS**.

Please answer every question.

MAKE SURE TO CLICK THE <Finish Survey> BUTTON AT THE BOTTOM OF THE PAGE WHEN FINISHED MAKING YOUR SELECTION

Thank you in advance for taking the time to complete this. Please complete it prior to Wednesday November 17th, 2010.

http://www.kwiksurveys.com/online-survey.php?surveyID=HHEEFI_49f2ccb9

1. * What was your involvement in the decision to add CAFS to district apparatus?
   (if you were not a member of the district when the decision was made, select not applicable)

☐ Very Significant

☐ Significant

☐ Neutral

☐ Insignificant

☐ Very Insignificant

☐ Not Applicable

Reset

2. * The advantages of adding CAFS to district appartaus has been clearly communicated:

☐ Strongly Agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly Disagree

Reset

3. * The plan for implementing CAFS was clearly communicated.
(if you were not a member of the district when CAFS was implemented, select not applicable)

☐ Strongly Agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly Disagree

☐ Not Applicable

Reset

4. * Adequate training on how to produce a CAFS fire stream has been provided.
(if you have not been trained in producing any fire streams at this point, select not applicable)

☐ Strongly Agree

☐ Agree

☐ Neutral

☐ Disagree

☐ Strongly Disagree

☐ Not Applicable

Reset

5. * There has been adequate training provided in how to apply CAFS fire streams tactically in the following situations;

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Wildland fires	☐	☐	☐	☐	☐
Vehicle fires	☐	☐	☐	☐	☐
Exposure protection	☐	☐	☐	☐	☐
Interior structure fire combat	☐	☐	☐	☐	☐
Exterior structure fire combat	☐	☐	☐	☐	☐
None	☐	☐	☐	☐	☐

Reset

6. * I have participated in the following CAFS training;
(if you were not a district member during the 2004 or 2008 dealer training, please select '*not applicable*')

	Yes	No	Not Applicable
Dealer provided training 2004	☐	☐	☐
Dealer provided training 2008	☐	☐	☐
On shift by co-worker	☐	☐	☐
self study (trade journal, internet, etc.)	☐	☐	☐
seminars/classes outside of the district	☐	☐	☐

Reset

7. * Rate the reliability of the CAFS on the district's apparatus.
(ability for the pump, compressor and foam proportioner to produce a quality fire stream when operated correctly)

☐ Always reliable

☐ Usually reliable

☐ Neutral

☐ Rarely reliable

☐ Never reliable

☐ I have never operated a CAFS system

Reset

8. * I have experienced the following problems with CAFS hose lines;
(If you have experienced a hose burn through due to exposure to heat first hand, please describe in the box provided below)

	Very Frequently	Frequently	Occasionally	Rarely	Never	Have not used a CAFS hoseline
Hose line kinking	☐	☐	☐	☐	☐	☐
Hose line burn through due to heat exposure	☐	☐	☐	☐	☐	☐
Unmanageable nozzle reaction	☐	☐	☐	☐	☐	☐
Slug flow	☐	☐	☐	☐	☐	☐

Reset

Burn through experience

9. * When properly applied,I believe that CAFS fire streams provide adequate fire flow to protect me thermal injury during interior structural fire attack.

☐ Yes

☐ No

Reset

10. * How likely are you to use CAFS as the primary fire stream in the following fire scenarios; (assuming flow rate matched fire involvment)

	Very Likely	Likely	Neutral	Unlikely	Very Unlikely	Will not use
Wildland fire	☐	☐	☐	☐	☐	☐
Car fire	☐	☐	☐	☐	☐	☐
Exposure protection	☐	☐	☐	☐	☐	☐
Interior structure fire combat	☐	☐	☐	☐	☐	☐
Exterior structure fire combat	☐	☐	☐	☐	☐	☐

11. * What is your name

Appendix E

Officer Contact Information

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Appendix F

Interview questions for individual from agencies that have implemented CAFS from within the Puget Sound region.

Interviewer:______________________________ Location:_____________________________

Interviewee:______________________________Location:_____________________________

Date: ______________________________ Time :
____

Interview conducted [ ] Face to face [ ] By telephone **Consent** [ ] Verbal [ ] Written

1. How many compressed air foam system equipped apparatus does your agency have?

2. Do your line firefighters utilized compressed air foam fire streams on a regular basis for;
   a. Wildland fires [ ] Yes [ ] No
   b. Car fires [ ] Yes [ ] No
   c. Exposure protection [ ] Yes [ ] No
   d. Interior structure fire combat [ ] Yes [ ] No
   e. Exterior structure fire combat [ ] Yes [ ] No
   f. Any other uses [ ] Yes [ ] No
   If yes, describe:

3. Who was involved in the decision to implement the addition of CAFS to your apparatus?

4. What was the implementation process and who was involved?

5. What types of training were provided to the firefighters?

6. Have you have any problems with the CAFS itself?

7. Have you have any problems with hoseline management?

8. Have there been any concerns by firefighters related to fire flow with CASF fire streams?

Appendix G

Survey Question 1 Results

What was your involvement in the decision to add CAFS to district apparatus?

Graph G

Total Population Results

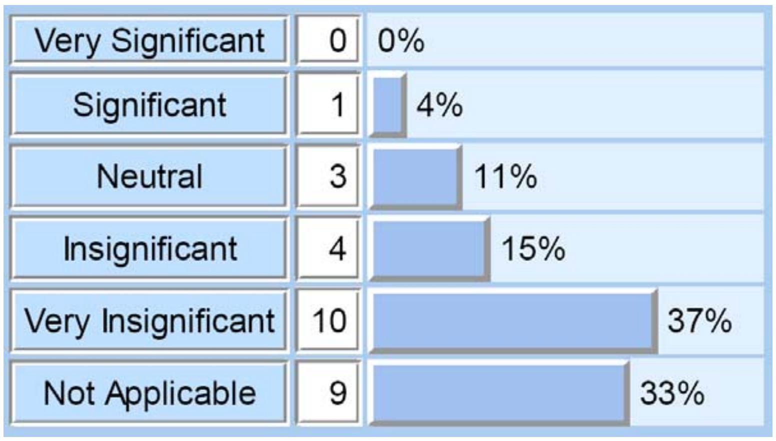

Table G

Results by Shift

A-Shift

Very Significant	
Significant	
Neutral	
Insignificant	37.5%
Very Insignificant	37.5%
Not Applicable	25.0%

B-Shift

Very Significant	
Significant	
Neutral	11.1%
Insignificant	
Very Insignificant	55.6%
Not Applicable	33.3%

C-Shift

Very Significant	
Significant	12.5%
Neutral	25.0%
Insignificant	12.5%
Very Insignificant	25.0%
Not Applicable	25.0%

Appendix H

Survey Question 2 Results

The advantages of adding CAFS to district apparatus has been clearly communicated.

Graph H

Total Population Results

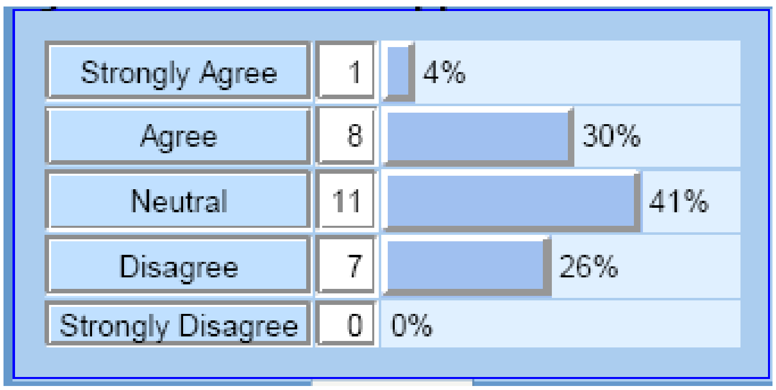

Table H

Results by Shift

A-Shift

Strongly Agree	
Agree	25.0%
Neutral	50.0%
Disagree	25.0%
Strongly Disagree	

B- Shift

Strongly Agree	
Agree	33.3%
Neutral	44.4%
Disagree	22.2%
Strongly Disagree	

C- Shift

Strongly Agree	12.5%
Agree	37.5%
Neutral	25.0%
Disagree	25.0%
Strongly Disagree	

Appendix I

Survey Question 3 Results

The plan for implementing CAFS was clearly communicated.

Graph I

Total Population Results

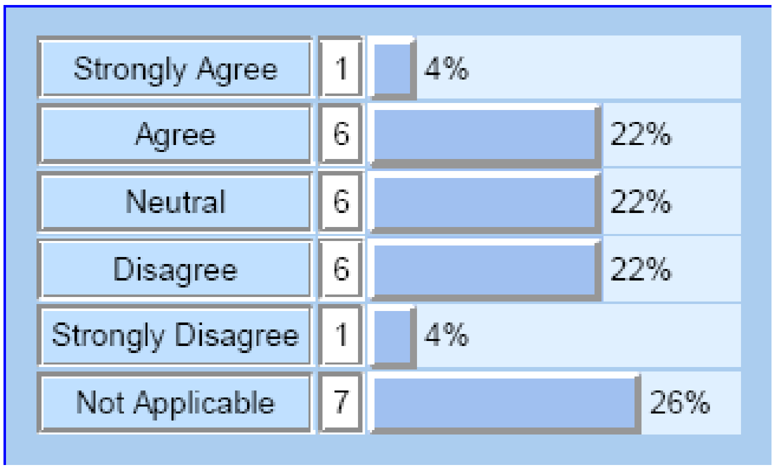

Table I

Results by Shift

A- Shift

Strongly Agree	
Agree	25.0%
Neutral	25.0%
Disagree	25.0%
Strongly Disagree	
Not Applicable	25.0%

B- Shift

Strongly Agree	
Agree	22.2%
Neutral	22.2%
Disagree	22.2%
Strongly Disagree	11.1%
Not Applicable	22.2%

C- Shift

Strongly Agree	12.5%
Agree	25.0%
Neutral	12.5%
Disagree	25.0%
Strongly Disagree	
Not Applicable	25.0%

Appendix J

Survey Question 4 Results

Adequate training on how to produce a CAFS fire stream has been provided.

Graph J

Total Population Results

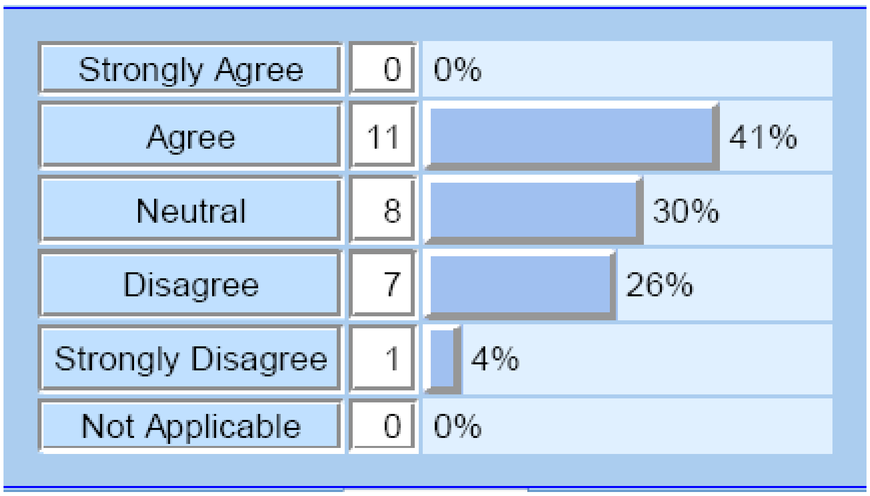

Table J

Results by Shift

A- Shift

Strongly Agree	
Agree	50.0%
Neutral	25.0%
Disagree	25.0%
Strongly Disagree	
Not Applicable	

B- Shift

Strongly Agree	
Agree	22.2%
Neutral	22.2%
Disagree	55.6%
Strongly Disagree	
Not Applicable	

C- Shift

Strongly Agree	
Agree	50.0%
Neutral	37.5%
Disagree	
Strongly Disagree	12.5%
Not Applicable	

Appendix K

Survey Question 5 Results

There has been adequate training provided in how to apply CAFS fire streams tactically in the following situations:

Table K1

Total Population Results

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Wildland fires	0%	33%	22%	37%	7%
Vehicle fires	4%	30%	30%	22%	15%
Exposure protection	7%	63%	15%	15%	0%
Interior structure fire combat	4%	19%	26%	37%	15%
Exterior structure fire combat	4%	48%	26%	22%	0%
None	0%	30%	52%	15%	4%

Table K2

Results by Shift

A- Shift

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Wildland fires		62.5%	12.5%	25.0%	
Vehicle fires		50.0%	25.0%	12.5%	12.5%
Exposure protection		75.0%	12.5%	12.5%	
Interior structure fire combat		50.0%	12.5%	25.0%	12.5%
Exterior structure fire combat		75.0%	12.5%	12.5%	

B- Shift

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Wildland fires			44.4%	44.4%	11.1%
Vehicle fires		11.1%	44.4%	22.2%	22.2%
Exposure protection		55.6%	11.1%	33.3%	
Interior structure fire combat	11.1%		22.2%	66.7%	
Exterior structure fire combat		22.2%	44.4%	33.3%	

C- Shift

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Wildland fires		50.0%	12.5%	25.0%	12.5%
Vehicle fires	12.5%	25.0%	25.0%	25.0%	12.5%
Exposure protection	25.0%	37.5%	25.0%	12.5%	
Interior structure fire combat		25.0%	37.5%	12.5%	25.0%
Exterior structure fire combat	12.5%	62.5%	12.5%	12.5%	

Appendix L

Survey Question 6 Results

I have participated in the following CAFS training:

Table L1

Total Population Results

	Yes	No	Not Applicable	Responses	Total
Dealer provided training 2004	7%	63%	30%	27	20%
Dealer provided training 2008	30%	59%	11%	27	20%
On shift by co-worker	70%	26%	4%	27	20%
self study (trade journal, internet, etc.)	78%	22%	0%	27	20%
seminars/classes outside of the district	15%	85%	0%	27	20%

Table L2

Results by Shift

A- Shift

	Yes	No	N/A
Dealer provided training 04		75.0%	25.0%
Dealer provided training 08	25.0%	75.0%	
On Shift by co-worker	75.0%	25.0%	
Self study	75.0%	25.0%	
Seminars	12.5%	87.5%	

B- Shift

	Yes	No	N/A
Dealer provided training 04	22.2%	44.4%	33.3%
Dealer provided training 08	22.2%	55.6%	22.2%
On Shift by co-worker	55.6%	44.4%	
Self study	66.7%	33.3%	
Seminars	11.1%	88.9%	

C- Shift

	Yes	No	N/A
Dealer provided training 04		62.5%	37.5%
Dealer provided training 08	50.0%	37.5%	12.5%
On Shift by co-worker	75.0%	25.0%	
Self study	87.5%	12.5%	
Seminars	25.0%	75.0%	

Appendix M

Survey Question 7 Results

Rate the reliability of the CAFS on the district's apparatus.

Graph M

Total Population Results

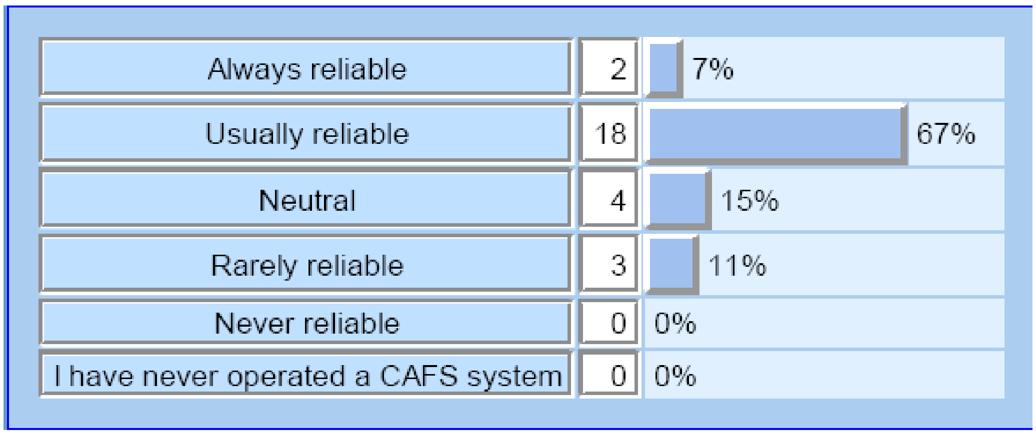

Table M

Results by Shift

A- Shift

Always reliable	12.5%
Usually reliable	87.5%
Neutral	
Rarely reliable	
Never reliable	
Have not operated CAFS	

B- Shift

Always reliable	
Usually reliable	44.4%
Neutral	22.2%
Rarely reliable	33.3%
Never reliable	
Have not operated CAFS	

C-Shift

Always reliable	12.5%
Usually reliable	62.5%
Neutral	25.0%
Rarely reliable	
Never reliable	
Have not operated CAFS	

Appendix N

Survey Question 8 Results

I have experienced the following problems with CAFS hose lines;

Table N1

Total Population Results

	Very Frequently	Frequently	Occasionally	Rarely	Never	Have not used a CAFS hoseline
Hose line kinking	11%	15%	48%	15%	7%	4%
Hose line burn through due to heat exposure	0%	0%	4%	7%	85%	4%
Unmanageable nozzle reaction	7%	19%	41%	26%	4%	4%
Slug flow	4%	22%	41%	22%	7%	4%

Table N2

Additional Comments If Respondent Had Firsthand Experience of Hose Burn Through

ID	Burn through experience
3231946	None
3245838	did not happen to me, but I know of one instance that it happened at JCFD 1 a number of years ago, I believe it was wildland related and was a result of hot ash and coals that were not seen

Table N3

Results by Shift

A- Shift

	Very Frequently	Frequently	Occasionally	Rarely	Never	Have not used CAFS
Hose line kinking	12.5%	25.0%	50.0%	12.5%		
Hose line burn through			12.5%	25.0%	62.5%	
Unmanageable nozzle reaction		12.5%	37.5%	25.0%	25.0%	
Slug flow	12.5%	25.0%	25.0%	37.5%		

B- Shift

	Very Frequently	Frequently	Occasionally	Rarely	Never	Have not used CAFS
Hose line kinking			44.4%	22.2%	22.2%	11.1%
Hose line burn through					88.9%	11.1%
Unmanageable nozzle reaction	22.2%	22.2%	44.4%			11.1%
Slug flow			66.7%	11.1%	11.1%	11.1%

C- Shift

	Very Frequently	Frequently	Occasionally	Rarely	Never	Have not used CAFS
Hose line kinking	25.0%	12.5%	50.0%	12.5%		
Hose line burn through				12.5%	87.5%	
Unmanageable nozzle reaction			37.5%	50.0%	12.5%	
Slug flow		62.5%	25.0%		12.5%	

Appendix O

Survey Question 9 Results

When properly applied, I believe that CAFS fire streams provide adequate fire flow to protect me from thermal injury during an interior structural fire attack.

Graph O

Total Population Results

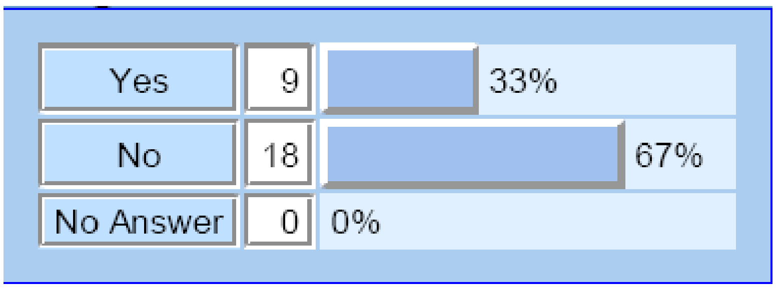

Table O

Results by Shift

A- Shift

Yes	No	N/A
25.0%	75.0%	

B- Shift

Yes	No	N/A
22.2%	77.8%	

C- Shift

Yes	No	N/A
62.5%	37.5%	

Appendix P

Survey Question 10 Results

How likely are you to use CAFS as the primary fire stream in the following fire scenarios?

Table P1

Total Population Results

	Very Likely	Likely	Neutral	Unlikely	Very Unlikely	Will not use
Wildland fire	0%	30%	15%	33%	19%	4%
Car fire	0%	41%	22%	22%	7%	7%
Exposure protection	26%	52%	15%	4%	4%	0%
Interior structure fire combat	0%	7%	19%	30%	26%	19%
Exterior structure fire combat	19%	48%	15%	15%	4%	0%

Table P2

Results by Shift

A-Shift

	Very Likely	Likely	Neutral	Unlikely	Very Unlikely	Will not use
Wildland fire		37.5%	12.5%	37.5%	12.5%	
Car fire		50.0%	25.0%	12.5%	12.5%	
Exposure protection	12.5%	50.0%	37.5%			
Interior structure fire combat			37.5%	25.0%	25.0%	12.5%
Exterior structure fire combat	12.5%	62.5%	12.5%	12.5%		

B- Shift

	Very Likely	Likely	Neutral	Unlikely	Very Unlikely	Will not use
Wildland fire		22.2%	11.1%	33.3%	22.2%	11.1%
Car fire		22.2%	11.1%	44.4%	11.1%	11.1%
Exposure protection	22.2%	44.4%	11.1%	11.1%	11.1%	
Interior structure fire combat		11.1%		44.4%	22.2%	22.2%
Exterior structure fire combat		55.6%		33.3%	11.1%	

C- Shift

	Very Likely	Likely	Neutral	Unlikely	Very Unlikely	Will not use
Wildland fire		25.0%	12.5%	50.0%	12.5%	
Car fire		37.5%	37.5%	12.5%		12.5%
Exposure protection	50.0%	50.0%				
Interior structure fire combat		12.5%	25.0%	12.5%	25.0%	25.0%
Exterior structure fire combat	37.5%	37.5%	25.0%			

Appendix Q

Results of Delivery Operational Instruction Quiz

Table Q1

Total Population Results

# correct	% correct
28	96.55%
28	96.55%
28	96.55%
27	93.10%
27	93.10%
26	89.66%
26	89.66%
26	89.66%
26	89.66%
26	89.66%
25	86.21%
25	86.21%
24	82.76%
24	82.76%
24	82.76%
23	79.31%
23	79.31%
23	79.31%
22	75.86%
22	75.86%
19	65.52%
19	65.52%
19	65.52%
17	58.62%
17	58.62%
17	58.62%
17	58.62%
16	55.17%
16	55.17%

Mean 78.48%

Passing score 70.00%

Table Q2

Results by Shift

A-Shift scores

# correct	% correct
27	93.10%
26	89.66%
26	89.66%
24	82.76%
24	82.76%
19	65.52%
19	65.52%
17	58.62%

Mean Passing score

B-Shift scores

# correct	% correct
26	89.66%
26	89.66%
22	75.86%
19	65.52%
17	58.62%
17	58.62%
17	58.62%
16	55.17%
16	55.17%

Mean

Passing score

C-Shift scores

# correct	% correct
28	96.55%
28	96.55%
28	96.55%
27	93.10%
26	89.66%
25	86.21%
24	82.76%
23	79.31%
22	75.86%

Mean

Passing score

Not assigned to a shift scores

# correct	% correct
25	86.21%
23	79.31%
23	79.31%

Mean Passing score

Appendix R

Results of Delivery Operational Instruction Quiz

Table R

Results of Delivery Operational Instruction Practical Test by Shift

A- Shift	Pass/Fail	Failure Explanation
Firefighter	Pass	
Captain	Pass	
Firefighter	Fail	Spread between different types of CAFS streams 24 GPM
Lieutenant	Pass	
Firefighter	Pass	
Lieutenant	Fail	Spread between different types of CAFS streams 2 GPM
Firefighter	Pass	
Firefighter	N/E	

B-Shift	Pass/Fail	Failure Explanation
Firefighter	Fail	Attempted to engage PTO with motor above an idle (damage potential)
Firefighter	N/E	
Firefighter	Fail	Spread between different types of CAFS streams 14 GPM
Firefighter	Pass	
Lieutenant	Fail	No air in system
Firefighter	Fail	No air in system/ no change in GPM.
Firefighter	Fail	To long duration of slug flow (no foam concentrate)
Captain	N/E	
Lieutenant	Pass	

C-Shift	Pass/Fail	Failure Explanation
Captain	Pass	
Lieutenant	Pass	
Firefighter	Pass	
Firefighter	N/E	
Lieutenant	Pass	
Firefighter	Pass	
Firefighter	Pass	
Firefighter	Pass	
Firefighter	Pass	

No Shift Assignment	Pass/Fail	Failure Explanation
Firefighter	Fail	No air in system
Firefighter	Pass	
Firefighter	N/E	

N/E = Not Evaluated