Project Number: MQP MTP 0003

The Feasibility of Protecting Residential Structures from Wildfires using a Fixed Exterior Fire Fighting System

A Major Qualifying Project
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WPI

Abstract

Wildfires pose a significant threat to residential structures in the wildland urban interface. Firebrands are the primary cause of home ignition because they can be transported miles from the flame front and ignite spot fires on or in very close proximity to dwellings. The overall project goal was to use a performance-based design approach to quantify the associated wildfire exposures and determine the feasibility of protecting residential structures from wildfires using an automatic fixed exterior fire-fighting system. The project team defined specific fire scenarios in which firebrands could ignite a home, determined an appropriate fire-fighting agent and put forth a proposed system design that includes the specification of system components and development of system discharge criteria and operation duration.

Capstone Design Statement

This project meets the requirements of the Accreditation Board for Engineering and Technology (ABET) for a Capstone Design Project. By addressing a number of different realistic constraints, as outlined below, the project team was able to apply knowledge and skills acquired in earlier course work to solve a real world engineering problem.

Economic

The cost of this system will ultimately be a limiting factor that controls the number of homeowners who will decide to install the system on their home. Although a complete cost analysis was not completed, the cost of several components was compared to inform certain decisions. For example, radiant energy detectors could potentially provide effective fire detection around the home. Unfortunately, they are prohibitively expensive. The linear heat detectors that we recommended can provide equivalent performance at a fraction of the cost.

Environmental

Since this system will be discharging on the exterior of a building, it has the potential to directly impact the environment surrounding the home. The use of a chemical foam concentrate was identified as the main environmental concern. NFPA 1150 *Standard on Foam Chemicals for Fires in Class A Fuels* was used to determine whether the specified foam concentrate meets established environmental regulations. This standard addresses mammalian toxicity limits (acute oral and dermal toxicity), aquatic toxicity, and biodegradability. The Class A foam concentrate that has been specified for this system meets all of the restrictions of NFPA 1150 and therefore we believe that the system will be environmentally safe.

Ethical

The design in this project is meant to protect the lives of people. Therefore, when designing the system proposed in this report, ethical decisions regarding risk and danger to people and the environment were strongly considered. The American Society of Civil Engineers has adopted a Code of Ethics to Guide Engineering Practices. Although all aspects of this code were not applicable, there were several canons of the code that we made efforts to actively uphold. First, engineers shall hold paramount the safety, health, and welfare of the public. Every decision that we made throughout the project served to create a final product that would be able to best protect the homes of those who chose to install it. Additionally, engineers shall perform services only in areas of their competence and shall only issue true statements. By carefully defining the project scope and also identifying limitations of the project, we were able to keep the project within the confines of areas that we felt competent in.

Health and Safety

Any fire suppression system, when designed and installed properly, will increase the level of safety in a particular structure. This system has been designed to preserve the structural integrity of residential structures during a wildfire event. The Society of Fire Protection Engineering

Performance Based Design Guide is an industry standard for solving engineering problems such as this one. By following the process in this guide and incorporating information from the National Fire Protection Association, Underwriters Laboratories, and FM Global, we are confident that this system will perform as intended to protect residential structures during a wildfire.

Manufacturability

To ensure that the system is easy to install, we have specified commercially available components that are already being manufactured. A manufacturer has been specified for each system component, but the engineer involved in each installation would have the freedom to select equivalent components from different manufacturers based on regional availability, pricing, or other considerations.

Sustainability

Sustainability is an important aspect for the desirability and success of any design. In connection to the economic design constraint, having a sustainable product will allow maintenance costs to be low which benefits the user or owner. The use of sustainable materials in the design is also advantageous to the environment. The proposed design and materials in this project report incorporate the importance of sustainability, as they are environmentally safe and tested and listed for external fire protection purposes. Using components that are weather resistant and listed for external use will allow the system to remain in place for as long as possible with minimal maintenance.

Professional Licensure Statement

Licensure is a process required for an individual to practice a regulated profession. Licensure must be administered by a state-level authority. The licensing process and requirements vary from state to state, but generally involve the same basic steps.

First, individuals must graduate from an Accreditation Board for Engineering and Technology (ABET) accredited engineering program. After, the graduate must take and pass the Fundamentals of Engineering (FE) exam to obtain their Engineering in Training (EIT) certification. Each exam incorporates fundamental topics such as calculus and physics as well as discipline-specific material. For example, the Civil Engineering FE Exam has questions on structural engineering, surveying, geotechnical engineering, and transportation engineering. After passing this exam, individuals must complete 4 years of work experience before applying for the Principles and Practice of Engineering (PE) exam. The number of years of work experience is one of the requirements that typically varies between states. Once the PE exam is passed, the individual will obtain their professional engineering license, granting them the ability to approve and stamp design documents for construction.

Obtaining a professional engineering license is a big accomplishment for any engineer, as it is a result of hard work and dedication to their profession. As this licensure advances careers, it also puts greater responsibilities on those that obtain it. Professional Engineers hold the safety of the design and of the people who are involved in the design and construction, as well as the people that will utilize the final product. They are held accountable for any liability that could result from the project. Licensure is important to the public because it sets uniform standards and ensures that individuals who are responsible for engineering designs have met minimum requirements for education and work experience.

Acknowledgements

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Table of Contents

List of Tables

List of Figures

Executive Summary

Wildfires in the United States are becoming more severe and more frequent. In an attempt to minimize the impact of wildfires, the United States Forest Service spent over 3.1 billion dollars on fire suppression in 2018; this accounted for over 50% of their budget (Amadeo, 2019; National Interagency Fire Center, 2018). Despite the money spent on fire suppression, over 25,000 structures burned down as a result of wildfires in 2018; 18,000 of these structures were residences (National Fire Protection Association, 2019). Homes in areas where human development mixes with the natural environment, also known as the wildland urban interface (WUI), are typically at the most risk. (Bracmort, 2014). The primary threat to structures in the WUI is firebrands. Depending on wind conditions, firebrands can be carried many miles away and arrive well before the flame front (Maranghides et al, 2013). Firebrands have the potential to initiate spot fires by igniting vegetation around the home and the structure itself (Caton and Gorham, 2016).

Firefighters who combat the flame front are not able to protect every structure; they will typically focus on extinguishing structure fires only if it will help their overall mission of stopping the wildfire spread (Hall Rivera, 2018). There are commercially available residential exterior suppression systems for wildfire management, but the effectiveness, performance and reliability of these residential systems remain in question. The commercially available systems that we researched use water as the suppressant. We identified foam as having the potential for more efficient fire suppression in an exterior setting. Foam concentrates lower the surface tension of water to allow improved penetration of the agent into fuels and certain foam solutions adhere better to vertical and horizontal surfaces. Additionally, foam systems require a lesser water demand and the suppressant can remain in place after discharging to provide enhanced exposure protection (Perry, 2001).

The overall goal of this project was to determine the feasibility of protecting residential structures from wildfire exposures using a fixed exterior firefighting system. We followed a performance-based design approach for this project consisting of the following steps:

1. Define project scope
2. Identify goals
3. Define objectives
4. Develop performance criteria
5. Develop fire scenarios and design fires
6. Develop trial designs
7. Evaluate trial designs
8. Modify design as necessary and re-evaluate
9. Select Final Design

A realistic fire scenario was developed and analyzed to model a pathway of home ignition via firebrand exposures. Firebrand exposures are a threat until the direct flame front has passed the house, which can take up to an hour from the time that the first firebrands begin to fall on or in close proximity to the house. Once initial ignition occurs, however, firebrands that fall on the house

contribute negligible heat compared to the growing fire, but do pose the threat of multiple ignition sources. In the scenario examined, firebrand accumulation in a mulch bed at the base of the home causes the mulch to ignite. The mulch fire ignites ornamental bushes planted within the mulch bed. Radiation from the bush and mulch fires then causes the siding of the home to ignite. The flames spread vertically up the wall until they reach the eaves. With no intervention from a fire fighting system, the time from mulch ignition to flames reaching the eaves was approximated to be 79 seconds. A conservative estimate of this fully developed fire is 3 MW, which includes the burning mulch, bushes and walls. With a fire fighting system in place, the fire scenario calculations indicate that the system will begin to discharge suppressant about 62 seconds after ignition.

We are recommending a fixed pipe compressed air foam system to protect homes from the firebrand exposures. This system consists of open nozzles installed at the eaves of the home to cover the walls and the ground around the home. The suppression system is split into four deluge zones that operate independently in order to conserve resources. The piping for each zone will run back to an enclosure in the backyard that houses the air cylinders, foam supply tank, and the control panel cabinet. We estimated a 6-ft by 6-ft space for this enclosure, while the water tank can be installed underground nearby. FireFlex was identified as the major manufacturer of fixed pipe compressed air foam systems, and their Integrated Compressed Air Foam (ICAF) System offers most of the components that were needed for this design. FireFlex does not specify a detection system for use with their ICAF System. Based on the conditions around the home and the characteristics of the fire scenario, we identified linear heat detection system as the best way to detect fires on the exterior of the home. When installed at two levels on each side of the home, linear heat detection can effectively detect fires in a timely manner. The detection system specified is also able to discriminate against short circuits to protect against nuisance alarms.

The threat of firebrand exposures was determined to be 1 hour. Therefore, the system must be equipped with sufficient resources to operate for this duration. It was determined that the system should discharge a minimum of 0.087 gpm/ft^2 over the design area. We are specifying compressed air foam at a 1 to 4 expansion ratio using a Class A foam concentrate proportioned at 0.3%. Based on these specifications, the system requires a minimum of 1310 gallons of water and 6 gallons of foam concentrate to discharge two zones for 1 hour. Additionally, the system will need sufficient power to operate independently since the power can be cut off in areas where a wildfire is occuring. It was determined that the detection system can be powered for 96 hours using two 12-Volt, 55 Amp-Hour batteries. Once the detection system actuates the ICAF system, the pressure from the air cylinders is enough to discharge the compressed air foam at the required density. Therefore, a fire pump is not required.

After obtaining the results of our project, we were able to conclude that the proposed system design is a feasible option to protect homes against firebrand exposures. The fire scenario calculations indicate that the proposed system design will be able to detect a fire, activate, and discharge foam within enough time to stop the flames from reaching the eaves of the home. All of the required components are commercially available, and the system will not occupy an excessive amount of space. Compressed air foam is more effective than water at suppressing Class A fires and the proposed system design will use less water than a water spray system. The total water flow rate for our system is 22 gpm, while FM would require at least 60 gpm for an exterior water spray system to protect this design area. Additionally, the Class A foam concentrate that we have specified is environmentally safe and non-toxic. This system, if installed at multiple properties, could relieve some of the stress on first responder assets as they make efforts to stop the advance of the flame front.

As we came to our recommendations, we found that there were several aspects of our analysis and design that could be further investigated to advance our proposed concept. FireFlex compressed air foam systems are only tested and listed with foam concentrates for use on Class B fires (flammable and combustible liquid fires). Additional work on the fire exposures and necessary system discharge would build confidence with our proposed system. Second, FireFlex uses a proprietary software for determining the hydraulic requirements of the system that is not distributed to the public. Third, by creating a system prototype or scaled model, future teams could test the system on Class A fires and determine an optimum expansion ratio and discharge density. Fourth, the enclosure of the components of the system has not been developed. The material and the specific design of the enclosure needs to be specified in more detail so that temperatures and other conditions within the enclosure can be properly maintained for effective system performance. Fifth, there is no one size fits all layout for the suppression system, as our simple house design is not universal to all homes in the WUI. Sixth, the aesthetics of the system could be improved; there will be pipes running along the siding of the house, nozzles attached to eaves, and a storage enclosure. The enclosure size may also restrict installations in small properties.

We did not consider the cost of the system installation during the design process. Further efforts are required to make an estimate of the proposed system cost and understand how the cost would change as the home size varies. Future research could also involve testing the activation time and determining ideal placement of the linear heat detectors on the wall. Our timeline assumes that the lower level of the linear heat detection will activate first. If the fire ignites the wall above this point, the detection system would be rendered ineffective and the system would not discharge in time. In terms of notification and user interface, a mobile app could be developed to provide homeowners with the ability to monitor the system integrity and potentially actuate the system manually. Since the proposed design combines products and systems that are already manufactured, some aspects of the system are not as effective as they would be if they had been specifically designed for this purpose. For example, special application nozzles with an extended horizontal coverage in one direction could be developed to protect the wall more efficiently with fewer nozzles. Another useful study could involve an investigation of the effect of compressed air foam on various construction materials. Homeowners will want to know if the foam discharge will damage their home before they invest in the system. It would also be advantageous to know how long the foam takes to dissipate after discharge.

1.0 Introduction

Wildfires in the United States are becoming more severe and more frequent. When comparing the time periods of 1970 to 1986 and 1986 to 2003, there are substantial differences in wildfire statistics. Wildfires in the latter time period burned four times as often, five times longer, and six times more land (Bradford, 2018). In an attempt to minimize the impact of wildfires, the United States Forest Service spent over 3.1 billion dollars on fire suppression in 2018; this accounted for over 50% of their budget (Amadeo, 2019; National Interagency Fire Center, 2018). Despite the money spent on fire suppression, over 25,000 structures burned down as a result of wildfires in 2018; 18,000 of these structures were residences (National Fire Protection Association, 2019). When considering costs resulting from structure loss, rebuilding, deaths, and tourism loss, the annual cost of wildfires is estimated to be in excess of 71.1 billion dollars (Levy, 2018). In reality, the costs are likely much greater due to difficulty in capturing the indirect costs associated with wildfires. Homes in areas where nature and the built environment meet, also known as the wildland urban interface (WUI), are typically at the most risk. (Bracmort, 2014). In California, over 75% of the 10,000 structures that burned from 2000 to 2013 were located in an area classified as WUI (Kramer et. al., 2018).

The primary threat to structures in the WUI is firebrands. The number of firebrands generated from burning fuels is so great that terms like “storm” and “blizzard” are used to describe the scene (Caton et al. 2016). Depending on wind conditions, firebrands can be carried many miles away and arrive well before the flame front. In one wildfire, firebrands arrived an hour before the flame front, from 6 miles away (Maranghides et al, 2013). Firebrands have the potential to initiate spot fires by igniting fuel beds and structures. The accumulation of small piles of brands have shown to contribute a high enough heat flux to ignite the home or vegetation around it. Certain parts of homes are specifically vulnerable to ignition by firebrands because they encourage firebrand buildup (Caton and Gorham, 2016).

Fire officials often recommend evacuations of residents in the wildland urban interface because the safety of residents is the primary concern in wildfire events (Cal Fire, 2019). In certain high-wildfire risk parts of the United States, residents can even be obligated by law to evacuate during a fire event (Lindroth, 2005). Once residents leave their homes, they are not able to defend against the approaching fire. Firefighters who combat the flame front are not able to protect every structure; they will typically focus on extinguishing structure fires only if it will help their overall mission of stopping the wildfire spread (Hall Rivera, 2018). Any other structure that ignites will be left to burn, which necessitates the development of an external suppression system that can protect residences in vulnerable areas even after the occupants have evacuated.

There are existing residential exterior suppression systems for wildfire management, but the effectiveness, performance and reliability of existing residential systems remains in question. One main concern is the effectiveness of the suppressant. Water is a popular choice for fire suppression, because of its relatively wide availability and excellent cooling capabilities. Unfortunately, it also has drawbacks that may limit its effectiveness in an exterior fire suppression system when considering a wildfire scenario. Water has a very high surface tension, which gives it a limited ability to penetrate fuels, such as wood and plastics. Water does not adhere to vertical surfaces or remain in place after being discharged (Ecuatepi, 2017). As a result, water spray systems must discharge a high density of water continuously for the entire duration of the fire even, which requires storage of massive amounts of water. However, even with large storage tanks of water, it is likely that the water supply will be exhausted before complete extinguishment of the burning house over the duration of the fire event. (FIRESafe Marin, 2019).

There are other fire suppression systems that are commonly used to fight fires inside of buildings CO_2, clean agents, water mist, and foam systems are available for use to control, suppress, and extinguish different types of these interior fires. Of these products, foam solutions have characteristics that exhibit the best potential for use in an exterior setting. Foam solutions lower the surface tension of water to allow better penetration of the agent into fuels and adheres to vertical and horizontal surfaces. Additionally, foam systems require much lower amounts of water, and remain in place after discharging (Perry, 2001).

The goal of this project is to assess the feasibility of an external automatic suppression system to protect one- & two-family residential structures against firebrand ignitions. To accomplish this goal, we used the performance-based design process outlined in the Society of Fire Protection Engineering Handbook to accomplish this project (Hurley, 2016). This process begins by developing goals, objectives, and performance criteria for this system. By considering the average size of homes in high wildfire risk areas as well as common house designs, we decided on a typical house design to use throughout the project. Next, several fire scenarios were developed to represent realistic pathways to ignition from firebrand exposures. The worst case scenario fire was identified and modeled in order to inform the development of a timeline of fire events. With all of this information in mind we proceeded to select a system type, identify system components, and propose a layout for the detection and suppression systems. The layout was then evaluated against the initial performance criteria to see if it could meet each performance criteria effectively.

2.0 Literature Review

This chapter aims to provide background information and context for the development of an external suppression system for homes in danger of wildfire attacks. The section begins by describing wildfire scenarios including ignition and spread, as well as existing mitigation techniques. It progresses to explain the existing codes and standards that are applicable to this project. Next, the fire exposures to homes are discussed, with a focus on firebrands. Then, there will be a discussion of available fire fighting, agents such as foam, followed by a discussion of the function and components of suppression systems and discusses the features of existing external suppression systems on the market. Finally, relevant stakeholders are identified.

2.1 Wildfire Ignition and Spread

Fire needs four things in order to burn: fuel, heat, oxygen and a sustained chemical reaction. In the wildland setting, oxygen is readily available in the atmosphere and fuel is typically available in large quantities in the form of trees, plants, and dead vegetation (Coffey, D). The third component, heat, is typically introduced by humans. Natural causes, namely wildfire and lava, are only responsible for 10 to 15% of wildfires in the United States. Humans are at fault for the remaining 85 to 90% of ignitions (Wolters, 2019). The National Interagency Fire Center (2012) reports that humans cause an average of 61,375 fires each year, while lightning ignites 9,941 fires. A study from the University of Colorado in 2017 analyzed the United States Forest Service's Fire Program Analyses-Fire Occurrence Database to attempt to break down the most common causes of human-ignited fires. Figure 1 reflects the data from the study. (Daley, 2017).

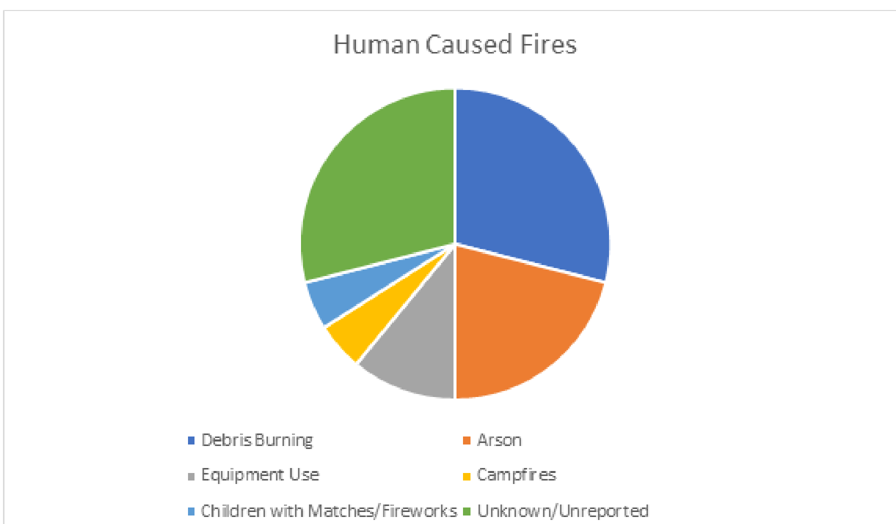


Figure 1. Most common causes of human-ignited fires.

Power lines are another source of wildfires and have been the subject of a lot of media scrutiny. High winds can blow branches into power lines or snap power line poles, or the equipment can otherwise fail in a variety of ways. (Atkinson, 2018). In November of 2018, California based utility company Pacific Gas and Electric made the decision not to de-energize power lines because of customer complaints, despite conditions that indicated high fire risk (St. John, 2018). A distribution line owned by Pacific Gas and Electric ignited what is known as the deadliest wildfire in California history, the Camp Fire, which would go on to kill 86 people and destroy 18,661 structures (Trabish, 2019). Over the course of 2017 and 2018, Pacific Gas and Electric was blamed for a total of 35 wildfire ignitions (Atkinson, 2018).

Wildfires are becoming more severe and more frequent. Four out of five of California's largest fires of all time have occurred since 2012. When comparing the time periods of 1970 to 1986 and 1986 to 2003, there are major differences in wildfire statistics. Wildfires burned four times as often, five times as long, and burned 6 times as much land in the latter period (Bradford, 2018). Climate change is one suspected cause of the increased wildfire problem. As greenhouse gases continue to accumulate in the atmosphere, temperatures are increasing around the planet. This, in combination with earlier snow melts, and the increased frequency and severity of droughts is making vegetation drier and easier to ignite (Coffey, 2018). Another major contributing factor to the current wildfire problem is fire suppression practices over the past century. The United States Government's historical focus on total suppression of all wildfires has led to incredibly dense accumulations of both dead and live vegetation in forests. Once a fire does occur, it is more likely to be on a catastrophic scale because of the high fuel density (Bradford, 2018).

2.1.1 Where Wildfires Occur

Although wildfires can occur anywhere, statistics show that they are more likely to occur in certain areas. Figure 2, developed by the Insurance Information Institute, provides wildfire statistics by state (Insurance Information Institute, 2019).

Rank	State	Number of fires	Rank	State	Number of acres burned
1	Texas	10,541	1	California	1,823,153
2	California	8,054	2	Nevada	1,001,966
3	North Carolina	3,625	3	Oregon	897,263
4	Georgia	2,572	4	Oklahoma	745,097
5	Florida	2,249	5	Idaho	604,481
6	Oregon	2,019	6	Texas	569,811
7	Arizona	2,000	7	Colorado	475,803
8	Washington	1,743	8	Utah	438,983
9	Oklahoma	1,707	9	Washington	438,834
10	Minnesota	1,344	10	Alaska	410,683

Figure 2. Ranking of top ten states in terms of number of fires and the number of acres burned in 2018.

This figure shows that there is no certain correlation between the number of fires and the number of acres burned. In 2018 Texas had over 2,500 more wildfire events than California, but there was over three times as much land burned in California. Nevada was number 2 when ranking states by the amount of burned area but did not even appear in the top ten list for number of fires. This suggests that states on the right side of the table tend to have fires that are more severe, while states on the left side of the table tend to have more frequent fires with less of an impact. From 2000 to 2014, 12 of the 20 most destructive fires in the U.S. burned in California (Kramer et. al., 2018). An analysis of data from the U.S. Forest Service's Fire Program Analysis Fire Occurrence Database (FPA FOD) conducted by The DataFace yielded Figure 3. It provides a useful visualization of where wildfires inflict the most damage across the country (Beckwith et. al., 2018).

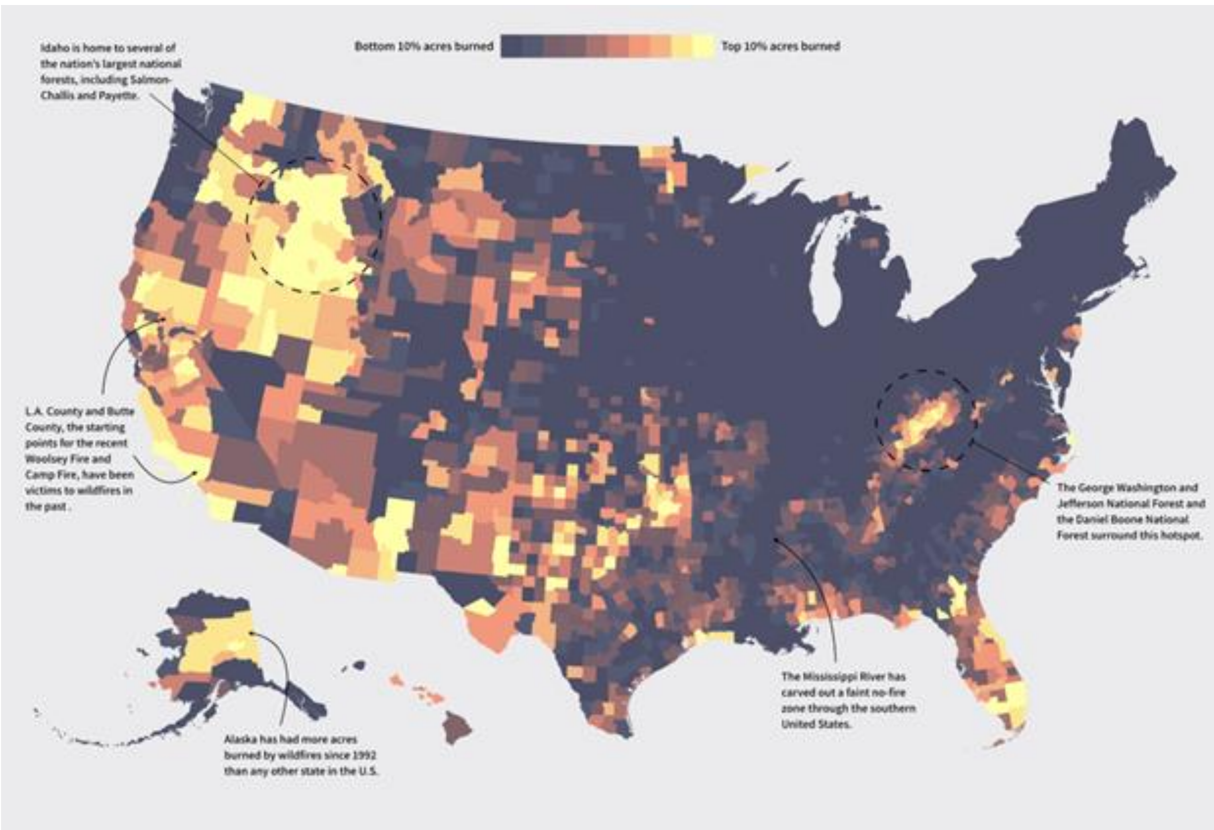


Figure 3. A visual map of the percentage of acres burned in each county in the United States from 1992 to 2015. Darker colors indicate less area burned (Beckwith et. al., 2018).

Several noticeable trends that are visible on the map include the apparent lack of wildfires in the Northeast and the Midwest, and large amounts of land burned in the West and Southwest. It should be noted that Alaska and Hawaii are not shown to scale in this image.

The wildland urban interface (WUI) is defined as the area "where humans and their development meet or intermix with wildland fuel (Bracmort, 2014). The WUI can be divided into two classifications. The interface area is where groups of buildings meet continuous stretches of vegetation, and the intermix area is where buildings are widely dispersed within vegetation (Kramer et. al., 2018). All 48 contiguous states contain land that is classified as WUI, and 10% of the total land in the 48 contiguous states is classified as WUI (Bracmort, 2014). Additionally, over 38% of homes in the United States are built on land in the WUI (Barth et. al., 2018). Human-caused fire ignitions are the most common in the interface (Hammer et. al., 2005). Despite this, not all areas of the WUI have a high wildfire burning risk. There are extensive areas of WUI in the Northeast that have historically had a low chance of burning. (Kramer et.al., 2018). Figure 4 shows the total amount of buildings in each state destroyed by wildfires as well as the percentage of these buildings that fell within the WUI. (Kramer et. al., 2018).

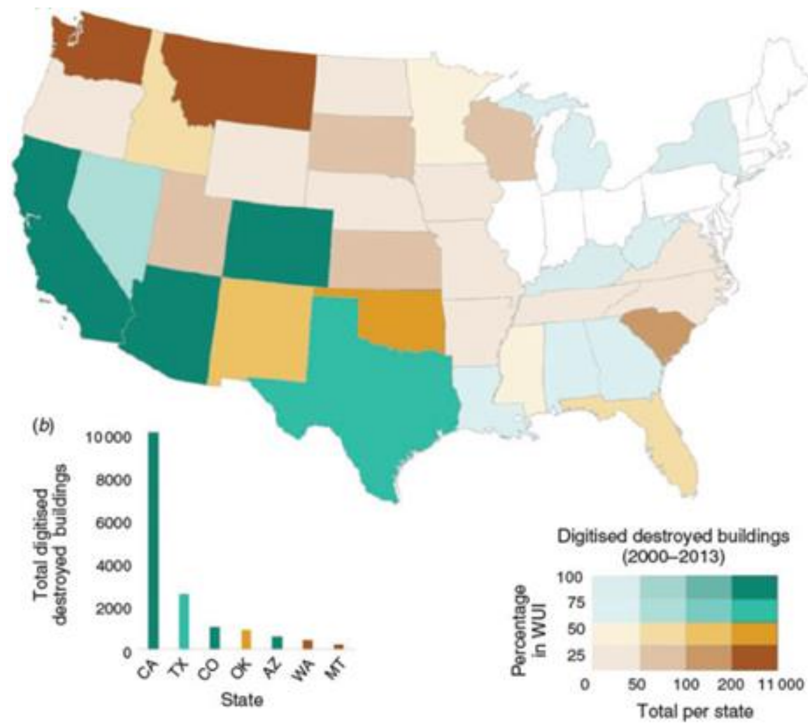


Figure 4. Percentage of total destroyed buildings located within the WUI, by state. Data is from 2000 to 2013.

In California, Arizona, and Colorado, over 75% of buildings that were destroyed by fire were in the WUI. In Montana and Washington, both of which had over 200 buildings destroyed during this time period, less than 25% of the destroyed structures had been located in the WUI.

2.1.2 Effects of Wildfires

Wildfires are destructive events that can lead to significant property damage, injuries, and deaths. In 2017, more than 71,000 fires burned approximately 10 million acres of land across the United States (National Fire Protection Association, 2019). In 2018, the U.S Forest Service and the Department of the Interior Agencies spent over 3.1 billion dollars on wildfire suppression costs (National Interagency Fire Center, 2018). Annually, fire suppression costs account for over 50% of the U.S. Forest service budget. (Amadeo, 2019). Despite the significant money spent on suppression, over 4,500 residential structures were destroyed by wildfires in 2015 (Dickie, 2016). Considering the direct cost of structure loss as well as costs from rebuilding, deaths, and tourism loss, the annual economic impact of wildfires is estimated to be anywhere from 71.1 billion to 347.8 billion dollars (Levy, 2018). The estimate is limited in accuracy because it is difficult to capture all of the indirect costs associated with wildfires. From 2010 to 2017, annual wildfire fatalities generally ranged from 8 to 15. 2013 is the outlier; there were 34 deaths that year after 19 firefighters died in a single fire in Arizona (National Interagency Fire Center). Intense flames during wildfires can also have negative environmental effects. Charred and damaged soil after a large fire can lead to landslides and floods in the area (American Forest Foundation, n.d.).

Wildfires, while destructive, can have a variety of positive effects on the environment around them. One major advantage is that intermittent burning can reduce the severity of future fires (Blackman, 2015). This is the principle behind techniques such as prescribed burning, in which controlled fires are purposely lit to burn excess dead fuel in the forest. Large amounts of nutrients are also returned to the soil by burning dead plant matter (American Forest Foundation, n.d.). These are nutrients that otherwise would have taken many years to be become available in the soil. The fire can also thin the forest canopies to allow more sunlight to reach the forest floor (Wolters, 2019) This, combined with the increased nutrient levels, will accelerate the growth of new plants and the larger trees that survived the fire. Certain species, such as the Sequoia Tree, depend on wildfires to trigger their seed opening cycles (deLacasta et. al., 2000; Wolters, 2019). Wildfires are also efficient killers of invasive plants, insects, or disease-ridden trees (American Forest Foundation, n.d.) Following the fire, native plants can repopulate the area. Certain species thrive in post-fire conditions, and the species composition of vegetation in an area can be altered by a fire event (Sackett, 1980).

2.2 Wildfire Prevention and Risk Mitigation

As wildfires continue to destroy millions of acres of land each year, tactics to prevent these disasters have become more prevalent (Insurance Information Institute, 2019). This section describes seven ways the authority has attempted to prevent wildfire ignition and development, as well as reducing the severity of these fires when they do occur.

2.2.1 Prescribed Burning

Prescribed burning employs intentional, controlled fires to burn excess surface fuel (Forest and Rangelands, 2014). The fires are carefully planned in advance and conducted at times when moisture levels are relatively high (Graham et. al., n.d.). Large fuels maintain moisture more effectively than surface fuels and are more likely to remain unharmed when a prescribed burn is conducted under moist conditions. A properly conducted prescribed burn will reduce the amount of litter while not affecting the total mass of woody fuels such as live, large trees. (Arthur, Blankenship & Alexander, 2017). A prescribed burning experiment conducted over 20 years by the United States Department of Agriculture showed that the total mass of dead fuels present in a given area of forest could be reduced from 43 to 65% from a single prescribed burn (Sackett, 1980). The most effective way to conduct prescribed burning is at regularly scheduled intervals. The time between burns varies depending on local conditions, but typically will not be less than one year (Sackett, 1980). Repeated burn treatments have been proven to be capable of reducing both the overall mass of dead fuel as well as the fuel continuity (Arthur, Blankenship & Alexander, 2017; Sackett 1980). By minimizing the amount of surface fuel present on the forest floor, the risk of catastrophic wildfires can be reduced. (Forest and Rangelands, 2014). Prescribed burning is best used in tree stands with low densities and minimal amounts of ladder fuels. It is also useful on steep slopes that may prohibit mechanical treatment (Omi, Pollet, 1999).

There are arguments against prescribed burning that prevent it from being implemented everywhere. Communities in the WUI are typically opposed to prescribed burning, even though it can reduce the risk of structure ignitions by lowering the risk of catastrophic fires and rapid fire spread. Some arguments against prescribed burning include inconvenient smoke production, negative aesthetic effects after the fire, and the risk of a fire "escaping" and spreading beyond the predetermined boundaries (Hesseln, 1999). Prescribed burns are restricted by law and are only scheduled during favorable weather conditions during which the fuel moisture, air temperature, wind speed, and humidity pose a low risk. One real concern regarding prescriptive burning is that it is not always precise in terms of burning the intended area (Omi, Pollet, 1999). When used over large areas, the unpredictable nature of fire can mean that there are varying densities of fuel left behind. Areas with large amounts of unburned fuel can form hotspots in future fires that can accelerate fire spread. Additionally, prescriptive burning requires that the personnel implementing it undergo extensive training to ensure the safety of the operation (Omi, Pollet, 1999).

2.2.2 Livestock Grazing

Considering the inherent risk involved in prescribed burning, several other methods of wildfire management have been developed. One of these methods is targeted livestock grazing. The introduction of more grazing animals to a region has been shown to correspond to a decrease in fire activity, spread, and connectivity if the animals are directed properly (Hessl et. al., 2016). By directing herds of animals (typically cattle) to eat the fine vegetation in certain areas, fire risk can be reduced by two main mechanisms. First, the overall amount of fine fuels available for combustion is reduced. Additionally, the fire spread can be restricted by interrupting fuel continuity. (Carlson, 2018). Throughout 2017 in Arizona, 31,000 acres of fuel were treated by grazing, while 33,000 acres of fuel were treated by mechanical tree thinning (Devoid, 2018). The United States Bureau of Land Management has also used targeted grazing on fine fuels, but these efforts have been mostly small scale (Carlson, 2018). While grazing is certainly a feasible strategy to manage vegetation, it can have negative effects if implemented without care. The main risk is overgrazing. This can create conditions that encourage the growth of invasive plants. Sometimes, these invasive plants are more flammable than the native ones; this can increase the fire risk (Devoid, 2018).

2.2.3 Mechanical Treatments

Mechanical fuel treatments involve the cutting, removing, and rearranging of plants and trees. Depending on the forest characteristics, the activities might include thinning dense stands of trees, piling brush, pruning low branches on trees, or creating fuel breaks (United States Forest Service, n.d.). Overall, the goal is to remove highly flammable undergrowth to reduce the probability of catastrophic fires, help maintain and restore ecosystems, and protect human assets (Eng, 2012; United States Forest Service, n.d.). Mechanical treatments utilize hand tools, bulldozers, and wood chippers to reduce vegetation in forests that are too densely packed or otherwise too hazardous to burn. (Omi & Pollet, 1999; United States Forest Service, n.d.). Sites that have implemented a program for mechanical fuel treatment have exhibited a dramatic reduction in fire severity as well as the amount of scorching in the crowns of trees. The mechanical treatments remove small diameter trees and ladder fuels, preventing the fire from spreading to the crown level of larger trees. Another advantage of mechanical fuel treatment is the precision that these methods offer. Before beginning a treatment, the organization in charge will typically specify the number of trees that should remain per unit area. This is much more accurate than prescribed burning, especially across large areas (Omi & Pollet, 1999). There have been concerns from various environmental organizations about the impact of mechanical treatments on ecosystem health. Implementation of this strategy has actually been shown to increase the diversity and health of a forest ecosystem, while having a minimum effect on wildlife in the area (Eng, 2012). The main limitation of mechanical treatments is that they can be very labor intensive, especially in remote areas or those with limited accessibility such as steep slopes in a dense forest (Omi & Pollet, 1999).

2.2.4 Herbicides

The application of herbicides is the final method that is commonly used to manage vegetation to reduce fire risk. Herbicides typically consist of a solution of water with low concentrations of chemicals that are sprayed over large areas to kill or injure the above ground portion of certain plants (deCalesta et. al., 2000). Like the other vegetation management methods discussed, herbicide applications are typically the most effective when combined with other strategies. For example, particularly thick vegetation may require an initial mechanical treatment followed by an herbicide application to achieve desirable results (Texas Forest Service, n.d.) Targeting invasive species with selective herbicides can preserve the health of native plant ecosystems by reducing competition for nutrients in the soil and encouraging the growth of desirable plant species (Texas Forest Service, n.d.). By suppressing the growth of small vegetation, more nutrients, water, and sunlight remain to encourage the growth of large trees (deCalesta et. al., 2000). The end goals of herbicide use coincide with those of the other vegetation management methods discussed previously: reduce the overall amount of small vegetation, while maintaining a population of large trees, and inflicting a minimum amount of damage to the environment. Herbicides used today are generally regarded as safe for people and the environment, but it is still important to be mindful of the chemicals' potential negative effects (Texas Forest Service).

2.2.5 Defensible Space

Managing land to mitigate wildfire risks in the wildland urban interface presents unique challenges because of the interaction of natural and manmade fuels. One of the most effective and commonly used tools to reduce the risk of wildfire damage to structures in the WUI is the creation of defensible space (Syphard et. al., 2014). The underlying principle of defensible space creation is similar to the principle management strategies used in forests: interrupting the continuity of horizontal and vertical fuels will slow or stop fire spread. Horizontal fuels include natural tree litter on the ground, grass, and low shrubs. Vertical fuels, also called ladder fuels, are typically in the form of small trees or tall brush that will provide the fire a path to reach the crowns of large trees (Colorado State Forest Service, 2012). Creating a defensible space around a home involves modifying or clearing select vegetation around a structure to increase the chance of fire survival. Removing 100% of vegetation around a structure is not feasible nor does it provide the maximum benefits. Generally, removing about 50% of natural vegetation (assessed from a plan view) and ensuring minimal fuel continuity will be sufficient to protect a structure while also discouraging the invasion of exotic grasses that may actually be more flammable (Syphard et. al., 2014). Generally, wildfire professionals recommend creating a defensible space of 30 meters around the home (Barth et. al., 2018). A study conducted in California that studied survival of homes from eight different fire events indicated that increasing the amount of defensible space over 30 meters will likely not provide additional benefits. The largest decrease in home destruction was noted between homes that had a defensible space measuring from 0 to 7 meters and those with a space measuring from 8 to 15 meters (Syphard et. al., 2014). This suggests that providing even a small amount of defensible space can noticeably reduce the risk of home destruction in a wildfire event. The following is a list of common tasks that may be performed to create a defensible space around a home: (Colorado State Forest Service, 2012)

- Prune branches up to 10 feet off the ground or one-third of the total tree height.
- Remove dead branches and prune shrubs periodically.
- Rake pine needles away from the base of large trees and from the house
- Trim grass regularly to maintain grass height below 6 inches.
- Store wood piles and combustible materials away from the house when possible

Different jurisdictions in the United States provide guidelines for defensible spaces based on local conditions. These guidelines may be enforced by community-based ordinances or by state-wide laws. As of 2005, California State law requires a defensible space of at least 30 meters around the home. However, local ordinances and many insurance companies across the state can require a defensible space up to 91 meters (Syphard, et. al., 2014). Real life studies have proven that creating and maintaining defensible spaces around homes can be effective in reducing the risk of structure ignition during wildfires. For instance, 83% of homes with defensible spaces in the 2010 Four Mile Canyon Fire survived the fire, compared to 63% of homes that did not have defensible spaces. Homes that had followed new policies (post-2000) to create their defensible spaces had a 100%

survival rate (Barth et. al., 2018). This suggests that as our understanding of fire increases over time, the strategies used to combat it become more effective.

2.2.6 Fire Resistant Building Materials

Creating a defensible space around residential structures is one action that can be taken to reduce home ignition risks from wildfires, but this alone is usually not enough. There are several different types of materials that can be used on the exterior of a residential structure to increase fire resistance and reduce home ignition risks from wildfires. Ignition resistant materials will resist ignition or sustained flaming combustion. This definition, provided in the latest edition of NFPA 1144 *Standard for Reducing Structure Ignition Hazards from Wildland Fire Hazards,* is not entirely quantifiable and leaves some room for interpretation. A noncombustible material will not ignite, burn, support combustion, or release combustible vapors when subjected to heat. Materials can be classified as noncombustible by passing ASTM E136 (*Standard Test Method for Behavior of Materials in a Tube Furnace at 750^{o}C)* or ASTM E562 (*Standard Test Method for Behavior of Materials in a Tube Furnace with a Cone Shaped Airflow Stabilizer, at 750^{o}C) (NFPA 1144, 2018).* Certain recommendations for building materials are simply suggestions and guidelines, while others are mandated by laws, codes, and standards. NFPA 1144 provides requirements for new construction in WUI areas. A major limitation of fire-resistant materials is that it is much easier to implement new construction. There is typically nothing forcing existing homes into compliance (Colorado State Forest Service, 2012). One requirement of NFPA 1144 is that all roof coverings shall be tested and rated as Class A by ASTM E108 or UL790. These test methods assess the fire resistance of roof coverings exposed to fires outside of a building. A covering may be awarded a Class A, B, or C rating, with Class A being the most fire resistant. Common Class A roof coverings include concrete shingles, clay shingles, and mineral reinforced shingles. Metal sheet roofing and fiber cement shingles can also achieve a Class A rating with a gypsum board underlayment. Bricks, stone, and concrete blocks are commonly used to build walls when a fire rated material is required; these materials can all achieve a 2-hour fire resistance rating. Below is a summary of NFPA 1144 requirements:

- Exterior walls shall be ignition resistant materials, fire retardant treated wood, noncombustible material, or have a 1-hour fire resistance rating
- Roof coverings shall be tested and rated as Class A by ASTM E108 or UL790
- Roof gutters, downspouts, and connectors shall be noncombustible and covered to minimize debris accumulation
- Vents shall be rested and rated to resist the intrusion of flames or ember by ASTM E2886, or be screen with non-combustible 1/8-inch wire
- Eaves shall be enclosed with fire retardant treated wood, ignition resistant materials, noncombustible materials, or materials tested and approved to resist wildfire penetration by ASTM E2957-15

- All overhanging projections (i.e. decks, balconies, patio covers, etc.) shall be constructed of heavy timber, noncombustible materials, fire retardant treated wood, or ignition resistant materials.

2.2.7 De-Energizing Power Lines

Power companies in wildfire-prone areas monitor humidity levels, temperatures, and high winds to predict when conditions may present a high fire risk. When a certain parameter is exceeded (i.e. wind gusts over 45 mph), the power distribution lines in the area are supposed to be de-energized to mitigate wildfire risk (St. John, 2018). Cameras and weather stations are used to monitor local conditions. Regular equipment inspections, infrastructure upgrades, and vegetation management can also mitigate wildfire risk (Trabish, 2019). The California Public Utilities Commission has adopted rules that will require utilities companies to de-energize power lines under certain conditions (Walton, 2018). Power companies are often reluctant to turn off the power because of backlash from customers. Following a line de-energization in October of 2018, California based Pacific Gas and Electric received 146 claims from customers, 25 of which claimed business loss or economic impacts (Trabish, 2019). This, combined with economic losses from not being able to sell electricity for the duration of the shut-down, will often keep power companies from de-energizing when conditions indicate they should. There is legislation in the works that aims to help utility companies offset some of the financial impacts associated with line de-energization (Walton, 2018).

2.3 Wildfire Suppression, Control, and Extinguishment

The previous section discussed actions that can be taken to reduce the intensity and likelihood of wildfires, but suppression and control methods are still needed once a wildfire ignites. The following methods are utilized by firefighting crews to manage and extinguish fires.

2.3.1 Aerial Firefighting

The first line of defense against wildfires, particularly those in remote locations, is aerial firefighting. Aircrafts are almost always able to reach the fire front before ground crews and can begin creating fire lines to control the spread of the fire (Calkin et. al, 2013). Direct attacks can be used to wet, smother, or quench the fire by application of the suppressant directly to the flames or burning fuel. Indirect attacks are typically executed when the fire is spreading rapidly and involve dropping the suppressant a distance away from the flame front to establish a control line (United States Department of Agriculture, 2019). Water and Class A Foams are typically used for direct attacks to cool the fire. Chemical retardant mixtures that will coat fuels and remain effective over time are used for indirect attacks (Gould et. al., 2007).

2.3.2 Ground Crew Firefighting

Firefighting crews on the ground work to extinguish, suppress, and control wildfires in various ways. One basic but effective method is the establishment of control lines. Control lines work on the principle of depriving the fire of fuel (Pedro Mountain Fire, 2019). Control lines may include roads, rocky features, or water features. Where these features do not exist, firefighters will remove all vegetation and dig down to mineral soil using either hand tools or bulldozers (Idaho Firewise, n.d.). The terms "control line" and "fireline" are often used interchangeably, but experts generally agree that there is a difference. A control line is a general term for any constructed or natural barriers used to control a fire, while a fireline is the portion of the control line that is constructed by digging down to bare mineral soil (National Wildfire Coordinating Group, n.d.). Fire lines are typically constructed to be from 6 inches to 3 feet wide, depending on the intensity of the fire and fuels present. The line needs to be wide enough to prevent smoldering, burning, or spotting by embers that may blow or roll across (National Park Service, 2017). Fires may jump control lines even when there is no fuel left in the immediate area, especially in windy conditions. To minimize the potential for this and increase the size of the control line, firefighters use a technique called burnout (Idaho Firewise, n.d.). Burnout involves igniting the unburned fuel within established control lines. Control lines may be constructed a great distance away from fast moving fires to ensure fire fighter safety. Burnouts can quickly treat large areas between the control line and the fire front to cut of the fuel supply from the main fire as soon as possible (Pedro Mountain Fire, 2019). Hotspotting is another technique that involves identifying and focusing on the most intense or fastest spreading parts of a fire (USDA Forest Service, n.d.). Hotspotting may take the form of concentrated attacks by using dirt or water to knock down the flames, or by building temporary fire lines to provide more time to construct the control line (National Wildfire Coordinating Group, 1996).

A less common, but very effective method to control wildfires is the use of explosives for various purposes. Explosives can rapidly build control lines by scattering debris and loosening mineral soil. A small crew with explosives can be deployed faster than a larger crew with traditional tools. Furthermore, this technique is more environmentally friendly than using bulldozers (National Wildfire Coordinating Group, 1996). Explosives can also be detonated directly at the flame front to knock down flames. The rapid pressure change and accompanying impulse of air can push flames away from the fuel (Hughes, 2014). Unfortunately, explosives are expensive and the individuals handling them must be highly trained (National Wildfire Coordinating Group, 1996). These are likely the two major reasons that limit the use of explosives.

In some cases, the best action may be to allow the fire to burn. Over the past century, the United States Government's policy of total suppression has created overgrown, dense forests that end up leading to more destructive fires (Oregon Forest Research Institute, n.d.). In the late 1970's, around the same time that prescribed burning began gaining traction, the government began to allow the use of managed wildfires. This practice involves using unplanned ignitions to meet various objectives (Forest and Rangelands, 2014). The use of managed wildfires can significantly reduce suppression costs as well as reduce damage and costs from future fires by decreasing the amount of fuel available to burn (Calkin, et. al., 2013). Under current laws, only the federal government is allowed to make the decision to allow fires to burn (Forest and Rangelands, 2014). Once the decision is made to allow a fire to burn, the fire's progress is closely monitored. The decision may change if the conditions become unsafe, particularly in the case of a change in wind direction that might drastically alter the fire's behavior (Rott, 2018). By strategically choosing to use these inevitable events to meet forest management goals and objectives, government agencies are able to save money, time, and resources.

2.3.4 Protecting Homes in the WUI

With an increasing number of homes in the WUI, firefighters are faced with the task of protecting more structures from wildfires. Because of a limited number of resources, firefighters need to perform a structural triage to determine where to focus their resources. Homes can be split into three groups:

- Category 1 – Needs little/no protection, will likely survive without intervention.
- Category 2 – Needs protection but is defendable with a reasonable amount of resources.
- Category 3 – Non-defendable/not worth defending. Will require too many resources, too much time, or would be unsafe to defend.

Firefighters will typically focus their efforts on homes in Category 2 in order to save as many homes as possible (Herlihy, 2008). Once firefighters have selected a home to protect, they will begin working around the exterior of the structure. If there is time, they will remove ignitable materials, close windows and awnings, and cover vents (National Wildfire Coordinating Group, 1996). Depending on the resources available, firefighters may then pre-wet fuels in the area with different agents (Department of Homeland Security, 2013). Even when there are resources and manpower available to protect a home, firefighters may be restricted by government policy. The Forest Service Manual prohibits the U.S. Forest Service from acting to suppress fire on structures, except for those that will reduce the overall risk of fire spread (Hall Rivera, 2018). The National Wildfire Coordinating Group's Wildfire Suppression Tactics Reference Guide (1996) breaks up the development of fire risk around the home into four stages:

1. **Spotting Zone** – Flame front has not arrived and firebrands may ignite spot fires. This stage can last for hours. Spot fires should be extinguished quickly.

2. **Full Containment** – Control lines will be able to stop the flame front from reaching the structure.

3. **Partial Containment** – Control lines and water can be used to split the fire around the home. Fire will move past structure before full control can be established.

4. **No Containment** – Fire cannot be stopped or knocked down before it reaches the structure. At this point, all hose lines shall be directed to the structure.

Ultimately, no property is worth a firefighter's life, and crews are always careful to properly assess risks before committing to protection (National Wildfire Coordinating Group, 1996). The Australian Government is a proponent of the active-defense shelter in place strategy. Controversial in the United States for the inherent risk involved, this strategy involves residents sheltering in their homes during the passage of the flame front. They also spend time outside the home before and after the flame front passes to extinguish any spot fires (Australian County Fire Authority, 2008). In some parts of the United States, residents are legally obligated to evacuate during a wildfire event (Lindroth, 2005). This clearly conflicts with the shelter in place strategy.

2.4 Exposures and Ignition

There are several ways a residential structure can ignite during a wildfire. Fuel on or around the structure such as siding, roofing, and deck materials or surrounding vegetation can all be at risk of ignition. In WUI fires, the heating of fuels causes flammable gases to be released until the flammable gases ignite on their own (auto-ignition) or are ignited by a spark (piloted ignition). The threat of ignition is posed to residences comes from three exposure sources which include radiant heat from the flame, direct flame contact from burning vegetation, and firebrands (Caton et al, 2016).

2.4.1 Radiation

Radiation is the heat energy that is emitted from the wildfire, and it is the one of the exposure conditions that can cause ignition of homes in wildfire events. Flames emit radiant heat that can travel away from the flame until they hit an object in their path. The radiant heat must be sustained at a high level for certain exposure duration in order to ignite a building material. Even if the radiation levels are not high enough to cause the building materials to auto-ignite, lower radiant heat levels can cause the material to pre-heat. This can cause the fuel to be more likely to ignite if later exposed to direct flame contact (Quarles, 2012). A study was conducted to understand the heat flux needed to ignite building materials. In the study, wooden wall assemblies were set up at varied distances for a burning fire and the heat flux was measured at the wall as a function of time. This test found that it's not an exact heat flux that causes ignition, but rather a certain accumulation of heat over time. The ignition threshold was found to be the flux-time integral value of 11,500 kJ/m^2. This means that any heat flux would have to be applied for a certain amount of time in order to reach this value before ignition could occur. If the flux-time integral does not reach the ignition threshold, the exposure is not strong enough for wall ignition. (Cohen, 2004). Critical heat flux for ignition has been calculated to be between 10 and 13 kW/m^2 for a range of wood products. For exposure to a constant heat flux, ignition times for solid wood typically ranged from 3 seconds for heat flux of 55 kW/m^2 to 930 seconds for heat flux of 18 kW/m^2 (White Dietenberger 2001). The actual crown fires produced in the study did not ignite the wooden panels at 20 m and beyond. Another study found that fuel samples exposed to a variant heat flux reached critical surface temperatures faster than under constant heat flux. Ultimately, the research done on radiant heat exposure has shown that unless flames are close to a structure, the structure is not likely to ignite

(Cohen 2000). The threat of radiative heat is greatly reduced by tending to the surrounding fuel and removing vegetation that can fuel the flames. Case studies of WUI fires have shown an approximate structure survival rate of 90 percent when vegetation is cleared between 10 and 20 meters away (Cohen 2004).

2.4.2 Direct Flame Contact

Direct flame contact is the second method by which a structure can ignite during a wildfire event. By following recommended wildfire risk mitigation techniques such as clearing away brush and wildland fuels, the threat of direct flame contract to the home can be significantly reduced. Only when nearby fuels catch on fire does direct flame contact become a threat. Studies have shown that direct flame contact can contribute fluxes of 50-70 kW/m^2 for laminar flames and 20-40 kW/m^2 for turbulent flames. Similarly to radiation from the main flame front, these fluxes are high enough to ignite combustible parts of structures if applied for enough time (Quintiere, n.d.).

2.4.3 Firebrands

Firebrands are pieces of flaming or smoldering debris that travel downwind of the flame front through the air (Urban et al, 2019). Firebrands are considerably the greatest threat to structures in the WUI because of their ability to travel far and ignite spot fires (Caton et al., 2016). Historical fires have proven that firebrands pose a serious threat to fire spread. In the London Fire of 1666, firebrands caused the roof of Saint Paul's Cathedral to ignite despite desperate efforts to save the church by creating a defense line. Firebrands have bypassed natural barriers such as rivers in the Chicago Fire of 1871 and roads in the San Francisco Fire of 1906. Firebrands even had the ability to spread the fire from mainland Japan across the sea to Moon Island in the 1923 Tokyo Fire (Koo et al. 2010). The Commonwealth Scientific and Industrial Research Organization conducted research on spot fires during the 2003 Canberra Fires and found that over 60% of the burned structures were the ignited only by firebrands, and that over 90% of the burned structures were destroyed without being contacted by direct flames of the fire (Leonard and Blanchi 2005).

Although it is difficult to quantify the number of ignitions that are caused by firebrands, there is clear evidence that these traveling embers are a contributor to the spread of wildfires, and it has been estimated that a majority of the structures lost in wildfires were ignited via firebrands (Maranghides & Mell 2013). One piece of evidence corroborating this idea is when a house burns down in a community where the flame front did not pass through, and all of the surrounding houses remain untouched. This indicates that a firebrand created a spot fire which caused the destruction of a home. In severe wildfires, firebrands will shower down like rain. Evidence of the effects of firebrands was presented by Jack Cohen when he investigated the Cerro Grande Fire in 2000. Figure 5 shows a completely destroyed home surrounded by relatively untouched vegetation. The home was separated from other burning homes by a road (Cohen, 2000). This provides evidence that firebrands ignited the home or fuels around the home that then caused it to ignite.

Figure 5. Evidence of firebrand effects in isolated burn (Cohen, 2000).

The ignition of a fuel by a firebrand can be broken down into three individual processes: firebrand generation, propagation/transportation, and target fuel ignition. Figure 6 by Urban et. al. shows the three steps of how firebrands initiate spot fires downwind of the flame front.

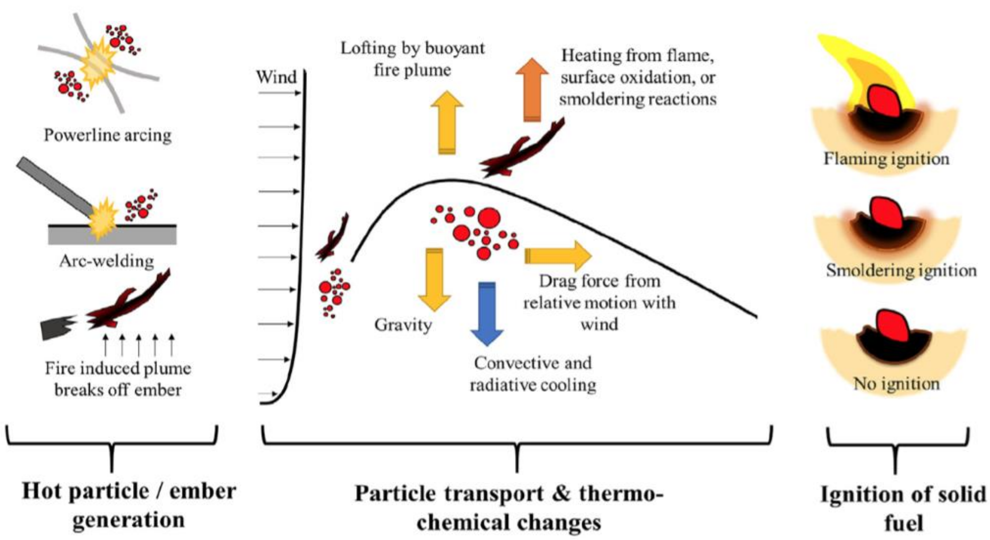


Figure 6. The three sub-processes of how firebrands ignite spot fires (Urban, 2019).

2.4.3.1 Generation

The first sub-process in firebrand spot fire ignitions is generation. Many studies have been conducted to gain an understanding of the generation of firebrands from vegetation, structural components, full structures, and actual fires in the WUI (Caton et al., 2016). Figure 7 shows that hot particles and embers can be generated by powerline arcing, arc-welding, and break-off of pieces from burning materials. The third method will be the focus of this discussion because the majority of the ember generation during fires in the WUI comes from the burning of vegetative and structural materials. The size of firebrands was found to vary anywhere between 5 and 40 millimeters in diameter and the weight can vary between 0.1 and 3 grams (Manzello et al 2007a). One study investigated the ability of roof materials to produce firebrands and found that wood-shingled roofs to produce the most firebrands and the maximum size was 38 mm by 38 mm with a thickness of 19 mm and weight of 3 grams (Koo et al., 2010). Two studies burned different fuel sources: one burned Douglas-fir trees (Manzello et al 2007a) and the other burned structures (Vodvarka 1969). The two studies found that larger fuel sources generate bigger firebrands. These studies were all conducted in lab settings and did not account for actual conditions like wind speed. Suzuki et al. conducted an experiment burning full-scale structures that were exposed to a 6 m/s wind. More than 90% of the firebrands generated and collected from these structures weighed less than 1 gram and had an area of less than 10 cm^2 (Suzuki et al., 2014).

2.4.3.2 Transportation

The second stage is transportation. Firebrands are transported by wind or by the plume of fire. The forces acting on firebrands in the air are the drag force due to the motion of wind, lofting by the plume, gravity, and cooling (Urban 2019). George M. Byram concluded that the hot air of the plumes from intense fires can carry embers high into the air and drop them far ahead of the front (Koo et al., 2010). As the scale of the fire increases, the plume size increases and more firebrands are lofted into the air (Urban et al, 2019). Therefore, as the fire gets bigger, it generates more firebrands which then help to further propagate the fire. Wind conditions are also a critical factor that affects the transport of firebrands. Strong wind conditions can increase the buoyant force in the plume. As a result, the plume is able to loft larger firebrands and transport firebrands further (Koo et al., 2010). Firebrands were found more than 10 km away from the flame in the Peshtigo Fire of 1871 (Koo et al, 2010). In addition, a NIST report on a community outside of San Diego that was affected by the 2007 Witch Creek and Guejito Fires found that firebrands can arrive one hour before the flame front and travel up to 9 kilometers (Maranghides et al, 2013). Models have shown that strong winds allow firebrands to travel further, but the increased flight time causes firebrand mass to decrease (Koo et al., 2010). This might cause firebrands to have less energy available to ignite a fuel bed after traveling far distances. Finally, a study was conducted by Vodvarka in which he collected firebrand data after an accidental fire. In this case, firebrands were found up to 274 meters away from the fire during which winds were fully developed at 10-25 miles per hour. Review of previous studies indicates that the distance a firebrand can travel is dependent on how high the plume lofts the firebrands as well as wind speeds during a fire.

2.4.3.3 Fuel Ignition

In order for fires to propagate through the wildland urban interface, fuels must continue to ignite in the path of the fire. Ignition is defined as the process by which a sustained combustion reaction occurs between a combustible material and an oxidizer, resulting in the release of heat. (Urban, 2108). Firebrands have the ability to directly ignite structures by landing on them or ignite surrounding fuels that subsequently contribute radiative heat and direct flame exposures to the structure (Urban and Fernandez-Pello 2018).

Ignition is a complex process that depends on many different variables. On a basic level, ignition will occur if the firebrand has enough energy to heat the fuel to a certain temperature. This temperature is the peak at which the pyrolysis reaction occurs, which is a general approximation for the temperature at which ignition can occur (Urban and Fernandez-Pollo 2018). This critical temperature is not the same for all fuels because it depends on the aforementioned factors. Whether or not ignition occurs when a firebrand contacts a fuel depends on (1) the properties of the firebrand, (2) the fuel, and (3) the ambient conditions.

1. The amount of energy supplied by firebrands depends on the size and the temperature of the brand when it lands on a fuel source (Urban 2018). The state of the firebrand upon landing can also affect the ignition probability. The two states are flaming and smoldering.
2. The properties of the fuel that affect ignition are the density, porosity, heat capacity, thermal conductivity and moisture content (Urban and Fernandez-Pollo 2018).
3. The ambient conditions also affect ignition by influencing the rate of pyrolyzate production and gas phase ignition. According to Fernandez-Pello, the most influential ambient conditions are "the gas flow velocity around the combustible material, thermal radiation from or to adjacent sources, and the ambient pressure and oxygen concentration" (Fernandez-Pello, 2011). Greater wind speeds were found to increase the ignition probability by supplying more oxygen (Koo et al. 2010).

Research in the field has begun to study and try to quantify the factors that affect the ignition of a fuel bed by a firebrand. Manzello et al. studied firebrand deposition in materials configured at different angles. He found that while accumulations of firebrands are capable of igniting common building materials, singular firebrands were not. Manzello et al. also exposed deck structures to firebrand showers driven by constant wind speeds. It was found that firebrand piles of 7 to 25 grams could initiate flaming ignition of the deck when exposed to an 8 m/s wind. When wind was applied at a speed of 6 m/s, a larger mass of firebrands was needed to ignite the deck (Manzello et al. 2012). Dowling conducted firebrand tests in bridge beams that were spaced 10 millimeters apart. The tests found that a 7-gram pile of firebrands induced ignition. Firebrands were studied at the University of Maryland to characterize their thermal properties. A single firebrand was shown to peak below 20 kW/m^2. The largest firebrand piles tested, with 9.6 grams of firebrands, were able to sustain a heat flux over 10 kW/m^2 for over 16 minutes. For firebrand pile masses between 4 and 10 grams the average peak heat flux ranged from 40-60 kW/m^2 (Hakes et al. 2018). Like the previous exposures of radiation and direct flame contact, it was necessary to maintain a critical heat flux for a given time to cause ignition and time to ignition decreased as heat flux increased. An important result of this study was that airflow was required for ignition and would produce higher heat fluxes. This corroborates the finding of Manzello et al. that wind plays a key role in ignition. Lastly, this study found that re-radiation and reheating within a pile of firebrands are contributing factors in the ignition of fuels, and these two processes are absent for single firebrands (Hakes et al., 2018). More research is needed to identify specific conditions that will result in ignition. Current literature suggests that an increase in wind and firebrand pile mass increases the likelihood of fuel ignition.

The combustion of a fuel can be categorized into three different types: flaming, glowing, and smoldering. Flaming combustion is gas-to-gas phase where the fuel has been turned into its gaseous phase and reacts with the oxidizer causing a visible open flame. Glowing and smoldering combustion occurs in the absence of open flame and is a reaction between the solid phase of the fuel and the oxidizer (White Dietenberger 2001). The difference is that glowing combustion produces a light from the fuel where smoldering produces neither flame nor light. Most firebrands stop flaming combustion and therefore land on fuels in a smoldering state but continue to generate heat through chemical reactions when in contact with the fuel (Caton et al 2016). The firebrands can cause the fuel to begin smoldering and then transition into flaming. For example, contact of firebrands with plywood at an angle of 60 degrees caused smoldering ignition that transitioned into flaming ignition (Manzello et al., 2009). High heat fluxes of 40 to 70 kW/m^2 can produce flaming ignition of wood and glowing combustion can occur at heat fluxes less than 40 kW/m^2 (Ellis, 2012).

2.4.4 Vulnerabilities of Structures

As a wildfire travels through the WUI, structures are exposed to the three aforementioned exposure methods. Certain components of the structure are particularly susceptible to ignition by these exposure methods, including the roof, deck, siding, and surrounding areas. These components are identified in Figure 7 below.

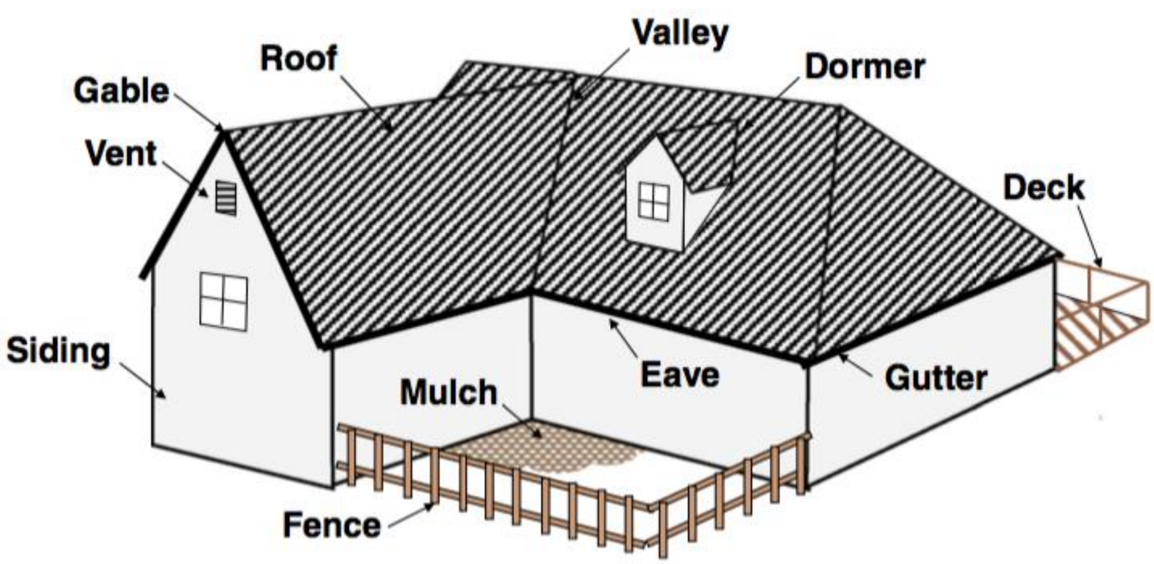


Figure 7. Vulnerability points of ignition on a home (Caton, 2016)

Certain roof materials increase the risk of ignition because they are easily ignitable. Wood shake and shingle roofs are two examples of materials that have a large surface area of flammable material. Wood shakes are known to produce a large number of firebrands; it was estimated after the 1991 Oakland Hills fire that non-retardant wood shake roofs caused the ignition of ten further homes (Caton, 2016). Important characteristics of roofs to prevent ignition and discourage fire propagation are the ability to resist fire spread into the attic, resistance to flame spread onto the roof covering, and resistance to firebrand generation (Caton, 2016). One study performed at the Insurance Institute for Business and Home Safety ran a full-scale experiment to expose a roof to a firebrand shower. The results showed that even fire rated roofs are susceptible to ignition at the crevices where the roof and siding intersect (Quarles, 2012).

Gutters are another pathway through which a home can ignite due to the buildup of dead material which can be easily ignited by firebrands upon landing in the gutter. Vents and eaves provide an opening for brands to enter the residence, but mesh can be used to reduce the potential for ignition (Manzello, 2010). Another major vulnerability point on the home is the wall. Direct flame contact and radiation are the two exposures that mainly cause side wall ignition, especially where corners of walls join as wind can cause the flame to recirculate in the corner and lead to a higher risk of ignition (Canton, 2016).

2.5 Water Spray vs. Alternative Systems

While there are consistent and dependable procedures to extinguish interior house fires, methods to suppress exterior fire exposures, specifically those due to wildfire, have not been proven. Several suppressants have been used in attempts to smother wildfire, including water, foam, and gel. Each suppressant presents unique advantages and disadvantages in regards to wildfire suppression.

2.5.1 Water

Although water may seem like an obvious fire suppressant due to its high specific heat and cooling potential, it is not the most efficient suppression agent to protect homes from wildfires. Water has a very high surface tension, causing droplets to roll off of fuel rather than penetrate and into the fuel bed. Due to this same characteristic, water does not adhere to vertical surfaces (Ecuatepi, 2017). Therefore, water would be ineffective in fighting fires that ignite the sides of homes. Furthermore, large amounts of water would have to be discharged at a constant high velocity to suppress a wildfire attack on a home. Existing external home suppression systems have used water tanks in the range of 5,000 gallons, and even then, the water supply would likely be exhausted before complete extinguishment of the fire (FIRESafe Marin, 2019). The amount of water and storage area that is required for an external water spray system is unrealistic for residences to implement.

2.5.2 Foam

Foam concentrates contain characteristics that enhance the properties of water. Different types of foam concentrates have been developed for specific applications. One foam that is commonly used for fire suppression is Aqueous Film Forming Foam (AFFF). AFFF contains fluorinated carbon-chain compounds, which make chemicals called perfluoro octane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA). Although effective in extinguishing large fires, these chemicals are “mobile chemicals that persist indefinitely in the environment, bioaccumulate in humans and animals over long periods of time, and bio-magnify as they are consumed up the food chain” (New Jersey DEP, 2019). These environmental impacts of AFFF have caused several lawsuits. AFFF is typically used to extinguish Class B fires which are flammable liquid pool fires in locations such as chemical plants and oil refineries (ITRC, 2018). Therefore, it is not relevant to wildfire suppression.

Class A foam, however, is a common suppressant used to fight Class A fires. Class A fires are fires involving ordinary combustibles such as wood or paper. Wildfires fall under this category (Mitrokostas, 2018). Class A foam is a combination of water, air, glycol, and hydrocarbon-based surfactants that create a bubbly mixture with a lower surface tension and density than water (Perry, 2001). These characteristics allow better penetration into the fuel bed, as well as adhesion to vertical surfaces. Foam also creates an oxygen barrier by forming a blanket over the fuel. By removing oxygen from the fire, the foam stops the combustion reaction between the oxygen and fuel. Furthermore, the bubbles release moisture, absorb heat, and produce steam to cool the fuel (Chemguard, 2019). The bubbles also help water to expand, resulting in a lower amount of water required for suppression, which is advantageous in areas susceptible to drought (National Wildfire Coordinating Group, 1993). A 10:1 expansion ratio creates 90% air, 9.9% water, and 0.1% concentrate. With a very low amount of water, the foam still has the ability to cover large areas. Expansion ratios can range from 1:1 (low expansion) to 1000:1 (high expansion), where low expansion has a greater density and high expansion has a lower density. Typically, the percent concentrate ranges from 0.1% to 1% (National Fire Protection Association, 2017).

Like all chemical suppressing agents, the use of Class A foam has its disadvantages. First, as a low-density product used outdoors, foam is susceptible to wind (Tafreshi, 1998). Second, the foam concentrate poses environmental concerns. The surfactants in Class A foam have previously been found to alter properties of soil, change infiltration rates, and increase hydrophobic contaminants in soils which could affect surface water (Perry, 2001). However, as foam concentrate compositions have been tested and refined, recent tests have found class A foam to be environmentally friendly and biodegradable (McNeal, 2018). As such, Class A foam has gained environmental and safety approval from both FM Global and UL. Refer to background section 3.0 “Codes and Standards” for NFPA references regarding test methods for the physical properties and environmental effects of Class A foam.

2.5.3 Gel

Where foam consists of air protected by water, gel consists of water surrounded by a polymer. This creates a thicker substance that is wind resistant. Gel creates a strong barrier between oxygen and fuel, and cools the heat source (Petrillo, 2018). A gel product that has proven effective against wildfires is GelTech's "FireIce." In addition to removing oxygen and heat from the fire, FireIce prevents reignition of the fuel. GelTech also claims its product to be environmentally friendly and non-toxic. FireIce has recently gained approval from UL (GelTech, 2018).

While gel suppression products present their advantages, they also contain several disadvantages. Gel is only effective when wet, and therefore does not provide long-term fire suppression (Megroz 2018). Gel agents also have a short shelf life, are difficult and expensive to clean up, and can stain homes (Consumer Fire Products, 2010). Since gel is normally applied by hose, it inconveniently requires personnel to be at the site of the fire. Gel is also is a slippery substance, which makes it dangerous for personnel to move around while using it (Megroz 2018). Furthermore, if the surface being protected is not completely covered by the gel, fire will burn around it (Consumer Fire Products, 2010).

2.6 Suppression Systems

Fire suppression systems can be manual or automatic. Manual systems require personnel to physically activate the system after notification of a fire event, while automatic systems will start immediately in response to the initiation of a fire detection device. Suppression systems classified by the piping configuration, the type of suppressant that is used, and the method of delivery. The following sections break down the different classifications of suppression systems.

2.6.1 Wet-pipe System

A wet-pipe spray system contains water in its piping system for immediate discharge when individual spray nozzle heads open due to fire detection. The nozzles are heat actuated by a glass bulb filled with a glycerin-based liquid, or by a fusible link containing a heat sensitive alloy. When the bulb heats to a certain temperature, the liquid expands, breaks the bulb, and opens the nozzle. Similarly, when the fusible link heats up, the alloy melts and opens the nozzle (QRFS, 2019). Wet-pipe systems are typically used indoors, where there is no risk of the water freezing inside the pipes (Muresan, 2019).

2.6.2 Dry-pipe System

A dry-pipe spray system contains pressurized air or nitrogen inside its pipes. When an individual spray nozzle head is opened, the pressurized air is pushed out of the spray nozzle. The release of air causes a pressure drop in the system, activating the fire pump, which propels water through the pipes for discharge. Dry-pipe spray systems are common in areas that are susceptible to freezing (Muresan, 2019).

2.6.3 Preaction System

Similar to a dry-pipe sprinkler system, a pre-action system contains pressurized air or nitrogen in its pipes. However, a pre-action system requires two different events to activate spray discharge. When a detection device recognizes a fire, the system's pre-action valve is prompted to open, which allows water to flow through the pipes. Water will only discharge if individual nozzles receive another form of detection and open to release the water. A pre-action system protects against false alarms. It is used in areas susceptible to freezing that store water-sensitive materials (Muresan, 2019).

2.6.4 Deluge System

A deluge system contains unpressurized dry piping. When a fire is detected and the deluge system is activated, foam-water flows through the pipes and discharges through every nozzle head in the system. This is unlike dry-pipe, wet-pipe, and pre-action systems, where nozzles open individually depending on the location of the fire. Deluge systems are necessary in high-hazard occupancy classifications, such as chemical and power plants, and aircraft hangars (Muresan, 2019).

2.6.5 Water and Foam Suppression Systems

There are numerous different suppressants that can be used to meet the goals of a particular situation. Two common suppression agents are water and foam. A water mist system a distribution system connected to a water supply or a water and atomizing media supplied that is equipped with one or more nozzles capable of delivering water mist intended to control, suppress, or extinguish fires (NFPA 750, 2019). A water spray system is an automatic or manually activated actuated fixed pipe system connected to a water supply and equipped with water spray nozzles designed to provide a specific water discharge and distribution over the protected surfaces or areas (NFPA 15, 2017). A foam water spray system is a piping network connected to a source of foam concentrate a water supply. The system uses either air aspirating or non-air aspirating nozzles to discharge foam onto the fire (NFPA 16, 2019). A compressed air foam system injects pressurized air into a stream of foam solution. Foam is generated through pipe friction or a mixing device, which creates a uniform network of bubbles (NFPA 11, 2016).

2.7 Detection Systems

In order to activate an automatic suppression system, there must be a detection system. The brain of a detection system is the Fire Alarm Control Panel (FACP). FACPs are powered by a constant power source from the home. They have the ability to power the fire alarm devices, receive signals from these devices, and automatically start the fire suppression system or notify personnel of a fire event. Detection devices are connected to FACPs through wiring (Buildings, 2009). To ensure the devices are receiving enough power from the FACP, voltage drop calculations are required. Voltage drop calculations take into account the length of wire from the FACP to the device, the gauge size of the wire, the amount of power the FACP can provide, and the amount of power the detection device requires (NFPA, 2020). The power supply and demand for the FACP and detection devices, respectively, can be found in the cut sheets from the product manufacturer. While detection systems for large areas may require additional power supplies, the average home would likely be able to power its detection system solely through the FACP. Additional information regarding fire alarm systems can be found in NFPA 72.

2.7.1 Initiating Devices

Smoke and heat detectors are unacceptable for external systems because they are susceptible to the effects of climate conditions. For example, dust or dirt particles blowing through the wind could falsely set off or clog a smoke detector, causing it to be an unreliable source (Chase, 2018). Instead, common detectors used for outdoor systems include infrared (IR) detectors and visual flame detectors.

An IR detector is a pyroelectric sensor that detects thermal radiation. The pyroelectric sensor consists of a lithium crystal that perceives flickering by a flame. This signal is then interpreted as a threat by computer algorithms (AZO Sensors, 2017). While IR detectors are efficient in smoky environments, it does pose several disadvantages. Water vapor, hot surfaces, and direct sunlight can cause inaccurate readings (Naranjo, 2019).

A visual flame detector uses live video images to capture incoming flames (AZO Sensors, 2017). Therefore, the effects of weather will not impact the accuracy of a visual flame detector. Reading ranges of visual flame detectors vary based on the type of device selected and can be found on the cut sheet from the manufacturer (Micropack, 2019). Since visual flame detectors rely solely on video imaging, smoke or fog can interfere with accurate readings (Naranjo, 2019).

2.7.2 Wiring

Wiring from the control panel to the detection devices can be classified as Class A or Class B. Class A wiring consists of redundant and looping wiring, where two separate paths of power run to the device, and loop back to the control panel. This is advantageous in the case of a broken wire, as the second wiring serves as a backup power source. In Class B wiring, the two wires that run to the device do not loop back to the control panel separately. Instead, they connect and terminate at an end of line resistor. Due to this connection, a broken wire will cause each device after the break to stop working (Krantz, 2019). Class B wiring is more commonly used, as Class A wiring is more complicated and expensive in terms of installation and material. Figure 8 below depicts Class A and Class B wiring for fire alarm systems.

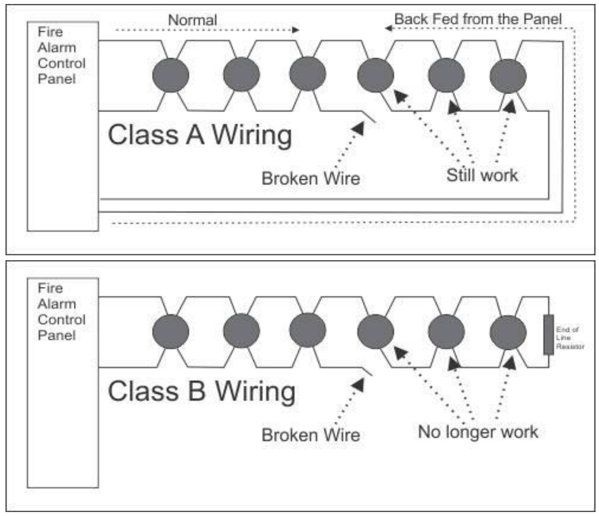


Figure 8. Class A and Class B wiring configurations for fire alarm circuits (Krantz, 2019).

2.8 Existing Systems

There are currently several commercially available systems that have been designed for the purpose of preventing houses from burning in wildfires. These systems are sold, installed, and operated by different consulting companies. Table 1 summarizes the features of five current systems on the market. The capabilities and limitations of each system will be discussed further.

Table 1

Features of Existing External Home Suppression Systems

System	Automatic Detection	Independent Power Supply	Independent Water Supply	Water Suppressant	Non-water Suppressant	Company Monitoring	Remote Monitoring
Roof Saver				X			
Flame Sniffer	X	X	X	X		X	X
FOAMSAFE	X	X	X		X		
Colorado Firebreak	X		X		X		
waveGUARD	X	X	X		X	X	

2.8.1 Roof Saver

The concept behind the Roof Saver Sprinkler kit is that the sprinklers will wet roofs, gutters, decks, and surrounding vegetation to make these fuels less susceptible to ignition. The effectiveness of this system depends on the number of sprinklers the owner chooses to install. The company claims that embers are the cause of "90% of homes ignitions" and the roof is the most vulnerable part of any home because "...shingles, leaves, [and] pine needles, on the roof or in gutters is usually the first thing to ignite" (Roof Saver Sprinklers, n.d.). According to the website, the system includes the components shown in Figure 9 below:

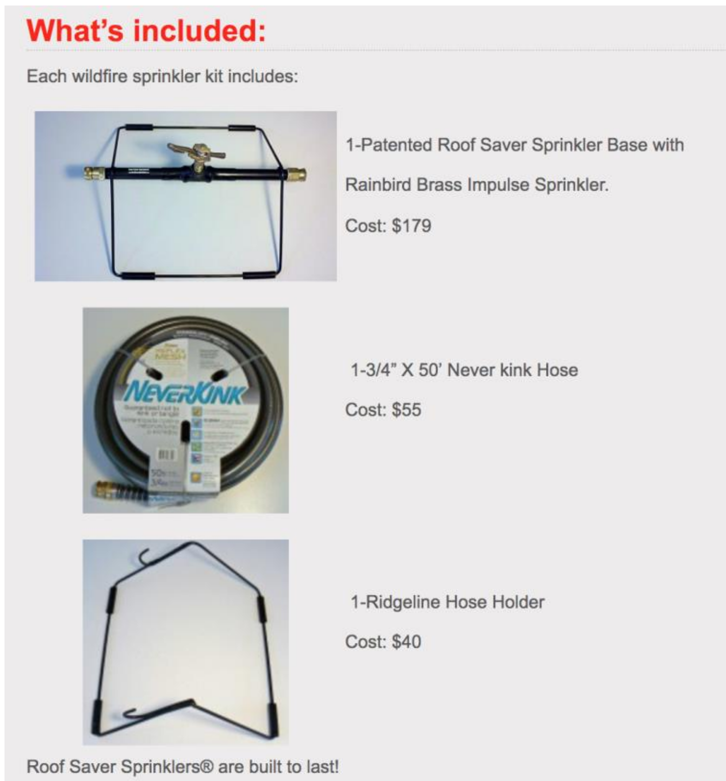


Figure 9. Features of the Roof Saver System.

While the Roof Saver System presents an affordable idea for homes in fire zones, it is far too simple. Not only are the sprinklers limited in their ability to reach the outskirts of the property, but they also fail to discharge water at a sufficient pressure to completely extinguish a wildfire attack on a home. The Roof Saver System is more of a preventative system than a suppression system. This is the most limited system and it lacks most of the features present in other systems.

2.8.2 FlameSniffer

The FlameSniffer claims to provide "peace of mind, whether you're home or away" through automatic, manual, and remote operation and remote monitoring (FlameSniffer, n.d.). Sensors are used to detect the fire automatically. These communicate with a control panel that operates the external spray system. The water spray extinguishes embers when they arrive on the property and maintains a barrier against the front of the fire. The FlameSniffer can also be activated manually by a remote and is connected to an app that sends the property owner regular updates and notifications of activation. The system is powered by an independent supply, as the external power will likely fail in a wildfire event. Unlike the Roof Saver system, FlameSniffer provides sprinklers that are located around the perimeter of the home. The FlameSniffer system also supplies an independent water source by collecting rainwater in a tank.

While the FlameSniffer has many capabilities, there are limitations of the system. The sensors monitor embers, flame, temperature, and smoke. The website says that when a “serious threat” is detected the system will automatically activate, but they fail to provide criteria for what defines such a threat. Another limitation is that the primary retardant in this system is water, which means that a lot of water will need to be supplied in order to suppress the fire if it ignites on the house.

2.8.3 FOAMSAFE FireMaster

The FOAMSAFE FireMaster™ system utilizes Class A foam as the primary fire retardant, as it can achieve better coverage and penetration on the structure’s facades than water. The company offers three models of the systems at different sophistication levels: the elite system, the basic system, and the manual system. The elite system has complete control and monitoring services that provide notification updates to the owner. The basic system provides the minimum features needed for a functioning automatic system. The manual system is made for owners who are looking to begin treating the property before evacuating. A photo of the system in action is shown below in Figure 10.

Figure 10. FOAMSAFE FireMaster™ System working to cover a house with foam.

Figure 10 shows that sprayers are located on the ground surrounding the home, as well as pointing down from the roof. The roof is one of the most important places to reach because of the vulnerability to ignition by firebrands yet the walls are the targeted area of protection and there is limited spray that reaches the roof. This is a limitation of the system design.

According to the website, The FOAMSAFE FireMaster™ System is an automatic wildfire protection system that activates automatically when its fire sensors see a wildfire approaching from up to 1/2 mile away. This claim, made by the vendors, promotes the ability of the system to detect an approaching flame front. However, firebrand showers are the main threat to homes, not the flame front. This could be a severe limitation if the sensor is only capable of detecting the front of the flame. Another limitation is the lack of an independent water supply at homes. The company offers a portable storage tank that can be purchased with the system that provides 500-3000 gallons of water for an additional cost (Consumer Fire Products).

2.8.4 Colorado FireBreak

Colorado FireBreak offers a wildfire protection system, designed to protect the home and the surrounding 50 ft area. It includes wildfire detection sensors that communicate with a master control panel via wireless signaling. Once the signal is transmitted, water is pumped from an underground storage tank and combined with FireIce® powder, creating a retardant gel. The system features lines installed on the home that deliver good coverage of the FireIce gel so that it covers the home. The FireIce gel is distributed by lines mounted to trees around the perimeter of the property. The Colorado FireBreak system is fully self-contained, including an isolated water tank and power sources. The system can be activated manually or automatically and relies on either electrical or gas power generation (Colorado Firebreak).

The main features that differentiate this system from other systems are the underground tank, the sprinkler heads on both the home and the surrounding trees, and the unique use of FireIce powder that create a gel.

2.8.5 waveGUARD

The last system under review is the waveGUARD system. Like some of the other systems, this one is automated, has an independent water source, autonomous power source, and is monitored by the installation company. The sensors are infrared flame detectors, and the system has an independent power source that can remain operational for up to two weeks. The system also allows homeowners to monitor their home via smartphone monitoring. The system uses a fire-retardant additive called Micro Blaze Out™. It is a “green” product that utilizes a live microbe and stays active for up to 14 days after dispensing upon rewetting. Micro Blaze Out™ has been tested and approved by UL and NFPA 18 *Standard on Wetting Agents* for both Class A and B fires. The sprinkler nozzles provide coverage of the home and up to thirty feet of surrounding space. In addition, the suppressant is discharged in cycles rather than constant distribution (waveGUARD™ Corporation).

2.9 Codes and Standards

There are currently a number of codes and standards that address various interior fire suppression systems. One common example is NFPA 13 *Standard for the Installation of Sprinkler Systems*, which provides requirements regarding system design, discharge criteria, and installation practices (NFPA, 2019). However, there is no equivalent code or standard that has been published for exterior suppression systems to protect against wildfires. Information regarding the design of such a system must be researched and connected from many other sources.

The National Fire Protection Association (NFPA) has created a public education page called "Firewise USA" that highlights NFPA code books which focus on wildfires, external foam-water spray systems, and Class A Foam (NFPA, 2019). These codes, however, are brief and reference very specific aspects of fire suppression systems, requiring the use of multiple code books in evaluating an external system. The NFPA codes that may apply to the development of an external foam-water suppression system for wildfires are listed below.

2.9.1 NFPA

- NFPA 11 (2016), *Standard for Low-, Medium-, and High- Expansion Foam*
  - Chapter 6 explains requirements for medium and high expansion systems that are applicable to both interior and exterior environments.
- NFPA 15 (2017), *Standard for Water Spray Fixed Systems for Fire Protection*
  - Chapter 6 contains information about fire detection devices. Chapter 10 indicates the flow and density of water discharge from the system, in regards to both interior and exterior applications.
- NFPA 16 (2019), *Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems*
  - This code book indicates the design, installation, and maintenance requirements for foam-water suppression systems.
- NFPA 19 (2017), *Standard on Wetting Agents*
  - Chapters 4 - 6 explains the use, test methods and requirements, and toxicity and environmental considerations of wetting additives.
- NFPA 20 (2019), *Standard for the Installation of Stationary Pumps for Fire Protection*
  - Chapter 4 specifies the component parts and operational requirements of a fire pump. The following chapters highlight the different types of pumps that exist.
- NFPA 22 (2018), *Standard for Water Tanks for Private Fire Protection*
  - This code book highlights the different types of water tanks that exist.
- NFPA 70 (2020), *National Electrical Code*
  - Chapter 9, Table 8 identifies resistance values, which are used in voltage drop calculations for the detection system.
- NFPA 72 (2019), *National Fire Alarm and Signaling Code*
  - Sections 17.8.3.2 and 17.8.5 indicate the requirements for visual flame detectors

in connection to fire alarm systems.

- NFPA 101 (2018), *Life Safety Code*
  - Chapter 5 highlights requirements for performance-based design.
- NFPA 550 (2017), *Fire Safety Concepts Tree*
  - Chapter 7 discusses the application of the fire safety concepts tree that helps define the objective of the suppression system.
- NFPA 1143 (2018), *Standard for Wildland Fire*
  - Chapters 4 - 8 highlight the logistics regarding a wildfire event. Topics include the preparedness of organizations associated with wildfire prevention, responsibilities of safety officers in response to a wildfire, and post-incident activities. This code book gives the Authority Having Jurisdiction the power to create the guidelines for structures exposed to wildfire.
- NFPA 1145 (2017), *Guide for the Use of Class A Foams in Fire Fighting*
  - Chapters 4 - 6 provide information regarding the properties of foam, the required hardware and proportioning devices, and the operation of foam systems.
- NFPA 1150 (2017), *Standard on Foam Chemicals for Fires in Class A Fuels*
  - This code book addresses the environmental concerns of Class A Foam and directs attention to the United States Environmental Protection Agency (EPA). Chapters 4 and 5 focus on the physical properties, the toxicity limits, and test methods for class A foam.

These standards are relevant because there is not currently a standard for external suppression systems. Instead, the synthesis of information from many standards is required to piece together standards for a new application such as this one.

2.9.2 International Code Council

The International Wildland Urban Interface Code (IWUIC) is a publication from the International Code Council (ICC). This code book defines the wildland urban interface as homes "located in areas 'where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.'" The IWUIC highlights safeguards for people and properties from exposure to wildfires and from adjacent structures. It suggests ways to mitigate the spread of wildfires in the wildland urban interface by providing construction and fire protection requirements for homes. The IWUIC does not apply to existing buildings (IWUIC, 2018).

2.9.3 Testing and Listing Agencies

Testing agencies are independent, third party organizations that are hired by companies to evaluate the performance, environmental safety, and human/animal toxicity of their products. Upon testing of these products, these agencies will either approve and list the product as safe and reliable, or they will reject the product. The two leading testing and listing agencies are Underwriters Laboratories (UL) and Factory Mutual (FM). Products with the (UL) and/or (FM) approval certification marks validate the product to consumers (Steve Brown & Associates, 2017). Figure 11 below indicates the steps involved in a typical UL listing process.

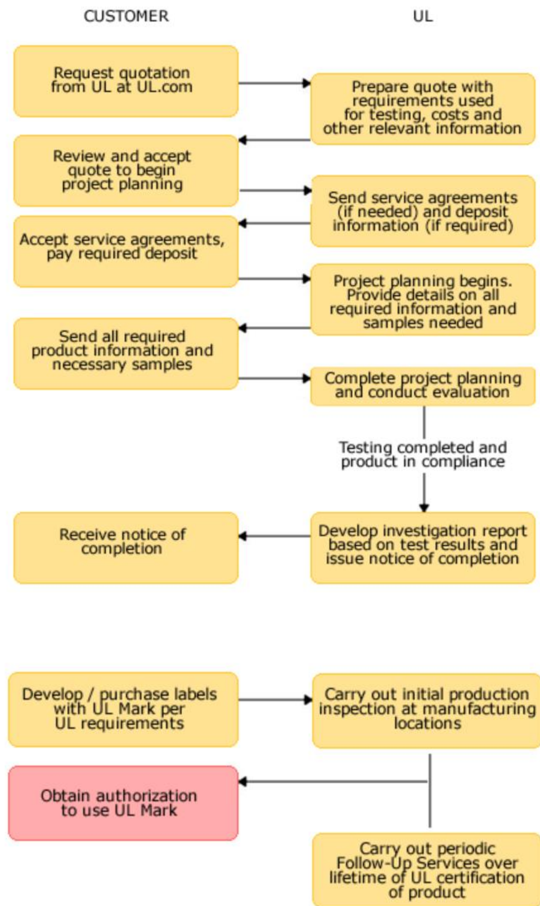


Figure 11. UL Testing and Listing Process

In summary, UL must approve a request for testing from a company, send a testing quote, receive acceptance and payment of the quote, obtain product information and samples, perform testing procedures, and confirm the product is in compliance with UL standards (UL, 2019). Similarly, FM Global follows a five-step procedure to test products (FM Approvals, 2019). The steps are as follows:

1. Manufacturer request
2. Proposal issue and manufacturer authorization
3. Review, testing, and first audit
4. Report, FM approved mark, and listing
5. Surveillance audits

In regards to fire protection systems UL and FM Global primarily assess materials and products used in the built environment and perform testing for indoor building fire scenarios. Other than the testing and approval of class A foam, and individual components of fire suppression systems, both companies contain limited information regarding external fire suppression systems as a whole and wildfire mitigation techniques. A resource that FM Global does provide is “Property Loss Prevention Data Sheets.” Chapter 2 of the *Wildland Fire* (DS 9-19) data sheet displays “Loss Prevention Recommendations,” which highlights specific recommendations for outside sprinkler protection. It provides charts that help to determine radiant heat exposure for buildings, efficient water flow rates for an outdoor sprinkler system, and recommendations for water supply (FM, 2017). Although this document is helpful, it merely suggests recommendations rather than requirements, indicating that more testing on external suppression systems must be implemented by FM Global for approval and listing.

FM, UL, and other organizations also produce fire test and listing standards that prescribe how a product should be evaluated. These tests can then be carried out by other qualified listing agencies. For example, a requirement of NFPA 1144 is that all roof coverings shall be tested and rated as Class A by ASTM E108 or UL790. These test methods assess the fire resistance of roof coverings exposed to fires outside of a building. A covering may be awarded a Class A, B, or C rating, with Class A being the most fire resistant. Any qualified listing agency may carry out the ASTM E108 or UL790 procedure to determine the fire resistance rating of the roof.

2.9.4 Performance Based Design

Performance based design is defined as “an engineering approach to fire protection design based on agreed upon fire safety goals and objectives, deterministic or probabilistic analysis of fire scenarios, and quantitative assessment of design alternatives against the fire safety goals and alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria” (Hurley, 2016). First introduced formally in the United States in the 1970’s when the U.S. General Services Administration began developing and practicing a goal-based approach to building fire safety, performance-based design has become more common over time as an alternative to traditional prescriptive codes. NFPA 101 *Life Safety Code* (2000 edition) was the first code from the NFPA to include a section on performance-based design, followed by the 2003 edition of NFPA 5000 *Building Construction and Safety Code* (Hurley, 2016). Even before performance-based design was formally referenced in codes, similar methods were used to meet building fire safety goals. Many NFPA codes have a provision in the first chapter regarding equivalent compliance. The applicable section from NFPA 101 *Life Safety Code* is as follows:

> **Equivalent Compliance.** Alternative systems, methods, or devices approved as equivalent by the authority having jurisdiction shall be recognized as being in compliance with this code.

While this code section allows for a departure from prescriptive code requirements, the authority having jurisdiction is left to determine whether an equivalent level of safety is provided. There are no details provided on how to achieve the equivalency.

2.10 Stakeholders Analysis

A stakeholder is defined as any entity that has an interest in or are affected by the outcome of a system. There are seven entities that have been identified as stakeholders in the creations of a wildfire suppression system. These stakeholders are summarized in the following table.

Table 2
Stakeholder Identification

Title	Description	Role	Relation to Project	Priority
Owners	Residents/building owners in the WUI whose property is at risk for wildfire damage	System users and operators	Direct, positive	1
NFPA	Agency that sets fire codes and standards	Assessor/ Regulator	Neutral	1
EPA	Agency that will regulate water and chemical use by the system.	Assessor/ Regulator	Neutral	1
Insurance companies	A means of protection from financial loss	Assessor/ Regulator	Indirect, positive	2
Manufacturing companies	The specific companies that manufacture the nozzles, sprinkler heads, and other fire equipment that will be used on the system	Suppliers	Indirect, positive	2

Companies with similar products	Companies with products that have commercial products with the same objective of preventing structures from burning Examples: Frontline, Consumer Fire Products, INC.	Competitors	Indirect, negative	2
Firefighters	Those fighting the fire at the fronts who sometimes put out house fires.	Authority	Indirect, positive	3
UL/FM	Leading testing/listing agencies in the US.	Assessor/ 3rd party testers	Neutral	2

The primary stakeholder in a wildfire suppression system is the owner. These are residents and building owners in the wildland urban interface whose property is at risk of destruction by wildfires. In a wildfire event, the safety of the residents is the utmost priority; fire officials call for evacuations to make sure all residents are cleared out of the path of the fire. The owners will ultimately pay for the installation of the system to protect their property. The needs of the owners must be at the forefront when considering how the system will be designed and operated. If the system does not meet the needs of the owners, they will not invest in it.

The NFPA and the EPA are both regulatory stakeholders in the systems. The NFPA is the agency that creates and fire codes and standards and ensures that they are met (NFPA, n.d.). Section 2.9.1 lists applicable NFPA codes and standards for a foam-water spray system. The Environmental Protection Agency (EPA) enforces regulations to maintain the health of the surrounding environment (U.S. Environmental Protection Agency, n.d.). There are two reasons why the EPA would be involved in the system: the regulation of water usage and the regulation of chemical usage. In areas of drought, water usage is regulated by the EPA to ensure that it is being used responsibly and conservatively. A fire suppression system that procured water would be an added use by residents. Therefore, the EPA would be concerned with how much water the system is using. Any chemical additive used will leach directly into the surrounding environment and could have a negative impact if the chemicals are not safe for the surrounding vegetation and wildlife. The chemical used by the system will require EPA approval.

Manufacturers of water spray systems and pumps are indirect stakeholders that will be positively impacted by the development of a suppression system. If the system becomes mainstream for new and old homes in the WUI, there will be a greater demand for the products that these companies manufacture. Examples of manufacturers of components for suppression systems include Tyco, Viking, Victaulic, and Pentair. Tyco, Viking, and Victaulic offer sprinkler heads, spray nozzles, and pipe parts or suppression systems while Pentair specializes in pumps (Johnson Controls, 2018; Viking, 2018; Victaulic, n.d.; Pentair, 2019).

A negative stakeholder of this system are the consultors that currently install similar suppression systems around houses. They provide expensive systems that are exclusive to average homeowners. If the costs of one of these suppression systems can be reduced enough to become mainstream and affordable for the average consumer, the current consulting companies will lose customers. The specific systems that are currently available on the market were discussed in the previous section.

In order for the system to be verified to function, it has to pass testing by third party assessors. FM Global is a property insurance company operating from the philosophy that most losses can be prevented. They provide insurance products and property loss prevention engineering services to protect their clients' worldwide operations. FM Global executes a five-step approval process before issuing the approval (FM Approvals 2019). Underwriters Laboratories (UL) is a product safety testing and certification company having developed more than 1,600 standards. UL is certifying, validating, testing, verifying, inspecting, auditing, advising and educating customers in many countries. In order to become UL Listed, the system must be tested and meet the safety requirements set. Systems having the UL mark are covered by the Underwriters Laboratories follow-up program, which continuously tests the products to ensure that the UL standards and requirements are always met (UL FSRI, n.d.).

3.0 Methodology

The scope and purpose of this project is to design a fixed external suppression system to protect one- & two-family homes from firebrand exposures during wildfires. The Society of Fire Protection Engineering's performance-based design approach was used as a framework for the design process. Figure 12 shows a flow chart from the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering (2016) outlining each step of the performance based design process. Details on each step of the design process can be found in the sections that follow, and a project schedule can be viewed in Appendix A.

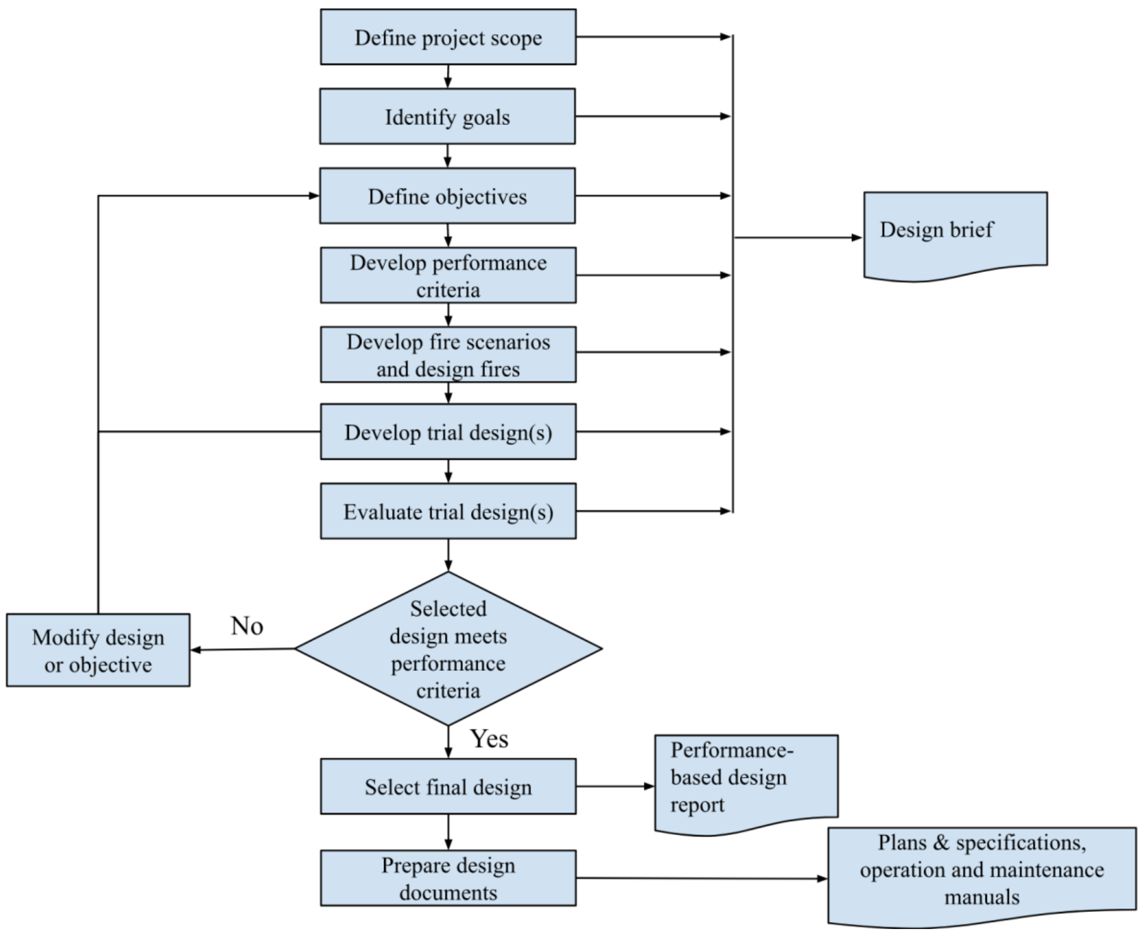


Figure 12. Performance based design process (Hurley, 2016).

3.1 Define Project Scope

The first step of this process involved defining the project scope. The Society of Fire Protection Engineering Guide to Performance Based Design (2007) recommends that information be gathered to identify and define the following topics: desired features, stakeholders, building construction, occupant characteristics, intended use and occupancy, applicable codes and regulations. Table 3 shows the definition of our project scope based on information from the literature review.

Table 3

Project Scope

Desired System Features	Automatic fixed exterior suppression system to protect suppress fires resulting from fire brand exposures on one- & two-family homes
Stakeholders	● Homeowners ● Local AHJ ● EPA ● Firefighters ● NFPA ● Testing/listing agencies ● Manufacturers ● Insurance agencies
Building Construction	Type V - Structural elements, walls, arches, floors, and roofs are made entirely or partially out of wood. Certain structural elements may have 1 hour of fire resistance (NFPA 5000, 2018).
Occupant Characteristics	Occupants are assumed to have evacuated at the time of system activation.
Intended Use and Occupancy	Residential (NFPA 101, 2018), Group R-3 (IBC, 2018)
Applicable Codes and Regulations	Local and State Building/Fire Codes Environmental Regulations
Assumptions	The roof of the home meets the requirements of ASTM E108 for a Class A roof.
Threat to Protect Against	Firebrand exposures

3.1.1 Location and Home Design

The next step of the design phase involved selecting a location and defining the features of the home that the design would center around. This was necessary in order to define the home size, building materials, and environmental features based on local data. We focused on finding an area of the country that was regularly impacted by wildfires. From 2000 to 2014, 12 of the 20 most destructive fires in the United States occurred in California. 10,000 buildings were destroyed by wildfires in the state from 2000 to 2013; Texas was the next highest with 2,5000 buildings destroyed during this time period (Kramer et. al., 2018). For these reasons, California was chosen as the state to focus on.

The area was then further refined by researching counties in California that have land in the WUI. The map of Communities at Risk from Wildfire produced by the U.S. Endowment for Forestry and Communities was utilized to assess the percentage of land that is classified as WUI in each county (Alvarez, n.d.). A snapshot of the interactive map with Santa Cruz data highlighted is presented below in Figure 13. Yellow represents a relatively low wildfire risk and dark red represents the highest wildfire risk.

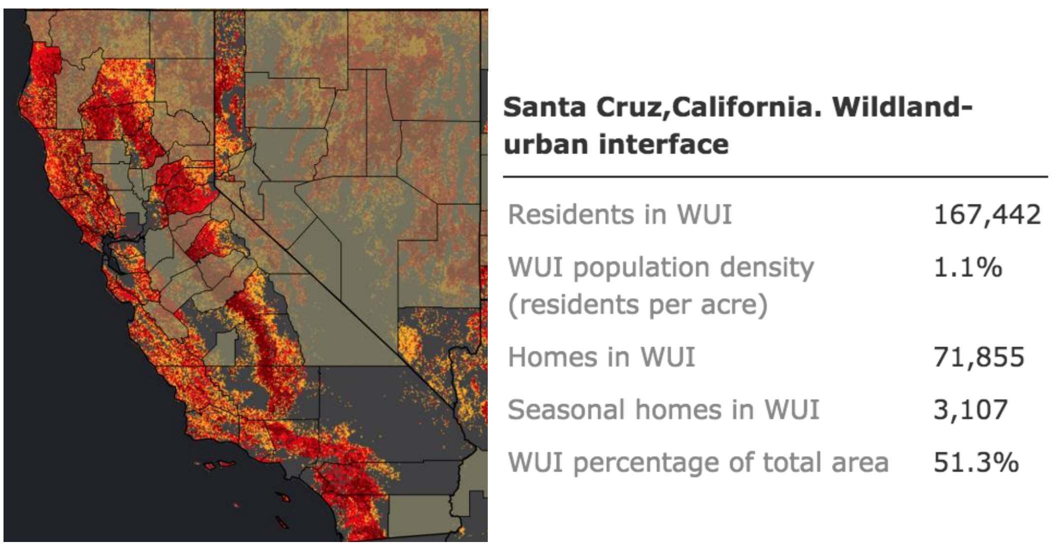


Figure 13. Communities at risk from wildfire statistics

The map also provided other statistics such as residents in the WUI, homes in the WUI, and WUI population density. Santa Cruz was selected as the county for the purposes of this project since it has the largest percent of land in the WUI at 51.3%. There are about 72,000 homes established within this area. We researched the average square footage of homes in Santa Cruz County, focusing on one- & two- family homes since they are already grouped into the same occupancy in NFPA 101 and the International Building Code. The average home size was found to be approximately 1450 ft^2; to model this, the house was assumed to be rectangular with dimensions of 33 ft. by 43 ft. (Dominion Enterprises, n.d.). Other details about the house were added to create realistic fire scenarios. The front of the house has 3 feet of mulch extending away from the house along the entire length, except for where the concrete steps lead to the front door. On either side of the steps, there are three manzanita bushes; these are typical landscape plants used in this part of California. There is a concrete foundation that extends 1 foot up from grade, at which point the cedar siding extends to the eaves. The house also has a 10' by 20' deck located at the back of the house. The house was modeled in Revit and is shown in Figure 14 below.

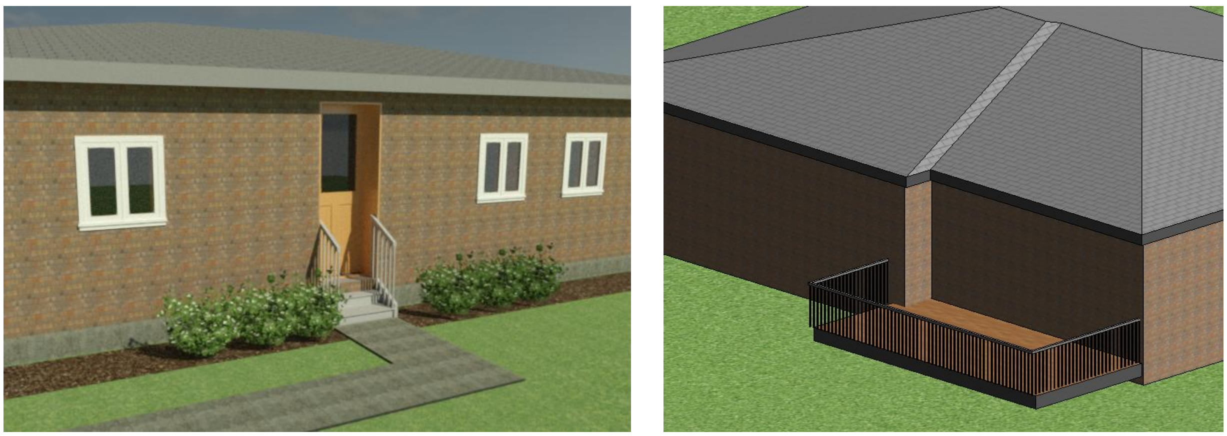


Figure 14. Revit model of the typical residence

3.2 System Goals, Objectives and Performance Criteria

This project scope served as a basis for the system design. Once the project scope was narrowed, the next step involved developing goals to express the desired fire safety outcomes in broad terms. The goals were written in such a way that people with no engineering background can understand how the building is intended to perform in a fire. The SFPE Handbook provides four fundamental goals for fire safety (Hurley, 2016):

1. Life Safety
2. Property Protection
3. Mission Continuity
4. Environmental Protection

By considering information from the literature review and the definition of the project scope, we determined that the primary goal that our system aligns with is providing property protection. Life safety was not a primary goal because our project scope assumes that building occupants have evacuated by the time the system activates. Environmental protection was a consideration when we selected a suppression agent, since the toxicity of the agent was evaluated. Mission continuity is not applicable to one- & two- family residences. With these fundamental goals in mind, specific goals for this project were then conceptualized. Four system goals were established and categorized into primary and secondary system goals. They are listed as follows:

Primary Goals:

1. Minimize fire related damage to the building and its contents.
2. System can operate independently from local utilities.

Secondary Goals:

3. System can remain in service with minimal attention from the homeowner.
4. Minimize the impact of system discharge on the environment and consider resource conservation

The primary goals are those that affect the components of the system and the way in which it's designed. The secondary goals are characteristics of the system that we have deemed important but are not controlling the design of the system.

For each goal above, the next step was to develop objectives to further define how the system is intended to operate. Objectives can be broken into two different types: stakeholder objectives and design objectives (Hurley, 2016). An example of a stakeholder objective would be limiting fire damage beyond the room of origin. A corresponding design objective would be preventing flashover in the room of origin (Society of Fire Protection Engineers, 2007). Design objectives typically help to quantify the goal. Since this project is a conceptual design being completed by three individuals with an engineering background, we skipped the stakeholder objective portion of the performance-based design and moved straight to developing design objectives. NFPA 550 *Fire Safety Concepts Tree* was also used as a basis for developing goals and objectives. This document examines generic fire safety objectives and was a useful resource to determine what the suppression system's intended purpose. A green path was added to the chart NFPA 550 in Figure 15 to highlight the fire safety objectives that apply to this project.

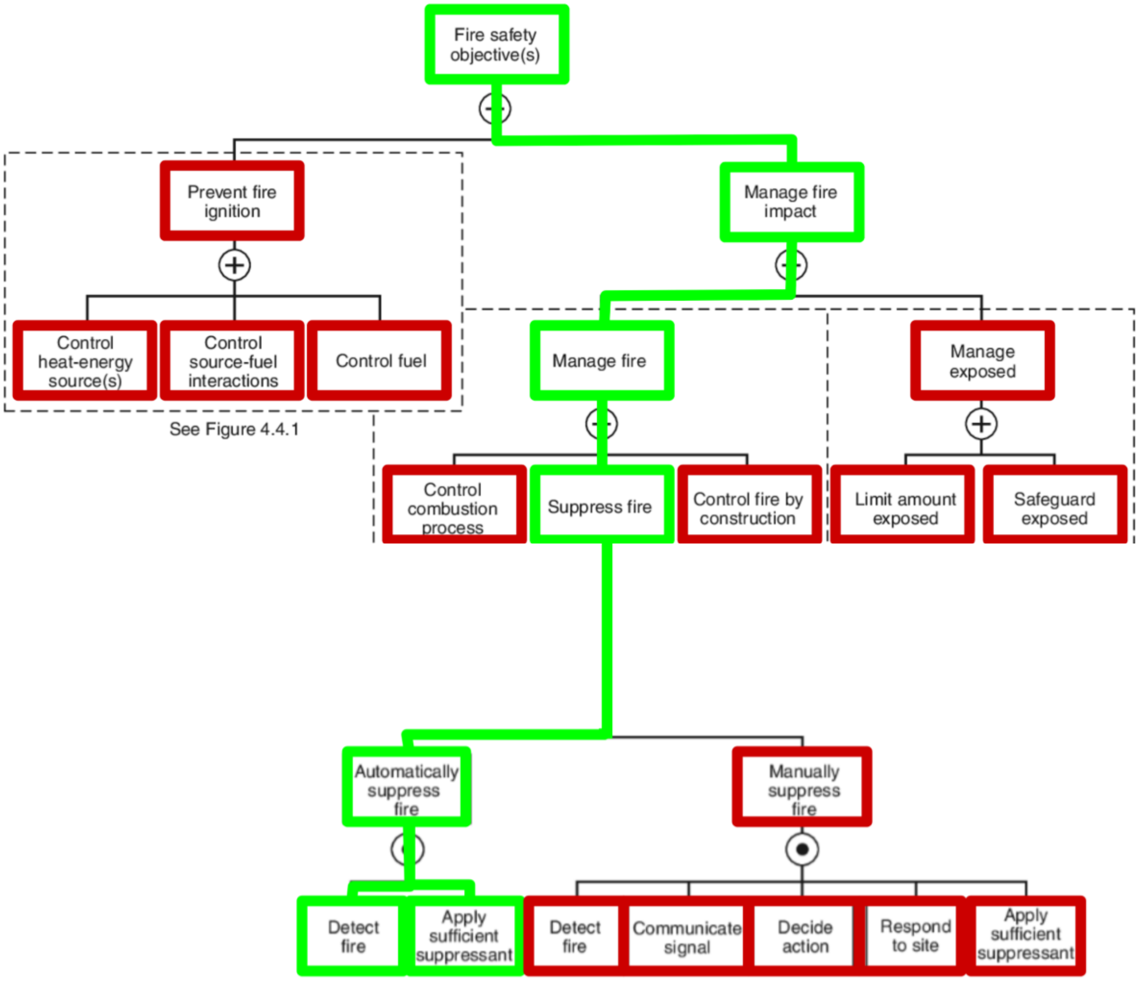


Figure 15. Fire Safety Concept Tree

The two green boxes located at the bottom of the flowchart, *Detect Fire* and *Apply Sufficient Suppressant*, are examples of objectives that further define a larger goal. Our four system goals with the corresponding objectives are shown in Table 4.

Table 4
Goals and Objective

Primary Goals	Objectives
1. Minimize fire related damage to the building	➢ Detect fire in a timely manner ➢ Activate suppression system before the fire reaches the eaves ➢ Discharge suppressant at a density sufficient to suppress fires resulting from firebrand accumulations ➢ Damage should be limited to building facade and auxiliary components
2. System can operate independently from local utilities	➢ Provide independent power supply ➢ Provide independent water supply
Secondary Goals	**Objectives**
3. System can remain in service with minimal attention from the homeowner.	➢ Use weather resistant components ➢ Provide simple user interface monitoring: low-pressure alarm, water tank level, tamper switches ➢ Inspection, testing, and maintenance protocols
4. Minimize the impact of system discharge on the environment and design the system in such a way to conserve resources.	➢ Used a zoned distribution system ➢ Suppression agent shall be biodegradable, non-toxic, and environmentally safe

3.2.1 System Goals

This section provides an explanation of each goal and details for the corresponding objectives.

Goal 1: Minimize fire related damage to the building

The first and paramount goal of the system is to minimize the fire related damage to the building. This is a broad goal that needs a more concise definition. By this we mean that fire related damage should not affect the structure of the building. There are four objectives that will help the system realize the first goal. First, the system should detect the fire and activate the suppression system in a timely manner. Then, suppressant should be discharged at a density large enough to suppress sport fires that result from firebrand accumulations. Lastly, the damage caused by the fire should be limited to the facade of the structure and auxiliary components. By auxiliary components we mean a deck, fence, or outdoor furniture, or any other feature surrounding the house. Our main goal is to preserve the structural integrity of the house.

Goal 2: System can operate independently from utilities

The second goal is integral to the operability of the system. The system needs to be equipped with components that allow it to function independently from local utilities. Often times the power supply will be cut to an area within the path of an approaching wildfire. If the system is reliant on the grid, it's unlikely that it will activate when the threat of a wildfire impends. Therefore, the system requires an independent power supply that can store and supply enough power for the duration of the fire event. The system will also need to have an independent water supply that stores enough water to provide the minimum discharge density for the length of the fire exposure.

Goal 3: System can remain in service with minimal attention from homeowner

The third goal is that the system can remain in service with minimum attention from the homeowner. The importance of this goal was realized when considering who the intended customer and user of the system is: the average homeowner. This suppression system is intended to be a worthwhile investment to protect homes from complete destruction and to prevent homeowners from having to rebuild their homes. If it requires a lot of time and money for maintenance, the value of the product will decrease and might not be worth the cost of installation. In order for it to be a worthwhile investment, the system will need to have minimum maintenance needs. The use of weather resistant components is one objective under this goal so that the components can withstand the external environment. Another objective is to provide a simple user interface that notifies the owners when something is down in the system so that the homeowner doesn't need to be technically savvy to know when and where to carry out maintenance. Finally, there should be a written protocol that comes with the system that lays out when to complete maintenance, inspection, and testing. Because the system would still be operable if this goal were not realized, we denoted this as a secondary goal.

Goal 4: Minimize the impact of system discharge on the environment and design the system in such a way to conserve resources.

The fourth goal is to minimize the impact of the system discharge on the environment and design the system in such a way to conserve resources. Wildfires often occur in times of drought when the water supply is already running low, therefore there's a scarce supply of water available for purposes of suppression. For this reason, the system would be broken up into a zoned distribution system that can detect and activate in four separate zones. If a spot fire ignites on one side of the house, the system only discharges suppressant in the localized zone of the spot fire rather than releasing suppressant over the entire house.

Unlike most suppression systems designed up until now that are located internally and designed for internal fires, this system is designed to suppress external fires and is located outside of the residence. Consequently, there are no boundaries preventing the discharged suppressant from running off into the surrounding environment. To prevent more environmental damage in the long run, the suppression agent used needs to be non-toxic and environmentally safe.

With goals and objectives defined, we then began to focus on the performance criteria for the project. Performance criteria are "threshold values that, if exceeded, indicated unacceptable damage has occurred" (Hurley, 2016). The performance criteria provided a quantitative basis for our project design. For every system objective defined, there is a corresponding performance criterion. The final performance criteria can be found in Table 7.

3.3 Define Fire Scenarios

Fire scenarios describe the conditions of exposure for which a design is intended to provide protection. Typically, the process of defining design fire scenarios involves first defining all possible fires that could occur in a building, and then reducing this to a manageable set of scenarios (Hurley, 2016). NFPA 101 *Life Safety Code* and NFPA 5000 *Building Construction and Safety Code* each provide eight different design fires to be considered in the performance-based design process. These fires have varying fuel loads, rates of growth, and ignition locations. Unfortunately, these design fires cannot be applied directly to this project because both NFPA 101 and NFPA 5000 apply to the interior of buildings. However, the varying characteristics of these design fires were helpful in determining the design fire scenarios on the exterior of a building exposed to firebrands. Three sets of characteristics need to be defined in order to characterize possible design fire scenarios (Society of Fire Protection Engineers, 2007):

1. Building Characteristics – Architectural and structural features, fire protection systems.

2. Occupant Characteristics – Occupants are assumed to have evacuated.

3. Fire Characteristics – Ignition sources, growth rate, location, duration.

While developing the fire scenarios, we also assumed that firebrands were the only threat to the house and that homeowners did not follow defensible space recommendations. The design fires that were considered for this project took into account various growth rates, fuels, and locations around the exterior of the house to determine the worst-case scenario; this was the one we designed the system to protect against. Fire scenarios were developed based on heat release rates of various building materials from Chapter 26 of the SFPE Handbook, as well as data on firebrand ignition processes from NIST and other sources identified in the literature review.

3.3.1 Length of Exposure

The length of exposure was an important thing to quantify in the fire scenarios since it ties back into the performance criteria of a few system objectives. The exposure time will have a major impact on how large the storage tanks for water and foam concentrate will need to be. Additionally, this will determine how long the system needs to be powered for. It was assumed that firebrands can only travel forwards, in the same direction that the flame front is spreading. Therefore, the firebrands will only be a threat until the main flame front passes by the house. This is consistent with what can be expected in a real wildfire; the wind that is driving the fire spread will concurrently be transporting the firebrands through the air in the same direction.

In order to estimate the length of exposure, two factors were considered: how fast wildfires spread and how far firebrands can travel in the air. As discussed in the literature review section, firebrands have been found as far as 6.2 miles away from the flame front in extreme wildfires (Koo et. al., 2010). Wildfire spread is a difficult phenomenon to quantify since it depends on many different variables: wind speed, fuel size and moisture content, and topography can all influence the speed at which a wildfire will spread across the landscape. There have been numerous studies that have attempted to estimate a realistic upper limit of flame spread speed. One article states that wildfires can spread up to 6 miles per hour in dense fuels and 14 miles per hour in grasslands (Natural History Museum of Utah. (n.d.). A book produced by the Australian Government dedicated to studying wildfire spread estimates that the general maximum speed of wildfires is from 9 to 12.5 miles per hour (Cheney & Sullivan, 2007). In this case, it is more conservative to consider a slow rate of flame spread combined with a large firebrand transport distance since this will yield the longest exposure time. Therefore, the length of exposure was estimated by using a transport distance of 6.2 miles and a fire spread rate of 6 miles per hour.

$$Exposure\ Time = \frac{Firebrand\ Transport\ Distance}{Wildfire\ Rate\ of\ \ Spread} = \frac{6.2\ miles}{6\ mph} = 1.03\ hours$$

An experiment done by Manzello and NIST exposed mulch beds to firebrand showers. The mulch beds were exposed to a firebrand number flux of $7.4/m^2$*s under 6 m/s winds. Flaming ignition was observed in under 6 minutes after the first firebrand landed on the pine bark mulch in every test (Manzello, Nii, & Suzuki, 2017). These tests indicate that it is realistic for a 1 hour exposure time to be long enough for firebrands to accumulate to initiate a spot fire. This means that the fire scenario that was developed for this project represents a real threat and a realistic pathway to ignition.

3.3.2 Fire Scenario 1: Deck Fire

The first fire scenario that we came up with and analyzed was the case of a deck fire. In this scenario, the firebrands will shower down on the 20’ x 10’ deck, shown in Figure 16. The wind will push the firebrands into the corner of the deck at the interface of two walls. The accumulation of firebrands will be enough to cause flaming ignition of the deck. This fire will then ignite the wall and spread vertically until it reaches the eaves.

Figure 16. Fire Scenario 1

3.3.3 Fire Scenario 2: Mulch Fire

The second fire scenario accounted for vegetation around the house. We modeled this design fire after watching an experiment done by the IBHS Insurance Institute for Business and Home Safety, pictures of both the model and the IBHS experiment are shown in Figure 17. The experiment simulated wildfire conditions by exposing a house to a firebrand shower. In the video, firebrands accumulate and ignite the mulch, which then ignites the bushes. The radiant heat flux from the bushes and the mulch ignite the wall, at which point the fire will spread vertically up the siding.

Figure 17. Fire Scenario 2

The front of the house has 3 feet of medium pine bark nugget mulch extending away from the house along the entire length, except for where the concrete steps lead to the front door. On either side of the steps, there are three Manzanita bushes. Figure 18 shows a screenshot of the 3D AutoCAD model representing the front of the house.

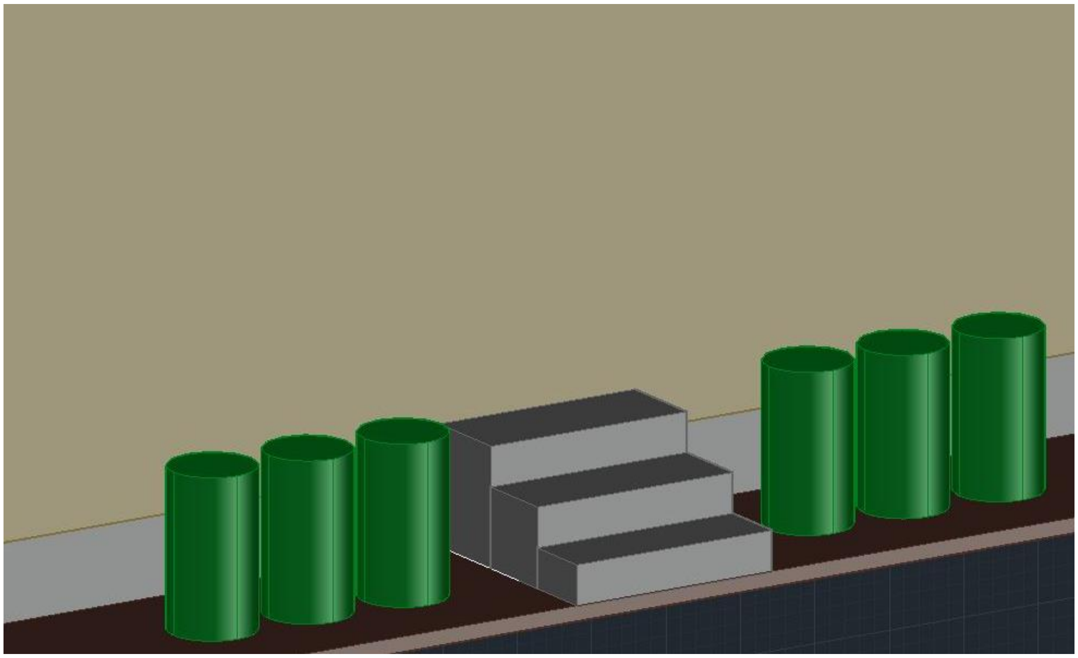


Figure 18. 3D AutoCAD Model of the Mulch Bed and Bushes.

Data from an experiment conducted at the University of Nevada indicates that fire spreads in this mulch at a rate of 0.066 ft/s. The experiment ignited mulch with a torch and then measured the spread rate of the fire under 10 to 15 mph winds (Smith & Quarles, 2011) This is similar to the winds that can be experienced during a wildfire. In order to compare the mulch fire to the deck fire scenario, the rate of opposed flow spread for flames on the deck surface was calculated. An important variable when determining the lateral flame spread rate is the flame spread parameter, Φ. The flame spread parameter has been tabulated for common materials. The pine boards of the deck are expected to have a value of $\Phi = 3.2\ kW^2/m^3$ (Babrauskas & Wetterland, 1995). The physical properties of southern yellow pine are also known. The wood has a density of 420 kg/m^3, a specific heat of 1632 J/kg*K, and a conductivity of 0.144 W/m*K (Engineering Toolbox, n.d.; Goss & Miller, n.d.). The ignition temperature of southern yellow pine is 320^oC (Tran & White, 1992). With this information known, the rate of opposed flow flame spread was calculated as follows (Quintiere, 2006):

$$v_p = \frac{\phi}{k\rho c(T_{ig} - T_s)^2} = \frac{3.2\ kW^2/m^3}{0.0987\ kJ^2K^{-2}m^{-4}s^{-1}(320^oC - 30^oC)^2} = 3.85\ E - 4\ m/s$$

This translates to a lateral rate of flame spread of only 0.00126 ft/s. This is an order of magnitude slower than the mulch rate of spread of 0.066 ft/s. This means that the mulch will be able to ignite more of the wall than the deck, which will lead to a larger fully developed fire. For this reason, a complete set of calculations were completed for the mulch fire scenario

3.3.4 Fire Scenario Calculations

This section presents a summary of key equations and concepts that were used to quantify the fire scenario and determine the ignition timeline. The calculations can be viewed in their entirety in Appendix B. To begin, it was necessary to define certain events that to include in the ignition timeline. The following events were identified as being important to the fire scenario based on observations from the IBHS firebrand experiment, information from the literature review regarding wildfire pathways to ignition and fire development, and our system goals.

- Mulch Ignition
- Center Bush Ignition
- Left/Right Bush Ignition
- Wall Ignition
- Flames Reach the Eaves
- Detector Actuation
- System Discharge

The calculations were completed with the goal of estimating a time to correspond to each of these events. We are assuming that the fire will start at the edge of the mulch furthest from the wall and the wind will spread the mulch towards the wall. This represents the worst case scenario because the fire in the mulch will spread much faster with the help the wind. This means that more mulch will ignite over time. The ignition time for the bush was assumed to be 8 seconds after the mulch fire reached the edge of the bush. This will be variable and dependent on a number of conditions, but it is believed to represent the realistic worst case scenario for the ignition of the bush. By the time the left and right bushes ignite, the center bush is only releasing 14 kW total. Because of this, it is safe to assume that the time to ignition of the left and right bush is controlled by the mulch fire and that the relatively small radiative flux from the center bush does not influence the time to ignition.

View Factors

Once the mulch and the three bushes were burning, the wall ignition was considered. View factors were used to determine how much of the radiation leaving the burning bushes would hit the surface of the wall. The view factor F_{12} is the fraction of energy exiting Surface 1 that directly impinges on Surface 2 (Martinez, 2020). View factors have been tabulated for a number of common configurations. Since the bushes have been approximated as cylinders, it is possible to apply these view factors to this fire scenario. The two view factors used in the calculations are shown below in Figure 19.

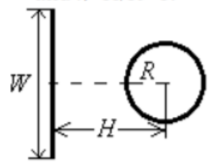
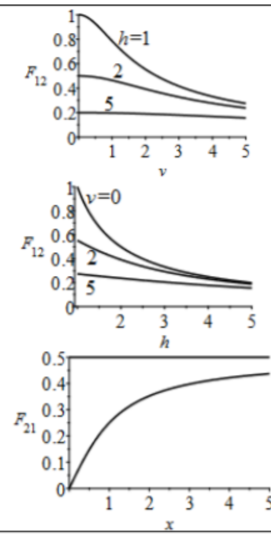
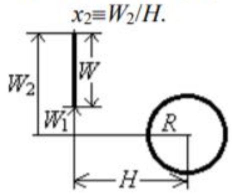
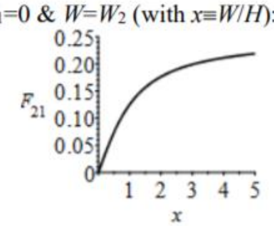
From frontal surface of strip (1) of width W to a cylinder (2) of radius R at a distance H between centres, with $v\equiv W/(2R)$ and $h\equiv H/R>1$. 	$F_{12}=\frac{\arctan\left(\frac{v}{h}\right)}{v}$ $F_{21}=\frac{\arctan\left(\frac{v}{h}\right)}{\pi}=\frac{\arctan(x)}{\pi}$ with $x\equiv v/h=(W/2)/H$ (e.g. for $W=R=H$, i.e. $v=1/2$, $h=1$, $x=1/2$, $F_{12}=0.927$, $F_{21}=0.148$)	
From frontal surface of off-centre strip of width W to a cylinder of radius R at a distance H to the strip plane. The solution is the composition of a strip of with W_1 and a strip of width W_2, with $v_1\equiv W_1/R$, $v_2\equiv W_2/R$, $h\equiv H/R>1$, $x_1\equiv W_1/H$, $x_2\equiv W_2/H$. 	For $W=W_2-W_1$: $F_{12}=\frac{\arctan(x_2)-\arctan(x_1)}{v_2-v_1}$ $F_{21}=\frac{\arctan\left(\frac{v_2}{h}\right)-\arctan\left(\frac{v_1}{h}\right)}{2\pi}$ For $W=W_2+W_1$: $F_{12}=\frac{\arctan(x_2)+\arctan(x_1)}{v_2+v_1}$ $F_{21}=\frac{\arctan\left(\frac{v_2}{h}\right)-\arctan\left(\frac{v_1}{h}\right)}{2\pi}$ (e.g. for $W_1=0$ & $W_2=R=H$, i.e. $v_1=0$, $v_2=1$, $h=1$, $x_1=0$, $x_2=1$, $F_{12}=0.463$, $F_{21}=0.074$)	For $W_1=0$ & $W=W_2$ (with $x\equiv W/H$): 

Figure 19. View Factors to Estimate Radiation from the Manzanita Bushes to the Wall (Martinez, 2020)

The first view factor shown in the figure was used to model the radiation from the center Manzanita bush to the wall. The second view factor was used to model the radiation from the left and right Manzanita bushes to the wall. The value of *W* needed to be defined in order to apply the view factor equations. *W* is the width of the wall area that is being considered. In this case, this was the area of the wall that is receiving the most radiation since this area will ignite first. To define a value for *W* to be used in the above view factor equations, it was assumed that the bushes are emitting significant radiation to the wall over the horizontal projection of a 90^{o} arc. it was possible to find the area where the radiation arcs of the three bushes will intersect. This is shown below in Figure 20.

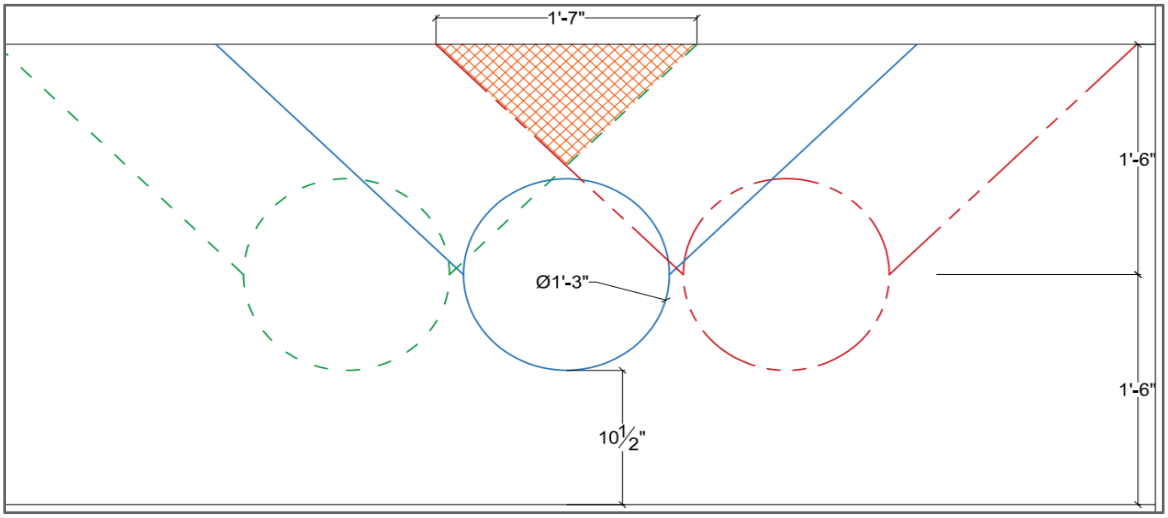


Figure 20. Determining Area of Wall Ignition Based on Bush Radiation.

The wall will receive the most radiation on a 19 inch wide strip in front of the center bush, highlighted in the figure by the orange cross hatch. The two view factors were calculated using 19 inches as the value for *W*, the view factor for the center bush radiating to the wall is 0.155 and the view factor for the side bushes radiating to the wall is 0.097.

Mulch Heat Flux to Wall

The SFPE Handbook (5th Edition - 2016) provides a series of graphs and equations in Chapter 25 that can be used to estimate the heat flux to the wall from the mulch. Figure 21 provides the vertical heat flux distribution along the centerline of a square propane burner fire adjacent to a flat wall.

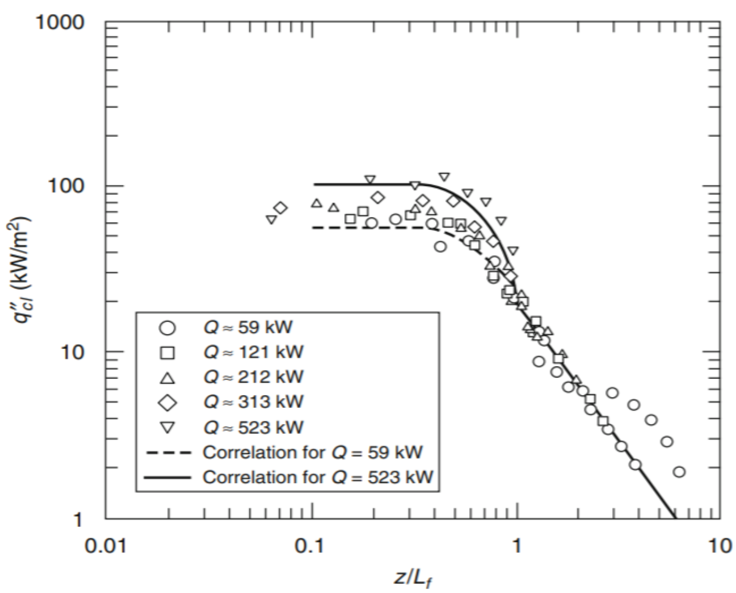


Figure 21. Vertical Heat Flux Distribution Along the Centerline of a Square Propane Burner Fire Adjacent to a Flat Wall.

In order to estimate the heat flux from the graph, it is necessary to define the value of z/L_f. The flame height from the mulch fire, L_f , was assumed to be 1.8 feet based on data from mulch flammability experiments (Zipperer et. al., n.d.). The value for z will be taken as 1 foot since the cedar siding of the house starts 1 foot above grade. Therefore:

$$\frac{z}{L_f} = \frac{1ft}{1.8ft} = 0.55\ \frac{ft}{ft} = 0.55$$

Examining the graph, the heat flux along the centerline is approximately 50 kW/m^2 when the value of $z/L_f = 0.55$. Figure 22 provides the lateral heat flux distribution with varying distance from the centerline of square propane burner fires against flat walls in the flaming region.

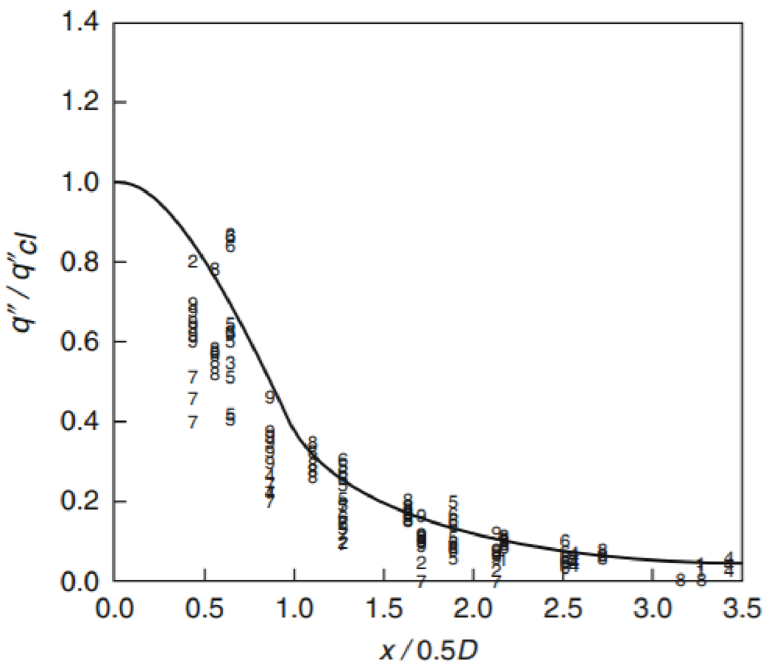


Figure 22. Lateral head flux distribution based on distance from centerline

The value of D is the length of the square area burning. The mulch fire can be approximated as a 3 foot square at this point, meaning that D = 3 ft. The value of x is the distance from the wall to the centerline of the fire; x = 1.5 ft. in this case since the fire is burning across the entire 3 foot depth of the mulch belt and is centered at 1.5 feet from the wall. Therefore:

$$\frac{x}{0.5D} = \frac{1.5ft}{0.5(3ft)} = 1\frac{ft}{ft} = 1$$

Examining the graph, the heat flux at the wall is approximately 40% of the heat flux at the centerline. Therefore, the target area of the wall is receiving 20 kW/m^2 from the mulch.

Wall Ignition

The wall is receiving a heat flux from a total of four sources: left bush, center bush, right bush, and the mulch. Each source has its own HRR curve, and its own view factor that determines how much of the radiation is reaching the wall. The total calculated heat flux from the four sources was used to calculate the time to ignition for the wall.

The critical heat flux for most species of wood is in the range of 9.7 kW/m^2 to 14 kW/m^2. This is the lowest external heat flux at which ignition of the material can occur (Rantuch et. al., 2017). The critical heat flux of the cedar siding was assumed to be 12 kW/m^2. The calculations below show that at ignition will take approximately 31 seconds with the critical heat flux impinging on the surface. Over this period, the wall would absorb 372 kJ/m^2.

Cedar Siding Physical Properties (Kumaran et. al., 2002):

$$k = 0.085\frac{W}{m}\cdot K \qquad c_p = 1880\frac{kJ}{kg} \qquad \rho = 336\frac{kg}{m^3} \quad k\rho c_p = 0.0537$$

Assume an initial surface temperature of T_s = 30 ^{o}C

Cedar ignites at approximately 354 ^{o}C (Drysdale & Yudong, n.d.)

$$t_{ig} = \frac{\pi}{4}k\rho c_p\left(\frac{T_{ig} - T_s}{\dot{q}_f^{"}}\right)^2$$

$$t_{ig} = \frac{\pi}{4}(0.0537)\left(\frac{354℃ - 30℃}{12kW/m\text{^}2}\right)^2 = 31\ seconds$$

$$q^{"} = t_{ig}\dot{q}_f^{"} = 31s\ (12\ kW/m\text{^}2\ ) = 372\ kJ/m^2$$

Since the heat flux to the wall is not constant, it is not accurate to calculate the time to ignition using a time constant heat flux. DiDomizio, Mulherin, and Weckman (2016) outline a process to calculate the time to ignition under a time varying radiant exposure. The first step was to graph the total heat flux to the wall over time from the four sources. The graph shows two separate curves because there is a discontinuity in the function at the time where we begin to account for the mulch heat flux to the wall. A best fit curve was identified for each part of the graph using Microsoft Excel. Figure 23 shows the graph of the heat flux to the wall (blue), the fit curves (red), and the fit curve equations.

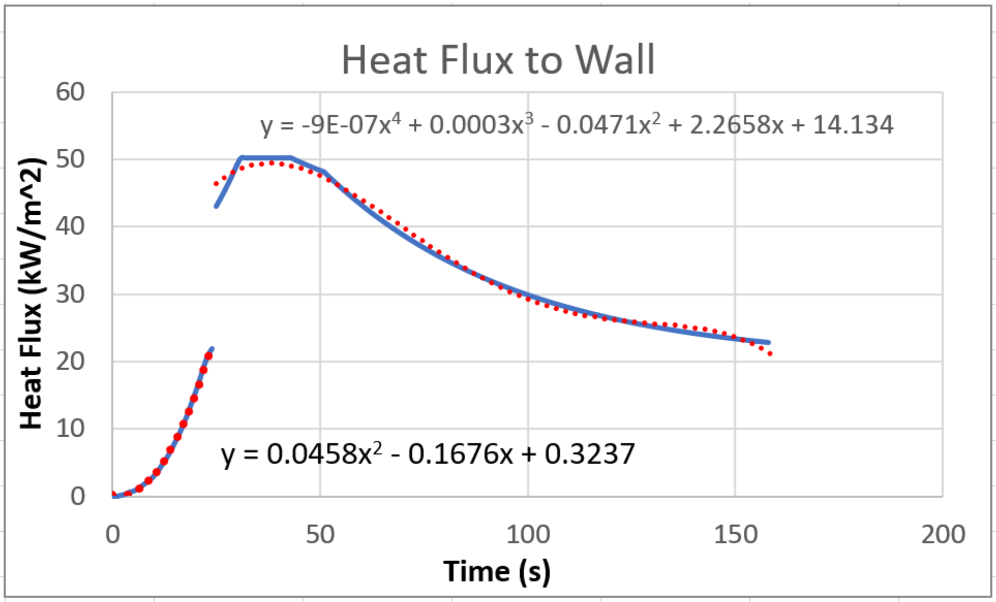


Figure 23. Graph of heat flux to wall from all sources

Integrating the best fit curves yielded the total heat impinging on a unit area of wall over a certain period of time. It will take approximately 32 seconds for the wall to receive the amount of heat that is required for ignition under the critical heat flux. Since this is around the same time required for ignition with the critical heat flux, it is reasonable to assume that the wall will ignite within 32 seconds.

Vertical Flame Spread on the Wall

As soon as the wall ignites, the flames will begin to spread upwards. James Quintiere outlines a process for estimating the rate of vertical flame spread in Chapter 8 of his book Fundamentals of Fire Phenomena (2006). The example in the book uses a constant heat release rate from the wall throughout the problem, which led us to believe this is a reasonable assumption. We assumed that the cedar siding material is burning at its peak heat release rate of 182 kW/m^2 (Dietenberger, Stark, & White, 2007). Quintiere (2006) gives typical values for peak incident flame heat flux to the upper wall from the burning portion below in the range of 20 kW/$m^{2\ to}$ 30 kW/m^2 for a wide variety of wall flames. Examining Figure 24 below, the results among all materials tested are remarkably similar.

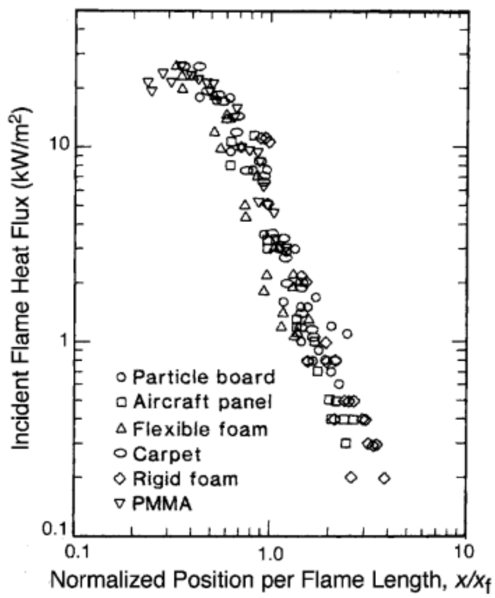


Figure 24. Incident heat flux to wall distribution based on normalized position

The trend indicates that the maximum value incident flame heat flux to the wall above is in the realm of 30 kW/m^2. This occurs when the normalized length is equal to 0.3 (i.e. flame length is far greater than the position. For this scenario, the heat flux to the wall was assumed to be 25 kW/m$^{2.}$ The process described by Quintiere for calculating vertical flame spread is summarized as follows:

Flame length on a vertical wall can be approximated by this relation:

$$y_f = 0.01\frac{m^2}{kW}\left(\dot{Q}''y_p\right)$$

The equation for vertical flame spread across a thermally thick surface is given.

$$v_p = \frac{(\dot{q}_f'')^2\,(\delta_f)}{\left(\frac{\pi}{4k\rho c_p}\right)\left(T_{ig} - T_s\right)^2}$$

Adopting *y* as the vertical coordinate, the equation becomes:

$$\frac{dy_p}{dt} = \frac{(\dot{q}_f'')^2\,(y_f - y_p)}{\left(\frac{\pi}{4k\rho c_p}\right)\left(T_{ig} - T_s\right)^2} = \frac{(y_f - y_p)}{t_{ig}}$$

Once the flame spread velocity was calculated, it was possible to determine the amount of time that it would take for the flames to reach the eaves of the home. The information from this section was used to construct a fire scenario timeline that is presented in the results section.

3.3.5 Firebrand Heat Contribution

Because the firebrands are a continuous threat even after ignition has occurred, it was necessary to determine the amount of heat that is contributed by the firebrand shower. If a spot fire ignites via firebrands a few minutes into the one hour exposure, the firebrands can continue to shower the house until the flame front passes. Therefore, the heat contribution should not be neglected. Experiments indicate that the realistic worst case for the number flux of firebrands landing on a surface is about $1.4/m^2*s$ (Thomas et. al., 2017). The design area in this case is the area of the mulch bed, which is 21 m^2. By carrying out a simple multiplication of the firebrand flux by the design area, we estimated that about 1750 firebrands can land in the design area in 1 minute. Using the literature we found that one firebrand releases an average of about 0.12 kJ/m^2, so over the design area an additional 3.5 kW is contributed by the firebrand shower. We will take this into account when deciding on the discharge density needed for the size of the design fire.

3.4 Develop Trial Design

With goals, objectives, performance criteria, and fire scenarios in mind, we began developing trial designs of the automatic external foam-water suppression system. The SFPE Handbook has identified six subsystems that can make up a trial design. These subsystems are divided in Table 5 below based on their relevance to this project.

Table 5
SFPE Subsystems

Priority 1 (Directly Applicable)	**Priority 2 (Indirectly Applicable)**	**Not Applicable**
● Fire Detection and Notification ● Fire Suppression	● Reduce Fire Initiation and Development ● Passive Fire Protection	● Spread, control, and management of smoke ● Occupant behavior and egress

3.4.1 Determine Suppression System Type

Based on the information presented in section 2.8 of the background, a full analytical criteria method was used to determine the system best suited for this application. The prioritization matrix and criteria that we used to identify the most favorable system for suppressing firebrand ignitions on homes is located in Appendix C.

In summary, after researching the different suppression systems we decided that water would not be an ideal suppressant to fight wildfires; water’s high surface tension causes it to roll off fuel rather than penetrate it and does not allow it to stick around and cling to vertical surfaces. Therefore we ruled out water mist and water spray systems. As we looked into foam as a suppressant, we found that it will remain in place after discharge which would help when there is a continuous fire brand exposure. It also has a lower surface tension allowing it to adhere to vertical and horizontal surfaces and create an oxygen barrier over fuel. Additionally, using a foam based system reduces the amount of water required for suppression. After choosing foam, we then researched foam water sprinkler systems and low med and high expansion foam systems. When we looked into low medium and high expansion foam systems, we came across compressed air foam systems, which we found has several advantages over foam water sprinkler systems. Foam water sprinkler systems and low medium high expansion foam systems make the foam at the end with foam makers that draw in air, which make the bubble sizes more variable, causing it to be less reliable and efficient. Compressed air foam systems make the foam early on, allowing for a uniform network of bubbles. This causes the foam to break down slower, have full coverage, and stick to vertical surfaces well. It also uses a lot less foam solution and water.

Looking into different types of foams, we found that although AFFF and protein/fluoroprotein foams have been effective, they contain a lot of toxins and are not environmentally friendly. Therefore, they are not suitable for outdoor uses. These two foams are also used for Class B fires, such as flammable liquid fires, whereas a wildfire ignition on a home would be a Class A fire, because homes are made of ordinary combustibles. Synthetic/detergent foams we found would be too light and therefore not suitable for outdoor use. Therefore, we landed on Class A foam, which accounts for all the characteristics of a foam solution, while being tested and listed for biodegradability and environmentally friendly.

In further research of compressed air foam systems, we analyzed several studies. In a study by the Los Angeles Fire Department (2001), water, Class A foam solution, and compressed air foam were evaluated. Each suppressant was tested through a handline hose, using a flow of 90 gpm. But as represented in Figure 25, the time that it took compressed air foam to knockdown the fire and drop the temperature, as well as the amount of water needed for knockdown was significantly less than both water and the Class A foam solution.

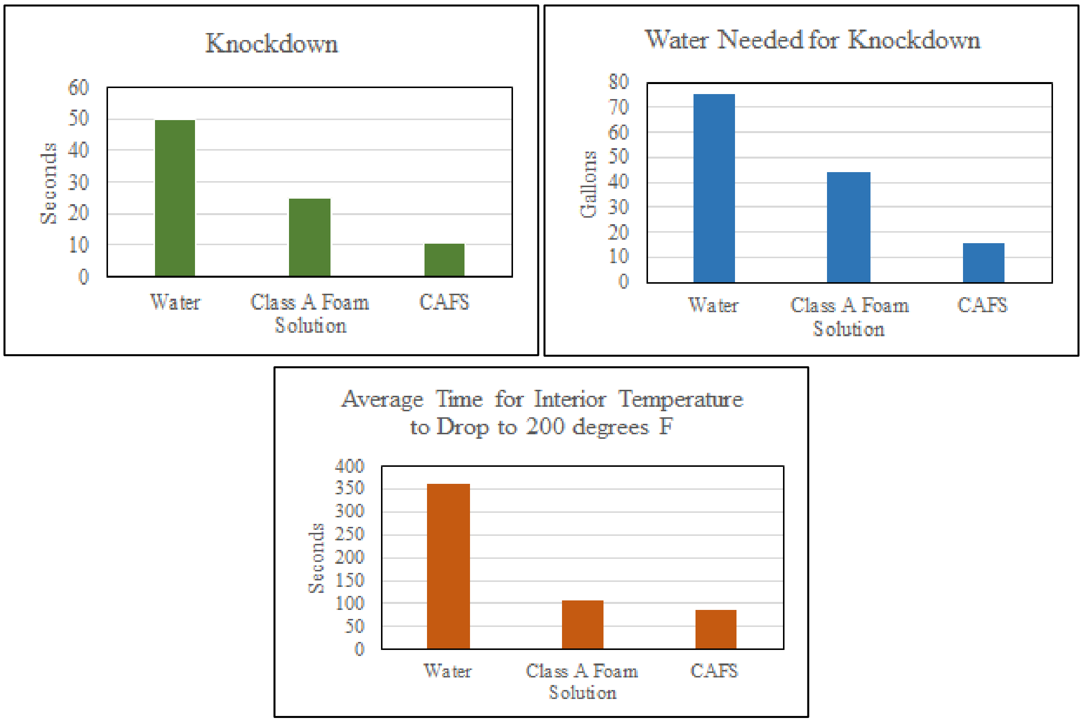


Figure 25. Suppression performance of CAF compared to water and class A foam solution.

A study by Kim and Dlugogorski (1997) also displays the advantage of compressed air foam systems over water mist and sprinkler systems. This study was based on a wood crib fire, and as you can see from the graphs in Figure 26, the compressed air foam system suppressed the fire much faster than the other systems. It took only about 60 seconds for the compressed air foam system to bring the fire from 500 kW to less than 50 kW, whereas it took the sprinkler system twice as long and the mist system 6 times as long.

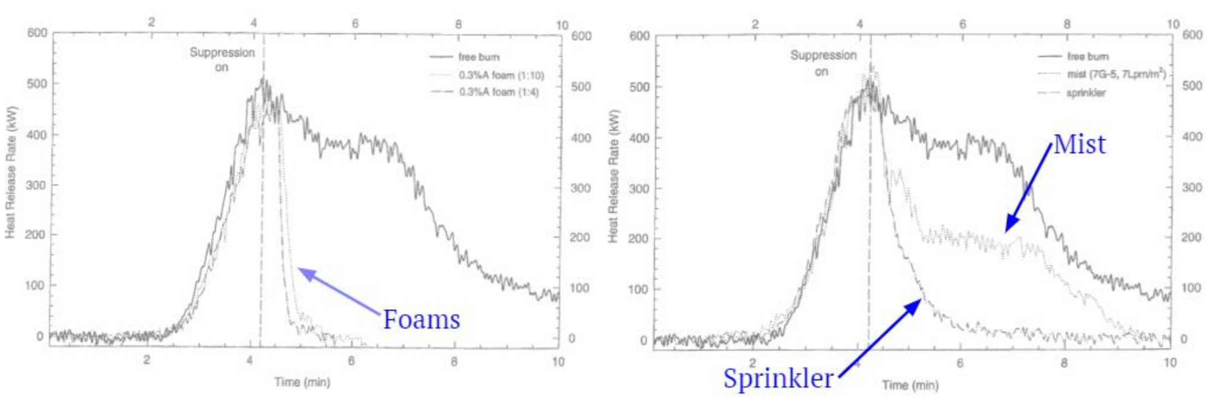


Figure 26. Suppression performance of CAFS compared to sprinkler system and water mist system

Another way that we assessed the different types of systems was by looking at the minimum discharge density requirements established by the NFPA. Specifically, we used NFPA 11 *Standard for Low-, Medium-, and High-Expansion Foam* which specifies discharge densities for indoor foam systems. The standard says that a minimum of 0.16 gpm/ft^2 is needed for Foam Water Sprinkler and Foam Water Spray Systems. For non-CAF low expansion foam systems, the minimum discharge density ranges from 0.1 to 0.5 gpm/ft^2 depending on the application. For CAF systems, the minimum discharge density requirement is 0.04 gpm/ft^2 on hydrocarbon fuels and 0.06 gpm/ft^2 for alcohol and ketone fires. Discharge density is the amount of suppressant that is released over an area, therefore the system that uses the lowest discharge density is the most efficient at suppressing the fire because it needs less suppressant to do the same job. Although these discharge densities are not directly applicable to our system because we are using a CAF system on Class A fuels, we can see from the standards that a CAF system is the most effective because it has the lowest minimum discharge density requirement.

3.4.3 Initiating Devices

Since occupants are assumed to have evacuated before the system discharges, the system needs to be provided with means of automatic detection. Several different types of automatic fire detectors were considered for this application. Smoke detectors are commonly specified for indoor use and can provide early fire detection in enclosed spaces. Unfortunately, the ambient conditions on the exterior of the home would likely lead to a significant number of nuisance alarms. Additionally, the detectors will not reliably activate without a ceiling to collect the hot gases and smoke (BRK Electronics, 2020). UV/IR flame detectors were also considered. These detectors monitor different bands of the light spectrum to detect a fire within a given zone. We found that these detectors were reliable for outdoor use and included two confirmation conditions before system activation. Even with the multi-criteria configurations, the best flame detectors can still be susceptible to nuisance alarms. (General Monitors, n.d.). To provide full coverage of the house at least eight detectors would be needed (two at each corner of the house). Each detector can cost in the range of $3,000 to $4,000, meaning that full coverage of the house may be prohibitively expensive (Petersen, 2016). With smoke detection and flame detection ruled out, linear heat detection was identified as the best option to automatically detect fires on the exterior of the home. This type of detector consists of a heat sensitive sheathing surrounding two metallic conductors, all within an outer covering. Once the detector is heated to a certain temperature, the heat sensitive insulation melts and allows the wires to come into contact; this sends the system into alarm (SAFE Fire Detection). Protectowire was identified as a major manufacturer of linear heat detectors with a range of options available to meet the design goals. In order to provide protection against nuisance alarms, the Confirmed Temperature Initiation Linear Heat Detector has been selected. This detector can discriminate against short circuits by using the conductors as a thermocouple to verify the temperature before sending the system into alarm. The CTI-X model has a weather resistant jacket that makes it suitable for outdoor use. (Protectowire, 2014). Data sheets for the Protectowire products can be viewed in Appendix D.

3.4.4 System Layout Design

Once the necessary system components had been identified and selected, several system layouts were drawn and compared in AutoCAD computer aided-design software (Autodesk Inc., 2019a). The system layouts were drawn in elevation and plan views to fully illustrate the proposed system design. The system was designed to have four separate deluge zones all piped from a common location. Each zone is able to operate independently in order to conserve resources. Nozzles were placed around the home under the eaves based on spray patterns found in the manufacturer cut sheets. The spray pattern for the Fire Flex-TAR 225L Nozzle can be seen in Figure 27.

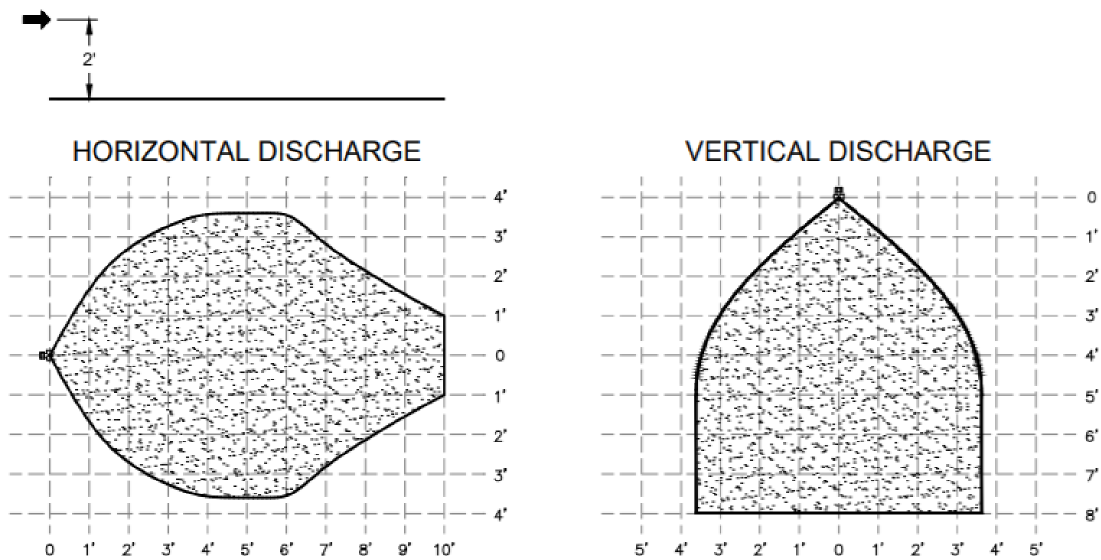


Figure 27. Vertical and Horizontal Spray Patterns of the Fire flex TAR-225L Nozzle (FireFlex, 2016).

Since the nozzles are installed in the pendant orientation at the eaves of the home, the vertical discharge pattern was used. Spray patterns were overlapped to provide as much coverage of the walls and the ground extending 3 feet away from the home as possible. Based on the timeline of the fire scenario discussed in the previous section, we are confident that the system will begin discharge before the flames reach the eaves of the home. For this reason, it was determined that gaps in coverage within 1 foot of the eaves would be acceptable.

The detection system layout was also drawn in AutoCAD to provide a basic visualization of the system wiring and the location of devices. Similar to the suppression system, the automatic detection system is designed in four different zones. If an initiating device actuates on one side of the house, the fire alarm control panel will release foam to the corresponding zone. The Protectowire will be installed in a Class B wiring configuration with an end of line resistor, which means that it can terminate at any point without needing to loop back to the interface module (SAFE Fire Detection, n.d.). Each side of the house will have Protectowire installed at two levels: 1.5 feet off the ground and 9 feet off the ground. The lower layer is expected to actuate first if the fire grows consistently with the fire scenarios that have been defined, since this area receives the most radiation from the burning bushes and mulch. The upper layer will be installed slightly below the eaves in case the wall ignites above the lower layer of Protectowire.

3.4.5 Detection Time

The time to ignition of the wall was estimated in the fire scenario calculations that are outlined in Section 3.3.4 using the following equation:

$$t_{ig} = \frac{\pi}{4} k\rho c_p \left(\frac{T_{ig} - T_s}{\dot{q}_f^{"}} \right)^2$$

We estimated the time to detector actuation by replacing the ignition temperature of the wall with the rated temperature of the Protectowire linear heat detector. Once the wall that the Protectowire is installed on reaches the rated temperature, we are assuming that the detector will actuate.

3.4.6 Discharge Delay

An important aspect in our timeline of fire ignition and system operation was the discharge delay, meaning the time between detection and system discharge. To determine this time, we researched literature regarding times to system discharge for fire protection systems. This research indicated that suppression systems operate anywhere from 9 seconds to 1 minute. We decided on 30 seconds as an initial estimate of the system activation time based on these numbers. A representative from FireFlex confirmed that although the times can vary depending on system size, this would be a conservative estimate for a small system (Mike Nagy, personal communications, 2020).

3.4.7 Discharge Criteria

One of the driving factors of the system design was the system discharge criteria. Typically, this is defined by a minimum discharge density in terms of gpm/ft^2. The system was designed so that every nozzle in the design area was capable of delivering the required density of suppressant agent over its entire coverage area. Current standards do not provide minimum discharge densities for compressed air foam systems utilizing Class A Foam to suppress Class A fires. The lack of a prescriptive requirement for this value led us to develop the discharge density for this system by compiling information from literature. NFPA 11 *Standard for Low, Medium, and High Expansion Foam* (2016) contains minimum discharge density requirements for compressed air foam systems using Class B Foam to suppress Class B fires. Systems designed to protect fires involving hydrocarbon fuels shall discharge at least 0.04 gpm/ft^2 over the design area and systems involving alcohol/ketone based fuels shall discharge at least 0.06 gpm/ft^2 over the design area. Although the characteristics of a Class B liquid pool fire are significantly different from what can be expected from a fire involving ordinary combustibles, these numbers served as a useful point of reference. Experiments by Kim and Dlugogorski (1997) discussed previously in Section 3.4.1 involving a fixed pipe compressed air foam system installed at the ceiling level served as one of the main determining factors for this design. The system used a 0.3% Class A Foam solution at a 1:4

expansion ratio. Examining the data from the experiments showed that a fixed pipe compressed air foam system delivering an average density of 0.087gpm/ft^2 was able to suppress a 500 kW wood crib fire down to a size of approximately 50 kW in 60 seconds. In order to apply this information to the design fire for this project, the heat release rate per unit area of the wood crib fire was calculated by dividing the heat release rate by the projected floor area of the crib. This was then compared to the heat release rate per unit area of the design fire on the exterior of the home. The wood crib fire from the experiment is releasing about four times more heat than the design fire for this project. The discharge density for this design was reduced proportionally to account for this.

Due to the extreme wind conditions present during a wildfire, it is likely that the spray patterns of the nozzles will be impacted and that all of the discharged foam will not land uniformly within the design area. There is currently a proposed change to NFPA 11 *Standard for Low, Medium, and High Expansion Foam* to include a 1.5 times safety factor on the discharge density figure when windy conditions are anticipated (S. Scandaliato, personal communication, 2019).

The data sheet for the FireFlex TAR-225L Nozzle states that the nominal flow of the nozzle is 5.94 gallons per minute. Based on the system layout that was developed in AutoCAD, each nozzle is covering approximately 69 ft^2. A nozzle flowing at this nominal flow over this area indicated a discharge density very similar to the one found in the first method, which indicates that the proposed system would be able to supply the required discharge density.

3.4.8 Power Supply

As discussed in the literature review, one wildfire management strategy is to cut power to areas of impending threat. The system will be connected to the grid for the primary power supply but will switch to battery power if the primary power source is lost. In order to estimate the power supply needed, we first had to estimate the amount of time the power could be cut for. To accomplish this we looked for information from Pacific Gas and Electric, one of the main power suppliers that was responsible for a series of planned power shut offs in the fall of 2019. According to their customer information pamphlet, the power is not restored until 24 to 48 hours after the weather has passed and weather conditions can last anywhere from several hours to several days (Pacific Gas & Electric, 2019). Using this information, we used the high end of each range to build in a safety factor estimated that the power could be shut off for about 96 hours (4 days).

The next step was to calculate the battery size needed to power the system for this amount of time. The total standby current required was calculated by obtaining the standby current draw of each system component from the manufacturer cutsheets. An alarm current draw was not accounted for since the system does not have any notification appliance circuits. Once the suppression system is actuated via the linear heat detectors, the system does not need power to operate.

3.4.9 Water Supply

Once both the length of exposure and the discharge density were determined, it was possible to estimate the size of the water supply for the system. We are assumed that the system will discharge simultaneously on two sides of the house at most: one short side and one long side. In addition to covering the walls, we are designing the system to cover the ground extending 3 feet away from the house. The discharge density discussed in Section 3.4.7 is the density of expanded foam coming out of the nozzles. Since a 1 to 4 expansion ratio foam is about 25% water and 75% air, the amount of water being discharged is one-fourth the amount of the calculated discharge density. The minimum water supply requirement was estimated by considering the total design area on two sides of the home, the discharge density, and the required discharge duration

3.4.10 Foam Concentrate Supply

The data sheet for the Class A foam concentrate that we are recommending for use with this system (Appendix D.6) provides the values for the ideal foam concentrate to water ratio for each type of foam system. This foam concentrate will perform best in a compressed air foam system when proportioned between 0.1% and 0.5%. The previously discussed study by Kim and Dlugogorski (1997) supports this concentration value. The experiments used Class A foam concentrate proportioned at 0.3% in a fixed pipe CAFS to effectively suppress the wood crib fires. Based on the information from these two sources, we recommend that the Class A foam concentrate in this system is proportioned at 0.3%. This value, combined with the discharge duration and system flow rate, was used to calculate the total amount of foam concentrate required for the system.

3.4.11 System Size

The physical footprint of the system was an important factor to quantify; a system that occupies too much space may be difficult to install in areas like Santa Cruz, CA that have a small average home size and property size. Previous case studies from FireFlex were studied to estimate the amount of space that a typical CAFS may occupy (FireFlex, 2020). Some components such as the number of air cylinders and the size of the foam concentrate tank will be dependent on the size of the system. The ICAF System Control Cabinet always occupies the same amount of space, independent of system size. We assumed that the system size would be proportional to the total amount of water discharged over the entire discharge period. This allowed us to compare our system to the systems in the various case studies. For a CAFS protecting a transformer, a total water discharge of 475 gallons required three high pressure air cylinders; this translates to 158 gallons of water per cylinder. For a larger CAFS protecting an underground flammable liquid storage facility, a total water discharge of 1,920 gallons of water required 10 high pressure air cylinders. Likewise, this means that each cylinder was responsible for forcing about 192 gallons of water through the system. These numbers allowed us to estimate the number of high pressure air cylinders needed for this system. The amount of foam concentrate required for the system was determined in the previous section. FireFlex provides the dimensions of foam concentrate storage tanks ranging from 15 to 500 gallons on the ICAF Foam Supply Tank Datasheet which can be viewed in Appendix D.5.

3.4.12 Weatherproof Components

This system requires special components compared to typical interior suppression systems. The components will be exposed to the elements and more vulnerable to weathering because of its placement outside of the house. One goal of the system is to minimize the maintenance needed for the components of the system by finding weatherproof and corrosion resistant materials. When researching specific components, the team specifically looked for those that were built for outdoor use as indicated by the manufacturer data sheets.

3.4.13 System Monitoring

In order for the system to reliably operate in the event of a fire, certain system components must be monitored. Since the system depends on many different components operating concurrently, an issue in one part of the system could render the entire system inoperable. There are different electronic components available to supervise the various components of the CAFS. If one of these devices detects a problem, it will send a supervisory signal to the fire alarm control panel but will not send an alarm signal to trigger system discharge. Table 6 below summarizes the different system functions and components that we believe should be electronically supervised (Potter Signal, 2020).

Table 6
Electronic supervision components

Component	Function
Water Temperature Switch	A water temperature switch will send a supervisory signal to the panel if the water in the tank drops below 40 ^{o}F. This is important to protect against freezing.
Water Level Switch	A water level switch will send a supervisory signal to the panel if the water level in the tank is outside of a predetermined range. Supervising the water level can detect problems such as leaks or tank overfilling.
Pressure Switch	A pressure switch is used to constantly monitor the system air supply and ensure that it is within a predetermined range. This ensures that there is a signal at the panel if the high pressure air cylinders are leaking.
Tamper Switch	Tamper switches are used to supervise control valves. If the valve is accidentally left in the closed position after maintenance, the tamper switch will send a supervisory signal to the panel.

3.4.14 Inspection, Testing, and Maintenance

Proper inspection, testing, and maintenance of the system was also considered. Once the system is installed on a home, homeowners will need to know exactly what needs to be done to keep the system functioning as intended. FireFlex states that inspection, testing, and maintenance of the Integrated Compressed Air Foam System should be completed in accordance with the requirements of Chapter 7 of NFPA 11 *Low, Medium, and High Expansion Foam.* The relevant requirements of this chapter are summarized in the results section.

3.4.15 Environmental Safety

Since the system will be used externally, all of the discharged suppressant will runoff directly to the surrounding environment. The suppressant used should be safe for the environment to prevent more environmental problems down the line. Manufacturer data sheets for Class A foams were utilized to ensure that the foam concentrate is not an environmental hazard.

NFPA 1150 *Standard on Foam Chemicals for Fires in Class A Fuels* was utilized to determine whether the chosen suppressant was suitable for this application. According to Section 4.21, the foam concentrate shall have the following health, safety, and environmental considerations:

- The foam concentrate shall not exceed the mammalian toxicity limits of $LD_{50} > 500$ mg/kg for acute oral toxicity and $LD_{50} > 2000$ mg/kg for acute dermal toxicity
- The LC_{50} should not exceed 10 mg/L for aquatic toxicity limits
- The foam concentrate shall have a minimum of 60% biodegradation within 42 days
- The foam concentration shall not exhibit a flash point below 60 ℃.

When researching Class A foam concentrates to use, material safety and data sheets were used to ensure compliance with NFPA 1150.

3.5 Evaluate Trial Design

The trial design was evaluated to determine whether or not they meet the performance criteria. Often times, an evaluation involves comparing the performance of each component or subsystem to the performance of a component or subsystem that has already been listed, approved, or prescribed by code (Hurley, 2016). This was not possible in this case because there are no existing codes to compare the exterior compressed air foam system to.

Hydraulic calculations are typically a key method used to evaluate a fixed pipe suppression system. The calculations involve calculating the friction losses of fluid flowing through the pipes and to ensure that the pressure at the most remote nozzle is sufficient to discharge the required amount of suppressant. Traditionally, hydraulic calculations were completed by hand using either the Darcy-Weisbach Equation or the Hazen Williams Equation (NFPA 12, 2019). The Hazen-Williams Equation, shown below, is sufficient for most situations involving water flow in pipes.

$$p = \frac{4.52 * Q^{1.85}}{C^{1.85} * d^{4.87}}$$

When completing hydraulic calculation by hand, a spreadsheet is typically used to organize data and evaluate equations. The K factor of each nozzle is an important parameter that is required to calculate the flow at different points in the system. The K factor is the nozzle discharge coefficient used to calculate the flow from a nozzle. A larger K factor means that it is easier for water to flow through the nozzle (NFPA 13, 2019). Some other important information that is needed to complete hydraulic calculations includes the pipe diameters, pipe schedules, length of pipe between fittings and nozzles, elevation changes in pipes, and friction losses due to fittings. By assigning nodes to each nozzle and fitting, the change in pressure and flow can be determined for small segments and then summed for the whole system.

With advances in technology over the past few decades, there are now a number of softwares available to assist with completing hydraulic calculations. One example is HydraCALC, a software that automatically calculates hydraulic calculations for the system based on the layout and specific inputs, such as the fire pump capacity, required discharge pressure, and pipe sizes (Hydratec Inc, 2019).

Regardless of whether the calculations are done by hand or with the assistance of a computer program, hydraulic calculations are an iterative process. Different pipe sizes are usually tested to determine how the sizes affect the pressure and flow. Once the initial set of calculations are completed for layouts, pipe diameters would be increased or decreased to optimize the system performance. The final design would be selected by choosing the system layout that provided the required flow at the lowest pressure.

Since a compressed air foam system carries both fluid and pressurized air through the piping network, the characteristics of the flow are much harder to quantify and traditional calculation methods cannot be applied. FireFlex has developed a hydro-pneumatic calculation software to run calculations for their Integrated Compressed Air Foam System (FireFlex, n.d.). We reached out to a FireFlex sales representative to request use of the software for research purposes, but unfortunately the company was not able to share the software with us. This meant that we were not able to complete hydraulic calculations for the proposed system design. The FireFlex representative was able to provide us with useful information regarding pipe sizes (Mike Nagy, personal communications, 2020). This information, combined with our calculated flow rate and information from the manufacturer data sheets allowed us to provide a range of likely values for system pressure, system flow, and required pipe sizes.

4.0 Results

This section presents the results gathered from the processes described in the Methodology. We defined performance criteria for each objective to quantify the system goals. In addition, a full timeline has been developed to show the results of the fire scenario analysis. We identified and specified all of the required system components, and finally prepared drawings to illustrate the proposed design.

4.1 Goals, Objectives, and Performance Criteria

Table 7 displays the performance based design goals, objectives, and performance criteria for our project. The performance criteria were determined from calculations as shown in Appendix B, product data sheets from the manufacturer as shown in Appendix C, and further research from literature.

Table 7

Performance Based Design Goals, Objectives, and Criteria

Primary Goal 1: Minimize fire related damage to the building and its contents

Objectives	Performance Criteria
Detect fire in a timely manner	Detect fire before wall ignites
Activate suppression system before flames reach the eaves	Begin discharge 30 seconds after fire detection
Discharge suppressant at a density sufficient to suppress fires resulting from firebrand accumulations against/on the home	Discharge foam solution at 0.087 gpm/ft^2
Provide coverage for vulnerable components around home.	Complete coverage of walls and perimeter of house within 3 ft
Damage should be limited to building facade and auxiliary components.	Structural components shall not ignite during the fire. No loss of integrity of structural components.

Primary Goal 2: System can operate independently from local utilities

Objectives	Performance Criteria
Provide independent power supply	Power supply will power the system for 96 hours under quiescent conditions (non-alarm) and an additional 60 minutes under operational conditions.
Provide independent water supply	Water tank will supply water for each zone to discharge for 1 hour

Secondary Goal 1: System can remain in service with minimum attention from homeowner

Objectives	Performance Criteria
Weather resistant components	Product data sheet indicates that the component is suitable for outdoor use
Provide simple user interface monitoring: low-pressure alarm, water tank level, tamper switches	System will send signal to homeowner in the event of trouble or supervisory signal
Protect against nuisance alarms	Detection system assesses for two separate conditions before initiating system discharge.

Secondary Goal 2: Minimize the impact of system discharge on the environment and design the system in such a way to conserve resources

Objectives	Performance Criteria
Suppression agent shall be biodegradable, non-toxic, and environmentally safe	Product data sheet indicates the suppressant complies with NFPA 1150 *Standard on Foam Chemicals for Fires in Class A Fuels*
Use a zoned distribution system	Zones can operate completely independently from each other

4.2 Fire Scenario Timeline

The process discussed in section 3.3 of the methodology chapter was carried out to model the ignition of the home via firebrand accumulation in the mulch bed. The major milestones that lead up to the ignition of the home include:

- Ignition of the mulch
- Spread of the flames along the mulch to the center bush
- Ignition of the center bush and then adjoining bushes
- Ignition of the wall due to radiation from the mulch and bush fires
- Vertical spread of the flames up to the eaves

The arrival of the flames at the eaves of the house is the last milestone on the timeline because that is the critical point at which we are assuming the house would be a total loss. If the flames make it to the eaves, they will have an access point to enter the house and the system will not fulfill the design objective to limit the damage to the building facade and auxiliary components. The timeline of each event is shown in Figure 28 below, as well as the estimated fire size at key points. The calculations used to obtain the values shown in the timeline are explained in Appendix B.

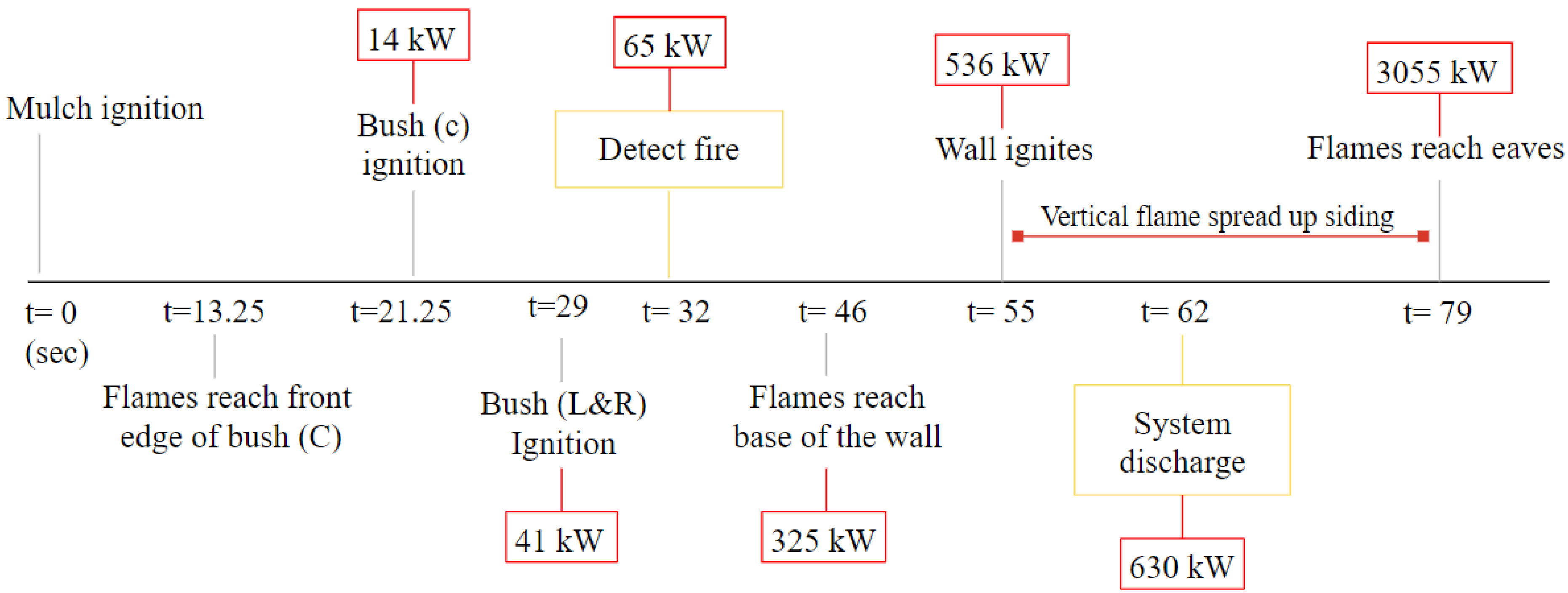


Figure 28. Timeline of design fire scenario

Using this completed model of the ignition scenario, we were able to estimate the total size of the fully developed fire. We assumed that all of the mulch, all six bushes (three on each side of the stairs) and the entire wall from the base to the eaves across from the bushes is burning in order to estimate the worst-case scenario. Table 8 breaks down the heat contribution of each individual element:

Table 8

Heat Contributions of Each Element to the Total Fire

Element	Size	Heat Contribution
Mulch	3.9 m^2 area	312 kW
6 Manzanita bushes	0.46 m diameter, 0.61 m tall	762 kW (127 each)
Wall	6.4 m^2 (horizontal length of 3 bushes, vertical length of base to eaves)	1978 kW
Firebrands	1.4/m^2*s over 21 m^2 design area	3.5 kW
	Total	3055.5 kW

The size of our design fire is about 3,060 kW, which was important to know when determining the discharge density of the system, as explained in 4.4.1. The expected size of the fire allowed us to determine how much compressed air foam is needed for suppression. This is discussed in more detail in Section 4.4.3.

4.3 System Components

Table 9 specifies the system components and manufacturers that we are recommending for our suppression system. The table also specifies whether the components are FM and/or UL listed, or if they comply with the requirements of the applicable NFPA Standard. Manufacturer data sheets for each of the components can be located in Appendix D.

Table 9
System Components

Suppression System Components

Component	Manufacturer	Product Name	Reference in Report	FM/UL/NFPA Listed?
Nozzle	FireFlex	TAR-225L Compressed Air Foam Local Application Nozzles	Appendix D.1	FM
Piping	Wheatland	Schedule 40 Fire Sprinkler Pipe	Appendix D.2	FM & UL
Air Cylinders	FireFlex	ICAF Air Cylinder Bank	Appendix D.3	FM
Water Tank	Highland Tank	ASME Pressure Vessel (3000 gallon)	Appendix D.4	Complies with NFPA 22
Foam Concentrate Tank	FireFlex	ICAF Foam Supply Tank (15 gallons)	Appendix D.5	FM
Foam Concentrate	Fomtec	Enviro Class A	Appendix D.6	Complies with NFPA 1150
System Control Cabinet	FireFlex	ICAF Cabinet Assembly	Appendix D.16	FM

Detection System Components

Component	Manufacturer	Product Name	Reference in Report	FM/UL/NFPA Listed?
Linear Heat detection	Protectowire	CTI-155-X	Appendix D.7	FM & UL
Interface Module	Protectowire	CTM-530	Appendix D.8	FM & UL
Conduit	National Pipe	NFP-U-PVC	Appendix D.15	UL

Other Components				
Control panel	Notifier	NFS-320	Appendix D.9	UL & FM
Secondary Power Supply	Notifier	Sealed Lead Acid BAT Series Batteries (55 Ah)	Appendix D.10	UL
Tamper Switch	Potter Signal	PCVS2-CRH	Appendix D.11	UL & FM
Water Level Switch	Potter Signal	WLS	Appendix D.12	UL
Water Temperature Switch	Potter Signal	TTS-S	Appendix D.13	UL & FM
Pressure Switch	Potter Signal	PS120	Appendix D.14	UL & FM

4.4 Suppression System Design Overview

The suppression system we are recommending consists of an automatic fixed pipe compressed air foam system. Open type nozzles are installed at the eaves of the home to provide coverage of the wall and the ground directly surrounding the home. The suppression system is split into four deluge type zones; each zone is able to operate independently from the other zones in order to conserve resources and provide efficient fire suppression. The piping network for each zone will run back to a common point at the corner of the house in the backyard. At this point, the piping will run underground to the enclosure in the backyard that houses the air cylinders, foam supply tank, and the control panel cabinet.

4.4.1 Discharge Density

Discharge density is the amount of suppressant discharged over a unit area. The discharge density of the system is 0.087 gpm/ft^2. The analysis of a study on the suppression of a wood crib fire via CAFS was used to arrive at this value, and information from the FireFlex CAFS datasheet was used to confirm that the system could supply the required flow rate to meet the discharge density requirement.

An experiment by Kim and Dlugogorski tested the suppression performance of a fixed CAF system on a wood crib fire. Upon analysis of their results, the team found that they used a discharge density of 0.087 gpm/ft^2 to effectively suppress a 500 kW fire. To see if this would be an appropriate discharge density for our design fire, we compared the heat release rate per unit area of the wood crib fire in the experiment and of our design fire. The wood crib had a projected floor area of 0.36

m^2 and the size of the fire was 500 kW. This translates to a heat release rate per unit area of 1388 kW/m^2. The design fire involving the mulch, the manzanita bushes, and the cedar siding was estimated to have a heat release rate of 3050 kW once it is fully developed. This is spread over an area of 8.9 m^2 which translates to a heat release rate per unit area of 343 kW/m^2. The wood crib fire from the experiment is releasing about four times more heat than the design fire for this project. The discharge density for our design was reduced proportionally to account for this.

$$\frac{1388\ kW/m^2}{343\ kW/m^2} = 4.05$$

$$\frac{0.087\ gpm/ft^2}{4.05} = 0.021\ gpm/ft^2$$

By incorporating the wind safety factor of 1.5 per the proposed change to NFPA 11 *Standard for Low, Medium, and High Expansion Foam*, the discharge density is brought to 0.032 gpm/ft^2 (S. Scandaliato, personal communication, 2019). This discharge density is significantly less than 0.087 gpm/ft^2. Therefore, choosing a discharge density of 0.087 gpm/ft^2 for our system is very conservative.

Once we determined this vale, we checked to make sure that a nozzle discharging this amount of foam would be able function as intended. The nominal flow rate specified by the manufacturer cut sheet for the FireFlex CAF nozzles is 5.94 gpm. This flow rate is not linked to the NFPA 11 requirements for minimum discharge density. Rather, this the likely the lowest flow rate that was resulted in sufficient pressure to produce the desired spray patterns The area of coverage of each nozzle is 69 ft^2; this includes the siding of the structure as well as the mulch bed that runs along the length of the structure and extends 3 ft beyond the base of the wall. By dividing the nominal flow rate by the area of coverage, we arrived at a discharge density of 0.086 gpm/ft^2. This means that if the nozzles are flowing at 0.087 gpm/ft^2 as previously determined, the flow rate will be sufficient to produce the desired spray patterns. For this reason, we are recommending 0.087 gpm/ft^2 as the discharge density for the system.

4.4.2 Water Supply Requirements

The design area for the system accounts for two adjacent zones discharging simultaneously. Because we are not specifying a fire pump for the system, a water pressure vessel has been specified to meet the system goals. The high pressure compressed air cylinders will pressurize this vessel in order to meet the minimum pressure requirements for system discharge (FireFlex, n.d.). In order to provide enough water to discharge the system for 1 hour, a water tank with a minimum size of 1,308 gallons is required. In reality, more water will be required since nozzles that are closer to the supply will be discharging at a higher flow rate. To account for this, a larger 3000 gallon water pressure vessel with a 2000 gallon water capacity is recommended for the system. This accounts for a 1.5 times safety factor on the water supply requirement. The specified tank required to contain this volume is 20 feet long and 5 feet in diameter. We are recommending that this is installed underground below the enclosure.

Ground Area - (3 ft. * 33 ft.) + (3 ft. * 43 ft.) = 228 ft^2

Wall Area - (10 ft.*33ft.) + (10'*43') = 760 ft^2

Total Design Area - 990 ft^2

Discharge Density - 0.087 gpm/ft^2 (foam)/4 = 0.022 gpm/ft^2 (water)

Discharge Duration - 60 minutes

Water Supply Requirement - 60 minutes * (0.022 gpm/ft^2) * (990 ft^2) = 1,307.8 gallons

4.4.3 Foam Concentrate Supply Requirement

We have determined that the Fomtec Enviro Class A Foam Concentrate should be proportioned at a 0.3% concentration based on the manufacturer literature and experiments conducted with fixed pipe compressed air foam systems. The minimum amount of foam concentrate required was calculated as follows:

$$2000\ gallons\ of\ water\ * \frac{0.003\ gallons\ of\ foam\ concentrate}{1\ gallon\ of\ water} = 6\ gallons\ of\ foam$$

4.4.4 Piping and Fittings

FireFlex recommends installing piping and fittings in accordance with NFPA 11 Chapter 4. Section 4.7.4 "Joining of Pipes and Fittings" indicates that piping and fittings can be achieved through threaded pipe, grooved pipe, or welded pipe. The contractor can choose between these three options. We are recommending Schedule 40 black steel pipe as referenced in Table 9 of this report.

4.4.5 Hydraulic Information

FireFlex sales representative Michael Nagy informed us that typical pipe sizes for the FireFlex ICAF System range from 1 inch to 3 inches in diameter. Two nozzles typically are able to be fed from a 1 inch pipe. As the system progresses back towards the source the pipe diameter is increased to minimize friction losses. A case study by FireFlex involving the protection of a flammable liquid storage facility using the ICAF System shows that smaller pipe sizes over long lengths will not result in excessive friction losses as is the case with foam-water systems (FireFlex, 2006). The system can operate with a water pressure in the range of 50 to 175 psi (FireFlex, n.d.). Our calculations show that the minimum flow rate with two zones discharging simultaneously will be 88 gpm.

4.5 Detection System Design Overview

Automatic fire detection will be accomplished via Protectowire Linear Heat Detectors installed on the exterior walls. The Protectowire CTI-155-X has a rated alarm temperature of 155 ^{o}F and offers excellent weather resistance. When combined with the CTM-530 Interface Module, these detectors are capable of discriminating against short circuits by utilizing the metal conductors in the detectors as thermocouples to verify the alarm temperature (Protectowire, 2014). Each side of the house will have Protectowire installed at two levels: 1.5 feet off the ground and 9 feet off the ground. The lower layer is expected to actuate first if the fire develops consistently with the fire scenario that has been defined since this area receives the most radiation from the burning bushes and mulch. The upper layer will be installed slightly below the eaves in case the wall ignites above the lower layer of Protectowire. The home will be split into four different detection zones; each zone will be provided with one interface module and enough Protectowire to provide full coverage. When the detector on one side of the house actuates, the fire alarm control panel will release suppressant to the pipes that serve that zone. The Protectowire for each zone will be routed underground through PVC conduit back to the fire alarm control panel. The detection system layout is illustrated in detail in Section 4.6.

4.5.1 Power Supply Requirements

Battery calculations were completed using the information from the manufacturer data sheets. Table 10 shows the results of the battery calculations. To power the system on standby for 96 hours, a 60 Amp-Hour battery is needed. In order to meet this requirement and also provide a safety factor, two 12-Volt, 55 Amp-Hour Notifier Sealed Lead Acid BAT Series Batteries are recommended to be wired in series to power the system.

Table 10

Power Supply Calculations

Component	**Standby Current per Unit**		**Quantity**		**Standby Time**		**Total Standby Current**
Fire Alarm Control Panel	0.35 A	*	1	*	96 hours	=	33.6 Amp-hours
Protectowire Interface Module	0.067 A	*	4	*	96 hours	=	25.8 Amp-hours
						Sum:	**59.4 Amp-Hours**

4.6 Sequence of Operation

The suppression system components and detection system components come together to create the complete system. The complete sequence of operation from actuation until resource exhaustion is summarized in Figure 29 (FireFlex, n.d.):

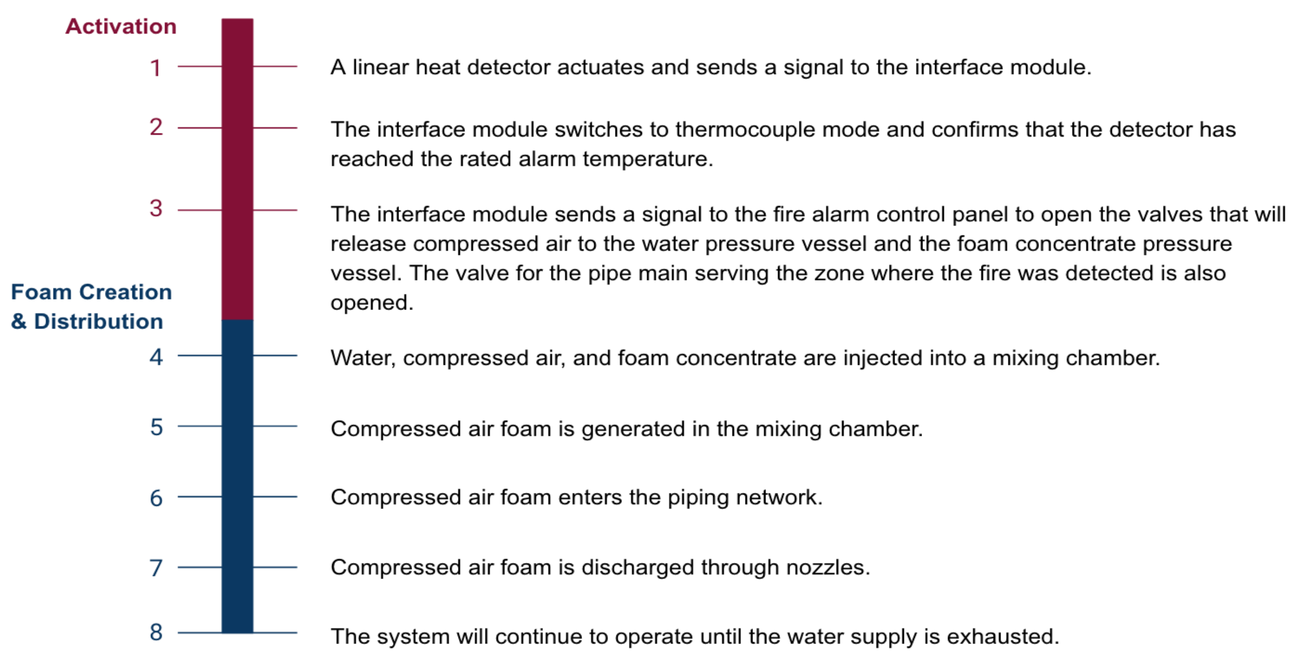


Figure 29. Sequence of operation.

4.7 Inspection, Testing, and Maintenance

FireFlex recommends that the Integrated Compressed Air System is tested and maintained in accordance with NFPA 11 *Standard for Low, Medium, and High Expansion Foam.* The relevant provisions of this standard are summarized in the next two sections.

4.7.1 Testing and Acceptance

Chapter 11 of NFPA 11 provides the testing and acceptance requirements for compressed air foam systems. The requirements are summarized as follows:

- Upon installation, complete a visual inspection to ensure the system has been installed in accordance with approved plans and specifications.
    - Check for continuity of piping as well as accessibility of controls, valves, and gauges.
- After system installation, flush the system piping using the system's air supply.
- The system shall be tested by qualified personnel in order to meet the AHJ's approval.
- All piping shall be subjected to a 2 hour hydrostatic pressure test at either 200 psi or 50 psi above the highest expected pressure, whichever is greater.

- All control valves shall be fully closed and opened under system pressure to ensure proper operation.

4.7.2 Maintenance

Chapter 12 of NFPA 11 provides the maintenance requirements for compressed air foam systems. The requirements are summarized as follows:

As Needed

- Pressure tests of normally dry piping shall be made when visual inspection indicates questionable strength due to corrosion or mechanical damage

Annually

- Thoroughly inspect and check the system for correct operation.
- Test the foam concentrate to ensure that its properties have not deviated more than 10% from those recorded during the initial inspection and acceptance testing. The test shall be accomplished by sending a sample of concentrate to the manufacturer or another qualified laboratory.
- Inspect the foam concentrate storage tank for signs of excessive sludging or deterioration.
- Compressed air foam generating equipment and accessories shall be inspected annually.
- Discharge devices shall be visually inspected annually for evidence of mechanical damage.
- Aboveground piping shall be examined to determine its condition and verify the proper pitch for drainage has been maintained.
- Control valves and all actuation devices shall be tested.

Every 5 years

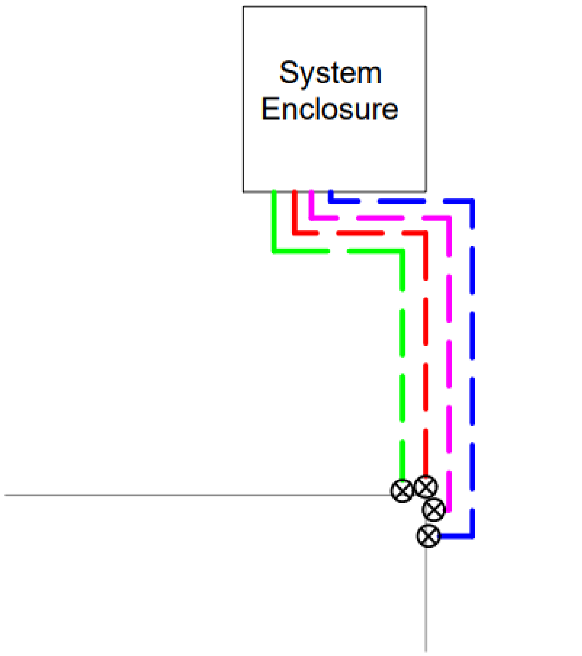
- Underground piping shall be spot checked for deterioration.
- High pressure air cylinders shall not be recharged without having undergone a hydrostatic test within the last 5 years.

Every 12 years

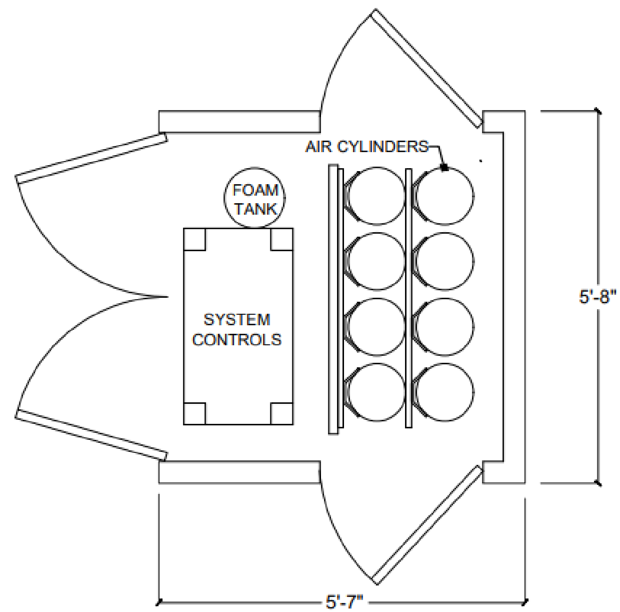
- High pressure air cylinders may remain in service for a maximum period of 12 years if they do not discharge. After 12 years, a hydrostatic test is required.

4.8 System Layout Drawings

Taking into account all of the results presented in this chapter, we drew the proposed system layout in AutoCAD. Both elevation and plan views of the suppression and detection systems are shown. Parts of the system enclosure detail drawing were imported from a FireFlex case study (FireFlex, 2006). The full drawing set is shown on the following five pages.



Underground Fire Protection Pipe Plan
Scale: 3/16" = 1'



System Enclosure Detail
Scale: 1/2" = 1'

Linetype Legend

- Underground Pipe/Conduit
- Linear Heat Detection
- Above Ground Pipe

Color Legend

- North
- South
- East
- West

Symbol Legend

- Pipe Rise
- Pipe Elbow Down
- Nozzle

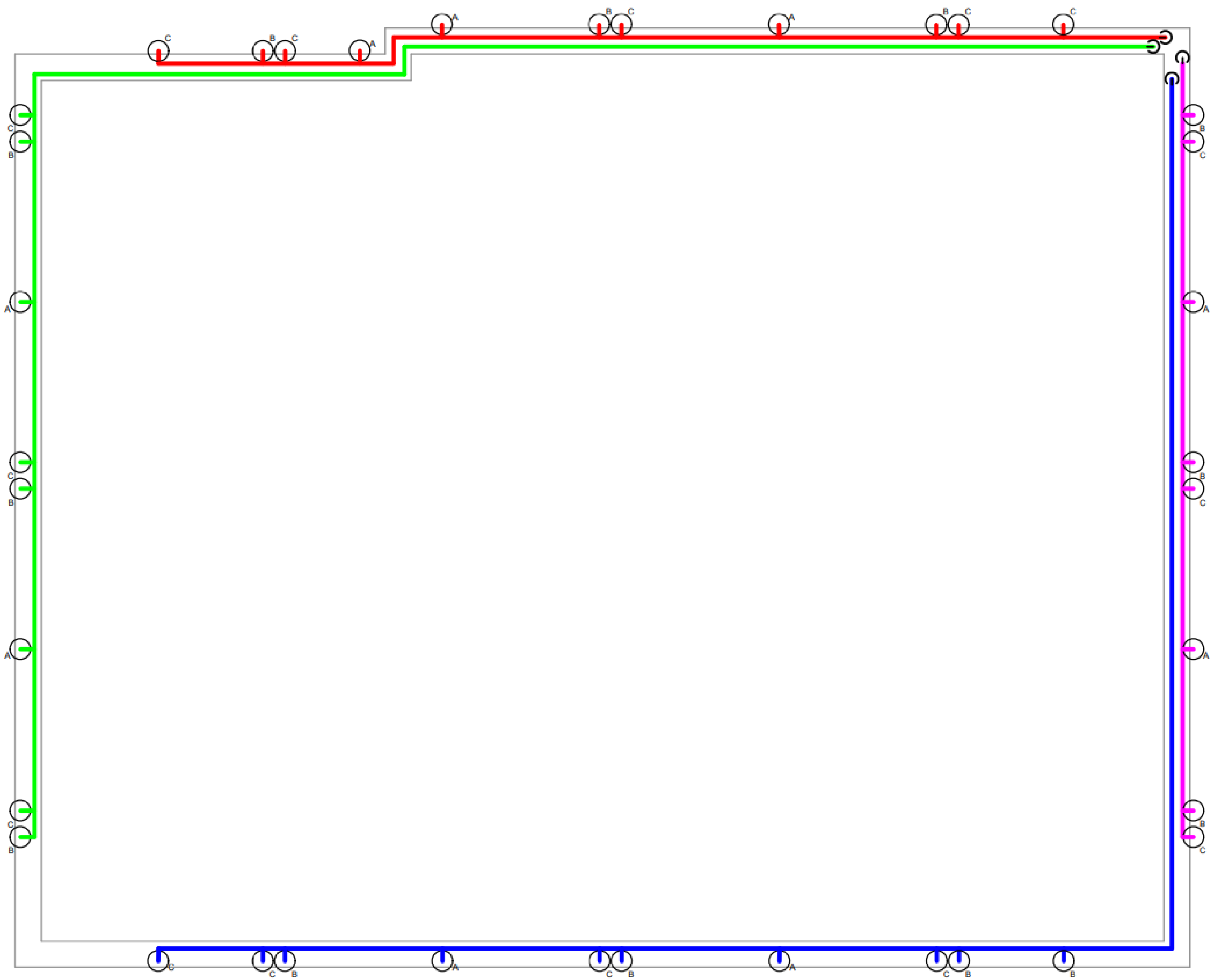
Subscript Legend

A Nozzle Installed in Pendent Orientation

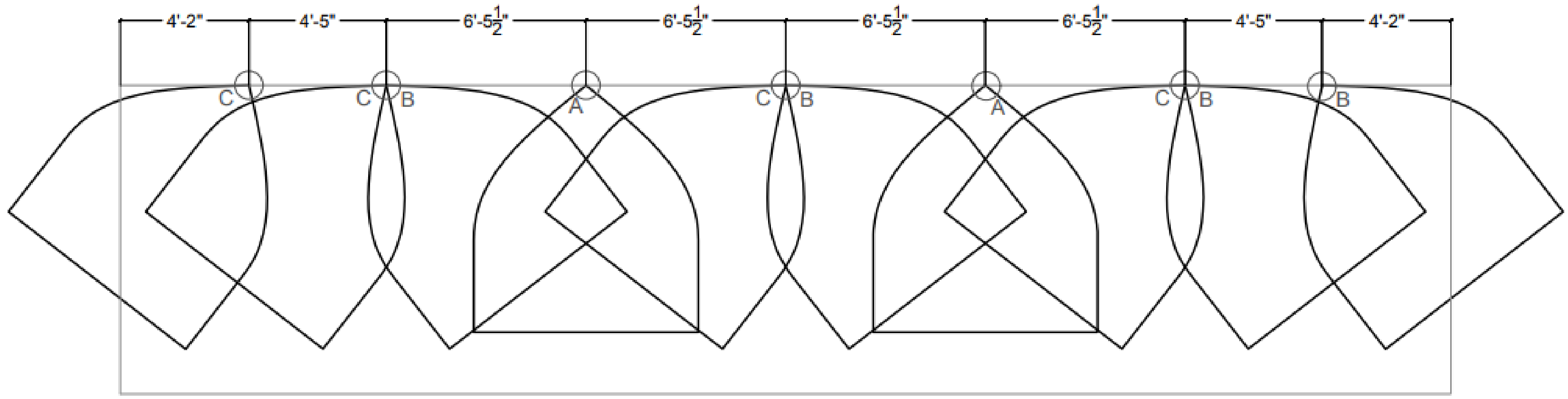
B Nozzle Angled 38 Degrees CW

C Nozzle Angled 38 Degrees CCW

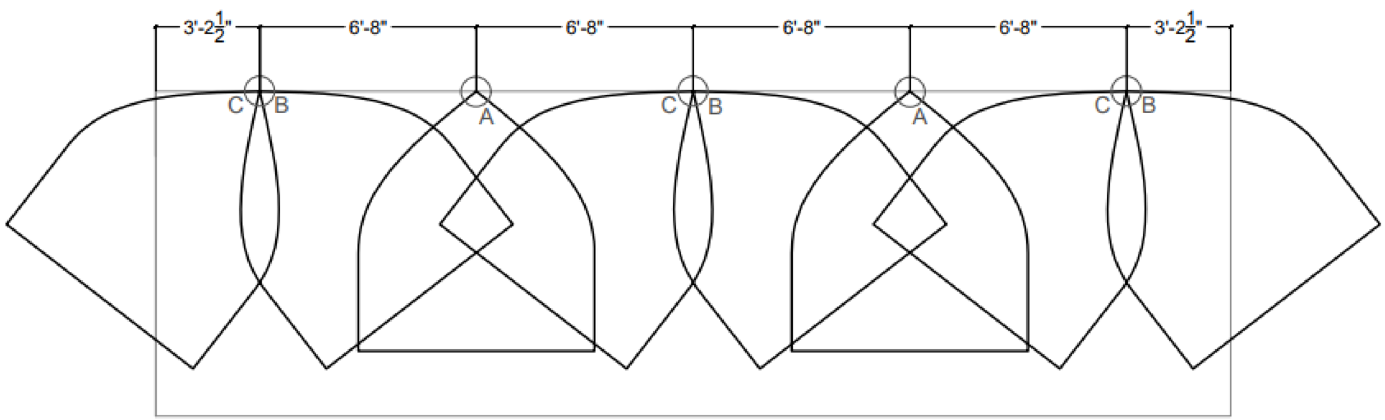
Date 3/5/2020	Fire Protection Plan - Ground Level		
Scale SEE DRAWING	FP-1.0	Revision 0	Sheet 1/5



Date 3/05/2020	Fire Protection Plan - Roof Level		
Scale 3/16"=1'	FP-1.1	Revision 0	Sheet 2/5

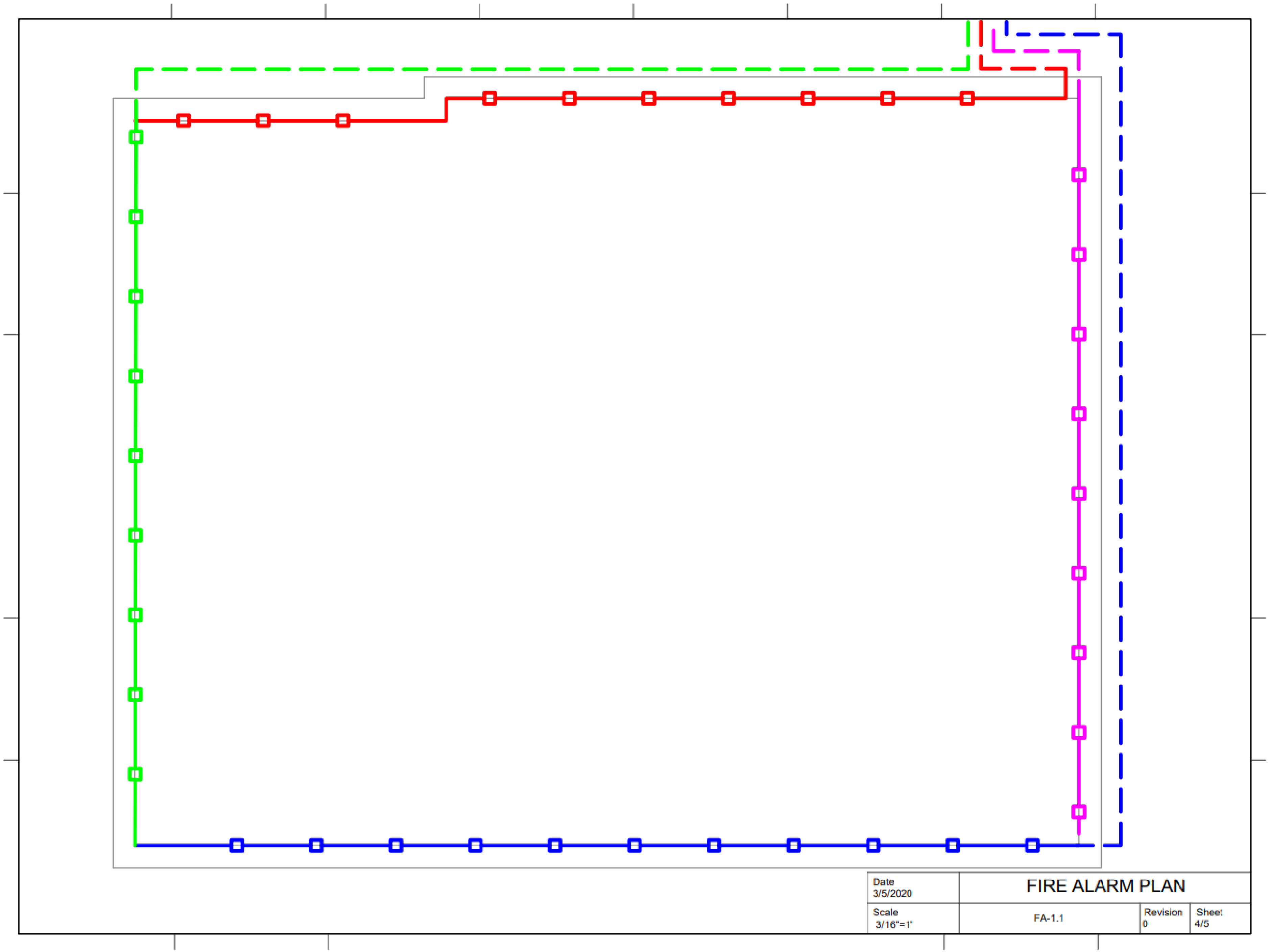


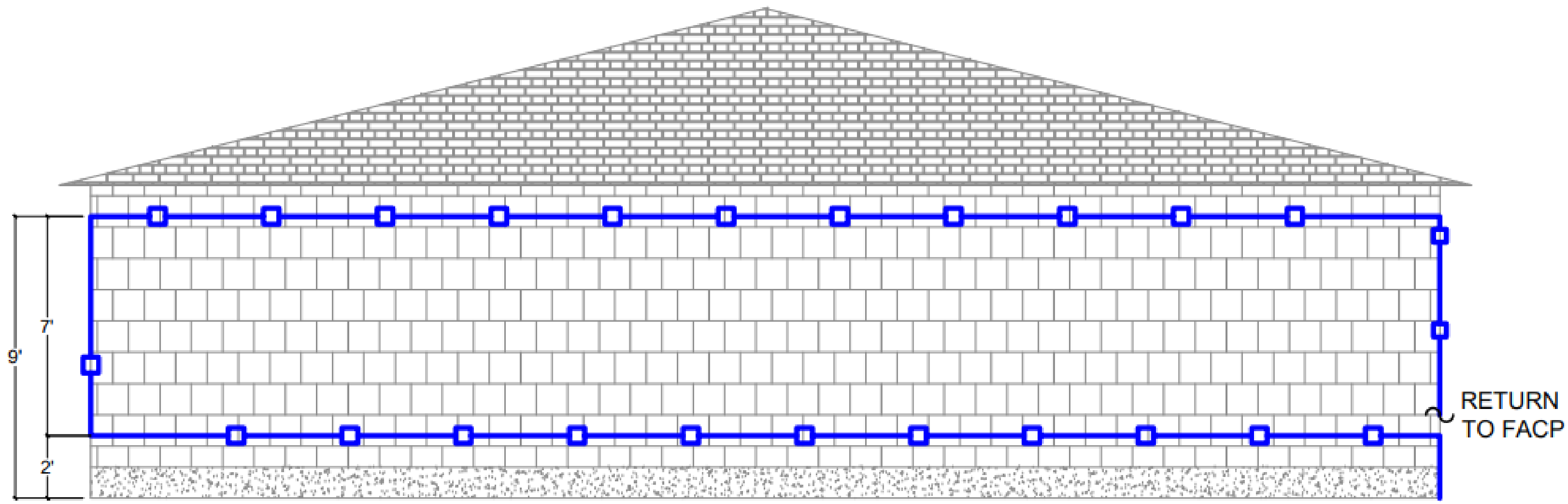
Elevation View - Long Side of House
Scale: 3/16" = 1'



Elevation View - Short Side of House
Scale: 3/16" = 1'

Date 3/05/2020	Fire Protection Elevations		
Scale 3/16"=1'	FP-1.3	Revision 0	Sheet 3/5


Date
3/5/2020
FIRE ALARM PLAN
Scale
3/16"=1'
FA-1.1
Revision
0
Sheet
4/5



Date 3/5/2020	FIRE ALARM ELEVATION		
Scale 3/16"=1'	FA-1.2	Revision 0	Sheet 5/5

5.0 Conclusions

The proposed system design is a feasible option to protect homes against firebrand exposures. The fire scenario calculations indicate that the system will be able to detect a fire, activate, and discharge foam within enough time to stop the flames from reaching the eaves of the home. We recommend a discharge density of 0.087 gpm/ft^2 based on the manufacturer literature and experimental data. The system will be able to suppress typical fires that may result from firebrand exposures on the exterior of a home with combustible walls and a moderate amount of combustible landscaping in the immediate vicinity of the walls. All of the components required to assemble and install the system are commercially available and listed for fire protection. Additionally, the system components do not occupy excessive space and can be contained within an enclosure in the backyard measuring about 6' by 6'.

Compressed air foam is more effective than water at suppressing Class A fires. Experimental data from several sources consistently indicates that CAF can perform better than water alone to extinguish Class A fires. A series of tests by the Los Angeles Fire Department in 2001 compared compressed air foam and water discharged through a handline. The CAF was able to knockdown the fire in 10 seconds using 15 gallons of water. The handline discharging water took 50 seconds to knockdown the fire and used 75 gallons of water. CAF also performs better than water when discharged through a fixed pipe overhead system. A CAFS was able to suppress a wood crib fire from a size of 500 kW down to 50 kW in ½ the time of a sprinkler system and ⅙ the time of a water mist system (Kim and Dlugogorski, 1997).

The proposed system design will use less water than a water spray system. At a 1 to 4 expansion ratio, CAF is approximately 25% foam solution and 75% air. This translates to a water discharge from the system of 0.022 gpm/ft^2. With two zones discharging simultaneously, the total water flow rate is approximately 22 gpm. This is less than if water alone was being used to protect the house. FM Data Sheet 9-19 (2020) provides minimum discharge density values for exterior sprinkler protection of homes exposed to radiant heat during wildfires. For combustible construction under the lowest heat flux range, FM recommends at least 60 gpm to protect a short wall of the home. NFPA 15 *Water Spray Systems for Fixed Protection* states that a general water spray application rate for most ordinary combustible solids shall be from 0.15 gpm/ft^2 to 0.5 gpm/ft^2. This is significantly more water than what is required for the CAFS to protect the house.

Class A foam concentrate is environmentally safe and non-toxic. Class A foams are used by firefighters on wildlands, therefore outdoor usage of class A foams is already practiced for wildfire maintenance. Enviro Class A foam from Fomtec is a concentrate that can be used to fight fires on class A fuels in CAF systems. It is compliant with NFPA 1150 which is the standard on chemicals for fires in class A fuels. Specifically, it is compliant with flash point, biodegradability, and oral and dermal toxicity limits put in place by NFPA 1150.

The proposed system would relieve pressure from first responders. This firefighting system would operate automatically and independently from municipal resources. After detection, compressed air foam would be discharged onto the structure and suppress the fire. First responders would not need to focus their attention on the home with this external system installed, allowing them to save other houses in the area in a timelier manner.

5.1 Limitations

We were able to identify several limitations that may restrict the implementation of this design. This section presents each limitation and the effect that each one may have on the application of the system to a real world scenario.

The house design used for this project was simple and may not accurately reflect the features of an actual house. Because this project was conducted as initial feasibility study, our team decided to use a home with a basic architectural plan for the design. The design house was a one-story 33’ x 43’ rectangle with a small corner indent on the back of the house where the deck meets the house. Realistically, it is rare that a house that is designed as a simple rectangle without any other features. If the system were to be used for a different house than the design house, the layout would need to be changed to fit the dimensions of the new house. A home with a garage, two stories, and complex architectural features would require a much more complex design than what has been presented in the results section. There is no “one size fits all" approach and it is important to use an engineering approach to consider the characteristics of each situation. Additionally, we assumed that the home would have a Class A non-combustible roof that meets requirements of ASTM E108, however older homes that were built before non-combustible roofs were recommended probably don’t have Class A roofs. In such cases where combustible roofs are present, this system would be ineffective against structure ignition via firebrand accumulation on the roof due to lack of roof protection.

The system was only designed to protect against firebrand exposures. The system is specifically designed to protect against a realistic “worst case scenario” design fire based on firebrand exposures for this particular house. The team did not consider protecting the house in the case of the main flame front passing through the property. We assumed that the house would be a complete loss in such a case because the extreme radiative heat flux and direct flame contact from the approaching flame front would be much present a much larger hazard than the fire scenario that was considered. A more robust system with different functionalities would be needed to defend against the scenario of an approaching flame front. One might consider studying the act of prewetting the house as a preaction measure to prevent ignition from the flame front, however that was outside of the scope of this project. A property maintained in accordance with the defensible space recommendations is unlikely to be subjected to radiation and direct flame contact form the main flame front, but it is not realistic to expect 100% of homes to maintain a complete defensible space.

The FireFlex Integrated Compressed Air Foam System has not been tested and listed for use with Class A foam concentrates. We identified FireFlex as the sole manufacturer of commercially available fixed pipe compressed air foam systems. Unfortunately, the FireFlex ICAF system has only been tested and listed use for Class B foam concentrates to suppress flammable liquid fires. We are recommending a Class A foam concentrate for use in the CAFS to suppress the fires resulting from firebrand exposures. Class A foams are designed specifically to suppress fires involving ordinary combustibles, such as the wood siding and vegetation around the home. Additionally, Class A foam concentrates are environmentally safe and comply with NFPA 1150 *Standard on Foam Chemicals for Fires in Class A Fuels* and compatibility with outdoor usage. In recent years, Class B foam concentrates such as AFFF have been identified as being dangerous to both the environment and human health due to the chemicals' persistence in drinking water supplies. For these reasons, we decided to specify a Class A foam concentrate even though it has not been tested with this specific system. In the Kim and Dlugogorski study, Class A foam was successfully used in a fixed pipe compressed air foam system. Therefore, we know that this application is not novel. Another limitation of the FireFlex ICAF system is that the hydro-pneumatic calculation software that the manufacturer has developed to size pipes and ensure that the flow and pressure requirements are met is not publicly available. The pipe sizes and air supply were estimated based on information from the manufacturer, but a comprehensive set of calculations would need to be completed for each installation to verify that the system would perform as intended.

The aesthetics of the system could be improved. Once the system is installed as specified in the layout drawings, it will be visible from all points on the exterior of the home. Nozzles are to be spaced every 4.5 to 6 feet apart along the eaves and pipe up to 3 inches in diameter will need to be installed along the sides of the house and the eaves. The 3,000 gallon water pressure vessel can be installed underground, but the rest of the FireFlex system components will require a 6' by 6' enclosure. This could either be accomplished by building a small enclosure off of the home or installing a stand-alone enclosure in the backyard. and the FireFlex CAFS tank will require installation in the backyard. Particularly small properties or homes without yards may not have space for such an enclosure.

5.2 Future Work

There are several topics related to the suppression system that our team was not able to address extensively in the duration of our project. Ultimately, we hope that further research can be done so that this system can be refined and installed to protect homes from wildfire exposures. An integral step towards this outcome would be to test and list the FireFlex ICAF system for use with

Class A foam concentrates to suppress fires resulting from firebrand exposures on homes. This would likely involve two main sets of experiments. First, it would need to be verified that the system functions as intended with a Class A foam concentrate instead of the Class B foam concentrate that is typically used. Because the foam concentrates have different chemical properties, it is possible that the spray patterns or another aspect of the system operation may be impacted. Following the validation of the Class A foam concentrate performance in the ICAF system, a prototype installation should be tested on a full scale home constructed for this purpose. By simulating different fire scenarios consistent with those described in this project, the system performance can be validated. Since current codes do not address minimum discharge density requirements for Class A compressed air foam, these experiments will allow for the determination of an optimum expansion ratio and discharge density. We determined the discharge density using a very conservative approach that worked in multiple safety factors. This conservative density necessitates a large water storage tank. If the discharge density is optimized, the water storage requirement can be decreased and the feasibility of installing of a water tank in a homeowners' yard will increase.

We did not consider the cost of the system installation during the design process. Further efforts are required to make an estimate of the proposed system cost and understand how the cost would change as the home size varies. Once an initial cost estimate is made, a study could also be done to determine if modifying certain aspects of the design would result in a cost reduction without sacrificing performance.

Another potential area of work regarding the suppression system would be to design and test special application nozzles to cover the walls. These nozzles may have a spray pattern that is elongated in one direction to provide more efficient coverage. This would advance spray coverage and suppression efficiency by potentially allowing for fewer nozzles to be installed. Regardless of which nozzles are used, it is also important to be able to quantify the effect of wind on the nozzle spray patterns and the actual delivery of suppressant to the burning surfaces.

Another area to investigate for future work is looking into the cleanup of the compressed air foam once the homeowner returns to their property. Currently, there is no information that indicates the effect of the compressed air foam on different construction materials. It's important to determine if there be residual damage to the walls due to the system discharge and if the siding of the structure would need to be replaced. These are questions that will need to be answered through further testing before the system can be marketed to potential customers.

The details of the enclosure design need to be fully developed and specified. The enclosure will house components required for both the suppression and detection systems such as the air cylinders, foam concentrate tank, and system control cabinet. One potential area to investigate will be how to maintain the temperature within the enclosure so that it is not too hot or too cold. The requirements for this will change based on the location and the local climate conditions. Another important factor is the fire resistance of the enclosure. Since it houses critical components, it must be able to withstand firebrands and other wildfire exposures.

Future work addressing detection and notification would also be important. It will be advantageous to test the linear heat detector activation time during these specific fire scenarios, as well as to determine the ideal placement along the house. Our fire scenario calculations assume that the that wall will ignite at 1 foot above grade and the lower level of Protectowire that is installed 2 feet above grade will actuate first. It is possible that the flames from the bushes may ignite the wall above this point which would render the design ineffective. Testing of the linear detection will indicate whether this is an accurate assumption or whether the wire will need to be placed higher or lower than the areas that we display.

Lastly, another interesting project for future teams would be to create a mobile app that homeowners can use to access various system functions from their smartphone. If interfaced with the fire alarm control panel, the app would be able to notify homeowners in the event of an alarm or supervisory signal. The app, if combined with a series of video cameras around the home, could also serve as an effective means of manual actuation. Since homeowners will likely be evacuated from their home during a wildfire event, they could use the app to remotely activate the system at the right time as an alternative to the automatic detection.

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Appendix A – Californian Counties

County	# Residents in WUI	Pop Density (%)	Homes in WUI	Seasonal Homes in WUI	WUI % of Total Area
Santa Cruz	167442	1.1	71855	3107	51.3
Nevada	101875	0.5	54277	8656	34
Sonoma	382538	1.1	166773	7637	32.9
El Dorado	177532	0.6	86599	12541	26.3
Contra Costa	675243	5.4	260138	1261	25.6
Amador	32564	0.4	17656	2368	23.5
Calaveras	41905	0.3	26245	6824	22.8
Placer	215894	1	101896	12274	21.6
San Mateo	246404	4	92080	849	21.2
Napa	111135	1.1	45414	1861	19.4
Marin	219165	3.8	98178	2467	17.1
San Diego	1023100	2.2	364756	4520	17.1
Santa Clara	458780	3.2	151184	847	17.1
Orange	521140	6.2	204072	3344	16.5
Butte	142846	0.8	63889	1428	16.4
Alameda	478482	6.6	178493	877	15.2
Los Angeles	1566416	4.1	571748	4996	14.7
Sacramento	173883	2.3	60127	343	12.1
Solano	245918	3.7	89533	335	11.8
Ventura	443237	3.2	162254	1152	11.7
Mariposa	15939	0.2	9026	1484	11.1
Shasta	152138	0.7	65981	1627	9.4
San Francisco	97561	34.4	28787	114	9.3
San Luis Obispo	191709	1.1	89643	6774	8.3

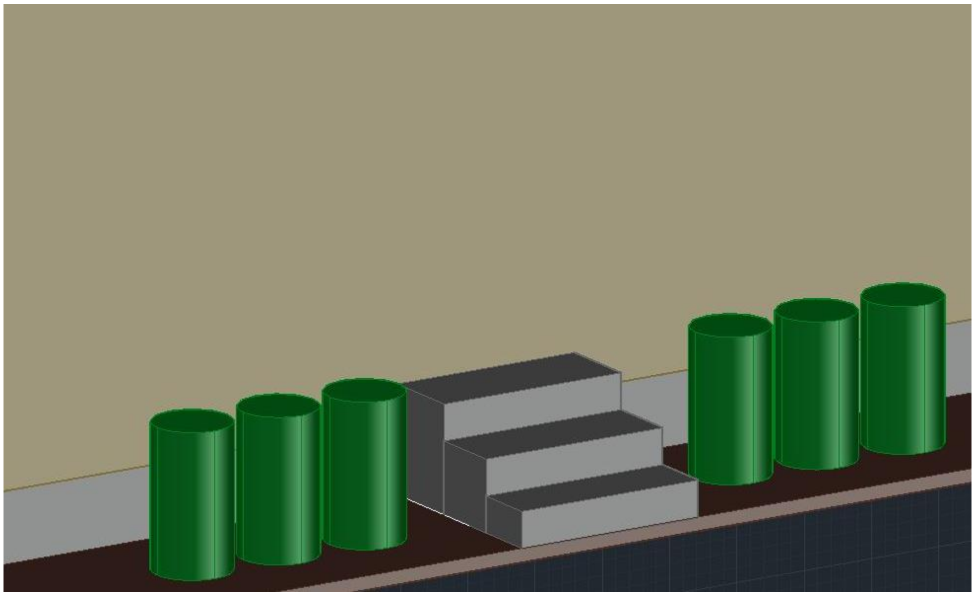
Appendix B – Fire Scenario Calculations

Fire Scenario 1: Firebrands accumulate at an inside corner where the deck intersects with the exterior walls of the home. The firebrand pile heats the deck and brings it to the point of smoldering ignition which eventually transitions to flaming combustion. The flames ignite the wall (exterior finish is cedar shake siding), and the flames will spread vertically up the wall to reach the eaves. This will provide a pathway for the fire to reach the interior of the home

Fire Scenario 2: Firebrands land in the mulch on the front of the home. The firebrands ignite the mulch which leads to ignition of a single manzanita bush (assume the center bush). The radiant heat from this bush as well as the heat from the spreading mulch fire will ignite the other two manzanita bushes. The radiant and convective heat from the mulch and the bushes will ignite the cedar shake siding on the wall. The flames will then spread vertically up the wall. The mulch fire scenario has been chosen as the basis for our design criteria since it represents the worst case scenario out of the two scenarios considered. Use Fire Scenario 2 as a basis for the design since this represents the worst case scenario.

House Layout

The front of the house has 3 feet of mulch extending away from the house along the entire length, except for where the concrete steps lead to the front door. On either side of the steps, there are three Manzanita bushes. The Manzanita bushes are approximated as cylinders that are two feet tall with a diameter of 1.25 feet. The bushes are only 1 inch away from each other and are 10.5 inches away from the wall. The screenshot below from the 3D AutoCAD model provides a visualization of the front of the house.

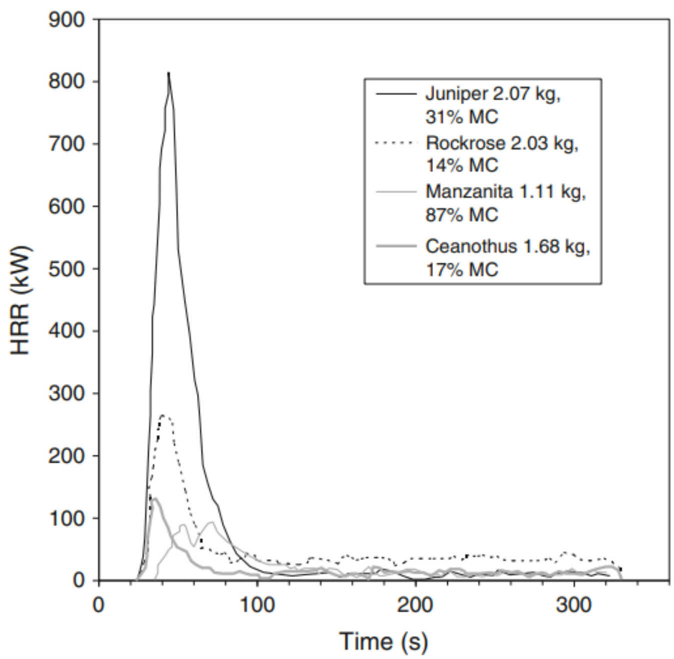


The SFPE Handbook (5th Edition - 2016) provides the heat release rates of various objects and materials in Chapter 26. The Manzanita Bush that is discussed in Chapter 26 is approximately 1.11 kg in mass and 0.5 m tall. The width of a Manzanita Bush is typically 25-50% less than the height; this 0.5 m tall bush can be assumed to have a diameter of approximately 0.3 m (Blooms and Branches, n.d.). Because the bush in the experiment is rather small, we decided to double the mass of the bush. As a result of this, we also assumed that the volume of the bush doubles. The initial volume of the bush, approximated as a cylinder, was 0.035 m^3. The new volume of the bush is assumed to be 0.07 m^3. This translates to a height of 0.61 m (2 ft) and a diameter of 0.38 m (1.25 ft).

The SFPE Handbook (5th Edition - 2016) provides an equation to estimate the peak heat release rate of a bush based on the moisture content and the mass of the bush.

$$\dot{q} = m\left(\frac{700}{1+0.1295MC}\right) = 2.22\,kg\left(\frac{700}{1+0.1295(87)}\right) = 127\,kW$$

The peak heat release rate will be higher for the larger bush but it is assumed that the bush will have the same fuel fire intensity (α) independent of the mass.



The 1.11 kg bush will reach a peak heat release rate of 90 kW at 20 seconds after the onset of established flaming ignition. The fuel fire intensity coefficient can be calculated by approximating the fire as a power law fire that grows as a function of the time squared.

$$\dot{Q} = \alpha t^2 \qquad 90kW = \alpha(20s)^2 \qquad \alpha = 0.225\,kW/s^2$$

A fire growth coefficient value of 0.225 kW/s^2 means that this fire most closely resembles an ultrafast fire which is typically taken to have a fuel fire intensity coefficient of 0.1876 kW/s^2. The 2.22 kg bush fire that we are modeling will grow at the same rate as the 1.11 kg bush but will take slightly longer to reach the peak heat release rate.

$$127kW = (0.225)t^2 \qquad t = 24\,seconds$$

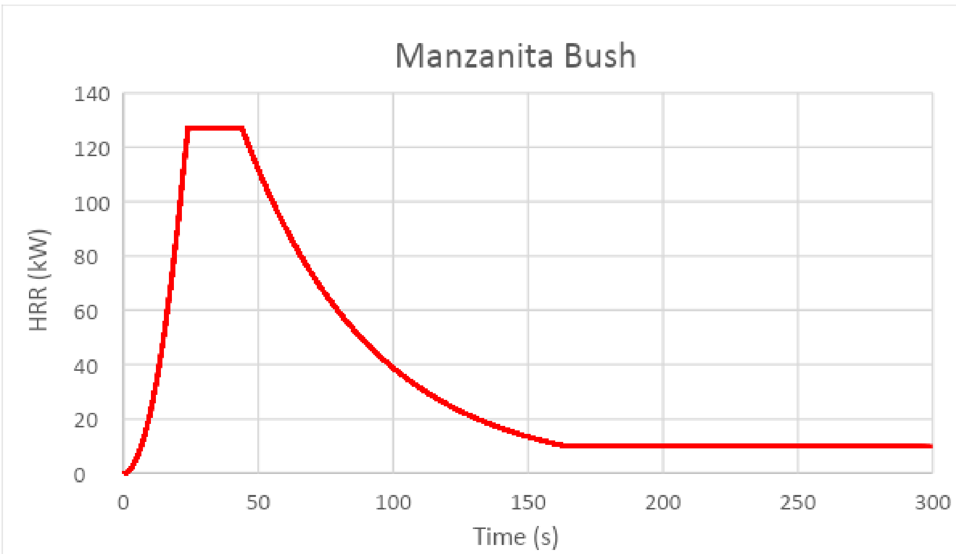
Once the fire reaches the peak heat release rate, it will burn steadily at 127 kW for approximately 20 seconds. After this point, it will begin a decay period. This can be modeled as an exponential decay function.

$$\dot{Q} = \dot{Q}_0 * exp\,(-kt)$$

The graph above shows that the fire decays from the peak value down to a value of approximately 10 kW over a period of 140 seconds. The value of k can be determined with this information in mind by using Excel's GOALSEEK function. The cell for the heat release value at t=164 used as the set cell at a value of 10 kW, and the value of k is varied until the heat release rate at t=164 is equal to 10kW. This yielded a value of k = 0.0211. The decay period of the fire is modeled as follows.

$$\dot{Q} = (127kW)\,exp\,(-0.0211t)$$

With the growth, fully developed, and decay period of the fire now modeled, we were able to graph the heat release rate of the bush fire over time.



Mulch Fire

To begin, it was assumed that the fire will start at the outside edge of the mulch (the interface of the mulch and grass) and that the wind will cause it to spread towards the house. This represents a worse case scenario because wind driven fire spread will be faster than opposed flow spread (Quintiere, 2006). If the fire was to start in the mulch against the wall, it may never ignite the bushes since it would need to spread against the wind. The mulch ignition will correspond to the start of the fire timeline. Once the front edge of the mulch ignites, it is assumed to be spreading both forwards towards the house and laterally through the mulch at 0.066 ft/s as discussed above. The flames in the mulch will reach the front edge of the center Manzanita bush first. It is difficult to quantify the exact convective and radiative exposures that the bush is subjected to from the mulch. For this reason, experimental data was used to estimate an ignition time. Manzanita bushes have been the subject of numerous ignition studies and experiments. An experiment by McAllister

& Finney (2014) subjected a Manzanita bush with a fuel moisture content of 97% to 600 ^{o}C convective heating. The time to ignition was 10.8 seconds. Another experiment subjected a Manzanita bush with a fuel moisture content of 73% to a radiative heat flux of 100 kW/m^2 (Fletcher et.al., 2007). The average time to ignition was 6.5 seconds.

The ignition time for the bush was assumed to be 8 seconds after the mulch fire reached the edge of the bush. This will be variable and dependent on a number of conditions, but it is believed to represent the realistic worst case scenario for the ignition of the bush. By the time the left and right bushes ignite, the center bush is only releasing 14 kW total. Because of this, it is safe to assume that the time to ignition of the left and right bush is controlled by the mulch fire and that the relatively small radiative flux from the center bush does not influence the time to ignition.

The pine bark nugget mulch has a heat of combustion of 20,700 kJ/kg. An experiment by Zipper et. al. (n.d.) showed that a bed of pine bark nugget mulch can release 80 kW when burning at the peak rate. The area of the plot of mulch in the experiment is not specified. The following equation relates the heat of combustion of a material to the heat release rate by using the mass loss rate.

$$\dot{Q} = \dot{m}\Delta H_c$$

If the fire is burning at a rate of 80 kW (80 kJ/s), the mass loss rate at this point can be calculated since the heat of combustion is also known.

$$\dot{m} = \frac{\dot{Q}}{\Delta H_c} = \frac{80\,\frac{kJ}{s}}{\left(20{,}700\,\frac{kJ}{kg}\right)} * \left(\frac{1000g}{1kg}\right) = 3.86\,\frac{g}{s}$$

This is consistent with the range of mass loss rates for one square meter of various solid wood samples in experiments by Tran & White (1992). Due to this, we can assume that this mass loss rate represents the mass loss rate from a unit area of burning mulch ($\dot{m} = \dot{m}''$). Therefore, the 80 kW value can be used as the value of $\dot{q}''$. In reality, the mulch fire heat release rate evolves very slowly over time; the fire takes 45 minutes to reach the peak heat release rate of 80 kW. Assume that once a given area of mulch is burning, it is burning at 80 kW/m^2.

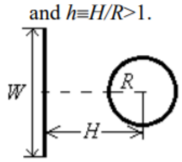
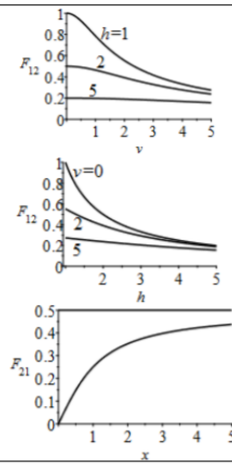
View Factors – Bush to Wall

$$W = 1.583\,ft \quad R = 0.625\,ft \quad H = 1.5\,ft$$

$$v = \frac{W}{2R} = \frac{1.583ft}{(2)(0.625ft)} = 1.27\,\frac{ft}{ft} = 1.27$$

$$h = \frac{H}{R} = \frac{1.5ft}{0.625ft} = 2.4\,\frac{ft}{ft} = 2.4$$

$$F_{21} = \frac{arctan\,(\frac{v}{h})}{\pi} = \frac{arctan\,(\frac{1.27}{2.4})}{\pi} = 0.155$$

From frontal surface of strip (1) of width W to a cylinder (2) of radius R at a distance H between centres, with $v \equiv W/(2R)$ and $h \equiv H/R > 1$. 	$F_{12} = \frac{\arctan\left(\frac{v}{h}\right)}{v}$ $F_{21} = \frac{\arctan\left(\frac{v}{h}\right)}{\pi} = \frac{\arctan(x)}{\pi}$ with $x \equiv v/h = (W/2)/H$ (e.g. for $W=R=H$, i.e. $v=1/2$, $h=1$, $x=1/2$, $F_{12}=0.927$, $F_{21}=0.148$)	

The other view factor we used was to calculate the fraction radiation that the left and right bushes would be emitting to the 19 inch target strip of wall. This view factor is used for an off center strip of wall, while the previous view factor was used for a strip of wall that is centered on the cylinder.

$$W = 1.583\,ft \quad W_1 = 0.542\,ft \quad W_2 = 2.125\,ft$$

$$R = 0.625\,ft \quad H = 1.5\,ft$$

$$v_1 = \frac{W_1}{R} = \frac{0.542ft}{0.625ft} = 0.87\frac{ft}{ft} = 0.87$$

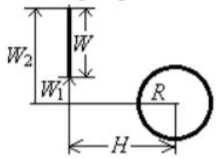
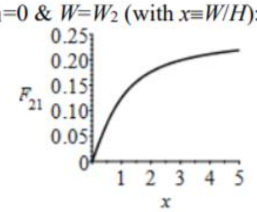
$$v_2 = \frac{W_2}{R} = \frac{2.125ft}{0.625ft} = 3.4\frac{ft}{ft} = 3.4$$

$$h = \frac{H}{R} = \frac{1.5ft}{0.625ft} = 2.4\frac{ft}{ft} = 2.4$$

$$x_1 = \frac{W_1}{H} = \frac{1.583ft}{1.5ft} = 0.36\frac{ft}{ft} = 0.36$$

$$x_2 = \frac{W_2}{H} = \frac{2.125ft}{1.5ft} = 1.42\frac{ft}{ft} = 1.42$$

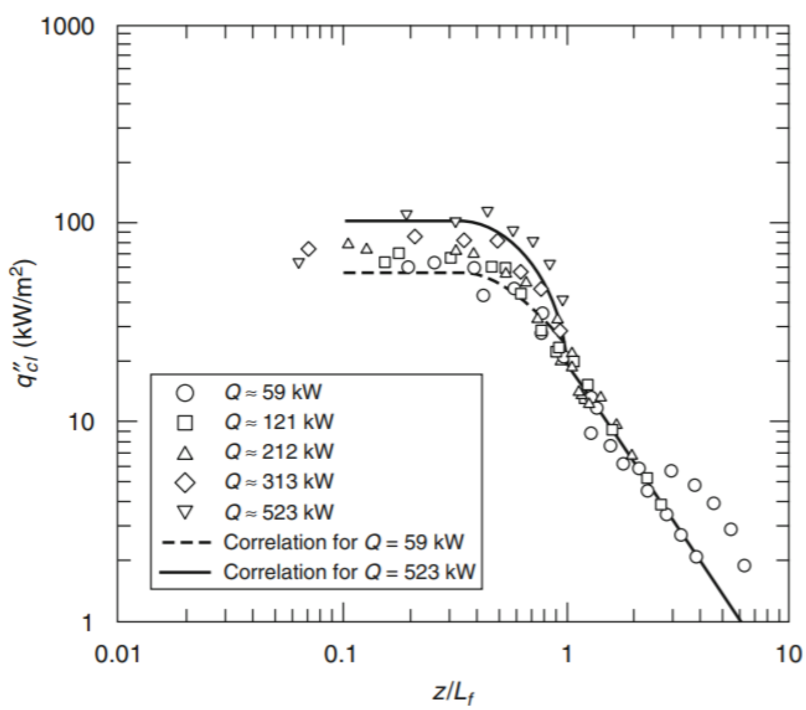
$$F_{21} = \frac{arctan\,arctan\,(x_2) - arctan\,(x_1)}{2\pi} = \frac{arctan\,arctan\,(1.42) - arctan\,(0.36)}{2\pi} = 0.097$$

From frontal surface of off-centre strip of width W to a cylinder of radius R at a distance H to the strip plane. The solution is the composition of a strip of with W_1 and a strip of width W_2, with $v_1 \equiv W_1/R$, $v_2 \equiv W_2/R$, $h \equiv H/R>1$, $x_1 \equiv W_1/H$, $x_2 \equiv W_2/H$. 	For $W=W_2-W_1$: $F_{12}=\frac{\arctan(x_2)-\arctan(x_1)}{v_2-v_1}$ $F_{21}=\frac{\arctan\left(\frac{v_2}{h}\right)-\arctan\left(\frac{v_1}{h}\right)}{2\pi}$ For $W=W_2+W_1$: $F_{12}=\frac{\arctan(x_2)+\arctan(x_1)}{v_2+v_1}$ $F_{21}=\frac{\arctan\left(\frac{v_2}{h}\right)-\arctan\left(\frac{v_1}{h}\right)}{2\pi}$ (e.g. for W_1=0 & $W_2=R=H$, i.e. v_1=0, v_2=1, h=1, x_1=0, x_2=1, F_{12}=0.463, F_{21}=0.074)	For W_1=0 & $W=W_2$ (with $x \equiv W/H$): 

As expected, the view factor for the bush to the off-center strip of wall is less than the view factor for the bush to the centered strip of wall.

Mulch Heat Flux to Wall

The SFPE Handbook (5th Edition - 2016) provides a series of graphs and equations in Chapter 25 that can be used to estimate the mulch heat flux to the wall. Assume flame height from the mulch fire of is 1.8 feet based on experimental data from Zipperer et. al. (n.d.). The graph below provides the vertical heat flux distribution along the centerline of a square propane burner fire adjacent to a flat wall.

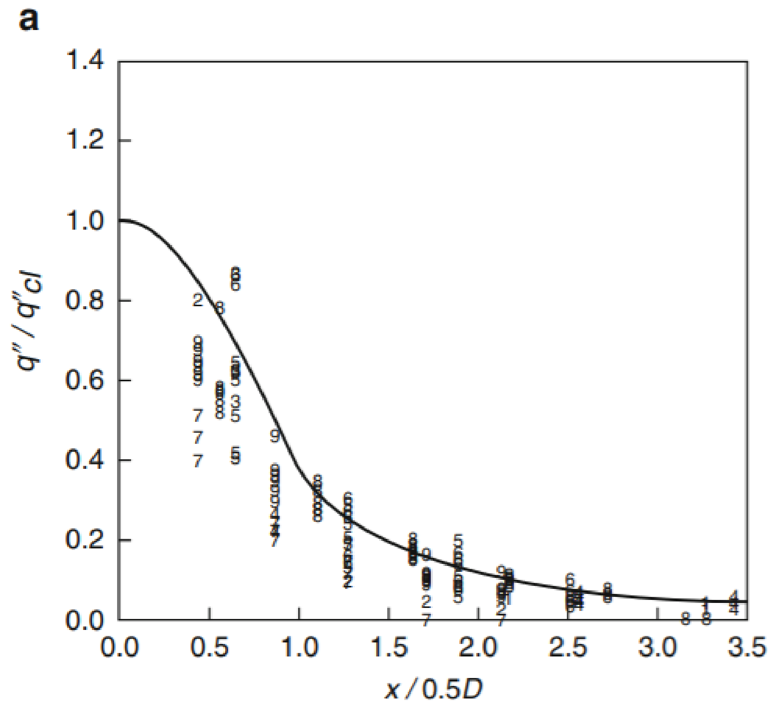


In order to estimate the heat flux from the graph, it is necessary to define the value of z/L_f. The flame height, L_f, will be taken as the maximum measured value for the mulch flames at 1.8 feet.

The value for z will be taken as 1 foot since the cedar siding of the house starts 1 foot above grade. Therefore:

$$\frac{z}{L_f} = \frac{1ft}{1.8ft} = 0.55\frac{ft}{ft} = 0.55$$

Examining the graph, the heat flux along the centerline when the value of $z/L_f = 0.55$ is approximately 50 kW/m^2. The graph below provides the lateral heat flux distribution with distance from the centerline of square propane burner fires against flat walls in the flaming region.



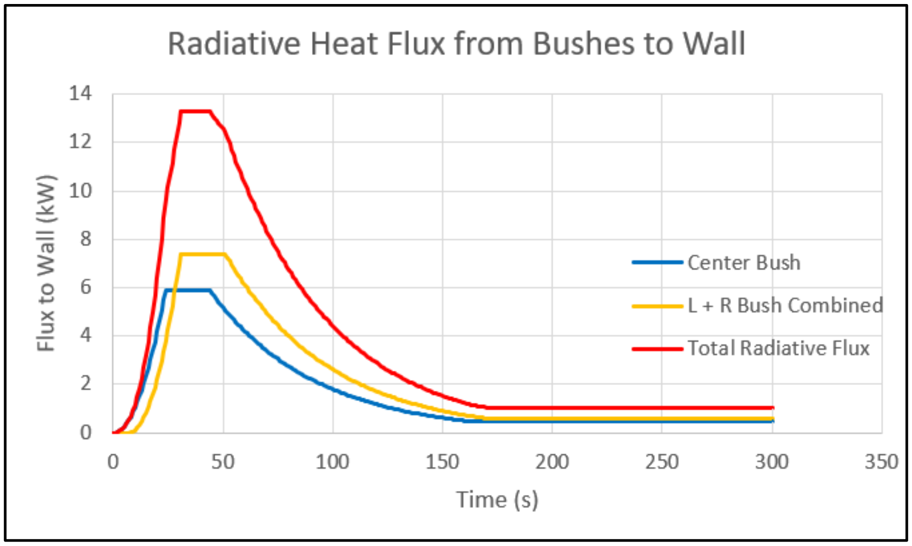
The value of D is the length of the square area burning. The mulch fire can be approximated as a 3 foot square at this point, meaning that D = 3 ft. The value of x is the distance from the wall to the centerline of the fire. x=1.5 feet in this case since the fire is burning the entire 3 foot depth of the mulch belt and is centered at 1.5 feet from the wall. Therefore:

$$\frac{x}{0.5D} = \frac{1.5ft}{0.5(3ft)} = 1\frac{ft}{ft} = 1$$

Examining the graph, the heat flux at the wall is approximately 40% of the heat flux at the centerline. Therefore, the target area of the wall is receiving 20 kW/m^2 from the mulch.

Wall Ignition

The wall is receiving a heat flux from a total of 4 sources: left bush, center bush, right bush, and the mulch. Each source has its own HRR curve, and its own view factor that determines how much of the radiation is reaching the wall. The graph below shows the radiative heat flux to the wall from the bushes. Time (t = 0) on this graph aligns with the ignition of the center bush.



Approximately 50% of the radiation from each burning bush that is calculated to be reaching the wall through view factors will actually just be hitting the concrete foundation that extends to 1 foot above grade. This leaves 50% to go into the wall. Assume the 1.58 foot area from before with a 1.5 foot height. This is the target area, 0.22 m^2. The total heat flux into the wall from the bushes is transformed into a heat flux per unit area by dividing by 0.22 m^2 and then dividing by 2 to account for the 50% loss into the foundation.

The critical heat flux for most species of wood is in the range of 9.7 kW/m^2 to 14 kW/m^2. This is the lowest external heat flux at which ignition of the material can occur (Rantuch et. al., 2017). The critical heat flux of the cedar siding was assumed to be 12 kW/m^2. The calculations below show that at ignition will take approximately 31 seconds with the critical heat flux impinging on the surface. Over this period, the wall would absorb 372 kJ/m^2.

Cedar Siding Physical Properties (Kumaran et. al., 2002):

$$k = 0.085\frac{W}{m}\cdot K \qquad c_p = 1880\frac{kJ}{kg} \qquad \rho = 336\frac{kg}{m^3} \qquad k\rho c_p = 0.0537$$

Assume an initial surface temperature of T_s = 30 ^{o}C

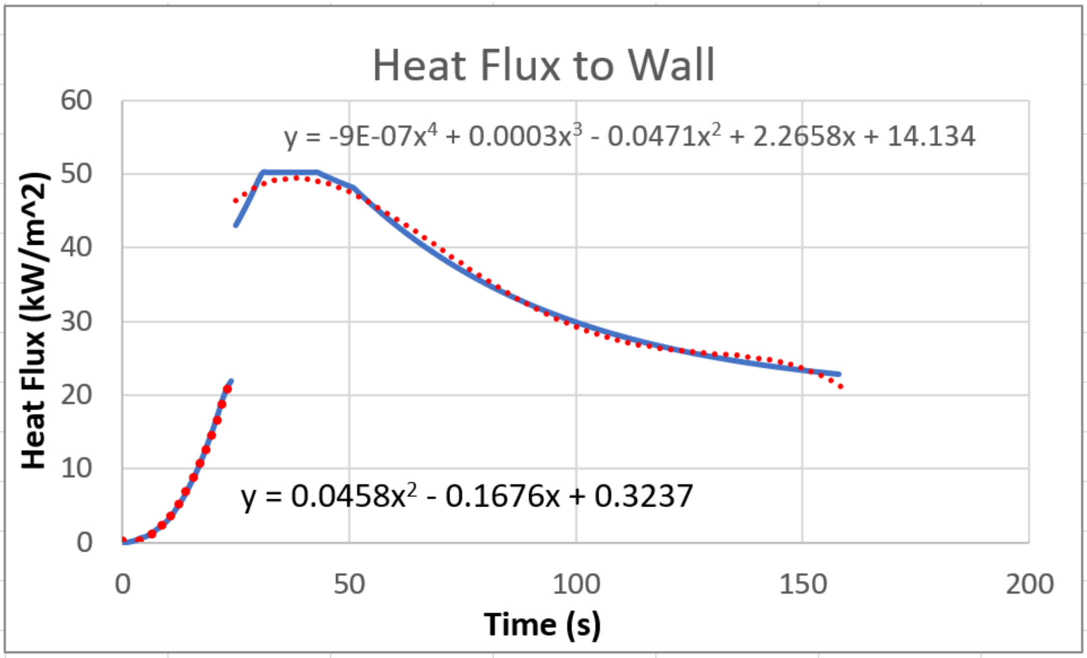
Cedar ignites at approximately 354 ^{o}C (Drysdale & Yudong, n.d.)

$$t_{ig} = \frac{\pi}{4}k\rho c_p\left(\frac{T_{ig} - T_s}{\dot{q}_f^{"}}\right)^2$$

$$t_{ig} = \frac{\pi}{4}(0.0537)\left(\frac{354°C - 30°C}{12kW/m\text{^}2}\right)^2 = 31\ seconds$$

$$q^{"} = t_{ig}\dot{q}_f^{"} = 31s\ (12kW/m\text{^}2\ ) = 372\ kJ/m^2$$

Since the heat flux to the wall is not constant, it is not accurate to calculate the time to ignition using a time constant heat flux. DiDomizio, Mulherin, and Weckman (2016) outline a process to calculate the time to ignition under a time varying radiant exposure. The first step was to graph the total heat flux to the wall over time from the four sources. The graph shows two separate curves because there is a discontinuity in the function at the time where we begin to account for the mulch heat flux to the wall. A best fit curve was identified for each part of the graph using Microsoft Excel. The graph is shown below with the heat flux to the wall (blue), the fit curves (red), and the fit curve equations.



Integrating the equation for each best fit trendline allowed for the calculation of the total incident heat to the wall over a certain time period.

$$\int (0.0458t^2 - 0.1676t + 0.3237)dt = 0.0153t^3 - 0.0838t^2 + 0.03237t$$

Evaluate the integrated equation from t = 0 to t = 24

$$(0.0153t^3 - 0.0838t^2 + 0.03237t)\ I_0^{24} = 171\ kJ$$

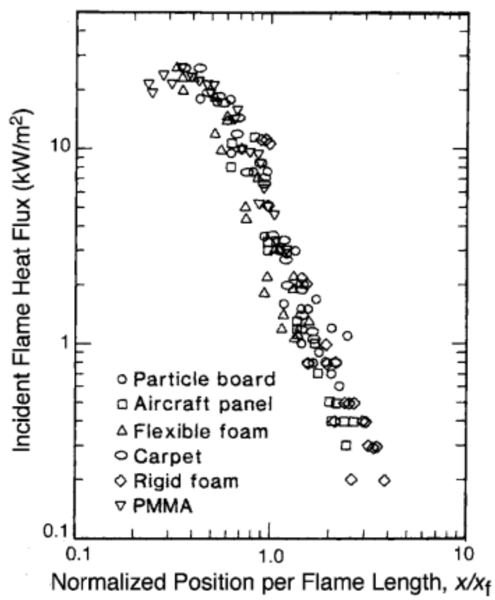
The wall has not received enough heat to ignite at t = 24. Evaluate the second integral to continue.

$$\int (-9(E-7)t^4 + 0.0003t^3 - 0.0471t^2 - 0.2658t + 14.134)dt$$
$$= -1.8(E-7)t^5 + 7.5(E-5)t^4 - 0.0157t^3 + 1.13t^2 + 14.134t$$

Evaluate the integrated equation at each time step until the wall has received an additional 200 kJ of heat. This will occur at t = 32.

Vertical Flame Spread

As soon as the wall ignites, the flames will begin to spread upwards. James Quintiere outlines a process for estimating the rate of vertical flame spread in Chapter 8 of his book Fundamentals of Fire Phenomena (2006). The example in the book uses a constant heat release rate from the wall throughout the problem, which led us to believe this is a reasonable assumption. We assumed that the cedar siding material is burning at its peak heat release rate of 182 kW/m^2 (Dietenberger, Stark, & White, 2007). Quintiere (2006) gives typical values for peak incident flame heat flux to the upper wall from the burning portion below in the range of 20 kW/m^2 to 30 kW/m^2 for a wide variety of wall flames. Examining the graph below, the results among all materials tested are remarkably similar.



The trend indicates that the maximum value incident flame heat flux to the wall above is in the realm of 30 kW/m^2. This occurs when the normalized length is equal to 0.3 (i.e. flame length is far greater than the position. For this scenario, the heat flux to the wall was assumed to be 25 kW/m^2. The process described by Quintiere for calculating vertical flame spread is summarized as follows:

Flame length on a vertical wall can be approximated by this relation:

$$y_f = 0.01\frac{m^2}{kW}\left(\dot{Q}''y_p\right)$$

$$y_f = 0.01\frac{m^2}{kW}\left(\dot{Q}''y_p\right) = 0.01\left(182\frac{kW}{m^2}\right)\left(y_p\right)$$

$$y_f = 1.82y_p$$

The equation for vertical flame spread across a thermally thick surface is given.

$$v_p = \frac{(\dot{q}_f^{"})^2 \, (\delta_f)}{\left(\frac{\pi}{4k\rho c_p}\right)\left(T_{ig} - T_s\right)^2}$$

Adopting *y* as the vertical coordinate, the equation becomes:

$$\frac{dy_p}{dt} = \frac{(\dot{q}_f^{"})^2 \, (y_f - y_p)}{\left(\frac{\pi}{4k\rho c_p}\right)\left(T_{ig} - T_s\right)^2} = \frac{(y_f - y_p)}{t_{ig}}$$

Solve for the time to ignition:

$$t_{ig} = \frac{\pi}{4} k\rho c_p \left(\frac{T_{ig} - T_s}{\dot{q}_f^{"}}\right)^2$$

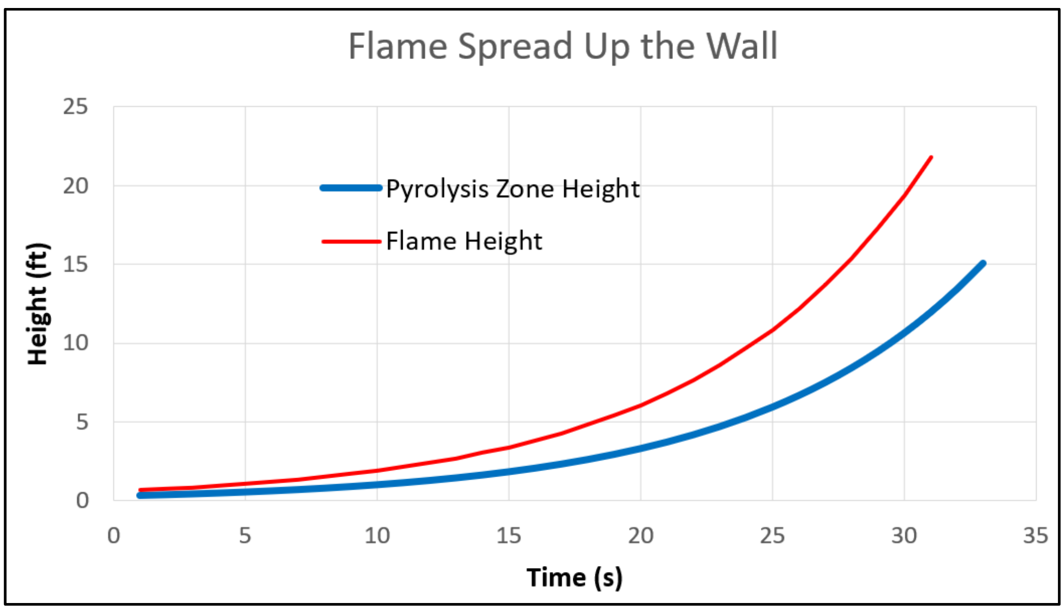
$$t_{ig} = \frac{\pi}{4}(0.0537)\left(\frac{354℃ - 30℃}{25\,\frac{kW}{m^2}}\right)^2 = 7\ seconds$$

Substitute derived values into the differential equation.

$$\frac{(y_f - y_p)}{t_{ig}} = \frac{1.82y_p - y_p}{7\ s} = 0.117y_p$$

$$y_p(m) = 0.1e^{0.117t}$$

The value of y_p at each time step can be graphed to obtain the position of the pyrolysis zone as time progresses. The given relationship of the flame zone to the pyrolysis zone can be used to estimate the flame height on the wall over time. The graph below shows these two curves.



Appendix C -Prioritization Matrix

Prioritization Matrix

MDH QI Toolbox
MINNESOTA DEPT. OF HEALTH
www.health.state.mn.us/qi

What is a Prioritization Matrix?

A prioritization matrix can help an organization make decisions by narrowing options down by systematically comparing choices through the selection, weighing, and application of criteria. Prioritization matrices:

- Quickly surface basic disagreements, so disagreements can be resolved openly
- Force a team to narrow down all solutions from all solutions to the best solutions, which are more likely to increase chances for successful program implementation
- Limits "hidden agendas" by bringing decision criteria to the forefront of a choice
- Increases follow-through by asking for consensus after each step of the process

How to Construct a Prioritization Matrix

There are three ways to construct prioritization matrices, but the **Full Analytical Criteria Method** is detailed below. This specific method is best used in smaller groups (3-8 people), which require few options (5-10 options) and few criteria (3-6 criteria). This specific method also requires the team to reach complete consensus on criteria and options. Stakes may be high if the plan fails.

1. Set a Goal

In order to agree on the ultimate goal, your group should produce a clear goal statement through consensus.

Example Goal: Buy a car for regular daily travel.

2. Set Criteria

Create a list of criteria by reviewing available documents or guidelines. The team must come to a consensus on criteria and their meaning, or the process is likely to fail.

Example Criteria: Cost, Reliability, Efficiency, Desirability
Example Options: New Chevrolet, Used Mercedes, Pre-Owned Ford, Uncle Henry's Old Clunker

3. Weigh Criteria for Importance

Use a matrix to weigh each **criteria** against another, in order to decide which criteria are most important.

A. Write Criteria

Write your criteria across the top of the columns. Add extra columns at the end for "Row Total" and "Relative Decimal Value" (you'll use those later). Write your criteria at the beginning of each row.

	Cost	Reliability	Efficiency	Desirability	Row Total	Relative Decimal Value
Cost						
Reliability						
Efficiency						
Desirability						
				Grand Total		

B. Weigh Criteria

Begin the process of deciding which criteria are more important. (Since we can't compare a criterion against itself, we'll start in the second cell of the first column.)

	Cost
Cost	-----
Reliability	

In this cell, ask yourself whether the criterion **above** (cost) is more or less important than the criterion to the **left** (reliability). Use the following weighting system to indicate whether it's more important, and by how much:

10 = Much more important
5 = More important
1 = Equally important
0.2 = Less important
0.1 = Much less important

Note: A whole number (10, 5, 1) should always represent the "desirable" rating. In some cases, this mean "more" of something (e.g., importance, reliability, educational value), and in others it may mean "less" (e.g., cost, travel time).

	Cost
Cost	-----
Reliability	5

<-- This indicates that **cost** is **more important** (5) than **reliability**.

Each time you record a **weight** in a row cell, you must record its **reciprocal value** in the corresponding column cell.

Weight of **10** --> Reciprocal value of **0.1**
Weight of **5** --> Reciprocal value of **0.2**
Weight of **1** --> Reciprocal value of **1**
Weight of **0.2** --> Reciprocal value of **5**
Weight of **0.1** --> Reciprocal value of **10**

	Cost	Reliability
Cost	-----	0.2
Reliability	5	-----

<-- The reciprocal value of 5 is 0.2; this shows that **reliability** is **less important** (0.2) than **cost**.

Continue weighting the remaining criteria and recording reciprocal values.

C. Calculate Totals

When finished, total each horizontal row and enter the sum under "Row Total." Add all row totals to reach a grand total.

	Cost	Reliability	Efficiency	Desirability	Row Total	Relative Decimal Value
Cost	-----	0.2	0.1	5	5.3	
Reliability	5	-----	0.2	5	10.2	
Efficiency	10	5	-----	5	20	
Desirability	0.2	0.2	0.2	-----	0.6	
				Grand Total	**36.1**	

D. Calculate Criteria Weighting

Divide each row total by the grand total, and enter this under "Relative Decimal Value."

	Cost	Reliability	Efficiency	Desirability	Row Total	Relative Decimal Value
Cost	-----	0.2	0.1	5	5.3	**0.15**
Reliability	5	-----	0.2	5	10.2	**0.28**
Efficiency	10	5	-----	5	20	**0.55**
Desirability	0.2	0.2	0.2	-----	0.6	**0.02**
				Grand Total	**36.1**	

These **relative decimal values** indicate how relatively important each criterion is to you—they are now called your "**criteria weighting**." You will use criteria weighting to compare options at the end of the process, in Step 6.

Criteria Weighting for All Options	
Cost	0.15
Reliability	0.28
Efficiency	0.55
Desirability	0.02

4. Weigh Options against Criteria

Use a set of matrices to weigh **options** within given criteria, in order to start deciding which options best meet your criteria.

A. Weigh Options

Using the same weighting and method as above, place one **criterion** in the upper left corner of its own matrix, and weigh **options** against each other. Use weights to indicate which option better meets the matrix's single criterion.

Remember: A whole number (10, 5, 1) should always represent the "desirable" rating. In some cases, this mean "more" of something (e.g., importance, reliability, educational value), and in others it may mean "less" (e.g., cost, travel time).

10 = Much less expensive 5 = Less expensive 1 = Same cost 0.2 = More expensive 0.1 = Much more expensive

COST	New Chevrolet	Used Mercedes	Pre-Owned Ford	Uncle Henry's Car	Row Total	Relative Decimal Value
New Chevrolet	-----	0.2	5	0.1	5.3	**0.12**
Used Mercedes	5	-----	10	0.2	15.2	**0.33**
Pre-Owned Ford	0.2	0.1	-----	0.1	0.4	**0.01**
Uncle Henry's Car	10	5	10	-----	25	**0.54**
				Grand Total	**45.9**	

Repeat this step with each criterion (cost, reliability, efficiency, desirability) using the same options and weighting method, until you have a matrix for each criterion. **There will be as many matrices as there are criteria**.

These relative decimal values indicate how well each option meets a given criterion—they are now called your "**option ratings**."

B. Optional: Compile Option Ratings

You may find it helpful to put your option ratings from each matrix into a single table to minimize confusion.

	Option Rating: **COST**	Option Rating: **RELIABILITY** (Matrix not shown)	Option Rating: **EFFICIENCY** (Matrix not shown)	Option Rating: **DESIRABILITY** (Matrix not shown)
New Chevrolet	0.12	0.24	0.40	0.65
Used Mercedes	0.33	0.37	0.10	0.22
Pre-Owned Ford	0.01	0.37	0.49	0.12
Uncle Henry's Car	0.54	0.01	0.01	0.01

5. Compare Options

Using another L-shaped matrix, compare each option based on all combined criteria.

A. Create Summary Matrix

List your **criteria** at the top of each column, along with their respective **criteria weighting** values from **Step 3**. Write each **option** at the beginning of a row.

SUMMARY	**Cost** (Weight: 0.15)	**Reliability** (Weight: 0.28)	**Efficiency** (Weight: 0.55)	**Desirability** (Weight: 0.02)
New Chevrolet				
Used Mercedes				
Pre-Owned Ford				
Uncle Henry's Car				

B. Multiply Criteria Weighting and Option Ratings

In each cell, multiply the criteria weighting values (found at the top of each column) by the option rating from each matrix in **Step 4**.

SUMMARY	**Cost** (Weight: 0.15)	
New Chevrolet	0.12 x 0.15 = **0.02**	<-- New Chevrolet option rating from Step 4 **cost** matrix = 0.12
Used Mercedes	0.33 x 0.15 = **0.05**	<-- Used Mercedes option rating from Step 4 **cost** matrix = 0.33
Pre-Owned Ford	0.01 x 0.15 = **0.002**	<-- Pre-Owned Ford option rating from Step 4 **cost** matrix = 0.01
Uncle Henry's Car	0.54 x 0.15 = **0.08**	<-- Uncle Henry's Car option rating from Step 4 **cost** matrix = 0.54

In this example, the RDV specific to a New Chevrolet was 0.12 from the cost matrix (shown above), 0.07 from the reliability matrix, 0.22 from the efficiency matrix, and 0.01 from the desirability matrix (not shown in Step 4).

SUMMARY	Cost (Weight: 0.15)	Reliability (Weight: 0.28)	Efficiency (Weight: 0.55)	Desirability (Weight: 0.02)
New Chevrolet	0.12 x 0.15 = **0.02**	0.24 x 0.28 = **0.07**	0.40 x 0.55 = **0.22**	0.65 x 0.02 = **0.01**

Repeat this for each option and criterion, pulling values from Steps 3 and 4.

SUMMARY	Cost (Weight: 0.15)	Reliability (Weight: 0.28)	Efficiency (Weight: 0.55)	Desirability (Weight: 0.02)
New Chevrolet	0.12 x 0.15 = **0.02**	0.24 x 0.28 = **0.07**	0.40 x 0.55 = **0.22**	0.65 x 0.02 = **0.01**
Used Mercedes	0.33 x 0.15 = **0.05**	0.37 x 0.28 = **0.10**	0.10 x 0.55 = **0.06**	0.22 x 0.02 = **0.004**
Pre-Owned Ford	0.01 x 0.15 = **0.001**	0.37 x 0.28 = **0.10**	0.49 x 0.55 = **0.27**	0.12 x 0.02 = **0.002**
Uncle Henry's Car	0.54 x 0.15 = **0.08**	0.01 x 0.28 = **0.002**	0.01 x 0.55 = **0.01**	0.01 x 0.02 = **0.0002**

C. Calculate Row Total

Add values across each row to reach a row total.

SUMMARY	Cost (Weight: 0.15)	Reliability (Weight: 0.28)	Efficiency (Weight: 0.55)	Desirability (Weight: 0.02)	Row Total
New Chevrolet	0.12 x 0.15 = **0.02**	0.24 x 0.28 = **0.07**	0.40 x 0.55 = **0.22**	0.65 x 0.02 = **0.01**	0.32
Used Mercedes	0.33 x 0.15 = **0.05**	0.37 x 0.28 = **0.10**	0.10 x 0.55 = **0.06**	0.22 x 0.02 = **0.004**	0.22
Pre-Owned Ford	0.01 x 0.15 = **0.001**	0.37 x 0.28 = **0.10**	0.49 x 0.55 = **0.27**	0.12 x 0.02 = **0.002**	0.37
Uncle Henry's Car	0.54 x 0.15 = **0.08**	0.01 x 0.28 = **0.002**	0.01 x 0.55 = **0.01**	0.01 x 0.02 = **0.0002**	0.09

D. Calculate Grand Total

Add all row totals to reach a grand total.

SUMMARY	Cost (Weight: 0.15)	Reliability (Weight: 0.28)	Efficiency (Weight: 0.55)	Desirability (Weight: 0.02)	Row Total
New Chevrolet	0.12 x 0.15 = **0.02**	0.24 x 0.28 = **0.07**	0.40 x 0.55 = **0.22**	0.65 x 0.02 = **0.01**	0.32
Used Mercedes	0.33 x 0.15 = **0.05**	0.37 x 0.28 = **0.10**	0.10 x 0.55 = **0.06**	0.22 x 0.02 = **0.004**	0.22
Pre-Owned Ford	0.01 x 0.15 = **0.001**	0.37 x 0.28 = **0.10**	0.49 x 0.55 = **0.27**	0.12 x 0.02 = **0.002**	0.37
Uncle Henry's Car	0.54 x 0.15 = **0.08**	0.01 x 0.28 = **0.002**	0.01 x 0.55 = **0.01**	0.01 x 0.02 = **0.0002**	0.09
				Grand Total	1.0

Criteria Weighting

	Water Use	Exposure Protection	Penetrates Fuel Bed	Environmental Damage	Suppression Capability	Column Totals	Relative Decimal Value
Water Use		0.4	0.4	0.2	1	11	0.3459119497
Exposure Protection	2.5		1	0.4	2.5	4.3	0.1352201258
Penetrates Fuel Bed	2.5	1		0.4	2.5	4.3	0.1352201258
Environmental Damage	5	2.5	2.5		5	1.2	0.03773584906
Suppression Capability	1	0.4	0.4	0.2		11	0.3459119497
					Sum:	31.8	

Ranking Systems by Water Use

	Water Spray	Water Mist	Foam Water Spray	Low/Med/High Expansion	CAFS	Column Total	Relative Decimal Value
Water Spray		5	2.5	5	5	1	0.02747252747
Water Mist	0.2		0.4	1	1	9.5	0.260989011
Foam Water Spray	0.4	2.5		2.5	5	3.5	0.09615384615
Low/Med/High Ex.	0.2	1	0.4		2.5	8.9	0.2445054945
CAFS	0.2	1	0.2	0.4		13.5	0.3708791209
					Sum:	36.4	

Ranking Systems by Exposure Protection

	Water Spray	Water Mist	Foam Water Spray	Low/Med/High Expansion	CAFS	Column Total	Relative Decimal Value
Water Spray		1	2.5	2.5	5	2	0.05714285714
Water Mist	1		2.5	2.5	5	2	0.05714285714
Foam Water Spray	0.4	0.4		2.5	5	5.6	0.16
Low/Med/High Ex.	0.4	0.4	0.4		2.5	7.9	0.2257142857
CAFS	0.2	0.2	0.2	0.4		17.5	0.5
					Sum:	35	

Ranking Systems by Ability to Penetrate Fuel Bed

	Water Spray	Water Mist	Foam Water Spray	Low/Med/High Expansion	CAFS	Column Total	Relative Decimal Value
Water Spray		0.4	5	2.5	2.5	3.5	0.09383378016
Water Mist	2.5		5	5	5	1	0.02680965147
Foam Water Spray	0.2	0.2		0.4	0.4	15	0.4021447721
Low/Med/High Ex.	0.4	0.2	2.5		1	8.9	0.2386058981
CAFS	0.4	0.2	2.5	1		8.9	0.2386058981
					Sum:	37.3	

Ranking Systems by Environmental Damage Risk

	Water Spray	Water Mist	Foam Water Spray	Low/Med/High Expansion	CAFS	Column Total	Relative Decimal Value
Water Spray		1	0.4	0.4	0.4	8.5	0.3346456693
Water Mist	1		0.4	0.4	0.4	8.5	0.3346456693
Foam Water Spray	2.5	2.5		1	1	2.8	0.1102362205
Low/Med/High Ex.	2.5	2.5	1		1	2.8	0.1102362205
CAFS	2.5	2.5	1	1		2.8	0.1102362205
					Sum:	25.4	

Ranking Systems by Suppression Capability for Given Conditions

	Water Spray	Water Mist	Foam Water Spray	Low/Med/High Expansion	CAFS	Column Total	Relative Decimal Value
Water Spray		0.4	2.5	2.5	5	3.5	0.09383378016
Water Mist	2.5		5	5	5	1	0.02680965147
Foam Water Spray	0.4	0.2		1	2.5	8.9	0.2386058981
Low/Med/High Ex.	0.4	0.2	1		2.5	8.9	0.2386058981
CAFS	0.2	0.2	0.4	0.4		15	0.4021447721
					Sum:	37.3	

Overall Scores

	Water Use	Exposure Protection	Fuel Bed Penetration	Environmental Damage	Suppression Capability	Total Scores
Water Spray	0.027473	0.057143	0.093834	0.334646	0.093834	0.075
Water Mist	0.260989	0.057143	0.026810	0.334646	0.026810	0.124
Foam Water Spray	0.096154	0.160000	0.402145	0.110236	0.238606	0.196
Low/Med/High Ex.	0.244505	0.225714	0.238606	0.110236	0.238606	0.234
CAFS	0.370879	0.500000	0.238606	0.110236	0.402145	0.371

Appendix D - Manufacturer Data Sheets

Appendix D.1- Nozzles

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
TAR-225L nozzle

FM APPROVED

CE

DESCRIPTION

FireFlex ICAF Nozzle Model TAR 225L is an open type (deluge) non-automatic nozzle specifically designed to be used with the FireFlex ICAF System.
TAR-225L Nozzles are used on local applications where flammable or combustible liquid spills can occur on surfaces other than horizontal and may result in a cascading pool fire. Flammable liquids can be both hydrocarbons and polar solvents. The specific hazard configuration will therefore be designed to provide a specific CAF discharge over the protected surfaces or areas.
Located near and directly aimed at the surface to be protected, the TAR 225L can be used for most Class B fire applications presently using AFFF foam concentrate or water spray systems. During fire conditions the ICAF Nozzle is designed to discharge CAF solution in a 360° radius toward the surface covered.

Characteristic

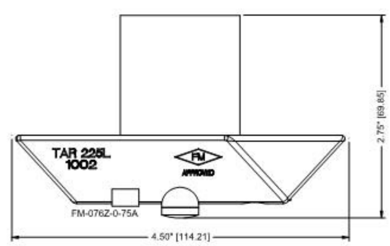
Nominal flow:	5.94 gpm (22.5 lpm)
Nominal expansion:	10:1
Connection:	1" NPT, Female

Nozzle materials:

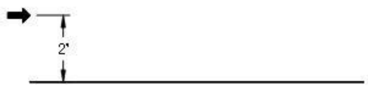
Base:	Stainless Steel 300
Tee:	Stainless Steel 300
Shaft:	Stainless Steel 300

Nozzle spacing and location

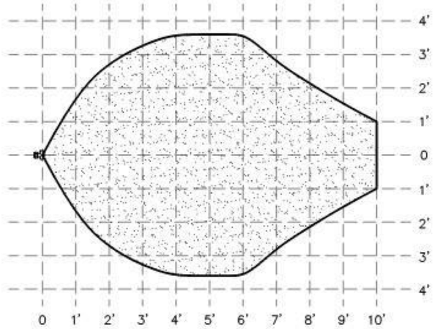
The TAR 225L nozzle spacing shall be based on the spray pattern design principle. Based on the distribution patterns shown on next page, nozzles shall be spaced and aimed so that their spray patterns will cover all surfaces adequately.



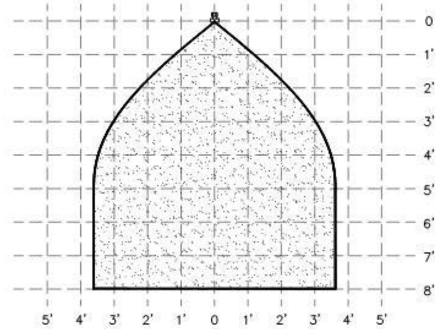
Nozzle dimensions & distribution patterns:



HORIZONTAL DISCHARGE



VERTICAL DISCHARGE



FIREFLEX Systems Inc.
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Boisbriand, Quebec
Canada J7N 1N8
Toll Free: (866) 347-3353
Website: www.fireflex.com

Appendix D.2 - Schedule 40 Steel Pipe

Fire Sprinkler Pipe

Schedule 10 and Schedule 40

Submittal Data Sheet

FM Approved and Fully Listed Sprinkler Pipe

Wheatland Tube's Schedule 10 and Schedule 40 steel fire sprinkler pipe is FM Approved and UL® and C-UL Listed.

Approvals and Specifications

Schedule 10 and Schedule 40 meet or exceed the following standards:

- ASTM A135, Type E, Grade A (Schedule 10, 1–8 NPS)
- ASTM A795, Type E, Grade A (Schedule 40, 1–2 NPS)
- ASTM A53, Type E, Grade B (Schedule 40, 2–8 NPS)
- ASTM A53, Type F, Grade A (Schedule 40, 1–4 NPS)
- NFPA® 13 and NFPA 14

Manufacturing Protocols

Schedule 10 and Schedule 40 are subjected to the toughest possible testing protocols to ensure the highest quality and long-lasting performance.

Finishes and Coatings

All Wheatland black steel fire sprinkler pipe receives a proprietary mill coating to ensure a clean, corrosion-resistant surface that outperforms and outlasts standard lacquer coatings. This coating allows the pipe to be easily painted, without special preparation. Schedule 10 and Schedule 40 can be ordered in black or hot-dip galvanized, to meet FM/UL requirements for dry systems that meet the zinc coating specifications of ASTM A795 or A53.

Product Marking

Each length of Wheatland fire sprinkler pipe is continuously stenciled to show the manufacturer, type of pipe, grade, size and length. Bar coding is acceptable as a supplementary identification method.

SUBMITTAL INFORMATION

PROJECT:	CONTRACTOR:	DATE:
ENGINEER:	SPECIFICATION REFERENCE:	SYSTEM TYPE:
LOCATIONS:	COMMENTS:	
☐ BLACK	☐ HOT-DIP GALVANIZED	

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Fire Sprinkler Pipe

Schedule 10 and Schedule 40

Submittal Data Sheet

SCHEDULE 10 WEIGHTS AND DIMENSIONS

NPS	NOMINAL OD		NOMINAL ID		NOMINAL WALL		WT./FT.	WT./FT. H_2O FILLED	PCS./LIFT	WT./LIFT 21'	WT./LIFT 24'	WT./LIFT 25'	UL
	in.	mm	in.	mm	in.	mm	lbs.	lbs.		lbs.	lbs.	lbs.	CRR*
1	1.315	33.4	1.097	27.9	0.109	2.77	1.405	1.814	70	2065	2360	2459	11.4
1¼	1.660	42.2	1.442	36.6	0.109	2.77	1.807	2.514	61	2315	2645	2756	7.3
1½	1.900	48.3	1.682	42.7	0.109	2.77	2.087	3.049	61	2673	3055	3183	5.8
2	2.375	60.3	2.157	54.8	0.109	2.77	2.640	4.222	37	2051	2344	2442	4.7
2½	2.875	73.0	2.635	66.9	0.120	3.05	3.354	5.895	30	2226	2544	2651	3.5
3	3.500	88.9	3.260	82.8	0.120	3.05	4.336	7.949	19	1730	1977	2060	2.6
4	4.500	114.3	4.260	108.2	0.120	3.05	5.619	11.789	19	2242	2562	2669	1.6
5	5.563	141.3	5.295	134.5	0.134	3.40	7.780	17.309	13	2124	2427	2529	1.5
6	6.625	168.3	6.357	161.5	0.134	3.40	9.298	23.038	10	1953	2232	2325	1.0
8	8.625	219.1	8.249	209.5	0.188	4.78	16.960	40.086	7	2493	2849	2968	2.1

SCHEDULE 40 WEIGHTS AND DIMENSIONS

NPS	NOMINAL OD		NOMINAL ID		NOMINAL WALL		WT./FT.	WT./FT. H_2O FILLED	PCS./LIFT	WT./LIFT 21'	WT./LIFT 24'	WT./LIFT 25'	UL
	in.	mm	in.	mm	in.	mm	lbs.	lbs.		lbs.	lbs.	lbs.	CRR*
1	1.315	33.4	1.049	26.6	0.133	3.38	1.68	2.055	70	2470	2822	2940	1.000
1¼	1.660	42.2	1.380	35.1	0.140	3.56	2.27	2.922	51	2431	2778	2894	1.000
1½	1.900	48.3	1.610	40.9	0.145	3.68	2.72	3.602	44	2513	2872	2992	1.000
2	2.375	60.3	2.067	52.5	0.154	3.91	3.66	5.109	24	1845	2108	2196	1.000
2½	2.875	73.0	2.469	62.7	0.203	5.16	5.80	7.871	20	2436	2784	2900	1.000
3	3.500	88.9	3.068	77.9	0.216	5.49	7.58	10.783	13	2069	2365	2464	1.000
3½	4.000	101.6	3.548	90.1	0.226	5.74	9.12	13.400	10	1915	2189	2280	1.000
4	4.500	114.3	4.026	102.3	0.237	6.02	10.80	16.311	10	2268	2592	2700	1.000
5	5.563	141.3	5.047	158.2	0.258	6.55	14.63	23.262	7	2151	2458	2560	1.000
6	6.625	168.3	6.065	154.1	0.280	7.11	18.99	31.498	5	1994	2279	2374	1.000
8**	8.625	219.1	7.981	202.7	0.322	8.18	28.58	50.240	5	3001	3430	3573	1.000

** Calculated using Standard UL CRR formula, UL Fire Protection Directory, Category VIZY. The CRR is a ratio value used to measure the ability of a pipe to withstand corrosion. Threaded Schedule 40 steel pipe is used as the benchmark (value of 1.0).*

*** 8 NPS Schedule 40 is FM Approved but not UL Listed.*

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Appendix D.3 – Compressed Air Cylinder

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
Air Supply for America

FM APPROVED

DESCRIPTION

Compressed Air Foam is constituted of 90% compressed air. Air is provided by DOT and TC certified compressed air cylinders *(V2)* pressurized to 2400 psi (16,536 kPa). Each cylinder is supplied with a cylinder valve *(V4)* equipped with a safety relief disc *(V3)* which provides relief at 3600-4000 psi.
Air pressure regulators *(V5)* are used to reduce the air pressure to a working pressure of 100 psi (689 kPa) for the system operation.
The cylinders bank pressure is supervised by a pressure transducer *(V7)* sending a low pressure supervisory signal when the pressure goes under the minimum pressure required to provide air supply for the specified discharge time.
A safety valve *(A2 - mounted in the cabinet)* is also used at the outlet of the air pressure regulator *(V5)* to protect the system from high pressure in case of malfunction. The maximum air operating pressure on the system side (downstream of the air regulator) is adjusted to 135 psi (930 kPa).
The cylinders bank is factory assembled on a painted steel skid and includes all the high pressure tubing, manifold (V8) and hardware.
Cylinder valve guards are used instead of cylinder caps, eliminating the repetitive costs associated with the use of cylinder caps. Cylinder valve guards protect the cylinder heads during shipment, therefore no protective caps have to be removed and most importantly, no tubing or fittings are required to be installed after receiving.

The cylinders bank manifold is also provided with a refilling port (V9) which allows refilling the complete bank on-site with a high pressure compressor, without having to remove any other parts or having to transport the cylinders to a filling plant.
The skid mounted cylinders bank is available with single or twin pressure regulator *(V5)* assemblies and is available in the following storage capacities:

- up to 2 cylinders
- up to 4 cylinders
- up to 6 cylinders
- up to 8 cylinders
- up to 10 cylinders

Air supply design and selection:

The number of cylinders *(V2)* and regulators *(V5)* established at the design stage is based on both the maximum system flow and discharge time required for the largest single hazard protected or group of hazards that are protected simultaneously. FireFlex hydropneumatic software will take that into account when computing the system capacity.

Note regarding air cylinders: The quantity of compressed air cylinders is calculated based on a storage temperature of 70˚F (21˚C), with a range of 60˚F to 80˚F (15.5˚C to 26.6˚C). Storage temperatures outside this range must be taken into consideration during the system design stage.

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
American Air Supply

Interconnection Piping to ICAF System

There is one interconnection line *(circled item #4)* provided on every air cylinder bank. The connection is used to supply compressed air between the cylinders bank and the ICAF System. The piping is factory prepared according to installation arrangement and is supplied with the system.

Cylinders Approvals:

D.O.T.: 3AA2300
T.C.: 3AAM176

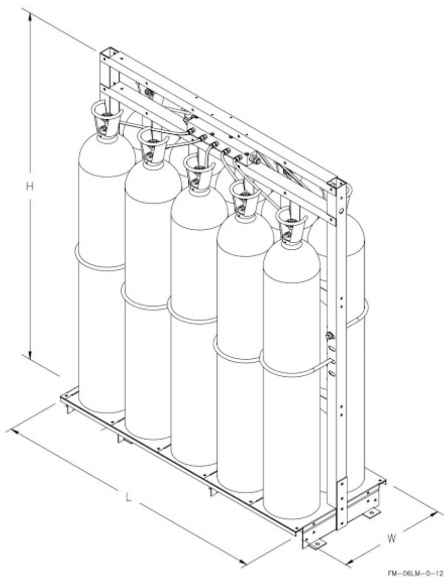
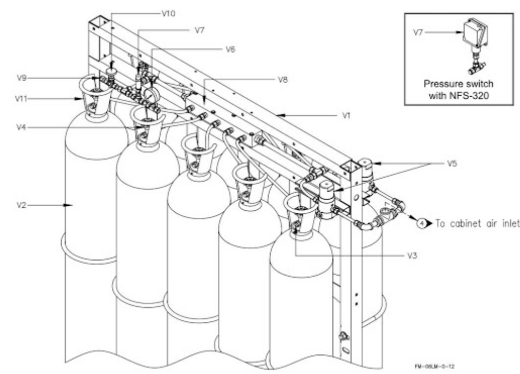


Figure 1 – Compressed Air Cylinder Bank



Air supply Components:

V1 Cylinder rack
V2 Compressed air cylinders
V3 Safety release disk
V4 Cylinder valve
V5 Pressure regulator
V6 Pressure gauge
V7 Pressure transducer
V8 High pressure manifold
V9 Refilling outlet
V10 High pressure isolation valve (option)
V11 Valve guards

Cylinders Bank Dimensions & Capacity:

Storage Capacity (Qty of cyls.)	Dimensions (inches)		
	Width (W)	Lenght (L)	Height (H)
2		14½	
4		27¼	
6	25	40	82¼
8		52¾	
10		65¼	

Note: Add 2" on both sides to the "L" Dimension to allow for the floor anchor angles.

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Appendix D.4 - Water Storage Tank

Highland Tank | count on our products. trust in our people.

asme fire protection vessels **HT-1122**

PRODUCT DETAILS

Fire Protection Tanks (FPT) are hydropneumatic water storage tanks specifically designed for use in private fire protection systems.

These ASME pressure vessels are required by fire codes in many commercial, industrial and institutional buildings for use with automatic sprinkler systems for fire suppression. FPT are designed, fabricated, tested, inspected and installed in accordance with the National Fire Protection Association NFPA Standard No. 22, "Water Tanks for Private Fire Protection."

During normal operation, this ASME pressure vessel is filled with water to 2/3 the volume of the tank and then pressurized with air to 125 psi. FPT can be located underground with all of the fittings located on one head that protrudes into the basement or a vault.

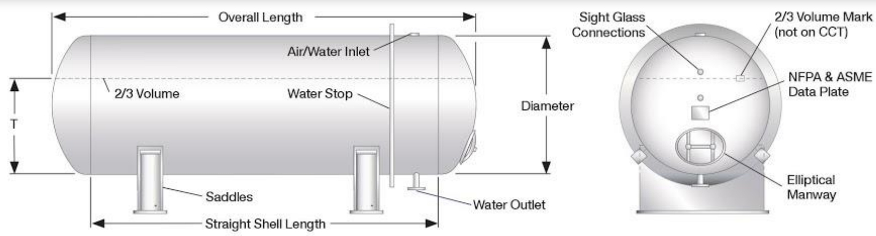
The outlet flange is located at the bottom of the vessel near this head and projects a minimum of 4" into the vessel. A water-stop with link-seal prevents water intrusion. FPT are fully compliant with factory-applied internal and external coatings with optional cathodic protection system on the buried end of the vessel.

Premium ASME Pressure Vessels from the Industry Leader

814.893.5701 | highlandtank.com

fire protection vessel sizing guide

HT-1122



Volume 100% - 2/3 Gallons	Dimensions Diameter	Straight Shell Length	Depth of ASME Head Inches	Overall Length	T Dimension @2/3Volume
300 - 200	3'-0"	5'-0"	10.5	6'-9"	22"
500 - 330	3'-6"	6'-0"	12.0	8'-0"	26"
1,000 - 667	4'-0"	10'-0"	13.5	12'-3"	29"
1,500 - 1,000	4'-0"	15'-6"	13.5	17'-9"	29"
2,000 - 1,320	4'-0"	21'-0"	13.5	23'-3"	29"
2,000 - 1,320	4'-6"	16'-0"	15.0	18'-6"	33"
3,000 - 2,000	4'-0"	32'-0"	13.5	34'-3"	29"
3,000 - 2,000	4'-6"	24'-6"	15.0	27'-0"	33"
3,000 - 2,000	5'-0"	20'-0"	16.5	22'-9"	36"
4,000 - 2,640	5'-0"	28'-0"	16.5	30'-9"	35"
4,000 - 2,640	6'-0"	18'-0"	19.5	21'-3"	44"
5,000 - 3,300	6'-0"	24'-0"	19.5	27'-3"	42"
5,000 - 3,300	7'-0"	16'-0"	22.5	19'-9"	51"
6,000 - 4,000	6'-0"	28'-0"	19.5	31'-3"	44"
6,000 - 4,000	7'-0"	20'-0"	22.5	23'-9"	51"
7,000 - 4,620	7'-0"	24'-0"	22.5	27'-9"	50"
7,500 - 5,000	7'-0"	25'-0"	22.5	28'-9"	52"
7,500 - 5,000	8'-0"	18'-6"	25.5	22'-9"	59"
8,000 - 5,280	7'-0"	27'-0"	22.5	30'-9"	51"
8,000 - 5,280	8'-0"	20'-0"	25.5	24'-3"	58"
9,000 - 6,000	7'-0"	30'-0"	22.5	33'-9"	52"
9,000 - 6,000	8'-0"	22'-2"	25.5	26'-5"	60"
10,000 - 6,600	8'-0"	25'-0"	25.5	29'-3"	59"
12,000 - 8,000	8'-0"	31'-0"	25.5	35'-3"	59"
15,000 - 10,000	8'-0"	40'-0"	25.5	44'-3"	58"
20,000 - 13,200	10'-0"	32'-0"	31.5	37'-3"	74"
25,000 - 16,500	10'-6"	38'-0"	33.0	43'-6"	75"
30,000 - 20,000	10'-6"	44'-0"	33.0	49'-6"	79"

Notes:

1. *Tanks are built in accordance with the latest edition of the ASME Unfired Pressure Vessel Code. All ASME vessels are welded, tested and inspected per ASME Code requirements and the stamped name plate.*
2. *Thicknesses are calculated per ASME Section VIII, Division I – UG 27.*
3. *Fitting details/locations are typical.*
4. *11" X 15" elliptical manway is typical for an inspection opening. All lined vessels require a 12" X 16" minimum elliptical manway.*
5. *Tanks with different/larger volumes, dimensions and pressures are available upon request.*
6. *ASME stamped vessels are required in most states. Where applicable, non-code hydropneumatic tanks are available upon request.*

All Highland Tank storage tank drawings are available for viewing or downloading in PDF or AutoCAD DXF format at highlandtank.com

Highland Tank

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Watervliet, NY
958 19th Street
Watervliet, NY 12189-1752
518.273.0801

Greensboro, NC
2700 Patterson Street
Greensboro, NC 27407-2317
336.218.0801

Lebanon, PA
2225 Chestnut Street
Lebanon, PA 17042-2504
717.664.0602

Friedens, PA
1510 Stoystown Road
Friedens, PA 15541-7402
814.443.6800

Clarkston, MI
4701 White Lake Road
Clarkston, MI 48346-2554
248.625.8700

Mancelona, MI
9517 Lake Street
Mancelona, MI 49659-7968
231.587.8412

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Appendix D.5 - Foam Concentrate Tank

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
Foam Supply

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CE

DESCRIPTION

Foam concentrate is stored inside a normally non-pressurized stainless steel pressure vessel type tank *(T1)* stamped according to ASME Section VIII Div. 1. Storage tank maximum working pressure is 150 psi (1033 kPa). The tank is supplied with a safety relief valve *(T8)* set at 135 psi (930 kPa) for protection against over-pressurization.
Foam storage tank is factory assembled and includes all the valves, trim and hardware as shown on Figure 1. Manual valves are provided to fill the tank *(T3 or T9)* with foam concentrate and to release the air pressure *(T6 or T9)* after a CAF discharge. A sight gauge *(T5)* is also provided to allow visual verification of the tank foam concentrate normal level.

Foam concentrate

CAF system shall be used with the following foam concentrates and concentrations:

Foam concentrate	Concentration
Hydrocarbons	
ANSULITE A334-LV 3%x3% AR-AFFF	2%
Dafo Fomtec AFFF 3%S C6	2%
Viking AFFF 3%S C6	2%
Polar Solvents	
ANSULITE A334-LV 3%x3% AR-AFFF	6%

Shelf Life
The shelf life of any foam concentrate is maximized by proper storage conditions and maintenance. Factors affecting shelf life are wide temperature changes, extreme high or low temperatures, evaporation, dilution, and contamination by foreign materials. Properly stored foam concentrates have been tested and shown no significant loss of firefighting performance, even after 15 years. For further details, see the Foam Concentrate Data Sheet.

Environmental and Toxicological Information
Foam concentrate used with Compressed Air Foam Systems are biodegradable. However, as with any substance, care should be taken to prevent discharge from entering ground water surface water, or storm drains. Since facilities vary widely by location, disposal should be made in accordance with federal, state and local regulations. For further details, see the foam Concentrate Data Sheet and Material Safety Data Sheet.

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
Foam Supply

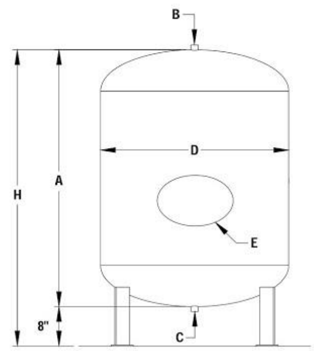
Foam tank design and selection

The capacity established at the design stage is based on both the maximum system flow and discharge time required for the largest single hazard protected or group of hazards that are protected simultaneously; FireFlex's design software will take that into account when calculating the system's capacity.

Interconnection Piping to ICAF System

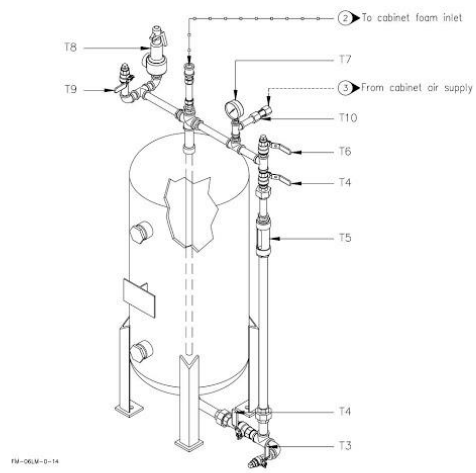
There are two interconnections lines provided on all foam storage tanks. One connection is used to pressurize the foam storage tank with compressed air *(item 3)*, the other to provide foam concentrate to the mixing chamber *(item 2)*. Piping between the foam storage tank and the ICAF System is factory prepared according to installation arrangement and is supplied with the system.

Storage tank dimensions & capacity:



Nominal Capacity USGal	Dimensions (in)			Outlet (NPTF)		Manhole
	A	D	H	B	C	E
15	50	11	N/A			
25	35	16	43	1		
35	23	24	31			
50	33	24	41			
75	46	24	54			N/A
100	64	24	72		1	
150	44	36	52	2		
200	54	36	62			
300	67	38	75			
400	63	48	71			
450	69	48	77	3 flange		16 X 12
500	65	54	73			

Note: 15 gallon tank is supported by brackets



Foam storage tank components:
T1 Foam storage tank
T2 Dip tube
T3 Storage tank drain valve/Foam refill valve
T4 Level sight gauge isolation valve
T5 Foam level sight gauge
T6 Vent valve
T7 Pressure gauge
T8 Pressure safety valve
T9 Vent valve
T10 Check valve

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Website: www.fireflex.com

Appendix D.6 - Foam Concentrate

fomtec
Fire Fighting Foams & Equipment

Fomtec® Enviro Class A

foam concentrate

Features

Approved by United States Department of Agriculture (USDA) Forest Service and QPL (qualified products List) listed

Independently tested for toxicity on mammals, fish and algae

100% biodegradable

Usage 0.1-1%

Description

Fomtec Enviro Class A is a specially selected blend of high activity hydrocarbon surfactants, selected for their environmental profile, solvents and stabilizers for use on class A fuel fires and smaller class B fires. Enviro Class A does not contain any hazardous substances and does not require any special labelling when transported.

Application

Enviro Class A provides excellent extinguishments of class A fires by providing deep penetration of the water into the burning material. At low concentrations it is also highly effective as a wetting agent. Enviro Class A is also effective on smaller class B fires. Enviro Class A can be used with both aspirating and non-aspirating discharge devices. It is compatible with all dry chemical powders.

Enviro Class A can be used in:

- Fire extinguishers
- Handline Branchpipes and Nozzles
- Helicopter Buckets
- Foam systems
- CAFS systems

Recommended Proportioning Ratio

- Helicopter Bucket 0.3% - 0.5%
- Aspirating nozzle 0.3% - 0.5%
- Non-aspirating nozzle 0.3% - 0.6%
- Compressed air foam system (CAFS) 0.1% -0.5%
- Aspirated foam on small class B fires 1%-3%

The % may vary depending on the quality of the

foam blanket required.

Fire Performance & Foaming

Enviro Class A has been designed to be applied as a Wetting Agent as well as a Class A fire extinguishing agent and can be effective if proportioned from 0,1% to 1,0% according to requirements. The foaming properties are depending on equipment used and other variables such as water and ambient temperatures. Average expansion 7:1, average ¼ drainage time 02:00 minutes using UNI 86 test nozzle.

Compatibility

Contact one of the Fomtec sales team with questions.

Environmental impact

Enviro Class A is non-hazardous, biodegradable substance totally free from fluorinated surfactants. The handling of spills of concentrate or foam solutions should however be undertaken according to local regulations. Normally sewage systems can dispose foam solution based on this type of foam concentrate, but local sewage operators should be consulted in this respect.

Full details will be found in the Material Safety Datasheet (MSDS).

Technical data

Appearance	Clear yellowish liquid
Specific gravity at 20°C	1,02 +/- 0.01 g/ml
Viscosity at 20°C	≤ 30 mPas
pH	6,5 – 8,5
Freezing point	-4°C
Recommended storage temperature	-4 - 55°C
Surface tension	≤ 25,0 dynes/cm

Storage / Shelf life

Stored in original unbroken packaging the product will have a long shelf life. Shelf life in excess of 10 years will be found in temperate climates. As with all foams, shelf life will be dependent on storage temperatures and conditions. If the product is frozen during storage or transport, thawing will render the product completely usable.

Synthetic foam concentrates should only be stored in stainless steel or plastic containers. Since electrochemical corrosion can occur at joints between different metals when they are in contact with foam concentrate, only one type of metal should be used for pipelines, fittings, pumps, and tanks employed in the storage of foam concentrates. We recommend following our guidelines for storage and handling ensuring favourable storage conditions.

Packaging

We supply this product in 25 litre cans and 200 litre drums. We can also ship in 1000 litre containers or in bulk.

Litres per piece	Packaging	Part no
25 litres	Can	11-1050-01
200 litres	Drum	11-1050-02
1000 litres	Container	11-1050-04
Bulk	Special request	

Approvals:

Qualified Products Listed (QPL) by US Forest Service in accordance to Forest Service Specification 5100-307a
Tested by UL to the ASTM E1321 – Lateral Ignition & Flame Spread Apparatus Testing (LIFT TEST)
Conforms to NFPA 18 and NFPA 1150

Revised: 08.11.2013

The independent alternative | Dafo Fomtec AB | P.O. Box 683 | SE-135 26 Tyresö | P: +46 8 506 405 66 | F: +46 8 506 405 29 | www.fomtec.com

Appendix D.7 - Linear Heat Detector

PROTECTOWIRE® FireSystems

DATA SHEET

Protectowire CTI™ Confirmed Temperature Initiation Linear Heat Detectors

Features

- Operates digitally with short circuit discrimination capable of distinguishing between short circuit and alarm conditions.
- Consists of multi-sensor heat detection technology.
- Includes confirmed temperature initiation for highest immunity to false alarms.
- Is compatible with Protectowire Alarm Point Location Meter.
- Approved for hazardous locations.
- Available in six alarm temperatures to accommodate a wide range of applications.

Description

The Protectowire family of Confirmed Temperature Initiation Linear Heat Detectors are advanced multi-sensor detectors consisting of models with alarm temperatures ranging from 135°F (57°C) to 356°F (180°C). Each detector is comprised of two special metallic alloy conductors individually insulated with a heat sensitive polymer. The insulated conductors are twisted together to impose a spring pressure between them, then wrapped with a protective tape and finished with a durable flame retardant outer jacket.

The detectors are fixed temperature digital sensors that are capable of initiating an alarm signal once their rated activation temperature is reached. At the rated temperature, the heat sensitive polymer insulation yields to the pressure upon it allowing the conductors to move into contact with each other, thereby creating a short circuit temperature measuring junction point. A CTM-530 Module is required to supervise all CTI Linear Heat Detectors. The CTM interface module is designed to detect a short circuit and enter a heat measuring thermocouple mode.

By entering the thermocouple mode, the interface module is able to identify the temperature at the short and determine the type of off-normal condition being created based upon the alarm temperature threshold of the detector.

If the interface module determines that the temperature at the short is above the predetermined alarm threshold temperature, the module initiates an ALARM condition and displays the location of the alarm if equipped with the Protectowire Alarm Point Location Meter. If, however, the interface module determines the temperature is below the alarm temperature threshold, it initiates a short circuit fault or TROUBLE condition and displays its location on the Protectowire Alarm Point Location Meter (if provided) so it can be corrected. The Protectowire advanced multi-sensor detectors are the first digital type linear heat detectors to provide true confirmed temperature initiation and mechanical short circuit discrimination. They provide reliable temperature response with verified alarm temperature confirmation for exceptional false alarm immunity.

Protectowire CTI™ Features & Benefits

- Uses advanced multi-sensor detection for highest immunity to false alarms.
- Measures and confirms the temperature at the alarm point to provide true Confirmed Temperature Initiation (CTI).
- Includes reliable digital operation with separate short circuit fault identification.
- Distinguishes between short circuits and true alarm conditions.
- Identifies and displays the location of an overheat or fire condition anywhere along its length when used with a Protectowire Alarm Point Location Meter.
- Meets intrinsically safe standards and is FM Approved for Class I, II and III, Division 1, Groups A, B, C, D, E, F and G.
- Is manufactured under U.S. Patent 8,096,708 and has patents pending in many countries around the world.

Installation

Protectowire CTI Linear Heat Detectors are approved as heat actuated automatic fire detectors and are intended to be used on a supervised initiating circuit with an approved fire protective signaling control unit. The detectors must be installed in continuous runs without taps or branches in accordance with applicable sections of NFPA 70 National Electrical Code, NFPA 72 National Fire Alarm Code, or as determined by the local authority having jurisdiction.

Protectowire may be installed at the ceiling level or on the side walls within 20 inches (50cm) of the ceiling, to protect areas within buildings. The detector has the additional benefit of being suitable for installation close to the hazard (i.e. cable trays) in order to provide a rapid response. This is known as proximity or special application protection.

Common practice is to locate the associated Interface Module within the hazard area and connect the CTI Linear Heat Detector directly to the module. When the application requires control modules to be located outside of the hazard area, "T" type thermocouple extension grade wire, of an approved type, with a minimum conductor size of 20 AWG, may be installed as interposing cable from the Interface Module out to the beginning of the CTI Detector portion of the initiating circuit. The Interface Module provides Form C (SPDT) contacts for Alarm, Trouble, and Short Circuit Fault connection to the host fire alarm control panel.

The CTI Detector portion of each initiating circuit shall begin and terminate at each end in an approved zone box or end-of-line zone box. In order to hold the cable securely, SR-502 Series Strain Relief Connectors shall be installed in all zone boxes where the CTI Linear Heat Detector enters or exits the enclosure.

Installation Accessories

A comprehensive range of mounting and installation accessories are available for the installation of Protectowire CTI Linear Heat Detectors. Only installation hardware supplied or approved by The Protectowire Company should be used.

Messenger wire is also available for the detector on special order. It consists of high tensile strength stainless steel wire, which is wound around the detector at the rate of approximately one turn per foot. It is a carrier or support wire that is designed to simplify the installation of the detector in areas where mounting is difficult. Consult The Protectowire Company for details regarding your specific application.

Specifications

Maximum Voltage Rating:	30 VAC, 42 VDC
Resistance:	.282 ohms/ft. (.925 ohms/m)
Conductor Polarity:	Un-insulated Copper Colored Conductor – Positive (+) Un-insulated Silver Colored Conductor – Negative (-)
Min. Bend Radius:	2.5 inches (6.4 cm)
Weight:	Nominal 7.5 lbs. / 500 ft. (3.4 kg / 152 m)

Temperature Ratings & Model Numbers

Product/Jacket Type	Model Number	Alarm Temperature	Max. Recommended Ambient Temperature	Max. Listed Spacing FM	UL/cUL
CTI Multi-Purpose/ Commercial & Industrial Applications	CTI-155	155°F (68°C)	115°F (46°C)*	30ft (9.1m)	50ft (15.2m)
	CTI-190	190°F (88°C)	150°F (66°C)	30ft (9.1m)	50ft (15.2m)
	CTI-220	220°F (105°C)	175°F (79°C)*	25ft (7.6m)	50ft (15.2m)
	CTI-280	280°F (138°C)	200°F (93°C)	25ft (7.6m)	50ft (15.2m)
	CTI-356	356°F (180°C)	221°F (105°C)	See Note 1	50ft (15.2m)
CTI-X High Performance/ Excellent Abrasion, Weathering & Chemical Resistance Properties	CTI-155X	155°F (68°C)	115°F (46°C)*	30ft (9.1m)	50ft (15.2m)
	CTI-190X	190°F (88°C)	150°F (66°C)	30ft (9.1m)	50ft (15.2m)
	CTI-220X	220°F (105°C)	175°F (79°C)*	25ft (7.6m)	50ft (15.2m)
	CTI-280X	280°F (138°C)	200°F (93°C)	25ft (7.6m)	50ft (15.2m)
	CTI-356X	356°F (180°C)	250°F (121°C)	See Note 1	50ft (15.2m)
CTI-XLT Exclusively for cold storage and freezers	CTI-135-XLT**	135°F (57°C)	100°F (38°C)	30ft (9.1m)	50ft (15.2m)

*For open area applications the recommended UL 521 maximum ambient temperature for CTI-155 models is 100°F (38°C), and CTI-220 models is 150°F (66°C). Temperatures shown in table are acceptable for UL Special Application use.
Note 1: FM Approved for special application use only. All models can be supplied on Messenger Wire. Add Suffix "-M" to the above model numbers.
**CTI-XLT has been UL Listed and FM Approved to -60°F (51°C)

SIGNALING c UL us LISTED FM APPROVED

Appendix D.8 - Linear Heat Detector Interface Module

PROTECTOWIRE® FireSystems

CTM-530 Series Protectowire Interface Module with Confirmed Temperature Initiation (CTI™)

Features

- Provides a single zone interface for Protectowire Type CTI™ Linear Heat Detectors
- Patented technology can distinguish between mechanical shorts and thermal alarm conditions (Short Circuit Discrimination)
- Integrated Protectowire Alarm Point Location Meter with field calibration
- 4x20 LED backlit LCD display
- Modbus over RS-485 communications
- 4-20mA outputs for Status and Alarm Point Location
- 64 Event History Log (FIFO)
- Optional intrinsically safe detection circuit available for use in hazardous locations.

General

The CTM-530 is a detection control module that acts as an interface between a main fire alarm control panel detection circuit or addressable node and Protectowire Type CTI Linear Heat Detector. The module provides one (1) supervised detection circuit that may be field wired for either Class A (Style D) or Class B (Style B) service. The alarm initiating circuit is capable of operating up to 4000 feet (1219 meters) of Protectowire Type CTI Linear Heat Detector. The CTM-530 initiating circuit currently does not support other types of normally open contact alarm initiating devices.

Description

The CTM-530 operates using Protectowire's patented CTI Confirmed Temperature Initiation technology. When paired with Protectowire Type CTI Linear Heat Detectors, the module can distinguish between a mechanical short in the linear heat detector and a thermal alarm activation thereby greatly reducing the risk of false alarms. This multi-criteria detection method provides for short circuit discrimination, a feature previously unavailable for digital type linear heat detectors.

The CTM-530 is designed for easy installation and is optionally available in a NEMA-4X* rated enclosure for mounting outside of the host fire alarm control panel or remotely near the hazard to be protected. In order to ensure proper operation, each CTM-530 module requires regulated resettable external power which is normally provided by the host fire alarm panel. Each module contains a green "Power-On" LED indicator, one (1) red "Alarm" LED indicator, one (1) yellow "Trouble" LED indicator and one (1) yellow "short fault" LED indicator. One (1) set of Form C alarm contacts, one (1) set of Form C trouble contacts and one (1) set of Form C short circuit fault contacts are also provided to connect the unit to the host fire alarm panel. The module also provides Modbus over RS-485 communications and two 4-20mA outputs, one which allows monitoring of the module status and the other for monitoring alarm point location information.
The standard CTM-530 module contains a built in Protectowire Alarm Point Location Meter. This meter will automatically display the distance from the beginning of the detector run to the heat actuated (shorted) portion of the detector. The Alarm Point Location Meter can be programmed to display in either standard units (Feet) or metric units (Meters). The meter display provides a sim-

ple "on screen" calibration procedure allowing the measurement to be field calibrated to the installed detector length and ambient temperature for optimal accuracy.

Specifications

Electrical
- Power input - Regulated 12 to 24 VDC (+10% / -15%) @ 1.6 Watt
- Power Limited, onboard surge and EMI protection devices

Inputs
- One initiating device circuit capable of monitoring up to 4000 Feet (1219 Meters) of Protectowire Type CTI Linear Heat Detector. For all CTI type detectors, twisted "T" type thermocouple grade extension wire is required for use as interconnecting cable on the detection circuit. Minimum conductor size is 20 AWG (0.812 mm), or as required by local code.

Environmental
- Ambient temperature range:
  Standard version (With integrated LCD display) -20° to 120°F (-29° to 49°C)
  LT version (Without integrated LCD display) -40° to 120°F (-40° to 49°C)
  Standard & LT Versions FM tested to 140°F (60°C) max
- Humidity: Max. 95% non-condensing

Indicators
- 4x20 Character LED backlit LCD display
- One green "Power" indicator
- One red "Alarm" indicator
- One yellow "Fault" indicator
- One yellow "Short Fault" indicator

Note: All specifications subject to change without notice.

Relay Outputs (Rated 1 amp @ 24VDC Resistive)
- One (1) set of Form C (SPDT) Fault Contacts
- One (1) set of Form C (SPDT) Short Fault Contacts
- One (1) set of Form C (SPDT) Alarm Contacts

Option I - Intrinsically Safe Detection Circuit
- Option I provides an intrinsically safe Class B detection circuit for use in those areas classified as hazardous. This feature utilizes one shunt diode barrier per zone and is FM Approved for Class I, II and III, Division 1, Groups A, B, C, D, E, F and G; Class I, Zone 0, AEx ia IIC T6 Ga -29°C ≤ Ta ≤+49°C.

Optional Enclosure Specifications
- 10.5" H x 8.5" W x 4.5" D (27cm x 21.5cm x 11.4cm)
- Add 1.6" (4cm) to overall height for external mounting feet
- Clear full view door
- NEMA 4X Rated (Rating UL listed only)*
  (Closest IEC equivalent - IP66)
  Option I increases enclosure size. Consult factory.

4-20mA Output Information

Description - The CTM 530 provides two 4-20mA outputs that allow for monitoring of the module status and active alarm point location reading. These outputs are intended for annunciation purposes only. Module monitoring is intended to be accomplished using the on-board dry contacts connected to a listed or approved fire detection control panel initiating device circuit. Consult Manual for detailed output levels for each status loop.

Modbus over RS-485 Description

The CTM-530 interface module provides integrated Modbus over RS-485 communications. Each module can be configured as a Modbus slave device on an RS-485 network. Once configured to communicate on a network, each module can be polled by a master device for a variety of module specific data. A master device, such as a PLC (Programmable Logic Controller) can monitor the status of one or more modules and take actions based on their status. Modbus over RS-485 communication is a convenient method for utilizing detector status information to implement equipment shutdown or other automation events.

Ordering Information

Model No.	Description
CTM-530	Interface Module for Protectowire Type CTI with LCD display and navigation buttons.
CTM-530E	Interface Module for Protectowire Type CTI with LCD display and navigation buttons mounted in a NEMA-4X (IP66) Enclosure.
CTM-530E-I	Interface Module with ISB for Protectowire Type CTI with LCD display and navigation buttons mounted in a NEMA-4X (IP66) Enclosure.
CTM-530LT	Interface Module for Protectowire Type CTI without LCD display and navigation buttons for use in low temperature environments. This model requires the use of a separately ordered hand-held programmer. Consult Factory for details.
CTM-530LTE	Interface Module for Protectowire Type CTI without LCD display and navigation buttons, mounted in a NEMA-4X (IP66) Enclosure. For use in low temperature environments. This model requires the use of a separately ordered hand-held programmer. Consult Factory for details.
CTM-530LTE-I	Interface Module with ISB for Protectowire Type CTI without LCD display and navigation buttons, mounted in a NEMA-4X (IP66) Enclosure. For use in low temperature environments. This model requires the use of a separately ordered hand-held programmer. Consult Factory for details.
CTMP-1	Hand-held programmer for CTM-530LT Models. Required for commissioning system, setting alarm temperature and accessing history log.

Appendix D.9 - Fire Alarm Control Panel

NFS-320

Intelligent Addressable Fire Alarm System

NOTIFIER® by Honeywell

Intelligent Fire Alarm Control Panels

General

The NFS-320 intelligent Fire Alarm Control Panel is part of the ONYX® Series of Fire Alarm Controls from NOTIFIER.

In stand-alone or network configurations, ONYX Series products meet virtually every application requirement.

The NFS-320's modular design makes system planning easier. The panel can be configured with just a few devices for small building applications, or networked with many devices to protect a large campus or a high-rise office block. Simply add additional peripheral equipment to suit the application. Wireless fire protection can be added with the SWIFT wireless gateway and devices.

For installations using NFS-320C, an optional ACM Series annunciator can be mounted in the same cabinet (up to 48 zones/points, order separately; *see DN-60085*).

***NOTE:** Unless called out with a version-specific "R", "C" or "E" at the end of the part number, "NFS-320" refers to models NFS-320, NFS-320R, NFS-320C, and NFS-320E.*

NFS-320

Features

- Certified for seismic applications when used with the appropriate seismic mounting kit.
- Approved for Marine applications when used with listed compatible equipment. *See DN-60688.*
- One isolated intelligent Signaling Line Circuit (SLC) Style 4, 6 or 7.
- Up to 159 detectors and 159 modules per SLC; 318 devices maximum.
  - Detectors can be any mix of ion, photo, thermal, or multi-sensor; wireless detectors are available for use with the FWSG.
  - Modules include addressable pull stations, normally open contact devices, two-wire smoke detectors, notification, or relay; wireless modules are available for use with the FWSG.
- Optional FWSG Wireless SWIFT Gateway supports wireless SLC devices.
- Standard 80-character display.
- Network options:
  - High-speed network for up to 200 nodes (NFS2-3030, NFS2-640, NFS-320(C), NFS-320SYS, NCA-2, DVC-EM, ONYXWorks, NFS-3030, NFS-640, and NCA).
  - Standard network for up to 103 nodes (NFS2-3030, NFS2-640, NFS-320(C), NFS-320SYS, NCA-2, DVC-EM, ONYX-Works, NCS, NFS-3030, NFS-640, NCA, AFP-200, AFP-300/400, AFP-1010, and AM2020). Up to 54 nodes when DVC-EM is used in network paging.
- 6.0 A power supply with four Class A/B built-in Notification Appliance Circuits (NAC). Selectable System Sensor, Wheelock, or Gentex strobe synchronization.
- Built-in Alarm, Trouble, Security, and Supervisory relays.
- VeriFire® Tools online or offline programming utility. Upload/Download, save, store, check, compare, and simulate panel databases. Upgrade panel firmware.
- Autoprogramming and Walk Test reports.
- Multiple central station communication options:
  - Standard UDACT
  - Internet
  - Internet/GSM
- 80-character remote annunciators (up to 32).
- EIA-485 annunciators, including custom graphics.
- Printer interface (80-column and 40-column printers).
- History file with 800-event capacity in nonvolatile memory, plus separate 200-event alarm-only file.
- Alarm Verification selection per point, with automatic counter.
- Presignal/Positive Alarm Sequence (PAS).
- Silence inhibit and Auto Silence timer options.
- NAC coding functions:
  - March time.
  - Temporal.
  - California two-stage coding.
  - Canadian two-stage.
  - Strobe synchronization.
- Field-programmable on panel or on PC with VeriFire® Tools program check, compare, simulate.
- Full QWERTY keypad.
- Battery charger supports 18 – 200 AH batteries.
- Non-alarm points for lower priority functions.
- Remote ACK/Signal Silence/System Reset/Drill via monitor modules.
- Automatic time control functions, with holiday exceptions.
- Extensive, built-in transient protection.
- Powerful Boolean logic equations.

FLASHSCAN® INTELLIGENT FEATURES

- Polls up to 318 devices in less than two seconds.
- Activates up to 159 outputs in less than five seconds.
- Multicolor LEDs blink device address during Walk Test.
- Fully digital, high-precision protocol (U.S. Patent 5,539,389).
- Manual sensitivity adjustment — up to nine levels.
- Pre-alarm ONYX intelligent sensing — up to nine levels.
- Day/Night automatic sensitivity adjustment.
- Sensitivity windows:
  - **Ion** – 0.5 to 2.5%/foot obscuration.
  - **Photo** – 0.5 to 2.35%/foot obscuration.
  - **Laser (VIEW®)** – 0.02 to 2.0%/foot obscuration.

– **Acclimate® Plus™** – 0.5 to 4.0%/foot obscuration.
– **IntelliQuad** – 1.0 to 4.0%/foot obscuration.
– **IntelliQuad™ PLUS** – 1.0 to 4.0%/foot obscuration

- Drift compensation (U.S. Patent 5,764,142).
- Degraded mode — in the unlikely event that the NFS-320's primary microprocessor fails, FlashScan detectors revert to degraded operation and can activate the control panel's NAC circuits and alarm relay. Each of the four built-in panel circuits includes a Disable/Enable switch for this feature.
- Multi-detector algorithm involves nearby detectors in alarm decision (U.S. Patent 5,627,515).
- Automatic detector sensitivity testing (NFPA-72 compliant).
- Maintenance alert (two levels).
- Self-optimizing pre-alarm.

FSL-751 VIEW (Very Intelligent Early Warning) Smoke Detection Technology

- Advanced ONYX intelligent sensing algorithms differentiate between smoke and non-smoke signals (U.S. Patent 5,831,524).
- Addressable operation pinpoints the fire location.
- Early warning performance comparable to the best aspiration systems at a fraction of the lifetime cost.

FAPT-851 Acclimate® Plus™ Low-Profile Intelligent Multi-Sensor

- Detector automatically adjusts sensitivity levels without operator intervention or programming. Sensitivity increases with heat.
- Microprocessor-based technology; combination photo and thermal technology.
- Low-temperature warning signal at 40°F ± 5°F (4.44°C ± 2.77°C).

FSC-851 IntelliQuad Advanced Multi-Criteria Detector

- Detects all four major elements of a fire (smoke, heat, CO, and flame).
- Automatic drift compensation of smoke sensor and CO cell.
- High nuisance-alarm immunity.

Intelligent FAAST® Detectors FSA-5000, FSA-8000, and FSA-20000

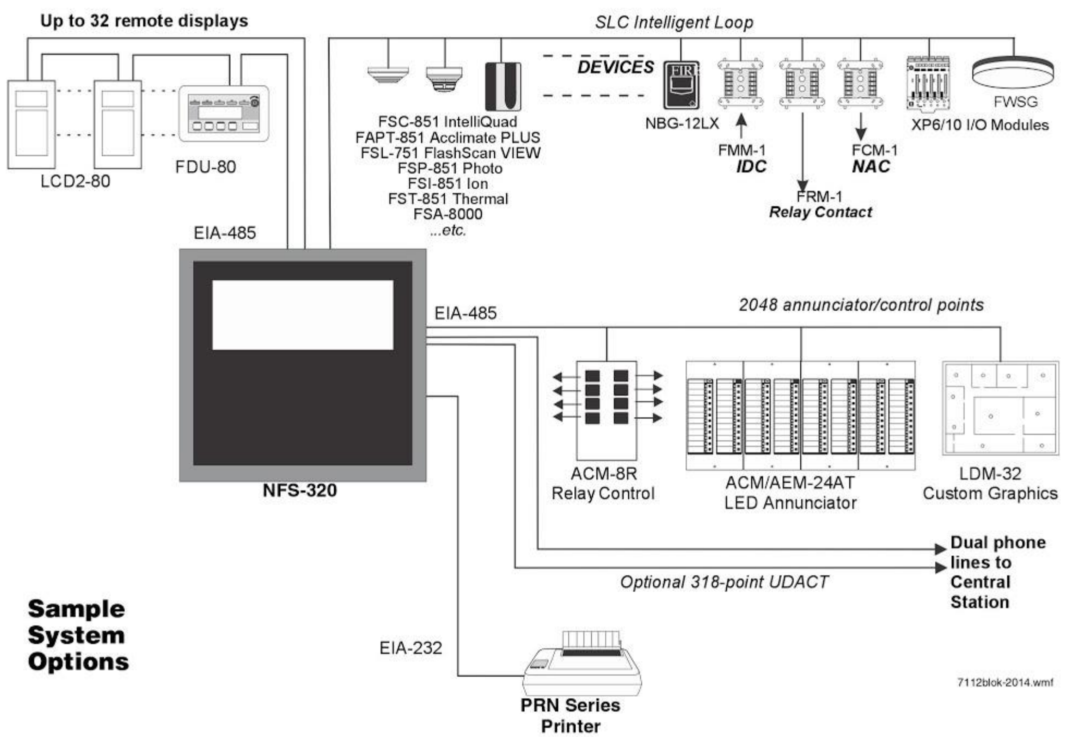
- Connects directly to the SLC loop of compatible ONYX series panels.
- Provides five event thresholds that can be individually programmed with descriptive labels for control-by-event programming; uses five detector addresses.
- Uses patented particle separator and field-replaceable filter to remove contaminants.
- Advanced algorithms reject common nuisance conditions
- FSA-5000 covers 5,000 square feet through one pipe.
- FSA-8000 covers 8,000 square feet through one pipe.
- FSA-20000 covers 28,800 square feet through one to four pipes.

FCO-851 IntelliQuad™ PLUS Advanced Multi-Criteria Fire/CO Detector

- Detects all four major elements of a fire.
- Separate signal for life-safety CO detection.
- Optional addressable sounder base for Temp-3 (fire) or Temp-4(CO) tone.
- Automatic drift compensation of smoke sensor and CO cell.
- High nuisance-alarm immunity.

SWIFT Wireless

- Self-healing mesh wireless protocol.



Sample System Options

- Each SWIFT Gateway supports up to 50 devices: 1 wireless gateway and up to 49 SWIFT devices.
- Up to 4 wireless gateways can be installed with overlapping network coverage.

RELEASING FEATURES

- Ten independent hazards.
- Sophisticated cross-zone (three options).
- Delay timer and Discharge timers (adjustable).
- Abort (four options).
- Low-pressure CO_2 listed.

VOICE FEATURES

- Integrates with FirstCommand Series. *See DN-60772.*
- Telephone applications require NFC-FFT.

HIGH-EFFICIENCY OFFLINE SWITCHING 3.0 A POWER SUPPLY (6.0 A IN ALARM)

- 120 VAC (NFS-320/NFS-320C); 240 VAC (NFS-320E).
- Displays battery current/voltage on panel (with display).

FlashScan, Exclusive World-Leading Detector Protocol

At the heart of the NFS-320 is a set of detection devices and device protocol — FlashScan (U.S. Patent 5,539,389). FlashScan is an all-digital protocol that gives superior precision and high noise immunity.

In addition to providing quick identification of an active input device, this protocol can also activate many output devices in a fraction of the time required by competitive protocols. This high speed also allows the NFS-320 to have the largest device per loop capacity in the industry — 318 points — yet every input and output device is sampled in less than two seconds. The microprocessor-based FlashScan detectors have bicolor LEDs that can be coded to provide diagnostic information, such as device address during Walk Test.

ONYX Intelligent Sensing

Intelligent sensing is a set of software algorithms that provides the NFS-320 with industry-leading smoke detection capability. These complex algorithms require many calculations on each reading of each detector, and are made possible by the high-speed microcomputer used by the NFS-320.

Drift Compensation and Smoothing: Drift compensation allows the detector to retain its original ability to detect actual smoke, and resist false alarms, even as dirt accumulates. It reduces maintenance requirements by allowing the system to automatically perform the periodic sensitivity measurements required by NFPA 72. Smoothing filters are also provided by software to remove transient noise signals, such as those caused by electrical interference.

Maintenance Warnings: When the drift compensation performed for a detector reaches a certain level, the performance of the detector may be compromised, and special warnings are given. There are three warning levels: (1) Low Chamber value; (2) Maintenance Alert, indicative of dust accumulation that is near but below the allowed limit; (3) Maintenance Urgent, indicative of dust accumulation above the allowed limit.

Sensitivity Adjust: Nine sensitivity levels are provided for alarm detection. These levels can be set manually, or can change automatically between day and night. Nine levels of pre-alarm sensitivity can also be selected, based on predetermined levels of alarm. Pre-alarm operation can be latching or self-restoring, and can be used to activate special control functions.

Self-Optimizing Pre-Alarm: Each detector may be set for "Self-Optimizing" pre-alarm. In this special mode, the detector "learns" its normal environment, measuring the peak analog readings over a long period of time, and setting the pre-alarm level just above these normal peaks.

Cooperating Multi-Detector Sensing: A patented feature of ONYX intelligent sensing is the ability of a smoke sensor to consider readings from nearby sensors in making alarm or pre-alarm decisions. Without statistical sacrifice in the ability to resist false alarms, it allows a sensor to increase its sensitivity to actual smoke by a factor of almost two to one.

Field Programming Options

Autoprogram is a timesaving feature. The FACP "learns" what devices are physically connected and automatically loads them in the program with default values for all parameters. Requiring less than one minute to run, this routine allows the user to have almost immediate fire protection in a new installation, even if only a portion of the detectors are installed.

Keypad Program Edit (with KDM-R2) The NFS-320, like all NOTIFIER intelligent panels, has the exclusive feature of program creation and editing capability from the front panel keypad, while continuing to provide fire protection. The architecture of the NFS-320 software is such that each point entry carries its own program, including control-by-event links to other points. This allows the program to be entered with independent per-point segments, while the NFS-320 simultaneously monitors other (already installed) points for alarm conditions.

VeriFire® Tools is an offline programming and test utility that can greatly reduce installation programming time, and increase confidence in the site-specific software. It is Windows®-based and provides technologically advanced capabilities to aid the installer. The installer may create the entire program for the NFS-320 in the comfort of the office, test it, store a backup file, then bring it to the site and download from a laptop into the panel.

Placement of Equipment in Chassis and Cabinet

The following guidelines outline the NFS-320's flexible system design.

Wiring: When designing the cabinet layout, consider separation of power-limited and non-power-limited wiring as discussed in the *NFS-320 Installation Manual.*

It is critical that all mounting holes of the NFS-320 are secured with a screw or standoff to ensure continuity of Earth Ground.

Networking: If networking two or more control panels, each unit requires a Network Communication Module or High-Speed Network Communication Module (HS-NCM can support two nodes; see "Networking Options" on page 4). These modules can be installed in any option board position (see manual), and additional option boards can be mounted in front of them.

KDM-R2 Controls and Indicators

Program Keypad: QWERTY type (keyboard layout).

12 LED Indicators: Power; Fire Alarm; Pre-Alarm; Security; Supervisory; System Trouble; Signals Silenced; Points Disabled; Control Active; Abort; Pre-Discharge; Discharge.

Keypad Switch Controls: Acknowledge/Scroll Display; Signal Silence; Drill; System Reset; Lamp Test.

LCD Display: 80 characters (2 x 40) with long-life LED backlight.

Product Line Information

- "Configuration Guidelines" on page 4
- "Networking Options" on page 4
- "Auxiliary Power Supplies and Batteries" on page 4
- "Audio Options" on page 4

CONFIGURATION GUIDELINES

The NFS-320 system ships assembled; description and some options follow. See "Enclosures, Chassis, and Dress Plates" on page 5 for information about mounting peripherals.

***NOTE:** Stand-alone and network systems require a main display. On stand-alone systems, the panel's keypad provides the required display. On network systems (two or more networked fire panel nodes), at least one NCA-2, NCS, or ONYXWorks annunciation device is required. (For NCA-2, see DN-7047.)*

NFS-320: The standard, factory-assembled NFS-320 system includes the following components: one control panel mounted on chassis (120 V operation — ships with grounding cable, battery interconnect cables, and document kit); includes integral power supply mounted to the main circuit board; one primary display KDM-R2 keypad/display; and one cabinet for surface or semi-flush mounting. *Purchase batteries separately. One or two option boards may be mounted inside the NFS-320 cabinet; additional option boards can be used in remote cabinets. (Non-English versions also available. NFS-320-SP, NFS-320-PO.)*

NFS-320R: Same as NFS-320, but in red enclosure.

NFS-320C: Based on NFS-320 above. NFS-320C supports installation of an optional ACM-series annunciator in the same cabinet. UL- and ULC-listed. *(Non-English version also available: NFS-320C-FR.) For NFS-320C, see DN-60085.*

NFS-320CR: Same as NFS-320C but in a red enclosure. *For NFS-320C, see DN-60085.*

NFS-320E: Same as NFS-320, but with 240 V operation. *(Non-English versions also available. NFS-320E-SP, NFS-320E-PO.)*

TR-320: Trim ring for the NFS-320 cabinet.

NETWORKING OPTIONS

NCM-W, NCM-F: Standard Network Communications Modules. Wire and multi-mode fiber versions available. *See DN-6861.*

HS-NCM-W/MF/SF/WMF/WSF/MFSF: High-speed Network Communications Modules. Wire, single-mode fiber, multi-mode fiber, and media conversion models are available. *See DN-60454.*

RPT-W, RPT-F, RPT-WF: Standard-network repeater board with wire connection (RPT-W), multi-mode fiber connection (RPT-F), or allowing a change in media type between wire and fiber (RPT-WF). Not used with high-speed networks. *See DN-6971.*

ONYXWorks: UL-listed graphics PC workstation, software, and computer hardware. *See DN-7048 for specific part numbers.*

NFN-GW-EM-3: NFN Gateway, embedded. *See DN-60499.*

NWS-3: NOTI•FIRE•NET™ Web Server. *See DN-6928.*

CAP-GW: Common Alerting Protocol Gateway. *See DN-60576.*

VESDA-HLI-GW: VESDAnet high-level interface gateway. *See DN-60753.*

LEDSIGN-GW: UL-listed sign gateway. Interfaces with classic and high-speed NOTI•FIRE•NET networks through the NFN Gateway. *See DN-60679.*

OAX2-24V: UL-listed LED sign, used with LEDSIGN-GW. *See DN-60679.*

AUXILIARY POWER SUPPLIES AND BATTERIES

ACPS-610: 6.0 A or 10.0 A addressable charging power supply. *See DN-60244.*

APS2-6R: Auxiliary Power Supply. Provides up to 6.0 amperes of power for peripheral devices. Includes battery input and transfer relay, and overcurrent protection. Mounts on two of four positions on a CHS-4L or CHS-4 chassis. *See DN-5952.*

FCPS-24S6/S8: Remote 6 A and 8 A power supplies with battery charger. See *DN-6927.*

BAT Series: Batteries. NFS-320 uses two 12 volt, 18 to 200 AH batteries. *See DN-6933.*

AUDIO OPTIONS

NFC-50/100: 25 watt, 25 VRMS, emergency Voice Evacuation Control Panel (VECP) with integral commercial microphone, digital message generator, and Class A or Class B speaker circuits. *See DN-60772.*

COMPATIBLE DEVICES, EIA-232 PORTS

PRN-6: 80-column printer. *See DN-6956.*

PRN-7: 80-column printer. See *DN-60897.*

VS4095/5: Printer, 40-column, 24 V. Mounted in external backbox. *See DN-3260.*

DPI-232: Direct Panel Interface, specialized modem for extending serial data links to remotely located FACPs and/or peripherals; mount on NFS-320 chassis. *See DN-6870.*

COMPATIBLE DEVICES, EIA-485 PORTS

ACM-24AT: ONYX Series ACS annunciator – up to 96 points of annunciation with Alarm or Active LED, Trouble LED, and switch per circuit. Active/Alarm LEDs can be programmed (by powered-up switch selection) by point to be red, green, or yellow; the Trouble LED is always yellow. *See DN-6862.*

AEM-24AT: Same LED and switch capabilities as ACM-24AT, expands the ACM-24AT to 48, 72, or 96 points. *See DN-6862.*

ACM-48A: ONYX Series ACS annunciator – up to 96 points of annunciation with Alarm or Active LED per circuit. Active/Alarm LEDs can be programmed (by powered-up switch selection) in groups of 24 to be red, green, or yellow. Expandable to 96 points with one AEM-48A. *See DN-6862.*

AEM-48A: Same LED capabilities as ACM-48A, expands the ACM-48A to 96 points. *See DN-6862.*

ACM-8R: Remote Relay Module with eight Form-C contacts. Can be located up to 6,000 ft. (1828.8 m) from panel on four wires. *See DN-3558.*

FDU-80: Terminal mode. 80-character, backlit LCD display. Mounts up to 6,000 ft. (1828.8 m) from panel. Up to 32 per FACP. *See DN-6820.*

LCD2-80: Terminal and ACS mode. 80-character, backlit LCD display. Mounts up to 6,000 ft. (1828.8 m) from panel. Up to 32 per FACP. *See DN-60548.*

LDM: Lamp Driver Modules LDM-32, LDM-E32, and LDM-R32; remote custom driver modules. *See DN-0551.*

SCS: Smoke control stations SCS-8, SCE-8, with lamp drivers SCS-8L, SCE-8L; eight (expandable to 16) circuits (HVAC only). *See DN-4818.*

TM-4: Transmitter Module. Includes three reverse-polarity circuits and one municipal box circuit; mount on NFS-320 chassis or remotely. *See DN-6860.*

UDACT-2: Universal Digital Alarm Communicator Transmitter, 636 channel. *See DN-60686.*

UZC-256: Programmable Universal Zone Coder provides positive non-interfering successive zone coding. Microprocessor-controlled, field-programmable from IBM®-compatible PCs (requires optional programming kit). Mounts in **BB-UZC**. *See DN-3404.*

COMPATIBLE INTELLIGENT DEVICES

FWSG Wireless SWIFT Gateway: Addressable gateway supports wireless SLC devices. Not appropriate for ULC applications. *See DN-60820.*

FSA-5000: Intelligent FAAST® XS Fire Alarm Aspiration Sensing Technology. Intelligent aspirating smoke detector for applications up to 5,000 sq.ft. For Canadian applications, order FSA-5000A.

FSA-8000: Intelligent FAAST® XM Fire Alarm Aspiration Sensing Technology. Intelligent aspirating smoke detector for applications up to 8,000 sq.ft. For Canadian applications, order FSA-8000A. *See DN-60792*

FSA-20000: Intelligent FAAST® XT Fire Alarm Aspiration Sensing Technology. Intelligent aspirating smoke detector for applications up to 28,800 sq.ft. For Canadian applications, order FSA-20000A. *See DN-60849.*

FSB-200: Intelligent beam smoke detector. *See DN-6985.*

FSB-200S: Intelligent beam smoke detector with integral sensitivity test. *See DN-6985*

FSC-851: FlashScan IntelliQuad Advanced Multi-Criteria Detector. *See DN-60412.*

FCO-851: FlashScan IntelliQuad PLUS Advanced Multi-Criteria Fire/CO Detector. *See DN-60689.*

FSI-851: Low-profile FlashScan ionization detector. *See DN-6934.*

FSP-851: Low-profile FlashScan photoelectric detector. *See DN-6935.*

FSP-851T: Low-profile FlashScan photoelectric detector with 135°F (57°C) thermal. *See DN-6935.*

FSP-851R: Remote-test capable photoelectric detector for use with DNR(W) duct detector housings. *See DN-6935.*

FST-851: FlashScan thermal detector 135°F (57°C). *See DN-6936.*

FST-851R: FlashScan thermal detector 135°F (57°C) with rate-of-rise. *See DN-6936.*

FST-851H: FlashScan 190°F (88°C) high-temperature thermal detector. *See DN-6936.*

FAPT-851: FlashScan Acclimate Plus low-profile multi-sensor detector. *See DN-6937.*

FSL-751: FlashScan VIEW laser photo detector. *See DN-6886.*

DNR: InnovairFlex low-flow non-relay duct-detector housing (order FSP-851R separately). Replaces FSD-751PL/FSD-751RPL. *See DN-60429.*

DNRW: Same as above with NEMA-4 rating, watertight. *See DN-60429.*

B224RB: Low-profile relay base. *See DN-60054.*

B224BI: Isolator base for low-profile detectors. *See DN-60054.*

B210LP: Low-profile base. Standard U.S. style. Replaces B710LP. *See DN-60054.*

B501: European-style, 4" (10.16 cm) base. *See DN-60054.*

B200S: Intelligent programmable sounder base, capable of producing a variety of tone patterns including ANSI Temporal 3. Compatible with sychronization protocol. *See DN-60054.*

B200S-LF: Low-frequency version of B200S. See DN-60054.

B200SR: Sounder base, Temporal 3 or Continuous tone. *See DN-60054.*

B200SR-LF: Low-frequency version of B200SR. *See DN-60054.*

FMM-1: FlashScan monitor module. *See DN-6720.*

FDM-1: FlashScan dual monitor module. *See DN-6720.*

FZM-1: FlashScan two-wire detector monitor module. *See DN-6720.*

FMM-101: FlashScan miniature monitor module. *See DN-6720.*

FCM-1: FlashScan control module. *See DN-6724.*

FCM-1-REL: FlashScan releasing control module. *See DN-60390.*

FRM-1: FlashScan relay module. *See DN-6724.*

FDRM-1: FlashScan dual monitor/dual relay module. *See DN-60709.*

NBG-12LX: Manual pull station, addressable. *See DN-6726.*

ISO-X: Isolator module. *See DN-2243.*

ISO-6: Six Fault isolator module. For Canadian applications order ISO-6A. *See DN-60844.*

XP6-C: FlashScan six-circuit supervised control module. *See DN-6924.*

XP6-MA: FlashScan six-zone interface module; connects intelligent alarm system to two-wire conventional detection zone. *See DN-6925.*

XP6-R: FlashScan six-relay (Form-C) control module. *See DN-6926.*

XP10-M: FlashScan ten-input monitor module. *See DN-6923.*

SLC-IM: SLC integration module, for VESDAnet detectors. *See DN-60755.*

ENCLOSURES, CHASSIS, AND DRESS PLATES

CAB-BM Marine System: Protects equipment in shipboard and waterfront applications. Also order **BB-MB** for systems using 100 AH batteries. For a full list of required and optional equipment, see *DN-60688.*

BB-UZC: Backbox for housing the UZC-256. Required for NFS-320 applications. Black. For red, order BB-UZC-R.

NFS-LBB: Battery Box (required for batteries larger than 26 AH).

NFS-LBBR: Same as above, but red.

SEISKIT-320/B26: Seismic mounting kit. Required for seismic-certified applications with NFS-320 and BB-26. Includes battery bracket for two 26 AH batteries.

SEISKIT-BB25: Seismic mounting kit for the BB-25. Includes battery bracket for two 26 AH batteries.

SEISKIT-LBB: Seismic kit for the NFS-LBB. Includes battery bracket for two 55 AH batteries.

OTHER OPTIONS

411: Slave Digital Alarm Communicator. *See DN-6619.*

411UDAC: Digital Alarm Communicator. *See DN-6746.*

IPDACT-2/2UD, IPDACT Internet Monitoring Module: Connects to primary and secondary DACT telephone output ports for internet communications over customer-provided Ethernet connection. Requires compatible Teldat VisorALARM Central Station Receiver. Can use DHCP or static IP. *See DN-60408.*

IPSPLT: Y-adapter option allow connection of both panel dialer outputs to one IPDACT-2/2UD cable input.

IPENC: External enclosure for IPDACT, includes IPBRKT mounting bracket; Red. For Black order **IPENC-B**.

IPGSM-4G: Internet and Digital Cellular Fire Alarm Communicator. Provides selectable configurable paths: cellular only, IP only, or IP primary with cellular backup. Connects to the primary and secondary ports of a DACT. *See DH-60769.*

NFS-320-RB: Replacement board with central processing unit (CPU). *NOTE: Keypad must be removed before shipping old unit out for repair.*

- NFS-320-RBE: Replacement CPU, Export.
- NFS-320-RB-PO: Replacement CPU, Portuguese.
- NFS-320-RB-POE: Replacement CPU, Export, Portuguese.
- NFS-320-RBC-FR: Replacement CPU, Canadian French.
- NFS-320-RB-SP: Replacement CPU, Spanish.

- NFS-320-RB-SPE: Replacement CPU, Export, Spanish.

NOTE: *For other options including compatibility with retrofit equipment, refer to the panel's installation manual, the SLC manual, and the Device Compatibility Document.*

System Specifications

SYSTEM CAPACITY

- Intelligent Signaling Line Circuits 1
- Intelligent detectors 159
- Addressable monitor/control modules 159
- Programmable internal hardware and output circuits 4
- Programmable software zones 99
- Special programming zones 14
- LCD annunciators per NFS-320/-320E 32
- ACS annunciators per NFS-320/-320E .... 32 addresses x 64 points

SPECIFICATIONS

- Primary input power
  – NFS-320: 120 VAC, 50/60 Hz, 5.0 A.
  – NFS-320E: 220/240 VAC, 50/60 Hz, 2.5 A.
- Current draw (standby/alarm):
  – NFS-320(E) board: 0.250 A. Add 0.035 A for each NAC in use.
  – KDM-R2 (Backlight on): 0.100 A.
- Total output 24 V power: 6.0 A in alarm.

NOTE: *The power supply has a total of 6.0 A of available power. This is shared by all internal circuits. See Installation Manual for a complete current draw calculation sheet.*

- Standard notification circuits (4): 1.5 A each.
- Resettable regulated 24V power: 1.25 A.
- Two non-resettable regulated 24V power outputs:
  – 1.25 A.
  – 0.50 A.
- Non-resettable 5V power: 0.15 A.
- Battery charger range: 18 AH – 200 AH. Use separate cabinet for batteries over 26 AH.
- Float rate: 27.6 V.

CABINET SPECIFICATIONS

NFS-320 cabinet dimensions:

- Backbox: 18.12 in. (46.025 cm) width; 18.12 in. (46.025 cm) height; 5.81 in. (14.76 cm) depth.
- Door: 18.187 in. (46.195 cm) width; 18.40 in. (46.736 cm) height; 0.75 in. (1.905 cm) depth.
- Trim ring: Molding width is 0.905 in. (2.299 cm).
- Shipping weight (without batteries): 36.15 lb. (16.4 kg).

TEMPERATURE AND HUMIDITY RANGES

This system meets NFPA requirements for operation at 0 – 49°C/32 – 120°F and at a relative humidity 93% ± 2% RH (non-condensing) at 32°C ± 2°C (90°F ± 3°F). However, the useful life of the system's standby batteries and the electronic components may be adversely affected by extreme temperature ranges and humidity. Therefore, it is recommended that this system and its peripherals be installed in an environment with a normal room temperature of 15 – 27°C/60 – 80°F.

AGENCY LISTINGS AND APPROVALS

The listings and approvals below apply to the basic NFS-320 control panel. In some cases, certain modules may not be listed by certain approval agencies, or listing may be in process. Consult factory for latest listing status.

- **UL Listed:** S635.
- **ULC Listed:** S635 (NFS-320C only, excludes IPDACT).
- **FM Approved.**
- **CSFM:** 7165-0028:0243.
- **MEA:** 128-07-E.
- **Fire Dept. of New York:** #6121.
- **City of Chicago.**

NOTE: *For additional information on UL- and ULC-listed model NFS-320C, see DN-60085. For information on NFS-320SYS, see DN-60637.*

Marine Applications: Marine approved systems must be configured using components itemized in this document. (See Main System Components, in "Product Line Information.") Specific connections and requirements for those components are described in the installation document, PN 54756. When these requirements are followed, systems are approved by the following agencies:

- **US Coast Guard** 161.002/50/0, 161.002/55/0 (Standard 46 CFR and 161.002).
- **Lloyd's Register** 11/600013 (ENV 3 category).
- **American Bureau of Shipping** (ABS) Type Approval.

NOTE: *For information on marine applications, see DN-60688.*

STANDARDS

The NFS-320 complies with the following UL Standards and NFPA 72, International Building Code (IBC), and California Building Code (CBC) Fire Alarm Systems requirements:

- **UL 864** (Fire).
- **UL 1076** (Burglary).
- **UL 2572** (Mass Notification Systems). (NFS-320 version 20 or higher).
- **LOCAL** (Automatic, Manual, Waterflow and Sprinkler Supervisory).
- **AUXILIARY** (Automatic, Manual and Waterflow) (requires TM-4).
- **REMOTE STATION** (Automatic, Manual, Waterflow and Sprinkler Supervisory) (requires TM-4).
- **PROPRIETARY** (Automatic, Manual, Waterflow and Sprinkler Supervisory). *Not applicable for FM.*
- **CENTRAL STATION** (Automatic, Manual, Waterflow and Sprinkler Supervisory) (requires DACT).
- **EMERGENCY VOICE/ALARM.**
- **OT, PSDN** (Other Technologies, Packet-switched Data Network).
- **IBC 2012, IBC 2009, IBC 2006, IBC 2003, IBC 2000** (Seismic).
- **CBC 2007** (Seismic).

For more information, contact Notifier. Phone: (203) 484-7161, FAX: (203) 484-7118.
www.notifier.com

Appendix D.10 - Batteries

DN-6933:D • E-205

BAT Series Batteries

Sealed Lead-Acid

NOTIFIER® by Honeywell

Power Supplies

General

BAT Series Batteries are Power-Sonic brand batteries. BAT Series (or Power-Sonic brand) batteries are recommended for secondary power or backup power for all NOTIFIER fire alarm control equipment.

6933cov.jpg

Features

- Provide secondary power for control panels.
- Sealed and maintenance-free.
- Overcharge protected.
- Easy handling with leak-proof construction.
- Ruggedly constructed, high-impact case (ABS).
- Long service life.
- Compact design.

Agency Listings and Approvals

The listings and approvals below apply to BAT Series Batteries. In some cases, certain modules may not be listed by certain approval agencies, or listing may be in process. Consult factory for latest listing status.

- **UL Recognized Components**: MH20845 *(Power-Sonic).*

Ordering Information

BAT-1250-BP: 10-unit bulk pack of BAT-1250 (12 V 5 AH).

BAT-1270-BP: 5-unit bulk pack of BAT-1270 (12 V 7 AH).

BAT-12120-BP: 4-unit bulk pack of BAT-12120 (12V 12 AH).

BAT-12180-BP: 2-unit bulk pack of BAT-12180 (12 V 18 AH).

BAT-12260-BP: 2-unit bulk pack of BAT-12260 (12 V 26 AH).

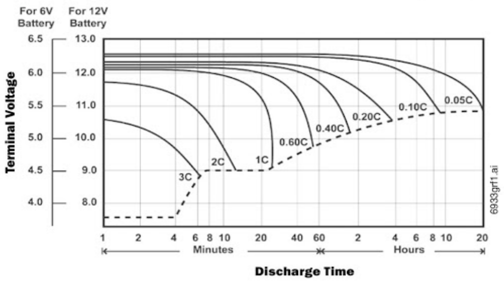
BAT-12550: single battery (12 V 55 AH).

BAT-121000: single battery (12 V 100 AH).

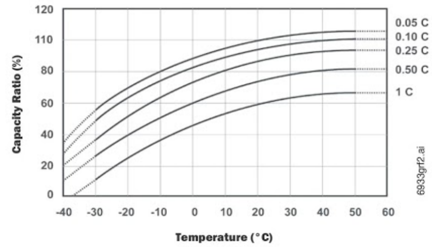
Part Number Reference & Specifications

Part Number	Power-Sonic Part Number	Battery Description			DIMENSIONS									
		Nominal Voltage V	Nominal Capacity @ 20 hr. rate A.H.		Width		Depth		Height		Height over terminal		Weight	
					in.	mm	in.	mm	in.	mm	in.	mm	lb.	kg.
BAT-1250	PS-1250	12	5	sealed	3.54	90	2.76	70	3.98	101	4.21	107	3.50	1.59
BAT-1270	PS-1270	12	7	sealed	5.95	151	2.56	65	3.7	94	3.86	98	4.8	2.18
BAT-12120	PS-12120	12	12	sealed	5.95	151	3.86	98	3.7	94	3.94	100	7.92	3.59
BAT-12180	PS-12180	12	18	sealed	7.13	181	3.00	76	6.59	167	6.59	167	12.6	5.72
BAT-12260	PS-12260	12	26	sealed	6.5	167	6.97	177	4.92	125	4.92	125	17	7.71
BAT-12550	PS-12550	12	55	sealed	9.04	230	5.45	138	8.15	207	8.98	228	36	16.33
BAT-121000	PS-121000	12	100	sealed	12	305	6.6	168	8.15	207	8.98	228	68	30.84

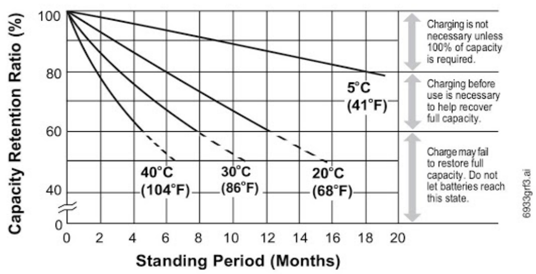
Discharge Characteristic Curves at 20°C (68°F)



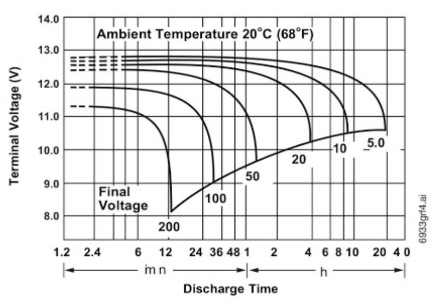
Effect of Temperature on Capacity



PS-121000 Shelf-Life and Storage



PS-121000 Discharge Characteristics



ISO 9001 CERTIFIED
ENGINEERING & MANUFACTURING QUALITY SYSTEMS

This document is not intended to be used for installation purposes.
We try to keep our product information up-to-date and accurate.
We cannot cover all specific applications or anticipate all requirements.
All specifications are subject to change without notice.

For more information, contact Notifier. Phone: (203) 484-7161, FAX: (203) 484-7118.
www.notifier.com

Appendix D.11 - Tamper Switch

POTTER
The Symbol of Protection

PCVS Series
Control Valve Supervisory Switch

Features

- NEMA 4X* (IP 65) and 6P (IP 67)
  **Enclosure is 4X. For additional corrosion protection of mounting hardware, use model PCVS-2 CRH*
- -40º to 140º (-40ºC to 60ºC) operating temperature range
- Visual Switch Indicators
- Two conduit entrances
- Adjustable length trip rod
- Accomodates up to 12AWG wire
- Switch detects tampering and valve closure
- RoHS compliant
- Two SPDT contacts

NOTICE

Before any work is done on the fire sprinkler or fire alarm system, the building owner or their authorized representative shall be notified. Before opening any closed valve, ensure that opening the valve will not cause any damage from water flow due to open or missing sprinklers, piping, etc.

SIGNALING c UL US LISTED · FM APPROVED · CE

Important: This document contains important information on the installation and operation of PCVS valve supervisory switches. Please read all instructions carefully before beginning installation. A copy of this document is required by NFPA 72 to be maintained on site.

Description

The Model PCVS is a weather proof and tamper resistant switch for monitoring the open position of fire sprinkler control valves of the wall and yard post indicator and butterfly types. Two SPDT (Form C) contacts are provided which will operate when the valve position is altered from an open state.
The unit mounts in a 1/2” NPT tapped hole in the post indicator or butterfly valve housing. The device is engaged by the indicating assembly of the post indicator or the operating mechanism of the butterfly valve, actuating switches when the valve is fully open. The unit should be installed where it is accessible for service.
The cover is held in place by two tamper resistant screws that require a special tool to remove. The tool is furnished with each device.

Testing

The operation of the PCVS and its associated protective monitoring system shall be tested upon completion of the installation and inspected, tested and maintained in accordance with all applicable local and national codes and standards and/or the Authority Having Jurisdiction, (manufacturer recommends quarterly or more frequently). A minimum test shall consist of turning the valve operating mechanism towards the closed position. The PCVS shall operate within the first two revolutions of the operating mechanism. Fully close the valve and ensure the PCVS does not restore. Fully open the valve and ensure that the PCVS restores to normal.

Technical Specifications

Dimensions	See Fig 10
Weight	1.0 lbs (0,45 kg)
Enclosure	Cover: Die Cast Finish: Red Powder Coat
	Base: Die Cast Finish: Black Powder Coat
	All parts have corrosion resistant finishes
Cover Tamper	Tamper Resistant Screws
	Optional Cover Tamper Switch Available
Contact Ratings	PCVS-2: Two Sets of SPDT (Form C)
	10.0 Amps at 125/250 VAC
	2.0 Amps at 30VDC Resistive
	10 mAmps minimum at 24 VDC
Environmental Limitations	-40º F to 140ºF (-40ºC to 60ºC)
	NEMA 4X (IP 65) and NEMA 6P Enclosure (IP67) (Use suitably rated conduit and connector)
	Indoor or Outdoor Use (See PIVSU-EX Bulletin 5400694 for Hazardous locations)
Conduit Entrances	Two Knockouts for 1/2” conduit provided (See Notice on Page 7 and Fig. 11 on Page 6)
Service Use	NFPA 13, 13D, 13R, 72

Specifications subject to change without notice

POTTER
The Symbol of Protection

PCVS Series

Control Valve Supervisory Switch

Theory Of Operation

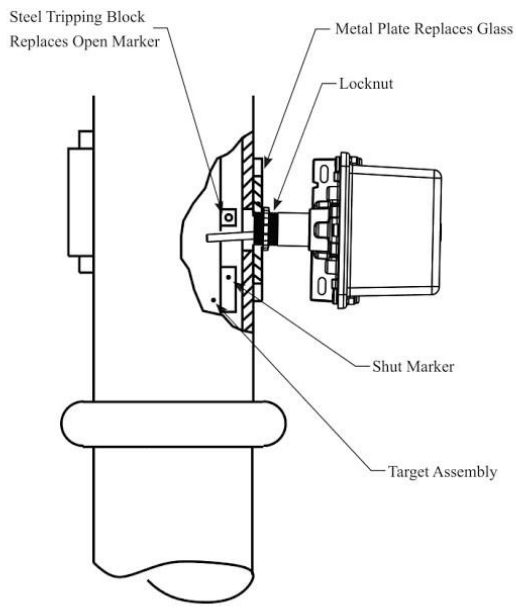
The PCVS is a spring loaded switch. It is in normal position when the trip rod is pulling against the spring force. Normal is when the switch is installed on the valve and the valve is fully open. As the valve closes, the valve actuator moves away from the trip rod of the PCVS and the spring on the PCVS pulls the trip rod over and trips the switch.

Alternate Window Installation and Moving Hood Installation

Target Moves Up as Valve is Shut

Fig 1

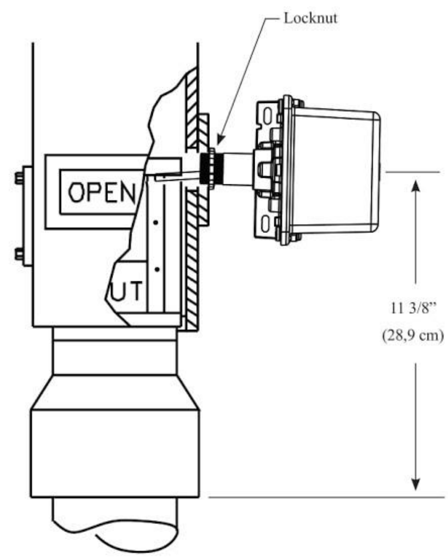
Subject to the approval of the "authority having jurisdiction" the alternate method of installation shown in Fig. 1 may be used. In this method, one of the glass windows of the housing is replaced with a 1/4" thick metal plate that is cut to fit in place of the glass and drilled and tapped to recieve 1/2" NPT pipe nipple. In some cases it may be necessary to attach an angle bracket to the target assembly to engage the PCVS trip rod.



Hood Moves Down as Valve is Shut

Fig 2

If the target is stationary and a hood arrangement is used, such as is shown in Fig. 2, the hood must be drilled with a 23/32" drill and tapped with a 1/2" NPT. The center line of this hole should be 1/8" below the portion of target assembly that strikes the PCVS trip rod. The 11 3/8" dimension shown is for a Clow Valve. Flexible conduit must be used for this type of installation. (More on pg. 3).



Typical Installations On Post Indicator Valve Housings

Fig 3

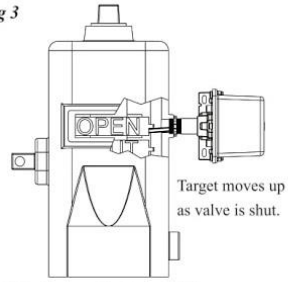
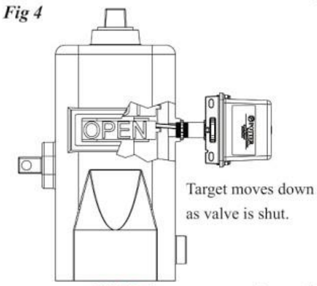


Fig 4



NOTE: Before any work is done on the fire sprinkler or fire alarm system, the building owner or their authorized representative shall be notified. Before opening any closed valve, ensure that opening the valve will not cause any damage from water flow due to open or missing sprinklers, piping, etc.

1. Position the valve to fully open ("OPEN" should appear in the window of the housing). Partially close the valve while observing the direction that the target assembly moves. Reopen the valve. If the valve housing is predrilled with a 1/2" NPT for installation of a monitoring switch, remove the 1/2" plug and fully open the valve. Make sure that "OPEN" appears in the window of the housing. GO TO STEP NO. 6.

2. If the valve is not pre-drilled for 1/2" NPT, remove the head and target assembly (consultation with valve manufacturer is recommended).

3. If the target assembly moved up as the valve was closed, measure the distance from the bottom of the head to the lower part of the target assembly that will contact the trip rod of the PCVS (see Fig. 3). This is usually a plate or bar on the target assembly, on a side adjacent to the "OPEN/SHUT" plates. Subtract 1/8" from the measurement. If the target moved down as the valve was closed, measure the distance from the bottom of the head to the upper portion of the target assembly that will contact the trip rod of the PCVS (see Fig. 4). Add 1/8" (3,2mm) to this measurement.

4. Mark the housing at the proper location. Using a 23/32" (18,2mm) drill bit, drill and then tap a 1/2" NPT in the housing on the side that coincides with the portion of the target assembly that will engage the trip rod of the PCVS.

5. Replace the head and target assembly.

6. Loosen the socket head screw that holds the nipple in the PCVS and remove the nipple.

7. Screw the locknut that is provided onto the nipple.

8. Screw the nipple into the 1/2" NPT hole in the valve housing hand tighten. Tighten the locknut against the valve housing to secure the nipple firmly in place.

9. Insert a scale or probe thru the nipple to measure the distance from the open end of the nipple to the target assembly. Subtract 1/2" (12,5mm) from this measurement.

NOTE: In some cases, it may be necessary to attach an angle bracket to the target assembly to engage the PCVS trip rod.

10. Using the special tool provided, loosen the two cover screws and remove the cover from the PCVS.

11. Loosen the locking screw that holds the trip rod in place and adjust the rod length, from the end of the collar to the end of the rod, using the dimension determined in Step 9. Tighten the locking screw to 5 in-lbs minimum to hold the rod in place and properly seal the enclosure.

12. Partially close the valve to move the target assembly away (3 to 4 revolutions of the handle/hand wheel).

13. With the PCVS positioned so the spring will pull the trip rod to follow the target as the valve is closing, slide the PCVS over the nipple. Tighten the socket head screw in the collar.

14. Carefully open the valve to the fully open position. As the target moves to the open position it should engage the trip rod and actuate the switch(es). There should be a minimum overtravel of 1/2 revolution of the handle/hand wheel after the switch(es) actuate (a continuity meter connected to each set of contacts is one method that could be used to determine this).

15. Slowly close the valve. The switch must operate during the first two revolutions of the handle/hand wheel or during 1/5 of the travel distance of the valve control apparatus from its normal condition.

NOTE: Small adjustments of the target position may be necessary (consultation with valve manufacturer is recommended).

16. Complete the required electrical wiring, connections and tests. The valve should be operated through the entire cycle of fully closed and fully open to determine the integrity of the PCVS installation and the signaling system. Check that all electrical and mechanical connections are secure.

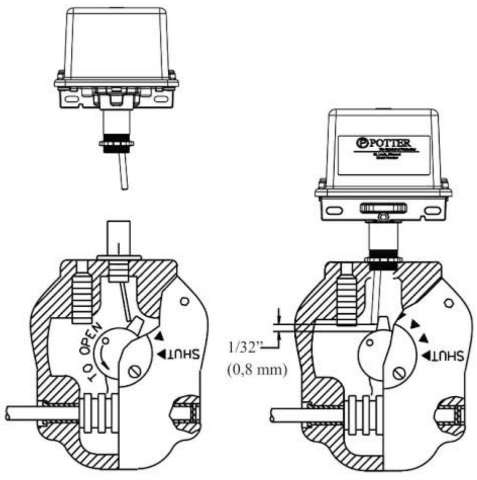
17. Reinstall the cover and tighten the cover screws to 15 in-lbs minimum to properly seal the enclosure.

18. When the installation and testing are complete, return valve to its proper position.

19. Alternative installation for other post indicator valve housing shown in Fig. 1 and 2.

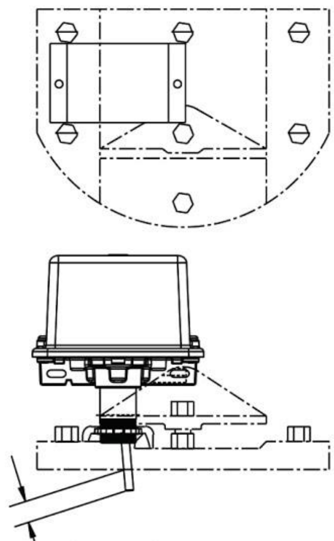
Typical Installation on a Butterfly Valve

Fig 5 Typical Indicating Butterfly Valve



Valve Partially Closed Valve Open

Fig 6 Dresser Indicating Butterfly Valve



1. Remove the 1/2" NPT plug from the gear operator case.
2. Loosen the set screw that holds the nipple in the PCVS and remove the nipple.
3. Screw the locknut that is provided onto the nipple.
4. Screw the nipple into the 1/2" NPT hole in the gear operator-hand tighten. Tighten the locknut against the case, to secure the nipple firmly in place
5. Partially close the valve to move the boss on the gear hub out of the way (3 or 4 revolutions of the hand wheel or crank).
6. Using the special tool provided, loosen the two cover screws and remove the cover from the PCVS.
7. Orient the PCVS so the spring will pull up the trip rod to follow the actuating cam inside the valve.

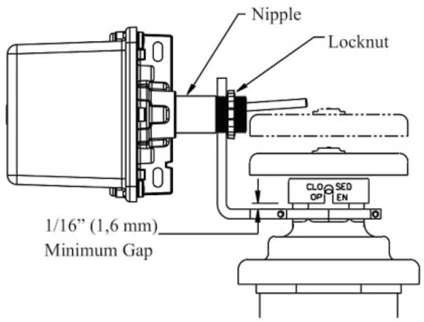
   NOTE: If trip rod length is excessive, loosen the locking screw and remove the trip rod from the trip lever. Using pliers, break off the one (1) inch long notched section (see Fig. 12). Reinstall the trip rod, tightening the screw to 5 in-lbs minimum, and repeat Step 7 procedure.
8. Remove device from nipple and shorten the trip rod 1/32" (0,80mm) (this is to prevent the trip rod from dragging on the gear hub inside the valve). Tighten the locking screw to hold the rod in place. Re-install the device on the nipple. Tighten the screw in the collar against the nipple.

   NOTE: In some cases it may be necessary to remove the gear box cover to ensure correct operation (consultation with the valve manufacturer is recommended).
9. Carefully open the valve to its full open position, as the boss on the gear hub moves to the open position it must engage the PCVS trip rod and actuate the switch(es). There should be a minimum overtravel or revolution of the crank or hand wheel after the switch(es) actuate (a continuity meter connected to each set of contacts is one method that could be used to determine this).

   NOTE: Slight adjustment of gear stops may be necessary to prevent overtravel of the trip rod (consultation with valve manufacture is recommended).
10. Carefully close the valve. The switch(es) must operate during the first two revolutions of the crank or hand wheel or during 1/5 of the travel distance of the valve control apparatus from its normal condition.
11. Complete the required electrical wiring, connections and tests. The valve should be operated through the entire cycle of fully closed and fully open to determine the integrity of the PCVS installation and signaling system.
12. Reinstall the cover and tighten the screws to 15 in-lbs minimum to properly seal the enclosure.
13. When the installation and testing are complete, return valve to its proper position.

Typical Pressure Reducer Type Valve Installation

Fig 7

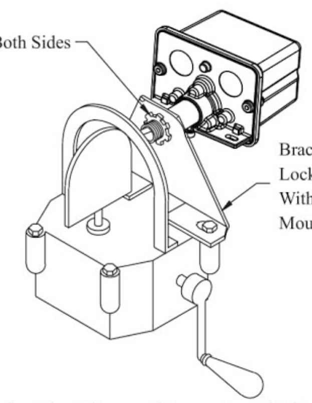


This figure shows the Model PCVS mounted on the valve yoke, with a bracket supplied by the valve manufacturer, to supervise a pressure reducer type valve.

NOTE: This application is subject to the approval of the authority having jurisdiction.

PBK - Butterfly Valve Kit for Valves with Internal Supervisory Switches

Fig 8



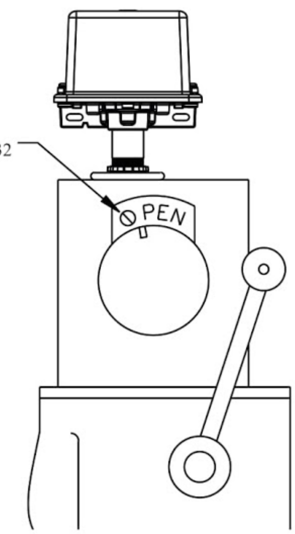
Pratt Butterfly Valve Kit as used to mount a PCVS on a Pratt Model IBV Valve.

Kits contain: Bracket, nuts and instructions

NOTE: Due to changes in valves, brackets may need to be modified by installer. This application is subject to the approval of the authority having jurisdiction.

PVK - Pratt PIVA Post Indicator Valve Kit

Fig 9

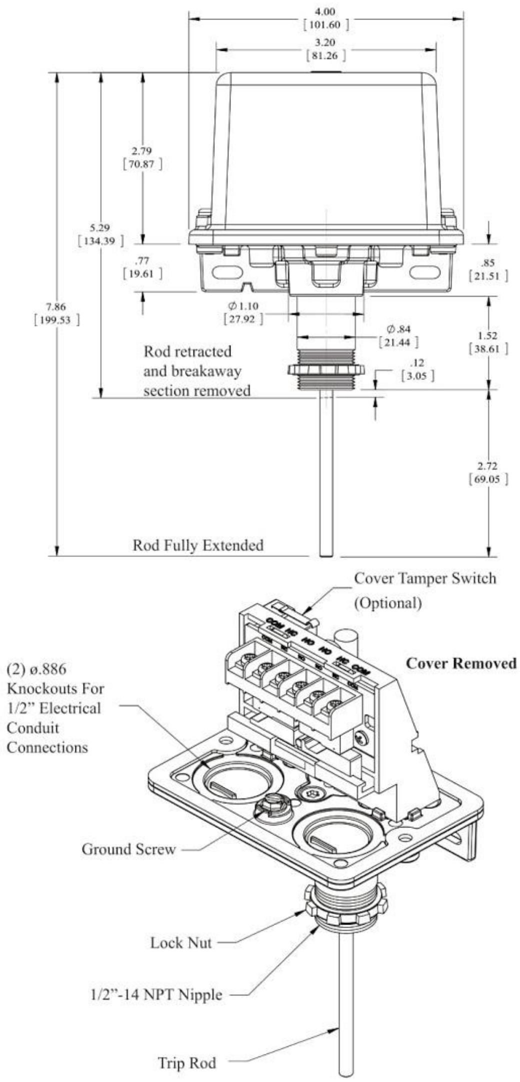


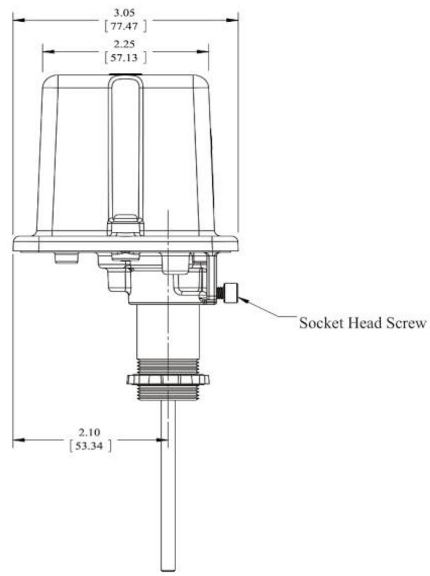
Pratt Valve Kit as used to mount a PCVS on a Pratt Model PIVA Valve.

Kit contains: Instructions, template, screw and nut.

NOTE: This application is subject to the approval of the authority having jurisdiction.

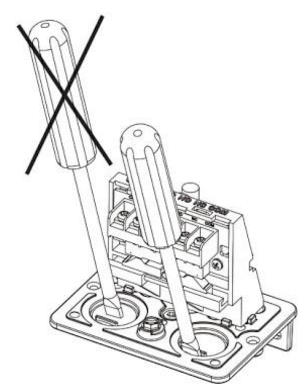
Dimensions
Fig 10





Knockout Removal
Fig 11

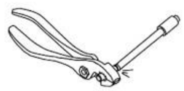
To remove knockouts: Place screwdriver at inside edge of knockouts, not in the center.



NOTE: Do not drill into the base as this creates metal shavings which can create electrical hazards and damage the device. Drilling voids the warranty.

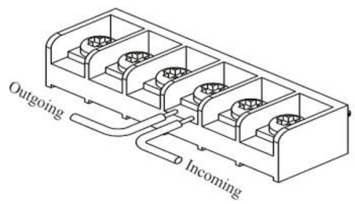
Breaking Excessive Rod Length

Fig 12



Switch Terminal Connections Clamping Plate Terminal

Fig 13



⚠ WARNING

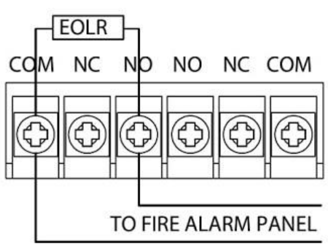
An uninsulated section of a single conductor should not be looped around the terminal and serve as two separate connections. The wire must be severed, thereby providing supervision of the connection in the event that the wire become dislodged from under the terminal. Failure to sever the wire may render the device inoperable risking severe property damage and loss of life. Do not strip wire beyond 3/8" of length or expose an uninsulated conductor beyond the edge of the terminal block. When using stranded wire, capture all strands under the clamping plate.

NOTICE

All conduit and connectors selected for the installation of this product shall be suitable for the environment for which it is to be used and shall be installed to the manufacturer's installation instructions. For NEMA 4, 4X, 6, 6P installations, the cover screws are recommended to be tightened to 15 in-lbs minimum and the trip rod locking screw tightened to 5 in-lbs minimum to properly seal the enclosure.

Typical Electrical Connections

Fig 14



Ordering Information

Model	Description	Stock No.
PCVS-2	Potter Control Valve Switch (double switch)	1010203
PCVS-2 CRH	Potter Control Valve Switch (double switch). Corrosion resistant 316 stainless steel hardware.	1010211
--	Cover Screw	5490424
--	Hex Key for Cover Screws and Installation Adjustments	5250062
PBK-S	Pratt Butterfly Valve Kit - 3" (75mm) to 12" (30mm)	0090133
PBK-M	Pratt Butterfly Valve Kit - 14" (355 mm) and 16" (406 mm)	0090146
PBK-L	Pratt Butterfly Valve Kit - 18" (457mm) to 24" (610 mm)	0090132
PVK	Pratt Valve Kit	1000060
--	Optional Cover Tamper Switch Kit	0090200
KBK	Kennedy Butterfly Valve Kit	0090143
TBK	Tycho Butterfly Valve Kit	0090150

For pressure reducer type valve installation kits (if required) contact valve manufacturer.

Engineering Specifications: Post Indicator & Butterfly Valves

UL, CUL Listed / FM Approved and CE Marked valve supervisory switches shall be furnished and installed on all post Indicator and Butterfly valves that can be used to shut off the flow of water to any portion of the fire sprinkler system, where indicated on the drawings and plans and as required by applicable local and national codes and standards. The supervisory switch shall be NEMA 4X and 6P rated and capable of being mounted in any position indoors or out and be completely submerged without allowing water to enter the enclosure. The enclosure shall be held captive by tamper resistant screws. The device shall contain two conduit entrances and two Single Pole Double Throw (SPDT) switches. The device shall contain a removable 1/2" NPT nipple and adjustable trip rod, the trip rod shall be held captive by a set screw accessible upon removal of the cover. The switch contacts shall be rated at 10A, 125/250VAC and 2A, 30VDC. Post Indicator and Butterfly Valve supervisory switch shall be model PCVS-2 manufactured by Potter Electric Signal Company LLC

NOTICE

Supervisory switches have a normal service life of 10-15 years. However, the service life may be significantly reduced by local environmental conditions.

Appendix D.12 - Water Level Switch

POTTER
The Symbol of Protection

WLS
Tank Water Level Switch

Features

- NEMA 4
- Suitable for use on pressure or gravity switches
- Mounts to wood or steel tanks
  NOTE: Wood tanks require optional buttress adapter
- Product includes a 5 year warranty

LISTED

Description

The Model WLS Water Level Switch is a float operated device for supervising water level in a sprinkler supply gravity or pressure tank.

The Model WLS has a bushing with 1 1/2" American Standard Pipe Threads for mounting in steel tanks. A 1 1/2" NPT x 2" NPT adapter bushing is available for mounting in existing 2" steel flanges. An optional bushing adapter with a buttress thread is available for mounting in wooden tanks.

The unit is capable of detecting the level of water before a 3" (7,6cm) rise and/or a 3" (7,6cm) fall in the water level in a pressure tank, as required for NFPA 72.

The cover is held in place with two tamper resistant screws (provided), which require a special key for removal.

Technical Specifications

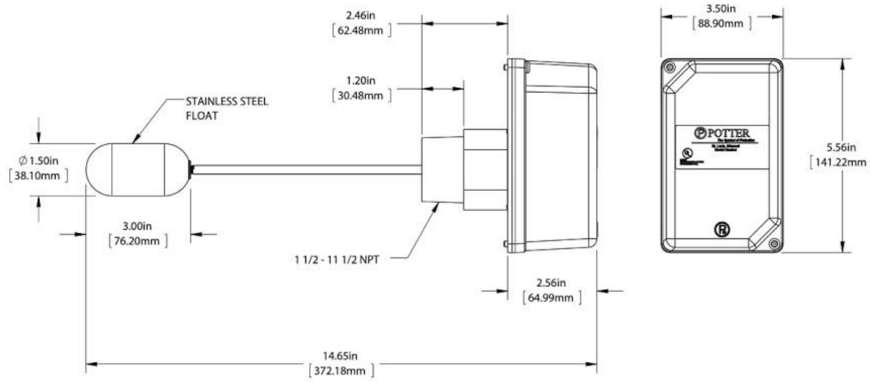
Dimensions	Housing - 5.56"H x 3.50"W x 2.56"D 14,1cm H x 8,9cm W x 6,5cm. See Fig. 1
Weight	3.25 lb / 1.47 Kg
Enclosure	Cover: Cast aluminum with red powder coat finish Base: Steel zinc plated
Applications	Steel or wood tanks (With the optional wood bushing adapter, Stock No. 5180199)
Contacts	Two sets SPDT (Form C) One set for high / One set for low Rated - 15.00 Amps at 125/250VAC 0.50 Amp at 125VDC 0.25 Amp at 250VDC
Detection Range	Before 3" (7,6cm) Rise /Before 3" (7,6cm) Fall
Environmental Specifications	• Suitable for indoor or outdoor use • Temperature range: 40°F to 140°F (4,5°C to 60°C) • NEMA 4 rated enclosure - when used with proper conduit fittings
Maximum Pressure	175 PSI (12,1 BAR)
Cover Tamper	Cover incorporates tamper resistant fasteners that requires a special key for removal. One key is supplied with each device

POTTER
The Symbol of Protection

WLS
Tank Water Level Switch

Dimensions

Fig 1



Installation Instructions

A buttress thread nut and gasket are available for use with devices on installations where the inside of the tank is accessible and it is not convenient to weld a flange on the tank. The nut and gasket can also be used in a wood tank that is not sound enough to hold a thread (see Fig. 2).

For installation in steel gravity tanks, weld a 1 1/2" NPT threaded flange (#6660225) 9" (23cm) below the required water level to receive the 1 1/2" bushing (see Fig. 3).

For wood gravity tanks, bore a 2 3/8" (60mm) hole in the center of a stave 9" (23cm) below the required water level and screw the buttress bushing adapter (#5180199) in place, allowing the bushing to cut its own thread, then install the WLS into the adapter (see Fig. 4).

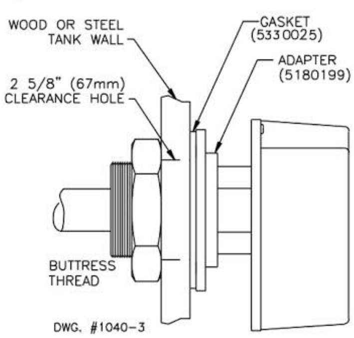
For pressure tanks, weld the 1 1/2" NPT threaded flange (#6660225) into the tank at the desired water level and use both high and low signals.

To replace an existing Potter WLS in a steel tank with a welded flange a 1 1/2" x 2" NPT bushing adapter (#5020126) is available. Thread the bushing adapter into the 2" welded flange securely then install the WLS into the adapter.

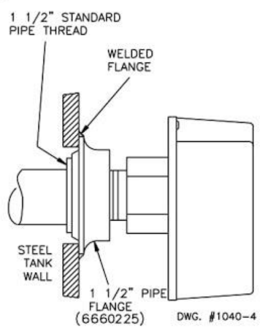
NOTE: The high signal is not required for gravity tanks and the WLS can be wired so that either High or Low or both switches may be used (see Fig. 5).

WARNING
Do not lift or hold device by float or float rod as bending may occur.

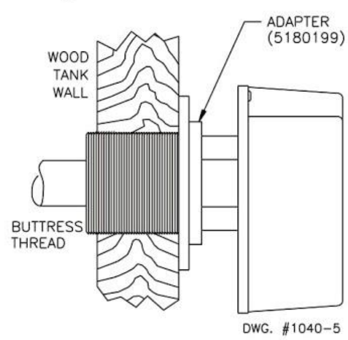
Wood or Steel Tank Installation
Fig 2



Steel Tank Installation
Fig 3

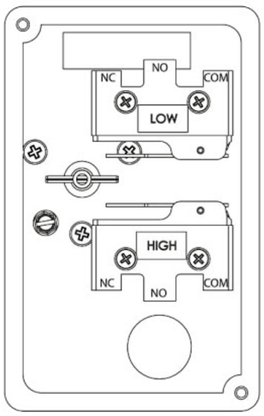


Wood Tank Installation
Fig 4



Orientation and Switch Placement

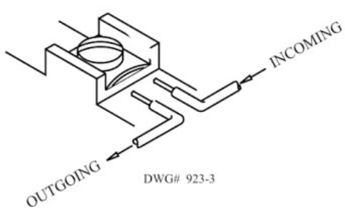
Fig 5



NOTE: Device must be oriented vertically with conduit entrance toward bottom of water tank.

Switch Plate Terminal Connections
Clamping Plate Terminal

Fig 6



⚠WARNING

An uninsulated section of a single conductor should not be looped around the terminal and serve as two separate connections. The wire must be severed, thereby providing supervision of the connection in the event that the wire becomes dislodged from under the terminal.

Ordering Information

Model	Description	Stock No.
WLS	Water Level Switch	1010117
1 1/2" Flange-Forged Steel		6660225
2 1/2" Buttress Nut-Bronze		6660083
Gasket-Neoprene		5330025
Buttress Adapter-Brass	1 1/2" NPT x 2 1/2"	5180199
Reducer Bushing Adapter-Brass	1 1/2" NPT x 2" NPT	5020126

Appendix D.13 - Water Temperature Switch

POTTER
The Symbol of Protection

TTS
TANK TEMPERATURE SUPERVISORY SWITCH

TTS-S

CUL, UL and CSFM Listed, FM Approved, and NYMEA Accepted
2 1/2" DIA x 17 1/2"L
(63,5mm DIA x 445mm L)

Ordering Information

Model Number	Stock Number
TTS-S (steel)	1010040
TTS-W (wood)	1010041
Accessories	
1" Flange	5020012
Buttress Nut	5020105
Gasket	5330035

The Model TTS is a water tank temperature supervisory switch preset to give a low temperature signal at 40°F/4,5°C and a high temperature signal at 140°F/60°C (±5°F/3°C). It is UL Listed and FM Approved.
A bi-metal thermostat is used for low temperature sensing and a bi-metal thermostat for high temperature sensing. A diode is used in this unit as a testing aid. When the polarity of DC current is reversed at the feed wires to a TTS, the diode in the circuit prevents the flow of current, proving the absence of a short circuit fault in the wiring or the device itself.

Testing

To test for a short or open in the TTS, connect an ohmmeter across the white and black TTS leads. With the meter connected positive to white and negative to black, the meter will read continuity (about 1 meg ohm). With the meter connected reverse polarity, the meter will read open. If using the diode tester setting on the meter, the meter will read .5 observing polarity and open with reverse polarity.
To test the thermostat, the device must be exposed to temperatures of 40°F and 140°F. The appropriate thermostat will open creating an open circuit regardless of polarity.

Wiring

The TTS is normally closed device that opens when the probe is exposed to the operating temperature of the thermostats. The device is polarity sensitive. The positive leg of the initiating device circuit must be connected to the white wire lead. The negative leg of the initiating device circuit must be connected to the black wire lead.
If the TTS is the last or only device on the initiating circuit, the EOLR must be wired in series with the TTS. It can be wired in series with either the black or white wire.

Contacts: .15 Amp at 115 VDC

The TTS, tank temperature switch is supplied with a one inch pipe thread for steel tanks (Model TTS-S) or with a buttress thread for wood tanks (Model TTS-W).

A buttress thread nut and gasket are available for use with the TTS-W for installations where the inside of the tank is accessible and it is not convenient to weld a flange on the tank.

The nut and gasket can also be used on a wood tank, which is not sound enough to hold a thread (see Fig. 1). Locate the switch at a point 24" (60cm) below the required water level of the tank.

For steel tanks, weld in a No. 282-1 pipe flange or drill and tap tank to receive the one inch pipe thread of the bushing (see Fig. 2).

For wood tanks, drill a 1 3/16" (30mm) hole in the center of a stave and thread the bushing into the tank allowing the buttress bushing to cut its own thread (see Fig. 3).

Installation

Fig. 1 TTS-W (Wood or Steel)

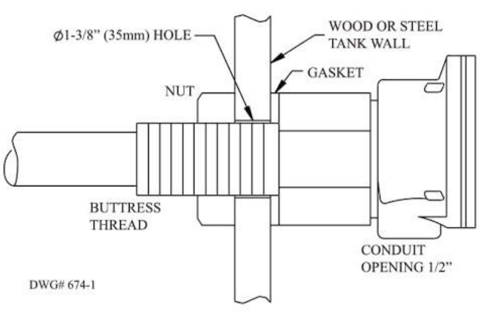
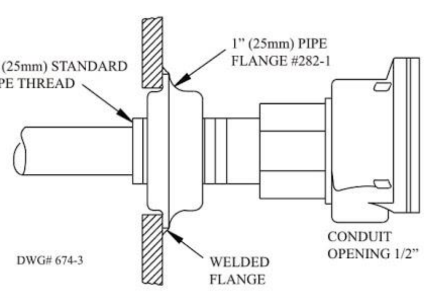


Fig. 2 TTS-S (Steel)



POTTER
The Symbol of Protection

TTS
TANK TEMPERATURE SUPERVISORY SWITCH

Fig. 3 TTS-W (Wood)

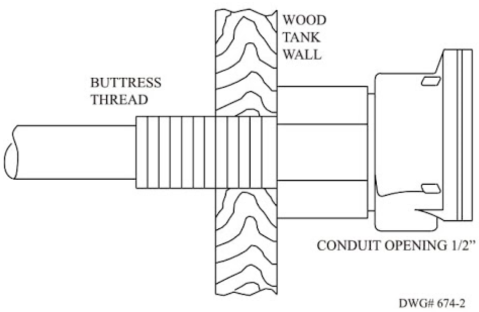
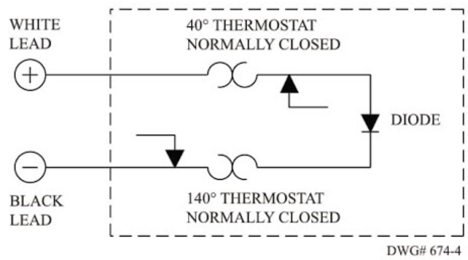
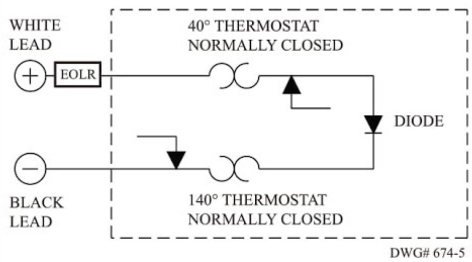


Fig. 4 TTS-S Simplified Schematic



Important: Observe lead polarity for use in normally closed circuit.



Important: Observe lead polarity for use in normally open circuit.

Appendix D.14 - Pressure Switch

POTTER
The Symbol of Protection

PS120 SERIES
SUPERVISORY PRESSURE SWITCH

UL, cUL, and CSFM Listed, FM and LPC Approved, NYMEA Accepted, CE Marked

Dimensions: 3.78" (9.6cm)W x 3.20" (8.1cm)D x 4.22" (10.7cm)H

Conduit Entrance: Two knockouts provided for 1/2" conduit. Individual switch compartments and ground screw suitable for dissimilar voltages

Enclosure: Cover- Die-cast with textured red powdercoat finish, single cover screw and rain lip.
Base- Die-cast

Pressure Connection: Nylon 1/2" NPT male

Factory Adjustment: PS120-1 operates on decrease at 110 PSI (7,6 BAR)
PS120-2 operates in increase at 130 PSI (9 BAR) and on decrease at 110 PSI (7,6 BAR)

Pressure Range: 25-175 PSI (1,7 - 12,1 BAR)

Differential: Typical 2 lbs. at 25 PSI (0,14 at 1,7 BAR)
8 lbs at 175 PSI (55 at 12,1 BAR)

Maximum System Pressure: 300 PSI (20,68 BAR)

Switch Contacts: SPDT (Form C)
10.1 Amps at 125/250VAC, 2.0 Amps at 30VDC
One SPDT in PS120-1, Two SPDT in PS120-2

Environmental Specifications:
NEMA 4/IP66 Rated Enclosure - indoor or outdoor when used with NEMA 4 conduit fittings.
Temperature range: -40°F to 140°F (-40°C to 60°C)

Tamper: Cover incorporates tamper resistant fastener that requires a special key for removal. One key is supplied with each device. For optional cover tamper switch kit, order Stock No. 0090200. See bulletin #5401200 PSCTSK.

Ordering Information

Model	Description	Stock No.
PS120-1	Pressure switch with one set SPDT contacts	1341203
PS120-2	Pressure switch with two sets SPDT contacts	1341204
	Hex Key	5250062
	Cover Tamper Switch Kit	0090200
BVL	Bleeder valve	1000018

Service Use:

Automatic Sprinkler	NFPA-13
One or two family dwelling	NFPA-13D
Residential Occupancy up to four stories	NFPA-13R
National Fire Alarm Code	NFPA-72

Installation

The Potter PS120 Series Supervisory Pressure Actuated Switches are designed primarily to detect an increase and/or decrease from normal system pressure in automatic fire sprinkler systems. Typical applications are: Wet pipe systems with excess pressure, pressure tanks, air supplies, and water supplies. The PS120 switch is factory set for 120 PSI (8,3 BAR) normal system pressure. The switch marked with the word LOW is set to operate at a pressure decrease of 10 PSI (0,7 BAR) at 110 PSI (7,6 BAR). The switch marked with the word HIGH is set to operate at a pressure increase of 10 PSI (0,7 BAR) at 130 PSI (9 BAR). See section heading **Adjustments and Testing** if other than factory set point is required.

1. Connect the PS120 to the system side of any shutoff or check valve.
2. Apply Teflon tape to the threaded male connection on the device. (Do not use pipe dope)
3. Device should be mounted in the upright position. (Threaded connection down)
4. Tighten the device using a wrench on the flats on the device.

Wiring Instructions

1. Remove the tamper resistant screw with the special key provided.
2. Carefully place a screwdriver on the edge of the knockout and sharply apply a force sufficient to dislodge the knockout plug. See Fig. 9
3. Run wires through an approved conduit connector and affix the connector to the device. A NEMA-4 rated conduit fitting is required for outdoor use.
4. Connect the wires to the appropriate terminal connections for the service intended. See Figures 2,4,5,6, and 8. See Fig. 7 for two switch one conduit wiring.

Adjustment And Testing

The operation of the pressure supervisory switch should be tested upon completion of installation and periodically thereafter in accordance with the applicable NFPA codes and standards and/or the authority having jurisdiction (manufacturer recommends quarterly or more frequently).
Note: Testing the PS120 may activate other system connected devices.
The use of a Potter BVL (see product bulletin 8900067 for details) is recommended to facilitate setting and testing of the PS120 pressure switch. When a BVL (bleeder valve) is used, the pressure to the switch can be isolated and bled from the exhaust port on the BVL without effecting the supervisory pressure of the entire system. See Fig. 3
The operation point of the PS120 Pressure Switch can be adjusted to any point between 25 and 175 PSI (1,7 - 12,1 BAR) by turning the adjustment knob(s) clockwise to raise the actuation point and counter clockwise to lower the actuation point. In the case of the PS120-2, both switches operate independent of each other. Each switch may be independently adjusted to actuate at any point acrosss the switch adjustment range. Initial adjustment can be made with a visual reference from the top of the adjustment knob across to the printed scale on the switch bracket. Final adjustments should be verified with a pressure gauge.

POTTER
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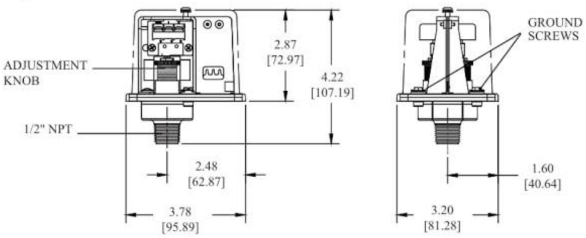
PS120 SERIES
SUPERVISORY PRESSURE SWITCH

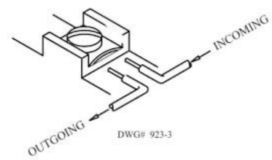
Dimensions
Fig. 1



NOTE: To prevent leakage, apply Teflon tape sealant to male threads only.

DWG# 930-1

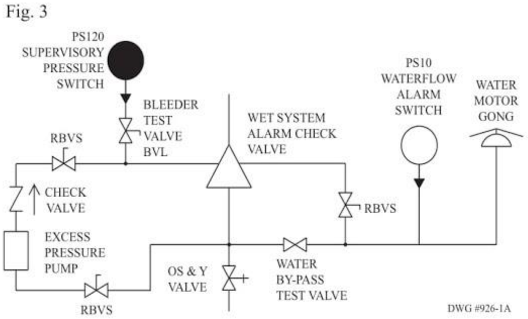
Switch Clamping Plate Terminal
Fig. 2



⚠WARNING

An uninsulated section of a single conductor should not be looped around the terminal and serve as two separate connections. The wire must be severed, thereby providing supervision of the connection in the event that the wire becomes dislodged from under the terminal.

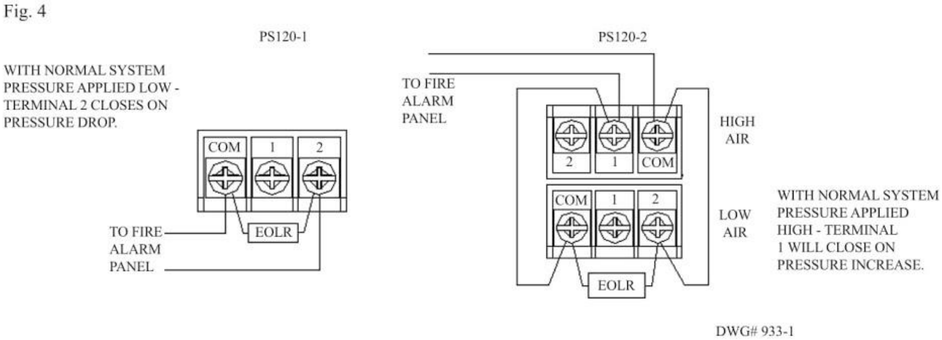
Typical Sprinkler Applications
Fig. 3



⚠ CAUTION

Closing of any shutoff valves between the alarm check valve and the PS10 will render the PS10 inoperative. To comply with IBC, IFC, and NFPA-13, any such valve shall be electrically supervised with a supervisory switch such as Potter Model RBVS.

Typical Connections
Fig. 4

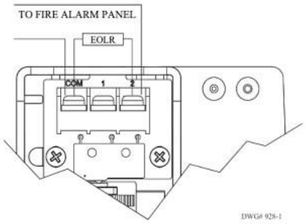


DWG# 933-1

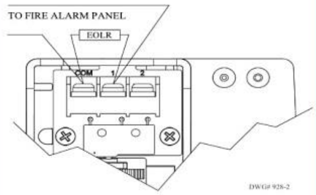
POTTER
The Symbol of Protection

PS120 SERIES
SUPERVISORY PRESSURE SWITCH

Low Pressure Signal Connection
Fig. 5

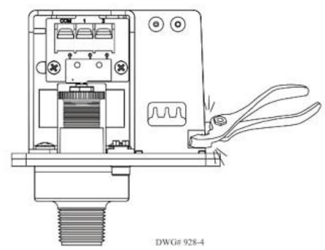


High Pressure Signal Connection
Fig. 6

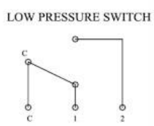


One Conduit Wiring
Fig. 7

Break out thin section of divider to provide path for wires when wiring both switches from one conduit entrance.

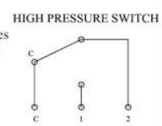


Changing Pressure
(With normal system pressure)
Fig. 8



Terminal #1: Closed under normal system pressure.

Terminal #2: Open under normal system pressure, closes on pressure drop. Use for low pressure signal.

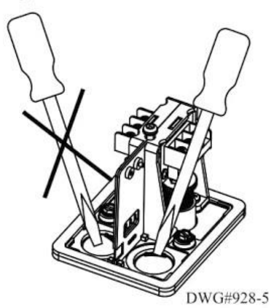


Terminal #1: Open under normal system pressure, closes on pressure increase. Use for high pressure signal.

Terminal #2: Closed under normal system pressure.

DWG# 930-3

Removing Knockouts
Fig. 9



DWG#928-5

Engineer/Architect Specifications Pressure Type Waterflow Switch

Pressure type supervisory switches; shall be a Model PS120 as manufactured by Potter Electric Signal Company, St. Louis, MO., and shall be installed on the fire sprinkler system as shown and or specified herein.

Switches shall be provided with a ½" NPT male pressure connection to be connected into the air supply line on the system side of any shut-off valve.

A Model BVL bleeder valve as supplied by Potter Electric Signal Company of St. Louis, MO., or equivalent shall be connected in line with the PS120 to provide a means of testing the operation of the supervisory switch. (See Fig. 3)

The switch unit shall contain SPDT (Form C) switch(es). One switch shall be set to operate at a pressure decrease of 10 PSI (0,7 BAR) from normal. If two switches are provided, the second switch shall be set to operate at a pressure increase of 10 PSI (0,7 BAR) from normal.

Switch contact shall be rated at 10.1 Amps at 125/250VAC and 2.0 Amps at 30VDC. The units shall have a maximum pressure rating of 300 PSI (20,68 BAR) and shall be adjustable from 25 to 175 PSI (1,7 to 12,1 BAR).

⚠ WARNING

- Installation must be performed by qualified personnel and in accordance with all national and local codes and ordinances.
- Shock hazard. Disconnect power source before servicing. Serious injury or death could result.
- Read all instructions carefully and understand them before starting installation. Save instructions for future use. Failure to read and understand instructions could result in improper operation of device resulting in serious injury or death.
- Risk of explosion. Not for use is hazardous locations. Serious injury or death could result.

⚠ CAUTION

- Do not tighten by grasping the switch enclosure. Use wrenching flats on the bushing only. Failure to install properly could damage the switch and cause improper operation resulting in damage to equipment and property.
- To seal threads, apply Teflon tape to male threads only. Using joint compounds or cement can obstruct the pressure port inlet and result in improper device operation and damage to equipment.
- Do not over tighten the device, standard piping practices apply.
- Do not apply any lubricant to any component of the pressure switch.

Appendix D.15 - Conduit

NFP Standard

NFP U-PVC Conduits according to NEMA TC - 2 (EPC 40 and EPC 80)

Nominal Pipe Size (inch)	Average Outside Diameter (mm)	EPC 40		EPC 80	
		Minimum Wall thickness (mm)	Nominal Weight (kg / m)	Minimum Wall thickness (mm)	Nominal Weight (kg / m)
1/2"	21.34	2.77	0.248	3.73	0.309
3/4"	26.67	2.87	0.329	3.91	0.418
1"	33.40	3.38	0.483	4.55	0.614
1 1/4"	42.16	3.56	0.652	4.85	0.850
1 1/2"	48.26	3.68	0.779	5.08	1.030
2"	60.32	3.91	1.040	5.54	1.430
2 1/2"	73.02	5.16	1.650	7.01	2.180
3"	88.90	5.49	2.160	7.62	2.900
4"	114.30	6.02	3.070	8.56	4.260
6"	168.28	7.11	5.41	10.97	8.130
8"	219.07	8.18	8.143	12.70	12.400

Note:
EPC 40 - Electrical Plastic Conduit for normal duty applications
EPC 80 - Electrical Plastic Conduit for heavy duty applications
The Standard Length of pipe is 3 m or 6 m

Appendix D.16 - ICAF Cabinet Assembly

FIREFLEX Systems Inc.
ADVANCED INTEGRATED FIRE PROTECTION SYSTEMS

Datasheet
Cabinet

Assembly with NFS-320 Control Panel

FM APPROVED

CE

Assembly with ARC-1 Control Panel

Description

The ICAF unit cabinet is made of sturdy 14 gauge steel, measuring 35¾" x 25" x 77" (908 x 635 x 1956 mm) or 46" x 25" x 77" (1168 x 635 x 1956 mm) depending on the configuration provided. Refer to table 1 and figure 1 for dimensions.

All surfaces are rust proof coated, inside and outside, with fire red, oven baked polyester powder on phosphate base. Cabinet is provided with two access doors to the hydraulic and electrical sections; one door is combined with the emergency release. A neoprene gasket between doors and cabinet allows to avoid vibrations.

Electrical junction boxes are integrated with the cabinet for connection of detection system, auxiliary contacts and signaling devices. Knockouts can be drilled by the installing contractor on-site but have to meet the restrictions indicated on figure 4.

Gauges to indicate air, water supply pressure and priming water pressure are all visible through clear Lexan windows.

IMPORTANT ! ICAF units are NOT designed to be installed where they will be subjected to outdoors and/or freezing conditions. Refer to ENVIRONMENTAL DATA for additional details. Subjecting the unit to conditions outside these limitations might hamper the normal operation of the system.

Cabinet doors are provided with hinges that can easily be disassembled on site to remove the door assemblies for servicing. The cabinet assembly is pre-assembled, pre-wired, and factory tested under ISO-9001 conditions.

Note: Once the left door opened, the control panel can be unlatched then rotated to give complete access to the mechanical section of the ICAF system and to the electrical junction box.

Table 1 – Cabinet dimensions (refer to figures 1 and 2)

Model	A	B	C	D	E	F	G
36"	35¾ (908)	25 (635)	77 (1956)	39¾ (1010)	15 (381)	37¾ (959)	12¾ (324)
46"	46 (1168)	25 (635)	77 (1956)	50 (1270)	15 (381)	48 (1219)	23 (584)

Dimensions are in inches (mm).

Figure 1 – Cabinet Dimensions

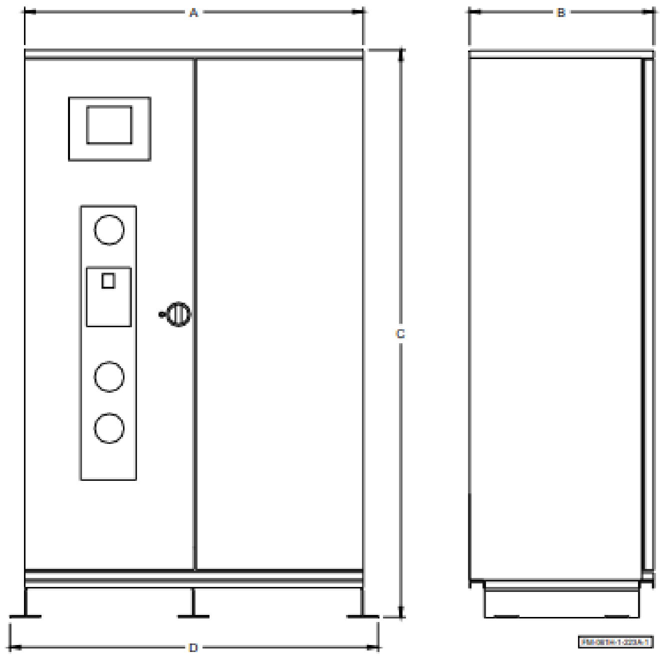


Figure 2 - Floor anchoring template

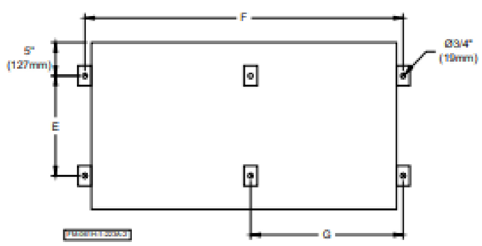
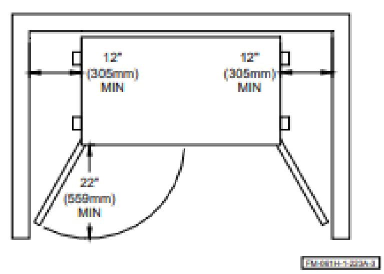


Figure 3 - Cabinet clearance



Note: Drain pipe shall be connected to an open drain.

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