Long-Term Fire Retardants: History, Innovation and Preparing for the Future of Wildfires

A Whitepaper by Perimeter Solutions

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PURPOSE STATEMENT

Long-term fire retardants were introduced 60 years ago. They have continued to evolve alongside wildland firefighting concepts and techniques adopted by the USDA Forest Service (USFS) and other fire management organizations. The purpose of this whitepaper is to track the evolution of fire retardant technology and to provide context on innovations that have been made, why they were made, and the impact the decisions to introduce those advancements will have on current and future wildland firefighting efforts.

Recent wildfire seasons have been historically intense and devastating. Many reasons are cited for the increased severity, including climate change, a greater portion of the population occupying the wildland-urban interface (WUI), a history of suboptimal fire management practices, along with a multitude of other causes. The truth is that all these variables have made an impact. As the effects of climate change intensify and homes continue to be built in high-risk areas, agencies and fire officials will need access to better tools to help their efforts to protect homes, property and critical infrastructure against the spread of wildfires.

Today, long-term fire retardants are helping firefighters prevent the spread of wildfires. There has been excellent work in understanding the composition of these long-term fire retardants in terms of firefighting effectiveness and environmental impact. As we look ahead to how we can be better in all aspects of wildland firefighting, we should reflect on how we arrived at where we are today. It is important to determine how past firefighting philosophies, technological advancements, major fire events and the people's lives they impacted have influenced wildfire management to understand what we need to do to ensure future success with prevention, protection and suppression efforts.

Perimeter Solutions and its predecessor companies, working alongside fire agencies and on the ground with the men and women who fight these fires, has been at the forefront of long-term fire retardant technology development over the last 60 years. As the business that has introduced most of the critical technology advances with long-term fire retardants, the history of this technology is inextricably intertwined with our own.

TABLE OF CONTENTS

The Evolution of Firefighting

Wildfires outdate humans, with the first evidence of wildfires dating back more than 420 million years ago in what is known as the Silurian period.[1] It would take more than 400 million years before people would even understand how to control fire[2] and then, predictably, ignite unintended blazes. Without a strategy or the means to contain these early fires, they would be free to burn and would shape the landscape for future generations.

In what would later become the United States, Native Americans adopted a practical approach to dealing with wildfires. They understood that fires were part of nature, and that fire brings inherent benefits to the ecosystem, including soil nourishment, consumption of organic matter, and reduced competition for light, moisture and nutrients. Indigenous people also practiced cultural burning (referred to today as prescribed burns) to promote healthy vegetation.[3]

Large Fires Promote Changes in Fire Philosophy

While indigenous communities embraced fire as an ally in preserving nature, once populations began to grow across the U.S., wildfires started to trigger unprecedented destruction of property and sometimes resulted in massive death tolls. Greater impact on people's lives led to government intervention and changes to how wildfires were addressed.

One of the first turning points for firefighting philosophies in the U.S. happened in October of 1871, the year of the Great Chicago Fire. Six years removed from the Civil War, the Fire destroyed more than 17,000 buildings across the Windy City, upended thousands of lives and devastated their thriving business community, which did not fully recover until the World's Fair came to Chicago in 1893.

The Great Chicago Fire left an indelible mark on the city, and much of its lasting impact came from the introduction of more sensible building codes. However, another fire broke out the same day as the Chicago Fire that few people ever discuss. It was much larger than the Chicago Fire, was more deadly and had a more significant influence on the federal government and its role in fire management.

The Peshtigo Fire broke out on the morning of October 8, 1871. It burned for three days, and while estimates vary, the consensus is that it killed more than 1,200 people – and is still the deadliest wildfire in American history.[4]

In addition to the number of people killed, the fire burned more than 1.2 million acres of land and spread to nearby towns, where it caused even more damage. The entire town of Peshtigo was destroyed within an hour of the start of the fire.[5]

News of the historical destruction spread slowly. People soon realized that in addition to the Great Chicago Fire and the Peshtigo Fire, another fire in Michigan that occurred at the same time burned more than two million acres.

The Government Gets Involved

Up to this time, the federal government did not have a strategy for dealing with wildfires of this magnitude. That is because they were typically in unpopulated areas and did not cause the devastation they witnessed in the fall of 1871. Charcoal evidence shows that between 1 A.D. and 1750, there was a general decrease in wildfires in the Americas, but that frequency increased until 1870[6]. As a result of the 1871 fire breakouts, the federal government saw that it needed to act. This led in 1876 to the creation of the Office of Special Agent in the U.S. Department of Agriculture to assess the quality and conditions of forests in the United States.[7] As the forerunner of the U.S. Forest Service, this was the first time that wildfire management was placed under government purview.

The government named Frank Hough to fill the role of Special Agent and the first Chief of the Division of Forestry. Known as the "Father of American Forestry," Hough had presented a highly influential paper on forestry in 1873.

Hough was an experienced census taker before he drafted his paper, *On the Duty of Governments in the Preservation of Forests,* having led census activities in 1855, 1865 and 1870.[8] During those years, he noticed that there was an alarming decline in the availability of timber. He argued that Mediterranean countries had harmed the environment by excessive harvesting of trees and that a similar problem faced the United States. As a result, he proposed that the federal government start regulating the use of the nation's forests and establish forestry schools to develop caretakers for our woodlands.

Hough's paper led to the development of a committee that he chaired, which was tasked with educating Congress and state legislatures on the dangers of deforestation.[9] In his Special Agent role, Hough began publishing his biennial *Report Upon Forestry,* which included details on forest ecology, tree planting, forest inventories, tree diseases, connections between forests and climates, wood usage, along with info on timber and other industries.[10] Hough's efforts helped to establish forestry work in the country and prompted government action in forest management at both the state and federal level.[11]

Succeeding Hough as the head of the USDA's Division of Forestry was Bernhard Fernow, known as the Father of Professional Forestry in the United States.[12] When Fernow assumed the Division of Forestry role, his goal was to establish a national forest system and introduce scientific forest management.[13] To that end, he created displays to present at the Chicago World's Fair that helped generate public support for establishing a national forest service and a system for educating professional foresters. The curriculum set up for the program taught at Cornell University served as the model for professional forestry programs in North America.[14] He also played a leading role in establishing the Forest Reserve Act of 1891, which gave the President the authority to unilaterally set aside forest reserves from land in the public domain,[15] liberally employed by President Theodore Roosevelt. In addition, Fernow launched the *Journal of Forestry* during his time at Cornell, which is still in publication today.

Fernow's efforts helped pave the way for the establishment of the U.S. Forest Service in 1905. Gifford Pinchot became the first Chief of the Service. He quickly moved to restructure the management of the national forests, increasing their area and number.[16] He also guided the Service toward a new philosophy, which realized that all decisions made by the Service had long-term implications. With the management strategies developed by Hough, Fernow, and Pinchot, the U.S. Forest system had made great strides from the time of the Peshtigo Fire. Nevertheless, in 1910 nature showed again that it is always in charge.

Suppression Takes Over

The Big Blow Up was a series of fires that broke out through Idaho, Montana, and Washington in late August of 1910.[17]

Drought conditions plagued the western portion of the United States that summer, and the Forest Service was reeling from the continued battering of fires in the region.

On August 20, hurricane-force winds invaded the West. Even tiny embers were easily carried for great distances to start new fires across the Northern Rockies. At this point, there was no hope of stopping or even containing the fires. Like with the Peshtigo Fire, entire towns were destroyed – facing flames more than a hundred feet high.[18]

When The Big Blow Up was all over, it is estimated that a total of 1,736 different fires burned more than three million acres of land, and at least 85 people perished. Smoke from the fires reached New England, and soot traveled as far as Greenland.[19]

The Big Blow Up's impact on fire control measures in the United States was far reaching and is still being felt to this day. The Forest Service had instituted a policy of extinguishing all fires as quickly as possible in 1908. That strategy was called into question, but Fire Chief Henry Graves, the second Chief Forester for the USFS, doubled down following the Big Blow Up, calling for a more aggressive fire prevention policy. Working with state agencies and private associations, he launched a campaign to remove fire from the landscape. His efforts would lead to the creation of the Weeks Act, which called for cooperation among federal, state, and private agencies to address fire protection. The Weeks Act has been credited with saving nearly 20 million acres of forestland by one historian.[20] Graves' efforts ultimately resulted in the launch of the Smokey the Bear campaign in 1944, and the Forest Service's efforts (as well as the efforts of partnering organizations) to extinguish every wildfire at all costs would dramatically change forest ecology throughout the country.[21]

The aggressive fire suppression policy reached its zenith in 1935 with the 10:00 am policy, which mandated that any fire spotted on a given day was required to be controlled by 10:00 am the following morning. However, these strong measures to suppress fires resulted in dried-out fuels that were allowed to accumulate and led to less diverse forests. Combined with the impacts of climate change, this resulted in far more intense and aggressive fires, which is well understood by fire ecologists and forest managers today.

Changes to the suppression policy took a long time, as the antiquated ideas around suppression were hard to change. But, in the 1960s, people started realizing that no new giant sequoias—in which fire is essential to their lifecycle—were growing in California forests.[22] By this time, the U.S. Fish and Wildlife Service had already realized that total fire suppression was an ineffective forest management strategy. The Secretary of the Interior, Stewart Udall, named a Special Advisory Board on Wildlife Management to investigate wildlife management problems in the national parks.[23] The Board was led by zoologist Aldo Starker Leopold, who broadened his research beyond wildlife and made a recommendation on the entire ecological system of America's parks in what became known as The Leopold Report.

The Leopold Report directly addressed fire and how it could be beneficial to our ecosystem, saying that fire's removal was a problem, and that fire should be used as a tool to improve America's forests. He also suggested the use of controlled burning. This led in the early 1970s to a change in Forest Service policy—to let fires burn when and where appropriate. It began with allowing natural-caused fires to burn in designated wilderness areas. From this, the 'let-burn' policy evolved.[24]

In addition to a changing philosophy from suppression to letting fires burn when appropriate, the 1970s also brought increased partnership among organizations to address fires. On September 26, 1970, the Laguna Fire started to burn in California, and a week later, it had destroyed 175,000 acres, 1,400 structures and caused an estimated $80 million in damages.[25] The destruction from the fire led to the development of Firescope, a system to coordinate interagency resources to address emergencies, including wildfires. This effort led to the development of the Incident Command System (ICS), which has been adopted by every emergency services organization in the U.S. through a Presidential directive.

The Laguna Fire was just a sign of more challenges to come as people and businesses began to populate greater areas of what became defined as the wildland-urban interface (WUI) – something that would put the new "let-burn" policy adopted by fire management organizations to the test.

The Growth of the Wildland Urban Interface

When it is said someone's house or business is in the WUI, it means that they are in the area of transition between wildland vegetation and human development – an area that is interfering with the natural growth of the wildlands and is in the danger zone for wildfires. According to the U.S. Fire Administration, more than 46 million residences across 70,000 communities were at risk for WUI fires in 2020. In the US, WUI areas grow by approximately two million acres every year, and between 2002 and 2016, an average of more than 3,000 structures per year was lost to fires.[26] Moreover, the National Academy of Sciences of the United States of America says that from 1990 to 2010, the WUI was the fastest-growing land-use type in the contiguous United States.[27]

With an increasing number of structures in the path of wildfires, firefighters and fire suppression agencies do not have the luxury of letting fires burn naturally. Instead, these fires must be contained and extinguished to avoid the incredible devastation they can cause in populated areas. This is becoming increasingly challenging as climate change and other contributing factors have extended the wildfire season dramatically over the past 30 to 40 years.

A Huge and Growing Issue

With each passing year, the wildfires of the Western USA, Australia and other regions become bigger news because of global, 24/7 news coverage. The problem with wildfires, however, is even larger and more complex than these news reports suggest. Here are some relevant statistics for Federal lands in the United States:

- **Federal USA fire suppression efforts averaged $1.6 billion/year (2000-2020)[28]**
- **The cost of all 2018 California wildfires to the USA economy was over $148.5 billion[29]**
- **In 2018, nearly 25,000 structures were destroyed by wildfire in the USA[30]**
- **In the 2020 fire season, the USA suffered over $16.5 billion in property damage[31]**
- **In 2020, over 10 million acres of land were burned in the USA[32]**
- **One in 7 Americans were exposed to at least one day of unhealthy and hazardous air quality due to wildfires in 2020[33]**
- **In 2020, 112 million metric tons of CO_2 were released by wildfires occurring in California[34]**
- **Global wildfires created more than 6.45 billion tons of CO_2 emissions in 2021[35]**

Wildfires are more than just a threat to property and lives in the regions they hit. They are a threat to human health, our economic well-being and the future of our planet.

Aerial Attack and Development of Long-Term Fire Retardant

All of these facts underscore the need for technologically sophisticated answers to fighting wildfires. Today, aerial and ground attack are the two most commonly used strategies. To understand how long-term retardant technology developed, we can look back to the beginning of modern firefighting. Modern firefighting via aerial attack was first attempted in the 1920s.[36] Containers of water were literally dropped from planes on active wildfires, but this practice presented dangers to firefighters on the ground, and it was also determined to be ineffective.[37]

Despite its challenges, fire management organizations saw promise in aerial firefighting and started more sophisticated attempts in the 1940s.[38] These efforts were rudimentary, as small planes were used with water serving as the extinguishing agent. The use of water was found to be inefficient and made accurate application virtually impossible. Chemicals were added that would thicken the water to improve its stability and effectiveness in dousing flames. By the 1950s, agencies started using air tankers with installed tanks to drop solutions with hydrating clays such as bentonite and borate and then onto gum-thickened waters, similar to gels used today.[39]

Understanding Wildland Firefighting Chemistry

Wildland Firefighting chemistry is at once very simple and particularly challenging in practice. The four ways that chemicals can help suppress wildfire are:

1) By quenching the flame upon application
2) By preventing or slowing down ignition
3) By reducing the intensity of burn
4) By rendering the fuel inflammable through a chemical chain reaction

Basic Firefighting

Water is the most universally used suppressant worldwide.[40] While water is highly efficient at suppressing fires, chemical additives have been developed to make water more efficient and enhance performance (Figure 1). In modern wildland firefighting, water plays an important role when used as a complementary tool with fire retardant. This is because on its own, shear, heat and wind cause the evaporation of water in the air. In addition, wind causes drift and decreased drop accuracy. As a result, water has potentially very low recovery under fire conditions because it evaporates or drifts away before it hits the ground.

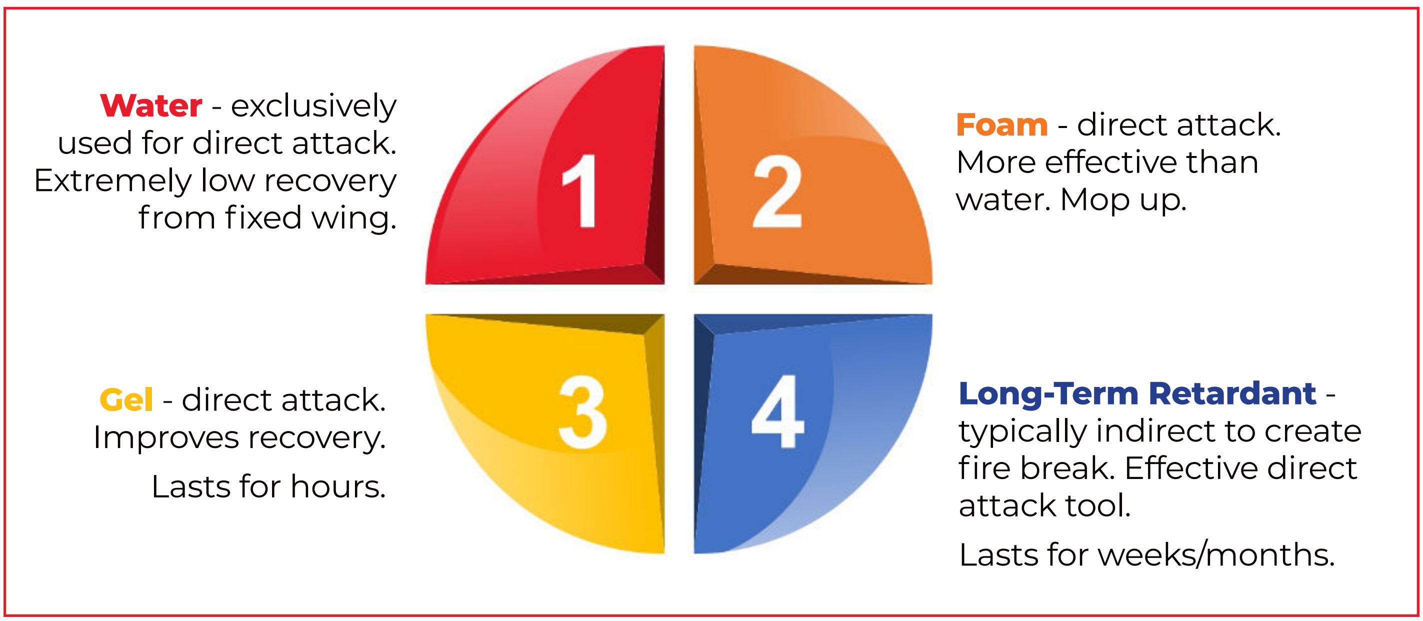

Figure 1: Approaches to Wildfire Control[41]

Various approaches have been developed to improve the effectiveness of water in wildfire suppression, including enhancing the viscosity of water through the use of various additives.

Firefighting foam (Class A) is used as a water enhancer to increase water penetration into the fuel and slow evaporation. While used for parallel attack, foam is mainly used as a direct attack method in hotspots or mop-up activities. Foams rely solely on the water it contains to be effective, and when the water is evaporated, which can take minutes to hours, it no longer provides protection. In deep fuel fires, foams are helpful as they penetrate the fire and provide deep-seated extinguishment. However, used from the air, the recovery rate of foams is very low.[42]

Similarly, gels were developed to enhance the effectiveness of water in direct attack operations. Gels are also used in parallel attack, but with the same reliance on water as foam, their length of effectiveness is short. Its adherence qualities make gel suitable for structure protection when it is only needed for minutes to a couple of hours.

Long-term retardants chemically render fuel non-flammable – a chemical reaction that does not rely on water for effectiveness. Though water is incorporated with long-term retardants, it functions merely as a tool to get the retardant to the fuel. Once the retardant is on the fuel, the water evaporates, leaving the retardant to function. Long-term retardant is used to create a fire break – but is also effective as a direct attack tool. Since retardant does not rely on the water it contains, it can last weeks to months, or until washed away by rain. Suppressants (foam and gels) rely on water they contain, and therefore are only effective as long as water is present. As a result, long-term fire retardants have become the dominant technology in fighting wildfires today.

Table 1 shows how these different firefighting product types align with different types of applications.

Table 1: Application Potential for Various Firefighting Product Types

APPLICATION	RETARDANT	GEL	CLASS A FOAM	WATER
Indirect Attack	✔✔✔✔	✔✔	✔	
Direct/Parallel Attack	✔✔✔✔	✔✔✔	✔✔	✔
Interior Structure Attack		✔✔	✔✔✔✔	✔
Structure Protection: -Indirect Application	✔✔✔✔	✔✔✔	✔✔	✔
Structure Protection: -Direct Application		✔✔✔✔	✔✔✔	✔
Mop Up	✔✔	✔✔	✔✔✔✔	✔
Prescribed Burn Control	✔✔✔✔	✔✔✔	✔✔	✔

✔✔✔✔ = **Superior Effectiveness** ✔✔✔ = **Excellent Effectiveness** ✔✔ = **Good Effectiveness** ✔ = **Baseline Effectiveness**

In 1958, Clinton Phillips and Henry Miller with the US Forest Service listed the ideal characteristics that a compound should have to be used as a retardant[43] - in addition to being effective, a retardant should:

1. Be reasonably inexpensive
2. Mix into suspension or solution easily
3. Remain in suspension over a long period
4. Not be toxic to plants or animals
5. Not be corrosive or abrasive to materials used in equipment
6. Adhere well to any type of vegetation
7. Not crack and crumble under extreme drying conditions
8. Not increase specific gravity excessively
9. Require a small amount of material per gallon of water to give a good slurry, thus minimizing transportation storage and handling costs
10. Easily be removed from any surface by washing with water
11. Readily be available in large quantities in many areas
12. Not be a desiccant to vegetation

How Fire Retardants Help Fight Fire

Fire spreads by preheating fuels (i.e., fallen leaves, grass, downed logs, twigs, tree branches etc.) as it advances, releasing combustible gases, which then ignite. When a retardant is applied to threatened vegetation, it coats fuels and alter the way fire burns, thereby decreasing the fire intensity and flammability and slowing the fire's advance, even after the water they originally contained has evaporated. When the approaching fire heats fire retardant salts, a chemical chain reaction occurs that results in the emission of water vapor and the elimination of flammable gases. A graphite-like carbon is formed, resulting in a non-flammable carbon coating. This starves the fire of any additional fuels and makes control easier. The water in the fire retardant slurry boils off, absorbing some heat and providing some cooling effect on the fire. Any fire retardant residue that is not consumed in the fire will continue to be effective in preventing ignition and flame spread until removed from the fuel by wind, flexing or rainfall. Any fertilizer salts not consumed in retarding the fire will later fertilize when diluted by rain.

The retardant is used in both direct attack and indirect attack. When used for direct attack, it is applied on the flaming front. In an indirect attack, it is applied to threatened vegetation and forms a chemical firebreak in front of an approaching fire. Fire retardants are ground-applied by equipment and dropped from fixed-wing or helicopter aircraft. Successive "drops" are often made by the aircraft to form a firefighting line. The ability to be used for both direct and indirect attack and the effectiveness of the solution to work when both wet and dry provides maximum versatility. No other wildland suppression chemical agent matches the versatility of long-term retardant.

Determining Effectiveness of Fire Retardant Chemistry

With the growth of fire retardant use in aerial and ground firefighting operations, there was a need to understand which chemical types could provide the best performance. This is particularly the case with aerial firefighting operations because of the high cost of aircraft and support equipment, accounting for a significant percentage of firefighting budgets.

Operation Firestop

In 1954, the US Forest Service created Operation Firestop – the first major study to look at firefighting effectiveness.[44] Taking place at Camp Pendleton Marine Corps Base Camp, it was designed as a one-year feasibility study. Its purpose was to explore the behavior and build-up of mass fires and to develop and demonstrate on actual wildfires some new attack methods that arose from science and technology that evolved during World War II.[45] Among the methods tested were aerial water bombing and sprays from both airplanes and helicopters, aerial backfiring from predetermined control lines, fog and smoke barriers to slow fire spread, fire retardant chemicals and sprays and the use of backfires to turn or slow down running fire fronts.[46]

One phase of Operation Firestop tested the effect of fire retardant chemicals on the ignition time of wood, on the fire intensity of burning wood, and the ability to suppress flaming wood. The study covered many chemicals that had been in use over the previous decades in firefighting products. Table 2[47] summarizes these chemicals relative to overall performance in this study. Several important revelations resulted from this study. First, it was apparent that phosphate chemistry was the most effective in reducing the impact of fires. At the same time, it was evident that chemicals, such as magnesium chloride, boric acid and polyvinyl acetate were not as effective. As a result, phosphate chemistry was on its way to becoming the industry standard for fire retardants.

Table 2 - Effect of Various Chemicals on Fire Intensity – 50 Percent of Fuel Treated*

Chemical	Percent Solution	Intensity Ratio	Peak Ratio
Monoammonium Phosphate	10	.63	.69
Sodium Silicate	10	.83	.83
Ammonium Chloride	20	.84	.89
Magnesium Chloride	20	.95	1.05
Boric Acid	1	1.01	1.00

*The intensity and peak ratios are determined by dividing the total heat output or peak heat output of treated fuel fires by comparable data from untreated fires

Early Technologies

In the 1960s, firefighting communities embraced clay and clay-like materials as a form of aerial fire retardant. These materials, which in themselves are relatively inert, form either a dispersed, flocculated or thixotropic colloidal system when mixed with water. These materials generally act as a water-carrying agent, which cools the fuels, raises ambient humidity, and forms a coating that inhibits the free access of oxygen and heat to the fuel and the free egress of volatile products from the fuel.[48]

Sodium calcium borate is an effective fire retardant. Still, it is undesirable because of its high cost, function as a soil sterilant, inefficiency in dry material per gallon used, and abrasiveness to equipment. Bentonite meets most of the above requirements, but several of its characteristics have not been tested.

The Chemical Composition of Fire Retardants

The active fire suppressing components employed in fire retardants include many well-known electrolytic fire suppressing salts and the more recently employed liquid ammonium phosphate materials, ammonium sulfate, and mixtures of these with other salts. These are chemicals commonly used as agricultural fertilizers.

Fire retardants mixed for delivery to the fire contain about 80%-85% water, 10%-15% fertilizer type salts and 5-10% minor ingredients—such as corrosion inhibitors, coloring agents, gum thickeners, stabilizers. The water they contain serves primarily as the carrier to aid in the uniform dispersal of the chemicals over the target area. It evaporates before the arrival of the fire and consequently contributes little in terms of fire retardancy.

Fire retardants can be supplied as dry powders or as concentrated liquids. The dry powder concentrates are mixed with water to form relatively dilute (10-15%) solutions before use in fire prevention or control. Retardants are formulated to provide low, medium and high-viscosity solutions.

Thickening Agents to Improve Targeting of Fires

Aerial fire retardants are typically thickened with various gum compositions and derivatives. Thickening agents are incorporated to increase elasticity, droplet size, adhesion and drop characteristics.

Fire Retardant Performance Additives

Fire retardants typically include various adjuvants, such as corrosion inhibitors, stabilizers and the like, and carriers for these adjuvants.

Enhancing Visibility of Fire Retardants in Use

When fire retardant solutions are applied by dropping from fixed-wing or helicopter aircraft, successive "drops" are often made by the aircraft to form a fire line. Under these circumstances, it is essential for the aircraft's pilot to visually determine where the preceding loads were dropped. Then, the pilot can drop the load from the aircraft to form a continuation of this line. Since the fire retardant components may be colorless or may be of colors that do not contrast well with the ground or vegetation, it has been common practice to mix coloring agents with the fire retardant composition. Coloring agents are used to give the fire retardant solutions their color. This color provides contrast with the hue of the ground vegetation, thereby enhancing the ability of the pilot to determine where the last loads of fire retardants were dropped in constructing a fire line.

Iron oxide was one of the early coloring agents used. However, these were found to be very colorfast, such that the ground and structures to which the fire retardant compositions were applied remained permanently or semi-permanently stained.

Consequently, many government firefighting agencies have required that aerially applied fire retardant compositions have so-called "fugitive" coloring agents. These fugitive solutions will fade over a short time (e.g., 30 days) to a color that does not objectionably contrast with the ground and ground vegetation.

The 1970 Blakely Report

In 1970, University of Montana Scientist Aylmer D. Blakely presented a paper entitled, *A Laboratory Method for Evaluating Forest Fire Retardant Chemicals.* Fourteen chemicals (Table 3) were selected for use in this study – many of which had been the subject of previous retardant studies. Blakely had developed a new system for evaluating the fire retarding ability of chemicals to give reliable and easily interpretable information. Blakely based his analysis on (1) fuel weight loss, (2) the amount of radiation emitted, and (3) the amount of residue after all combustion had ended as the fuel burned. Based on these three measurements, Blakely developed the Superiority Factor Method to measure and rank effectiveness.[49]

TABLE 3: Chemicals Tested in 1970 Blakely Study[50]

- Ammonium chloride
- Ammonium phosphate (dibasic)
- Ammonium phosphate (monobasic)
- Ammonium sulfate
- Boric acid
- Calcium chloride
- Magnesium chloride
- Magnesium sulfate
- Phosphoric acid
- Potassium carbonate
- Potassium chloride
- Sodium tetraborate
- Sodium silicate

The overall ranking of chemicals (Table 4) showed that diammonium phosphate, monoammonium phosphate, phosphoric acid, and potassium carbonate consistently ranked higher than any of the other chemicals in all three parameters. Ammonium pentaborate, sodium tetraborate, and boric acid were the next group that ranked high to moderate for effectiveness. Ammonium sulfate was moderately effective for decreasing weight loss and radiation and was next to the least effective for increasing the residue. Magnesium sulfate showed little retarding effect on any parameter. Of the four chlorides used, only magnesium chloride showed moderate effectiveness for retarding combustion within the radiation parameter.[51]

This study confirmed the results from Operation Firestop that phosphate chemistry offered the highest effectiveness for fire retardancy and positioned these as the chemistry of choice for the industry in the years ahead.

Table 4[52] Chemicals ranked in order by overall effectiveness*

Ranking Order by Rate of Weight Loss Curve	Significant Difference in Curves	Ranking Order by Radiation Curves	Significant Difference in Curves	Ranking Order by Residue Curves	Significant Difference in Curves
	Percent		Percent		Percent
Monoammonium Phosphate	60	Phosphoric Acid	94	Diammonium Phosphate	99.95
Diammonium Phosphate	60	Diammonium Phosphate	94	Monoammonium Phosphate	99.95
Sodium Tetraborate	99.8	Monoammonium Phosphate	97	Ammonium Phosphate	99.95
Phosphoric Acid	95	Potassium Carbonate	91	Phosphoric Acid	99.95
Potassium Carbonate	80	Ammonium Pentaborate	99.95	Potassium Carbonate	99.95
Ammonium Sulfate	90	Magnesium Chloride	99.7	Sodium Tetraborate	99.95
Ammonium Pentaborate	98	Boric Acid	78	Boric Acid	99.5
Ammonium Chloride	70	Ammonium Sulfate	80	Sodium Silicate	80
Boric Acid	85	Sodium Tetraborate	93	Calcium Chloride	99.9
Magnesium Chloride	75	Potassium Chloride	95	Potassium Chloride	91
Calcium Chloride	99.7	Calcium Chloride	99.9	Magnesium Sulfate	99.95
Magnesium Sulfate	45	Magnesium Sulfate	99.9	Magnesium Chloride	99.95
Sodium Silicate	50	Ammonium Chloride	99	Ammonium Sulfate	99.95
Potassium Chloride	98	Sodium Silicate	76	Ammonium Chloride	99.95

*Compares weight loss, level of radiation, and amount of residue during fire tests.

The First Modern Specification for Fire Retardant and the Qualified Products List

In the late 1950s, the United States Department of Agriculture's U.S. Forest Service began working with scientists and manufacturers on fire retardant efficacy and usage through its National Technology and Development Program (NTDP).[53] The NTDP is a problem-solving organization for the Forest Service. NTDP seeks and implements solutions to problems and technical challenges faced by the U.S. Forest Service. It also oversees Fire and Aviation Management equipment research, including Fire and Safety Specifications, Fire Shelters and Wildland Fire Chemicals.[54]

For Wildland Fire Chemicals, the objective of this work included:

• Application of innovative science and technology

• Knowledge synthesis and transfer

• Specifications and standards development

In 1962, PHOS-CHEK® was the first phosphate-based fire retardant approved for use by the USFS.[55] This began the evolution of the USFS Qualified Product List (QPL) for fire retardant products that were eligible for use on United States Federal and State lands, which has become a de facto global standard for fire retardant products.

In 1986, the USFS created the first modern specifications for long-term fire retardants – Specification 45100-304.[56] The specification covers a broad range of issues relating to efficacy and use of fire retardant chemicals, including:

• Uniform and intergranular corrosion

• Product stability

• Fire-retarding effectiveness

• Physical parameters

• Mammalian toxicity, including oral toxicity (ingestion), dermal toxicity (absorption through the skin), eye irritation, and skin irritation

• Aquatic toxicity

• Human health and ecological risk assessments using data from toxicity tests and safety data sheets (SDS)

Wildland Fire Chemical Systems (WFCS) focuses on two areas: Wildland Fire Chemicals and Aerial Delivery Systems. NTDP's Wildland Fire Chemical Systems provides land management agencies with detailed information to help the agencies safely and effectively use fire suppression chemicals and aerial delivery systems. They publish a Qualified Products List (QPL) that shows which products have passed all tests administered by WFCS. After a fire chemical has completed all the required tests, WFCS adds it to the QPL. Products on this QPL are authorized for use by federal agencies, states, and others. Becoming qualified on the QPL requires that a product goes through 18-24 months of testing.[57]

To date, every product on the Long-Term Fire Retardant QPL save one is based on phosphate chemistry.

The Environmental Impacts of Fire Retardants

One of the significant criteria used in determining whether a fire retardant product gets included on the QPL is potential environmental effect. Every product based on phosphate chemistry has undergone extensive testing for mammalian toxicity, oral toxicity (ingestion), dermal toxicity (absorption through the skin), eye irritation, and skin irritation. Because these retardants either land or are washed into bodies of water, they also undergo aquatic toxicity analyses.

The potential human health hazards posed by the components in phosphate-based fire retardants are disclosed on accompanying safety data sheets (SDS), if the ingredient is deemed hazardous under applicable regulatory criteria. Under most U.S. regulatory standards, hazardous components present in a mixture at levels below 1% (0.1% for carcinogens) are not considered to contribute to the hazards of the overall formulation.

PHOS-CHEK retardants consist primarily of ammonium phosphate or ammonium polyphosphate. These salts function as the active fire retardant component in the composition. Ammonium phosphates and ammonium polyphosphates are used in agricultural fertilizers as nitrogen and are considered safe. The technical-grade phosphates used in the dry powder PHOS-CHEK retardants are considerably purer than fertilizer-grade phosphates.

Ammonium phosphates are classified by the U.S. Food and Drug Administration (FDA) as Generally Recognized As Safe (GRAS).[58]

Gum thickeners used in PHOS-CHEK retardant formulations are also used as components in food products, such as ice cream. The thickeners and fire retardant salts used in PHOS-CHEK are dry powders before mixing in the retardant and are considered hazardous under some regulatory criteria because of their potential respiratory irritation properties (see discussion below on respiratory sensitization).

Wildland fire retardant solutions also contain inhibitors to protect handling, mixing and delivery hardware from corrosion. Very small quantities of several different additives are used to protect the various types of metal with which the solutions come in contact. These additives may be considered hazardous in bulk or used in high concentrations because of their potential to cause eye, skin, and respiratory irritation. However, all are present in PHOS-CHEK retardants in quantities too low (less than 5% in the concentrates) to be considered hazardous ingredients or to lead to the classification of the overall formulation as hazardous. Further, no known adverse long-term or chronic health effects have been attributed to PHOS-CHEK.

Biodegradability of Fire Retardants

When a material can be consumed or degraded by organisms, it is considered biodegradable. Inorganic compounds, such as fire retardant salts, cannot be digested by bacteria or other organisms, but do provide nutrients for use by plants. It should be noted that 85% - 95% of the PHOS-CHEK retardant solution is water. The gum thickener and other organic compounds are biodegradable.[60]

PHOS-CHEK Fire Retardants: 60 Years of Continuing Innovation

After working as part of a cooperative effort with the U.S. Forest Service since the mid-1950s, PHOS-CHEK became the first Agency-approved phosphorus-based wildland fire retardant in 1962.

PHOS-CHEK products were the first commercialized gum-thickened retardants with a range of viscosities. Previously, the only options for the fire manager were no-viscosity (un-thickened) or high-viscosity retardants. This innovation allowed the federal agencies to optimize retardant characteristics based on the delivery system, topographical situation, fuel and specific fire characteristics.

PHOS-CHEK introduced iron oxide colored PHOS-CHEK 259-R in 1971.[61] PHOS-CHEK 259 is the only retardant that meets the corrosion requirements for critical magnesium components in helicopters with fixed tanks.

PHOS-CHEK developed and introduced the first "fugitive colored" retardant in 1975.[62] This critical innovation provided fire management agencies the ability to effectively fight fires in aesthetically sensitive areas such as National Parks and wildland-urban interface areas, where iron oxide-colored retardants were less desirable or unacceptable. Fugitive-colored retardants also reduced the risk of staining private property, airport runways, taxiways and other exposed areas. PHOS-CHEK fugitives today remain the only "true-fugitive" fire retardants where the red color disappears in less than a month.

PHOS-CHEK commercially introduced retardants based on a synergistic blend of ammonium sulfate and ammonium phosphates in 1985.[63] This blend provides fire retardant performance similar to ammonium phosphate retardants at a considerably lower cost.

All PHOS-CHEK fire retardants are available and qualified for use in ground engines and other ground application apparatuses. These retardants give fire management agencies a valuable tool for fire prevention, suppression, and prescribed burning.

As a complement to the chemistry of their fire retardants, Perimeter Solutions pioneered "eductor mixers" that could continuously mix dry-powder retardants at a rate of 21,000 gallons per hour using only one person.[64] Today, Perimeter Solutions offers eductor systems capable of mixing 30,000 gallons of retardant per hour.

Ground-Based Fire Retardants

Ground-based fire retardants have been employed for decades to complement or even supplant aerial fire retardant application. These uses include:

Reinforcing conventional control lines – Application of retardant can increase the width and therefore the effectiveness of roads, mineral earth lines and other natural features, which can be used to contain a wildland fire or a prescribed burn.

Establishing a control line – Retardants can provide a line from which to burn. Together, the burn buffer and retardant line provide a control line for a prescribed burn without the necessity of clearing a line to mineral earth.

Limiting spotting – Application outside the control line can minimize the possibility of spot fires.

Controlling a fire within the burn – Application inside the burn can help reduce the fire intensity and flame height as the burn approaches the control line. In addition, application around the base of fire-sensitive trees can help protect them from damage in understory burns. This may also reduce mop-up time.

Protecting assets – Application along fences, on and around power and telephone poles and structures can help them from burning or scorching.

Stopping Fires Before They Start

Data shows that over 80% of human-caused wildfires are ignited in high-risk areas adjacent to roadsides and under utility lines.[65] With the use of fire retardants, many of these fires should be preventable. Estimates have shown that from a cost standpoint, prevention of wildfires using ground applied long-term fire retardants is 35 times more cost-effective than the firefighting efforts it replaces.[66]

PHOS-CHEK ground-applied long-term retardants are a valuable fire management tool that can help stop wildfire in its tracks. They allow precise, cost-effective placement and can be applied well in advance of fire occurrence.

PHOS-CHEK long-term retardants help prevent the start of wildfires by making wildland fuels non-flammable – protecting vegetation against fire risk. They can be applied by almost any standard equipment that sprays, including Perimeter Solutions' custom ground-applied equipment. All products have a high level of fire retardant effectiveness, with differences in product form, adherence to vegetation and durability through weathering.

Short-term and Long-term Solutions

Today, Perimeter Solutions offers a comprehensive range of ground applied fire retardants – PHOS-CHEK FORTIFY® for season-long protection and PHOS-CHEK technology for fast application during scheduled burn or emerging wildfire conditions (See table 5). These are proven technologies with a track record of performance.

PHOS-CHEK LC-95W and related grades are on the USDA Forest Service Qualified Products List (QPL) and are the fire retardant of choice for the US Forest Service and various state agencies. PHOS-CHEK FORTIFY is also on the QPL and is an effective solution on both state and federal lands.

PHOS-CHEK FORTIFY Fire Retardant

PHOS-CHEK FORTIFY is an ideal fire retardant for applications when season-long protection is required, since it can provide retardant effectiveness even after a significant rain event. It can be used in multiple ways to add an extra layer of protection against wildfires:

- Treatment of high-risk fire areas, including utility pole brushing & vegetation management
- Underneath utility lines to keep them energized, averting Public Safety Power Shutoffs (PSPS)
- Around critical infrastructure assets (substations, buildings, communication towers)
- Protection for power poles, easements and rights-of-ways
- Along railroad lines and railways in high-risk areas
- Ingress and egress paths in at-risk communities
- Pre-treatment of Prescribed Fire Control lines far in advance of ignition
- Military bases in active munition areas
- Hillsides and roadsides near communities with high fire-risk
- Extending roadway fire breaks
- Protection for wildland-urban interface areas, campgrounds, and other common ignition areas
- Protection for historical areas, national monuments and sensitive and endangered habitats

PHOS-CHEK LC-95W Fire Retardant Technology

PHOS-CHEK LC-95W is the technology of choice for rapid deployment and potential fire events scheduled within days of application. Perimeter Solutions offers several grades of this technology for different application environments:

- All applications requiring QPL status
- Pre-treatment of utility easements and infrastructure
- Utility rapid response efforts ahead of a fire
- Around homes and communities with pending wildfire danger
- Ingress and egress paths ahead of a fire
- On physical utility poles with fires approaching
- Support of prescribed fires being conducted within days of application

Ground-Based Fire Retardant Proven Effective

In the 2019 paper, *Wildfire Prevention Through Prophylactic Treatment of High-Risk Landscapes Using Viscoelastic Retardant Fluids*, the authors stated that "polyphosphate fire retardants are a critical tactical resource for fighting fires in the wildland and the wildland-urban interface."[67] Municipalities, businesses, communities, and homeowners are catching on to that fact and are starting to use ground-based retardants proactively to protect critical areas from wildland fires.

In the summer of 2018, a total of 37 fire starts were recorded along a four-mile stretch on California's Route 118 between Ventura and Los Angeles County in what is known as the Rocky Peak. Before the 2019 wildfire season, PHOS-CHEK FORTIFY was applied to that same stretch of road. The application was funded by The Woods Institute for Energy and Environment at Stanford University and a grant from the Caltech Rocket Fund and support from CAL FIRE and CalTrans. Following the treatment, not one fire was recorded that summer.[68]

During the devastating 2020 wildfire season, two central Arizona animal rescue organizations worked with Perimeter Solutions to apply PHOS-CHEK LC95W Fire retardant on their properties in early July. The Arizona Equine Rescue Organization (AERO) is a highly specialized health center for horses that require intensive medical care. They often house more than 20 horses on the five-acre property that specializes in the rehabilitation of horses.

"We're in a community that has a large number of livestock in a small area. Fires move rapidly, which makes it difficult to get animals out. I had been researching solutions for fire prevention on the Web, and I ran into PHOS-CHEK. It matched what we were looking for since it is approved for use by the USDA Forest Service, it's a long-term fire retardant that is environmentally friendly, and it stores well, so we can apply it year over year," said Soleil Dolce, Vice President of AERO. "We want to become an example for the community to demonstrate different ways you can do fire protection – even in times like this year, where high winds are causing ember jumps of 300 feet. We'd like to encourage other property owners and even the Arizona Department of Transportation to engage in the kind of proactive preventative measures that fire retardants can provide."[69]

AERO and the Southwest Wildlife Conservation Center, a shelter for more than a dozen animal species, applied LC95W on critical areas around their properties and then held on to more of the solution to apply when needed.[70]

Working with CSAA Insurance Group, a AAA insurer, Perimeter Solutions launched a pilot program in 2020 and expanded the program in 2021 for the application of PHOS-CHEK FORTIFY. This program helped to preventatively treat members' homes in high-fire threat areas, as well as protect homes from incoming fires. The results (not one property was damaged by wildfire) and the customer feedback were overwhelmingly positive.[71]

Looking Ahead

The retardant industry needs innovation to continue finding new technologies to help firefighters do their jobs better. Firefighters need to be equipped with tools to help keep people safer and fight these fires more effectively. However, this must be done in a thoughtful way that ensures there are no unintended consequences. Retardant is dropped out of planes onto wildland, on people and animal life, and the industry needs to understand the limits, hazards, and how it should be used. The capabilities of phosphate-based retardants are well known and have been demonstrated for decades. Testing has proven its effectiveness, and that is why phosphate-based retardants are included on the USFS QPL.

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