A MILLENNIAL VIEW OF FIRE SUPPRESSION

Richard G. Gann
Building and Fire Research Laboratory
National Institute of Standards & Technology

"A little fire is quickly trodden out; Which, being suffered, rivers cannot quench."
William Shakespeare, *King Henry VI. Part III. Act IV*

INTRODUCTION

The ability to control fire is universally and exclusively human. The history of that controlled use is also the history of civilization. Indeed, it has been so important to our development that no branch of the hominid family tree has survived without it.

While individuals likely recognized the first principles of fire control, it was the rise of organized societies that led to structured activities and, later, products to mitigate the unwanted outcomes of fires. Now, the application of chemicals, manually and by mechanical devices, to control fires has become a mainstay of modern society. In particular, the development of the use of chemicals has a rich history.

The evolution of human culture has led to changing definitions of successful fire control and changing acceptability of the various means for effecting that control. We in the year 2000 are the legatees of millennia of this evolution. The following is a pass through this heritage, indicating the implications for the 21st century and concluding with the author's anticipation of how a 22nd century book on fire suppression might conclude.

PRESERVE THE FIRE

There is geologic evidence of fires as far back as there is evidence of vegetation on this planet, about 350 million years ago. Started by frequent natural events, lightning strikes and volcanoes, this was still the case when the first hominids appeared, some 3-5 million years ago.

In the earliest years, small nomadic groups of these pre-humans observed the nature of fire. While they could see its destructive power. they soon recognized its benefits as well. They saw that animals ran from it, and thus it became a tool for trapping food. They found that animals and nuts that had been exposed to the flames were easier to eat. They enjoyed the radiant warmth from the fire on cold nights. They no doubt observed that rain made the fires stop; some may have even noticed that there were few fires following a rainstorm.

By about 400,000 years ago, the sparse nomadic clusters of homo erectus had learned how to "capture" fire and use it for their own purposes, both domestic and martial. Since the initial source of this benefactor occurred only episodically, they spent considerable effort to keep the fire from going out. A few burns and the occasional loss of a temporary dwelling was a small price to pay for its continuous availability.

PRESERVE THE COMMUNITY

The number of humans and their standards of living accelerated about 20,000 to 30,000 years ago, toward the end of the last glacial age. Over the next 10,000 years, the ability to use **fire** for clearing land for agriculture and capturing livestock engendered the rise of towns. Further amenities became available as fire was used to bake clay pots (about 20,000 years ago) and later (about 7000 years ago) to work with metal. It would be time for the appearance of codes to preserve these more permanent communities.

Yet, the first written records, about 5000 years ago in Mesopotamia, made little mention of fire. It is thus presumed that there was little concern for its use or misuse. Perhaps this was because **all** members of a family were well versed in **the** art of using fire, preserving it, and regenerating it when needed. Interestingly, there were two types of words for fire: one for intentional fires, another for dangerous ones. The hazard of a house fire was not regarded **as** paramount. Buildings were small and generally constructed of stone or mud brick, since these materials were readily available. With the small number of people and the ready availability of land, the dwellings were not tightly spaced. If a fire started, the interior wood framing (if any), the thatched roof, and the contents were lost, since there was little water available to quench the flames. Attempts to protect neighboring houses depended on wet cloths and a limited number of buckets of water. People had long since learned the use of firebreaks for clearing land intentionally, and these were used to contain fire spread in the residential clusters. The Code of Hammurabi (about 1780 BC), a collection of rules for everyday life that also reflects the serious crimes of the era, has no mention of arson or of fire prevention. However, theft of goods during a fire was punishable by death in that fire. The first mention of an arson penalty (full reparation) appears in the laws of the Hittites, some 100-600 years later, but there was still no text on controlling fires. In short, destruction by fire was not the most severe threat facing these early communities, and their only weapon against it, water, was not plentiful on short notice.

The citizens of Rome appear to have had the first formal building code for fire safety. Houses could not be built too high, with separations of at least 2.5 feet and with means of escape. Tenants were often required to have a bucket of water in their flats, and intentional fires within those flats were often forbidden. Nonetheless, over 40 large conflagrations were recorded between 31 BC and **AD** 410, including the famous fire in **AD** 64 during which Emperor Nero supposedly fiddled while one third of the city was destroyed.

The city of Rome also had an official fire brigade, and because it was unable to cope with its charge, several private brigades arose as well. The official brigade was improved by Emperor Augustus and then doubled in number over the next century. These featured intensive patrols to catch fires early and bucket brigades with access to the city's superb aqueduct system. Of course, virtually none of this existed in the Empire outside of the capital city.

Pre-industrial Europe continued to have numerous major urban conflagrations even past the Middle Ages (e.g., London 1212; Venice 1514; London again in 1666; Rennes 1720). Most urban construction was now of wood and clay, which were cheaper than stone and brick. This was the era when the latter began to connote wealth, in large part due to the ability of the rich to afford fire safety. Buckets of water were still the only major means for stopping fire spread. In urban areas, legal measures were often instituted to bolster this limited capability. In the event of a fire, people were to leave the building and sound the alarm immediately; there were severe fines for removing their possessions first.

In the rural areas. fire control reflected an earlier time. The crime of arson, resulting from a grudge or as a threat to extort money, was considered second only to murder and punished accordingly.

An enabling breakthrough in Eire suppression came in the late 17th century, with the invention by Jan van der Heyden of Holland of the rollable fire hose. In 1725, Richard Newsham of London patented an improved pump design that could take advantage of van der Heyden's hoses. Soon a variety of hand pumps were devised to move water (still the suppressant of choice) efficiently from a city reservoir to the fire. During the Industrial Revolution in the mid-nineteenth century, these pumps became fire- (i.e., combustion-) powered.

Nonetheless, for the remainder of that century, large city fires continued to be a problem (e.g., Hamburg 1842; Newcastle 1854; Chicago 1871; Boston 1872). The loss of life was significant, as city population densities rose and the buildings became taller, wider, and more densely situated. The San Francisco fire of 1906 was the "last" of the major urban conflagrations. This is attributed to the rise of brick, concrete and steel for urban construction, the spreading of residences (e.g., single family units with yards), and general adoption of improved firefighting technology and procedures. Water continued to be the only suppressant.

PRESERVE THE PROPERTY; PRESERVE THE PEOPLE

The scientific and technologic revelations of the 18th and 19th centuries led to new capabilities for the control of fires. In particular, James Watt's invention of the steam engine in 1769 led to two major innovations. In 1812, William Congreve received a patent for a steam-driven, perforated pipe water distribution system. In the middle of the century, the fusible link and self-opening valve were added, making the system fully automatic. In 1852, Moses Latta produced the first steam-powered, self-propelled fire engine, and the first commercially successful ones followed in 1867. Now there were ways to bring water, still the predominant suppressant. to the fire. It thus became possible to react in time to save a complex commercial or residential structure and many of the people within. What remained was the development of technology to assure the safety of the contents.

Just after the turn of the 20th century. another scientific advance stimulated just this capability. The prior years had produced breakthroughs in the understanding of the electrical behavior of solutions. Now, a process for the electrolysis of salt water enabled a large supply of inexpensive chlorine. This soon was used to make carbon tetrachloride (CCl_4), which came into use as a fire suppressant in both glass "grenades" (thrown at the fire) and mechanical pump extinguishers.

CCl_4 was the first clean agent, that is, unlike water it caused no damage to a huilding or its contents and left no residue itself. It was also the first halon—Halon 104. However. concerns soon arose about its toxic effects on firefighters and others at the fire scene. The chemical had briefly seen use as an anaesthetic, a practice that stopped when it was found that the difference between the amount which produced unconsciousness and that which produced death was small. There was also an awareness of the interaction with the large amounts of alcohol that firefighters consumed before, during, and after their efforts at the fire scene. Nonetheless, the use of carbon tetrachloride continued through World War II, in which it was used extensively.

By this time, the chemical similarities of the elements within a column in the periodic table were well known, and soon the neighboring halogen, bromine, was also considered as a possible component of fire suppressant compounds. Methyl bromide (Halon 1001) appeared in the 1930s in the **US,** but did not find much acceptance since it was found to be more toxic than CCl_4. The Germans developed and used chlorobromomethane (Halon 1011) as their clean suppressant of choice during World War II. It was more efficient than Halon 104, and after the war it found broad use elsewhere.

This recognition of the need to consider agent toxicity is another milestone in the evolution of fire suppression technology. The drawbacks of water had been operational in nature, e.g., mechanical hurdles to overcome in its bulk transport to the fire, damage to building contents. Now the suppressant itself would need to be examined for its possible effects on firefighters and building occupants. Clearly, the value system of this era appreciated the benefits of these new halogenated agents in protecting property and people. Some selection from among the effective halocarbons was in order, and toxicity was the new criterion on the list.

In 1948, the US Army commissioned the Purdue Research Foundation to search for a suppressant of high fire suppression efficiency but low toxicity. The Army coined the term "halon," short for halogenated hydrocarbon, and devised the naming system that shows the numbers of the types of atoms in the molecule in the order: carbon, fluorine, chlorine, bromine, iodine (terminal zeroes dropped). During the 1960s and 1970s, two of the compounds tested emerged as commercial successes. Halon 1301 found widespread use as a total-flooding agent and Halon 1211 became the predominant streaming agent. By the 1980s, most computer rooms, nearly all commercial and military aircraft, and numerous museums were protected by these halon systems. As a footnote, their acceptance signaled the end of CCl_4, a prophetic result, as it was later determined that carbon tetrachloride was a carcinogen.

Almost in parallel with the emergence of the halons was the use of powdered fire suppressants. After limited use at the beginning of the 20^{th} century, D.J. Block patented a mixture of sodium bicarbonate with a small amount of magnesium stearate to eliminate clumping. This enabled the use of the powder in practical systems. While the powder was not "clean" like the halons, it was very efficient in suppressing flames from liquid fuel fires and was nominally nontoxic. During World War II it was recognized that suppression efficiency increased with decreasing particle size. In 1958, Ray Neill showed that potassium bicarbonate was twice as effective as the sodium salt. Other alkali metal salts were examined, but none achieved the same degree of usage.

As the third quarter of the 20^{th} century was ending, the industrialized societies of the world had clearly established a cultural value for fire safety. Unlike the early stages of our evolution, the everyday use of fire had become rare (except for smoking). Universal hands-on familiarity with its safe use and the potential hazards had been lost. Thus, fire control in the form of fire containment, less flammable products (the subject of extensive regulation) and fire suppression were to be provided. People, property, and buildings were to be protected **as** part of the societal contract.

PRESERVE THE ENVIRONMENT

In 1974, F. Sherwood Rowland and Mario Molina published a paper showing that certain chlorinated compounds (chlorofluorocarbons or CFCs), released into the atmosphere, would rise to the stratosphere where they would deplete the earth's delicate protective ozone layer. As the nations of the world moved toward an international agreement to protect the environment, it was realized that some brominated compounds were potentially even more dangerous than their chlorinated cousins. The halons (with the name mistakenly used to mean brominated perhalocarbons) were named in the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. Soon they were in restricted production, and in January 1994. nearly all production ceased. After a period of bewilderment, denial, and indecision, manufacturers and users of the halons began searching for safe replacements and alternatives. The early solutions were identified during the quest for replacement refrigerants, a far larger commercial market. Some of these, such as the hydrochlorofluorocarbons or HCFCs, were ozone depleters themselves and were soon generally disregarded as suppressants. A major Department of Defense program, completed in the early 1990s, found that the best commercially available compounds for their purposes were two hydrofluorocarbons or HFCs: C_2F_5H (HFC-I25) and C_3F_7H (HFC-227ea). Other commercial products includeed mixtures of inert gases and blends of halocarbons.

Even before replacements for the CFCs and halons could be implemented. an additional threat to the global environment was identified. Since the middle of the 20th century. there had been concern that anthropogenic carbon dioxide was increasing in the lower atmosphere. Its increasing absorption of infrared radiation from the planet surface and re-radiation back to that surface would lead to warming of the earth. The term “greenhouse gas” was invoked. and it was soon realized that most of the replacements for clean fire suppressants fell into this category. This added yet another constraint to the search for the successors to the halons.

Nor has water been spared environmental scrutiny. The water applied to a fire, whether by hose or by sprinkler. spreads over the ground, contaminated with the byproducts from whatever had burned. Since this could lead to pollution of streams and the municipal water supply, there has been some pressure to minimize the use of this suppressant.

The dense and growing population had been informed of a threat on a global scale, and the nations of the world had clearly decided that fire safety must be weighed against other cultural values. For the fire safety community, this was a new paradigm. Effective fire suppression technology was available and was no longer limiting. The prior bounds on saving lives. property and the community had generally been local: budgets limitations, interferences with other social amenities, etc. Now, the protection of the world as a whole took priority over local safety, which presumably could be provided in some other manner.

PRESERVE FIRE SAFETY

In the United States, fires annually claim over 4000 lives and seriously injure 25 times as many people. These losses are diminishing only slowly. The cost of lost property, well under one tenth of the overall cost of fire, is approaching 9 billion dollars and is rising. Equivalent statistics for all nations are not available. However, a (quite unjustified) simple linear extrapolation to the world population leads to an estimated 100,000lives lost, *2* million serious injuries, and 200 billion dollars in property loss. A similar, equally unjustified extrapolation for the worldwide total cost of fire would exceed 2 trillion dollars.

These are certainly numbers of global significance. The total cost figure is qualitatively similar to the world’s current expenditures on armies and armaments, while the fire casualties greatly exceed those from combat during each of the last 50 years or so. The Hunger Project (www.thp.

org) estimates annual deaths from hunger to be a much larger number, about **9** million, and falling at a gratifying rate. Certainly 2 trillion dollars, properly spent, would significantly ameliorate that number further.

And yet fire safety is not considered a global issue like the environment, war, and food. Citizens expect their governments to legislate safe air and water, to provide them with defense against military attack, and to ensure a plentiful, affordable supply of comestibles. Thus there are prominent governmental agencies to effect these. There are also occasional reminders (pollution alerts, wars, food price hikes) to remind us of their importance. By contrast, the magnitude of the fire problem and the associated costs are not recognized by the general population. Our success at localizing the impact of a fire, the cumulative benefit of millennia of empiricism and science, has moved **fire** control far down the list of perceived societal necessities. Fires exist and there are people who put them out.

We *can* thus presume that when the next issue affecting fire suppression arises, the outcome will be comparable to what we have experienced over the past decade. **A** further enlarged set of cultural values, manifested as societal criteria, will emerge. The fire protection community will be called upon to re-assess the necessity of **fire** suppression in each application. For those where such capability is an integral part of providing safety, continuity of operation, preservation of property, etc., we will develop new criteria for acceptable agents and systems, then commence the research and engineering to realize the needed capability within the new bounds.

THE VIEW FROM THE 22ND CENTURY

There are forces, already in motion, that over the next few decades will define the future of how fire safety is delivered. Thus, by the end of the 21st century:

- Performance-based codes will have replaced the current prescriptive versions. Facility constructors, owners and operators will be required to provide a communally chosen degree of safety. They will have broad flexibility of design and will have to demonstrate that they have achieved the safety objectives.
- Driven by increased international trade, fire standards for product qualification will have been harmonized worldwide, likely within the construct of performance-based codes. Because of the conservative nature of countries and industries, many of these standards will be compromises and thus have the potential to fall short of their purposes.
- People around the world will have accumulated increased possessions and furnishings, as already enjoyed by those in the wealthier countries. As a result, fire loads will increase, presenting a larger challenge to building and fire codes.
- The development of fire safety technology, much of it derived from military research investments, will continue to be a (limited) commercially successful undertaking.
- The public will have high expectation for low (i.e., perceived zero) risk.
- Environmental risk and benefit will receive increased attention.
- Municipal budgets (e.g., for fire service staff) will continue to be under pressure.
- The average age of the population will have continued to rise, increasing the demands for safety measures.
- More sophisticated systems will have become more automated to improve reliability in the face of an insufficient pool of knowledgeable service people.

All of these will drive the development and implementation of installed fire control technologies. By the end of the 21st century, I believe that life loss from fires in the United States and the other developed countries will diminish by over an order of magnitude. New hardware and materials technology will have enabled this accomplishment while decreasing the total cost of fire as well.

Success in the delivery of fire safety has generally resulted from the compounded effectiveness of redundant tactics, e.g., fire resistant walls *plus* fire-retardant products. Performance-based codes are intended to reduce cost and improve design flexibility, both of which are easier to provide when including a fire suppression system. I thus expect that automatic fire suppression will become far more widespread than it is today. In particular, by the end of the 21st century. I expect we will at least see the following:

- Smart and early fire detection combined with next-generation fire suppression devices will ensure the quenching of most fires at non-hazardous levels and with no complications from nuisance alarms.
- **All** commercial and public buildings and spaces with contents of high or unique value will be protected with low volume water systems or systems based on a new generation of solid propellant gas generators (SPGGs) or next-generation clean suppressants.
- All new and renovated residences will have fixed central or localized suppression systems using the above technologies.
- In current dwellings that are still occupied and unrenovated 100 years from now, plug-in units. probably based on SPGGs, will be installed.

RESOURCES

Auck, S.E., "Short History of Halogenated Fire Extinguishing Agents," in *An Appraisal of Halogenated Fii-e Extinguishing Agents,"* National Academy of Sciences, Washington, 1972.

"Chemistry and the Atmosphere," *Chemical und Engineering News Special Report,* American Chemical Society, Washington, March 28, 1966.

Ford, C.L., "An Overview of Halon 1301 Systems," in Gann, R.G., ed., *Halogenated Fire Suppressants,* ACS Symposium Series 16, American Chemical Society, Washington, 1975.

Goudsblom, J., ***Fire** and Civilization*, The Penguin Press, London, 1992.

Karter, Jr., M.J., "1998 Fire Loss in the United States," *NF'PA Journal*, pp. 88-95, September/October 1999.

Lyons. J.W., *Fire,* Scientific American Library, New York, 1985.

Lyons, P.R.. *Fire in America!*, National Fire Protection Association, Boston, 1976

Meade, W.P.. *A First Pass ut Computing the Cost of Fire Safety in a Modern Society,* NIST-GCR-91-592, National Institute of Standards and Technology, Gaithersburg, 1991.

Molina, M.J., and Rowland, F.S., "Stratospheric Sink for Chlorofluoromethanes: Chlorine Atom Catalyzed Destruction of Ozone," *Nature* 249, 810-812, 1974.

Nash, P.. and Young, R.A., *Automatic Sprinkler Systems for Fire Protection*, Victor Green Publications, London, 1978.