

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT

4215101

May 5, 1966

NBS REPORT

9307

Fire Protection
Materials and Structures

by

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NOT FOR PUBLICATION

Prepared for distribution at
46th Annual Meeting of
The Society of American Military Engineers
May 23, 1966

National Bureau of Standards
Gaithersburg, Maryland

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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ABSTRACT

Fire Protection covers all efforts to safeguard life and property from the harmful effects of unwanted fires. It includes systems for extinguishing fires once started, confining fires, and early detection. It also includes activities in the area of prevention, such as the gathering and dissemination of information on ignition, growth and spread, flammability, smoke and toxicity, etc. Only through better knowledge and understanding of these phenomena can effective, efficient, and economical prevention be practiced.

The advancement of fire protection is made through basic studies to increase understanding of the related phenomena; through application of this understanding in preparation of new or improved test methods, design practices, performance criteria, and regulations; and through the development of materials, systems, and structures to implement the intent of the regulations and criteria.

The National Bureau of Standards has been active in fire research and fire protection for half a century. They have worked in nearly all related areas except the development of new materials or equipment for fire protection. However, their work has been instrumental in improving the Nation's capability for measurement of such developments against appropriate criteria.

Fire Protection - Materials and Structures

By

J. V. Ryan

1. INTRODUCTION

The protection of life and property from the effects of unwanted fires is the ultimate application of the work of many people in government, industry, universities, and societies. These include fire fighters, materials and equipment manufacturers, research workers and others.

The testing of building elements for fire endurance in this country began in the last years of the nineteenth century. However, structures had been designed with fire problems in mind at least a century earlier. In fact, ordinances on fire resistive construction were signed by King John following the London fire of 1212, three years before he signed the Magna Charta [1]. Apparently the first ordinance specifically requiring a fire test in this country was the 1899 New York City Building Code. For a more detailed history of fire testing, the reader is referred to the paper by Shoub [2].

The development and adoption of a test method provides the standard necessary for the effective implementation of regulations, be they the regulations of a political jurisdiction or those imposed by the building's owner in the design process. The average home buyer is not conscious of fire protection when he tours model homes or sketches out what the family wants. The concern with fire protection of many owners of commercial buildings does not extend beyond meeting the code requirements of the jurisdiction within which they operate. The owner most conscious of fire protection is the Federal Government. It is not subject to local code requirements and, therefore, is both free and, as the largest single owner of buildings in the country, is required to think about the fire protection desired. This thinking must involve the concept and degree of protection to be provided, the materials and structures to be used, and the means by which it is determined that these materials and structures do provide the desired degree of protection. As a result of this last consideration, the Government agencies involved in construction--General Services Administration, Corps of Engineers, Bureau of Yards and Docks, Air Force Office of Construction, and others--have been active in test method development as well as in encouraging and supporting NBS in its efforts.

The title of this paper, "Fire Protection - Materials and Structures", could be subtitled "Of or By?". It is a very pertinent question. Some groups are concerned with the protection of materials or structures; others are concerned equally with the protection afforded by the materials or structures employed; many, and particularly the Government, are concerned with both. In this paper, we will try to touch both the "Of" and the "By".

2. FIRE PROTECTION SYSTEMS

Fire protection is provided by several different kinds of systems, preferably used in combination. In certain instances, a single system may be adequate. However, none of them are absolutely beyond the possibility of failure. Therefore, when the risk is serious, several systems may well be used.

2.1 Detection

Simple detection of a fire does not in itself have any effect on the fire, either as to its extent or severity. A detection system should be coupled with a mechanism whereby effective countermeasures are brought into play. The detector may be a watchman, a simple fusible element, or an elaborate complex of electronic and sonic equipment. Yet how many fires are detected by the observant passerby! The countermeasures may be public or private, and may act to extinguish or to confine the fire. The NBS Fire Research Section over the years has done work on detection systems for various Government agencies. This ranged from operational checks on samples of fire call boxes submitted with bids for the District of Columbia's alarm system to studies of the basic phenomena involved so that detector requirements could be spelled out. A case in point was the problem of reliable fire detection in the engine spaces of aircraft. Since most aircraft engine-space extinguishing systems discharge completely in one, or at most two, applications, there is great concern about possible false alarms. The high speed and often laminar airflow in these spaces worked against the use of thermocouples or other essentially point detectors. The presence of red-hot exhaust systems made radiant detectors unreliable. In short, the highly specialized conditions existing in aircraft engine spaces during flight were such that no one of the principles-of-detection then employed could be relied upon both to detect a fire and not to give false alarms. The Fire Research Section made a careful study of such things as the spectrum of flames, flicker and other characteristics, and how these characteristics were affected by high winds. The data provided the basis for a report that was a performance standard for an aircraft engine-space fire detector. The sponsor (U. S. Air Force) used that report as the basis for contracts with private industry to develop suitable and reliable detectors.

2.2 Extinguishment

Extinguishment of unwanted fires is accomplished by many means. These include the work of professional fire companies using water streams, water fogs, foams, carbon dioxide gas, dry powders, and inerting atmospheres. Sprinklers and other built-in systems, plus portable "first-aid" equipment employ some of the same extinguishing agents. Most firemen agree

that very little of the water in a solid stream is effective. The development, by industry, of spray and fog nozzles was motivated by the need to make more efficient and effective use of water supplies. Industry has sought to develop better extinguishing systems of all types, either by more effective use of a particular agent or by development of better agents. The Fire Research Section has sought a better understanding of the mechanism of extinguishment. Such knowledge should be useful to industry in its development work.

Water is very effective extinguishing agent for certain fires. It is believed that the mechanism of extinguishment is that of cooling the combustible fuel below its ignition temperature. Also, solid sheet of water flowing over a surface would cut off the oxygen supply, but that is difficult to achieve. Fires in liquid fuels rarely can be fought effectively with solid streams of water because the fuels float on the water. There is little thermal contact with the burning surface and, therefore, little cooling; there is no interference with the oxygen supply. Water is made more effective against such fires through the use of fog nozzles, or the use of foaming agents. If a complete blanket of foam is built up, the outside air is cut off. Other extinguishing agents found effective against liquid fuel fires include carbon tetrachloride, chlorobromomethane, carbon dioxide gas, and the dry powders (most commonly bicarbonate of soda). The first of these is almost out of use because of toxicity problems and problems with extinguisher designs.

For many years it was believed that the mechanism of extinguishment for bicarbonate of soda was that it broke down in the presence of flames to release carbon dioxide gas which put out the fire. The carbon dioxide was believed to displace oxygen, thereby "inerting" the fuel-atmosphere mixture, or rendering it noncombustible. But it was observed that large amounts of the powder remained after fires had been put out. Careful measurements on standard liquid fuel fires showed the minimum amounts of carbon dioxide gas and of bicarbonate of soda powder required to put out identical fires. Simple chemical calculations showed that there would not have been enough carbon dioxide gas if all the bicarbonate broke down. Yet most of the latter was laying on the ground around the fire pit! This triggered a series of investigations, not yet completed, into the mechanism of extinguishment, and the mechanism of combustion. It has been shown that the interference in the radiative heat transfer from the flames back to the liquid fuel reduces the rate of evaporation to an important degree. However, powders of similar physical properties but dissimilar chemical compositions were found to have quite different effectivenesses. Present work is aimed at better understanding of the chemical or physical effects of various inhibiting (extinguishing) agents on the processes of combustion. Points of study are the electron capture characteristics of the inhibitors and the production of ions in flames, with and without inhibitors.

2.3 Confinement

The overall damage caused by a fire in a building will be less if it can be confined to the room of origin than if additional parts of the building become involved. If the room-of-origin is provided with built-in effective extinguishment, the time during which the walls, floors, etc. must confine the fire may be minimal. The actual time will be a function of many variables such as contents (fire load), ventilation, and how the contents are distributed or packaged, as well as the extinguishing system. The time may be somewhat longer if reliance is placed on nearby fire fighters. If the building is remote and does not have its own provisions for extinguishment, the time may well be that required for the total burnout of the rooms' contents. The time during which a building element can withstand a fire is known as its fire endurance (or still fire resistance in some quarters). It is measured by procedures spelled out in a test method published by ASTM [3], NFPA [4], and UL [5]. The method calls for exposing a representative test specimen to a standard fire under appropriate load and restraint. The standard fire is defined by a sequence of prescribed temperatures (average of several points in the furnace chamber) at elapsed times [3], referred to as the Standard Time-Temperature Curve [6]. The specimen is to be as representative of actual use as possible, as to materials, design, and workmanship. The conditions of loading and restraint also are to be representative of expected use. Constructions expected to carry loads in use must sustain the applied load throughout the test, except that steel columns or beams may be tested without load if protected by materials not intended to carry load. In that case, they are judged against an average temperature of 1000°F at one cross-section or a maximum of 1200°F. Walls and partitions, floors and roofs must not allow the passage of flames or gases hot enough to ignite cotton waste. Neither may heat transfer through them be such as to raise the average temperature on the unexposed surface by 250°F or the maximum by 325°F. A separate test for ceilings under lofts or attics has been used very infrequently. A hose-stream test for walls or partitions may be made on the fire endurance specimen or a duplicate exposed for a shorter period.

As indicated in the preceding paragraphs, structural elements often need protection, and frequently the protection is provided by materials having comparatively low strengths. Unprotected steel members will lose strength and fail in a few minutes [7, 8]. The same members have been protected by materials such that the resulting systems exhibited fire endurance of several hours in actual tests. Sprinklers have been used also as protection for bare structural steel systems. Unprotected wood ignites and burns but continues to support design loads until well charred. With heavy timber construction, this may be for a

significant time[7, 9]. Conventional wood frame construction can be protected so that the resulting assembly has two hours fire endurance [9, 10, 11] although some building code provisions limit ratings of assemblies containing combustibles to a maximum of one hour.

The materials used to protect structural elements may be used to encase or otherwise follow the general outlines of columns, beams, girders, etc., or as a membrane (ceiling or partition) between the structural system and the potential fire. Commonly used materials usually have low thermal conductivity, high heat capacity, resistance to thermal shock, or undergo endothermic changes of state; or exhibit several of these properties. All must remain in place to continue their protective functions for meaningful time periods. All should have very little, if any, combustible content. Mineral and glass fiber or foam insulations offer low thermal conductivities. Brick and concrete have high heat capacity, due in part to their high densities. Some bricks, tiles, and plasters, and especially the ceramics, have good resistance to thermal shock. The plasters, and to a lesser extent concretes, undergo changes involving the liberation of water of crystallization. Both the release of the water, and its subsequent evaporation, are endothermic. These are but a few of the many fire protective materials, some of which have several of the desirable properties. Even wood, which ultimately adds fuel to the fire, has low thermal conductivity. However, it is not generally considered to be a fire protective material.

Various assemblies of structural and fire protective elements have been tested, according to the standard test method [3], by recognized laboratories. The results of these tests have been used by many local building officials in assigning ratings or approvals for construction within their respective jurisdictions. However, the many demands on the time of the local building officials have lead to their increasing reliance on others, such as central state offices, the model code groups, or the insurance bureaus for expert advice as to ratings. Through the latter groups, the expertise of a few is made available to many. This is accomplished through analysis of very special constructions plus the publishing of lists of ratings based on actual fire test results. The lists serve not only as guides to the local official, but also to the engineer (Government, industry, or private), architect, and building owner. Some lists are primarily generic, i. e., they reference constructions in terms of material descriptions (2 x 4 studs, 1/2-in gypsum wall-board, 3.4 lb expanded metal lath, plaster or concrete by mix and aggregate), and the rating may be assumed to apply to any material complying with the given description. The description of the specimen and its component materials frequently includes physical properties and reference to applicable nationally recognized standards and specifications. Other ratings lists are primarily proprietary, i. e., they reference constructions in terms of the proprietary materials actually tested, and the description involves the trade name and manufacturer's designation. Such

a list is published by the Underwriters' Laboratories [10], which organization also authorizes the labeling of tested products to indicate they are the same as those used to achieve specified ratings. Of course, for example, proprietary acoustical tile is used, and tested, under 2 x 8 joists. Also, the more comprehensive lists include ratings based on data from all available sources and include both proprietary assemblies and generic assemblies [7].

3. Fire Protection Problems

Although the overall goal of fire protection - safety of life and property - is easily recognized and justified, the full implementation of fire protection requires adequate understanding of the problems that are encountered. Research aimed at providing protection is most effective only when the hazard to be protected against is well known or is studied. In fact, the program of study of the hazard often produces the protection. Penicillin was discovered in the course of a general study of the characteristics of bacteria.

The hazards to life and property may be subdivided into areas corresponding to fields of study into the defenses against fire. The Bureau has work in progress in some of these areas.

3.1 Ignition

The ignition characteristics of materials are of primary importance in determining either the hazard they represent or the protection they can offer. We have all been warned, from childhood, of the danger of the pile of oily rags in the closet and the old newspapers in the attic. More recently we have heard of "exploding sweaters." There are two problems here. One is ease of ignition, when exposed to an outside source, the other is the problem popularly called "spontaneous ignition." More accurate terms are "self heating" and "self ignition," which have been defined clearly [6] and are used by technical people in the field.

Self-heating is, as the name implies, the phenomenon whereby a material undergoes temperature increases as a result of exothermic reactions. The action of bacteria in stored grain, and the setting of portland cement are both examples. If the reaction produces only a moderate amount of heat or the material configuration is such that it can escape rapidly, there is relatively little temperature rise and no problem. If the material is in large masses, so that the heat at the center cannot escape rapidly as it is liberated, the temperature will increase more and problems may arise. As the temperature differential between inside-the-pile and the ambient increases, the rate of heat conduction increases.

Unfortunately, the reaction, and rate of heat production, also go up with temperature increase. So long as the rate of heat production exceeds the rate of heat loss, the material increases in temperature; i.e., it "self heats." This can, and often does, continue until ignition occurs. The self-ignition temperature is defined [6] as the minimum initial temperature from which self-heating will lead to ignition.

The Bureau undertook a study of a particular example of this problem after a disastrous Army warehouse fire in 1950 [12]. This was followed by more fundamental studies of the phenomenon and of the effects of pile size and ventilation [13]. An adiabatic furnace was developed which simulated the behavior at the center of a perfectly insulating (infinitely large) pile. From these studies, suggestions were made regarding maximum size of unventilated piles in warehouses, as a function of the maximum ambient to be expected.

The original warehouse fire had been due in part to the fact that the wood fiberboard had been stacked while still hot from the manufacturing-process dryers. This is another, related, problem that should be kept in mind by the military who so often purchase quantities too large to be supplied from stock.

Ease of ignition is one of the two characteristics of flammability. The other is being subject to rapid flaming combustion. This rapidity can lead to high-speed flame spread over appreciable distances. This aspect will be discussed later in this paper. At this point, we will consider mainly ease of ignition and rapid combustion without spread over large distances. We are all familiar with the easily ignited flammable liquids such as the petroleum-based fuels, solvents, vehicles, and cleaners. They volatilize at or near room temperatures. The vapors mix with air to form, within certain ranges of proportions, combustible mixtures which require but a spark for ignition. Not so familiar are the ignition characteristics of some fabrics, particularly those produced with a fuzzy, or brushed, texture which is subject to surface flash. Several deaths or serious injuries have resulted from ignition of clothing made from such materials. The Bureau has recently made a study of various test methods for fabric flammability and now is studying their applicability to non-woven films of plastics, which constitute a small but increasing percentage of wearing apparel. This work is in connection with the responsibility assigned to the Secretary of Commerce in the Flammable Fabrics Act [14], which makes specific reference to two test methods [15, 16].

A final problem on ease-of-ignition, of greater interest to the military engineer than to the general populus, is the effect of new and exotic materials on the ignition properties of conventional materials. For example, liquid oxygen greatly increases the ignitability of many common materials.

3.2 Growth and Spread

If you have ever tried to burn out a tree stump, or even a four-by-four timber, you know that it does not ignite easily nor burn vigorously. Yet an equal amount of wood in shavings will burn with well-nigh explosive rapidity. Dust explosions are well documented, occurring in sawmills, mines, grain storage, and similar cases. Bureau studies have developed increased understanding of the parameters affecting fire growth in the range between slow smoldering and flash fires. One very important variable is the amount of fuel available. Of equal or greater importance is its distribution. The ratio of surface area to volume and the amount of air available both enter in. For liquid fuels, this means the broad shallow pool burns more vigorously than the narrow deep pool. For solid fuels, the size and packing of the individual pieces are determinants. However, as spacing becomes large, another effect becomes noticeable. The rate of burning decreases due to the reduced intensity of thermal feedback from the flames to the fuel. This is part of the difficulty with burning the stump or the single four-by-four. No other flame source is feeding energy to the burning member.

The amount of air available, or the ventilation, has been mentioned as an important factor in the rate-of-burning. It has been pointed out how the dispersion of the fuel may regulate the ventilation and, thereby, the growth of the fire. However, in many building fires, the growth is controlled by the room ventilation, rather than by the fuel array. The Fire Research Section staff have shown the effect of compartment ventilation on the growth of fires. The rate-of-burning increases linearly with increase in ventilation up to a transition area where the rate drops off. Further increase in ventilation is accompanied by a linear increase in rate, parallel to but offset from the original line of increase. The second section of the line continues to a level-off, or constant rate. The initial portion of the line corresponds to the condition where the fuel (wood) is giving off combustible volatiles which burn at the ventilation opening. The portion of the line above the transition zone corresponds to the condition where ventilation is adequate for the volatiles to burn at the fuel crib in the compartment. The final constant rate portion corresponds to the condition where compartment ventilation no longer regulates the fire. The crib is burning freely, regulating the fire by its own geometry, essentially as it would in the open.

We have seen that the growth of a fire in the room-of-origin is controlled by the amount of fuel and by ventilation. The growth, or spread, to other parts of the building cannot take place unless there is fuel and oxygen in other parts. However, the mechanism by which it spreads may or may not be dependent on a continuous, oxygen-supplied path of fuel. Gases hot enough to ignite combustibles have travelled along corridors, stairwells, and elevator shafts with the result that the fire spreads to distant locations without necessarily involving intervening locations. This may include

bypassing combustibles if the hot gases displace the oxygen to the extent that there is not enough left to support combustion. Also, the hot gases themselves may be combustible, needing only an air supply for ignition.

A second common mechanism of fire growth, still not involving the burning of all the combustibles available along the way, is surface flame spread. Flames spread rapidly over the surfaces of many materials used to decorate or finish floors, walls, or ceilings; some of these materials do not burn readily in bulk. The ceiling surfaces are particularly susceptible, due to the buoyancy of flames or hot gases. Also, some surfaces not originally susceptible to rapid flame spread become so through the build-up of grease, grime, or multiple coats of paint. The latter becomes a particularly serious problem in ducts and old structures.

The hazard represented by surface flame spread has been the subject of much concern by building and fire officials, designers and others. Many individuals and groups have worked toward the development of a reliable test method for measuring it. ASTM has adopted a method developed by Underwriters' Laboratories, E-84 [18], and one developed by NBS, E 162-T [19]. The former employs a 25-ft long specimen; the latter a 6- by 18-in. specimen. UL has used their method for rating materials since about 1950 and it has been referenced by many building code groups or officials, and by government construction agencies. The radiant panel method was developed with the aim of providing a small inexpensive apparatus and a simple rapid test procedure suitable for installation and use by manufacturers in their research and development work. It has proved to be of interest to some building code officials and to the government construction agencies [20].

The two flame spread methods mentioned in the preceding paragraph are intended primarily for rigid finish materials or finishes permanently applied to rigid substrates. They also have been used for measurements of flammability of fabrics and similar materials not ordinarily a part of the building and, therefore, not always subject to the same building code or other regulatory provisions. The hazards involved in such materials are those of a light, well-ventilated, and often easily ignited fuel source, plus a material used in such a manner that it may permit the spread of a very localized ignition to other combustibles in a room, or to cut off escape. How many wastebaskets are near draperies? How many dropped cigarettes fall on carpets? Partly because of the different conditions of use and the particular ignition sources to which they are exposed, several special tests have been developed for fabrics and other thin sheet materials [15, 16, 17]. Our work with some of these has been mentioned in comments on clothing problems.

3.3 Life Hazard

Thus far, we have discussed fire protection primarily in terms of the building and its contents. This was not because life safety was considered to be of secondary importance. It appeared more logical to describe some of the structure-material considerations before describing how they applied to life safety.

The protection of life from fire can be accomplished by a great number of means, but these can be placed under two broad categories: (1) escape from dangerous proximity, and (2) protection from the effects of fire until rescue can be effected. These categories are broad and there is much overlap. The same building elements that would protect people if trapped in a building may well prevent the entrapment by keeping the fire from blocking escape routes.

There are a few fire associated hazards to life that are not property hazards, and vice versa, but for the most part, what is protection for one is protection for both. Therefore, most of what has been covered thus far in this paper applies to life safety. I trust the application is obvious enough that it need not be restated in detail. For example, reexamination of the fire endurance test criteria [3] in section 2.3 Confinement, will show that although they are phrased in terms of safety to materials, they will assure tenable conditions in most adjoining spaces.

Now let us consider life hazards not normally property hazards. The development of non-life-supporting atmospheres is probably the most significant. Toxic gases are usually produced as products of combustion. Phosgene, chlorine, hydrochloric acid, and other exotic gases are produced by the combustion or thermal decomposition of some organic materials; large amounts of carbon monoxide are produced by nearly all. Carbon monoxide has been believed to be the most dangerous because of the much greater quantities produced and the fact that it is odorless and colorless. However, there is growing belief that a major portion of fire associated fatalities are cases of smothering; i.e., concentration of non-toxic gas (such as carbon dioxide) builds up to the point that the oxygen content falls below that required to sustain life. The same effect may result if the fire depletes the oxygen. For example, after the fire storm at Hamburg in World War II, large numbers of people were found dead in underground shelters, with no signs of burns, poisoning, or violence. On the contrary, they were in relaxed positions. The severe fire had reduced the atmospheric oxygen content sharply.

It appears that relatively little is known about toxic gases and their effects on human life. The dearth of knowledge approaches totality when the subject shifts to mixtures of toxic gases. Obviously, this is an area in which direct experimentation would be most difficult. As a result, the approach has been to avoid toxic gases rather than to learn man's limits of tolerance. This is just as well for, among other good reasons, the concentrations developed and the duration of exposure resulting from a building fire would be almost as unpredictable and uncontrolled as the fire itself. At present, there is increasing concern over the inclusion in buildings of materials known or thought likely to produce toxic gases if involved in a fire.

The other category for means of life protection is escape. This encompasses requirements for adequate and well-marked exits, fire doors, enclosed stairwells, fire escapes, internal alarm systems, fire drills, and directions for alternates such as escape over roof-tops and through adjoining buildings. A very important subcategory to escape is the rescue equipment and training of the available fire departments. I am sure we are all greatly indebted to the fire departments for the many truly heroic rescues they make, only a few of which receive "front page" recognition.

Several years ago, the Bureau conducted surveys of the traffic capabilities of corridors, stairways, and exits [21] which served as a guide in the building exits provisions in codes. Recently, we have completed a study of the effectiveness of dwelling doors, and of modifications to them, as barriers to fire and smoke [22]. We are engaged in continuing studies related to the development of smoke and toxic gases from materials. A paper describing a method for measuring smoke will be presented next month at the Annual Meeting of the American Society for Testing and Materials. As many of you know, a smoke-blocked corridor represents just as much a barrier, psychologically, as a wall of flames or of brick, to most people. This was demonstrated tragically in some recent fires and is receiving greatly increased attention by building officials. It is to be hoped that the effects of discipline make this a less significant hazard to military personnel.

3.4 Property Hazards

A fire in a building represents a great hazard to the building and its contents. The direct effects of heat and flame include ignition and combustion, structural damage and collapse, smoke damage, etc. Broadly speaking, "smoke damage" can range from a lingering smell, through discoloration, to harmful chemical changes and rapid corrosion. The same hydrochloric acid that could kill those trapped in a building could ruin a storage of precision military equipment. The water used to fight a fire can be just as damaging to the contents as the fire. Of course,

with the water there is hope of reducing extent of damage to something less than total. The merit of adequately designed and maintained sprinkler systems is the ability to attack the fire quickly and to minimize the extent of the fire, and of water damage.

However, the hazard due to a fire is not confined to the building of origin. Mrs. O'Leary's cow kicked over the lantern on a very windy day in Chicago. Direct impingement of flames from a burning building to an unignited one, flying brands, and thermal radiation all represent means of ignition to nearby structures or materials. The Bureau has studied the susceptibility of materials to ignition from all these sources, often at the request of the military agencies, although we do not now have any on-going work on any of them. The Japanese, Canadians, and British are all working, or have done work recently, on the spread of fires between buildings.

3.5 Non-Building Fires

Although this paper is directed toward building fires, it seems appropriate to make brief mention of non-building fires. Many of these are of importance to the military.

Shipboard fires are most often in the public eye in terms of commercial or passenger vessels. This falls under the interests of the Coast Guard (Treasury Department) and the Maritime Administration (Commerce Department). However, the same considerations apply to military transport vessels. Some years ago, during the design of the SS United States, the Bureau's Fire Research Section conducted a full-scale stateroom burnout. More recently, we provided a member of a committee to investigate the need for rules (by Coast Guard) on the fire safety procedures for empty tankers. At present, we are providing a Technical Advisor to the U. S. Delegation to the Inter-governmental Maritime Cooperative Organization.

Aircraft fires are also a serious public hazard. The Federal Aviation Agency has had a fire program for several years. The Bureau has helped FAA, both with particular studies and with the development of FAA's in-house facilities and competence.

Fires are a problem to other transport systems. Buses, trucks, trains, and private automobiles are all susceptible to fires, particularly as an aftermath of accidents. The Interstate Commerce Commission has regulations on the handling of hazardous cargoes.

Natural resource fires represent a great loss in themselves and a hazard to buildings, transportation systems, and other materials. The Bureau of Mines is very active in the area of fire safety in mines and oil wells. The Forest Service is concerned with forest and prairie fires, and maintains several excellent laboratories. The Department of Agriculture publishes information on the specialized problems of farms and the application of fire technology to those problems.

4. Non-Government Activity

The extent of non-government fire research and fire protection activity is difficult to assess. Industry carries on a very large program of research and development; its description is beyond the scope of this paper. However, it is a very important and significant source of technical progress. A few examples must be mentioned. These include the work of the Underwriters' Laboratories [10] and Factory Mutual Engineering, of Ohio State University and Southwest Research Institute; the publications of the National Fire Protection Association [12, 17, 23, 24] and the American Insurance Association (formerly National Board of Fire Underwriters) [7, 11]; and the model codes developed and promulgated by the Building Officials Conference of America [25], the International Conference of Building Officials [26], the Southern Building Code Congress [27], and AIA [28]. The Portland Cement Association has excellent facilities in Skokie, Illinois. Several individual companies have installed furnaces, tunnels, radiant panels, smoke measurement equipment and/or other fire test apparatus. These are used for the development of proprietary products. Several trade associations that do not have their own facilities have been very active sponsors of tests or studies in commercial or university laboratories. Because industry is interested mainly (and quite naturally) in publicizing only those final developments it chooses to market, the extent of their work is not obvious. The large number of new products that come on the market indicate that industry's efforts are quite large. The development of fire-fighting equipment is largely an industry activity, responsive to the needs of fire departments. In addition to new products, industry has produced many of the test methods and of the improvements thereto.

5. Summary

This paper has attempted to describe technical considerations involved in the field of fire protection and, thereby, point out the breadth and complexity of this field. It has pointed out areas in which the National Bureau of Standards is working or has worked. To a lesser degree, it has made mention of the work of other Government agencies, and of non-government organizations. This is not intended to slight in any way the work of others than NBS; it merely reflects the author's greater familiarity with the work of NBS.

The field of fire protection has been broken into areas such as material (or occupancy), structure, and life safety. It has been viewed under the subjects of ignition, growth and spread, confinement, detection, extinguishment, and smoke and toxic products. Yet the complexity of the problem, and the ingenuity of some of the technical advances, are such that rarely can it be properly said that any one item falls clearly under only one area and subject.

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