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Overview

Fire has been a scourge of society for a very long time now, both in terms of its human and economic impact: fire fatalities, fire injuries, and direct and indirect losses from fire. North America, in particular, has the dubious distinction of hosting the highest fire fatality rate per capita in the industrialized world.

The traditional way in which fire studies have been made is by using fire tests, of various degrees of usefulness, which measure a particular fire property (or fire-test-response characteristic, in ASTM fire parlance). The results have then been used to rank materials based on a single fire property. Unfortunately, fire performance (response of materials or products in fires rather than fire tests) is often poorly predicted by many tests which have usually not been designed based on sound engineering principles.

It has now become clear that there needs to be better predictive ways to make fire safety decisions. These predictive tools are fire models, which are used to analyze (or assess) the danger (fire hazard) associated with burning a particular material, product, or assembly in a specified situation (fire scenario). Thus, ASTM has defined fire hazard as "the potential for harm to people, property, or operations" (ASTM Terminology Relating to Fire Standards, E 176-91d). However, fire hazard presupposes that a fire will take place. Fire risk is a measure of fire loss (life, health, animals, or property) that combines (a) the potential for harm in the various fire scenarios that can occur and (b) the probabilities of occurrence of those scenarios, within a specified period, in a defined occupancy or situation. As such, fire risk does not assume that a fire will take place, but it incorporates the probability of the fire occurring. Thus, whereas fire hazard measures the potential for harm with respect to one single scenario, fire risk measures the potential for harm in the full range of all possible scenarios, using the probabilities of each one of those scenarios to measure the relative importance of each of them. Therefore, a fire risk measure is a statistic derived from an underlying probability distribution on a measure of fire hazard. It is important to stress, however, that by its nature, a fire risk measure is not applicable to the prediction of the occurrence or of the potential for harm of an individual fire.

With the expansion of the capability of large computers and the increased use of the personal computer, it has become possible for many people to manipulate large amounts of information, and to use it in order to predict fire performance. Among the consequences of this has been the appearance of a number of fire models that can predict fire hazard or fire risk.

The ASTM board has adopted a policy on fire standards. This policy acknowledges the existence of three kinds of fire standards: fire-test response standards, fire hazard assessment standards, and fire risk assessment standards. The board gave committee E-5 on Fire Standards the exclusive authority to write fire hazard or fire risk assessment standards. In order to better understand what this involves, Subcommittee E-5.35 on Fire Hazard and Fire Risk Assessment is working on standard guides for the development of fire hazard and fire risk assessment standards. Several other subcommittees are also working, and have made various degrees of progress on a number of fire hazard assessment standards.

In order to aid in the understanding of fire hazard and fire risk assessment models, ASTM Committee E-5 has organized this international symposium, conceived within subcommittee E-5.32 on Research, held in San Antonio, TX, on 3 Dec. 1990.

The 16 papers published herein can be divided into 5 broad categories: (1) Introduction to Fire Hazard and Fire Risk Assessment, (2) Use of Fire Tests for Fire Hazard Assessment, (3) Fire Hazard Assessment, (4) Fire Risk Assessment, and (5) Fire Risk Assessment and Building Codes.

Introduction to Fire Hazard and Fire Risk Assessment

This section includes papers that deal with important aspects that need to be considered in order to carry out a fire hazard or a fire risk assessment.

A common misconception in the public view of fire hazard is that fire hazard is primarily or exclusively a matter of smoke toxicity. The paper by Debanne et al. summarizes the two most important sets of human forensic studies carried out to investigate the issue of smoke toxicity and its implications for fire hazard. The studies showed that the victim population distributions are very different for fires and non–fire carbon monoxide fatalities, but that the blood carboxyhemoglobin distributions, once equal populations are compared, are very similar. Furthermore, the importance of carbon monoxide in fire atmospheres has not changed between the 1940s and the 1980s. The authors conclude that death in fires, by smoke inhalation, appears to be overwhelmingly associated with carbon monoxide poisoning. Moreover, their work shows that carbon monoxide can kill human beings (rather than test animals) at blood carboxyhemoglobin levels much lower than was previously thought possible. The combination of this finding and the fact that most small scale smoke toxicity tests cannot predict carbon monoxide levels adequately means that such tests, and smoke toxicity in general, must play a small role in fire hazard assessment.

It is often thought that fire hazard and fire risk assessment is necessarily the result of complex mathematical models. Watts shows that heuristic models of fire safety, which he calls fire risk rating schedules, can be used as indicators of fire safety. He presents in his paper, three examples of fire risk rating schedules which have varying degrees of sophistication. The first one is the prediction of heat release rates of upholstered furniture by using a model that combines laboratory scale heat release measurements with various empirical parameters. The next one is the basis for ASTM Practice for Assessment of Fire Risk by Occupancy Classification (Commentary), E 931, which developed an occupancy classification based on a Delphi approach and assigned various weighting values to a number of elements. Although this is no longer accepted as a form of fire risk assessment, it is a very useful simple means to give numerical results to common sense. The final example is a trade-off model, again derived from a Delphi approach, to trade off various fire safety alternatives, such as active (smoke detectors, sprinklers) and passive (products with better fire performance) fire protection measures.

Use of Fire Tests for Fire Hazard Assessment

The papers in this section deal with means by which fire tests can be used to predict fire hazard in a variety of fire scenarios.

One of the types of fire which has the most serious potential is the case of the high intensity fires which can occur in petrochemical facilities, or when liquid fuels are transported. In ASTM Subcommittee E-5.11 there is work in progress to develop a standard test method to address such fires. Keltner et al. addresses one aspect of this problem, when dealing with petrochemical plant fires. They show that it is essential in such cases to adequately characterize the fire environment. Moreover, in that connection they discuss those cases where fire temperature is the dominant issue to be addressed and those other cases where fire heat flux is the more important parameter, since there is no univocal correlation between the two. They conclude that for good fire testing practice both temperature and heat flux should be taken into consideration before making a fire safety decision.

Electrical cables carry energy and are surrounded by combustible coatings. They are, thus, a constant potential threat of fire, at least in concept. In fact, the number of fires proven to be caused by electrical cables are relatively few. This is likely due, at least in part, to the fact that cables are regulated by the National Electrical Code (NEC). However, the code requires large-scale testing of cables, mainly for flame spread. Recent developments have suggested that rate of heat release is a property which is at least as important as flame spread and which can be measured in a small–scale instrument, for example the cone calorimeter. This paper shows the way to predict the results of large-scale vertical cable tray tests from small-scale cone calorimeter tests, by using simple linear correlations. Two other findings are of further interest: that large scale testing facilities can differ in many details and yet give very similar heat and smoke release results and that the smoke obscuration resulting from full-scale fires is very closely associated with the heat released and the amount of cable burnt.

Traditional plumbing materials have been metals and cement. However, in recent years there has been an exponential growth in the number of plastic materials used to make pipe, tube, or conduit. Zicherman investigates, by using a number of fire tests that measure fire penetration, particularly ASTM Methods for Fire Tests of Through-Penetration Fire Stops, E 814 and ASTM Method for Fire Tests of Building Construction and Materials, E 119, the fire hazard associated with these systems. The author presents a very comprehensive literature survey to analyze the fire performance of plastic pipe, tube, and conduit. From it he develops a generic fire performance ranking of these plastic products depending on chemical composition. The author concludes that the use of plastic materials for these applications does not cause increased fire hazard, provided each product is used for the correct application and adequate assembly and installation procedures are followed. Moreover, in order to carry out fire hazard assessments, these installation guidelines should be accompanied by the use of results of standard tests together with knowledge of field performance.

Fire Hazard Assessment

The papers in this section address specific fire hazard assessment problems, by using computer models, statistics, a combination of models and engineering judgment, or a combination of experiments and analyses.

DiNenno and Beyler address the way in which new, unconventional materials (composites) might be used to replace traditional materials in naval applications. The new materials had not been expected to offer the same degree of fire protection, but were known to yield various other advantages. Thus, the authors indicate that the results of various fire response tests can then be used, in conjunction with a "fire hazard analysis package" to determine an acceptable level of fire hazard. Unfortunately, the authors argue that the failings of the existing "packages" make it necessary to use sound engineering judgment to overcome their limitations, and to combine different approaches. Once that has been done, progress can be made in evaluating fire hazard and in weighing the results against the other advantages and disadvantages.

Pressure liquefied gas tanks, especially when used in transportation, need to offer particular protection because of the potential intense energy of any resulting fire. The best known examples of such fires are the Boiling Liquid Expanding Vapor Explosions (BLEVEs) which have caused many serious accidents. Sumathipala et al. have developed a zone fire model, which they call PLGS-1, together with computational rules, PLGS-2D, to describe the behavior of such tanks when there is an external pool fire in their proximity. Results from experiments involving both midsize (40 L) and large externally-heated partially-filled horizontal cylindrical vessels have been compared with the predictions of the computer models. This work has focussed on heat transfer and pressure response parameters, in order to improve the understanding of the physical phenomena and develop fire protection strategies.

Fatal fires in aircraft seldom occur. However, when such a fire occurs, often following a survivable crash, the results can be catastrophic. Hill et al. have initiated a study of the benefits and disbenefits of installing an onboard aircraft cabin water spray system. The study, which is currently underway, involves aviation authorities of various countries, including the United States, United Kingdom, France, and Canada. This system has been shown by the authors in full-scale aircraft fire tests, to decrease fire temperatures, and thus, lower burning rates, heat release rates, and smoke emission rates. On the other hand, such a system is generally incapable of extinguishing the fire and can cause a series of unwelcome consequences in case of false discharges. The final result of the study will likely determine whether such systems will be installed in commercial aircraft.

Fire Risk Assessment

This section contains papers which address the problem of fire risk, either by explaining what a fire risk model is, or by using one to apply to a specific fire scenario.

After lengthy discussions and disagreements, both based on fundamental concepts and terminology, the paper by Hall is an attempt to clarify what a comprehensive fire risk assessment is and is not. The paper describes the most common misconceptions about fire risk analysis. The paper also describes key concepts in fire risk analysis and shows how fire risk is simply one facet of overall risk. In particular, it explains the types of fires and types of human behavior that should not be excluded. The paper poses questions to the reader in order to ascertain whether the model in question is a fire risk assessment model or something else.

The concepts discussed by Hall are illustrated in the work of a research team put together by the National Fire Protection Research Foundation (NFPRF) to develop a comprehensive fire risk assessment methodology that could be applied to a large number of fire scenarios and a large number of products. The paper by Bukowski et al. is one result of that program. The authors start by explaining the methodology developed, which is based on the use of the fire hazard model HAZARD I, followed by an 8-step procedure. In this approach, after the product/occupancy set has been selected, representative characteristics are chosen and incorporated into the fire model. The model is then run for a base case product, which can represent the average of what is presently being used, or a particular product of specific interest, for whatever reason. The fire risk assessment is then carried out for the base case. The product characteristics are then changed to those of a new product and the fire risk assessment carried out again. The process ends with the two results being compared. This paper describes four cases studied: (1) upholstered furniture in residences (the single fire scenario associated with the largest number of fire deaths), (2) carpets in offices (a very low fire risk scenario), (3) concealed combustibles (electrical cables) in hotels (a low fire risk scenario, but one which has been associated with public controversy), and (4) interior finish in restaurants (a case which would address heavily regulated products and would introduce vertical flame spread into the model). In every case, the results are compared with the fire experience. The work succeeded in developing a methodology and applying it satisfactorily to a variety of scenarios.

A different kind of fire risk assessment methodology is applied by Steciak and Zalosh to the use of gaseous (Halon 1301) extinguishing systems in computer rooms. The methodology uses occurrence probability data applied to the different failure scenarios for its calculations. Finally, the effects of various measures, such as human intervention, inspection intervals, and system tests were also analyzed. The scenarios investigated were: an electrical fire inside a cabinet, a paper trash fire in the room, and a fire outside the room causing smoke to enter the room. The extinguishing system was found to be most effective against the electrical fire and to be least effective against the paper trash fire, which can easily reignite once the gas has been depleted.

A storage facility for liquefied petroleum gas can present considerable fire risk. Barry examines this for a plant with four very large LPG tanks by using a combination of fire risk assessment techniques and engineering judgment. He applies a combination of probabilistic and deterministic modeling techniques to assess the risk of off-site human fatality. The potential events being investigated include BLEVEs, unconfined vapor cloud explosions, and flash fires. Ignition potential is assessed taking into account statistical data and fuel properties. All of the information is condensed into an event tree used to develop the potential fire and explosion scenarios. The resulting risk profiles depict the probability of fatalities occurring based on distance from the facility.

Fire Risk Assessment and Building Codes

All the papers in this section deal with fire risk assessment methods which are geared to use by building code officials or local authorities.

A group at the University of Sydney (Australia), the Warren Centre, developed a fire risk model that could be used by Australian building regulations. The resulting fire risk assessment model, described in the paper by Beck et al., serves to identify cost effective combinations of fire safety measures that will ensure the same level of fire safety that is being mandated with prescriptive measures. This project was followed by the development of the Australian National Building Safety Systems Code which provides flexible procedures for building design, based on sound technological decisions. The fire risk assessment model used submodels for detailed design and specification of individual fire safety issues. The project developed some demonstration risk assessment models, particularly for high rise buildings.

The model described in the previous paper was also used in Canada to develop analytical tools for assessing the cost effectiveness of fire safety and protection provision in buildings. The paper by Hadjisophocleous and Yung describes the application of the model to a 28-story high rise apartment building. They investigate nine combinations of alarm and sprinkler systems and present the results in terms of expected risk–to–life and fire cost expectation. This would allow designers to provide a fire performance approach to building design: they need to prove only that their proposal gives an expected risk-to-life no greater than that obtained from the prescriptive code requirements. At the same time it allows the designer to choose between different approaches, that is, the one that has the lowest fire cost expectation.

The Ontario (Canada) Ministry of Housing, responsible for the Ontario Building Code, sponsored the development of an analytical model to assess the social and economic impact of potential changes to the Building Code; fire risk assessment is just one of the elements in this model. The model developed deals with some 20 different building types. Overall base case fire risk, in terms of property damage, injury, or loss of life, is established from fire statistics. A national Delphi panel has estimated the probabilities for individual fire events in the base case, using specially prepared risk event trees. The same Delphi panel also estimates the revised individual probabilities associated with any specific code change proposal and the resulting overall risk. The paper by Katzin et al. describes the overall model in general and focusses on the fire risk assessment aspect. The application example presented discusses the effects of mandating the use of sprinklers in all new low-rise residential dwellings governed by the Ontario Building Code.

The final paper is an application of the concepts of fire risk assessment at the community level. Harvey, a fire chief, has been instrumental in using the concepts encompassed in a fire risk assessment model to evaluate fire safety in his community of Boulder, CO. Local planners, building and fire officials, owners, designers, and builders worked as a team to use new engineering methods for enhancing fire safety in the community while minimizing cost increases. This involved not only fire protection measures in the buildings themselves (sprinklers were eventually mandated) but also in the number of fire stations and their equipment. Entry into the system was voluntary at first but became mandatory when it was found that overall cost savings were attained, with no opposition from the public who could see the benefits.

Conclusions

The papers summarized above should provide the reader with a broad understanding of the issues involved in fire hazard and fire risk assessment and with an overview of some of the most interesting techniques available today. The diversity of papers is probably sufficient to offer different perspectives and tools both for workers in the field and for other readers concerned with fire safety. This is an area where advancements are occurring in leaps and bounds; however, the papers presented here should serve as an excellent literature data base. The symposium chairman thanks the other members of his committee, in particular Dr. Harry K. Hasegawa (Lawrence Livermore National Laboratory) and Dr. James R. Mehaffey (Forintek) for their invaluable assistance to make this publication possible. He also acknowledges the efforts of the authors and of the ASTM personnel who made this happen.

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