HISTORY OF FIRE TECHNOLOGY

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Abstract

The history of fire technology is explored for clues to guide future fire technology efforts. Emphasis is placed on those factors that encouraged, retarded, or restricted past efforts. The data were gathered from a series of interviews with persons involved in many of the past advances. Specific discussion is given to advances in the areas of risk appraisal, suppression, compartment fire modeling, and structural endurance.

My charge is to trace the development of selected fire protection methods. I have been asked to report on 1) the forces leading to the development and use of the methods, 2) the barriers that were faced, how they were overcome, the lessons learned, and 3) how did we get to where we are today. I approached this task by conducting a series of interviews with persons who have been in the forefront of the development of some of today's fire protection engineering computational method. In some cases, I was able to obtain some very good information; in others, hardly more than a chronology of events. In no case was I able to completely answer all of the questions raised by the Steering Committee of this Conference on Firesafety Design in the 21st Century. I believe, however, that I obtained interesting and useful information that can be helpful to this assembly in its deliberations.

The forces at work varied widely. They included industries seeking a new market or striving to protect an existing one, nations protecting their assets during war, a nation attempting to recover from the devastation of war, government programs in the US and elsewhere fulfilling their charge to improve the lot of their people or meet national interests, NFPA Committees striving to either improve a standard or keep up with the changing environment of the hazard being addressed and the fire insurance industry responding to demands to insure higher risk facilities.

Two common barriers that had to be overcome were obtaining the resources needed for development and gaining acceptance of the product produced. In those instances where research and development were well funded, a blossoming period occurred. Acceptance is another problem. Technology transfer in any field requires a technical consensus on the validity of new methods. In our profession it is often difficult to develop truly professional consensus. The small academic base is, in my opinion, part of the problem. In other engineering disciplines, academic achievement and acceptance is an integral part of the technology development procedure. In fire protection engineering education, the academic departments have historically tended to accept and teach practice rather than produce methodologies.

In fire protection, there is an additional acceptance problem. Many critical fire protection decisions, of types that in other professions would be reserved to professional engineers, are made by non-engineers using various codes and standards in lieu of engineering analysis. Frequently, the first demand upon an emerging fire protection engineering technology is to reduce it to written words, tables, and on rare occasions curves that can be used by persons who do not have engineering competence. Often, even those having engineering credentials will press for this same type of simplification. One result often is a gestation period from the entry of a technology and its passing through conversion to non-engineering application in the field before the next stage of advance can take place. Sometimes the simplified approach becomes the accepted standard, and as such, the new obstruction to be overcome. This process may continue for months or years.

Back to the main theme, Dr. John Bryan of the University of Maryland, discussing how the profession has developed, capsulized the history of fire protection engineering into three phases. As Dr. Bryan put it, the first phase starts at about the turn of the century and continues up to World War II. During this phase, the prime interest of the fire protection engineer related to fire insurance underwriting and was concerned with evaluation of risk and determination of potential. The objective was economic return on investment (premium verses loss) and dollar loss limitation (maximum probable loss).

During World War II, the Federal Government mobilized fire protection engineering as part of the war effort. The thrust shifted to conservation of the industrial capacity and protection of the war resources. After the war various federal agencies, particularly the Navy and the Atomic Energy Commission (now part of the Department of Energy) continued significant fire protection engineering staffs. A few industries, such as DuPont, followed a similar pattern. The fire protection engineers working in government and industry often were part of the design team. As such, they were directly involved in fire protection system design and installation.

The third phase is our current phase. Dr. Bryan referred to it as the trend towards the fire protection engineer consultant. A large percentage of fire protection engineers today offer their services for a fee either as an independent or part of a consulting firm. They tend to specialize in first appraising risk followed by the design of the specific hardware and systems needed to manage that risk. Most consider their main stock-in-trade their ability to analyze risk and the consequences of a design change. Conservation of property is still important and in some areas paramount but very frequently, the question is life safety. Often, today's fire protection engineer in practice is called in to resolve the conflict between a set of requirements and the objectives of an owner. Recurrently, the challenge has shifted from one of the conservation of a resource to determining the least expensive, most effective, or most mission-compatible method of meeting an obligation.

For an ethical engineer, this presents a difficult problem. Today, the consultant is asked to trim away any excess conservatism. The only way he can ethically reduce safety factors or find excessive requirements is with sound technical knowledge.

The emergence of fire protection knowledge has occurred by bits and pieces and spurts from many sources. While this presentation does not cover every development involved, I believe that it presents enough vignettes to provide this body with a sense and a spectrum of the mechanisms involved. The rest of this presentation focuses on four areas of activity: risk analysis, suppression, compartment fire modeling, and structural endurance.

Risk Analysis

Risk Analysis is the essential tool for managing fire safety. Properly done, it provides the mechanism for the engineer to communicate with the decision maker. The decision maker may be an owner, an underwriter, a legislative body, or other authority.

The Dean Schedule. The story of risk analysis in the fire protection profession starts during the last decades of the nineteenth century. At that time fire insurance was sold as a competitive product with rates based on what the market would bear or undercutting of the competition. In those areas where the competition was high, rates were sometimes so low as to jeopardize the ability of the insurance company to pay losses. Conversely, in other areas, where competition was not high, the user was taxed beyond the comparative risk in an effort to optimize profit. In the late 1890's, an insurance executive, A. F. Dean, campaigned for a more equitable way to determine an appropriate premium that would assure sound insurance companies an equal treatment of the various insured parties.

Out of this grew the Analytic Schedule for the Measurement of Relative Fire Hazard, more commonly known as the Dean Schedule. The Dean Schedule is a fascinating document. The bulk of the document is a catalog of charges. More important, however, are the introductory chapters. Dean broke down the measurement of fire risk, as needed by an insurance company, in terms of ignition probability, fire development probability, and damageability. He further broke each of these down into its component elements. For example, in the case of ignition, his weighted probabilities included potentials from traffic, meaning the casual passage of persons and items, labor, power, and natural events such as lightning. The system could generate any of the charges in the catalog from the concepts set forth in the introductory chapters. The Dean Schedule went through many editions and survived as a major element in fire insurance ratings in that portion of the US from the Rockies and the Appalachians for more than half a century.

Returning to our basic theme, the driving force was economics and survival of an industry, at least in the eyes of Dean and his colleagues. This brings out a repetitive theme that has emerged from my interviews. Often, advances have centered upon individuals who both champion the cause and undertake the effort involved.

Until the period following World War II, fire insurance rates were the only real measurement of fire risk. In my early days in this profession, there were many attempts to relate the insurance rates to overall fire safety. So long as the objective was purely economic and, as is characteristic of fire insurance, averaged over a large number of facilities, such was often useful. Even today, where the objective is underwriting, fire insurance rates can continue to perform a valuable risk measurement function. They, however, are insufficiently general when the subject matter is beyond economics such as protection of life or where the concern is for an individual operation on its own merits rather than as a member of a class of risks.

Fire Grading of Buildings (UK). The next vignette and, to the best of my knowledge, the chronologically next step in risk measurement, occurred in the U K just after World War II. Both the war-time attacks and the use of alternative materials (some of which we now know were very combustible) caused the British to realize that there was a wide range of the speed of fire development, spread of fire between buildings, and other aspects of fire danger permitted by their bylaws and regulations. The British, at this time, also started to assemble one of the more important fire research and development groups in modern time, the Joint Fire Research Organization. Aspects of that organization live on in the Fire Research Station.

In this vignette the sponsor and driving force was the British government desiring to derive some benefit from its war time experience to do a better job in safeguarding its people. It occurred at a time when governments were willing to invest in the technical basis for regulations. The result was the document, "Fire Grading of Buildings". Similar to the Dean Schedule, it assigns points and scores in various methods of assembling them. The prime difference was an aim at protection of life. To my knowledge, this grading system was never adopted as a regulation. It, however, had a tremendous influence, particularly in the UK.

Building Codes and NBS Report BMS 92. Even though it is not actually a risk measurement system it would be inappropriate to move forward without mentioning the Building Materials and Structural Report, BMS 92, "Fire Resistance Classification of Building Construction". This was published as a National Bureau of Standards (now the National Institute of Standards and Technology) report and is the result of the work of an organization known as the Subcommittee on Fire Resistance Classification of the Central Housing Committee on Research Design and Construction. This Committee was made up of representatives from the several federal agencies responsible for both federal buildings and the financing of private construction. It is an example of the type of product that is produced from time to time by various committees. The report was published in 1942. It is the prototype underpinning of almost every building code in this nation. The source data from the report covers information on evacuation rate, fire loads, construction types and arrangements collected in the preceding twenty years. It represented the break between the early specification code and what was then referred to as a performance code. Today, we would more correctly refer to it as a component performance code. The BMS 92 report gave birth to the concept where individual items such as doors, walls, and protection systems are specified on the basis of performance. This, in terms of hourly ratings, flame spread ratings, discharge densities, and similar measurable values, gives the user wide latitude in the choice of material or item to fulfill the specific needs but very little latitude in substituting one component for another. The impact of the component performance code is to emphasize testing rather than risk appraisal. BMS 92 and the code concepts it spawned were both an important advances and a simplification that had a retarding effect on engineering advance. The component performance code by its nature leads to conformance rather than measurement of risk.

At this point the discussion of risk management systems moves into a sphere where I've either been personally involved or close enough to have a fair understanding of the process.

Goal-Oriented System for Fire Safety in Buildings. Let me first talk about the Goal-Oriented System for Fire Safety in Buildings. This was one of my first risk measurement systems and while it has died out, it is the underpinning of the Fire Safety Engineering Method developed here at Worcester Polytechnic Institute by Professor Fitzgerald. The goal-oriented system was itself a child of the International Conference on Fire Safety in High Rise Buildings held in 1971 at Airlie House, Virginia. That Conference was championed by the then Commissioner of Public Building Service, Arthur F. Sampson. Mr. Sampson was a new and dynamic leader who felt that the General Services Administration should step from a following position in building design management to that of a leader.

The concern for fire was but one of his many thrusts and the fire at One New York Plaza in New York was the triggering mechanism. He assigned me the problem of doing something worthwhile and visible to make GSA a leader in the attack on this problem. The result was the Airlie House Conference in 1971. There were a number of conclusions to that Conference but one of the main ones was that there was no systematic approach to handling fire safety in high rise buildings (or for that matter in other business and commercial buildings). Design concepts then in use did not consider specific problems arising in the modern high rise building with its vertical transportation, control environments, stack effects, and mass population.

Following through on the Airlie report, we put together an outline description of all of the elements fire and fire protection making a simple first cut of what eventually became the Event Logic Tree. This was presented to a group of federal fire protection leaders. Interestingly, there was one outsider at that meeting, Rolf Jensen. I don't remember why he was there but he stated that there was a strong potential in the idea presented but it had to be quantified and, in his words, "scrubbed out." We took that as a challenge and extended the Event Logic Tree to a rational full scope statement of the problem. This included the probablistic mathematical relationship for all the items in the tree. The goal oriented system itself was used only a few times for the development of fire protection for significant buildings. It fell into disuse after I left GSA. Its children, however, continued in the NFPA Decision Tree, the Building Fire Simulation Model, and the work of Bob Fitzgerald and the many items that work has spawned.

Returning to our theme of how did it come about and what were the forces, this is an example of a situation where an individual, myself in this case, accepted the need, had the opportunity and put in the effort. The environment at GSA at that time was very encouraging to me and in this case I would place both the environment setup by Mr. Sampson and myself as the co-champions.

<u>Fire Safety Evaluation Systems (FSES).</u> The next vignette is the Fire Safety Evaluation Systems (FSES). In terms of impact of the systems, I believe that the Fire Safety Evaluation Systems are second only to the Dean Schedule. An FSES is a grading system designed to develop descriptions of alternative total fires protection systems that are equivalent to but different from the system that would result from explicit compliance with the NFPA Life Safety Code. There are currently six different FSES's covering health care, board and care, detention and correction, and business occupancies. This discussion focuses on the first set -- health care facilities. The Fire Safety Evaluation Systems were originally born out of the success of fire safety advocates. These advocates persuaded the Congress to include in federal law a requirement that every nursing home must comply with the Life Safety Code to qualify for medicare and medicaid benefits. Once the law was passed, an elaborate oversight and inspection system involving contracts between the federal government and every state in the union established inspection systems. Sometimes these were under the direction of the State Fire Marshal and sometimes under the direction of the State Health Department. However, each investigator was required to certify in writing that the facility completely complied with the Life Safety Code except for the listed deficiencies. In nursing homes, enforcement was very complete and many facilities either closed down or undertook major renovations. Federal regulations also extended the requirement to comply with the Life Safety Code to hospitals but included the Joint Commission on Accreditation of Hospitals (JCAH) as an alterative approach to certification. This led in some areas to a competition between the state inspectors and the JCAH inspectors to see who could be most critical.

Much of the cost of improvement was paid by the taxpayer out of the medicare/medicaid fund. The Department of Health, Education, and Welfare (now the Department of Health and Human Services) in 1975 asked the National Bureau of Standards to investigate the possibility of meeting the intent of the Life Safety Code without rigid conformance to every requirement of the Life Safety Code. Their action was driven by a combination of; an obligation to assure fire safeguarded facilities, an economic concern, and a desire to reduce conflicts arising out of the ongoing program. The Fire Safety Evaluation Systems were the result. Here we have the case of a public authority that was responsible both for the safety and to a significant extent the cost of installing that safety cost effectively within budget.

The Fire Safety Evaluation System effort is a good place to discuss barriers. The largest single barrier in this case has been acceptance. The prime mechanism used to gain acceptance was submission of the system for inclusion in the Life Safety Code. This provided a broad based forum for review and comment. A number of persons expressed concern when the FSES concept was presented for adoption. Those with concern relative to the validity of this proposal fell into two overlapping camps. Both related to the capability of the Fire Safety Evaluation System to develop an alternative set of requirements for a facility that could differ from those of the Life Safety Code. An owner or his agent using the FSES could generate a package of requirements (a tailored code if you will) unique to that facility. In such a case, some of the requirements would likely be more stringent and some less stringent than that required by explicit compliance with the Life Safety Code. Sometimes, an FSES analysis produce hundreds of alternative approaches from which the decision maker could choose that which most suited his needs and desires.

There was concern that some of the solutions producible by the system could be seriously flawed. This problem was addressed by developing computerized systems that determined all of the potentially acceptable solutions. These were reviewed to determine any that had the possible flaws. Such cases were then studied by review groups composed of the potential users and other experts. Some flawed solutions were found and the system adjusted to provide the necessary conservatism to avoid these. This cycle of studying all of the possible solutions and including the users in the study surmounted that objective.

The second area of concern is more difficult to resolve and continues as of this date. It is endemic to any evaluation system whether it is automated like the FSES or individually developed by a consulting fire protection engineer. This is the concern among the regulatory authorities that this type of evaluation system passes control of acceptance or rejection from the regulatory authority to the owner or his agent. While I personally believe that is how it should be, this is not universally shared throughout the fire community. That this barrier will persist well into the future on all analytical systems that quantity hazard or risk.

Suppression.

We now move to suppression. Here we concentrate on two aspects of hydraulic design. First the design itself and then the determination of where it can be used and what requirements should be placed on it.

Hydraulic Design of Sprinkler Systems. Twenty or so years ago, one of the main distinctions between a fire protection engineer and anybody else practicing applied fire protection was the engineer could calculate the hydraulic design of a sprinkler system. Interestingly, most hydraulic design is now done on personal computers operated by design technicians. Russ Fleming's soon to be published book notes that early designers of sprinklers (i.e., in the last two or three decades of the nineteenth century) used a combination of trial and error and the recently developed Hazen-Williams friction loss equations to develop pipe arrangements for the earliest sprinkler installations. The concept of a single riser and a graduated system of feeder and branch mains dates to the earliest sprinkler systems. The concept of individual system hydraulics design, however, was very soon replaced as a number of organizations developed piping schedules. These were later solidified with the organization of the National Fire Protection Association into the Sprinkler Standard. Piping schedules dominated the design of sprinkler systems for most of the first century after their introduction in the late 1870's. As you are all aware, this restricted the sprinklers to a single approach, now usually referred to as a Christmas Tree. Loops and bird cages and other connections were not considered or permitted.

Looping of course was prevalent in underground systems. In 1936, Professor Hardy Cross at the University of Illinois published a paper describing approaches to evaluate such loop systems. Included in his paper were examples of hand calculations on looped and even multi-level loop systems. The Hardy Cross method was used in the design of water distribution systems but not in sprinkler systems.

Specially hydraulically designed systems were used in spray protection systems for oil filled transformers and similar special hazards. Each was individually designed and required competent hydraulic engineering. A major turning point occurred with the start of World War II. There was a significant loss of a large portion of the nation's rubber supply due to a fire that occurred within days of the start of the war. The problem of rubber was severe and the government established the Rubber Reserve Board. The Rubber Reserve Board conducted tests to determine the rate of heat input from water sprays to reaction vessels and the density of water required to keep the vessel temperature at a safety level in synthetic rubber reaction vessels. This resulted in a significant increase in the use of hydraulically designed water spray protection systems. The hydraulic calculations necessary to design those systems were done by mechanical engineers. They were also concerned with protection of the scarce national stockpile of natural rubber and rubber products. Realizing that normal sprinkler densities of the day could not handle the problem the Rubber Reserve Board engineers looked for answers. Specified hydraulically calculated high water discharge densities was one of the solutions. In another wartime area, deluge systems were introduced for the protection of aircraft hangers. The systems were of such size that they also had to be hydraulically calculated.

After the World War II, federal agencies, particularly the Navy, continued strong fire protection engineering programs. The Navy program was headed by Wilbur D. Stump. As far as I have been able to determine, Stump was one of, if not the first, to specify area density requirements for the design of fused head sprinkler systems. By 1958 the Navy had published manuals specifying hydraulic design for systems in warehouses and other hazardous locations. Initially, only one or two sprinkler companies were able to fulfill the designs. In 1961, however, Clyde Wood of the Automatic Sprinkler Corporation of America published his book on hydraulic calculations. This was primarily a collection of tables of friction loss and some instructions on calculations. Prepublication versions of Wood's work were submitted with sprinkler system designs to the Navy in 1958.

Initially, the calculations were performed by hand with slide rule or mechanical calculators. I remember checking designs using Wood's tables, yellow paper, and a slide rule. The availability of

Wood's data, however, opened the field and hydraulic calculation became a principal tool available to fire protection system designers. It wasn't very long before large companies had developed main frame computer programs for their internal use and special hydraulic slide rules and other devices began to appear. Hydraulic calculations started to be taught in the fire protection engineering curriculum but it was still a tedious operation and most of the systems continued to be Christmas Tree design. It was with the advent of the personal computer that all of this changed. Hydraulic design was combined with the Hardy Cross method. Very quickly there was a proliferation of proprietary programs for hydraulic analysis. Over the years, these have expanded in their scope and characteristics and now have reached the point of being a technician's tool used to fulfill the demand criteria set by the fire protection engineer or other authority. Today, virtually all sprinkler systems are hydraulically designed.

Initially, the thrust that pushed hydraulic design into the fused head system were the pressures of World War II and the hazards involved in the manufacture of synthetic rubber. The developers used civil engineering hydraulics, primarily the friction loss equations of Hazen and Williams, the Hardy Cross method, and the friction loss data published by Woods. Some of the barriers faced related to acceptance and are similar to the problems now being faced by the advocates of compartment fire modeling. Initially, there was only a small cadre of people who understood the calculation approach. The various authorities found themselves pressed to accept the calculations based on the judgment and eminence of the submitter. The complexity of the original calculation methods also made it difficult for the then emerging small sprinkler firms to compete with the established big sprinkler companies. At first, these were resolved by increased use of engineers throughout the sprinkler industry and a growing familiarity with the approach. Eventually, the advent of the personal computer and the development of hydraulic calculation programs simplified the operation. The hydraulic design of sprinkler systems is now contained in a black box but a black box that is technically accepted by the community.

<u>High Rack Storage.</u> About the same time as the hydraulic calculation approach was just getting started, high rack storage and other types of high piling emerged. At that time, I served on the Committee on General Storage where most of the work was aimed at storage heights of twelve and fifteen feet. The Factory Insurance Association (FIA), now the Industrial Risk Insurers (IRI) then had a policy of not insuring anything where storage heights were higher than twenty-five feet. This resulted in a situation where many desired storage systems would be uninsurable. Insurance is an essential business need. At that time, Roger Russell was Research Director of FIA. He urged that this dichotomy be resolved by gaining new knowledge and spearheaded the organization of a test effort with a broad range of representation. I am not sure of all of the participants but Ford Motor, Eastman Kodak, Minnesota Mining, Sears, National Fire Sprinkler Association, FIA, Factory Mutual, and Underwriters Laboratories were involved. A rack storage fire protection committee was formed. It undertook a testing program and in this process established a testing steering committee headed by Chet Schirmer. Out of this came the NFPA Standard 231C. There was a lot of interesting test planning, data analysis, and derivation of engineering procedures involved in the development of 231C. That, however, is not the subject of this presentation. What is most important here is the pressure that occurred when the underwriters felt they could not insure a facility type and arrangement that was desired by industry. The pressure of this conflict popped up the money, organized the necessary research, and developed answers in a very brief time. When money is at stake, action takes place.

Compartment Fire Modeling.

As the story of the development in suppression has been primarily one of the efforts of private enterprise, the development of the compartment fire model has been one of government work and government sponsorship of academic work. In today's practice of fire protection engineering, compartment fire modeling has taken much of the center stage. It is the new, sometimes questionable, star of the 90's that hydraulic calculation was in the 60's. A few years ago, mathematical modeling was a curiosity used only occasionally and by very few practitioners. Now wherever I go, and in virtually every problem in which I am involved, I find our professional colleagues using these models. The models promise us an ability to predict the impact on an environment that results from the burning of materials in a building. It is becoming the cornerstone of hazard measurement and hazard measurement is the essential item in risk appraisal.

Compartment fire models are generally divided into two classes: zone models and field models. I am going to address zone models. In my opinion, field models involve a level of complexity and difficulty that precludes their frequent use in the day-to-day practice of fire protection engineering. I mention them primarily, however, since field models have capabilities of detail and abilities to examine fundamental concepts that cannot ever be achieved in a zone model. Cases will arise where the engineer will seek out the resources and the specialized consultants in the combustion field that can set up, run, and interpret the results of these models. So much for field models, let's return to zone models.

The story of fire modeling starts in the post World War II era. I've already discussed the impetus for the establishment of fire research in the United Kingdom. In Japan, the fire research impetus came from the need to determine the usefulness of war damaged, but not destroyed, structures.

OCD and RANN Programs. In the United States, the first major new fire research thrust was sponsored by the Office of Civil Defense (OCD). It was aimed at analyzing the potential fire impact of aerial attack against the United States. In the US, this included important work at Illinois Institute of Technology Research Institute (then Armour Research Institute) related to the development and spread of fire once ignited. Their work, primarily concentrated on the phenomena of flashover with little concentration on the pre-flashover fire development stages.

In the late 60's and early 70's, there was a national policy decision that the non-military research should be less concentrated in the Department of Defense. That research removed from the Department of Defense was taken over by the National Science Foundation in a program entitled Research Applied to National Needs (RANN). The RANN project included a fire program under the direction of Dr. Ralph Long. Dr. Long established fire-related research programs and "Centers of excellence" at a number of universities. Many of these contributed to the understanding of fire phenomena that is the basis for fire modeling. The one most important to our discussions is the Home Fire Project at Harvard University under the direction of Dr. Howard Emmons. In addition to Dr. Emmons and others at Harvard, the Home Fire Project included the resources of the Factory Mutual Research Corporation. A second RANN grant of importance was that made to Dr. Edward Zukoski at the California Institute of Technology. Chronologically, however, these grants were relatively late in the game and the most important prior work occurred in England and Japan.

Kawagoe. While there are probably many contributions by the Japanese, the key one of interest to this presentation is the observation by K. Kawagoe that early in the development of a room fire, a reasonably clear cut layer (zone if you will) is established. Kawagoe further established that in the simple situation where there are no fans or other devices forcing air into the space, the available air for combustion is limited to that which can be drawn into the room through the openings to replace the mass expelled through the opening. Kawagoe mathematically expressed this phenomena in what we frequently refer to as the Kawagoe equation.

There is an anecdote of Kawagoe visiting Cal Tech and talking to Zukoski about this phenomena which was then contrary to many commonly held beliefs. According to the anecdote, Zukoski challenged Kawagoe to prove it and they went to a laboratory at Cal Tech where they imitated the phenomena with a liquid tank. They piped a heavy density liquid into a light density liquid as an analog to the fire scene and clearly saw the layer develop.

About this same time, several things occurred. First was the Livonia fire in the General Motors Hydraulic Transmission Plant. Actually, this fire was in the mid-50's but the research on approaches to prevent recurrence continued well into the 60's. While the impact of this fire on modeling was small it provided added impetus for the later work resulting from the Jaguar fire in a similar large automotive plant in England.

Woods Hole Impact. One of the legacies of the Civil Defense Fire Research Program carried on through the RANN Program was the National Academy of Science Committee on Fire Research. That Committee sponsored a four week conference on fire research needs, in Woods Hole, Massachusetts, during the summer of 1962. When you speak of Woods Hole, the two most prominent names that emerge are Dr. Hoyt Hottel of MIT and Dr. Howard Emmons of Harvard. One of the major themes running through much of the Woods Hole discussions was the desirability of being able to use both physical and mathematical models in fire research.

In the United States, a bill was proposed in Congress in 1963 to establish a National Fire Research Program similar to those in other nations. This bill, however, got nowhere. The representatives of the fire safety community in the United States opposed it. They opposed it primarily on the grounds that they did not want Federal interference in a private enterprise problem, that industry was already doing all relevant research, and that the basic problem in the United States was not lack of knowledge but rather lack of enforcement. I would expect that there are many in the fire community that would agree today with this position. The proposed research program was therefore never enacted. However, the fundamental research being sponsored by the National Science Foundation continued.

Emerging Science. During this period there emerged in the fluid dynamics field, several empirical models for plume entrainment. Most important of these was that developed by Morton, Taylor, and Turner. These models were presented in the Ninth International Symposium of the Combustion Institute in 1964.

Activities in UK. Set this knowledge aside for a moment and move back to the response to the Jaguar fire. In contrast to the historical position of the United States, the UK industry and government frequently have combined to attack a problem of mutual interest. The Joint Fire Research Organization (JFRO) was interested in undertaking something significant that could be used to better understand fire and Colt Industries, a major ventilation manufacturing firm, was interested in developing a new market. As with the Lovinia fire in the US., many fire protection advocates in the UK thought that roof venting was a viable response to the problems raised by the Jaguar fire.

Colt and the JFRO entered into a fifty/fifty funding program of research. Vestiges of this relationship continue to this day. Basically, the question was how do you make vents work? It is in this work that we have the joining of the two concepts of the zone or layer and the entrainment in the plume.

The underlying concept of the gravity venting of fire products was simply to remove a mass of smoke material at the top of the building as fast as it entered the lower face of the smoke layer. Conceptually, the faster you removed it, the higher this interface. To calculate this, it was necessary to understand the plume and exercise conservation of mass equations. The first and most influential of the products produced was Technical Paper No. 10 by Thomas. These concepts now permeated through the work of Butcher and Parnell, NFPA Standard 204M on Smoke and Heat Venting and the recently produced document, NFPA Standard 92B on Venting of Atrium, Malls and Other Large Spaces.

The scene now moved to the United States. The next phase of efforts almost entirely were a result of government investment arising out of both the general commitment to better science under the direction of the RANN Program and the commitment of the National Institute of Standards and Technology's Center for Fire Research to the goals and objectives of the America Burning report issued by the National Commission on Fire Prevention and Control.

Home Fire Project. One of the main segments of the Home Fire Project was a detailed study and attempt to analyze the development of a fire from its early ignition through flashover in a bedroom situation. For three years the project conducted one well instrumented and carefully directed test each year. They then spent the entire next year analyzing it, often inviting colleagues from other fire research programs to join in the analysis. Much attention was directed at establishing the equations that would define the individual phenomena involved. Eventually, it reached a point where Professor Emmons brought in help, particularly Dr. Henri Mitler, and they started to write a predictive fire model. Their eventual product was the Harvard Model.

Quintiere's RUNF. At roughly the same time (in 1974), Dr. James Quintiere, at the Center for Fire Research, presented a paper at an ASTM Symposium discussing the possibility of creating a fire model. During the next year, he generated such a simple model which he called RUNF. That model has never been in common use but it influenced thinking on the part of both Ron Pape at IIT Research Institute and Ed Zukowski at Cal Tech. Pape produced the IITRI Model. The IITRI Model was actually the first published room fire model, hitting the street slightly ahead of the Harvard Model. It's possible that the presence of the IITRI Model encouraged the authors of the Harvard Model to demonstrate their product.

The Available Safe Egress Time model (ASET). Also, at this point, Zukowski produced a set of equations suitable for modeling the impact of fire in a room which were then used by Dr. Leonard Cooper, at the Center for Fire Research, to produce what we now know as ASET (Available Safe Egress Time). A singularly important event, in my opinion, was the development by W. D. (Doug) Walton of ASET-B. The ASET Model as originally produced by Cooper was designed for main frame computers and had by comparison, a tedious input program. Walton took the basic equations and reduce them to a 200 line simple Basic program that could run at a very high speed on the first iterations of portable computers. This improved accessibility to the practicing engineer.

Fire and Smoke Transport Models (FAST and BRI-2). In 1983 Dr. T. Tanaka of the Building Research Institute of Japan published his paper "A Model of Multi-room Fire Spread" He had spent a year as a visiting scientist at the Center for Fire Research expanding on his prior work in Japan. After he return to Japan, work continued on his model in both Japan and in the US. His efforts produced the model BRI-2. BRI-2 has been used in Japan as part of a proposed total systems approach to fire safe design. Of more interest to this assembly, is the course taken by Dr. Walter Jones at NIST. Jones extensively revised and extended Tanaka's initial program to the point of the development of a distinct separate model. That model is titled Fire And Smoke Transport (FAST); it is currently used as the core model of the HAZARD I Fire Hazard Assessment System.

Initially, the barriers were acceptance and the availability of the computer equipment and the lack of know-how required by the user. The availability of computer equipment is fast being resolved by time. User know-how also is rapidly improving. However, the acceptability barrier remains. This is somewhat parallel but a good deal more complex than the problems and questions that arose when hydraulic calculations first entered the scene. I expect that the question will be resolved but that the practicing fire protection engineer is going to find it necessary to upgrade his fundamental physics and science capabilities in order to use these tools effectively and with confidence.

Structural Endurance.

The final area that I want to address is structural endurance. Structural endurance or building fire resistance, is one of the oldest requirements in fire protection. For the commercial, industrial or business building, it often represents the largest single fire safety investment. For the manufacturer of structural materials involved, it is a very important market factor. The history of the development of fire endurance capabilities started with simple specifications where designers attempted to put together non-combustible and thermal-resisting materials that they assumed would cause structural fire protection. This was followed by the traditional tests that we still use. Test furnaces date, as so much else in fire protection, from approximately the turn of the century. The ASTM E119 Time Temperature Curve was first published in 1916, but this is testing and our subject is computations.

The first attempt to compute fire resistance that I'm familiar with is Appendix B of the 1942 document BMS 92. This two page appendix presents two sets of equations titled "General Method for Estimating the Ultimate Fire Resistance Periods of Walls and Partitions" and "General Method for Estimating the Ultimate Fire Resistance of Columns".

In the 1950's, John McGuire then with the Joint Fire Research Organization, UK, (McGuire later joined the National Research Council of Canada) developed an analog method for determining fire resistance. His apparatus consisted of electrical circuits, resistors, and capacitors, imitating heat transfer mechanisms. McGuire produced curves of expected temperature conditions throughout a member or assembly. Out of this, he derived a good deal of theory that became important to later work.

Two vignettes I want to now address, both relate to steel construction. The first an attempt to gain a market; the second to avoid losing one.

Calculating Fire Resistance for Exterior Steel. After World War II, many architects followed a practice of showing the framing of buildings on their exterior. For steel framed buildings, this meant exposed steel. Initially, the fire resistance requirements for the exterior columns prevented this approach except as a false facade. I remember advising designers of the two high rise federal office building being built in Chicago in the late 60's and early 70's that the exterior columns had to be fireproof. If they wanted to show the steel, they would have to put a false member on the outside. That is exactly what they did.

About this same time, the American Iron and Steel Institute (AISI) Research Committee established its long term plan for improving the competitiveness of steel by improving the knowledge of its capabilities in fire. Their program, spread across twenty well funded years, made major contributions to the technology.

The steel industry believed that the mass of the exterior of steel plus the difference in heat transfer of an exterior flame impingement from that of an interior room fire held promise of reducing the applied fireproofing requirements for exterior steel. In 1967 the steel industry ran a series of tests at Underwriters Laboratories that produced promising results. Review of the prior work by S. Yokoi in Japan also indicated that the plume out the window would not produce the same fire exposure as that produced in the building by the source fire. AISI then contracted with Margaret Law to gather all the applicable data from laboratories around the world, analyze it, report and produce a design procedure for determining the actual impact on exterior steel. Law produced two comprehensive volumes. In the eyes of the American Iron and Steel Institute, her work was excellent but not transferrable to American practice. AISI then hired University of Maryland staff, particularly Jack Watts and Phil DiNenno who developed the design guide converting Law's work into the step-by-step procedure suitable for the US desire for simple systems. The steel interests carried this to the code committees, initially Building Officials Conference of America (BOCA), to receive their acceptance and move it into practice. Now, calculation of fire resistance capabilities of members is common and widely accepted.

End Restraint and FASBUS. The second story is that of end restraint. Again, during the mid-60's to early 70's, direct applied fire proofing became the popular method of protecting steel members. There was a immediate emergence of a number of corporations making applied fireproofing materials and a resulting competition to demonstrate the value of their materials using ASTM E119 tests. The common wisdom at that time was -- somewhere between 1000 and 1100°F steel would lose sufficient strength so that a member could no longer dependably support its load. Tests, however, started to emerge with steel temperatures in the 1800 to 2000°F range with the floor still maintaining its load. There was serious consideration that this may have been an artifact of the test furnace and that the members would not perform as well in reality. There was a counter contention that the same sort of resistance as presented by the furnace would occur in most of the portions of a building frame. Several jurisdictions, however, wanted to restrict any members to those which did not exceed the 1000 to 1100°F range.

A decision to mandate a temperature limit would impact on the competitive position of steel verses concrete or other framing materials. Here again, the American Iron and Steel Institute sponsored an extensive research program. The initial work was done at IITRI, primarily looking at the diaphragm analysis of the floor systems and the relationship to fire. Following this, an extensive series of well instrumented tests were conducted for the steel industry by Professor Richard Bletzaker at Ohio State University. They produced good data.

With this material in hand, the AISI representatives searched for a prominent structural engineer who would be interested in such a fire project and whose work would be respected throughout the industry. They chose Professor Boris Bresler at the University of California at Berkeley. Professor Bresler previously had studied and modeled the migration of fire temperatures through structural members as part of the RANN Program. Soon after the program got underway, Professor Bresler joined the firm of Weiss, Jenny, and Elsner and continued this effort. At Weiss, Jenny, and Elsner, he was joined by Bob Eiding who combined the structural knowledge of Bresler's background and computer capability.

At the same time, American Iron and Steel Institute sponsored Dave Jeanes as a Research Associate at the Center for Fire Research (CFR). With this combination, they developed the FASBUS Program. This is a structural analysis program combining the heat transfer capabilities brought by Bresler with strength of materials and the classic analysis of forces and moments of structural engineering. The end result was a finite element model that predicted how bays and sections would work under the stress of fire. Full scale testing in a two story, four bay test array at the CFR facility gave good replication of the prediction presented by the FASBUS calculations. It then was used as the basis for developing code recognition of structural restraint and identifying where unrestrained ratings would have to be required.

The steel industry used the results their extensive research effort to demonstrate that end and axial restraint were commonly available in most building structural bays. This supported their contention that greater heat transfer and therefore thinner fire proofing should be accepted in many situations. The product developed by their research (FASBUS II) also identified those areas such as corner or cantilevered bays where restraint was unlikely. Their primary objective has been achieved.

Most codes are now accepting restraint as a positive fire endurance factor. FASBUS II has been used in a few special occasions to help design a building or to answer questions about the need to upgrade a facility where the applied fire proofing thickness was less than the specified amount. It however has not become a general engineering tool for the design of fire resistance of buildings. It is complex and requires significant expertise on the part of the user. FASBUS II however has been a part of the a broad general acceptance of the concept of heat transfer, heat capacity of the mass of steel, and the impact of restraint. Tables of fire proofing thickness now reflect this and most of the sponsors objectives can now been met without resorting to the full power and expense of FASBUS II. In most cases, the look-up tables are adequate. It is possible to apply the basic principles for special cases. In our profession however, the proclivity to substitute tables for engineering calculations is so great that there are probably not more than a handful of people capable of undertaking fire endurance analysis on a truly scientific or engineering basis.

Conclusions.

A premise set forth in the white paper for this conference was "Over the last two decades, there has developed a log jam of new fire technology waiting to be applied to today's fire safety problems". My review of the history of fire technology leads me to a conclusion that there is some but not overwhelming support for this position. In our past history, we have had cases such as Margaret Law's work on the fire resistance of exterior steel that were based extensively on abstracting and analyzing material from previous work. In that case, there was however, a major effort by the world wide steel industry to build the data base that enabled her output. Another classic example that is probably more frequent is amplified by Phil DiNenno's papers on the radiation from large pool fires. Some of Phil's background came from pool fire experiments but the majority of his analysis and development was from classic heat transfer.

Just as often, as in the case of protection for high rack storage and in the development of the compartment fire models, the advance has been the result of an organized research effort to attack and solve a problem.

Some of the information we need does exist and needs to be used but as we move forward we are going to find a lot of gaps in information, a lot of development that needs to be done to make the technology useful, and a lot of proof testing, in the lab or in the field, that must be accomplished.

Most of all we need champions to seize the opportunity of taking on the often difficult tasks involved and to persist till the job is done. In the past champions came from industry, government, and occasionally from the engineering profession itself. I expect this will continue in the future. I believe we can now add those who teach fire protection engineering to this list. To date, we have seen very little advancement of the technology from the academic curricula at IIT, Maryland, Worcester, or Edinburgh. Now I see this situation changing. This meeting is but one example of leadership from the fire protection engineering majors. My fondest hope is for a partnership of industry, education, insurance and government in the dual tasks of creating and disseminating technically sound and scientifically based fire protection engineering knowledge.

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