

# **A PROPOSAL FOR A MODEL CURRICULUM IN FIRE SAFETY ENGINEERING**

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# **A Introduction**

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# **A INTRODUCTION**

## **1. OBJECTIVES AND SCOPE**

### **1.1 Background and history of working group**

The International Working Group on Fire Safety Engineering Curricula was formed at the Second International Symposium on Higher Fire Technical Education, which was held in Edinburgh on the 19-21 June 1989. Professor Sven-Erik Magnusson of the Department of Fire Safety Engineering at Lund University in Sweden was appointed as chair of the International Working Group. Representatives of Lund University, the University of California at Berkeley, the University of Edinburgh, the University of Maryland, the University of New Brunswick and Worcester Polytechnic Institute have served on the International Working Group; representatives of other organizations, including the Society of Fire Protection Engineers, have participated in the deliberations of the working group.

The development of a new general curriculum for fire safety engineering was considered by attendees at the second symposium to be an important task for the newly formed working group. Based on preliminary discussions in Edinburgh, the International Working Group decided that another important task would be to define the knowledge framework of Fire Safety Engineering in order to identify topics of mutual interest with other engineering disciplines as well as topics of unique interest to Fire Safety Engineering. As a consequence of these deliberations, two main objectives were established for the working group:

- \* Define the knowledge framework for Fire Safety Engineering
- \* Develop a model curriculum for Fire Safety Engineering

The development of a model curriculum is considered to be the central purpose for the working group. Such a model helps to identify the discipline of Fire Safety Engineering and to distinguish Fire Safety Engineering from other engineering disciplines. It also serves as a possible basis for the development of new programmes and may help in the critical assessment and evaluation of existing programmes. From a professional development standpoint, a model curriculum helps define the subject matter that an employer can expect an employee who is a Fire Safety Engineer to have mastered.

The International Working Group has met on a number of occasions since the Edinburgh meeting. Meetings have been held in Gaithersburg, Maryland, in Boras, Sweden, in Worcester, Massachusetts, and in College Park, Maryland. The working group also met at the Third International Symposium on Fire Safety Science in Edinburgh during July 1991, where an open forum on education in Fire Safety Engineering was held by the working group at the conclusion of the symposium. A preliminary version of this report was discussed at a meeting on fire science education at the Fourth International Symposium on Fire Safety Science in Ottawa, June 1994. The working group has also corresponded among the members. Thus, this report represents the fruit of several years of labor by the International Working Group.

## 1.2 The knowledge framework of fire safety engineering

A context for the task of defining the knowledge framework is illustrated in Figure 1, which is intended to show that Fire Safety Engineering encompasses topics of mutual interest with other engineering disciplines as well as topics of unique interest to Fire Safety Engineering. This context is the same for all the engineering disciplines.

The task of defining the knowledge framework began with the development of an inventory of subject areas related to Fire Safety Engineering. Early on, the need to consider the tools used in professional practice was recognized. One goal of the working group has been to arrange the course material so that graduates possess the skills needed to identify and use these tools.

The starting point for the development of a structure for this knowledge framework has been the outline developed by Rasbash<sup>1</sup>. Rasbash identified 12 modules related to a course in Fire Safety Engineering. The working group decided that the first 5 modules identified by Rasbach represent the core of a Fire Safety Engineering degree program. These 5 modules include:

- \* Fire Fundamentals
- \* Enclosure Fire Dynamics
- \* Active Fire Protection
- \* Passive Fire Protection
- \* Human Behavior and Fire

Efforts to define the subject matter of each of the 5 core modules were initiated, with an individual assigned to oversee each module.

Once development of the core modules was begun, it became apparent that a description of basic modules defining the knowledge base of the fundamental engineering sciences would also be useful. The concept was to identify the subject matter of the fundamental engineering sciences related to Fire Safety Engineering. Consequently, basic modules in the following subjects have been developed:

- \* Fluid Mechanics
- \* Thermodynamics
- \* Heat and Mass Transfer
- \* Solid Mechanics

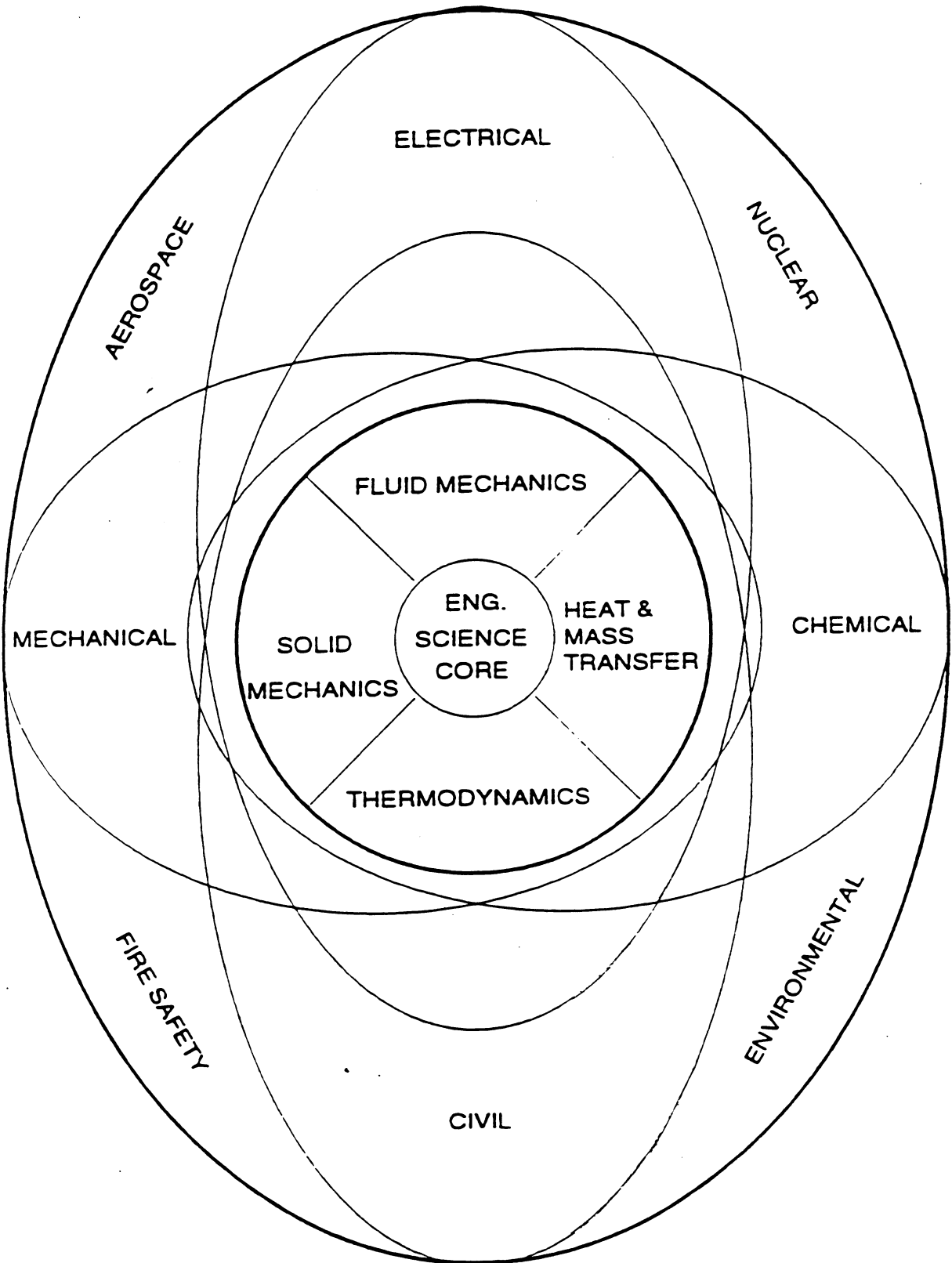
Two additional fire modules have also been defined since the description of the core modules. These modules include:

- \* Risk Management
- \* Industrial Fire Protection

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<sup>1</sup> Rasbash, D.J., "A Modular Approach to the Subject of Fire Safety Engineering," *Fire Safety Journal*, **3**, 1980/81.

FIGURE 1  
BODY OF ENGINEERING KNOWLEDGE



These 11 modules provide the framework for the description of the subject matter of Fire Safety Engineering. The details of the subject matter of these 11 modules are described in subsequent sections of this report.

Originally, members of the working group responsible for each module attempted to identify the subject matter of the module and to estimate the number of lecture hours for four different programs of study:

- U1 Undergraduate courses leading to a general degree in FPE or FSE  
Example: University of Maryland, Lund University
- U2 Undergraduate courses in other engineering disciplines with an option in FSE  
Example: University of Edinburgh
- G Graduate courses in FPE or FSE  
Example: WPI, University of Maryland
- D Studies for a PhD  
Example: University of California at Berkeley

Subsequently, this has been changed to consideration only of the U1 and G categories. Currently, each module is structured as follows:

- \* Division into topics and subtopics
  - Contents
  - Practical skills
  - Detailed references
  - Topical assignments
- \* Number of lecture hours appropriate for the coverage anticipated by developer
  - U1 - Undergraduate program in FPE or FSE
  - G - Graduate program in FPE or FSE

These modules represent the efforts of the International Working Group to identify and document the body of engineering knowledge that defines the discipline of Fire Safety Engineering. The subject matter is very broad and constantly changing, so a comprehensive treatment would seem unattainable. Nonetheless, the working group feels it has achieved a reasonable start in the development of this compilation.

### **1.3 Some important qualifications**

It is important to realize, that the proposed curriculum constitutes one model for the university education of Fire Safety Engineers and that other models, equally representative and valid could have been constructed. The working group finds it rather unlikely that a real curriculum to one hundred per cent could be based on this proposal; rather the proposal can be seen more as a general knowledge framework and the practical and local circumstances must determine the degree of conformance. At the same time the working groups wants to emphasize that in broad outlines the subject contents and the

scope of the tabled curriculum describe the need of present and future fire safety and fire protection engineers.

The curriculum tries to outline a logical and rational sequence of courses but is certainly neither complete in its coverage nor without a certain amount of overlapping. As an example of material left out, a course teaching the link between environmental engineering and consequence analysis of major industrial hazards will probably be a standard item in a future fire safety engineering education. As an example of overlapping, topics such as ceiling jets and vent flows may appear in more than one module.

Also, some of the organization of the material is open for discussion. Again as an example, topic E in the module "Industrial Fire Protection and Explosion Protection" could equally well have been included in the module "Fire Fundamentals".

Ideally, in a university-level education, a reference to a standard should be included only for a critical evaluation and discussion of that document. It has not been possible to follow this policy strictly throughout the document. Furthermore, most referenced standards are written by USA-based organizations. It is emphasized that standards should never be introduced without an evaluation of the engineering and scientific background and that standards from non-US countries would be equally applicable.

The working group wants to emphasize that the model curriculum has not been endorsed by their respective parent organizations.



## **2. GENERAL GOAL OF ENGINEERING EDUCATION**

### **2.1 Goals of an engineering education**

The main objective of university-level engineering education is to produce engineers capable of solving industrial problems. This implies an education targeted towards a defined profession with a high degree of specialization. At the same time, the engineering training must produce the base for a research education on a postgraduate level and for research and development in general.

The engineering education aims at providing the skill for engineering use of front line techniques. This means that the graduate after some years of professional practical experience shall have the ability to develop new designs, new processes and new products. He (she) is also expected to be able to gather new knowledge from the international technical-scientific literature in the professional area and to transform such knowledge to technical applications. The education must also provide knowledge in basic subjects in the natural science and technical area. Such solid basic knowledge will be the core of the education.

Understanding of the more applied subject areas will require that knowledge is constantly taken from this core. It is of extreme importance that the different elements and factors are integrated into a unity and that the education leads to an understanding of systems analysis.

The balance between basic and applied knowledge is a difficult one to strike. If tilted too much towards basic science there is an evident risk of losing technically orientated students and providing graduates with skills not directly relevant to industry. On the other hand it is required that the education is broad enough, has inherent long lifetime and constitute a suitable base for continuing supplementary and additional training in the later stages of professional life.

### **2.2 Changes in the engineering role**

The general trend in engineering education can be summarized as follows:

Technical developments and structural changes in society influence the role of the engineer. An engineer can no longer expect to be working within a specialized sector during his/her professional life. A specialty becomes obsolete or changes so rapidly and radically that in reality it becomes a new specialty. At the same time the total knowledge base is broadened and deepened. As a consequence, the specialist knowledge that a first university degree gives is possibly sufficient for the engineer's first working tasks. After a relatively short time a continued education within one's own specialty as well as emerging areas becomes necessary.

The primary task of the first university education then becomes to give the student partly the qualification to collect and assimilate new knowledge during the whole professional career, partly a thorough preparation in methodology for formulating and solving qualified technical tasks.

The role of the engineer is influenced by increased societal requirements for a global perspective in technical and industrial activities. The engineer has a responsibility for the consequence of technical development on humans and society; e.g. environmental consequences of new technology. Societal and ethical aspect must therefore be integrated into the engineering education.

### **3. GENERAL TRENDS IN FIRE SAFETY ENGINEERING**

Trends in fire safety engineering have been motivated by the accrual of fire research. This is influencing the course of formal education for fire protection engineers, and is promoting more engineering design in the practice of conforming to regulations. The effects of fire research will be examined, and their consequences discussed. The current view of the profession of fire protection engineering and its practice, primarily in the United States of America, will be described. A perspective on the relative immaturity of the field of fire protection engineering compared to other branches of engineering will be offered, and the factors necessary for continued scientific growth in fire protection engineering will be given.

#### **3.1 Accrual of research**

Research over the last twenty-five years in fire has provided an improved basis for evaluating the hazards due to fire, and has potentially given the engineer new tools to perform his job. As a result, the SFPE has published a Handbook (1988), comparable in scientific scope to other engineering disciplines. Also the Journal of Fire Protection Engineering was initiated at the same time to transfer current scientific research and methods to the profession. During this period of research accrual, the need for more advanced education in fire protection engineering was realized. A Master's Degree program in fire protection engineering was begun at the University of Edinburgh in 1973. In 1979, Worcester Polytechnic Institute began a similar program followed by M. S. programs at the University of Maryland (1990) and the Victoria University in Australia (1992). Other efforts are also underway in various universities to bring advanced scientific knowledge to the education of fire protection engineers. Some of these include the University of British Columbia, the University of Ulster, the University of Canterbury (New Zealand), Lund University (Sweden), and Hong Kong Polytechnic. In Japan, which has no such degree, but has the education of fire safety engineers built in to their traditional disciplines, a revised version of a fire protection handbook was published in the early 1980's. The handbook was very similar to the SFPE Handbook in scope and style, thus illustrating the worldwide dissemination of fire research knowledge. Moreover, the International Association for Fire Safety Science (IAFSS) was founded in 1985 to enhance the transfer of fire research among scientists and engineers. The IAFSS holds Symposia every three years and publishes proceedings which contain nearly 100 peer reviewed papers covering a wide range of fire science and engineering. Subsequently, the International Standards Organization created a new committee, ISO TC92/SC4 "Fire Safety Engineering", to facilitate the use of fire computational methods originating from research.

#### **3.2 Consequences of research**

The accrual and dissemination of fire research has enabled its useful application to problems in fire safety engineering. This has stimulated advanced education programs in fire safety engineering in order to provide the knowledge to students by deliberate means. Secondly, it has stimulated designers and regulators to examine alternative code compliant approaches through quantitative engineering analyses. And thirdly, the application of "fire modelling" or quantitative methods to the reconstruction of actual accidental fires for the purpose of settling litigation claims has increased as investigators have come to appreciate the value of scientific methods for fire. Both formal and professional education in fire safety engineering is clearly on the increase. However, curriculum for advanced education is still evolving, and textbooks are lacking. In the area of code compliance there is evidence that more scientific practices

are creeping into standards, and it is the perception of some that a true performance code for fire safety based on scientific methods is in the offing. The Conference on Firesafety in the 21st Century organized by David Lucht of the Center for Firesafety Studies, Worcester Polytechnic Institute, suggested a viable goal: "By the year 2000, the first generation of an entirely new concept in performance-based building codes [for fire safety] be made available to engineers, architects and authorities...". Large claim litigation suits, as a result of large loss and multiple death fire accidents, have sought to use fire modelling to allay responsibility. Since claims have been exceedingly high, this has been a significant motivator for the application of fire models and for the establishment of their veracity.

### 3.3 Current demography

The employment pattern varies from one country to another. In US and according to the Society of Fire Protection Engineers (SFPE) the current demography of employment for fire protection engineers is given nominally as follows:

consulting	25 %
industry/government	20
insurance	30
equipment/devices	10
other	15.

In recent years there has been an increasing trend to employ more in the consulting field. Nearly 70 % of the practicing engineers have Bachelor of Science degrees, but only roughly 25 % have a B. S. degree in fire protection engineering. The number of people with advanced degrees is about 30 %, and it is safe to say that few are in fire protection engineering.

At universities outside USA some have undergraduate or graduate programs specifically targeted towards the national fire brigade service. As an example, roughly 85% of the graduates from Lund University are employed by the national rescue service.

### 3.4 Current practice

Two factors, the legal basis of fire safety and the technical complexities of fire, have restricted the function of fire protection engineering. The profession has had to cope with a broad array of tough problems through the application of rigid rules or the use of technical judgement. Until recently, little has been available to provide flexibility through the use of design and analysis methods.

Characteristics that describe the current activities within fire protection engineering are listed as follows:

*Practices and procedures are administered according to prescribed standards and regulations.*

The engineering must have a working knowledge of the local codes or industrial safety standards to assure compliance in construction and operations of facilities. In most cases, the methodology does not arise from scientific principles, but from a consensus process based on technical judgement and experience.

*Available technologies are used to solve fire safety problems.*

Sprinklers and smoke detectors are two examples of technological developments that add to the practice of fire protection. Both of these represent products of research transferred into practice. Sprinklers were motivated by the insurance industry, while smoke detectors were motivated by the concern for the safety of people in their homes. Concerns about the environmental impact of halons, and their potential ban on atmospheric dispersion will likely change suppression strategies in fire protection engineering.

*Empirical test data that can not be generalized to specific applications are relied upon.*

Nearly all fire tests for materials and products provide relative performance rankings dependent on the test conditions. The test results do not provide data for general analysis to other applications, and many tests (e.g. flammability) intended for the same purpose do not give consistent results.

*Engineering methods from other branches of engineering are used.*

Although one can associate distinct technical subjects with fire behavior and safety, distinct classes of problems and their problem solving methodology do not exist in present practice. For example, the design of the water supply for sprinkler systems--a prevalent practice--comes from standard practices in other branches of engineering. However, the response of a sprinkler to fire and its performance in suppression are two distinct problems in fire protection that require technical solution methods. Although research has provided some methods for calculating sprinkler response, design is still based on a prescribed spacing for head locations.

*Fire safety tends to react as problems arise.*

Because of the limited analytical tools, fire safety finds itself responding to disasters or to cases where the introduction of new market place products caused unexpected fire problems. For example, the introduction of foam plastics in the 1970's led to problems of rapid fire growth despite good performance of these materials in standard fire tests. Despite limited research efforts to correct these anomalies, the solution to the foam plastic issue has not been solved. The same tests are still required, but the use of these materials has been restricted. Thus we still do not have the predictive ability to analyze and anticipate the potential hazard of these materials in use.

### **3.5 Relationship to other branches of engineering**

Fire is a complex system which is more complicated and less technically developed than problems that define other branches of engineering. Michael Faraday, the noted 19th century scientist, is reported to have said that the processes in a candle flame represent the scope of physics in the universe. But only in recent times would it be feasible to attempt to mathematically simulate these processes. Combustion in controlled systems has only made significant advances in predictive methods during the last 50 years. Modern textbooks on combustion theory, including some application to fire have only emerged in the last 25 years, e.g.

Frank-Kamenetskii, D.A., *Diffusion and Heat Transfer in Chemical Kinetics*, 1969.

Glassman, I., *Combustion*, 1977.

Kanury, M., *Introduction to Combustion Phenomena*, 1975.

Kuo, K.K., *Principles of Combustion*, 1986.

Williams, F. A., *Combustion Theory*, 1965.

Indeed, very few engineering schools even teach the theory of combustion (other than aspects of chemical thermodynamics), and then only on a graduate level. It is unlikely that you would find a fire protection engineer claiming to be an expert in combustion; it would also be rare to find a "combustion" engineer or scientist claiming to know much about the problems of fire safety. This places the fire protection engineer at a distinct disadvantage since so little of fire behavior has lent itself to conventional engineering analysis. Since combustion needed to rely on the solution to basic problems in fluid mechanics and heat transfer, it is not unreasonable to find the study of fire -- uncontrolled combustion -- lagging behind other areas in scientific development. Thus, the complex nature of fire and the recent limited advances in combustion theory contribute to the immature state of fire protection.

Other engineering branches are more technically mature, and have had more time and effort invested in their development. Their development has been spurred by advances in technology and the economics of the marketplace. In contrast, advances in fire protection must rely on motives for the protection of property, the protection of people, and the concerns for liability. Societal losses due to fire place a drag on the economy, they do not advance the gross national product. Hence other branches of engineering have had different economic and societal forces motivating their advancement compared to fire protection.

Mature branches of engineering have distinct subject matter associated with their fields for which analytical and measurement methods exist. For example one can associate Ohm's Law as the analytical tool governing current flow in circuits as a basic element of electrical engineering; Newton's "Law of Cooling", governing convective heat transfer, underpins mechanical engineering; and the wind tunnel allows the aeronautical engineer to determine the drag and lift of airfoils. These subjects form the scientific components of the particular branch of engineering, and form the infrastructure for knowledge to be expanded in that area. Scientific progress has given the engineer the framework for practical solutions to complex problems.

In engineering, usually complex problems have been dealt with by simple mathematical relationships which yield quantitative results for design and analysis. For example, the friction factor gives a formulation to compute the pressure loss in complex pipe flow systems, and the convective heat transfer coefficient provides a means to estimate heat transfer from surfaces in flowing media. For each of these phenomena, a vast amount of research has provided data and sophisticated mathematical solutions for determining these parameters. An established infrastructure has developed which builds research results into simple methodologies that the average engineer can utilize. As we will see, the basis for such a scientific infrastructure for fire protection engineering is just emerging.

### **3.6 Evolution of fire protection engineering**

Let us consider the necessary elements to allow the evolution of fire protection engineering toward a mature engineering discipline.

*It must implement quantitative methods to establish the performance of fire safety systems.*

The practice must move from a prescriptive to a performance orientation. These two approaches might appear in conflict, but the current prescriptive practices could be evaluated by performance methods as they become available. Then the prescriptive practices could be assessed and modified as necessary. Although there may not be the full means to establish a national performance code, there is a slow trend in this direction. Sweden allows design methods for the fire endurance of structural members as an alternative to furnace tests. The United Kingdom has authorized methods that provide equivalent levels

of safety to the current fire safety regulations. And high-rise building designers in Japan are using computer modeling to meet fire safety criteria in buildings. These are some examples of this trend.

*A core curriculum based on scientific principles must be adopted and supported by textbooks in the subject areas.*

The book by Drysdale, entitled *Fire Dynamics*, has been a start in this direction, but it is limited in scope. It might be necessary to add special courses to the fire protection curriculum: for example, a fluids course with emphasis on fire applications, in addition to the current standard courses. The subject area of fire safety engineering must be more scientifically structured and presented in textbooks.

*The knowledge base of research must be organized into useful forms.*

This has already been done with the publication of the SFPE Handbook of Fire Protection Engineering, and the availability of computer based tools such as the contribution of Hazard I from NIST. These offerings must be supported by objective institutions and must be acceptable to a broad technical consensus.

*The research pipeline on significant phenomenological problems in the field. eg. plumes, ignition, ... must be maintained.*

Fire problems are complex and interdisciplinary so that significant research results take time to develop and establish credibility. There are many gaps left to fill before fire protection engineering has a complete set of analytical tools.

### **3.7 Conclusions**

Recent trends in fire protection engineering have been motivated by the accrual of fire research and its application to practice. This has motivated the need for advanced formal education in fire protection engineering, and the view that more scientifically-based performance codes are practicable and possible.

This experience has recognized the need for an intimate relationship between fire research, education, and the professional practice of fire protection engineering. It gives fire protection the comparability of scientific equivalence with other more mature branches of engineering. It also places responsibilities and demands on the three institutions. Education must process the new scientific information, maintain relevance, and produce textbooks and new courses. The research community must continue to provide the scientific infrastructure, and address real world problems of the profession. The practicing fire protection engineers must articulate their problems for solution by research, and must continue to develop the skills to enable the adoption of performance-based engineering practices.

#### **4. SPECIAL PROBLEMS IN EDUCATION AND TRAINING OF THE FIRE SAFETY PROFESSIONAL**

Fire Safety Engineering has now become recognised as an identifiable discipline within the remit of the engineering professional. Its late emergence, compared with Chemical Engineering or Building Services Engineering, can be attributed to two factors:-

- (i) fire safety has always been of concern to society; and
- (ii) fires are not a common occurrence.

The former may seem anomalous, but society has always dealt with issues relating to fire safety post hoc - i.e. by introducing prescriptive rules and regulations with the benefit of hindsight and the objective of avoiding reoccurrence. The aftermath of the Great Fire of London is a prime example of this approach. It is a significant indictment of the general attitude towards fire safety throughout the world that this mode is still dominant. Fires involving major life loss occur with depressing regularity, for example: the Coconut Grove Night Club, Boston, MA (1942), 491 fatalities; l'Innovation Department Store, Brussels, Belgium (1967), 322 fatalities; Andraus Building, Sao Paulo, Brazil (1972), 168 fatalities; the MGM Grand Hotel Fire, Las Vegas (1980) 85 fatalities; the Stardust Club Fire, Dublin (1981), 45 fatalities; the King's Cross Underground Station Fire, London (1987), 31 fatalities; the Piper Alpha Disaster, UK Sector of the North Sea (1988), 165 fatalities.

With the introduction of new, synthetic materials throughout the workplace and the home, the hazards have become much more widespread, and the risks to life and property are now much greater, particularly in view of the size and complexity of buildings that are now being erected to serve all sectors of society (high-rise buildings, shopping malls, airport terminal buildings, etc.). The general public is becoming increasingly aware of the problems and the risks, and there is now a perceived need to deal with fire safety in a more organised, ad hoc, fashion in which engineering solutions are introduced at an early stage, either to prevent the outbreak of fire, or to mitigate its effects to an extent that the losses are small, and considered "acceptable" in the circumstances.

A major problem which is relevant to the establishment of a solid corps of fire safety professionals lies in the need to break free from the past and convince society at large, and the young aspiring engineer in particular, that the discipline exists, that there are alternative solutions to complex fire safety problems, and that exciting career prospects for the aspiring engineer are to be found. Only in the USA and Sweden is Fire Safety Engineering seen to be a subject which has life outside the traditional fire service. The message is slowly gaining ground elsewhere, but therein lie problems unique to each country. The local situation does have significant implications regarding the approach which should be adopted if fire safety engineering is to be bootstrapped to the position of a professionally recognised engineering discipline in different countries.

Matters that need to be resolved include questions such as:

- \* Will the FSE graduates be employed by the fire service, by industry in general, or in consultancy organisations?
- \* At what level in the organisation will the FSE be employed?
- \* Can the skills of the FSE be fully utilised within the organisation to which he belongs?

The answers to these will largely determine whether or not the Fire Safety Engineer should have an all-round, undergraduate education in the subject, or attend a postgraduate degree programme, to build on an existing engineering degree in one of the traditional disciplines (Civil, Mechanical, Electrical or Chemical). The former may be more suited to the individual who wishes to enter the Fire Service through the lower ranks, or be employed as a Fire Safety Engineer in the Insurance Industry, where interaction with other professional engineers is a key part of his job. The latter would be more appropriate for someone joining an engineering consultancy where his/her existing skills, for example as a structural engineer, are fundamental to the type of work to be undertaken, or where the individual with a degree in (say) chemical engineering wishes to broaden his portfolio to improve his employment prospects in the petrochemical and offshore industries.

Any document on the education and training of fire safety engineering professionals must address the full scope of this problem. Fire safety engineering effectively overlaps all the other engineering disciplines as can be seen in Figure 1, implying in turn that the student must also be conversant (to a level which it is difficult to define) with basic chemistry and physics. The model curriculum reflects this complexity, firstly by identifying a series of background courses which are essential for a detailed understanding of the fire process, and secondly by defining five "fundamental" modules which build on the background material (defined as prerequisites). This material in its own right presents a significant intellectual challenge to any student intending to embark upon a career in Fire Safety Engineering. If all was to be taught, the study of the discipline would be deemed too daunting for any one individual. Consequently, it is essential that the descriptions that are set out in this document are used for guidance only. They are not prescriptive - if they were, one of the underlying *raison d'etres* of the discipline, viz. to achieve flexibility of solution, would be negated.

Nevertheless, to teach Fire Safety Engineering in a way that will benefit the student in his subsequent career, as well as society as a whole, the components must be covered to an appropriate level. An attempt is made to identify how much time should be spent on each component, but this is based on the opinions of a group of people who have been fortunate enough to have taught in institutions where the discipline has been allowed to develop, and the balance of the subjects reflects their own experiences. The balance must reflect the students' background and skills, the capabilities and resources of the institution, and - most importantly - the desired outcome of the entire process.



## 5. DEFINITION OF THE END PRODUCT

### 5.1 Job description and skill set

The role of the Fire Safety Engineer in the modern world of industry and commerce must be clearly defined. In view of the wide spectrum of activities through which he can contribute to promote fire safety, the Fire Safety Engineer must be involved at all stages of a project, from inception to commissioning and beyond. To some extent, he holds a position similar to that of the Architect during the design and construction stages of a building project. However, in order to achieve the fire safety objectives that are becoming realistic as the discipline of Fire Safety Engineering develops, the Fire Safety Engineer must be given the opportunity to apply his skills to improve fire safety from the design stage onwards. In fact, he should be consulted from the concept stage, even before the design process has begun.

Accordingly, the Fire Safety Engineer must be able to interact at all stages of a project with professionals from a wide range of disciplines. The stages are summarised in Table 1.

**Table 1.**

- Conception
- Design
- Construction
- Commissioning
- Operation
- Alteration/modification
- Decommissioning/demolishing.

It may be surmised from this list that as a project progresses the professionals with whom he must deal will change: this is illustrated in Table 2 for a building project. Tables of this kind could be prepared to illustrate the full range of project types: For example, in the design, construction and operation of a petrochemical plant, there would be continuing involvement with other engineering professionals, and he would be working in an environment in which safety is seen to be a key issue in view of the nature of the materials and processes involved. In particular, the FSE would be expected to apply the techniques of quantitative risk assessment.

**Table 2. Interaction between the Fire Safety Engineer and Other Professionals**

<b><u>Conception</u></b>	Client, Architect, Building Control Officer, Local Planning Authority, National Planning Authority, Environmental Health Officer.
<b><u>Design</u></b>	Architect, Structural Engineer, Building Services Engineer (H & V), Electrical Engineer, Fire Protection Systems Engineers (company-based), Other Services, Interior Designer, Building Control Officer, Fire Authority, Owner/client.
<b><u>Construction</u></b>	Architect, Master of Works (project manager), Site Manager, Contractors.

<b><u>Commissioning</u></b>	Client, Architect, Building Services Engineer, Fire Protection Systems Engineers, Building Control Officer, Fire Authority, Environmental Health, Health and Safety Executive.
<b><u>Operation</u></b>	Chief Executive, Building Manager, Works Manager, Training Officer, Security, Maintenance Department.
<b><u>Alteration</u></b>	Chief Executive, Building Manager, Works Manager, Training Officer, Security, Maintenance Department.
<b><u>Decommissioning</u></b>	Architect, Building Control Officer, Fire Authority, Security, Contractors.

The Fire Safety Engineer must be able to comment and advise at all stages on the impact that proposed design, or changes to design, will have on fire safety. At the present time, arguments based on quantitative risk assessment are necessary in the Nuclear and Petrochemical industries to make a case for a particular fire safety engineering solution: it is likely that this will become more widespread requirement in future.

While an individual fire safety engineer may have his own specialism, such as in the design a fire detection system, he must have sufficient knowledge of the rest of the discipline to be able to recommend an overall fire safety strategy, specifying performance requirements for the other components of the system (e.g. automatic suppression, alarm and indicating equipment, escape routes, etc.).

The skills set he must have is broad, and must include the ability to communicate with the spectrum of individuals that is outlined in the above table. The skills may be encompassed under three broad headings:-

- \* Identification of fire hazards
- \* Identification of appropriate fire protection strategies
- \* Application of appropriate techniques of risk analysis to enable the most cost-effective solution to achieve an acceptable level of fire risk.

These headings hide a multitude of detail that must be incorporated into any taught course. They hide the fact that the Fire Safety Engineer must have knowledge not only of fire chemistry and fire dynamics, but also have some understanding of building design and construction, of the hazards associated with materials and building geometry, of the interaction between fire and people. In addition, he must know about all the techniques of fire detection and suppression as well as understand the interaction with the local authority Fire Brigade/Department. Finally, he has to have an appreciation of the methods of risk analysis and how this can be applied to various types of "occupancy". Some of these points are summarised in Table 3.

**Table 3. The Skills Set**

<b>Identification of Fire Hazard</b>	<b>Identification of Fire Protection Strategies</b>	<b>Identification of Cost-Effective Solutions</b>
Need to know: Heat Transfer Properties of Materials Fire Chemistry Fire Dynamics Compartment Fire Dynamics Building Construction People/Fire Interactions	Need to know: Fire Prevention Fire Detection Fire Communications Escape Route Design Fire Suppression Fire Control Fire Resistance	Need to know: Fire modelling QRA Cost-benefit analysis Presentation skills

## **B Detailed description of background courses (modules)**

<b>1. Fluid mechanics</b>	<b>20</b>
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1.3 Contents of the module	20
<b>2. Heat and mass transfer in fire</b>	<b>24</b>
2.1 Introductory statement	24
2.2 Prerequisite matter	24
2.3 Contents of the module	24
<b>3. Classical thermodynamics</b>	<b>30</b>
3.1 Introductory statement	30
3.2 Prerequisite matter	30
3.3 Contents of the module	30
<b>4. Solid mechanics</b>	<b>33</b>
4.1 Introductory statement	33
4.2 Prerequisite matter	33
4.3 Contents of the module	33

## **B DETAILED DESCRIPTION OF BACKGROUND COURSES (MODULES)**

### **1. MODULE: FLUID MECHANICS**

#### **1.1 INTRODUCTORY STATEMENT**

The objective of this course is to provide a basic understanding of fluid mechanics as this subject relates to the analysis of fire suppression system design and the analysis of enclosure fire dynamics.

#### **1.2 PREREQUISITE MATTER**

A. Calculus                      B. Statics and Dynamics

#### **1.3 CONTENTS OF THE MODULE**

##### **I Fluid Fundamentals**

**Topic A                      Fluid Properties**  
(U1: 3 hrs; G: 1 hrs)

Contents:                      The definition of a fluid. Density. Specific weight Specific volume. Specific gravity. Compressibility. Ideal fluid. Viscosity. Surface tension. Capillarity.

References:                      Any textbook on Fluid Mechanics (This applies to all topics in the Fluid Fundamentals and Suppression System Applications sections.)

**Topic B                      Fluid Statics**  
(U1: 4 hrs; G: 2 hrs)

Contents:                      Definition of pressure. Stress at a point. Pressure as a scalar quantity. Pressure variation in a static fluid. Pressure head. Absolute and gage pressures. Pressure measurement. Manometers. Force on a plane area. Center of pressure. Forces on a curved surface. Buoyancy. Fluid masses subject to acceleration.

**Topic C                      Kinematics of Fluid Flow**  
(U1: 2 hrs; G: 2 hrs)

Contents:                      Classification of flow types. Laminar and turbulent flow. Steady flow and uniform flow. Streamlines. Pathlines. Flow rate and mean velocity. Continuity equation. One-, two- and three-dimensional flow. The flow net. Velocity and acceleration in steady and unsteady flows.

**Topic D                      Conservation Equations for Systems and Control Volumes**  
(U1: 6 hrs; G: 6 hrs)

Contents: Conservation of mass. Newton's second law. The Euler equation. The impulse-momentum principle. The first law of thermodynamics. Bernoulli's equation. Reynolds transport theorem. Control volume theory. Conservation equations in control volume form.

**Topic E Basic Hydrodynamics**  
(U1: 3 hrs; G: 3 hrs)

Contents: Differential equation of continuity. Rotational and irrotational flow. Circulation and vorticity. The stream function. Basic flow fields. Velocity potential.

**Topic F Boundary Layer Concepts**  
(U1: 4 hrs; G: 4 hrs)

Contents: Differential momentum equations. Von Karman Pohlhausen integral solution. Blasius solution. Friction factor and wall shear stress. Laminar and turbulent flow.

**Topic G Similitude and Dimensional Analysis**  
(U1: 5 hrs; G: 5 hrs)

Contents: Definition of similitude. Geometric similarity. Kinematic similarity. Dynamic similarity. Reynolds number. Froude number. Scale ratios. Dimensional analysis. Rayleigh method. Buckingham pi theorem. Dimensionless differential equations with buoyancy. Application to fire - ceiling jets, plumes, unsteady flows, salt water modeling.

## **II Suppression System Applications**

**Topic A Energy Considerations in Steady Flow**  
(U1: 3 hrs; G: 3 hrs)

Contents: Kinetic energy of a flowing fluid. Potential energy. Internal energy. General equation for steady flow of any fluid. Bernoulli's equation. Power considerations in fluid flow. Energy line. Hydraulic grade line.

**Topic B Steady Incompressible Flow in Pressure Conduits**  
(U1: 9 hrs; G: 6 hrs)

Contents: Laminar and turbulent flow. Critical Reynolds number. General equation for friction in circular pipes. The Darcy-Weisbach equation. Laminar flow in circular pipes. Turbulent flow in pressure conduits. Pipe roughness - friction factors. The Colebrook equation. The Moody diagram. Empirical equations for pipe flow. The Hazen-Williams equation. Minor losses - equivalent lengths. Pipe networks. The Hardy Cross method.

**Topic C Orifice Flow and Other Fluid Measurements**  
(U1: 3 hrs; G: 3 hrs)

Contents: Static pressure measurements. Velocity measurement with pitot tubes. Anemometers.

Rotameters. Discharge measurement. Orifices, nozzles and tubes. Jet velocity and pressure. The coefficient of contraction. The coefficient of velocity. The discharge coefficient. Venturi tube. Flow nozzle. Orifice meter. Weirs.

**Topic D      Centrifugal Pumps**

(U1: 6 hrs; G: 3 hrs)

Contents:      Definitions. Classifications. Size and rating of pumps. Head delivered. Specific speed. Pump characteristics. Efficiency. Cavitation. Affinity laws.

**Topic E      Compressible Flow**

(U1: 6 hrs; G: 6 hrs)

Contents:      Speed of sound. Isentropic nozzle flow. Mach number. Shock waves. Combustible mixtures and explosions. Deflagrations and detonations. Flame speed.

### **III Enclosure Fire Applications**

**Topic A      Fire Plumes**

(U1: 6 hrs; G: 6 hrs)

Contents:      Axisymmetric point source plumes. Line source plumes. Atmospheric thermal stratification. Fire plume. Entrainment into flames and plumes.

References:    Heskestad (1988); McCaffrey (1988); Delichatsios (1988)

**Topic B      Ceiling Jets**

(U1: 5 hrs; G: 5 hrs)

Contents:      Differential equation for axisymmetric ceiling jet. Transient and steady correlations for velocity and temperature. Smoke filling of a closed compartment.

References:    Evans (1988)

**Topic C      Vent Flows**

(U1: 4 hrs; G: 4 hrs)

Contents:      Wall vents. Ceiling vents. Smoke control - critical pressure or Froude number.

References:    Emmons (1988)

**Special note:**    Parts of Topics A - C can be taught in the module "Enclosure Fire Dynamics".

#### **REFERENCES:**

Delichatsios, M.A., Air Entrainment Into Buoyant Jet Flames and Pool Fires, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-19.

Emmons, D.D., Ceiling Jet Flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-8

Evans, D.D., Ceiling jet flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-9.

Heskestad, G., Fire Plumes, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-6.

McCaffrey, B.J., Flame Height, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-18.



## 2. MODULE: HEAT AND MASS TRANSFER IN FIRE

### 2.1 INTRODUCTORY STATEMENT

This is a fundamental course in heat transfer with emphasis and specific content needed in Fire Protection Engineering. The course is designed very similar to any other undergraduate engineering heat transfer course except with emphasis on applications and topics related to fire science. The module is intended for undergraduate instruction but contains some topics suitable for a graduate level curriculum.

Any standard undergraduate text can be used for this course. The particular text used for organizing most of the material in this module was:

Holman, J.P., *Heat Transfer*, 7th Ed. (McGraw-Hill Publ. Co.), 1990.

Appropriate references, excluding the above text, are noted for those topics as needed. For graduate level instruction, other heat and mass transfer texts may be considered.

For the mass transfer area, an appropriate textbook is the relevant parts of:

Welly, J.R, Wilson, R.E. and Wicks, C.E., *Fundamentals of Momentum, Mass and Heat Transfer*.

### 2.2 PREREQUISITE MATTER

- A) It is suggested that the students would have already completed courses in Thermodynamics and Fluid Mechanics.
- B) Normal background for a engineering student in basic engineering science and mathematics, up to ordinary differential equations, is assumed.
- C) Use of numerical methods for solution of some problems would warrant a knowledge of computer tools and higher level computer language.

### 2.3 CONTENTS OF THE MODULE

#### I Conduction Heat Transfer

**Topic A Introduction and Modes of Heat Transfer**  
(U1: 2 hrs.)

Contents: Introduction to heat transfer phenomenon and description of the three modes of heat transfer; conduction, convection and radiation. Description of the importance of heat transfer in fire problems through use of specific demonstrative examples.

**Topic B Steady-State Conduction**  
Subtopic B1 **One-Dimensional Steady-State Conduction**

(U1: 8 hrs)

**Contents:** Introduction to 1-D Steady-State Conduction and application to specific cases such as, the plane wall, insulation and insulation critical thickness. One-dimensional heat conduction with a heat source and contact resistance.  
Radial systems (cylinders) Cylinder with heat sources.  
Convective boundary conditions producing conduction-convection systems such as fins and the concept of overall heat transfer coefficient.

**Subtopic B2      Steady-State Conduction in Multiple Dimensions**  
(U1: 5 hrs., G: 3 hrs.)

**Contents:** Introduction to Multi-Dimensional Conduction. Use of mathematical and graphical analysis of 2-D heat conduction. Solution of 2-D partial differential equation of conduction using separation of variables technique. Numerical method of analysis employing Gauss-Seidel Iteration and other techniques. Application of different boundary conditions such as convective boundary, insulated boundary, etc. Numerical accuracy, numerical convergence and well-posed boundary conditions. Use of electrical circuit analogy.

**Topic C              Unsteady-State Conduction**

**Subtopic C1      One-dimensional Systems**  
(U1: 5 hrs., G: 3 hrs.)

**Contents:** Introduction to Unsteady state. Lumped mass systems, the Biot number and characteristic time and length scale concepts.  
Transient heat flow in a semi-infinite solids. Analytical solutions for constant heat flux and constant surface temperature cases as well as a convective boundary conditions. Use of Heisler charts and analytical solutions for infinite plates, cylinders, etc.  
Definition and significance of the Fourier number.

**Special Note:** Application of lumped-mass system to a heat detector or sprinkler link is a good example. Concepts such "thermally thin" and "thermally thick" barriers can be incorporated as useful FPE related examples.

**Subtopic C2      Multi-dimensional Systems**  
(U1: 2 hrs., G: 4 hrs.)

**Contents:** A very brief overview of multi-dimensional unsteady heat transfer with emphasis on numerical solution techniques, numerical instabilities and available commercial software packages.

**Special Note:** A problem to solve a transient 2-dimensional problem for a FPE application using numerical methods is strongly suggested here.

**Subtopic C3      Fire Resistance of Structures and Assemblies**  
(U1:1 hr., G:4 hrs.)

Contents: Computational methods (finite difference, finite element), standard fire time-temperature curves, heat flux conditions in fire, stress-strain effects.

References: Any appropriate text book on computational methods may be used.  
Lie (1988); Milke (1988); Jaluria (1988); White (1988).

## II Convection Heat Transfer

### Topic A Introduction and Background (U1: 5 hrs.)

Contents: Introduction to convection heat transfer, and overview of the fluid mechanic fundamentals such as viscous and inviscid flows, internal and external flow, definition of the boundary layer flow, laminar sublayer and development of the energy equation. Definition and relations for the thermal and momentum boundary layer thickness. Discussion of the turbulent boundary layer with emphasis in development of the layer thickness, eddy diffusivity and eddy viscosity concepts.

### Topic B Forced Convection Heat Transfer (U1: 5 hrs., G: 3 hrs.)

Contents: External flows, bulk fluid temperature and fluid property evaluation. Turbulent--boundary layer heat transfer, Turbulent-boundary layer thickness, heat transfer in laminar tube flow, turbulent flow in a tube (Brief) and flow across cylinders and spheres.

**Special Note:** Flow over flat plates should be applied to a discussion of the ceiling heat transfer problem. Heat detector and sprinkler element heat transfer modelling can be used as examples of convective heat transfer to cylinders and spheres.

### Topic C Natural Convection Heat Transfer

#### Subtopic C1 Flow over Flat Plates, Cylinders and Spheres (U1: 4 hrs., G: 3 hrs.)

Contents: Introduction to natural convection systems and non-dimensional parameters, Grashoff, Prandtl and Nusselt numbers.  
Free-convection heat transfer on a vertical flat plate, empirical relations for free convection, free convection from vertical planes, cylinders and spheres. Free convection from horizontal plates, free convection from inclined surfaces

#### Subtopic C2 Free Convection in Enclosed Spaces (U1: 1 hr., G: 2 hrs.)

Contents: A general and qualitative discussion of heat transfer to and from compartment surfaces and induced convective currents.

References: In addition to Holman; Jaluria (1980)

**Topic D            Fire Induced Convective Heat Transfer**

Subtopic D1:    **Heat Transfer to Ceilings**  
(U1: 1 hr., G:3 hrs.)

Contents: Fire and Buoyant plume ceiling heat transfer. Analytical and experimental results.

References:     Cooper and Woodhouse (1986).

Subtopic D2:    **Heat Transfer to Vertical Walls**  
(G: 2hrs.)

Contents:        Fire and buoyant plume wall heat transfer. Corner effects.

References:     Jaluria (1988); research papers.

**III Radiation Heat Transfer**

**Topic A            Introduction to Radiation Heat Transfer**  
(U1: 2 hr.)

Contents:        Physical Mechanism, thermal radiation, Stefan-Boltzmann law and Planck's constant. Radiation properties, emissivity, black and grey body radiations and Wien's displacement law.

**Topic B            Black Body Radiation**

Subtopic B1     **Shape Factors**  
(U1: 2 hrs.)

Contents:        Radiation shape factor and view factors. Mathematical relations for the derivation of the shape factors. Use of charts. Shape factor algebra.

**Topic C            Non-Black Body Radiation**

Subtopic C1     **Enclosure Radiation Exchange**  
(U1: 3 hrs., G: 1 hr.)

Contents:        Heat exchange between enclosure surfaces, radiosity and irradiation. Use of electrical circuit analogy. Applications of infinite parallel planes and radiation shields.

Subtopic C2     **Gas Radiation**  
(U1: 2 hrs., G: 2 hrs.)

Contents:        Gas absorption and emission. Lambert-Beer's law. Mean beam length. Heat exchange between gas volume and enclosure surfaces.

Subtopic C3     **Total Enclosure Radiation Problems**  
(U1: 2 hrs., G: 3 hrs.)

Contents: Radiation exchange between specular surfaces. radiation exchange with transmitting, reflecting and absorbing media. Radiation heat transfer coefficient and application of numerical solutions to the more complicated problems.

Subtopic C4 **Zone Model Enclosure Radiation Exchange**  
(G: 2hrs)

Contents: Radiation exchange formulation for two-gas-layer fire concept.

Subtopic C5 **Flame Radiation**  
(U1: 1 hr., G: 3 hrs.)

Contents: Soot-combustion gas effects, flame shape, non-homogeneity effects, radiation exchange.

## **IV Mass Transfer**

**Topic A Isothermal Mass Transfer**  
(U1: 2hrs., G: 2 hrs.)

Contents: Fick's Law, diffusion coefficient, Stefan's law of mass transfer and droplet evaporation

**Topic B Simultaneous Heat and Mass Transfer**  
(U1: 1hr., G: 6 hrs.)

Contents: Formulation of governing equations, thermo-diffusion, droplet evaporation, Lewis number, stagnant boundary layer formation, B-number, wet-bulb temperature.

**Topic C Relationship to Flammable Liquids**  
(G: 2hrs.)

Contents: Flammability limits, applications on evaporation of flammable liquids.

Subtopic C1 **Mass Transfer**  
(U1: 2hrs)

Contents: Fick's Law of Diffusion, Diffusion in Gases, the mass transfer coefficient and non-dimensional parameters, Schmidt and Lewis numbers.

### **REFERENCES:**

Cooper, L.Y. and Woodhouse, A., *J. of Heat Trans.*, Vol. 108, 1986, pp. 822-826.

Fleischmann, C., Analytical Methods for Determining Fire Resistance of Concrete Members, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-7.

Holman, J.P., *Heat Transfer*, 7th Ed. (McGraw-Hill Publ. Co.), 1990.

Jaluria, Y., Natural Convection Wall flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-7.

Jaluria, Y., *Natural Convection, Heat and Mass Transfer*, Pergamon Press, 1980, Ch. 8.

Lie, T.T., Fire Temperature-Time Relations, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-5.

Milke, J., Analytical Methods for Determining Fire Resistance of Steel Members, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-6.

White, R.H., Analytical Methods for Determining Fire Resistance of Timber Members, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-8.

### 3. MODULE: CLASSICAL THERMODYNAMICS

#### 3.1 INTRODUCTORY STATEMENT

This is a fundamental course in Classical Thermodynamics and is intended as a background core course for Fire Protection Engineering curriculum. The course is designed very similar to any other undergraduate engineering thermodynamics course except with emphasis on applications and topics related to fire and combustion. The module is only intended for undergraduate instruction and not for a graduate level curriculum.

Any standard undergraduate text can be used for this course. The particular text used for organizing the material in this module was:

Van Wylen, G.J. and Sonntag, R.E., *Fundamentals of Classical Thermodynamics*, 3rd Ed. (John Wiley and Sons, Inc.), 1985.

#### 3.2 PREREQUISITE MATTER

- Normal background for a engineering student in basic engineering science and mathematics, up to ordinary differential equations, is assumed.

#### 3.3 CONTENTS OF THE MODULE

##### I Introductory Material and Concepts

###### Topic A Introduction

###### Subtopic A1 Concepts and Definitions (U1: 2 hrs.)

Contents: Introduction to thermodynamics, power generation, thermodynamic system and control volume, thermodynamic properties, macroscopic vs. microscopic point of view, thermodynamic properties and state of a substance. Process and cycle.

###### Subtopic A2 Properties of a Pure Substance (U1: 3 hrs.)

Contents: Definition of a pure substance. Phase equilibrium for a pure substance. Independent thermodynamic properties. Equation of state, and ideal gas law. Compressibility. Thermodynamic property tables.

##### II Conservation of Mass and Energy

###### Topic A Work and Heat (U1: 2 hrs.)

Contents: Introduction to the thermodynamic definition of work and heat. Work in a quasiequilibrium process. Interaction between heat and work. The pressure-volume diagram and its application for calculation of work in simple compressible systems.

**Topic B First Law of Thermodynamics**  
(U1: 3 hrs.)

Contents: Development of the first law for a system undergoing a cycle and subsequent development for a change in the thermodynamic state of a system. Definition of internal energy and enthalpy and their relation. Definition of the specific heats and specific focus on the ideal gas case.

**Topic C Conservation of Mass and Energy**  
(U1: 6 hrs.)

Contents: Development of conservation of mass for system and control volume. Development of the first law as a rate equation (i.e. the conservation of energy for a control volume) Application of the energy equation (or First Law) to the special cases of Steady-State, Steady-Flow Process and the Uniform-State, Uniform-Flow Process.

### **III Thermodynamic Cycles**

**Topic A Second Law of Thermodynamics**  
(U1: 2 hrs.)

Contents: Definitions and descriptions in the context of thermodynamic cycles, heat and refrigeration engines. Reversible and Irreversible Processes. Carnot cycle and Carnot efficiency.

**Topic B Entropy**

Subtopic B1 **System Entropy**  
(U1: 3 hrs.)

Contents: Definition of Entropy. Clausius inequality. Entropy in a system and calculations for a cycle. Entropy change in a reversible process. Entropy change for an ideal gas. Principle of increase of entropy.

Subtopic B2 **Polytropic Processes**  
(U1: 2 hr.)

Contents: Use of reversible polytropic process for ideal gas and calculations for a cycle. Entropy change for an ideal gas.



Subtopic B3      **Application of the Second Law for a Control Volume**  
(U1: 3 hrs.)

Contents:      Development of the equation of the second law for a control volume using the conservation of mass. Specific cases of the second law applied for Steady-State, Steady-Flow and transient processes. Efficiency calculations.

**Topic C      Irreversibility and Availability**  
(U1: 2 hrs.)

Contents:      General concepts and application of the reversible work and irreversibility to processes and cycles, especially to processes involving chemical reactions will be covered.

## **IV Thermodynamic Relations, Mixtures and Chemical Reactions**

**Topic A      Thermodynamic Relations**  
(U1: 2 hr.)

Contents:      Definitions and introduction of the Maxwell Relations, Clapeyron Equation and application of the relations involving internal energy, enthalpy and entropy with emphasis on ideal gas conditions.

**Topic B      Mixtures of Ideal Gases**  
(U1: 3 hrs.)

Contents:      Definitions of mole and mass fractions, and application of the ideal gas law for gas mixtures. Dalton and Amagat's models. Application of the first law to Gas-Vapor mixtures. Wt and dry bulb temperatures. Partial molal properties. The Psychometric chart.

**Topic C      Chemical Reactions**  
(U1: 4 hrs.)

Contents:      Fuels and their chemical structure. The simple combustion process and stoichiometric reactions. Enthalpy of formation. First law analysis of a system involving a combustion process. The adiabatic flame temperature. Heat of reaction (or combustion).

## 4. MODULE: SOLID MECHANICS

### 4.1 INTRODUCTORY STATEMENT

Solid mechanics normally is a part of a basic engineering curriculum. It usually includes the areas of statics (analysis of bodies at rest), dynamics (analysis of bodies in motion), and mechanics of Materials (analysis of internal resistance of materials in relation to external forces). Concepts in statics are prerequisite to dynamics and mechanics of materials. In most engineering curricula, this material is included in three distinct courses (or subjects). The material described here is intended to identify subject matter that is useful background for applications in fire protection. Dynamics, while it is a useful prerequisite to fluid mechanics, is not included in this module because it is not necessary for passive fire protection analysis.

This module is intended only for undergraduate instruction and not for a graduate level curriculum. In many cases, topical content is included in order to provide continuity of learning the subject matter in order to develop an understanding for the fire protection applications. Many standard textbooks are available for these subjects. The texts that were used to organize the material for this module were:

Beer and Johnston, *Engineering Mechanics: Statics*, 5th Ed. (McGraw-Hill Publishing Company)  
Beer and Johnston, *Mechanics of Materials* (McGraw-Hill Publishing Company)  
Fitzgerald, R. W. *Mechanics of Materials*, 2nd Ed (Addison-Wesley Publishing Company)

### 4.2 PREREQUISITE MATTER

Mathematics including differential and integral calculus is assumed.

### 4.3 CONTENTS OF THE MODULE

#### I Statics

**Topic A**            **Basic Force Systems**  
(U1: 4 hrs)

Contents:            Forces; vectors; resultants; components of a force; moments; couples.

**Topic B**            **Equilibrium**  
(U1: 16 hrs)

Contents:            Analysis of concurrent and non-concurrent force systems; analysis of statically determinate beams, frames, and complex machines and structures for distributed and concentrated forces.

**Topic C**            **Internal Forces**  
(U1: 8 hrs)

Contents: Analysis of internal shear, moment, and normal forces in statically determinate beams, frames, and complex machines and structures for distributed and concentrated forces; shear, moment, and normal force diagrams.

**Topic D Hydrostatics**  
(U1: 3 hrs)

Contents: Analysis of external and internal forces in structures that are subjected to hydrostatic forces.

## **II Mechanics of Materials**

**Topic A Axial and Shear Stress and Strain**  
(U1: 10 hrs)

Contents: Axial and shear stress and strain; deformations; stress-strain diagram and mechanical testing; elastic and plastic behavior; statically indeterminate problems; temperature changes; stress concentrations; transformations of stress.

**Topic B Torsion**  
(U1: 4 hrs)

Contents: Torsional stress and strain; axial and torsional loadings and transformation of stress; qualitative behavior of non-circular members.

**Topic C Flexure**  
(U1: 4 hrs)

Contents: Analysis and design of statically determinate beams for flexural and shear loads.

**Topic D Deflection of Beams**  
(U1: 4 hrs)

Contents: Present one of the techniques to determine the deflection of statically determinate beams for concentrated and distributed loads.

**Topic E Statically Determinate Beams**  
(U1: 4 hrs)

Contents: Analysis of statically indeterminate beams by superposition using the beam deflection and rotation procedures of Topic D; shear and moment diagrams.

**Topic F Inelastic Behavior**  
(U1: 6 hrs)

Contents: Axial, torsional, and flexural behavior in the inelastic range; ductility; shape factor; statically indeterminate structures and force and moment redistribution.

**Special Note:** These topics are normally not included in an undergraduate mechanics course. However, this topic becomes the main purpose in fire protection have a sense of the

indeterminate structures. An awareness of the fire behavior of statically indeterminate structures can be incorporated into this material.

**Topic G**      **Column Behavior**  
(U1: 3hrs)

Contents:      Concepts of elastic stability; failure intermediate, and long columns; development of design.

Special Note:      The topic of column behavior in fires can be due to elevated temperatures, the influence of the connections, and the influence of the when it is subjected to elevated temperatures.

## **C Detailed description of fundamental courses courses (modules)**

<b>1. Fire fundamentals</b>	<b>37</b>
1.1 Introductory statement	37
1.2 Prerequisite matter	37
1.3 Contents of the module	38
1.4 Laboratory experiments	40
<b>2. Enclosure fire dynamics</b>	<b>43</b>
2.1 Introductory statement	43
2.2 Prerequisite matter	43
2.3 Contents of module	43
2.4 Number of lecture hours	48
2.5 Laboratory experiments	48
<b>3. Active fire protection</b>	<b>50</b>
3.1 Introductory statement	50
3.2 Prerequisite material	50
3.3 Contents of module	50
<b>4. Passive fire protection</b>	<b>58</b>
4.1 Introductory statement	58
4.2 Prerequisite material	59
4.3 Contents of module	59
<b>5. Interaction between fire and people</b>	<b>63</b>
5.1 Introductory statement	63
5.2 Prerequisite matter	63
5.3 Contents of module	63
5.4 Number of lecture hours	66

# **C DETAILED DESCRIPTION OF FUNDAMENTAL COURSES (MODULES)**

## **1. MODULE: FIRE FUNDAMENTALS**

### **1.1 INTRODUCTORY STATEMENT**

The objective of this module is to provide the basic chemistry and physics necessary for the understanding of fire and draw them together with some of the other fundamental topics (in particular, heat and mass transfer) required to synthesise a knowledge of fire processes. The following main topics will be introduced:

Polymers: their structure, properties and thermal behaviour.

Chemical kinetics, including free radical reactions, chain branching and inhibition.

Premixed and diffusion flames; the products of complete and incomplete combustion.

The burning of liquids and solids, including the concepts of ignition, flashpoint and firepoint.

Self-heating and spontaneous combustion.

On completion, the students should be able to:

Classify combustible materials according to their polymeric structure.

Identify the likely physical and chemical behaviour of different combustible materials when exposed to fire conditions.

Understand the principal mechanisms by which flame retardants operate and comment on the likely effectiveness of a given FR treatment in reducing fire risk.

Interpret flammability limit diagrams and apply them in the context of the prevention and mitigation of gas/vapour explosions.

Use the concepts of flammability limits, etc., to interpret the ignition of liquids and solids.

Relate burning rates to the fundamental properties of liquid and solid fuels.

Relate burning rate and flame height.

### **1.2 PREREQUISITE MATTER**

A) Basic chemistry

B) Modules in heat and mass transfer, thermodynamics and thermochemistry.

## 1.3 CONTENTS OF THE MODULE

### I Components

#### Topic A **Polymers and polymer decomposition**

(U1: 6hrs; G: 3 hrs)

Contents: Natural and synthetic polymers - their structure and composition. Relation between chemical/physical properties and structure (degree of polymerisation, branching, crosslinking, etc.). Production of fire retarded modifications. Effect of temperature on polymers. Distinction between thermoplastic and thermosetting polymers. Modes of decomposition - unzipping vs. random scission, and relevance to the composition of products. Rates of decomposition and their measurement. The effect of fire retardants on decomposition.

References: Askeland (1990); Cullis and Hirschler (1981); Beyler (1985); Beyler (1988) Lyons (1970).

#### Topic B **Chemical processes**

##### Subtopic B1 **Chemical reactions**

(U1: 2hrs; G: 1hr)

Contents: Stoichiometry. Global reaction vs. elementary reactions. Rates of reactions: molecularity and order. Reaction mechanisms. Homogeneous (gas phase) and heterogeneous (gas/solid) reactions.

References: Atkins (1978); Moore (1972); Benson (1960)

##### Subtopic B2 **Flame chemistry.**

(U1: 7hrs; G: 4hrs)

Contents: Free radical reactions; chain reactions - linear and branched. Auto ignition and its measurement. Catalysis and inhibition. Combustion kinetics, using the H<sub>2</sub>/O<sub>2</sub> reaction as an example.

References Moore (1972); Benson (1960); Barnard and Bradley (1985); Atkins (1978).

## II Synthesis

### Topic A **Flames and Fire Plumes**

#### Subtopic A1 **Premixed flames** (U1: 12hrs; G: 8hrs)

Contents: Analysis of the structure of the reaction zone. Flame temperature. Flammability limits, including flammability diagrams: their measurement and interpretation. Thermal theory of the limits. Ignitability. Explosions. Deflagration and detonation. Suppression of a premixed flame - physical and chemical processes. Flame arresters and "explosion proof" electrical equipment.

References Barnard and Bradley (1985); Kanury (1975); Lewis and von Elbe (1987); Drysdale (1985); Glassman, (1977); Beyler (1988).

#### Subtopic A2 **Diffusion flames** (U1: 8hrs; G: 4hrs)

Contents: The Burke-Schumann model. Structure of the reaction zone (laminar flame): relevance to CO, soot formation, etc. Momentum jet flames - laminar and turbulent. Relationship between flame height and fuel flowrate. Hottell and Hawthorne's equation. Buoyant diffusion flames: structure of the fire plume using McCaffrey's correlations of temperature and velocity with height and heat output. Concept of flame height. Correlation of flame heights with rate of heat release.

References: Barnard and Bradley (1985); Kanury (1975); Lewis and von Elbe (1987); Hottel and Hawthorne (1949); McCaffrey (1979).

Special note: The relevance of the "fire plume" to detector operation and sprinkler operation and performance should be noted.

#### Subtopic A3 **Burning of Liquids and Solids** (U1: 10hrs; G: 5hrs)

Contents: Application of the B-number to the evaporating and burning of fuel droplets. Boundary layer, with and without combustion. Importance of the ratio  $\rho H/L_v$ . Relevance to the burning of liquid pools in air. Blinov and Khudiakov's data and Hottel's interpretation. Simple thermal model for the steady burning of liquids and solids. Heats of gasification. Measurement of the rate of heat release using oxygen depletion calorimetry. Combustion efficiency.

References: Spalding (1955); Kanury (1975); Tewarson (1988); Babrauskas (1988); McCaffrey (1988).

#### Subtopic A4 **Ignition of liquids and solids** (U1: 8hrs; G: 4hrs)

Contents: Classification of liquids. Flash points and their relationship to flammability limits. The wick effect and its relevance to the ignition of high flashpoint liquid pools. Application of the concepts of flash point and fire point to the ignition of solids. Rasbash's fire point equation and the use of the B-number. Effect of the nature of the polymeric fuel



(chemical composition, rate of decomposition, etc.) and its mode of decomposition. Effect of the physical form of the fuel on ignitability and flame spread.

References: Drysdale (1985); Tewarson (1988); Kanury (1975); Cullis and Hirschler (1981); Beyler (1995).

## **Topic B Incomplete combustion processes**

### **Subtopic B1 Gas phase combustion** (U 1: 6hrs; G: 3hrs)

Contents: Definition of combustion efficiency. Gaseous products of combustion; formation of soot and smoke. Effect of reduced oxygen concentration. Gas phase pyrolysis processes. Scenarios for incomplete combustion. Generation of products of incomplete combustion: equilibrium considerations.

References: Tewarson (1988); Beyler (1985); Friedman (1988).

### **Subtopic B2 Smouldering and Spontaneous Combustion** (U 1: 6hrs; G: 3hrs)

Contents: Smouldering as a heterogeneous oxidation process. Identification of materials which will undergo this type of combustion (porous, char-forming). Combustion products. Rate of spread and transition to flaming. Initiation, by pilot (smouldering source) or by spontaneous combustion. Frank-Kamenetskii's model for spontaneous combustion. Methods of assessing risk of spontaneous combustion.

References: Drysdale (1985); Ohlemiller (1988); Beever (1988); Bowes (1984).

## **1.4 LABORATORY EXPERIMENTS**

1. Measurement of flashpoint and firepoint for pure liquids and liquid blends. Use Pensky-Martens Closed Cup Apparatus (or equivalent) and the Cleveland Open Cup Apparatus.
2. Ignition of combustible solids exposed to radiant heat (e.g. from a cone heater). (Measure time to ignition as a function of heat flux: deduce critical heat flux; relationship between  $t_{ig}$  and  $k\rho c$ ; observe behaviour of the solid during pre-ignition stage (does it char, melt, bubble, etc.?) Experiment can be carried out with sample horizontal and/or vertical.)
3. Measurement of fundamental burning velocity of gas/air mixtures using the cone angle method. (Premixtures burning as on Bunsen Burner; cone angle of the premixed flame measured directly;  $S_u$  related to cone angle, the linear flowrate of mixture exiting from the tube and the fuel/air ratio. Use propane, methane and ethene. Observe flame stabilisation and flashback. This experiment is very easy/cheap to set up and can be used to illustrate the difference between premixed and diffusion flames.)
4. Rates of burning of liquid pools. Pure liquids (e.g. hexane, kerosene and methanol) can be burned in Pyrex Petri dishes of various diameters from 5cm up to 15cm or more. A load cell may be used to monitor weight loss. Flame height can be measured and related to the rate of heat release as calculated from the rate of mass loss and an effective heat of combustion. The results can be

compared with Blinov and Khudiakov's correlations, and with standard correlations between flame height and RHR. (There is opportunity for much greater sophistication with this experiment, particularly if a porous bed gas burner can be used, and the products of combustion can be measured in a hood/duct assembly.)

5. Smoke and toxic gases measurement from combustible materials. (Either using a piece of standard equipment, such as the NBS Smoke Chamber, or the Cone Calorimeter, or some other facility, e.g. burning materials in a "large" (ca 14m<sup>3</sup>) smoke box and measuring the optical density of the accumulated smoke. It is valuable to make comparisons between different liquid fuels, and combustible solids such as PMMA, PP, PS, etc.)

- References:
- Askeland, D.R., *The Science and Engineering of Materials*, Second Edition (Chapman and Hall, London), 1990.
- Atkins, P.W. , *Physical Chemistry*, (Oxford University Press) 1978.
- Babrauskas, V., *Burning Rates*, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 2-1.
- Barnard, J.A. and Bradley, J.N., *Flame and Combustion Phenomena* (Chapman and Hall, London), 1985.
- Beever, P.F., *Self-Heating and Spontaneous Combustion*, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988 Chapter 1-22.
- \* Benson, S., *Chemical Kinetics*, (Academic Press, New York?), 1960.
- \* Beyler, C.L., *1st International Symposium on Fire Safety Science* (Hemisphere Publishing Corporation, New York), 1985, p.431
- Beyler, C.L., *Thermal Decomposition of Polymers*, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 1-12.
- Beyler, C.L., *Fire Chemistry*, (in preparation, to be published by John Wiley and Sons, New York), 1995.
- Bowes, P.C., *Self-Heating: Evaluating and Controlling the Hazards*, (HMSO, London), 1984.
- Cullis, C.F. and Hirschler, M.M., *The Combustion of Organic Polymers*, (Oxford University Press, Oxford), 1981.
- Drysdale, D., *An Introduction to Fire Dynamics*, (John Wiley and Sons, Chichester), 1985.
- Friedman, R., *Chemical Equilibrium*, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 1-11.
- Glassman, I., *Combustion* (Academic Press, New York), 1977.
- Hottel, H.C. and Hawthorne, W.R., *3rd Symposium (International) on Combustion* (Williams and Wilkins, Baltimore), 1949, pp. 255-266.
- Kanury, A.M., *Introduction to Combustion Phenomena*, (Gordon and Breach), 1975.
- Lewis, B. and von Elbe, G., *Combustion, Flames and Explosions of Gases*, 3rd Edition (Van Nostrand, New York), 1987.
- Lyons, J.W., *The Chemistry and Uses of Fire Retardants*, (John Wiley and Sons, New York), 1970.
- McCaffrey, B.J., *Purely Buoyant Diffusion Flames: Some Experimental Results* NBSIR 79-1910 (National Bureau of Standards, Washington DC), 1970.
- McCaffrey, B.J., *Flame Height*, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 1-18.

Madorsky, S.L., Thermal Decomposition of Organic Polymers, (John Wiley and Sons, New York), 1964.

Moore, W.J., Physical Chemistry, Fifth Edition (Longman, London), 1972.

Ohlemiller, T.J., Smouldering Combustion, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 1-23.

Spalding, D.B., Some Fundamentals of Combustion, (Butterworths, London), 1955.

Tewarson, A., Generation of Heat and Chemical Compounds in Fires, SFPE Handbook, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Chapter 1-13.

## 2. MODULE: ENCLOSURE FIRE DYNAMICS

### 2.1 INTRODUCTORY STATEMENT

The objective of the course is to give an understanding of room fire growth and spread mechanisms and the influence of the associated chemical and physical processes.

The following main topics will be introduced

- \* basic compartment fire concepts, the concept of flashover
- \* flammability characteristics of wall linings and of combustible contents
- \* burning rates of common fuel packages and fuel assemblies
- \* chemistry of room fire combustions, potential for upper layer ignition
- \* the fluid dynamics of vent flows, the derivation of hydrostatic pressure differences
- \* heat flow into enclosing structures
- \* the post-flashover compartment fire
- \* the two-zone, quasi-steady flow compartment fire
- \* the accumulation of filling phase of the compartment fire

Upon completion of this module, the student should have the following capabilities

- \* assess the pressures generated by a compartment fire
- \* understand the various compartment fire categories and stages possible by combining different ventilation and burning conditions
- \* have the ability to estimate by simple hand calculation methods heat and mass flows generated by a compartment fire
- \* have an understanding of the limitation and potentials inherent in computer-based zone models such as CFAST
- \* be able to undertake a rational hazard assessment of a specified room fire scenario

### 2.2 PREREQUISITE MATTER

- A) Modules in heat and mass transfer, thermodynamics and fluid mechanics (as defined previously).
- B) The module Fire Fundamental.

### 2.3 CONTENTS OF MODULE

#### I Room Fire Components

**Topic A**            **Material flammability characteristics**  
(U<sub>1</sub> 8 hours, G 6 hours)

Subtopic A1        **Ignitability, solid materials**

Content:            Understand the concept of thermal ignition by convective and radiative heating. The concept of critical surface temperature. Relation to fire point theory. Write equations for radiative heating

- neglecting cooling  
- with linearized cooling  
and compare solutions for semi-infinite solid and thin materials. Determination of material flammability parameters such as  $k\rho c$ , minimum flux for ignition.

Outline of standard test methods.

References: Drysdale (1985); ISO (1994)

Special note: Linked to "fire point theory" discussed in Fire Fundamentals. Laboratory experiment essential.

### Subtopic A2 **Flame spread**

Content: Various factors influencing flamespread. Various spread modes. Generalized equation for flame spread. Solutions for rapid, concurrent mode. Solutions for lateral flame spread. Determination of flame spread coefficient.

Outline of standard test method.

References: Drysdale (1985); Quintiere (1988); ISO (1990).

Special note: Laboratory demonstration essential. Theoretical derivation not to be explicitly based on Laplace-transform techniques.

### Subtopic A3 **Burning rates**

Contents: Fire growth and burning rates of various fuel packages or fuel assemblies. Various factors influencing burning and guidelines for estimating or measuring burning rate.

References: Babrauskas (1988)

Special note: Important background for description of fire scenarios and design fires. Video of experiments should be shown. Cone calorimeter apparatus and results discussed in "Fire Fundamentals", subtopic "Generation of heat and chemical compounds".

## **Topic B Chemistry of room fire combustion**

(U<sub>1</sub> 8 hours, G 6 hours)

Contents: Repetition of relevant basics of thermal decomposition of polymers, generation of heat and chemical compounds, equilibrium and non-equilibrium calculation of composition of products discussed in module "Fire Fundamentals". Stoichiometry combustion efficiency. Fuel lean and fuel rich regions. Equivalence ratio. Composition of upper gas layer of a non-vented room fire as a function of combustion efficiency. Adiabatic flame temperature of upper gas layer. Potential for layer ignition. For vented room fires: Flashover and the concepts of critical equivalence ratio and critical energy density.

References: Williamson (1988)

Special notes: Simple spread sheet type of calculation by the students. Linkage to relevant sections

of Fire Fundamentals essential. Product composition and toxic hazard is treated in the module "Interaction between fire and people".

**Topic C**            **Vent flows**  
(U<sub>1</sub> 6 hours, G 4 hours)

Subtopic C1        General equations for flow through openings

Contents:            Calculation methods for flow in openings. Flow coefficients.

Reference: Textbook in fluid mechanics

Subtopic C2        Hydrostatic pressure differences

Contents:            Hydrostatic pressure differences for one- and two-zone room fire idealizations. Concept of neutral layer, massbalance equations. Pressure differences calculated for general room temperature distributions.

Reference: Emmons (1988); Walton and Thomas (1988) (part)

Special note:        This is the Kawagoe-Prahl/Emmons-Rockett flow model.

Subtopic C3        Explicit calculation of mass flow

Content:             Derivation of  $\dot{m} \approx 0.5A\sqrt{H}$  formula.

Reference: Drysdale (1985).

**Topic D**            **Heat flow calculation**  
(U<sub>1</sub> 4 hours, G 3 hours)

Contents:            Heat flow calculations  
upper gas layer - walls and ceilings in contact  
upper gas layer - floor and lower part of walls  
radiation from flames

References:         Walton and Thomas (1988) pp 2-18 - 2-19; Tien et al. (1988) pp 1-101 - 1-103.

Special notes:      Repeat concept of heat transfer coefficient (convective, radiative, total).  $h_k$  for semi-infinite solid, neglecting surface resistance. Flame treated both as a point source and as an extended surface.

**Topic E**            **Ceiling flames and ceiling jet**  
(U<sub>1</sub> 6 hours, G 4 hours)

Contents:            Ceiling flame geometry and length. Non-dimensional correlations, ceiling jet flow characteristics. Steady fires. Transient ( $t^2$ ) fires.

Reference: Drysdale (1985); Ceiling jet as in Evans (1988) pp 1-138 - 1-141.

Special note: Unconfined vertical flame and plume characteristic treated in Fire Fundamentals. A major difficulty is here the understanding of time scaling and non-dimensional quantities for the  $t^2$ -fires.

Ceiling flame should be demonstrated by model scale experiments based e.g. on Fig 4.21 in Drysdale (1985). (Laboratory experiment 1)

For the case ceiling jets and vent flows have been taught in the fluid mechanics module only a repetition is needed here.

## II Room Fire Synthesis

**Topic A Basic concepts**  
(U<sub>1</sub> 4 hours, G 3 hours)

Contents: Qualitative description of room fire growth and spread for simplified scenarios. Factors affecting fire build up. The flashover phenomena. 4 phases of room fire build up and pressure characteristics  
room filling (no vent, accumulation)  
transient pre-flashover flow  
quasi-steady, pre-flashover flow  
post-flashover

References: Drysdale (1985); A number of other publication (papers by Thomas, Quintiere and others)

**Topic B Post flashover fire**  
(U<sub>1</sub> 6 hours, G 4 hours)

Contents: Energy and mass balance equations  
Fuel bed control versus ventilation control  
Quantification of energy and mass balance  
Importance of  $A\sqrt{H}/A_t$   
Approximate formulas for calculation gastemperature-time curves

References: Drysdale (1985) ch. 10.2 - 10.3; Walton and Thomas (1988) pp 2-23 - 2-27

**Topic C Accumulation or filling phase**  
(U<sub>1</sub> 8 hours, G 6 hours)

Contents: The first law of thermodynamics for a finite control volumes applied to a room with no or small opening  
Hand calculation (for an adiabatic room) of pressure, gas layer depth and temperature by using the first law

Alternate methods for deriving equations describing pressure, layer depth and temperature  
Upper layer ignitability

References: Zukoski (1978); Walton and Thomas (1988) pp 2-16 - 2-23; Tanaka-Yamana (1985)

Special note: It is important to point out the difference in approaches and use of conservation equations and control volumes

**Topic D Two-zone, quasi-steady flow room fire**  
(U<sub>1</sub> 6 hours, G 6 hours)

Contents: Mass and heat transfer interaction  
Various methods to divide into zones  
Approximate formulas for T<sub>g</sub> for natural and forced ventilation fires  
Criteria for flashover; thermal analysis and chemical analysis (critical ignition equivalence ratio, critical energy density of upper gas layer)

References: Walton and Thomas (1988) pp 2-16 - 2-23; Technical manual for a PC-program such as CFAST

Special note: Experiments with a scaled down fire compartment, checking predictions against measured values are valuable

**Topic E Smoke and heat venting**  
(U<sub>1</sub> 6 hours, G 4 hours)

Contents: Smoke and heat venting  
Pressure characteristics, flow formulas, selection of flame and plume model, practical aspects

References: Tanaka and Yamana (1985); Hinkley (1988)

Special note: Alternative reference to Hinkley is NFPA 204 M  
Laboratory work with a scale model is essential

**Topic F Summary of module**  
(U<sub>1</sub> 6 hours, G 6 hours)

Contents: Review of course material in the form of computer models; HAZARD I, ASK-FRS, FPE-TOOL, ASET, DSLAYV

References: Technical manual for program(s) of choice. The validation paper by Duong

Special note: It is essential that the student gets hands on experience with as many computer models as possible. The most important model is probably HAZARD I



## **FINAL NOTE**

As evidenced by the outline, the material for this course has to be taken from a considerable number of sources, most of which are not really suitable as teaching material especially on the undergraduate level. Among other things, terminology and basic approach varies from one paper to another. As a consequence, much of the material will have to be rewritten by the teacher before handed out to the students.

## **2.4 NUMBER OF LECTURE HOURS**

Room Fire Components			Room Fire Synthesis		
Topic	Subject	No of U1 G	Topic	Subject	No of U1 G
A	Material flammability characteristics	8 6	A	Basic concepts	4 3
B	Chemistry of room fire combustion	8 6	B	Post-flashover fire	6 4
C	Vent flows	6 4	C	Accumulation or filling phase	8 6
D	Heat flow calculations	4 3	D	Quasi-steady flow, two-zone room fire	6 6
E	Ceiling flames and ceiling jets	6 4	E	Smoke and heat venting	6 4
			F	Summary, computer models	6 6

## **2.5 LABORATORY EXPERIMENTS**

### **1. Flame spread under ceiling**

Deflection of a gas burner flame beneath a model of a corridor ceiling. Determination of the flame length under ceiling depending on the burner location (corner, wall, free) and distance to the ceiling. Identification of the change from turbulent flame to "cellular flame".

### **2. Ignitability and RHR**

Use of cone calorimeter to determine the fire properties of fibre and particle boards: RHR, ignition time, temperature.

### 3. Surface flame spread

The surface flame spread method. Illustration of horizontal flame spread over a vertical surface according to IMO, res.A516. Determination of the flame spread coefficient.

### 4. Compartment fire

Fire in surface materials in 1/3-scale model fire compartment with fibre or particle boards on the walls and in the ceiling. Determination of RHR, temperatures, time to flashover. Comparison with laboration 2.

### 5. HAZARD I

Calculation exercises on a PC with HAZARD I.

#### REFERENCES:

Babrauskas, V., Burning Rates, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 2-1.

Drysdale, D., *An Introduction to Fire Dynamics*, (John Wiley and Sons, Chichester), 1985.

+Duong, The Accuracy of Computer Fire Models: Some Comparisons With Experimental Data from Australia, *Fire Safety Journal*, Vol 16 No 6.

Emmons, D.D., Ceiling Jet Flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-8.

Evans, D.D., Ceiling jet flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-9.

Hinkley, P.L. Smoke and Heat Venting, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 2-3.

ISO WD5658, *Fire Tests - Reaction to Fire - Surface Spread of Flame of Building Products*, part 2, 1990.

ISO/TC92/SC1/WG1 TR11696, *Fire Tests - Reaction to Fire - Application of Test Results to Predict Fire Performance of Building Products*, 1994.

Quintiere, J.G., Surface Flame Spread, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-24.

Tanaka, T. and Yamana, T., Smoke Control in Large Scale Spaces, part 1 and part 2, *Fire Science and Technology*, 1985, Vol 5, No 1, pp 31-54.

Tien, C.L. et al. Radiation Heat Transfer, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-5.

Walton, W.D. and Thomas, P.H., Estimating Temperatures in Compartment Fires, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 2-2.

Williamson, R.B., Lecture notes Fall 1988, Engineering 291B.

Zukoski, E.E., Development of a Stratified Ceiling Layer in the Early Stages of a Closed Room Fire, *Fire and Materials*, 1978, Vol 2, No 2, pp 54-62.

### **3. MODULE: ACTIVE FIRE PROTECTION**

#### **3.1 INTRODUCTORY STATEMENT**

The objective of this module is to develop an understanding of the analysis and design of active fire protection systems, which are those systems that respond to the presence of fire. Active fire protection systems include:

- \* Fire detection systems
- \* Fire protective signaling systems
- \* Automatic fire suppression systems
- \* Manual fire suppression systems
- \* Smoke management systems

Upon completion of this module, the student should have the following capabilities:

- \* The ability to analyze the need for different types of active fire protection systems
- \* The ability to analyze the suitability of active systems for specific hazards
- \* The ability to establish appropriate design objectives for active fire protection systems
- \* The ability to analyze the performance of active fire protection systems
- \* The ability to design and specify active fire protection systems in conformance with recognized standards
- \* The ability to design and specify active systems to achieve specified design objectives.

#### **3.2 PREREQUISITE MATERIAL**

- A) Modules in fluid mechanics, heat and mass transfer.
- B) Modules in Fire Fundamentals, Enclosure Fire Dynamics

Note: Parts of this module may be taught without a comprehensive treatment of the prerequisite material. This material can be supplemented by a more thorough treatment at a later date.

#### **3.3 CONTENTS OF MODULE**

##### **I Fire Detection Systems**

- Topic A Fire Signatures**  
(U<sub>1</sub> 3 hours, G 3 hours)

Content: Chemical and physical processes of fire.  
Conversion of energy and matter in a fire.  
Types of fire signatures: Aerosols, Gas, Energy.  
Transport of fire signatures - Convection and Radiation.  
Effects of fire signatures on people, on structures and on fire detection devices.

References: *Fire Alarm Signaling Systems Handbook* - Ch. 1; *Fire Suppression and Detection Systems* - p. 323-328; Bryan (1986)

**Topic B Enclosure Fire Dynamics**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Aspects of enclosure fire dynamics relevant to fire detection. (or why do we put detectors at the ceiling?)  
Heat release rate/smoke generation rate/composition.  
Fire plumes - entrainment, temperature and velocity correlations.  
Ceiling jets - temperature and velocity correlations.  
Hot gas layer - influence on plume/ceiling jet correlations.  
Obstructions/channel flow.

References: Beyler ; Heskestad (1988); Evans (1988)

**Topic C Fire Detection Devices**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Types of fire detection devices/operating principles.  
Characteristics/attributes of fire detection devices.  
Testing/approval of fire detection devices.

References: *Fire Alarm Signaling Systems Handbook* - Ch. 3, 11; *Fire Suppression and Detection Systems* - Ch. 10-14; Moore (1991)

**Topic D Fire Detection System Design**  
(U<sub>1</sub> 6 hours, G 6 hours)

Contents: Design objectives/criteria.  
Design parameters/standards.  
Spacing/location/placement of detection devices.  
Installation of detection devices.  
Acceptance and periodic testing.  
Documentation of system design.

References: *Fire Alarm Signaling Systems Handbook* - Ch. 9, 10, 12; *Fire Suppression and Detection Systems* - Ch. 10-14; NFPA 72E.

**Topic E Fire Detection System Analysis**  
(U<sub>1</sub> 6 hours, G 6 hours)

Contents: Lag times associated with fire detection.  
Performance characteristics of detection devices.  
Fire plume/ceiling jet temperature and velocity correlations.

The DETACT models.  
The temperature/smoke density analogy.  
Limitations of current analysis techniques.

References: Mowrer (1990); NFPA 72E - App. C; Schifiliti (1988)

**Topic F Fire Protective Signalling Systems**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Basic components of a fire alarm system.  
Local systems, components and features.  
Auxiliary systems, components and features.  
Remote station systems, components and features.  
Central station systems, components and features.  
Proprietary systems, components and features.  
Emergency voice/alarm communication systems.  
Public fire service communication systems.

References: *Fire Alarm Signaling Systems Handbook* - Ch. 2, 14; NFPA 71, 72, 72H, 1221: Wilson (1991:1)

## **II Automatic Fire Suppression Systems**

**Topic A Suppression Agents and Extinguishing Mechanisms**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Life Cycle of Fire/Fire Triangle/Fire Tetrahedron.  
Theories of suppression and extinguishment.  
Suppression agents/attributes.

References: *Fire Suppression and Detection Systems* - Ch. 1-2; Friedman (1991)

**Topic B Water-Based Suppression Systems**  
(U<sub>1</sub> 18 hours, G 18 hours)

Contents: Basic components of water-based suppression systems.  
Types of systems / components / applications.  
Attributes of system components.  
Hazard classifications/System design criteria.  
Spacing / location / placement of discharge devices.  
Methods for sizing piping / piping configurations.  
Hydraulic calculations.

References: *Automatic Sprinkler Systems Handbook; Automatic Sprinkler and Standpipe Systems*; Solomon (1991:1); Fleming (1991:2); Solomon (1991:2); Fleming (1991:1); Cote and Fleming (1991); Hodnett (1991); Fleming (1988)

**Topic C      Foam Suppression Systems**

(U<sub>1</sub> 3 hours, G 3 hours)

Contents:      Basic components of foam suppression systems.  
Types of systems / components / applications.  
Attributes of system components.  
System design criteria.  
Spacing / location / placement of discharge devices.  
Methods for sizing piping / piping configurations.  
Hydraulic calculations.

References:    *Fire Suppression and Detection Systems* - Ch. 3-4; Meldrum (1991); Hickley (1988)

**Topic D      Carbon Dioxide Suppression Systems**

(U<sub>1</sub> 3 hours, G 3 hours)

Contents:      Basic components of carbon dioxide suppression systems.  
Types of systems / components / applications.  
Attributes of system components.  
System design criteria.  
Spacing / location / placement of discharge devices.  
Methods for sizing piping / piping configurations.  
Agent supply requirements.  
Safety considerations.

References:    *Fire Suppression and Detection Systems* - Ch. 6; NFPA 12; Wysocki (1991)

**Topic E      Halon Suppression Systems**

(U<sub>1</sub> 3 hours, G 3 hours)

Contents:      Basic components of water-based suppression systems.  
Types of systems / components / applications.  
Attributes of system components.  
Hazard classifications.  
System design criteria.  
Spacing / location / placement of discharge devices.  
Methods for sizing piping / piping configurations.  
Agent supply requirements.

References:    *Fire Suppression and Detection Systems* - Ch. 7; NFPA 12A, 12B; Taylor (1991); Grant (1988)

**Topic F      Dry and Wet Chemical Suppression Systems**

(U<sub>1</sub> 3 hours, G 3 hours)

Contents:      Basic components of dry and wet chemical suppression systems.  
Types of systems / components / applications.  
Attributes of system components.

System design criteria.  
Spacing / location / placement of discharge devices.  
Methods for sizing piping / piping configurations.

References: *Fire Suppression and Detection Systems* - Ch. 6; NFPA 17; Haessler (1991)

### **III Manual Fire Suppression Systems**

**Topic A            Portable Fire Extinguishers**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents:            Classifications of portable fire extinguishers.  
                         Testing of portable fire extinguishers.  
                         Spacing / location / placement of discharge devices.

References:        *Fire Suppression and Detection Systems* - Ch. 2; NFPA 10; Demers (1991)

**Topic B            Standpipe and Hose Systems**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents:            Basic components of standpipe and hose systems.  
                         Types of systems / components / applications.  
                         Attributes of system components.  
                         System design criteria.  
                         Spacing / location / placement of discharge devices.  
                         Methods for sizing piping / piping configurations.

References:        *Automatic Sprinkler and Standpipe Systems* - Ch. 1; NFPA 14; Shapiro (1991)

**Topic C            Fire Department Operations**  
(U<sub>1</sub> 3 hours, G 3 hours)

(To be completed by Bob Fitzgerald)

### **IV Smoke Management Systems**

**Topic A            Smoke Production in Fires**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents:            Smoke measurements.  
                         Mass yields/mass fractions/molar yields/molar fractions.  
                         Smoke release rate/heat release rate.  
                         Entrainment.  
                         Optical characteristics/optical density/Bouguer's Law.  
                         Mass optical density/specific optical density.  
                         Visibility through smoke.  
                         The influence of ventilation on smoke production.

References: Babrauskas ; Benjamin ; Heskestad

**Topic B Principles of Smoke Movement**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Air flow principles.  
Gas expansion.  
Buoyancy/stack effect/local heating.  
HVAC systems.  
Wind.

References: NISTIR 4551; Klote and Nelson (1991); Klote (1988); Marchant (1984)

**Topic C Principles of Smoke Management**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Objectives of smoke management.  
Passive smoke management methods.  
Active/mechanically-assisted smoke management methods.  
    Opposed air flow  
    Stairwell pressurization  
    Zoned smoke control  
    Smoke exhaust

References: NFPA 92A; Heskestad (1991)

**Topic D Stairwell Pressurization Systems**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Single injection systems.  
Multiple injection systems.  
Compartmented stairways.  
Vestibules.  
Activation methods.

References:

**Topic E Zoned Smoke Control Systems**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Operating modes.  
Venting requirements.  
Analysis methods.  
Activation methods.

References:

**Topic F Smoke Management for Large Spaces**  
(U<sub>1</sub> 3 hours, G 3 hours)



Contents: Venting requirements.  
Natural ventilation through roof and wall openings.  
Mechanical smoke exhaust systems.  
Stratification.  
Activation methods.

References: NFPA 92B

**Topic G Testing of Smoke Management Systems**  
(U<sub>1</sub> 3 hours, G 3 hours)

Contents: Full scale tests.  
Simulation methods.  
Measurement equipment and instrumentation.

References: NBSIR 87-3660

**REFERENCES:**

- +*Automatic Sprinkler and Standpipe Systems.*
- +*Automatic Sprinkler Systems Handbook.*
- +Babrauskas, Applications of Predictive Smoke Measurements.
- +Benjamin, The Challenge of Smoke.
- +Beyler, Fire Plumes and Ceiling Jets, *Fire Safety Journal.*
- +Bryan, Damageability of Buildings..., *Fire Safety Journal*, 11 (1986).
- Cote, A.E. and Fleming, R.P., Fast Response Sprinkler Technology, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch. 5-13.
- Demers, D.P., Selection, Operation, Distribution and Maintenance of Fire Extinguishers, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch. 5-23.
- Evans, D.D., Ceiling jet flows, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-9.
- +*Fire Alarm Signaling Systems Handbook.*
- +*Fire Suppression and Detection Systems.*
- Fleming, R.P., Automatic Sprinkler Systems Calculations, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-2.
- Fleming, R.P., Automatic Sprinklers, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 5-12.
- Fleming, R.P., Theory of Automatic Sprinkler Performance, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch. 5-10.
- Friedman, R., Theory of Fire Extinguishment, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch 1-6.
- Grant, C., Halon Design Calculations, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-4.
- Haessler, W.M., Dry Chemical Agents and Application Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch. 5-19.
- +Heskestad, G., Engineering Relations for Fire Plumes.
- Heskestad, G., Fire Plumes, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-6.
- Heskestad, G., Venting Practices, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991*Fire Protection Handbook* (17th ed), Ch. 6-8.
- Hickley, H.E., Foam System Calculations, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-3.

Hodnett, R., Care and Maintenance of Water-Based Extinguishing Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-16.

Klote, J.H., Smoke Control, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-9.

+Marchant, Effect of Wind on ..., *Fire Safety Journal*, No 7, 1984.

Meldrum, D.N., Foam Extinguishing Agents and Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 5-20.

Moore, W., Automatic Fire Detectors, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch 4-5.

+Mowrer, Lag Times Associated ..., *Fire Technology*, Aug, 1990.

+NBSIR 87-3660.

+NFPA 10.

+NFPA 12.

+NFPA 12A, 12B.

+NFPA 14.

+NFPA 17.

+NFPA 71, 72, 72H, 1221.

+NFPA 72E.

+NFPA 92A.

+NFPA 92B.

+NISTIR 4551.

Klote, J.H. and Nelson, H.E., Smoke Movement in Buildings, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 6-7.

Schifiliti, R.P., Design of Detection Systems, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-1.

Shapiro, J., Standpipe and Hose Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-14.

Solomon, R., Automatic Sprinkler Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-9.

Solomon, R., Water Supplies for Sprinkler Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-11.

Taylor, G., Halogenated Agents and Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-18.

Wilson, D., Protective Signaling Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch 4-2.

Wilson, D., Waterflow Alarms and Sprinkler System Supervision, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch 2-3.

Wysocki, T.J., Carbon Dioxide and Application Systems, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991 *Fire Protection Handbook* (17th ed), Ch. 5-17.

## **4. MODULE: PASSIVE FIRE PROTECTION**

### **4.1 INTRODUCTORY STATEMENT**

The primary objective of this module is to develop an understanding of the traditional practices of the traditional code approach to the structural aspects of passive fire protection for buildings. A secondary objective is to develop an awareness of the concepts involved in the rational design of building elements for heat energy effects of a fully developed fire. The following main topics will be incorporated:

- \* Anatomy of building construction
- \* Building construction features that influence fire performance
- \* Fundamentals of reading plans and specifications
- \* The traditional code approach to passive fire protection
- \* Concepts of rational fire design for structural members.

Upon completion of this module a student should be able to:

- \* Describe common building components and their normal construction practices.
- \* Identify the common problem areas with regard to building construction and fire propagation.
- \* Read building plans and specifications.
- \* Describe the standard fire test procedures, the presentation of results, and strengths and limitations of the standard test with regard to building performance.
- \* Select the code requirements for fire endurance for a set of building plans.
- \* Describe the basic concepts of rational fire design for common structural materials.

### **4.2 PREREQUISITE MATERIAL**

- a. Elementary courses in statics and mechanics of materials.
- b. To understand the basic concepts of rational fire design, the student should have completed the module on post flashover enclosure fires.

## 4.3 CONTENTS OF MODULE

### I Building Construction Fundamentals

**Topic A            The Anatomy of Buildings**  
(U1 8 hours, G 6 hours)

Content:            The planning and construction process; architectural planning; structural framing systems; interior partitions and fire walls; exterior walls; mechanical and electrical systems; people movement systems; fire protection systems.

References: There does not seem to be a reasonable small number of references on the fundamentals of building construction for individuals who are not involved in construction engineering. Until a book is written to address the needs of fire protection engineers the instructor will be required to select readings from a variety of specialized reference books on each topic.

As an initial base for study, the following books are suggested:

Gewain and Jeans (1991) is an introduction to the topic.

**Topic B            Reading Plans and Specifications**  
(U1 3 hours, G 3 hours)

Content:            The organization of a complete set of construction drawings; reading plans and obtaining specific information needed for fire safety; the organization of specifications and their role in the construction process; use of specifications to determine construction details relating to firesafety.

References: DCPA book on SST Chapter 3; Specifications text.

### II Traditional Code Procedures

**Topic A            Building Code Requirements**  
(U1 2.5 Hours, G 1.5 hour)

Content:            Format and structure of building codes; code administration and enforcement; use and occupancy, construction types, and height and area; modifications; code requirement rationale.

References: Any model building code for the geographical region; Code requirement rationale is difficult to identify; Babrauskas and Williamson (1978) is a good basis. Papers by Ingberg, Culver, Issen provide additional background; Cote (1991); Gewain and Jeans (1991); American Iron and Steel Institute.

**Topic B            Structural Fire Testing**  
(U1 2, G 1)

Content: Standard fire testing for structural elements, doors, and windows; identification of strengths and limitations of the test in relation to performance behavior.

References: The corresponding ISO and authority test standards for the elements; Fitzgerald (1991)

## **Topic C Rational Fire Design**

### **Subtopic C1 Structural Behavior Review** (U1 Not Applicable, G 8Hours)

Content: Failure criteria; elastic behavior of beams (determinate and indeterminate), columns, and frames; inelastic behavior; structural properties at elevated temperatures.

References: Conventional structural steel design textbook; Conventional inelastic design textbook.

### **Subtopic C2 Uninsulated Steel Beams** (U1 Not applicable, G 7)

Content: Review post flashover compartment fires; heat balance; geometry; emissivity; steel temperature; failure criteria; critical load based on type of load and support characteristics; behavioral characteristics as influenced by thermal profile, shapes, axial restraint, lateral restraint; assumptions and limitations.

References: Pettersson et al (1976)

### **Subtopic C3 Insulated Steel Beams** (U1 Not Applicable, G 1.5)

Content: Heat balance; insulation thermal properties; geometry; steel temperatures; critical load; behavior, assumptions, and limitations.

Reference: Pettersson et al (1976)

### **Subtopic C4 Steel Beams with Membrane Ceiling Protection** (U1 Not applicable, G 1.5 hours)

Content: Ceiling behavior; heat balance; steel temperature; critical load; behavior, assumptions, and limitations.

Reference: Pettersson et al (1976)

### **Subtopic C5 Steel Columns** (U1 Not applicable, G, 6 hours)

Content: Column behavior at normal temperatures; descriptive column behavior at elevated temperatures; Analytical buckling load at elevated temperatures (free expansion);

Modification for longitudinal column restraint; critical buckling load for uninsulated and insulated columns; behavior, assumptions, and limitations.

Subtopic C6     **Reinforced Concrete Structural behavior Review**  
(U1 NA, G 3)

Content:        Failure criteria; design concepts for normal design; limit state design; moment redistribution; material properties at elevated temperatures; Thermal properties.

Subtopic C7     **Reinforced Concrete Beams**  
(U1 NA, G 3)

Content:        Isothermal diagrams; support conditions; thermal restraint; behavior, assumptions, and limitations

Subtopic C8     **One Way Slabs, Two Way Slabs**  
(U1 NA, G 2)

Content:        Temperature distribution; support conditions; thermal restraint; qualitative behavior at elevated temperatures; behavior, assumptions, and limitations.

Subtopic C9     **Columns**  
(U1 NA, G 2)

Content:        Normal column behavior; qualitative behavior at elevated temperatures;

Subtopic C10    **Timber Construction**  
(U1 NA, G 6)

Content:        Charring; thermal and structural properties at elevated temperatures; reduced area calculations for joists, beams, and columns; special problems in timber construction (eg trusses, connections, glulam, etc)

Subtopic C11    **Equivalent Fire Endurance**  
(U1 NA, G 5)

Content:        Historical equivalency; European equivalent fire endurance; calculation methods to obtain the same fire endurance as would be attained in standard fire tests.

**REFERENCES:**

+American Iron and Steel Institute, Fire Protection Through Modern Building Codes.

Babrauskas and Williamson, The Historical Basis of Fire Resistance Testing, Parts I and II, *Fire Technology*, August, November, 1978.

Cote, A.E., Building and Fire Codes and Standards, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 6-12.

+DCPA book on SST Ch. 3.

Fitzgerald, R.W., Structural Integrity During Fire, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 6-5.

Gewain, R. and Jeans, D., Building Construction, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 6-3.

Gewain, R. and Jeans, D., Classification of Building Construction, *Fire Protection Handbook*, 17th Edition, ed A.E. Cote (NFPA), 1991, Ch. 6-2.

Pettersson, O., Magnusson, S.E. and Thor, J., Fire Engineering Design of Structures, Swedish Institute of Steel Construction, 1976.

## **5. MODULE: INTERACTION BETWEEN FIRE AND PEOPLE**

### **5.1 INTRODUCTORY STATEMENT**

There are many aspects to the way people interact with fire. People cause fires to ignite, by accident or by arson, and they become the victims of fire if they are unable to escape its smoke and heat. The movement of people is one of the main concerns of Fire Safety Engineers. Fire fighters must also be considered, and it is important to remember that they have to enter burning structures in order to perform their searches and fire suppression activities.

Some of the topics in teaching human factors in a course of Fire Safety Engineering can be summarized with the following questions which the students should be able to answer:

1. How do people react to the ignition of a fire?
2. How do people escape a fire?
4. How do people fight a fire?
5. How do people become victims of a fire?

In this module we will try to identify the topical subject matters that make up the area of study "Interaction Between Fire and People". We will discuss the prerequisite knowledge students can be expected to have when they enter into a study of Fire Safety Engineering. We will also discuss some of the subject material in the specific area of interactions between people and fire. Finally we will indicate the approximate lecture or contact time which are appropriate for the topical subject matters identified for the area.

### **5.2 PREREQUISITE MATTER**

Most engineering or science students can not be expected to have taken a course in psychology or human factors. They may or may not have observed human behavior in fire situations, and this module can be expected to be the first exposure of many of the students in this area.

### **5.3 CONTENTS OF MODULE**

#### **I Components**

##### **Topic A Human Behavior in Fires and Other Emergency Situations**

Subtopic A1 Behavioral Response of People  
(U1: 5 hrs.; G: 3 hrs.)

Contents: Awareness of cues. Behavioral responses of occupants. Behavioral response studies of actual fires. Adaptive and nonadaptive behavior. People movement through smoke. Handicapped or impaired occupants.

References:Pauls (1988); Canter (1980)



Subtopic A2      Effects of Harmful Agents Preventing Escape & Causing Injury or Death  
(U1: 6 hrs.; G: 4 hrs.)

Contents:        Two main views as to why smoke toxicity appears to be an increasing problem: the materials based approach and the combustion products based approach. Toxicity as part of the total fire hazard. Dose/response relationships and dose estimation in the evaluation of toxicity. Irritant fire products. Exposure of fire victims to heat. Fire scenarios and victim incapacitation. Toxicity test methods.

References: Jin (1989); Levin (1984); Bryan (1977)

**Topic B:**        **Effect of Human Beings on Fire Occurrences**  
(U1: 3 hrs.; G: 2 hrs.)

Contents:        How people are involved with fire ignition. Accidental and intentional start of fire. Ignition of fire involves human error in which unwanted heat transfer occurs between and ignition source and a target fuel. There is a need in curriculum to cover "fire starting behavior."

References: Vreeland (1978); Scott (1974)

## **II    Synthesis**

**Topic A        Escape**

Subtopic A1      Considerations of Physical, Psychological, and Physiological Aspects of Escape Including Movement of People in Buildings Under Normal and Emergency Conditions  
(U1: 8 hrs.; G: 6 hrs.)

Contents:        Knowledge of this topic is crucial to understanding how to analyze the risk to people in fire. List of subtopics as follows:  
a) Crowd behavior and management  
b) Movement safety and design of circulation routes  
c) Evacuation procedures in tall buildings  
d) Evacuation time criteria  
e) Calculation methods for evacuation times.  
f) Computer simulation models for people movement.

This list of topics is a foundation for rationally based exit codes.

Subtopic A2      Communication Systems and Signs for Emergencies  
(U: 3 hrs.; G: 1 hrs.)

The need for, and design of information communication systems for emergency conditions, including audibility of fire alarms and clarity of emergency instructions and signs. This could also include warnings about particularly flammable products or materials, and how to ensure that they are used safely.

References: Collins (1990)

Subtopic A3      Interaction and Relative Value of the Components of Escape Route Design

(U: 4 hrs.; G: 2 hrs.)

Contents: Closely related to previously mentioned topics, and with the inclusion of smoke movement and control, it is also dependent on all the other topics of fire dynamics, active and passive fire protection systems, as well as fire fundamentals.

References: Kendik (1986); Kendik (1988); Kendik (1983)

Subtopic A4 Influence of Fire Safety Education and Training  
(U: 3 hrs.; G: 1 hrs.)

Contents: Objectives and content for training programs for fire safety. This might be a very important topic for some students but of only secondary importance for others.

**Topic B Analysis of Fire Scenarios Involving People**  
(U: 16 hrs.; G: 12 hrs.) [Much of this time would be in a laboratory.]

Contents: The use of "fire scenarios" for the analysis of fire safety has gained wide acceptance in recent years. A fire scenario is a generalized description of a possible fire incident that includes a description of the prefire conditions, the fire itself, and the subsequent behavior of people and the fire protection devices. Williamson notes that they can be either based on actual fires or on fictitious fires and he notes that fire scenarios have emerged as a major tool in the analysis of fire hazards associated with the design, construction and operation of buildings, aircraft and other facilities. The analysis of fire scenarios is analogous to the use of the "case method" in the study of law or business since it allows professional focus on either a broad or narrow, well defined (but perhaps hypothetical) situation. There could be a progression of scenarios to be used in this module that would be used throughout the sequence of topics. It would also be possible to require that the students perform various tasks in the development of the scenarios. For instance, the students might participate in the interviews of fire victims and eye witnesses, and the creation of "time-lines".

This is one of the most important ways for students of Fire Safety Engineering to study the complex issues of how humans behave in fire. It can also be used to make the connections to the other areas of Fire Fundamentals, Fire Dynamics, and Active & Passive Fire Protection Engineering.

References: National Materials Advisory Board (1980); Williamson (1993)

## 5.4 NUMBER OF LECTURE HOURS

I. COMPONENT			
TOPIC	SUBJECT	U1 (hrs)	G (hrs)
A	HUMAN BEHAVIOR IN FIRES & OTHER EMERGENCIES	--	--
A1	Behavioral Response of People	5	3
A2	Effects of Harmful Agents Preventing Escape etc.	6	4
B	EFFECT OF HUMAN BEINGS ON FIRE OCCURRENCES	3	2
II. SYNTHESIS			
TOPIC	SUBJECT	U1 (hrs)	G (hrs)
A	ESCAPE	--	--
A1	Considerations of 3 Aspects of Escape & Movement of People	5	3
A2	Communications Systems and Signs for Emergencies	3	1
A3	Interaction & Relative Value of the Components of Escape Routes	4	2
A4	Influence of Fire Safety Education and Training	3	1
B	FIRE SCENARIOS [Much of this time would be in a laboratory.]	16	12

### REFERENCES:

- Bryan, J.L., Smoke As a Determinant of Human Behavior in Fire Situations: Project People (National Bureau of Standards, Washington ) 1977, NBS GCR 77-94.
- Canter, D. ed., Fires and Human Behaviour (Wiley, London) 1980.
- Collins, B.L., Dahir, M.S., and Madrzykowski, D., Evaluation of Exit Sign in Clear and Smoke Conditions (National Institute of Standards and Technology, Gaithersburg, MD) 1990, NISTIR 4399.
- Jin, T., and Yamada, T., Experimental Study of Human Behavior in Smoke Filled Corridors, in Fire Safety Science, Proceedings of the Second International Symposium eds.: T. Wakamatsu, et al. (Hemisphere Publishing Corp., New York) 1989.
- Kendik, E., Determination of the Evacuation Time Pertinent to the Projected Area Factor in the Event of Total Evacuation of High-rise Office Buildings Via Staircases, Fire Safety Journal, 1983, vol. 5, nos. 3-4, pp. 112-232.
- Kendik, E., Methods of Design for Means of Egress: Towards a Quantitative Comparison of National Code Requirements, In Fire Safety Science, Proceedings of the 1st International Symposium, Gaithersburg, MD, October 7-11, 1985, eds.: C.E. Grant, and P.J. Pagni, (Hemisphere Publishing Corp., New York) 1986.
- Kendik, E., Means of Escape - 1988. How Close Are We to Modelling Egress from Buildings in Fire?, Fire and Materials, 1988, vol. 13, pp. 1-31.
- Levin, B.M., Human Behavior in Fire: What We Know Now, (Society of Fire Protection Engineers, Boston) 1984, SFPE Technology Report 84-3.
- National Materials Advisory Board, Fire Safety Aspects of Polymeric Materials - Fire Dynamics and Scenarios, v. 4 (National Academy of Sciences, Washington) 1980.

Pauls, J., Movement of People in SFPE Handbook, 1st ed., ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston) 1988, Ch. 1-15.

Scott. D., The Psychology of Fire (Scribner's, New York) 1974.

Vreeland, R.B., and Waller, M.B., The Psychology of Firesetting; a Review and Appraisal (National Bureau of Standards, Washington) 1978, NBS-GCR 79-157.

Williamson, R.B., and Dembsey, N.A., Advances in Assessment Methods for Fire Safety, Fire Safety Journal, 1993, v. 20, no. 1, pp. 15-38.

## **D Detailed description of applied courses (modules)**

<b>1. Risk management for fire and explosions</b>	<b>69</b>
1.1 Introductory statement	69
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# **D DETAILED DESCRIPTION OF APPLIED COURSES (MODULES)**

## **1. MODULE: RISK MANAGEMENT FOR FIRE AND EXPLOSIONS. DESIGN BASED ON PERFORMANCE**

### **1.1 INTRODUCTORY STATEMENT**

The objective of this module is to provide a working knowledge of risk management which incorporates risk assessment, decision analysis, and the economics of decisionmaking. Although the main focus is on applications involving fire and explosions, the techniques will be applicable to a wide variety of uses in risk analysis and management. The scope of this module is broad in order to address both the technical areas of risk assessment as well as management applications involving social, financial, and corporate decisionmaking.

A final topic will deal with the subject of performance-based codes and fire safety in buildings.

## **2 PREREQUISITE MATERIAL**

An elementary knowledge of probability and statistics is important. A background in some area of engineering design and an understanding of business organization is useful, but not required.

## **3 CONTENTS OF MODULE**

### **Topic A Concepts in Risk Management** (U1: 9 hours G: 6 hours)

Contents: Distinction between hazard and risk; business organization and decisionmaking; role of risk assessment, function of risk management; financial considerations; time considerations; consequences, uncertainty, and utility (risk aversion); identification of the alternative courses of action of accepting risk, transferring risk, and reducing risk and the allocation of those options; introduction to decision analysis; the economics of information.

References: Head and Horn, (:1) Ch. 1, 3, 4, 5, 6; Samson Ch. 1; Henley and Kumamoto Ch. 1.

### **Topic B Risk Assessment**

#### **Subtopic B1 Hazard Identification** (U1: 3 hours, G: 2 hours)

Contents: Loss exposures; preliminary hazards analysis; identifying accident sequences; failure modes and effects analysis; cause consequence analysis; criticality analysis.

References: American Institute of Chemical Engineers Ch. 1,2; Henley and Kumamoto Ch. 1

Subtopic B2     **Risk Assessment**  
(U1: 3 hours G 3 hours)

Content:            Event tree; fault tree; success tree; alternative network structures;

References: American Institute of Chemical Engineers Ch. 3, Appendix D; Henley and Kumamoto Ch. 2.

Subtopic B3     **Quantification**  
(U1 6 hours G 4 hours)

Content:            Review mathematics of probabilistic analysis; objective probability techniques; subjective probability techniques; statistical data bases; Selection of risk measures; risk calculation; confidence limits; sensitivity; reliability.

References: American Institute of Chemical Engineers Ch. 4, 5, App. E, F, G, H; Henley and Kumamoto, Ch. 4 - 9.

Subtopic B4     **Decision Support Systems**  
(U1 9 hours G 6 hours)

Content:            Decision support systems; simulation techniques; expert systems; artificial intelligence.

References: Samson, Ch. 14.

Subtopic B5     **Decision Analysis**  
(U1 4 hours G 3 hours)

Content:            Structuring the problem; decisionmaker needs; bias and utility; multiattribute functions; multidimensional functions; the value of information.

References: Samson, Ch. 2, 3, 5, 6, 7, 10, 11; Ramachandran (1988)

Subtopic B6     **Risk Management**  
(U1 3 hours G 2 hours)

Content:            Project management; identifying goals, objectives, user needs, and acceptable risk; development of risk management programs;

References: Head and Horn, (:2).

**Topic C:            Design based on performance**  
(U 8 hrs, G 6 hrs)

Contents:           The general concept of performance based standards applied to fire safety in buildings. Historical developments. Components of a fire safety system. Objectives and criteria. Qualitative design review. Building and occupant characterization. Deterministic design procedures. Probabilistic design procedures. Subsystem design procedures.

Reference:          BSI Draft Code (1994)

**REFERENCES:**

- +American Institute of Chemical Engineers, Chemical Process Quantitative Risk Analysis.
- +Head and Horn, Essentials of the Risk Management Process, Vol I, Insurance Institute of America..
- +Head and Horn, Essentials of the Risk Management Process, Vol II.
- +Henley and Kumamoto, *Reliability Engineering and Risk Assessment* (Prentice Hall).
- Ramachandran, G., Utility Theory, *SFPE Handbook*, 1988.
- +Samson, *Managerial Decision Analysis*, Irwin Press.
- BSI Draft Standard Code of Practice for the Application of Fire Safety Engineering Principles to Fire Safety in Buildings, London, 1994.



## **2. MODULE: INDUSTRIAL FIRE PROTECTION AND EXPLOSION PROTECTION**

### **2.1 INTRODUCTORY STATEMENT**

The objective of this module is to provide an engineering framework for evaluating industrial fire and explosion hazards and to apply engineering principles to select appropriate fire and explosion protection measures for industrial occupancies. The following main topics are included:

- \* Hazards analysis for flammable liquids and gases
- \* Hazards analysis for gas and dust explosions
- \* Hazards analysis for warehouse and industrial processes
- \* Engineering analyses and fire and explosion protection selection.

Upon completion of this module, the student should be able to:

- \* Evaluate safe separation distances for structures exposed to potential fires and explosions.
- \* Analyze and design smoke control and smoke venting systems for industrial facilities.
- \* Design and analyze the potential effectiveness of sprinkler protection for warehouse and industrial facilities.
- \* Design and evaluate the potential effectiveness of suppression systems for flammable liquids and liquified gases.
- \* Calculate unmitigated explosion pressures and time scales and describe their consequences to structures and people.
- \* Analyze and design vented gas and dust explosions.
- \* Understand conceptual design and applications for explosion suppression, suppression, and inerting approaches.
- \* Understand blast wave theory and applicability to vapor cloud explosions.

### **2.2 PREREQUISITE MATERIAL**

Modules on fire fundamentals, enclosure fire dynamics, active, and passive fire protection; probability and statistics.

## 2.3 CONTENTS OF MODULE

### Topic A **Framework for Analysis.**

(U1 Not applicable; G 5 hours)

Content: Statistical and *historical* overview of industrial fires and explosions; scenario identification; consequence analysis; protection overview *plant* siting and layout; *identification and isolation of hazardous locations*; framework for alternative protection identification and selection.

References:Zalosh (1991), Ch. 1, 2, Appendixes A, B, C; NFPA Handbook Sections 4, 5, and 6 as appropriate; *NFPA Journal Large Loss Surveys*

### Topic B **Fire and Smoke Isolation**

(U1 Not applicable; G 5 hours)

Content: Fire resistant construction; fire walls and doors; roofing; smoke isolation and venting; hazard segregation.

References:Zalosh (1991) Chapters 3, 4; Milke (1988); Fleischmann (1988); Hinkley (1988); Klote (1988)

### Topic C **Warehouse and Storage Protection**

(U1 Not applicable G 4 hours)

Content: Warehouse *commodity flammability testing and classification; storage arrangements and their effect on sprinkler protection requirements; warehouse fire heat release rates; ceiling and in-rack sprinkler protection; special hazard commodities.*

References:Zalosh (1991) Ch. 5, 6; NFPA Standards 231, 231C; Beever (1988); NFPA Handbook, Section 8 Ch. 4 - 8.

### Topic D **Flammable Liquids**

(U1 Not Applicable G 15)

Content: *Flammable liquid ignitability; types of flammable liquid fires; flammable liquid storage and use, flammable extinguishability with water based and special suppression agents; protection for flammable liquid storage tanks, drums, and small containers.*

References:Zalosh (1991) Ch. 7, 8; Beever (1988); NFPA Standard 30, 58, 59; NFPA Handbook Sections 2, 3, and 8 as appropriate.

### Topic E **Explosions**

(U1 Not applicable G 15)

Content: Closed vessel gas-air deflagrations; thermochemical equilibrium calculations; dust explosions; deflagration pressure vs time; flame speeds and burning velocities; Chapman-Jouguet *Detonation* Theory; deflagration to detonation transition.

References: Drysdale (1988); Friedman (1988); Zalosh (1988); CET89 Code Users Manual; Strehlow (1984), Ch. 2,3,4,8,9; Eckhoff (1991).

**Topic F**            **Explosion Protection**  
(U1 Not applicable G 15)

Content:            Vented gas explosions; vented dust explosions; explosion venting design; explosion suppression and isolation systems; inerting criteria and applications; blast wave theory and correlations; vapor cloud explosions.

References: Zalosh (1988); Eckhoff (1991) Chapter 6, Sections 1.4, 1.5; Bartknecht (1989) Chapters 5.3.3.3, 5.3.5; NFPA 68 Guide for Venting Deflagrations Chapters 4-6; NFPA 69 Explosion Prevention Systems; Chas, Zalosh, Brown, Advent

**Topic G**            **Electrical Equipment**  
(U1 Not applicable; G 4 hours)

**Content:**            ***Electric cable flammability, grouped cable and cable tray protection, relationship between electrical protection devices and fire protection, transformer fires and explosions, switchgear room suppression systems, electrical equipment in hazardous locations.***

References: Holdado (1985); Earley et al (1990); Various FMRC, NIST, UL Reports, Papers by Hirschler, Tewarsen, etc., NEMA; EPRI Reports on Transformer Explosions.

**REFERENCES:**

- Bartknecht, W. *Dust Explosions Course, Prevention, Protection* (Springer-Verlag), 1989.  
Beever, P.F. (1988), Self-Heating and Spontaneous Combustion, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-22.  
+CET89 Code Users Manual.  
+Chas, Zalosh, Brown and Advent, *An Expert System for Explosion Vent Design*.  
Drysdale, D.D., Thermochemistry, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-10.  
Earley, M. et al, *National Electrical Code Handbook* (NFPA), 1990.  
Eckhoff, R., *Dust Explosions* (Elsevier), 1991.  
Fleischmann, C., Analytical Methods for Determining Fire Resistance of Concrete Members, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-7.  
Friedman R., Chemical Equilibrium, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 1-11.  
Hinkley, P.L. Smoke and Heat Venting, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 2-3.  
Holdado C., *Flamability of Electrical and Electronic Materials*, Technomic, 1985.  
Klote, J.H., Smoke Control, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-9.  
Milke, J., Analytical Methods for Determining Fire Resistance of Steel Members, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 3-6.

- +NFPA 68 Guide for Venting Deflagrations Ch. 4-6.
  - +NFPA 69 Explosion Prevention Systems.
  - +NFPA Handbook Sections 2, 3, 4, 5, 6, and 8 as appropriate.
  - +*NFPA Journal Large Loss Surveys*.
  - +NFPA Standard 30, 58, 59.
  - +NFPA Standards 231, 231C.
- Strehlow, R., *Combustion Fundamentals* (McGraw-Hill), 1984.
- Zalosh, R. G., *An Engineering Approach to Industrial Fire Protection*, Third Draft (Worcester Polytechnic Institute), 1991.
- Zalosh, R.G., Explosion Protection, *SFPE Handbook*, 1st Edition, ed. P.J. Di Nenno (Society of Fire Protection Engineers, Boston), 1988, Ch. 2-5.