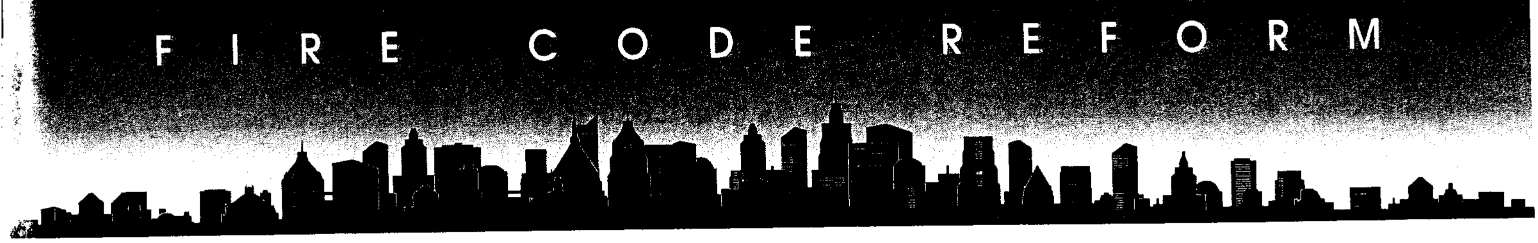

Technical Report
FCRC – TR 95-01

Recent Approaches to Regulating the Fire Performance of Materials In Buildings

FCRC Project 2 – Stage A
Fire Performance of Materials

Fire Code Reform Research Program
December 1995

Important Notice

Background

The Fire Code Reform Research Program is funded by voluntary contributions from regulatory authorities, research organisations and industry participants.

Project 2 of the Program required investigation of the fire performance of materials used extensively in building construction and currently controlled by regulations. The objectives were to confirm the need for regulatory control and identify the necessary levels of fire performance required from the materials, taking into account the different occupancy and fire conditions that could apply and the likely existence of other required fire safety system components.

This Report was prepared during the course of the work and deals specifically with a review of existing approaches to the regulation of building construction materials. The Report was prepared by CSIRO-Division of Building, Construction & Engineering, Graham Rd, HIGHETT, (P 0 Box 56), Victoria 3190..

Acknowledgements

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The Board and management of Fire Code Reform Centre Ltd acknowledge with sincere thanks receipt of these financial contributions. The company also acknowledges the permission of CSIRO, Division of Building, Construction and Engineering to re-produce and publish this document.

Comments

Comments on the content or other aspects of this document are always welcome and should be addressed to:- Fire Code Reform Centre Limited, Suite 1201, 12th Floor, 66 King Street, Sydney, NSW 2000, Australia. Tel: +61 (2) 9262 4358 Fax: +61 (2) 9262 4255

FIRE CODE RESEARCH PROGRAM

PROJECT 2

FIRE PERFORMANCE OF MATERIALS

Commissioned by Fire Code

Research Paper 1

RECENT APPROACHES TO REGULATING THE FIRE PERFORMANCE OF MATERIALS IN BUILDINGS

by

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PREFACE

This Report has been prepared by CSIRO Division of Building, Construction and Engineering as part of the Fire Code Reform Research Program funded by the Fire Code Reform Centre Ltd. Specifically it forms part of Project 2: Fire Performance of Materials.

CONTENTS

RECENT APPROACHES TO REGULATING THE FIRE PERFORMANCE OF MATERIALS IN BUILDINGS

PROJECT 2 OF THE FCRC PROGRAM

1. INTRODUCTION

There is a world-wide trend (Bukowski, 1993) to performance-based regulations for fire safety in buildings which will provide flexibility, lower costs and the application of new technology. This trend is facilitated by advances in fire science and fire engineering methodologies which have occurred in the last decade.

These advances have also fostered the development of a new generation of laboratory methods for assessing the fire characteristics of materials and building contents. These methods are designed to provide data in a form suitable for input into numerical models for fire development. This linkage provides the opportunity to assess the validity of these new test procedures as regulatory tools by comparing the predictions of the models with actual fire scenarios.

The formulation of performance-based codes and their practical use is still in the formative stages and thus, there is still a need for prescriptive 'deemed-to-satisfy' requirements (Bukowski and Babrauskas 1994). However, there is also a need to upgrade these requirements to encompass new materials and technologies taking advantage of the advances in fire science and engineering and of the availability of new generation test procedures.

Project 2 is designed to upgrade the Building Code of Australia requirements for the control of the use of combustible materials in buildings and this paper reviews recent developments in areas relevant to this project in order that it can be carried out effectively and efficiently.

The objectives of Project 2 are:

(a) To examine the basis and need for control of fire properties of materials in general.

(b) Identify the appropriate control tool [test method(s)] and the level of performance (in terms of that tool) required for different occupancy categories, considering any other required fire-safety system component.

(c) Provide definitions of level of performance that may be used in flexible performance-oriented regulations.

The strategy developed to realise these objectives is summarised in Figure 1 and is based upon the project activities and extensive discussions held at two planning meetings which involved representatives of all the members of the FCRC research consortium and of the ABCB. In brief, the strategy comprises:

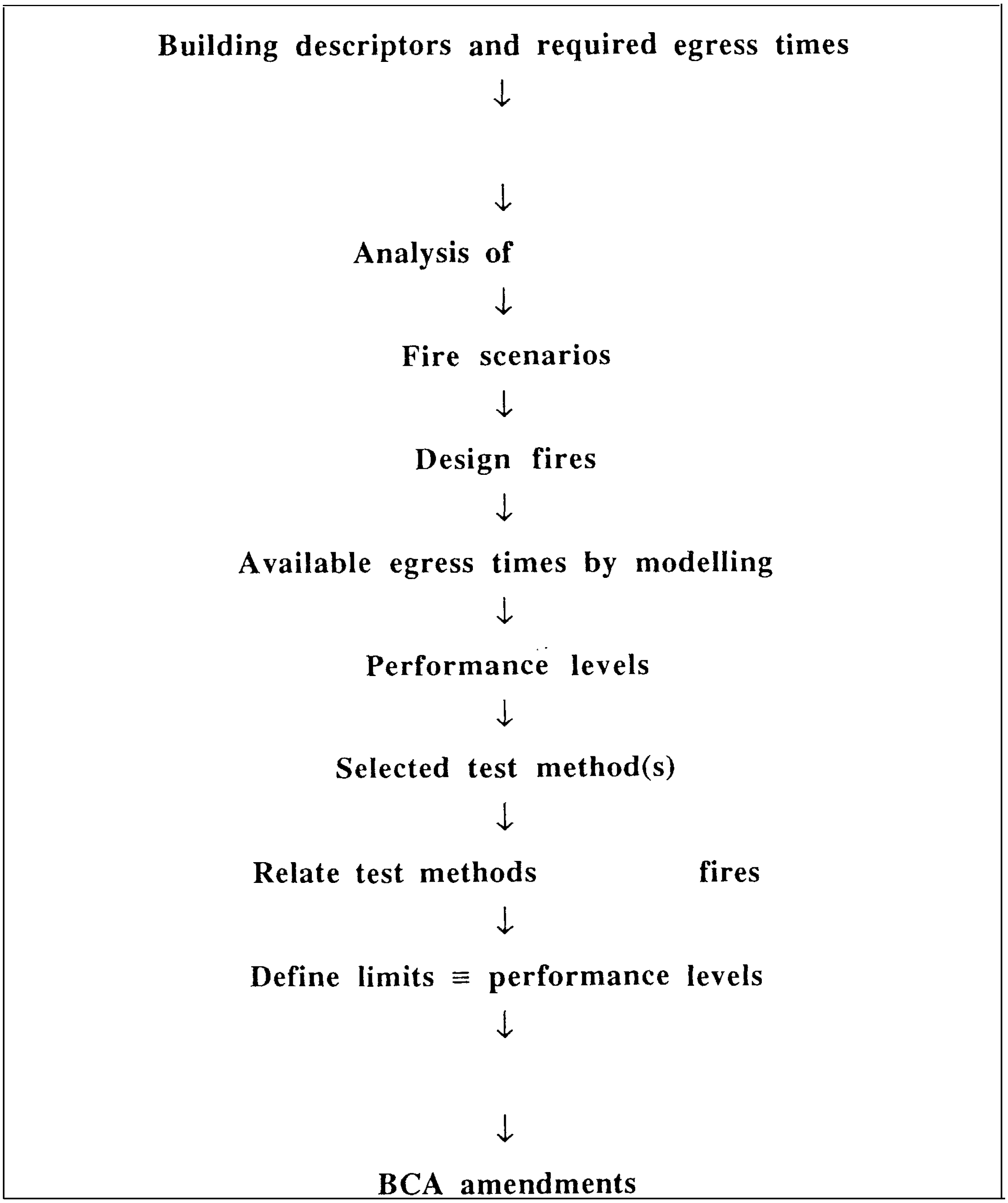

Figure I. Project 2 strategy.

(a) Grouping of building types on the basis of Project 1 and egress characteristics and the calculation of generic required egress times.

(b) Establishment of regulatory objectives taking overseas trends into account.

(c) Analysis of available fire data to determine relevant fire scenarios and corresponding design fires.

(d) Calculation of available egress times for generic building types using mathematical models and design fires for various materials.

(e) Comparison of available egress times with required egress times to determine performance required for generic building types.

(f) Selection of test methods and determination of relationship with design fires used in (d).

(g) Definition of limits for material acceptability, based upon performance levels determined in (e), using test results.

(h) Experimentation to confirm validity of(g).

(i) Writing of BCA amendments setting further test procedures and requirements for generic building occupancies and fire protective measures.

This review covers several areas – numerical models and their use in hazard assessment, test procedures and their evaluation, and setting of limits for regulatory purposes.

2. NUMERICAL MODELS

Numerical fire models range in complexity from simple mathematical representatives of some aspect of fire behaviour to complex assemblies of algorithms used to predict the development and progress of a fire. The simple models are often computerised for convenience and collected together for use as ‘fire engineering tools’ whereas the complex models need to be computerised and are generally presented as stand-alone methods.

Examples of the first type can be found in packages such as FPETOOL (incorporating FIREFORM), ASKFRS and FIRECALC. Examples of the second type which are in common use include FAST and its successor CFAST, ASET-B, JASMINE and the Harvard family.

Fire models have been reviewed by Jones (1983), Bukowski (1986), Beard (1990) (Table 1) and Friedman (1990, 1992a, 1992b), and ASTM has published a guide to evaluating fire models (ASTM 1992b). Bukowski (1995) contends that only models which are rigorously documented should be allowed in any application involving code considerations.

TABLE 1.
UNIVERSITY OF EDINBURGH EVALUATION
REPORTS ON FIRE MODELS (Beard 1990)

Report No.	Scope
1.	ASET: Qualitative assessment[a]
2.	ASKFRS: Qualitative assessment
3	HAZARD 1: Qualitative assessment[b]
4.	FIRST: Qualitative assessment
5.	JASMINE: Qualitative assessment
6.	ASET: Quantitative assessmenta
8.	HAZARD 1: Quantitative assessment[b]
9.	FIRST: Quantitative assessment
10.	JASMINE: Quantitative assessment
11	Overview

a. Includes Appendix on ASET-B.
b. FAST (version 17) only.

The models are generally based either on a simple zone concept or the far more complex field concept of multiple control volumes for analysis. Zone models are the type of computer fire models most frequently used, examples being FAST/CFAST (incorporated in HAZARD 1), ASET-B and the Harvard family (including the WPI Fire Code). As all zone models involve major simplifications, their accuracy is limited. Mitler (1985a) suggests that errors of 20% are probably acceptable in view of the complexity of fires.

Field models for fire have generally been adapted from models used for other purposes such as modelling of airflows and furnace environments. The most commonly used field model is JASMINE.

2.1 Collections of Fire Engineering Tools

These collections can be used in fire engineering assessments where simple but limited analysis is appropriate.

2.1.1 FPETOOL

FPETOOL (Nelson 1990b, 1990c, 1990d) is a collection of relatively simple engineering equations and models for estimating fire hazard in a single room. It represents an approach that is ‘faster but less rigorous than HAZARD I’ (Nelson 1990b). FPETOOL incorporates FIREFORM (Nelson 1986), MAKEFIRE and FIRE SIMULATOR. MAKEFIRE allows input files for use by FIREFORM or FIRE SIMULATOR to be constructed. FIRE SIMULATOR is a room filling and effluent model. Nelson (1990b) provides some data on comparison of results from FIRE SIMULATOR with experimental data. FIRE SIMULATOR slightly over-predicted upper layer temperatures, but achieved very similar results for interface height and oxygen concentration. FIREFORM incorporates the simple room-filling model ASET-B, discussed below, as well as a suite of fire engineering calculations which are listed in Table 2.

Nelson has used FIREFORM/FPETOOL in the analysis of actual fires (Nelson 1987, 1989, 1990c; Nelson and Tu 1991) and FIREFORM has been reviewed by who points out that the onus is on the user to validate results.

TABLE 2.
FIREFORM PROGRAMS (Nelson 1990c)

Item No.	Item title
1	ASETBX Room Fire Model
2	Atrium smoke temperature
3	Buoyant gas head
4	Ceiling jet temperature
5	Ceiling plume temperature
6	Egress time
7	Fire/wind/stack forces on a door
8	Mass flow through a vent
9	Lateral flame spread
10	Law's severity correlation
11	Plume filling rate
12	Radiant ignition of a near fuel
13	Smoke flow through an opening
14	Sprinkler/detector response
15	Thomas' flashover correlation
16	Upper layer temperature
17	Ventilation limit

2.1.2 ASKFRS

ASKFRS (Chitty and Cox 1988) is a similar collection to FIREFORM. It also contains ASET-B as its room filling model and programs are listed in Table 3. No published account of ASKFRS (other than of ASET-B) being compared with experimental data, or being used for analysis of fires or being used in fire engineering assessments were found in this review of literature. ASKFRS has been reviewed by and more extensively by Beard (1990, Report 2), who concludes that it should only be used by a person familiar with fire science as there is a risk of inappropriate use or interpolation.

TABLE 3.
ASKFRS PROGRAMS VERSION 2.06
(Chitty and Cox 1988)

Item No.	Item title
1	Fire heat release
2	Flame height
3	Plume Calculations
4	Plume rise
5	Compartment layer temperature
6	Flashover
7	Compartment filling time
8	Roof venting
9	Egress
10	Toxic hazard
11	ASET*

* Not in earlier versions

2.1.3 FIRECALC

Originally merely a metricated version of FIREFORM, FIRECALC (CSIRO 1993) has been extended by the addition of further engineering calculations and programs. Like FIREFORM, FIRECALC includes ASET-B, but it also includes other room-filling models, such as HOTLAYER, PLENUM and TWOROOMS all of which are based on PLUME. The full list of programs is given in Table 4.

TABLE 4.
FIRECALC PROGRAM VERSION 2.3 (CSIRO 1993)

Item No.	Item title	Program name
1.	Sprinkler/Detector Response Time	
2.	One-Room Hot Layer Model (ASETBX)	
3	Smoke Flow Through a Roof Opening	
4	Buoyant Pressure of Hot Gases	
5	Thomas' Flashover Correlation	
6.	Law's Fire Resistance Time	
7.	Plume Filling Rate	
8	Lateral Flame Spread	
9.	Radiant Ignition of Adjacent Fuel	
10.	Hot Layer Temperature	UL
11.	Steel Beam Load Bearing Capacity	
12.	Atrium Smoke Temperature	
13.	Ceiling Plume Temperature	
14.	Ceiling Jet Temperature	
15.	Egress Times	WAYOUT
16.	Plume Flow and Temperatures	PLUME
17	Smouldering Fire	
18.	One-Room Hot Layer Model	HOTLAYER
19	Two-Rooms Hot Layer Model	TWOROOMS
20.	One-Room Natural Roof Ventilation	
21.	Door-and-window Ventilation Model	
22.	Smoke Control with a Common Plenum	PLENUM
23 .	Fire Resistance Time	
24.	Heat Radiation	

No published accounts of the fire models, other than ASET-B and PLUME (Shestopal and Grubits 1993), being compared with experimental data or being used for analysis of fires and fire engineering assessments were found in the present review of the literature.

2.1.4 FIRESYS

This collection is in use in New Zealand and Buchanan (1994, p.67) gives a brief overview of its structure and uses. It includes a materials properties database and a section on design fires. Table 5 summarises the contents of this collection.

TABLE 5.
FIRESYS PROGRAMS
(Buchanan 1994, p.67)

Segment	Item
Data base	Table A Calorific values Table B Fire load energy densities Table C Energy release rates Table D Materials properties Table E Time-temperature values
1. Fire loads	1A Ambient calorific value 1 B Fireload survey (moveable items) 1C Fireload survey (built-in items)
2. Ventilation	2A Effective wall opening 2B Effective roof opening
3. Design Fires	3A t^2 fire model 3B Triangular fire model 3C Ventilation-controlled fire model
4. Flames	4A Flame sizes from openings 4B Flame heights under ceilings
5. Smoke	5A Smoke production rate
6. Trial Designs	6A Firecell parameters 6B Firecell sizes 6C Flashover/ventilation limit/equivalent time 6D Radiation
7. Fire Resistance Ratings	
8. Fire Separation	8A Separation distance for a single opening
9. Fire Egress	9A From rooms 9B Doors and corridors 9C Stairs and landings
10. External Fire Control	10A Water requirements

2.2 Major Models

The following models, representative of both the zone and field types, are probably the most commonly used.

2.2.1 FAST/CFAST

FAST is a zone model used to describe fire growth and smoke transport in multi-compartment structures (Jones 1984; Jones and Peacock 1989). Mitler (1985a) has compared the utility of a number of zone models, including FAST. He considered factors such as the numerics, documentation, physics, validation and structure. He found FAST to be numerically robust and that the physics had been at least partially experimentally validated. He found the overall accuracy of FAST in the validation tests to be about 10%.

Comparisons of FAST with experimental data have been done by a number of workers, including Jones (1984), Peacock et al. (1988), Jones and Peacock (1989), Beard (1990, Report 8) and Duong (1990). Jones found good agreement between FAST and experimental data for upper layer temperature in rooms 4.3 x 3.3 x 2.3 m high and 2.3 x 2.3 x 2.2 m high. Peacock *et* al. found that upper layer temperatures were always over-predicted by the model for his room/corridor (2.3 x 2.3 x 2.2 m high/2.4 x 12.2 x 2.4 m high) arrangement, while Duong found that FAST over-predicted hot layer temperature in his very large room (20 x 21 x 13.5 15 m high; no walls room below 12 m).

Beard compared predicted upper layer temperatures with temperatures measured at various heights in fire experiments in a room, a house and a department store. Beard found that predicted and measured data were not easy to compare, and that further consideration of this problem was necessary.

Levine and Nelson (1990) used FAST v. 18.3 to model a fire in a two-storey detached residence. They found that FAST was ‘excellent for predicting the upper layer average content of CO, CO_2 and O_2 in rooms remote from the fire, when given the proper input data.’

Gandhi (1993) has compared data from room fire tests conducted according to the ASTM proposed method (ASTM 1983a) with FAST simulations. He found that FAST provided reasonable results for interface height and upper layer temperature, though some interpolation of experimental data is needed to enable comparisons to be made.

CFAST (Peacock *et* al. 1993a; 1993b) in a combination of FAST with the program CCFM.VENTS (Forney and Cooper 1990). Peacock (1993a; 1993b) have compared

CFAST predictions with experimental data, finding for room/corridor and multiple storey layout the model generally over-predicted upper layer temperatures.

2.2.2 ASET-B

ASET-B (Walton 1985a, 1985b) is a *zone* model derived from the program ASET (Cooper and Stroup 1982), and is a simplified version of it. ASET-B predicts only the temperature and depth of the hot layer, whereas ASET can also predict smoke and gas concentrations. ASET and ASET-B were originally developed to provide estimates of Available Safe Egress Time in compartments of fire origin. Cooper (1988) gives guidelines on how to apply the model to multi-room situations. Cooper (1988) has compared ASET with experimental data for a room/corridor configuration. He found 'favourable agreement between the results of theoretical and experimental interface position' for this multi-room set up.

Beard (1990, Reports 1 and 6) has evaluated ASET and ASET-B. In his quantitative assessment (Report 6; see Table 1), he compared ASET-B predictions with data from experimental fires in a room, a house and a department store. He found that ASET-B predicted a shorter time to hazard than the room and house fire experiments predicted, but a longer time to hazard than the department store experiment predicted.*

The most commonly used versions of ASET-B are those incorporated in the FPETOOL/FIREFORM, FIRECALC and ASKFRS fire engineering computer collections. Nelson has used ASET-B in analyses of fires at the Dupont Plaza Hotel (Nelson 1987), First Interstate Bank (Nelson 1989), Pulaski Building (Nelson 1990a) and Hillhaven Nursing Home (Nelson and Tu 1991). In all these cases, ASET-B was used in conjunction with FPETOOL/FIREFORM.

Johnson and Timms (1995) used ASET, in conjunction with other smoke filling models, in their fire safety analysis of a large shopping centre, finding that simple zone models, if used carefully, 'can provide some reasonable estimate of fire growth and smoke layer development' in such configurations.

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* Beard (1990) uses the following indicator of hazard in all his assessments: (a) Temperature: 183°C above eye level; 100°C below eye level; (b) Smoke obscuration: 0.6, 1.0 and 2.0 obscuras; (c) Carbon monoxide concentration: 0.3% by volume; and (d) Interface height: 1.5 metres above floor level.

2.2.3 HARVARD FAMILY

The Harvard Computer Fire Code (CFC) developed at Harvard University by Emmons and coworkers forms the basis of a number of fire models. Harvard Mark V (Mitler and Emmons 1981) is a single room, whilst Harvard Mark VI (Rockett and Morita 1985, 1986) is a multi-room model. Variants include Mark 5.3, which has additional features related to smoke production (Mitler 1985b).

FIRST (Mitler and Rockett 1987) is based on Mark V, and hence is a single room model. It incorporates various enhancements that were made after the project terminated at Harvard.

The WPI Fire Code (Barnett 1992) is a single room fire model based on Harvard 5.3.

Rockett (1982) has compared data from mattress fire experiments with Harvard 5.1. Differences between measured and predicted results led to modifications of the model.

Rockett (1984) has conducted simulations of ‘hotel-like rooms’ using Harvard 5.2. He compared his predictions with results from full-scale room fire experiments, and with results from furniture calorimeter experiments on furniture items. He found the model predicted the ‘free bum’ results in the furniture calorimeter more closely than it predicted the room fires.

Beard (1990, Reports 4 and 9) has conducted qualitative and quantitative assessments of FIRST. In the qualitative assessment he found FIRST to be a useful tool, though some inputs, such as ‘product of combustion generation rate’, ‘fire spread rate parameters’, ‘combustion efficiency’ and ‘ignition temperature of secondary object’ may be sources of large errors. The choice of plume model may also be inappropriate on occasion. In the quantitative assessment, predictions were compared with experiments for a room fire, a house fire and a department store fire. It was found that for the room fire, the predicted time to hazard was shorter than the experiment suggested, whilst for the house fire and department store fire, it appears longer than is suggested by experiment.

2.2.4 JASMINE

Perhaps the most commonly used field fire model, JASMINE (Cox and Kumar 1987) is usually applied in single enclosure of large size or irregular dimensions. Cox *et al.* (1986) compared predictions from JASMINE with several experimental fire configurations (6 x 4 x 4.5m high; 7.3 x 7.9 x 2.7 m high; and 390 x 5 x 4 m high), all with forced ventilation. For all cases agreement was found to be quite satisfactory except in the immediate vicinity of the fire source. Cox *et al.* (1990) also used JASMINE to help evaluate smoke control strategies in a six-storey atrium. They used the output in their appraisal of occupant escape times.

In his qualitative assessment of JASMINE, Beard (1990, Report 5) comments that it is capable of modelling cases for which zone models are inappropriate, especially cases involving large spaces or unusual geometry. In his quantitative assessment of JASMINE, Beard (1990, Report 10) found that when comparing predicted time to hazard with experimental data for fires in a room, a house and a department store, the predicted time to hazard was shorter than suggested by the experiments for the room and the department store (single enclosures), but longer for the house (multiple enclosures).

2.2.5 Harwell-Flow 3D

After the Kings Cross underground fire, the field model HARWELL-FLOW 3D was used to simulate the hot gas flow (Simcox *et al.* 1992), and played an important role in understanding the fire dynamics, drawing attention to the ‘trench’ effect. The existence of this effect was verified by scale experiments (Drysdale *et al.* 1992; Moodie and Jagger 1992).

3. FIRE HAZARD ANALYSIS

Although the numerical methods described above can be used individually or collectively in fire hazard analysis, their use is limited in scope and applicability. Integrated packages with modules which include fire development, smoke and toxic gas movement and the effects of the fire on human egress are required.

Such packages have been the subject of developments such as the Warren Centre Project and the Draft National Building Fire Safety Systems Code briefly discussed below, but the most viable package is that of HAZARD 1 which comprises a number of computerised numerical modules.

Both deterministic and probabilistic approaches to fire hazard analysis are possible. Deterministic approaches provide only limited hazard analysis on their own. However, they can be used to provide input into probabilistic risk assessment models, thereby providing a more comprehensive fire hazard analysis.

3.1 Warren Centre Project

In the Warren Centre’s Fire Safety and Engineering Project (Warren Centre 1989) design fires were used to provide input into fire models. The design fires chosen were based on experimental data for the rate of heat release obtained from the burning of actual items of building contents, and related to specific occupancies. The fire models used were Smoulder, which is now included in FIRECALC (CSIRO 1993), and FAST (Jones 1984).

The design fires and building details were used as data inputs for the fire models, the outputs of which included 'untenability' criteria such as toxicity (concentration of carbon monoxide at head height) and visibility (smoke density at head height). This allowed the time to untenability to be calculated at selected locations, and matched against computed egress times. Times, along with other data, were used as inputs to a risk assessment model which determined the hazard to life.

3.2 National Building Fire Safety Systems Code (NBFSSC)

In the NBFSSC (Beck *et* al. 1991) design fires for an occupancy are determined by:

(i) experimentation, taking into account enclosure geometry and fuel load;

(ii) standard test procedures, including cone calorimeter and furniture calorimeter;

(iii) mathematical simulations, including t^2 fires; and

(iv) any appropriate combination of (i), (ii) and (iii).

This data is then used as input into models such as Smoulder (CSIRO 1993), Harvard Family (Mitler 1985b), FAST (Jones 1984) and Yardstick (IFE 1990). As in the Warren Centre Project, this data is used to calculate untenability times in specific buildings, data which in turn can be fed into a risk assessment model to predict hazard to life.

3.3 NFPA Life Safety Code

The Life Safety Code (NFPA 1991) addresses hazard to life from fire in buildings by equating life safety primarily with egress (Lathrop 1989). Egress is addressed by provision of adequate fire-isolated exits and control of travel times to exits (Lathrop 1991). A life safety evaluation required for occupancies such as assemblies may include, but are not limited to:

(a) Human behaviour

(b) Exit system

(c) Construction and structure

(d) Contents and finishes

(e) Detection

(f) Emergency notification procedures and systems

(g) Smoke management

(h) Fire suppression systems (NFPA 1991, p.266).

The Life Safety Code is not a fire hazard analysis system, merely requiring occupancies to be classed as ‘low’, ‘ordinary’ or ‘high’ hazard. Classification of hazard of contents is based on life safety, rather than difficulty of extinguishment. The hazard of contents is the relative danger of the start and spread of fire, the danger of smoke or gases generated, and the danger of explosion or other occurrence with the potential to endanger the lives and safety of the occupants (Lathrop 1991, p.31). Under the Code’s definitions, occupancies with the 'low hazard’ contents or ‘high hazard’ contents are rare; the majority having ‘ordinary hazard’ contents (Lathrop 199 1).

3.4 HAZARD 1

HAZARD I is a fire safety engineering package developed at NIST (Bukowski *et al. 1989,* 1991; Peacock *et al.* 1991). It contains a central zone model, CFAST (its predecessor being FAST), and a number of submodels – EXITT, the evacuation model; DETACT, the sprinkler activation model; and TENAB, the ‘untenability’ model. Bukowski (1990) has described HAZARD I as ‘a set of procedures combining expert judgement and calculations to estimate the consequences of a specified fire’.

Peacock and Bukowski (1990) give an overview of the HAZARD I methodology, and provide a flowchart of the elements and interactions that need to be considered in performing a quantitative fire hazard analysis (Figure 2). Peacock *et al.* (1991) note that whilst the first version of HAZARD I can model up to six rooms on multiple floors of a building, data against which its results can be compared ‘are only available for structures of the general dimensions of single-family homes’.

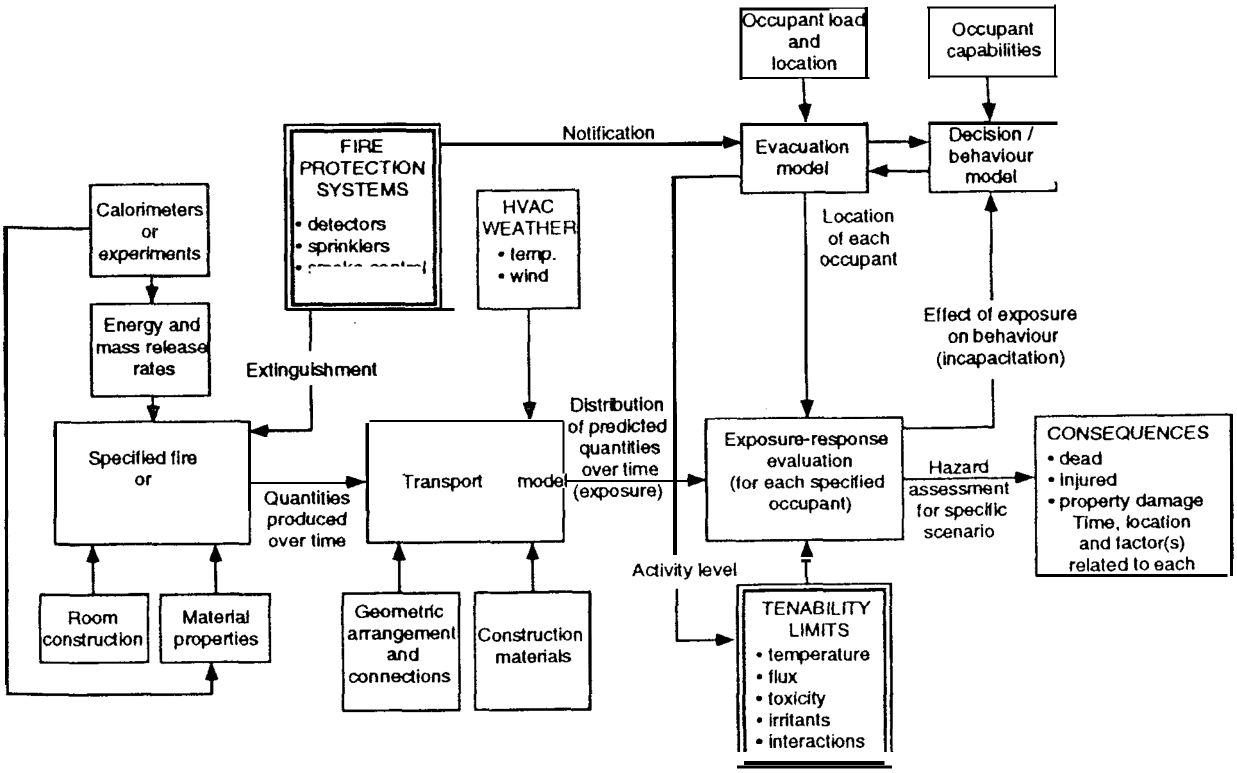

Figure 2. Inter-relationships of major components of afire hazard model (Peacock and Bukowski 1990).

Beard (1990, Report 3) has conducted a qualitative assessment of HAZARD 1. He concluded that HAZARD 1, and specifically EXITT and FAST, were useful supportive tools for fire hazard analysis, but that they should not play a central part in any decision making with regard to fire safety.

HAZARD I has been used in the analysis of actual fires. Bukowski et *al.* (1992) analysed the Happyland Social Club fire, which involved modelling rooms on two levels, the largest being 13 x 3 m (height unstated), as well as a stairwell. They found that ‘HAZARD I predicted conditions quite similar to those reported for the actual incident, including times to and cause of death for the building occupants consistent with observations’.

4. FIRE TEST METHODS

The need for more sophisticated data for use in fire modelling has led to the development of a new generation of fire test methods. This has been coupled with a more international approach to the assessment of fire hazard of building materials driven by the need for less trade restrictions, specifically in Europe, but generally worldwide. At present the most important of these new test methods are the Cone Calorimeter, the IMO/LIFT apparatus, the furniture calorimeter and various room fire tests. Babrauskas and Grayson (1992, p.63 1) list laboratories which have rate of heat release test procedures; using their tabulation and adding known new facilities in the Australasian region, the international distribution of these test methods is as follows:

Cone Calorimeter – 69 laboratories in 17 countries
Room fire test – 21 laboratories in 11 countries
Furniture calorimeter – 10 laboratories in 5 countries
Large room fire test – 9 laboratories in 3 countries

The availability of these methods in Australia and New Zealand is:

Cone Calorimeter – AMRL, BRANZ, CSIRO and LOSC* *
Room fire test – CSIRO
Furniture calorimeter – CSIRO

4.1 Cone Calorimeter

The Cone Calorimeter was developed from extensive studies of calorimeter methods at the National Bureau of Standards (NBS) in the 1970s. The primary purpose of these calorimeters was to measure the heat release rate of products in order to estimate their contribution to a room fire (Babrauskas 1982a). The Cone Calorimeter differed in two major ways from the other calorimeters being developed at NBS – it was bench-scale, and it used the recently re-established principle of oxygen consumption (Huggett 1980). The Cone Calorimeter, first standardised by ASTM in 1990, is now the subject of a number of standards – both general test methods and methods for specific products (Table 6). The method has been assessed in round robin trials conducted by EUREFIC (Bluhme 1989), IS0 (Janssens 1989) and ASTM (ASTM 1990). The purpose of these round robins was to investigate repeatability of the method in individual laboratories and reproducibility between laboratories, and to determine whether changes in procedure were indicated. The outcomes were procedural changes, which have been incorporated in the published ASTM and IS0 methods (Table 6), and statements that said, in effect, that both repeatability and reproducibility were satisfactory for a fire test of this type.

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* AMRL: Aeronautical and Maritime Research Laboratory, Defence Science and Technology Organisation
BRANZ: Building Research Organisation of New Zealand
CSIRO: CSIRO Division of Building, Construction and Engineering
LOSC: Londonderry Occupational Safety Centre, Workcover Authority of NSW

TABLE 6.
CONE CALORIMETER STANDARD TEST METHODS

Standard	Current version	Applications	Comments	Reference
ASTM E 1354	1994	General		ASTM 1994
NFPA 264	1992	General		NFPA 1992
IS0 5660-l	1993	Building materials	No smoke measurement	IS0 1993a
ULC-s 135	1992	Building materials	Determines 'degrees of combustibility'	ULC 1992
ASTM E 1474	1992	Upholstered furniture and mattress components or composites		ASTM 1992a
NFPA 264A	1990	Upholstered furniture components or composites and mattresses		NFPA 1990
MIL-STD-203 1	1991	Composite material systems used in submarines		DOD 1991

It should be noted that ASTM E 1354 is a general test method standard, whilst IS0 5660-l is intended specifically for building materials, and that ASTM E 1354 includes smoke measurement whilst IS0 5660-l excludes this. Apart from the smoke measurement, the methods are technically identical.

In Australia there are currently three Cone calorimeters, whilst New Zealand also has one. A joint Australian/New Zealand standard for the Cone calorimeter, modelled on, and technically identical to, ASTM E 1354, is being developed. A preliminary round robin between three Australian Cone calorimeter operators has been held, and a full round robin including the New Zealand operator is planned.

4.2 LIFT Apparatus

In 1968, the International Standards Organization (ISO) initiated a study for an apparatus design and test procedure to evaluate ignitability and flame spread of materials (ASTM 1993). The International Maritime Organization (IMO) became interested in the ISO spread of flame test method (Robertson 1979). In 1985, the Department of Transportation, Federal Aviation Administration (FAA) sponsored a study at the National Institute for Standards and Technology (NIST) to develop and analyse the measurement of flame spread properties (Quintiere and Harkleroad 1984, 1985) leading to an ASTM method.

The IMO test was published in 1984 (IMO 1984) and ASTM E 1321 was first published in 1990. Jianmin (1992) describes the LIFT (Lateral Ignition and Flame spread Test) apparatus as ‘the most common of the tests by which engineering (as opposed to regulatory) measures of flame spread are currently taken’. Its success is credited to the sound technical theory (Quintiere and Harkleroad 1984) which is available to interpret its results. A model to predict LIFT data from Cone calorimeter measurements has been developed (Jianmin 1990, 1992) though at this stage it has only been imperfectly validated.

4.3 Furniture Calorimeter

The term ‘furniture calorimeter’ is a generic term covering a variety of larger than bench-scale apparatus used for measuring rate of heat release of items such as pieces of furniture. The only aspects that all furniture calorimeters have in common is that the item is burnt under a hood in which all the combustion products are collected, and the rate of heat released is determined by oxygen consumption (Babrauskas 1992). Variables include overall capacity (typically 1 to 5 MW), air flow, air flow control, hood dimensions, and duct size and orientation. Ignition sources are also varied as required.

Early furniture calorimeters were developed at NBS (Babrauskas et *al.* 1982), and FMRC (Heskestad 198 1). The NBS furniture calorimeter was modified by researchers at the Swedish National Testing and Research Institute (SP), Division of Fire Technology
1987), who produced the first formally standardised furniture calorimeter (Nordtest 1987). Underwriters Laboratories (UL) have since released two application standards (UL 1988, 199 1) which use furniture calorimeters similar to the Nordtest apparatus. The UL methods are somewhat simplified and do not include measurements of smoke and some combustion gases. The crib ignition sources are different to that in the Nordtest method, and the UL methods include pass/fail criteria for the assessment of upholstered furniture and mattresses respectively.

4.4 Room Fire Test

Whilst full-scale fire tests of rooms with combustible linings have been carried out for many years (Wickström *et* al. 1983), it is only recently that attempts have been made to create a standard room fire test. The room/corner test method, initially suggested by ASTM (ASTM 1983a), has been standardised firstly by Nordtest (Nordtest 1986) and secondly by IS0 (IS0 1993b). This method employs a room 2.4 x 3.6 x 2.4 m high. At this stage, ASTM has not published a standard method, although a round robin has been completed (Beitel 1994). It was found in the ASTM round robin that the test method provides good (i.e. reproducible) results in terms of heat release rate, flux levels and temperatures. The smoke measurements were more variable. It was concluded that the round robin results provided a basis for estimating the accuracy and precision of the method, but that there was room for improvement. A room fire test round robin has also been conducted as part of the EUREFIC program (see later). This round robin involved five laboratories, in Denmark, Finland, Norway, Sweden and the United Kingdom (Mangs *et al.* 1991). It was found that the reproducibility of the method was good, and similar to that in other large scale fire tests, such as fire endurance tests using large furnaces.

Gandhi (1993) has compared room fire test data for the ASTM proposed method with computer simulations using the fire model FAST (Jones and Peacock 1989). whilst Janssens has considered the problem of data reduction of room fire tests for zone model validation in some detail (Janssens 1990; Janssens and Tran 1992).

Kokkala (1993) has investigated the sensitivity of the test to variations in experimental set up, comparing specifically IS0 and ASTM set ups. He found that the test was not over-sensitive to the small differences in room size between the two methods or to the different burner size.

At the Swedish National Testing and Research Institute (SP) there is a large fire test facility (Kokkala *et al.* 1992). The room dimensions are 6.75 x 9.0 x 4.9 m high, with a door 2 x 2 m in the centre of the longer wall. Gases issuing from the door are collected in a hood for analysis in a similar manner to that used in the standard room. This large room fire test was used in the Eurefic program (see later).

4.5 Other Test Methods

The Ohio State University (OSU) calorimeter was first described in 1972 (Smith), and standardised in 1983 (ASTM 1983b). It operates by correlating the rate of heat release with measured temperature increase in exhaust gas. Some workers have questioned its accuracy (Babrauskas 1982b), whilst others have claimed improved results if rate of heat release is correlated to oxygen consumption (Krause and Gann 1980; Tran 1990). Östmann et al. (1985) have found a good correlation between the OSU calorimeter, using oxygen consumption, and the cone calorimeter for the heat release rate of a range of building materials. However, the Cone Calorimeter appears to be favoured over this method.

The IS0 Ignitability Test (IS0 1986) adopted in Australia as AS 1530.5 (SAA 1989a), uses a cone heater similar to that in the cone calorimeter. In fact, the cone heater in the cone calorimeter is derived from the IS0 cone heater (Babrauskas and Parker 1987). Therefore, it would be expected that the two methods give similar results for time to ignition under the same it-radiance. Accordingly, a number of studies have been carried out comparing ignitability in the

ISO Ignitability Test and the cone calorimeter (Babrauskas and Parker 1987; Östmann et *al.* 1985; Östmann and Tsantaridis 1990; Mikkola 1991). These workers all found that whilst the results are generally similar, there were systematic differences traceable to details of apparatus. Östmann and Tsantaridis (1990) concluded that the cone calorimeter should be used for determination of ignitability instead of the IS0 Ignitability Test as other fire parameters are obtained in the cone calorimeter simultaneously and independently.

4.6 Current Australian Test Method

The test method that is currently cited in the Building Code of Australia for controlling combustible wall and ceiling linings is AS 1530.3 (SAA 1989b). This method was developed because of perceived shortcomings in the method previously in use to assess the hazard of wall boards (Ferris, 1955). One shortcoming seen in the previous method was that it excluded ignitability (Ferris, 1955). The new method, AS 1530.3, originally provided an 'Index of Early Fire Hazard', summing together results for 'Ignitability', 'Spread of Flame' and (radiant) 'Heat Developed'. In this system ignitability was weighted to give half the maximum possible score, a high score being a poor performer. At a later stage, the 'Index of Early Fire Hazard' was discarded, and a 'Smoke Developed' measurement added (Keough, 1969), thereby reducing the emphasis on ignitability. In fact, regulators ignored the 'Ignitability Index' and called up only the 'Spread of Flame Index' and the 'Smoke Developed Index'. The Standard (SAA, 1989b) now requires actual results to be reported, though allowing for assignment of 'Indexes' for regulatory purposes.

Spread of flame is measured indirectly only (Ferris, 1955). What is actually measured is a rate of increase in radiation emitted by the specimen following ignition. A relationship between time for an increase of 1.4 kW/m^2 to occur, and flames to reach the top of 2.74 m room comer was developed (Ferris, 1955). The time at which the flame are steady on the ceiling is assumed to be a critical time in the growth of a fire (Ferris, 1955; Moulen et *al.*, 1980). though this has been disputed (Gardner and Thomson, 1988).

A number of studies comparing the AS 1530.3 test with large-scale corner tests have been conducted. Moulen et *al.* (1980) attempted to verify Ferris' relationship between flame spread time in the comer test and radiation increase in AS 1530.3, but found that the proportionality factor varied for different comer test conditions. Martin and Dowling (1979) noted that there is a dependence of flame spread time upon time to ignition, caused, in part at least, by different levels of imposed radiation. Brown and Martin (1983) obtained results more consistent with Ferris' correlation, but using a lower ceiling (2.39 m) and having no air-gap behind the specimens in the room corner test. Moulen et al. (1980) found that smoke developed measurements in the AS 1530.3 test relate to smoke developed in the early stages of fire development in the comer of a room, though Quintiere (1982) conducted an analysis of the data and was not able to find a meaningful correlation.

There is only one published paper comparing the AS 1530.3 test with a full room test, as opposed to room comer tests. Gardner and Thomson (1988) carried out room fire tests in accordance with the ASTM proposed method (ASTM 1983a). They compared flame spread data and ignition data from the AS 1530.3 test with time to flashover in the room fire test. They found that there was no significant relationship between AS 1530.3 ‘Spread of Flame Index’ and the time to flashover. They did find a correlation between time to ignition in AS 1530.3 and time to flashover in the room fire test. However, as materials tested were all similar cellulosics, this correlation may be limited in scope.

4.7 Evaluation of Test Methods in the EUREFIC Project

The EUREFIC Project was a three year program initiated by NORDTEST to raise the current technical level of evaluating surface linings in the Nordic countries (EUREFIC 1991). However, as moves towards **a** united Europe proceeded, the EUREFIC program was linked to the broader European activities. The objective of the program was to put forward new IS0 methods to be employed in Europe for evaluating the fire hazard of building products. Participants in the EUREFIC program are listed in Table 7. The program consisted of ten projects which are listed in Table 8.

TABLE 7.
PARTICIPANTS IN AND TECHNICAL CONTRIBUTORS TO
EUREFIC RESEARCH PROGRAM (WICKSTRÖM 1993)

Country	Organisation
Participants	
Denmark	Dantest
Finland	Technical Research Centre of Finland (VTT)
Norway	Norwegian Fire Research Laboratory (SINTEF NBL) – in cooperation with University of Trondheim, Division of Building Technology
Sweden	Swedish National Testing and Research Institute (SP)
Technical contributors	
United Kingdom	Fire Research Station (FRS)
Italy	Laboratorio di Studi e Ricerche sul Fucco
Japan	Research Institute for Marine Engineering
Denmark	Rockwool Systems
Sweden	Swedish Institute for Wood Technology Research (TRATEK)
Sweden	University of Lund
USA	National Institute of Standards and Technology (NIST)

Projects 1 and 2 investigated the suitability of the Cone Calorimeter (Bluhme 1989) and Room Fire Test (Mangs et *al.* 1991) methods for use in any testing and classification scheme. Both investigations became involved in broader IS0 developments. The Cone Calorimeter round robin became a contribution to the IS0 round robin (Janssens 1989), whilst the Room Fire Test method was accepted as an international standard in 1991, and published in 1993 (IS0 1993b). The outcome of these two Projects was the acceptance of the Cone Calorimeter and Room Fire Test as suitable test methods for use in testing and classification of building materials.

TABLE 8.
PROJECTS OF THE EUREFIC RESEARCH PROGRAM (WICKSTRÖM 1993)

Project No.	Project title
1.	Interlaboratory calibration and repeatability of the Cone Calorimeter, ISO 5660.
2.	Interlaboratory calibration and repeatability of the Room/Corner test NT Fire 025, IS0 9705.
3.	Tests in larger scale than NT Fire 025 and sensitivity analysis of the method.
4.	Model for predicting the fire growth in the Room/Corner test based on results from the Cone Calorimeter.
5.	Models for flame spread and application of test data.
6.	Correlation of test results with existing Nordic test methods.
7.	Correlation of test results with other European test methods.
8.	Preparation of a new classification system for surface products based on the Room/Corner test and the Cone Calorimeter.
9.	The effects of the new classification system on products and building costs.
10.	Coordination and information about the Nordic research program.

In Project 3, larger scale Room Fire Tests were carried out on wall/ceiling linings which had previously been assessed in the standard Room Fire Test (Kokkala et al. 1990, 1992). The purpose of the tests was to determine whether there were scaling effects that limited the usefulness of data obtained *in* the standard Room Fire Tests. The large (6.75 x 9 x 4.9 m high) room fire tests were found to be a less severe exposure than the standard-size Room Fire Test, with higher heat outputs from the gas burner being necessary to produce progressive flame spread, and flashover occurring with less specimens – even with the higher burner output (100 kW for 10 min, followed by for 10 min, followed by 900 kW for 10+ minutes).

Flashover in the standard Room Fire Test was defined as a gross heat output of 1 MW (Mangs et al. 1991), whilst in the large room fire tests a more subjective definition of total room involvement/ventilation control appears to have been used (Kokkala et al. 1992).

Project 4 was a core part of the EUREFIC program, and consisted of four major parts:

Part 1	Data base;
Part 2	Room Fire Tests and Cone Calorimeter tests:

Part 3 Model for smoke production; and
Part 4 Heat release predictions in the Room Fire Test based on Cone Calorimeter results.

In Part 1, the data produced in the Cone Calorimeter and Room Fire Tests were converted to a standard format, known as FDMS (Babrauskas *et al.* 1991; Portier 1994) by the use of DCS (Data Converting System) (Lønvik and Opstad 1991; Opstad and Lønvik 1993). This data has been obtained by CSIRO for evaluation. The experiments used to generate the data formed Part 2 of Project 4, and cover the standard Room Fire Tests (Söderbom 1991) and Cone Calorimeter tests (Thureson 199 1).

The data generated in Part 1 and 2 of Project 4 was used in Part 3 to develop models to estimate the smoke production in the standard Room Fire Test from Cone Calorimeter results (&man et al. 1992), and in Part 4 to develop a model to estimate the heat release in the standard Room Fire Test from Cone Calorimeter results (Gbransson and Wickström 1990; Göransson 1991). Whilst the heat released model has been described as ‘promising’ (Wickström 1993), the smoke correlation appears to be more material dependant.

Another outcome of Part 4 of Project 4 is the computer program Cone Tools (CT) (Lønvik and Opstad 1993). This software, which has also been obtained by CSIRO for evaluation, is designed to use data from the Cone Calorimeter in classification and flashover (in the room tire test) calculations.

Surface flame spread was studied in detail in Project 5 (Kokkala 1993; Baroudi and Kokkala 1992; Opstad 1991), leading to models for upward flame spread in a room comer (Baroudi and Kokkala 1992) and flame spread on surface linings using Cone Calorimeter data (Opstad 1991) and the three dimensional field model KAMELEON.

The remaining projects (Table 8) were concerned with classification schemes and are discussed in the next section.

5. DEFINITION OF LIMITS AND CLASSIFICATION

Having decided upon an appropriate test method for the purpose of regulating materials the limits for acceptability for various circumstances need to be defined. This is often done in the form of classifications although this is not fundamentally necessary as ‘limits’ themselves are just as suitable for regulatory purposes and allow for future flexibility.

5.1 European Reaction to Fire Classification

In Projects 6 and 7 of the EUREFIC Project results obtained in the Room Fire Test were used to classify linings (Hovde 1990), and these classifications compared with existing Nordic (Hovde 1991) and European (Bluhme 1991) classification schemes. It was concluded that there could be no simple correlation between classifications based on existing test methods and a classification based on Room Fire Tests, and therefore a change in approach was needed.

Project 8, development of a new classification system (Sundstriim 1991), proceeded in parallel with the previous two projects, and is in part based on work done prior to the EUREFIC program (Sundström 1986b; Sundstriim and Göransson 1988). Materials to be classified are assessed in the IS0 9705 Room Fire Test (IS0 1993b). The material to be tested is fixed to three walls and the ceiling. The gas burner input is 100 kW for 10 minutes, followed by 300 kW for 10 minutes (Sundstriim 1991). In this classification scheme (Table 9) Class A and B materials must not cause flashover in the 20 minute test, as well as satisfying other heat release rate and smoke production rate criteria. Materials of Classes C, D and E must not cause flashover in the first 12, 10 and 2 minutes of the test respectively, as well as satisfying other less stringent (in some cases) heat release rate and smoke production rate criteria. Materials that do not meet the requirements of Class E are designated UC – unclassified. Some materials that have been tested and classified by this system are listed in Table 10.

In establishing the Class A criteria, it was first determined from statistics (Takeda and Yung 1991) that in residential buildings the death rate from non-flashover tires was far less than that from fires that went to flashover. Flashover, therefore, was accepted as a benchmark of hazard. It was then estimated that a 1 MW fire in a small bedroom would cause flashover, and that the standard fire test room represented a small bedroom. The Class A criteria are set so that there is no flashover ‘even for a strong ignition source’ such as the 300 kW gas burner which provides nearly 1/3 of the energy needed for flashover. It is suggested that the level of performance consistent with Class A could be required in escape routes, for example (Sundstriim 1991). No direct correlation between small bedrooms and escape routes is attempted.

TABLE 9.
PROPOSED CLASSIFICATION CRITERIA FOR SURFACE PRODUCTS TESTED TO IS0 9705 (SUNDSTRÖM 1991)

Class	Minimum time to flashover	Heat release rate			Smoke production rate	
	(min)	Peak^a (kW)	Peak^b (kW)	Average^a (kW)	Peak (m^2/s)	Average (m^2/s)
A	20	300	1 000	50	10	3
B	20	700	1 000	100	70	5
C	12	700		100	70	5
D	10	900	1000	loo	70	5
E	2	900	1 000	–	70	–

a. Burner excluded. b. Burner included

TABLE 10.
CLASSIFICATION OF SOME MATERIALS BY PROPOSED EUREFIC CLASSIFICATION SCHEME (SUNDSTRÖM 1991)

Material	Class	(Test duration for classification^a (min)	Heat release rate		Flashover	Smoke production rate	
			Peak (kW)	Average (kW)		Peak (m^2/s)	Average (m^2/s)
Gypsum plaster board	A	20	20	5	–	1	0
Painted gypsum plaster board	A	20	130	30	–	4	2
Paper wallcovering 130 g/m^2 on plasterboard	B	20	525	40	–	5	0.5
PVC wallcovering 190 g/m^2 on plasterboard	B	20	480	25	–	60	2
FR particle board	C	12	350	40	–	30	4
Intumescent coat on particle board	C	12	200	17	15.15	51	4
Melamine faced high density non-combustible board	D	10	20	<10	–	3	1
Textile wallcovering on gypsum paper plaster board, [illegible]	D	10	470	70	1 l:oo	12	2
Melamine faced particle board	E	2	200	40	7.45	25	5
Wood panel	E	2	500	150	2.18	18	2
FR, expanded polystyrene, 25 mm	UC^b		–	–	1:20	22	–
Polyurethane foam	UC^b	–		–	0.14	300	–

[a] Flashover must not occur in this time period.
[b] UC = unclassified. Not meeting the requirements for any class.

The benchmarks used in constructing the classifications were:

Class A: defines a situation where the heat release from the product is so limited that the fire is confined to the room, i.e. there is no flashover.

Class E: based on growth rate of fires involving wood products.

In Project 9 the costs of implementing a new classification system were studied (Pulakka and Kokkala 1992). The analysis suggested that, for the same level of fire safety, the additional building costs would be only partially offset by perceived savings (Wickström 1993).

The EUREFIC research program was essentially concluded in 1991, having achieved its goal of contributing 'to the development of future European test method and classification criteria' and more specifically having attained the objective of 'putting forward new IS0 methods to be employed in Europe for evaluating the fire hazard of building products' (Wickström 1993). The adoption of any outcomes of the research now rests with the European Commission.

5.2 Canadian 'Degrees of Combustibility' Classification

In the 1950s and '60s there was an enormous increase in the use of building products in Canada that were generally considered non-hazardous but were still classified as combustible by the Canadian non-combustibility test. Therefore, in 1971, the Canadian Commission on Building and Fire Codes (CCBFC), the body responsible for writing the NBCC, asked the Underwriters' Laboratories of Canada (ULC) Fire Test Committee to develop a standard which could distinguish non-hazardous products such as gypsum board, fire retardant treated wood and modern exterior insulation and cladding systems from other combustible materials by ranking building materials according to their 'degree of combustibility' (Richardson 1991).

The Canadian non-combustibility test identifies those building materials which do not aid combustion by adding heat to a fire. ULC concluded that a test to quantify the 'degree of combustibility' of a material should measure the amount of heat that a material might contribute to a fire: that is the rate and amount of heat release by a material (Richardson 1991).

In 1989 scientists from the National Research Council of Canada (NRC), Institute for Research in Construction (IRC), described how they were able to measure heat release from materials with very low 'degree of combustibility' using an ASTM E 906 heat release rate calorimeter (ASTM 1983b) and oxygen depletion measurements (Richardson 1991).

At the Canadian National Forest Industries Technical Centre (Forintek), Ottawa, scientists demonstrated that the ASTM E 1354 cone calorimeter (ASTM 1994) provides a better means for measuring the heat that building materials might contribute to a fire. They also showed that classification of the 'degree of combustibility' of materials requires determination of both the peak heat release rate and the total amount of heat released by materials exposed to a minimum radiant heat flux of 50 kW/m^2 for 15 minutes (Richardson 199 1).

Responding to a recommendation that the Cone Calorimeter method for determining the ‘degree of combustibility’ of building materials be referenced in the NBCC, in 1991 ULC circulated the second draft of ULC-S135M (Richardson 1991).

The standard was published in November 1992 (ULC 1992). A suggested classification using this scheme (Table 11) was published in 1991 (Richardson and Brooks). However, at this stage the scheme has not been adopted in regulations (Richardson 1994).

TABLE 11.
A SUGGESTED CLASSIFICATION SCHEME FOR ‘DEGREES OF COMBUSTIBILITY’ USING HEAT RELEASE DATA FROM THE CONE CALORIMETER[a]
(RICHARDSON AND BROOKS 1991)

Category	Peak heat release rate (kW/m^2)	Total heat release (MJ/m^2)	Examples
1	10 or less	5 or less	mineral fibre insulation board
2	100 or less	25 or less	(paper-faced) gypsum plaster
3	150 or less	50 or less	FR Plywood
4	300 or less	100 or less	white pine planks; red oak flooring
5	300 or less	100 or less	expanded polystyrene[b]

[a] Test duration 15 min; irradiance 50 kW/m^2.
[b] Presence/absence of fire retardants not stated.

5.3 New Zealand Classification Scheme for External Claddings

In New Zealand, a scheme has been proposed whereby the need for external claddings to be submitted to the combustibility test (SAA 1984) would be replaced with performance criteria based on the peak heat release rate and total heat release in the Cone Calorimeter (Wade 1995). The test conditions of 15 minutes exposure at 50 kW/m^2 are the same as those suggested in Canada (Richardson and Brooks 1991).

6 SUMMARY

The Project 2 strategy is in line with current developments worldwide, and can make use of specific developments, such as some outputs of the EUREFIC Projects. Numerical models are the subject of continuous improvement, but at this stage are not sufficiently developed to provide total answers. In any case, they should be used only by practitioners who understand their limitations, and results should be verified by experiment. Zone models such as CFAST, ASET-B and the Harvard Family are all used in analysis of simple multi-room fire scenarios, whilst field models (CFD models) such as Jasmine and Harwell-Flow 3D are most likely to be used in the analysis of complex single enclosure fire scenarios.

Performance-based fire hazard analysis systems are in their infancy, with definitions of hazard and acceptable levels of performance still not agreed, although measurements of available egress time is one accepted way to assess hazard. The computer package HAZARD 1 is commonly used as one tool in fire hazard analysis.

Fire test method development has centred on rate of heat release methods such as the Cone Calorimeter, Furniture Calorimeter and Room Fire Test, and flame spread tests for which there is strong theoretical justification, such as the IMO/LIFT apparatus. The IS0 Ignitability Test does not provide any information not obtainable from the Cone Calorimeter.

In the EUREFIC Project the Cone Calorimeter and Room Fire Test were evaluated in detail and found to be suitable test methods for use in testing and classification of building materials. Preliminary empirical models using Cone Calorimeter data to predict performance in the Room Fire Test were developed.

A classification scheme for building materials was proposed in the EUREFIC Project. This scheme used data from the Room Fire Test, with prediction from Cone Calorimeter data a possibility. So far, this proposed classification scheme has not been adopted in regulation.

Two other schemes, in Canada and New Zealand, propose controlling building materials by Cone Calorimeter results rather than by combustibility criteria. Neither scheme has been adopted in regulations yet.

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