FLAMMABILITY TESTS FOR ASSESSING CARPET PERFORMANCE

J.M.BLACKMORE, M.A.DELICHATSIOS

FIRE Science and Technology Laboratory
CSIRO Division of Building, Construction and Engineering
14 Julius Avenue, North Ryde, NSW 2113
Australia

ABSTRACT

The potential of building materials to contribute to fire growth and spread has lead to extensive regulatory control. Various and numerous small-scale tests are used to simulate and characterize flammability, flame spread and smoke production. Recently Fire Science and Technology Laboratory at CSIRO (FSTL) conducted an extensive research project into the performance in fire of flooring and floor coverings (Blackmore, and Delichatsios 1999). The purpose of this work was to investigate whether few tests (one or two) could be used to provide key flammability properties so that the multiplicity of tests currently available can be validly reduced.

The project focussed on an evaluation of four tests, the Cone Calorimeter, the Flooring Radiant Panel, the LIFT Apparatus and the Early Fire Hazard Test (EFH). The reason behind the test selection was that the first three tests are internationally recognised while the fourth is a valuable, well-documented and validated Australian test. EFH was originally developed to regulate wall lining materials but its use has been extended to regulate almost everything else, including floor coverings. Detailed test measurements in these apparatus included ignition times in the cone and EFH, critical heat flux in the cone, FRP, LIFT and EFH, and rate of heat release and smoke yield in cone and EFH. Comparisons of similar parameters were made to investigate consistency of test results within the present regulatory requirements for floor coverings. In addition, prediction of flooring material behaviour in each of these tests based on results from the rest of the tests was explored.

This work established that the performance measured in and regulated by the Flooring Radiant Panel is complementary to that measured in the Cone. While the Early Fire Hazard Test and Cone provide information to assess the fire performance of materials for upward flame spread, the Flooring Radiant Panel (and LIFT) gives a suitable complementary measure (critical heat flux) of flame spread on horizontal surfaces. While The Flooring Radiant Panel does not currently measure smoke generation nor is it suitable for determining upward flame spread for floor coverings used on stairs or ramps, the Cone Calorimeter can provide the additional data needed for these predictions.

KEYWORDS:

Building material performance; floor coverings; flammability properties; test methods; fire.

INTRODUCTION

Recently Fire Science and Technology Laboratory at CSIRO (FSTL) conducted an extensive research project into the performance in fire of flooring and floor coverings (Blackmore and Delichatsios, 1999). A previous project had studied wall and ceiling linings (Dowling and Blackmore, 1998). The aim of the project was to recommend tests that provided suitable controls for regulating the use of floor coverings. The resulting recommendation was that to evaluate the hazard presented by floor coverings two tests were needed, and the tests selected were the Cone Calorimeter and the Flooring

Radiant Panel (FRP). In addition to regulatory controls, the proposed tests can provide data for fire safety engineering.

The project focussed on an evaluation of four tests, the Cone Calorimeter, the Flooring Radiant Panel, the LIFT Apparatus and the Early Fire Hazard Test (EFH). The reason behind the test selection was that the first three tests are internationally recognised while the fourth is a valuable, well-documented and validated Australian test. EFH was originally developed to regulate wall lining materials but its use has been extended to regulate almost everything else, including floor coverings.

The selected tests measure various aspects of a material's potential for fire spread, fire growth and smoke generation. The Cone Calorimeter measures time to ignition, heat released as a function of time and smoke generated in terms of optical density. The FRP provides the critical heat flux at which horizontal spread stops. The LIFT Apparatus measures lateral flame spread and provides a critical heat flux that involves the same physics as the critical heat flux measured in the Flooring Radiant Panel. IMO has justifiably chosen to use the LIFT apparatus to regulate carpet applications in ships, acknowledging that the apparatus is not suitable for assessing the performance of melting materials. Because of its physical similarity to FRP, LIFT was not included in the experimental program. EFH results are reported in the form of indices that are related to ignition (Ignitibility Index), upward fire spread (Spread of Flame Index), fire growth (Heat Evolved Index) and smoke production (Smoke Developed Index). As we will discuss later, EFH was developed to assess the performance of vertical wall linings.

It is difficult to correlate parameters (for example, indices and properties) deduced from measurements in the selected tests. For example, the critical heat flux in the Cone is calculated from ignition time at different levels of irradiance, and is not assisted by radiation from burning material. The critical heat flux of the FRP (that is defined as the heat flux at which flame spread stops) is primarily affected by the contribution of conductive heat from the flame front and to a lesser degree by the radiation from the flame. Nonetheless, such correlations (or the lack of them) can give us a clear indication of the usefulness of the tests in assessing hazard. Here, we look at a number of comparisons to show why two tests are currently needed to characterise the behaviour of floor coverings, and the reasons for selecting the Cone Calorimeter and the FRP.

In this paper we examine the suitability of tests to measure vertical and horizontal flame spread. We compare various measurements in the Cone Calorimeter with the Critical Heat Flux in the FRP and we look at ways of using data from the Cone Calorimeter to predict upward flame spread. We look at methods of validating flame spread predictions from the FRP in large fire scenarios, and finally we discuss the usefulness of various smoke measurements.

VERTICAL AND HORIZONTAL FLAME SPREAD

The Early Fire Hazard Test (EFH) is a medium-scale test that is currently called up by the Building Code of Australia (BCA) to control the use of building linings (floors, walls and ceilings). We include a brief description of the test, as it might not be familiar to those outside Australia. A specimen of floor covering 600 x 450 mm is clamped in a vertical holder which faces a gas-fired radiant panel. The specimen holder is moved towards the radiant panel in a series of programmed steps over a period of 20 minutes, or until the specimen ignites, at which time the movement is stopped. Ignition is promoted by a gas pilot flame mounted 15 mm clear of the centre of the exposed face of the specimen, triggering the decomposition products rather than the specimen itself. If ignition occurs the radiation and smoke production of the specimen are monitored for 2 minutes (or more in certain cases) (Dowling and Blackmore, 1998).

EFH is a medium scale test for predicting flame spread on vertical surfaces. Under the current Australian Standard, data obtained can be used to derive indices that are generally suitable for application in deemed-to-satisfy regulations. However, the data is not suitable for use in fire engineering calculations, and the test method itself is not without problems. Its applicability for predicting performance of horizontal surfaces is not appropriate. In addition, certain materials, especially those that melt and drop away from the backing when exposed to heat, give low indices because of the lack of burning material at the point of most intense radiation. This does not reflect their behaviour in a horizontal orientation, where molten material will stay in place until it is burnt. Other materials that have a high critical radiant flux and thus do not ignite easily can produce high flame spread indices in the EFH because these indices are calculated from measurements taken from the time of ignition, regardless of the incident radiant flux at which ignition occurs.

The Early Fire Hazard test was originally developed to overcome difficulties experienced in the use of BS476.7, Surface Spread of Flame Test, for vertical flame spread. BS476.7 measures lateral flame spread on a specimen exposed to a decreasing radiant field. John Ferris of the Commonwealth Experimental Building Station, where the test was developed, was aware that vertical flame spread was different from horizontal flame spread, and that BS 476.7 did not take into account the heat release rate that was necessary to predict vertical spread. He developed the EFH to overcome these difficulties. In the EFH the radiation levels as the panel approaches the burner simulate the radiation levels measured by Ferris in the ASTM or ISO room corner test. EFH became an Australian Standard and measurements in the form of indices for spread of flame and smoke developed were subsequently invoked in regulations to control the use, not only of vertical linings as originally intended but also of horizontal linings.

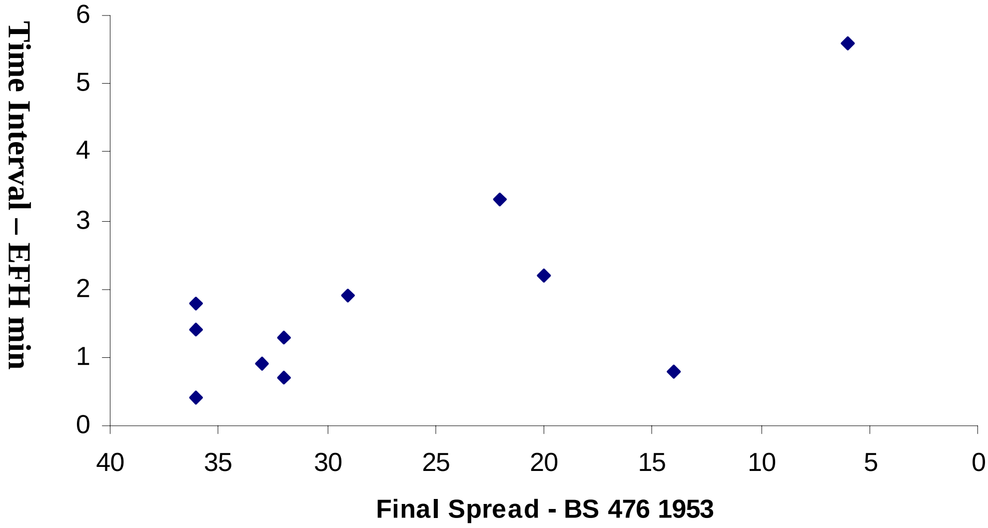

Figure 1 – Time Interval (EFH) v Flame Spread (BS 476:1953)

Figure 1 shows a comparison between Flame Spread as measured in accordance with BS 476:1953 and Time Interval (defined as the time from ignition to that for flames to reach a height corresponding to a 9ft high ceiling, which is related to the Flame Spread Index in the current EFH standard) measured in the Vertical-spread-of-flame Apparatus (as EFH was then known). The comparison shows that there is little or no correlation between the two values. This early observation, taken from a paper written by Ferris in 1955, showed clearly that the Vertical-spread-of-flame Apparatus (as EFH was then known) is suitable for measuring upward flame spread for wall linings, but it cannot characterise horizontal flame spread. Unfortunately the detailed work of Ferris was subsequently overlooked when the EFH was adopted for control of flame spread on horizontal surfaces.

RELATION OF CONE CALORIMETER DATA AND FRP CRITICAL HEAT FLUX

FRP measures the critical heat flux at which flame spread stops. The Cone measures time to ignition, heat release history and the critical heat flux needed to sustain burning.

During the course of the Project a number of materials were tested in the different apparatus. A brief description of the floor covering materials tested is given below:

W2b – Wool carpet
W5 – Wool carpet
N9 – Highly flammable nylon carpet
RF1 – Smooth vinyl flooring
P14 – Polypropylene carpet
N13 – Nylon carpet
N14 – Nylon carpet
N20 – Nylon carpet

Additional data from previous experiments is also used in some of the comparisons. Further details of the materials are given in the Project Report (Blackmore and Delichatsios, 1999).

Attempts have been made to correlate Critical Radiant Flux in the FRP with various measurements in the Cone. Some of these attempts are illustrated in Figures 2, 3 and 4.

In Figures 2 and 3, we directly compare different aspects of heat release rate history obtained from the Cone with values of Critical Radiant Flux (CRF) obtained from the FRP. Figure 2 looks at the maximum heat release rate while Figure 3 compares the average heat release rate over 300s. The heat release rate in the cone is affected by pyrolysis rate as well as the heat of combustion, whereas the CRF in the FRP is not affected by pyrolysis rate. The CRF in the FRP is determined by the convective/conductive heat flux close to the flame front plus the external heat flux, but the convective/conductive heat flux does not depend on the pyrolysing or heat release rate. Both proposed correlations (Figures 2 and 3) are empirical because they lack any physical reasoning. Both proposed selected values of heat release rate are arbitrary.

For example, Figure 2 shows that if we use the maximum heat release rate in the Cone, although there is some general trend we cannot discriminate the behaviour of the material in horizontal situations. Thus the maximum heat release rate is not a useful measure to predict horizontal flame spread.

It has been argued that Figure 3 shows an empirical correlation between the average heat release over 300 s and CRF in the FRP. However, this correlation is fortuitous as is shown by the inclusion of Material x, that was tested and added to Figure 3 after the completion of the Project (Blackmore and Delichatsios, 1999). For this material the average heat release rate over 300 s (at an imposed radiation level of 35 kW/m^2) is 165 kW/m^2, while the correlation suggested in Figure 3 by using the data from the other materials would indicate a value of about 85 kW/m^2 for a CRF in the FRP of 8.4 kW/m^2.

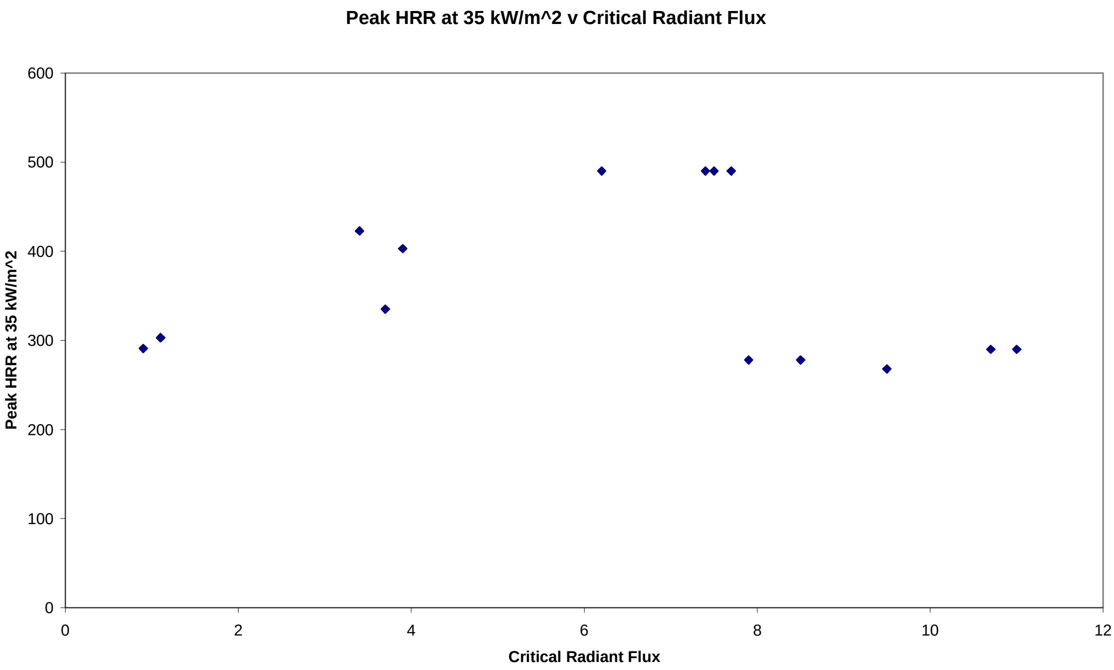

Figure 2 Peak HRR at 35 kW/m² v Critical Radiant Flux

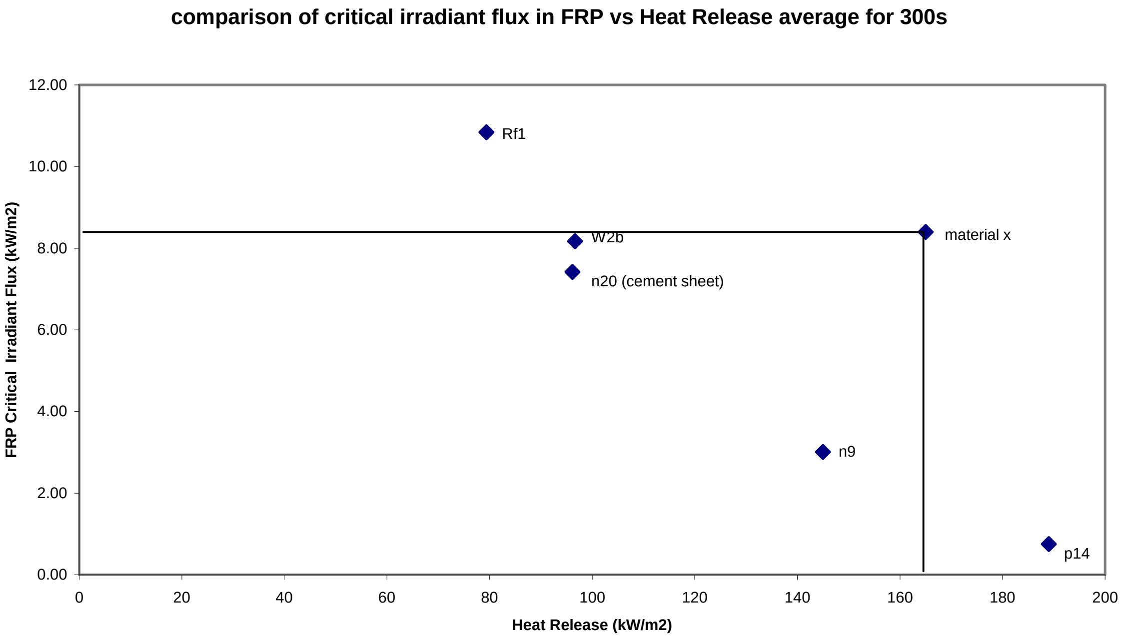

Figure 3 Critical Heat Flux in FRP vs Average Heat Release over 300s

Finally, Figure 4 compares the critical heat flux in the Cone with the CRF in the FRP. It is obvious from the figure that there is no correlation. This result agrees with the following interpretation. In the Cone pyrolysis is induced from the imposed heat flux only. The FRP characterises opposed flow horizontal flame spread and pyrolysis is induced by both the external heat flux and convection/conduction from the flame at the front. We would therefore expect the "nominal" critical heat flux in the Cone to be higher than in the FRP.

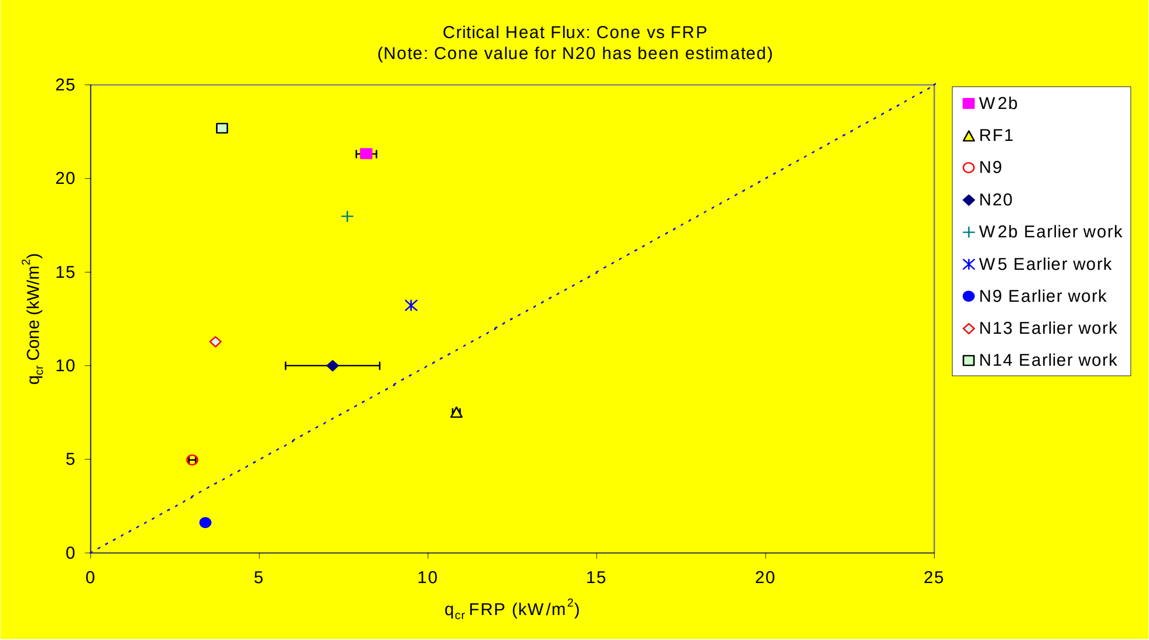

Figure 4 Critical Heat Flux in Cone v Critical Radiant Flux in FRP

PREDICTING UPWARD FLAME SPREAD USING CONE DATA

Based on the above discussions it is apparent that to characterise the flammability of any material in a horizontal orientation we need measurements from both the Cone Calorimeter and the FRP. We will also argue that the Cone can provide a suitable measure of smoke. Next we discuss how data from the Cone can predict vertical flame spread, which applies to both wall linings and floor coverings used on stairs or in situations where flame spread is wind-assisted (Van Hees 1997).

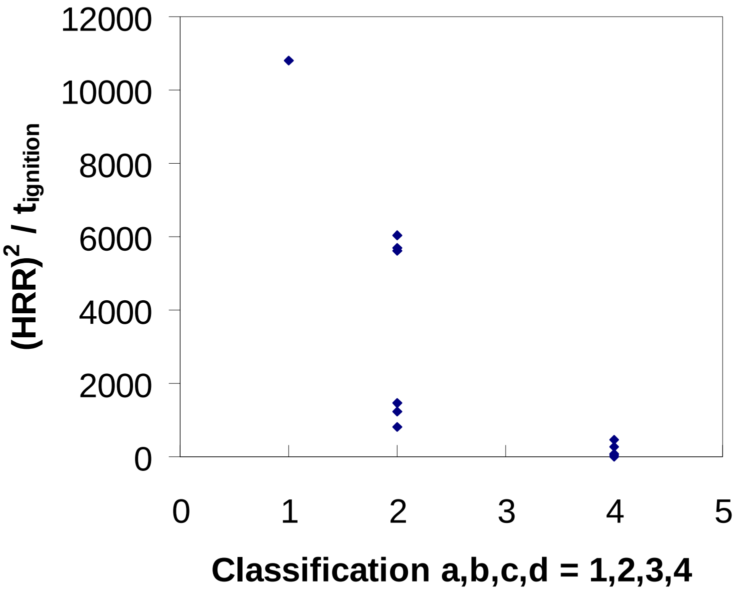

Figure 5 FSTL correlation using Japanese data

We have shown in this work that measurement of lateral flame spread is insufficient to predict upward flame spread (see also Ferris 1955). For vertical surfaces, Heat Release Rate will affect the ability for fire to spread. Figure 5 shows maximum HRR^2 / $t_{ignition}$ (both measured at 50 kW/m^2) against classification based on time to flashover in the ISO Room Corner Test. This parameter determines a characteristic flame spread speed (Delichatsios, 2000). The correlation is good. We propose that this parameter should be used to classify the hazard of floor coverings used on stairs. An alternative approach that also shows that Cone data can be used to predict the ISO Room classification has been proposed by Kokkala (Dowling and Blackmore, 1998).

VALIDATING FRP PREDICTIONS

The appendix to the ASTM Standard Test Method for Critical Radiant Flux describes some experimental studies that investigated the appropriateness of the FRP as a control on floor linings. The experiments described show that, under conditions of moderate exposure (a crib or furniture fire spreading from an open door to a corridor), the extent of fire propagation from the source was inversely related to Critical Radiant Flux. However for more severe exposures only two of twelve floor coverings tested stopped burning at distances corresponding to their Critical Radiant Flux. In the other cases it was apparent that the flux to the floor had been augmented by the heat release from the floor covering itself and probably from burning pyrolysis gases from the room fire that had migrated to the corridor. These effects will be influenced by the building geometry and ventilation.

Similar tests carried out in the FSTL full-scale corridor using a peak heat release rate of 2.5 MW in the adjacent room agree with the findings reported in ASTM E648 (McArthur, 1997). Under these conditions for three of the five floor coverings tested the fire propagated to the end of the corridor (see Figure 6). The two carpets for which fire did not propagate to the end of the corridor had considerably lower heat release rates. From these tests we cannot determine whether floor coverings with Critical Heat Flux between 4 and 7.5 kW/m^2 would propagate to 10 m or not. An additional parameter to determine how far fire will spread for floor coverings with Critical Heat Flux within this range is the heat release rate from the floor covering. This parameter is measured in the Cone Calorimeter, as previously discussed.

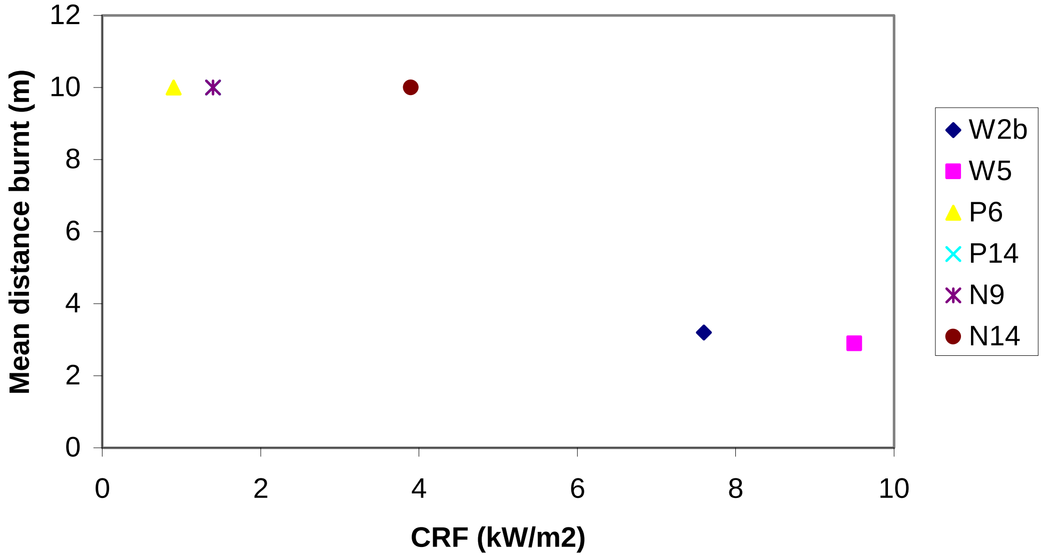

Figure 6 Mean distance burnt in FSTL corridor v CRF

SMOKE MEASUREMENTS

With increasing use of fire retardants, materials with considerably reduced fire initiation and growth characteristics have become common. These materials tend to produce much more smoke and unburned pyrolysis products than the materials they have replaced. Thus it is necessary to assess and regulate smoke (and other toxic gas) production as well as fire initiation and fire growth. In addition, in real fire situations copious quantities of smoke can be produced in oxygen reduced areas such as the hot layer in a room fire, where pyrolysis but no combustion occurs. It is important to consider smoke (and other gas) production for these situations.

The hazard caused by smoke (and other gas) production is related to the total production rate (kg / s) in a given situation. If the rate of fire growth is known and the products yield (kg / kg) is known, it is straightforward to calculate the production rate and the local product concentration. Knowledge of lethal toxicity levels (for various products) provides criteria for fire safe design. ISO TC 92 follows this approach.

Only the Cone Calorimeter or similar apparatus provides product (including smoke) yields for materials under over-ventilated burning conditions. It is known that the method used in the EFH apparatus for smoke characterization is qualitative and in some cases unreliable (it can predict less smoke hazard than actually exists). A method proposed for the FRP, but not adopted by ISO TC 92, is similarly lacking.

In parallel to a complete engineering design, a simple approach is desirable to assess the smoke hazard for screening and regulatory purposes. Such an approach has been developed at FSTL (Blackmore and Delichatsios, 1999).

It is based on the following considerations:

- The mass production rate of smoke (for example) is : $\dot{m}_S = \dot{m}'' Y_S A$ where $\dot{m}''$ is the burning rate per unit area , Y_s, is the smoke yield and A is the area involved in burning at a given time.
- The area involved in burning depends on how fast the fire grows. It is larger for wall linings for example than for carpets. For a wall or carpet of width W the area at time t is
  A= W U t where U is the spread velocity.
- Both the vertical and horizontal velocity vary with the external heat flux. The vertical spread velocity can be many times larger than the horizontal spread velocity. The vertical spread velocity depends also on the heat release rate.
- Neglecting the complications of spread velocities (these can be addressed by modelling), we have suggested that an important discriminating parameter is the smoke mass production per unit area $\dot{m}_S / A = \dot{m}'' Y_S$. It is remarkable that this quantity is nearly the same both for ventilated burning conditions and pyrolysis in a nitrogen flow, for the same imposed heat flux.
- Notice that the mass pyrolysis rate is related to heat release rate by $\dot{m}'' = \dfrac{HRR}{\Delta H_c}$ and the smoke yield, Y_s, is proportional to SEA as measured in the Cone Calorimeter.
- Within an acceptable margin of classification reliability, we can use the following simple parameter to provide a measure for smoke classification:
  HRR (per unit area) x SEA
  Different limits should be set on this value for vertical and horizontal orientations because of the difference in spread rates. From Figure 7a and 7b we can observe that this parameter (which is proportional to the smoke mass production per unit area) is of the same magnitude for the material whether it burns in ambient air and pyrolyses in nitrogen. For example, pyrolysis

conditions in nitrogen represent the decomposition conditions of materials in the upper hot layer of a developing room fire.

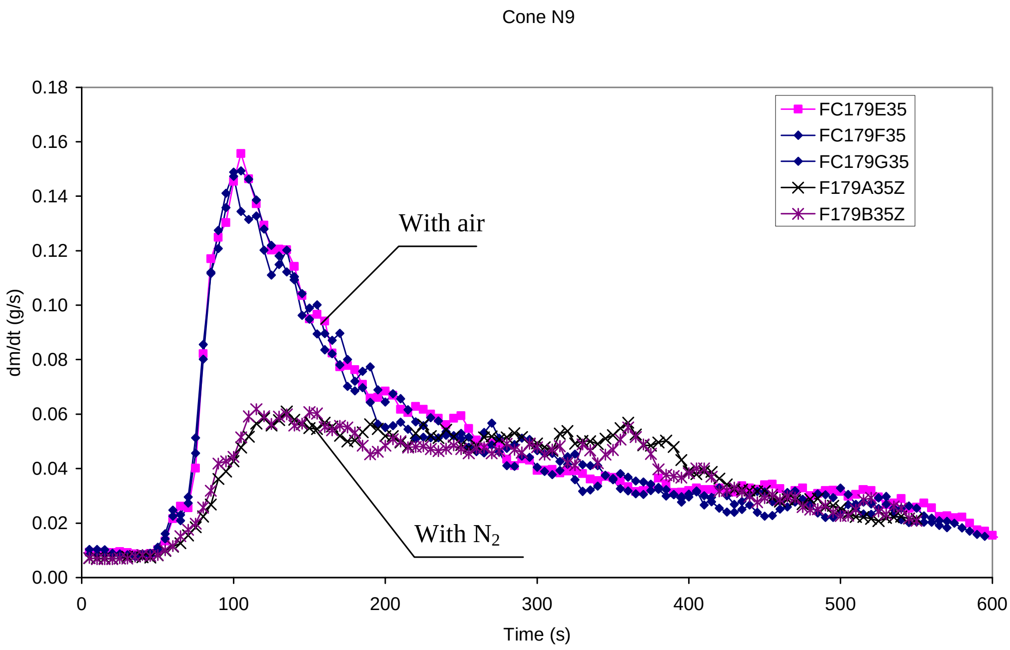

Figure 7a Mass Loss Rate v Time for Nylon Carpet

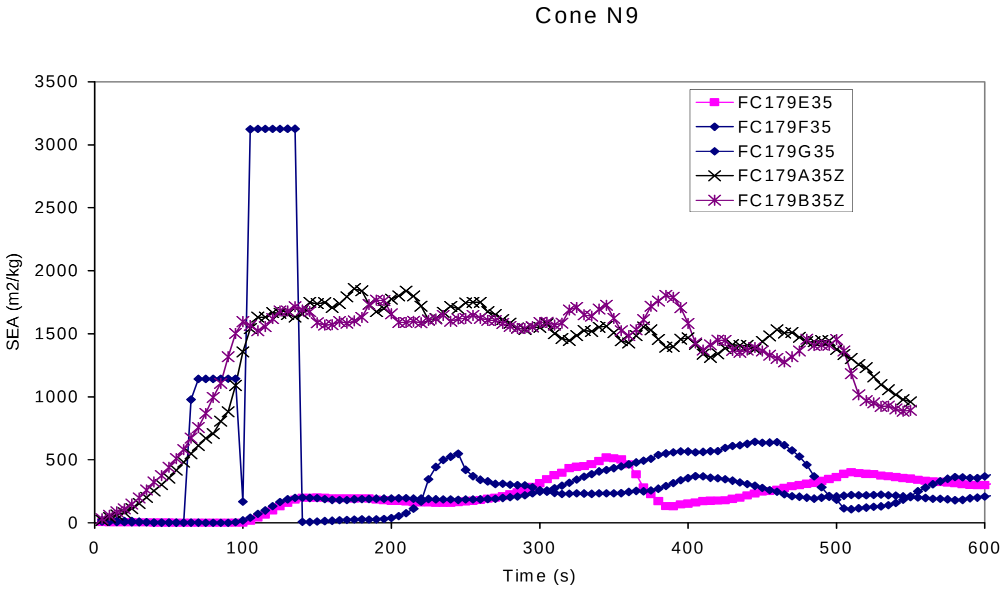

Figure 7b – Specific Extinction Area v Time for Nylon Carpet

INCORPORATING DATA INTO FIRE ENGINEERING MODELS

Currently most models used by fire engineers rely on either an αt^2 fire or the input of a design fire specified by the user in terms of heat release rate against time. Smoke generated is modelled using a constant value of optical density. The next generation of fire models will be much smarter at reproducing the pyrolysis process, and at modelling the spread of fire from object to object. While data in the form of indexes generated by tests such as the EFH can be used for approval purposes, the data generated by the recommended tests (Cone and FRP) will in addition provide direct input to fire engineering models. These models will require the following properties determined from the Cone:

1 critical heat flux for ignition in the Cone
2 k, ρ, C
3 Heat Release Rate
4 Charring properties
5 Smoke and toxic gas yields,

in addition to the critical heat flux to sustain horizontal flame spread measured in the FRP (as discussed before, this differs from the critical heat flux measured in the Cone). The proposed tests therefore not only give a realistic assessment of the hazard presented by floor coverings, but also allow the same test data to be used in sophisticated engineering calculations.

FSTL is already using such calculations to demonstrate the suitability of certain floor coverings in both specific and generic groups of buildings. Scenarios are chosen that illustrate the propensity of fire to spread, by the carpet alone and then taking other fire load into account. If there is sufficient fuel for a flashover fire to develop without the carpet, will the carpet produce smoke or will fire spread to the carpet in an adjacent space? Scenarios are chosen that represent the likely fuel load and geometry of the building and, using data from both the FRP and the Cone Calorimeter, the influence of the carpet on the safety of those escaping the fire can be accurately predicted.

CONCLUSIONS

The main conclusions are:

- Cone Calorimeter data cannot be used to predict Critical Radiant Flux as measured in the Flooring Radiant Panel (see Figures 2, 3 and 4).
- To characterise the flammability of any material we need measurements from both the Cone Calorimeter and the FRP.
- Maximum $HRR^2 / t_{ignition}$ is a suitable parameter to classify the hazard of floor coverings used on stairs.
- Large-scale corridor tests (ASTM E648 – 97, McArthur 1997) provide insufficient data to predict the performance of floor coverings under severe fire exposure. The heat release rate measured in the Cone Calorimeter is needed to predict this performance.
- It is necessary to consider smoke to predict the toxicity hazard posed by floor coverings. A suitable means of assessment using data from the Cone Calorimeter is
  HRR (per unit area) x SEA (see “Smoke Measurements” above).
- The proposed tests provide data that is suitable for sophisticated fire engineering calculations as well as for the development of regulatory controls (see “Incorporating Data into Fire Engineering Models” above).

ACKNOWLEDGEMENTS

FSTL wishes to thank the Fire Code Reform Centre, Sydney, Australia for sponsoring part of the above Project.

REFERENCES

ASTM E648 – 97, “Standard Test method for Critical Radiant Flux of Floor-covering Systems Using a Radiant heat Energy Source”, American Society for Testing and Materials, March 1997

ASTM E1354 “Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter”, American Society for Testing and Materials, 1999

Australian Building Codes Board, “Building Code of Australia,1996”, Sydney, Australia, CCH Australia Ltd

Blackmore J.M. and Delichatsios, M.A., “Fire Performance of Floors and Floor Coverings, Final Report Project 2 Stage B-1”, December 1999, Sydney, Australia, Fire Code Reform Centre

Delichatsios, M.A., “Flame Heat Fluxes and Correlations of Upward Flame Spread Along Vertical Cylinders in Various Oxygen Environments” 29th International Symposium on Combustion, in press 2000

Dowling V.P. and Blackmore J.M. “Fire Performance of Wall and Ceiling Linings, Final Report Project 2 Stage A”, 1998, Sydney, Australia, Fire Code Reform Centre

FSTL/CSIRO, Confidential Report on Technical Appraisal of Floor Covering, June 2000

Ferris, J.E. “Fire Hazards of Combustible Wallboards”, Commonwealth Experimental Building Station, Special Report No 18, Sydney, October 1955.

Leonard, J, Personal correspondence, FSTL/BCE January 2000-10-01

McArthur, N and Jolliffe, C.B., “Development of a Demountable Fire Test Corridor for Assessment of Floor Coverings”. Fire Safety Science – Proceedings of the Fifth International Symposium, IAFSS 1997

Standards Australia, AS/NZS 1530.3:1999 “Methods for fire tests on building materials, components and structures - Simultaneous determination of ignitability, flame propagation, heat release and smoke release” Sydney, Australia Nov 1999

Van Hees, P, Vandevelde, P, “Mathematical Models for Wind-Aided Flame Spread of Floor Coverings”. Fire Safety Science – Proceedings of the Fifth International Symposium, IAFSS 1997