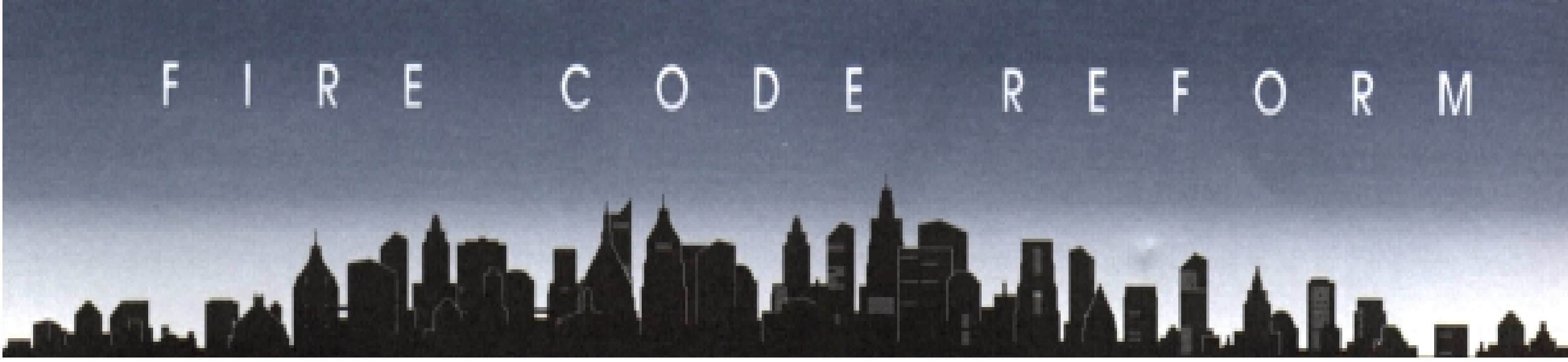

Project Report
FCRC PR 01-01

Investigation of Methods and Protocols for Regulating the Fire Performance of Materials with Applied Fire Retardant Surface Coatings

FCRC Project 2 B-3
FIRE PERFORMANCE OF MATERIALS

Fire Code Research Reform Program
March 2001

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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 Final Report of Stage “B3” of the Project related to fire retardant coatings on materials were prepared by the Building Research Association of New Zealand, Private Bag 50 908, Porirua City, New Zealand, at the conclusion of its work as principal consultant.

Acknowledgements

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Comments

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BRANZ
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BRANZ REPORT

FCR 4

Investigation of Methods and Protocols for Regulating the Fire Performance of Materials with Applied Fire Retardant Surface Coatings

C. A. Wade, S. J. Callaghan,
G. S. Strickland and A. F. Bennett

The work reported here was prepared for and funded by the Fire Code Reform Centre Limited, Australia.

Preface

This is a report on an investigation of test methods and protocols for regulating the fire safety performance of materials intending to meet BCA performance requirements by application of surface coatings and surface treatments.

Acknowledgments

This work was funded by the Fire Code Reform Centre Limited, Australia.

Note

This report is intended for regulatory authorities, fire researchers, scientists, engineers and manufacturers of materials and systems used for internal linings and external claddings.

Investigation of Methods and Protocols for Regulating the Fire Performance of Materials with Applied Fire Retardant Surface Coatings

By C. A. Wade, S. J. Callaghan, G. S. Strickland and A. F. Bennett.

REFERENCE

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ABSTRACT

This study investigated the use of fire-retardant coating systems on wood products and the effects of varying application rates and simulated weathering/ageing by carrying out small scale fire tests to determine their characteristic reaction to fire properties, prior to and following the simulated weathering. Coating-substrate combinations investigated included: a clear intumescent coating system on plywood, an opaque intumescent coating system on plywood, an opaque intumescent coating system on western red cedar, and an ablative fire-retardant coating on a wood fibre insulation board. The effect of three different weathering/ageing procedures were examined on the results obtained in the AS/NZS 3837 (cone calorimeter) test and the AS1530 Part 3 (early fire hazard) test. The durability procedures included exposure in a fluorescent ultra-violet condensation weatherometer to simulate exterior exposure conditions, and exposure to changes in temperature and humidity in a chamber to simulate interior conditions, and a manual washing procedure to simulate periodic cleaning of interior surfaces over the expected life of the coating.

For the interior systems, the fire test results indicated longer ignition times after simulated weathering/ageing. This was mainly attributed to changes in the behaviour of the protective top coat causing it to become less ignitable following weathering, rather than changes in any of the intumescent base coats. This may have been a result of the removal of components from the top coat such as coalescing solvents during initial weathering and/or bound water absorbed by the top coat during weathering. Several methods for classifying the fire growth and flame spread performance based on cone calorimeter results for each system at an irradiance of 50 kW/m^2 were investigated. It was concluded that there is a need to carry out a number of full-scale room/corner fire experiments with fire-retardant coatings on combustible substrates in order to assess the appropriateness of any regulatory classification system. The validity of determining reaction to fire properties on substrates without their intended applied coatings was also questioned. Suggested approaches to durability assessment for fire-retardant coated materials have been recommended.

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1. EXECUTIVE SUMMARY

Summary of Key Conclusions and Recommendations

Fire-retardant coatings should be permitted to be used to enable materials or substrates to meet surface finish reaction to fire properties under the Building Code of Australia provided there is sufficient evidence of the durability and long-term effectiveness of the coating system.

Coatings should not be exempt from meeting reaction to fire properties for surface finishes in the BCA. It has been shown that surface coatings may significantly change reaction to fire properties compared to a bare substrate.

For fire-retardant coatings on exterior claddings, either:

- use a protective top coat with proven durability (e.g. APAS certified), in which case a less demanding and quicker accelerated weathering procedure could be used prior to fire testing. This would permit testing of much larger specimens such as those proposed in the 'Vertical Channel Test'. Any such weathering test needs to include: changes in temperature, humidity and wetting. Further work would be required to evaluate potential test methodologies but options range from simple heat/rain tests such as that specified in AS/NZS 2908.2 (with a much greater number of cycles) to a programmable cyclic chamber test similar to that used for the interior products in this report (with a wider temperature range); or
- prove the durability of the entire coating system by carrying out a detailed assessment (could include evaluation under the Australian Paint Approval Scheme). In any case there will be a need to either use accelerated weathering using a fluorescent ultra-violet condensation or xenon-arc weatherometer or actual field weathering to allow 4-5 years of outdoor exposure to be simulated.

For fire-retardant coatings on interior linings, additional testing is recommended on a wider range of coating types. It has not been conclusively shown that accelerated ageing procedures are required prior to fire testing of interior linings. But since the range of interior coating systems examined in this project is small and in the case of the intumescent systems a protective top coat was always used, it is possible that deterioration in fire properties may occur if the coating systems were more sensitive to moisture effects than the particular coating systems selected for use in this study. If accelerated ageing is found to be appropriate, a simplified and inexpensive procedure such as the washing procedure used in this study may be an effective approach.

Full-scale testing of fire-retardant coatings on a combustible substrate (preferably in the ISO 9705 room (ISO, 1993)) is needed to be able to better evaluate suitability of Kokkala's (or any other) classification method proposed for regulatory control.

The weathering protocols examined in this project were not designed to simulate mechanical damage or physical abuse of the materials and/or coating systems. This aspect can only be effectively dealt with through a process of routine inspection and recoating/repair where necessary.

2. INTRODUCTION

2.1 Background

The Building Code of Australia (ABCB, 1996) states, 'Paint or fire-retardant coatings must not be used in order to make a substrate comply with a required *Spread-of-Flame Index, Smoke-Developed Index or Flammability Index*' (Specification C1.10, paragraph 6). The objective of this project is to investigate the use of fire-retardant coatings and to make recommendations on how and where these materials may be used and how they can be accommodated within the Building Code of Australia whilst also addressing concerns regarding the durability and susceptibility to damage of such coatings. Testing protocols for fire-retardant coatings were investigated for the correct and effective use of such coatings for both interior and exterior applications.

2.2 Objectives

The objectives of this research project included:

- A literature review of the role and performance of fire-retardant coatings and review of any case studies from domestic and international fire records.

- A review of research (industry/academic/government) and testing relating to the fire performance of fire-retardant coatings and the identification of potential test methods used for regulatory purposes.

- Identification and review of the current regulations relating to the use of fire-retardant coatings in the Building Code of Australia.

- Investigating the relationship of performance of fire-retardant coatings to anticipated variations in the quality of their application, the effects of durability, and the ignition and fire spread scenarios, and areas of end-use application that are or may be regulated by the Building Code of Australia. These considerations are to include both interior and exterior applications.

- A review of candidate test methods for accelerated weathering and durability assessment of fire-retardant coatings.

- The development of a suggested protocol for preparation of samples including a range of quality of coating application from 'as per manufacturer's instructions' to a reasonable worse case situation (i.e. lesser quality/thickness of application).

- Evaluation of the flammability performance of a representative group of combustible substrates and coatings of varying quality of application.

2.3 Scope of this Report

2.3.1 Coatings

This report includes an experimental investigation of the weathering and fire performance testing of two types of fire-retardant coating: organic-based intumescent coatings and a non-flammable ablative coating. Three varieties of intumescent coating systems were investigated; an interior opaque intumescent, an exterior opaque intumescent and an interior clear varnish intumescent. The ablative coating investigated is a commercially available ablative coating that comes factory-applied to a cellulose based fibre insulation board.

Passive insulative coatings, epoxy-based clear varnish intumescent coatings and silicate-based intumescent coatings, although also sometimes used, are not specifically considered in this report due to cost, durability or usage reasons (Bhatnagar and Vergaud, 1981/82; McDonald, 1987; and Bulewicz, Pelc, Kozlowski and Miciukiewicz, 1985). Insulative coatings are cheap but are generally non-decorative, non-durable and require a thicker layer of coating in order to achieve the required fire protection. Examples of these types of coatings are cementitious products which are suited more to the fire protection of structural steel. Sodium silicate can act as an effective foaming agent and has uses in door and window seals. However, as a coating it is susceptible to leaching due to its high solubility and is also prone to carbon dioxide attack. Epoxy-based intumescent coatings are highly durable for interior use but tend to be expensive and usually require the mixing of two different ingredients and hence are more difficult to handle.

Fire retardants applied to timber using pressure-impregnated processes and the use of fire protective coatings to alter the fire resistance properties of a substrate material or component are outside the scope of this project.

2.3.2 Substrates

The substrates selected for use in the experimental work are timber-based products. They are commonly used combustible building materials to which fire-retardant coatings are most likely to be applied. The three products used in the experimental investigation are radiata pine plywood (interior use), western red cedar (exterior use) and a fire retardant coated (factory-applied) cellulose fibre insulation board. Both the plywood and western red cedar products, untreated, have slightly higher values for spread-of-flame index (8 and 10 respectively) and smoke-developed index (3 and 4 respectively) when compared to other timbers tested to AS 1530.3 (Gardner and Thomson, 1987). The outcomes of the experimental program are expected to be representative of other similar substrates and coating systems.

2.3.3 Combustion of wood

Wood is a complex material built up from a mixture of natural polymers. It is non-homogeneous and its properties vary depending on the direction, relative to the grain, in which it is measured. Wood is essentially comprised of three polymers; cellulose (~50%), hemicellulose (~25%) and lignin (~25%). Wood also contains a small amount of polymers known as extractives. All the polymers and extractives in wood combust or degrade at different temperatures. Wood generally discolours and chars above 200-250°C but prolonged heating at 120°C has the same effect. The physical structure of wood breaks down rapidly at 300°C and above. Burning of wood is a complex process and described in some depth in the literature (Drysdale, 1998). Fire protection of wood occurs by either coating the wood with a material which reduces the temperature at the wood surface during a fire or by altering the wood structure causing it to decompose or degrade at higher temperatures.

3. FIRE-RETARDANT COATING SYSTEMS – OVERVIEW

Fire-retardant coating systems can be divided into two main categories: non-flammable ablative coating and insulative coating systems. Both types of coating systems, unlike many impregnated fire retardant systems, do not affect inherent substrate timber panel strength, nor do they degrade the inherent service life or reliability of the substrate (US patent 5,968,669, 1999).

Non-flammable ablative coating systems usually consist of metal oxides and halogen chemical additives contained in a paint matrix. This system relies on the chemicals reacting with the paint matrix to produce a char layer to protect the substrate. This coating system also relies on the formation of chemicals, which in the vapour phase are able to inhibit some flame reactions (Kirk-Othmer, 1993). However, while non-flammable ablative coating systems do not contribute fuel or promote burning, they can only provide limited protection of the substrate. Once subjected to a direct flame the coating provides little insulation of the substrate. In the case of wood, once the substrate reaches a certain temperature, volatile gases are released and ignition occurs, irrespective of the integrity of the coating. Therefore, thin layer ablative coatings, irrespective of spread of flame properties, tend to have poor ignition resistance.

Insulative coating systems can be further divided into two types: passive insulative and chemically reactive intumescent coating systems. Passive insulative coating systems usually contain some non-flammable mineral additive such as mica or perlite. Chemically reactive intumescent systems contain a specific set of chemicals, which on exposure to high temperatures react in such a way as to produce a foamed insulating layer protecting the substrate.

Intumescent coating systems have been stated to be among the most effective means for protecting a combustible substrate from the temperatures in a fire (Wladyka-Pryzbylak and Kozlwoski, 1999; Lloyd-Lucas, 1989 and Bhatnagar and Vergaud, 1981/82). The foamed char layer formed by intumescents performs two main functions, firstly it creates an inert physical barrier, which inhibits oxygen, a necessary ingredient for combustion, from permeating through to the surface. It also creates a thermal barrier that insulates the substrate from excessive temperatures (Wladyka-Pryzbylak and Kozlwoski, 1999). The combination of these effects inhibits combustion, by preventing the substrate from burning also hindering flame spread.

4. DURABILITY OF FIRE-RETARDANT COATINGS

4.1 Chemistry

4.1.1 General

In order to understand how fire-retardant coating systems are likely to behave in the long term, it is essential that the chemistry, and the likely effect the applied environment may have on this chemistry, be understood. This is extremely important when considering the effects of both outdoor weathering and indoor durability studies for intumescent paint systems. Coatings subjected to outdoor exposure are subjected to temperature, moisture and UV light fluctuations whereas coatings used indoors are subjected mainly to humidity variations and chemical attack from cleaning agents. Most of the previous research on coating systems that rely on chemically reactive systems has been based on optimising the paint and fire protection properties, with the long-term durability effects either not addressed or the use of these paints restricted to avoid this issue.

Clear intumescent fire retardant basecoats contain little or no pigment but contain resins which are water soluble. Opaque intumescent fire retardant base coats which provide the protection are often highly filled or pigmented. Highly filled or pigmented coatings contain a higher amount of pigment or filler compared to the resin binder. Fire retardant paint coatings can fail for a number of reasons, but provided the coatings are applied correctly the main reason for failure is the leakage or loss of components from the fire retardant base coat.

Generally paints have a pigment volume concentration (PVC) of 20-40% (see Figure 1) whereas fire retardant paints have a much higher pigment volume concentration (50-70%) because of high loadings of fire retardant additives. Paints with higher PVC produce coatings which are chalky, porous, less ductile and less durable. Because in fire retardant paints it is the fire retardant additives which provides fire resistance, there must be a compromise between durability and fire resistance.

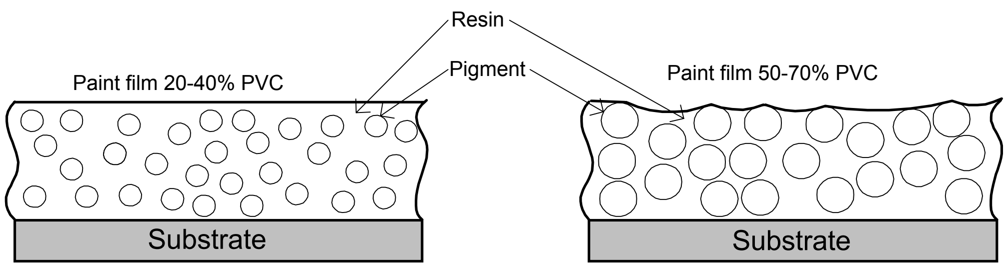

Figure 1: Representation of Paint Films with Low and High PVC Content

The most effective way to protect a fire-retardant coating against weathering is by using a durable top seal. The topcoat or seal protects the fire retardant base coat from moisture, abrasion and damage. The selection of the top coat for a fire retardant system is of great importance. It not only protects the fire retardant base coat but can also strongly affect the fire performance of the complete system. The top coat may be easily ignited and contribute additional fuel to the detriment of the surface flame-spread properties. All the intumescent coating systems investigated in this study included a top coat.

4.1.2 Chemistry of the Coating Systems Investigated

Intumescent Coatings

A typical intumescent paint contains a minimum of three active chemical ingredients: a phosphorous-based mineral catalyst; a carbon source, and a blowing agent that releases non-combustible gases (Vandersall, 1971; Rhys, 1980). These ingredients are normally incorporated in a paint matrix containing resinous binders combined with a variety of other paint additives. These other additives are necessary to provide the general coating properties of a standard paint.

Traditionally, there have been three types of organic-based intumescent fire-retardant coating systems commercially available. These are ones that are based on water-soluble mono-ammonium phosphate (MAP), relatively water-insoluble ammonium polyphosphate or on melamine phosphate. However, MAP is extremely water soluble and reacts with other pigments and paint resin polymers which results in a coating with poor paint properties in terms of rheology and stability. The relatively water-insoluble ammonium polyphosphate and melamine phosphate intumescent systems comprise the two major types of organic intumescent coatings commercially available (Vandersall, 1971). Despite improvements in the chemical properties of intumescent coatings, most commercially available organic-based intumescents still rely on having a phosphate as the catalyst. Moreover, despite the variation in the phosphate species, the three phosphate systems above all rely on the same specific chemical reaction system in order to provide the protective insulative foamed char barrier.

The commercial melamine phosphate paint systems are organic, oil-based formulations. These paints are able to provide good adhesion, improved water-resistance and also good intumescing properties. However, they do not provide good paint properties such as brushing and flow usually expected of a typical paint. Furthermore, these paints also contain organic solvents and have a high VOC (volatile organic content) which detracts from the fire performance of the dry coating as the small amount of solvent remaining contributes to the fuel in a fire situation (Vandersall, 1971).

The most recent intumescent paint formulations are based upon water-borne paint resins like latexes. The more insoluble intumescent fillers are often selected for coatings or are microencapsulated where each pigment is surrounded by water insoluble polymers. Ablative additives are also added to these intumescent paints to improve the fire resisting properties of the char.

Non-Flammable Ablative Coatings

Non-flammable ablative coating systems usually contain antimony oxide in a highly chlorinated or other halogenated matrix. Fire retardancy in this case generally results from antimony halide species, formed at high temperatures, operating in both the condensed and vapour phases (Kirk-Othmer, 1993). In the condensed phase, a char is formed because the polymer, antimony oxide and halogen compounds are able to reduce the decomposition rate of the polymer matrix, which in turn hinders the direct exposure of the substrate (Kirk-Othmer, 1993). In the vapour phase antimony trihalide compounds are able to inhibit some radical flame reactions. This is thought to occur through a series of chemical reactions that progressively decompose the metal trihalide and form halogen radicals, which are able to suppress radical flame reactions (Bhatnagar, Varshney and Mohanty, 1993 and LeVan, 1984). However, while non-flammable ablative coating systems of this type do not contribute fuel or promote burning, they can only provide limited protection of the substrate from the flame front aided by the formation of halogen radicals. Prolonged exposure to a flame will cause the substrate to heat up and in the case of wood, release volatile gases which may then ignite.

One shortfall of these systems is that they usually require the paint to be highly filled with additives to ensure a reasonable degree of flame retardancy (Kirk-Othmer, 1993). As such, the ratio of ablative retardant chemicals to paint resins and pigments involved tend to make these paints viscous, chalky and non-durable.

4.1.3 Water Resistance

One of the most important areas relating to the long-term durability of intumescent coatings is the ability of intumescent coatings to resist exposure to high humidity and/or washing (Vandersall, 1971; Saxena and Gupta, 1990 and Rhys, 1980). This is a serious issue as the water solubility of some of the active chemical species means they can be leached out over time with washing or fluctuating humidity. Furthermore, this type of deterioration is concealed, and is not likely to be realised until the protection of the intumescent is needed (Lloyd-Lucas, 1989). Not surprisingly, this issue was stated to be one reason why the durability section of BS 8202 Part 2 (BSI, 1992; Lloyd-Lucas, 1989), which covers coatings for fire protection of building elements, was necessary. Hence investigating the durability of intumescent coatings, with respect to moisture sensitivity, is an absolute necessity when it comes to assessing the long-term effectiveness of such coatings. As a corollary to this, some performance limit should be placed on the minimum acceptable fire protection provided by these coatings.

Articles (Alexiou and Gardner, 1986; Saxena and Gupta, 1990; and McDonald, 1987) have suggested overcoating the intumescent with a more water resistant acrylic finishing layer. From testing carried out, the acrylic finishing layer had the effect of providing more water resistance when subjected to water-leaching and water absorption tests. However, it also had the side effect of contributing fuel to the fire. So while reducing the performance of the intumescent system alone, the intumescent/acrylic combination still improved the results for the BS476 Part 7 test (BSI, 1987) compared to a bare wooden substrate. The time to ignition was reduced, but was still longer than a bare wooden substrate. This coating combination approach may certainly have its merits for use of an intumescent outside where the long-term durability of acrylic and poor water resistant properties of intumescent coatings are well known. This approach to external uses may also mean that the intumescent undercoat/acrylic topcoat coating system may prove adequate for fire protection purposes, if well maintained and the coating system was fully reapplied every 5-8 years. However, the application of additional coats of intumescent base coats and/or top coats over previously applied coatings is likely to have a detrimental effect in terms of ignition and flame-spread properties.

4.1.4 Ultra-Violet Radiation

The effects of ultra-violet radiation on paints and coatings is a crucial consideration in Australia and New Zealand as the intensity of the ultra-violet radiation is significantly more severe in the southern hemisphere compared to an equivalent position in the northern hemisphere (McKenzie and Bodeker, 2000). It was calculated that there is a 15% increase in ultra-violet radiation due to the southern hemisphere being closer to the sun during a southern hemisphere summer than an equivalent northern hemisphere position is during a northern hemisphere summer. This, combined with the generally smaller amount of atmospheric pollutants in the atmosphere above Australia and New Zealand compared to Europe, means that there can be as much as a 50% increase in the intensity of ultra-violet radiation experienced in Australia and New Zealand. The intensity varies with latitude and season. Differences between northern and southern latitudes in Australia will be greatest in the winter months. When simulating real-life UV levels in accelerated weathering devices, careful selection of the lamp which emits the UV radiation is necessary to ensure that the most realistic weathering results are obtained.

Like any organic-based coating, fire retardant paint systems will be susceptible to the damaging effects of the ultra-violet radiation. In general terms, the energy contained in wavelengths in the ultra-violet spectrum are large enough to initiate oxidative scission, cross-linking and modification reactions in organic species (Brydson, 1995; Davis and Sims, 1983). With respect to the intumescent and ablative coating systems, the organic paint binder and perhaps some of the active retardant chemicals will be susceptible to all three types of photochemical degradation reactions. This will result in the breakdown of the polymer matrix that binds the active chemicals and may affect the chemistry of the intumescing and retardant chemicals. The breakdown of the polymer matrix will cause erosion and chalking which will then lead to a reduction in film thickness over time. Also the breakdown of the polymer matrix will cause the paint to become more porous, which will assist the leaching of water-soluble chemicals necessary for intumescence and induce the further loss of additives especially in the heavily filled ablative paints. It will also lead to the depletion of other additives such as ultra-violet stabilisers, antioxidants and pigments, which will in turn decrease the resistance of the paint to further exposure to ultra-violet radiation.

Physically, the loss of additives will cause the paint to recede and it may become more brittle and hence more susceptible to any movement in the substrate (see section 4.3). Furthermore, any cracking that develops in the paint coating will result in the indirect exposure of the substrate and hence will negate the protective ability of any fire protective coatings. Hence, it is essential that exposure to ultra-violet radiation is addressed when assessing the long-term durability of fire-retardant coatings for exterior applications.

4.1.5 Temperature

In order for intumescence to occur, the set of consecutive chemical reactions must occur in the appropriate order. First the phosphorous-based compounds must decompose to yield the dehydrating acid, which must then go on to react with the carbon source. Next the carbon source must simultaneously begin to char with the evolution of gas from the blowing agent. As with all chemical reactions, the temperature at which this reaction sequence occurs is extremely important. Hence, aside from the long-term water resistance issues, the effectiveness of the intumescent coating, in both the long and short term, is also heavily dependent on temperature.

Vandersall in 1971 summarised a study by Taulli (unpublished results) that compared three paint formulations with different phosphorus-based compounds and found that the decomposition (burning) temperature was dependent on the paint formulation. However, as the decomposition temperatures of the formulations studied were all over 150^{o}C, this is unlikely to be a concern for long-term durability. However, the long-term stability of intumescent paints with respect to fluctuating temperature, prior to application, has been questioned in the past (Rhys, 1980) but this is unlikely to have any effect on the intumescent properties of the coating provided the maximum temperatures are kept in normal operating limits (eg. typically no more than 85°C for exterior paints). Physical damage to the fire-retardant coatings in the form of cracking and loss of adhesion is more likely to occur due to movement of a wood substrate at fluctuating temperatures. Furthermore, it is also possible that paint resins themselves may be susceptible to thermal oxidation (for example alkyd resins) once applied to a substrate.

Similarly, for ablative fire-retardant coatings to work, they also rely on a set of temperature-dependent chemical reactions to form a char and volatiles. Although no studies regarding this topic have been found to date, it is expected that fluctuating temperatures may have a similar long-term effect on the durability of some paint matrix types which house the ablative chemicals.

In addition, the final colour of the topcoat directly affects the surface temperature so that surfaces that are dark and opaque absorb more thermal radiation than surfaces that are white and opaque. Hence, inclusion of testing regimes that contain fluctuating temperatures is worthy of consideration and the colour of the topcoat worthy of note in any testing regime.

4.2 Coating Thickness

Not surprisingly the degree of fire protection afforded a substrate by a fire-retardant coating is dependent on the coating thickness and amount of active ingredients in the paint (Sarvaranta, 1996; White, 1983; McDonald, 1987). This requirement is potentially hard to control given the poor brushing properties and differing viscosity of intumescent paints compared to normal house paints. This was observed during the preparation of specimens used in this project.

In practice, erosion over time, due to exterior weathering, also limits the performance of fire-retardant coatings (Sarvaranta, 1996). This aspect cannot easily be incorporated into artificial weathering over short time frames. Further, any loss of pigment from a coating system may not be obvious to detect as it may not alter the coating thickness substantially or its appearance. However, any visible discoloration or indication of pigment leaching from the coating should be noted as this may indicate that some erosion has taken place. This gives further weight for setting a minimum performance level for fire-retardant coatings used on the exterior of a building. A further consideration regarding this aspect is the performance of additional coatings of a fire retardant applied to a substrate with an already weathered coating (see also section 4.3).

4.3 Timber Substrate

Unlike substrates such as concrete, metal and plasterboards, wood is a relatively unstable substrate for coatings. Dimensional changes with moisture content vary considerably with species and the way the timber is sawn. Extractives and resins in timber can affect the adhesion of coatings to timber. As noted (Bennett, 1996) if a coating is applied over a wooden substrate that has surface cracking, then the subsequent movement in the timber, due to thermal/moisture cycling can stress the coating and effect rapid deterioration. Furthermore, Bennett (1996) noted that the surface of timber deteriorates rapidly with outdoor exposure if left uncoated and that this can significantly reduce the adhesion of coatings.

This means that the surface condition, period of exposure, and moisture content of timber needs to be taken into account when considering the likely performance of the coating before applying it to timber. For this report, the condition of the simulated wooden exterior cladding will represent an ideal situation in which the board will be conditioned at a known humidity and temperature and also be prepared in a covered environment.

4.4 Other Considerations

In general terms, other properties considered necessary for fire protective coatings include flexibility, adhesion, cleanability, scrub, stain and solvent resistance, hardness, gloss and colour (Scriven, Chang and Ross, 1994). Furthermore, when applying any cladding or other material that may require fire protection to a building, one must be satisfied with the suitability of the environment to which that feature is being subjected. Also, with any coating system it is advisable that the substrate movement and moisture content is taken into account before the coating is applied (Day, 1989).

Specifically relating to interior use, it is also advisable that the relative humidity and temperature conditions at the time of application are noted. Regarding the factors listed above (Scriven, Chang and Ross, 1994), the resistance of coatings to cleaning solutions, scrubbing and staining are important with respect to durability issues concerning interior uses.

In the case of exterior use, it is advisable that the conditions at the time of application are noted (relative humidity, temperature and sunlight conditions). Also durability issues listed above including flexibility, adhesion, solvent resistance, hardness, impact resistance, abrasion, gloss and colour are important but not always quantifiable influences on service life.

However, this report and the test protocol recommended can only attempt to address quantifiable durability issues regarding long-term weathering/ageing effects on the performance of fire-retardant coatings. Hence, it is good practice to ensure that the considerations mentioned above are taken into account when applying these coatings in practice.

4.5 Previous Durability Testing Regimes

Despite the acknowledged shortcomings of fire-retardant coating systems, it was not until recently that the performance evaluation of these coatings over time (or establishing some long-term performance criteria) has been considered.

As mentioned previously, some attempt was made to consider or provide a solution for the long-term effects of moisture on intumescent coatings. Alexiou and Gardner, 1986 and Saxena and Gupta, 1990 considered the performance of intumescent coatings on wooden substrates that had a layer of an exterior acrylic paint applied over the intumescent paint in order to assist the durability of intumescent coatings exposed in exterior or high humidity environments. Alexiou and Gardner investigated the ability of the intumescent coatings to ensure adequate protection of a wooden substrate. They found that even though the intumescent coating was still able to provide some fire protection, the performance was much poorer than if the intumescent coating provided the finishing layer. Saxena and Gupta investigated the protection that the acrylic topcoat would provide against the effects of moisture leaching out the active ingredients in the intumescent coating. They found that the acrylic topcoat did provide a greater degree of protection from moisture in both leaching and moisture absorption tests.

Section 8 in BS 8202 Part 2 Coatings for fire protection of building elements (BSI, 1992) was developed to address the performance of intumescent coatings on metal substrates and in particular contains a durability section (section 8) to address the effect of weathering conditions including the well known poor water resistance properties of intumescent coatings. As a performance criterion, this standard states that weathered specimens should have a fire resistance time within 25% of the fire resistance time of an unweathered specimen. This section also supplies a testing matrix for metal substrates in both interior and exterior environments and makes some provision for coated metal substrates in special environments. Table 1 summarises the durability test programme listed in this standard for substrates exposed to interior and exterior environments. Although this durability regime does not specifically address the durability issues for all fire protective coatings and is written with steel substrates in mind, most of the general principles of this section are applicable generally to the durability of fire-retardant coatings.

4.6 Recommended Weathering/Ageing

In order to develop a test protocol, the intended environment needs to be assessed for potential factors that may have an adverse effect on the long-term durability of fire-retardant coatings. Accordingly the factors considered for interior and exterior environments are substantially different, and as such the artificial weathering/ageing regimes are detailed separately in sections 4.6.1 and 4.6.2 below. It should be noted that all weathering and test regimes assume that the fire-retardant coatings are applied as per manufacturer's recommendations.

4.6.1 Interior

The factors most likely to have a significant effect on the long-term durability of fire-retardant coatings exposed to an interior environment are humidity and temperature fluctuations. Exposure to ultra-violet radiation is not considered to have a substantial effect as it is well known that glass absorbs almost all UV-B and most of UV-A. Any residual exposure to ultra-violet radiation is unlikely to be a determinant effect when considering the long-term durability of these coatings. A proposed interior accelerated ageing regime is suggested in Table 2.

Table 1: Summary of BS8202: Part 2:1992 Durability Test Programme

Exposure	**External**	**Internal**
Description	Fully exposed to weather, including ultra-violet light, temperature cycles, wind-driven rain, salt spray	Not exposed to weather but subject to temperature and humidity variation
Heat Exposure Test 6 months exposure at 50°C± 2 °C in a controlled environment	✓Yes	✓Yes
Washing Test 20 cycles, each cycle consisting of thoroughly wetting the sample with a 2.5% (m/m) solution of powdered soap and water and leaving to air dry without rinsing	✓Yes	✓Yes
Freeze-Thaw Test Cycle consisting of 24 h at 20°C followed by 24h at +20°C	✓Yes, 10 cycles	✓Yes, 5 cycles
Humidity Test In accordance with BS 3900:Part F2:1973	✓Yes, 1000 hours	✓Yes, 250 hours
Weatherometer Test In accordance with BS 3900:Part F3:1973 using an I-beam	✓Yes, 2000 hours	× Not applicable
Salt Spray Test In accordance with BS 3900:Part F4:1968	✓Yes, 2000 hours	× Not applicable
Natural Exposure Test a) in an industrial environment b) in a marine environment	✓Yes, 2 years min	× Not applicable

Table 2: Proposed Weathering Regime (Interior)

Task	Test Conditions	Time
Sample Preparation In accordance with AS 1580.101.1 Air Drying Conditions – Paints and Related Materials; ASTM G147-96 Conditioning and Handling of Non-metallic Materials	Temperature, T 23± 2°C Relative Humidity, RH 50±5%	As per manufacturer's instructions
Dry Film Thickness[1] Using an ultrasonic measuring device based on AS 2331.1.4:1994 and ASTM D1400-94	(for measuring thickness) Temperature 23± 2°C Relative Humidity 50±5%	n/a[2]
Cyclic Humidity/Temperature Testing Adapted from AS 1580.452.1-1992 Resistance to Humidity – Paints and Related Materials and BS 3900: Part F2:1973 Determination of Resistance to Humidity under condensation conditions	Cycle: 6 hours 95% RH 30°C 6 hours 67% RH 15°C	250 cycles

[1]It should be noted that the same measuring protocols from these standards are used although the standards mentioned specifically relate to using magnetic-based equipment for measuring dry film thickness where either or both the substrate or the coating contains metal.

[2] not applicable

The interior weathering regime proposed in Table 2 was devised based on the information supplied in the preceding sections. The sample preparation and weathering regime is based on the following relevant standards:

British Standard:

BS 3900 Part F2: Determination of resistance to humidity (cyclic condensation) (BSI, 1973).

Australian/New Zealand Standards:

AS/NZS 1580.101.1 Methods of test for paints and related materials: air drying conditions (SA, 1986).

AS/NZS 1580.452.1 Methods of test for paints and related materials: resistance to humidity under condensation conditions (SA, 1992).

AS/NZS 2331.1.4 Methods of Test for Metallic and Related Coatings – Local Thickness Tests (SA, 1982).

American Standards:

ASTM G147-96 Standard Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests (ASTM, 1996a).

ASTM D1400-94 Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base (ASTM, 1994).

Table 3: Proposed Weathering Regime (Exterior)

Task	Test Conditions	Time
Sample Preparation In accordance with AS 1580.101.1 Air Drying Conditions – Paints and Related Materials; ASTM G147-96 Conditioning and Handling of Non-metallic Materials	Temperature, T 23 ± 2^{o}C Relative Humidity, RH 50 ± 5%	As per paint manufacturer's instructions
Dry Film Thickness[1] Using an ultrasonic measuring device based on AS 2331.1.4 and ASTM D1400-94	(for measuring thickness) Temperature, T 23 ± 2^{o}C Relative Humidity 50 ± 5%	n/a[2]
Weatherometer Testing[3] In accordance with AS 1580.483.2 – Resistance to Artificial Weathering – Paints and Related Materials, ASTM G53 - 96 Standard Practice Operating UV-Condensation Apparatus and adapted from ASTM D4587 –91 Conducting Tests of Paint and Related Coatings using a UV-Condensation Apparatus	Cycle: 8 hours UV-light on, T 60± 5^{o}C 4hours UV-light off, T 50± 5^{o}C (UVA fluorescent lamps)	2000 hours

[1]It should be noted that the same measuring protocols from these standards are used although the standards mentioned specifically relate to using magnetic-based equipment for measuring dry film thickness where either or both the substrate or the coating contains metal.

[2] not applicable

[3] It should also be noted that 2000 hours weathering in a QUV Weatherometer is only likely to give indicative results for Australasian climates (see section 4.1.4).

4.6.2 Exterior

The factors most likely to have a significant effect on the long-term durability of fire-retardant coatings in an exterior environment are exposure to ultra-violet radiation, varying humidity, the washing effect of rain and temperature fluctuations. These factors can all be represented to a varying extent by ageing the test samples in a fluorescent UV-condensation weatherometer (referred to as a QUV weatherometer in this study). However, it should be noted more effective weathering can be achieved in a relatively more sophisticated xenon-arc weatherometer which mimics natural sunlight more accurately and incorporates a washing cycle that is better able to wash the sample surface of degraded compounds that may occlude further ageing. The fluorescent UV-condensation weatherometer was used in this study. A proposed exterior accelerated ageing regime is given in Table 3.

The above exterior weathering regime, detailed in Table 3, was devised based on the information supplied in the preceding sections. The sample preparation and weathering regime is based on the following relevant standards:

British Standard:

BS 3900-Part F2 Coatings for Fire Protection of Building Elements (BSI, 1973).

Australian/New Zealand Standards:

AS/NZS 1580.101.1 Methods of Test for Paints and Related Materials: Air Drying Conditions (SA, 1986).

AS/NZS 1580.483.2 Methods of Test for Paints and Related Materials: Method 483.2: Resistance to Artificial Weathering – Fluorescent UV-condensation Type Instruments (SA, 1992).

AS/NZS 2331.1.4 Methods of Test for Metallic and Related Coatings – Local Thickness Tests (SA, 1982).

American Standards:

ASTM G147-96 Standard Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests (ASTM, 1996a).

ASTM D1400-94 Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base (ASTM, 1994).

ASTM G53-96 Standard Practice for Operating Light- and Water-Exposure Apparatus (Fluorescent UV-Condensation Type) for Exposure of Nonmetallic Materials (ASTM, 1996b).

ASTM D4587-91 Standard Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus (ASTM, 1991).

5. HISTORICAL FIRE RECORD

5.1 Fire Brigade Statistics

The Fire Code Reform Centre (FCRC, 1996) concluded that Australian Fire Incident Reporting (AFIRS) data provided only sufficient information to differentiate between combustible and non-combustible wall and ceiling linings. The use of fire-retardant coatings over combustible linings firstly, is not permitted under the BCA to satisfy regulatory requirements and therefore would not be expected to show up in Australian incident reporting data. Secondly, even if the use of fire-retardant coatings was currently common, it would only be a small fraction of lining materials and therefore would still be unlikely to be able to be differentiated in the incident reporting data. Also the collection of fire incident statistics is not sophisticated enough that the use of fire-retardant coatings would be noted by Fire Brigade personnel.

Examining the standard classifications for incident reporting in NFPA 701 (NFPA, 1995), there is a category for 'finish on substrate or solid supporting material' that allows for paint and stain to be identified, but a more detailed subdivision to allow for fire-retardant coatings is not provided; and most likely would not be warranted as the expertise required to identify such coatings would be normally beyond the expertise held by those carrying out the assessment.

Therefore historical fire incident statistics are unable to provide any useful information on the performance or effectiveness of fire-retardant coatings involved in real fire incidents.

6. REVIEW OF BUILDING REGULATIONS

6.1 Building Code of Australia 1996

The Building Code of Australia (ABCB, 1996) is a performance-based building code comprising objectives, functional statements, performance requirements, deemed to satisfy provisions and verification methods. Those identified here are considered to be directly relevant to situations affecting fire properties of internal linings and external claddings.

6.1.1 Performance Requirements

Objectives relevant to the fire spread properties of interior and external surfaces are:

CO1 The objective of this Section is to –
(a) safeguard people from illness or injury due to a fire in a building; and
(b) safeguard occupants from illness or injury while evacuating a building during fire; and
(c) facilitate the activities of emergency services personnel; and
(d) avoid the spread of fire between buildings; and
(e) protect other property from physical damage caused by structural failure of a building as a result of fire.

Functional Statements relevant to the fire spread properties of interior and external surfaces are:

CF2 A building is to be provided with safeguards to prevent fire spread –
(a) so that occupants have time to evacuate safely without being overcome by the effects of fire; and
(b) to allow for *fire brigade* intervention; and
(c) to *sole-occupancy units* providing sleeping accommodation; and
(d) to adjoining *fire compartments;* and
(e) between buildings.

Performance Requirements relevant to the fire spread properties of interior and external surfaces are:

CP2 A building must have elements which will, to the degree necessary, avoid the spread of fire –
(a) to exits; and
(b) to sole-occupancy units and public corridors; and
(c) between buildings; and
(d) in a building, appropriate to –
    (i) the function or use of the building; and
    (ii) the fire load; and
    (iii) the potential fire intensity; and
    (iv) the fire hazard; and
    (v) fire brigade intervention; and
    (vi) other elements they support; and
    (vii) the evacuation time.

CP3 A patient care area of a Class 9a building must be protected from the spread of fire and smoke to allow sufficient time for the orderly evacuation of the building in an emergency.

CP4 A material and an assembly must, to the degree necessary, resist the spread of fire to limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to –
(a) the *evacuation time*; and
(b) the number, mobility, and other characteristics of the occupants; and
(c) the function or use of the building; and
(d) any active *fire safety systems* installed in the building.

6.1.2 Deemed to Satisfy Provisions

All building materials and assemblies in Class 2 to 9 buildings are required to comply with BCA Specification C1.10 (fire hazard properties). The general requirements given in Specification C1.10 Clause 2 are applicable as follows.

Except where superseded by Clause 3 or 4, any material or component used in a Class 2, 3, 5, 6, 7, 8, or 9 building must –

(a) in the case of a *sarking-type material*, have a *Flammability Index* not more than 5; or

(b) in the case of other materials, have –

    (i) a *Spread-of-Flame Index* not more than 9; and

    (ii) a *Smoke-Developed Index* not more than 8 if the *Spread-of-Flame Index* is more than 5; or

(c) be completely covered on all faces by concrete or masonry not less than 50 mm thick; or

(d) *(special requirements for composite member or assemblies*)

BCA Specification A2.4 requires the smoke-developed and spread-of-flame indices to be determined in accordance with AS 1530.3.

BCA Specification C1.1 contains requirements for the fire-resisting construction of building elements. Specification C1.1 Clause 2.4 (a) gives requirements for attachments to fire rated walls not to impair fire resistance. This would also apply to any type of construction (A, B, C).

a. A combustible material may be used as a finish or lining to a wall … which has the required FRL if –

   (i) the material is exempted under Clause 7 of Specification C1.10 or complies with the Early Fire Hazard Indices prescribed in Clause 2 of Specification C1.10; and

   (ii) it is not located near or directly above a required exit so as to make the exit unusable in a fire; and

   (iii) it does not otherwise constitute an undue risk of fire spread via the façade of the building

b. The attachment of a facing or finish, … , to part of a building required to have an FRL must not impair the required FRL of that part.

Paragraph 6 of Specification C1.10 requires that fire-retardant coatings are not to be used to make a substrate comply with the required AS 1530 Part 2 or Part 3 indices. This is due to a concern that the coatings are susceptible to damage. There is an exception in New South Wales where special provisions apply regarding certification of coatings in respect of products covered by BCA Specification C1.10 4d (New South Wales BCA Appendix). This variation refers to materials in a Class 9b building used as a theatre or public hall and where it is used in any part of fixed seating in the audience area or auditorium.

Note that these provisions do not apply to materials where fire retardancy is achieved through a pressure impregnation process rather than application of a surface treatment or coating. Therefore, it is currently acceptable for pressure-impregnated fire retardant timber to be tested to AS 1530.3 without any further assessment of durability of the fire retardant.

Paragraph 7 of Specification C1.10 exempts paint, varnish, lacquer or similar finishes from requirements for spread-of-flame, smoke-developed or flammability indices. This means that fire testing of substrate material only would normally be carried out where the final intended surface finish comprises a site-applied coating. This exemption is significant and is discussed later in this report in relation to protective top coats of fire-retardant coatings.

6.2 Finland

Internal surface finish requirements depend on the fire class for the building (similar to a type of construction classification). Walls and ceiling fire performance may need to be:

- non-combustible according to ISO 1182 (1990).

- ignitability class, 1 (best), 2 or no requirement according to NT FIRE 002 (Nordtest, 1985a) or NT FIRE 033 (Nordtest, 1986).

- fire-spreading class, I (best), II or no requirement according to NT FIRE 004 (Nordtest, 1985b).

Fire-retardant treated wood (including use of fire-retardant coatings) can be class 1/I and therefore can be widely used to meet requirements in the National Building Code of Finland, Part E1, fire safety of buildings (Ministry of the Environment, 1997). The first value refers to the ignitability class while the second refers to the fire-spreading class. Non-treated wood would mainly be classified for use in class 2/-.

6.3 United Kingdom

Reference was made to the Approved Document B Fire Safety 2000 Edition (DoETR, 2000).

Linings are required to meet certain classifications (Class 0, Class 1 or Class 3) depending on their location in a building. The classifications are based on tests in BS476 Part 6 and Part 7. However Parts 4 and 11 (noncombustible/limited combustibility) can also be used to achieve a Class 0 classification.

Typical Class 0 materials include any non-combustible materials or those of limited combustibility, brickwork, block work, concrete and ceramic tiles, plasterboard, woodwool cement slabs and mineral fibre tiles or sheets with cement or resin binding.

Typical Class 1 materials include phenolic or melamine laminates on a calcium silicate substrate and flame retardant decorative laminates on a combustible substrate.

Class 3 materials typically include timber or plywood with a density of more than 400 kg/m^3, painted or unpainted, particleboard, hardboard and standard glass fibre reinforced polyesters.

Class 3 timber products may be brought up to Class 1 with appropriate proprietary treatments (including impregnated treatments or surface coatings).

Therefore, it is acceptable in the United Kingdom to use applied coatings to improve the fire properties of a substrate lining material without a durability assessment of the coating.

BS 8202 (Code of practice for the use of intumescent coating systems to metallic substrates for providing fire resistance) is not listed in standards referenced by Approved Document B (DoETR, 2000).

6.4 Canada

In the National Building Code of Canada (NRCC, 1995), 'fire retardant treated wood' is a defined term and means wood or wood product that has had its surface-burning characteristics, such as flame spread, rate of fuel contribution and density of smoke developed, reduced by treatment with fire-retardant chemicals.

Flame spread ratings and smoke developed classifications for walls and ceilings are determined according to CAN/ULC-S102-M Test for Surface Burning Characteristics of Building Materials and Assemblies (ULC, 1988). (This is similar to ASTM E-84).

Substrates are fire tested with applied surface coatings without consideration of the longevity of the coating.

6.5 USA – NFPA 703

This standard (NFPA, 2000a) applies to fire retardant impregnated wood and fire-retardant coatings for building materials. With respect to fire-retardant coatings, the following definition is given.

Fire Retardant Coating – A coating that reduces the flame spread of Douglas Fir, and all other tested combustible surfaces to which it is applied, by at least 50 percent or to a flame spread classification value of 75 or less, whichever is the lesser value, and has a smoke developed rating not exceeding 200.

Two classes of fire-retardant coating are then defined as follows:

Class A Fire Retardant Coating – As applied to building materials, shall reduce the flame spread to 25 or less, and have a smoke developed rating not exceeding 200.

Class B Fire Retardant Coating – As applied to building materials, shall reduce the flame spread to greater than 25 but not more than 75, and have a smoke developed rating not exceeding 200.

General requirements include:

- Coatings to remain stable and adhere to the material under all atmospheric conditions the material is exposed to
- Coating and application rate to be the same as indicated on fire test report and applied in accordance with manufacturer's instructions
- AHJ may require the application be certified by the applicator
- Fire retardant coating shall not be overcoated with any material unless the coating and the overcoat have been tested as a system and meet the requirements of a fire retardant coating

The fire test method specified is: NFPA 255 Standard Method of Test of Surface Burning Characteristics of Building Materials (NFPA, 2000b) (same as ASTM E84). Where fire-retardant coatings are to be subjected to sustained humidity of 80 percent or more or exposure to the weather, then a test laboratory is required to certify that there is no increase in the listed classification when subjected to the Standard Rain Test described in ASTM D2898-94 Standard Methods for Accelerated Weathering of Fire Retardant-Treated Wood for Fire Testing (ASTM, 1999).

Regarding maintenance of the coating, NPFA 703 (NFPA, 2000a) says coatings shall possess the required degree of permanency and be maintained to retain the effectiveness of the treatment under the service conditions encountered in actual use.

6.6 USA – Uniform Building Code

Refer to the Uniform Building Code 1997 (ICBO, 1997a).

Interior walls and ceilings require a flame spread index from UBC 8-1 test method (ICBO, 1997b) for surface burning characteristics of building materials (based on ASTM E84-84). There are no special limitations on the use of fire retardant products to achieve the required flame spread index. In some instances non-combustible materials can be replaced with fire retardant treated wood.

Fire retardant treated wood is a defined term. It is: – `*any wood product impregnated with chemicals, by a pressure process or other means during manufacture, and which, when tested in accordance with UBC Standard 8-1 for a period of 30 minutes, shall have a flame spread of not over 25 and show no evidence of progressive combustion. In addition, the flame front shall not progress more than 3200 mm beyond the centre line of the burner at any time during the test. Materials that may be exposed to the weather shall pass the accelerated weathering test and be identified as exterior type, in accordance with UBC Standard 23-4 (based on ASTM D 2898-81). Where material is not directly exposed to rainfall but exposed to high humidity conditions, it shall be subjected to the hygroscopic test and identified as interior type A in accordance with UBC Standard 23-4.'*

Therefore under the UBC, a fire-retardant coating applied to a wood substrate is not considered to be 'fire retardant treated wood'.

UBC Standard 23-4 (ICBO, 1997c) fire retardant treated wood specifies tests of durability and hygroscopic properties.

UBC makes extensive use of non-combustible external walls but combustible external walls passing a full scale façade test are acceptable. There do not appear to be any particular requirements with regards to the use of fire-retardant coatings on timber substrates. Furthermore, since these systems are not 'fire retardant treated wood', the accelerated weathering test does not apply.

6.7 USA – International Building Code

The International Building Code (ICC, 2000) is similar to the Uniform Building Code (ICBO, 1997a).

Section 2303.2 defines fire retardant treated wood. It is: – `*any wood product which, when impregnated with chemical by a pressure process in accordance with AWPA C20 or AWPA C27, or other means during manufacture, shall have, when tested in accordance with ASTM E 84, a listed flame spread of 25 or less and show no evidence of significant progressive combustion when the test is continued for an additional 20-minute period. In addition, the flame front shall not progress more than 3200 mm beyond the centreline of the burners at any time during the test.'*

AWPA C20 (AWPA, 1998) and AWPA C27 (AWPA, 1988) are standards for fire retardant treatment of structural lumber and plywood by pressure processes respectively.

Materials that may be exposed to the weather shall pass the accelerated weathering test and be identified as exterior type, in accordance with ASTM D 2898 (ASTM, 1999).

6.8 New Zealand

Fire test requirements for internal linings and exterior claddings called up by the New Zealand Building Code (NZBC) Acceptable Solutions (BIA, 2001) do not exclude the use of applied coatings in order to achieve the required AS/NZS 1530 Part 3 indices (SA, 1999).

While the same test method is used in New Zealand as in Australia, in New Zealand there is no exemption for paint finishes i.e. the substrate with any applied coating is subjected to the fire test. This applies to pressure impregnated methods of fire retardancy as well as surface applied coatings.

The NZBC B2 `Durability' clause requires that coatings comply with B2.3 where they are necessary to achieve compliance with any other NZBC clause. With regard to fire protection, if a fire coating was specified to ensure compliance with any aspect of NZBC C2-C4, the coating would need a minimum of five years durability and possibly longer depending on access and ease of replacement. However, neither NZBC Clause B2 nor Clauses C2-C4 currently prescribe any specific test method to demonstrate adequate durability.

In New Zealand it is rare for any weathering or ageing of samples to be undertaken prior to carrying out a fire test.

6.9 Vanuatu

National Building Code (Pacific Buildings Standard Project, 1990) specification NC1.6 Clause 6 states:

> *`When paint or fire-retardant coatings are used in order to make a substrate comply with a required Spread-of-Flame Index, Smoke-Developed Index or Flammability Index, this fact must be clearly marked on an easily visible label or labels and permanently fixed to the building element so that the coating will not be scraped off or otherwise made ineffective, without recoating to preserve the fire-retardant properties. If any coating used will retain the required fire-retardant properties for only a limited period, it must be replaced before the expiry of such a period so that the required properties are not diminished.'*

The Vanuatu National Building Code, although not normally cited for comparison purposes, is interesting for the requirement for labelling so that the use of fire-retardant coatings can be identified in the field.

7. LITERATURE REVIEW

There are various papers in the literature discussing fire performance of timbers with and without fire-retardant coatings, but very little information is available where weathering or durability of the coating was also considered. In cases where durability issues have been investigated, these almost always concerned the use of pressure impregnated fire retardants with timber, rather than coatings and hence were outside the scope of this study.

Pettitt and Routley (1978) developed a procedure for assessing the change in flame spread characteristics of paints when subjected to washing (relevant to interior use). Natural ageing of interior paint systems during average useful life is unlikely to cause more than a slight change in flammability performance. However painted surfaces which are washed down at intervals could affect fire retardant properties of paint film. All paint systems are sensitive to water to some extent but some (certain fire retardant paints) will degrade rapidly because additives used in the formulation for enhancing fire properties are capable of being leached out of the film. They proposed the following washing procedure on the basis that it would be reasonable to expect that an interior wall or partition will be repainted every seven years and will be washed down once every 18 months (i.e. about 4 times during its service life).

Apparatus

1.1 A framework of sufficient size to support the painted specimen at an angle of 30° from the vertical. At the top of the framework is fitted a bar sprinkler to produce jets of fresh water impinging on the painted specimen within 1 cm of, and along the length of, the top edge. It shall be arranged that water running over the painted specimen shall fall freely from the bottom edge and not form pools which immerse the lower edge of the painted specimen. A bar sprinkler can be constructed from a length of metal or plastic pipe, approximately 10 mm internal diameter, with 1 mm holes at 1 cm centres in line and along its length.

1.2 Two in number sponges approximately 150 mm x 100 mm x 50 mm in size.

1.3 0.5% v/v solution of neutral detergent in fresh water

Procedure

2.1 Mount the painted specimen in the frame and make an identifying mark on the top edge.

2.2 Thoroughly wet a sponge with the detergent solution and starting at the top, wash the painted surface by moving the sponge on the surface in strokes side to side parallel to and starting at the top edge, alternate strokes being in opposite directions and approximately 100 mm away, so that the width of each stroke overlaps by at least 40 mm. Only light pressure should be used. Continue washing until the whole of the painted surface has been washed.

2.3 Repeat 2.2 but using strokes up and down parallel to and starting at one side.

2.4 On completion of the washing, turn on the bar sprinkler and rinse the painted specimen with free-flowing water for 1 min.

2.5 Thoroughly wet the second sponge with fresh water (no detergent) and rinse the painted surface in the manner described in 2.2 and 2.3.

2.6 Turn on the bar sprinkler and rinse as in 2.4.

2.7 Allow to drain for 5 min.

2.8 Remove the painted specimen from the framework and allow to dry in a vertical position at room temperature with free access to air for 24 h.

2.9 Repeat 2.1 to 2.8 for a further three cycles except that for the second and fourth cycles the painted specimen shall be placed on the framework in the inverted position, ie the top edge in cycles one and three will be the bottom edge in cycles two and four.

2.10 Allow the painted specimen to dry at room temperature for a further six days before testing.

They observed variability in the results of the washed panels possibly due to water entering the edges of the panels and reducing the adhesion of the paint to the substrate. They suggested that large enough panels be used to permit a border 75 mm wide to be discarded when cutting the fire test specimens.

The fire test method used in the Pettitt and Routley (1978) study was the small scale flame spread apparatus and procedure described in BS 476 part 7 (BSI, 1987). They used two substrates, a 3.2 mm standard hardboard and a 12 mm wood fibre insulation board. They found the change in performance in the fire test was more consistent using the hardboard substrate. Eight paint systems were examined from three manufacturers. The systems were chosen to represent a range of performance both from the view of flame spread and washing resistance. Fire testing was carried out on washed and unwashed samples. A requirement was suggested that the change in average flame spread due to the paint system being subjected to the washing procedure shall not exceed 75 mm as measured using the small scale surface spread of flame apparatus (BS 476 part 7). This would appear to preclude paint systems having a low resistance to washing.

Ohlemiller and Shields (1999) investigated the ability of various commercial coatings to prevent flame spread on fiber/organic resin composite materials. Four commercial coatings were tested over an unretarded vinyl ester/glass composite. In addition an uncoated phenolic/fibreglass composite and a polyester/fibreglass composite coated with a fire retardant resin were tested. The test configuration was a 3.3 m high corner with a 53 cm square gas burner at the base with an output of 250 kW. The results showed that, with proper choice of coating, fire growth can be effectively suppressed. They concluded that intumescent coatings can control the potential for fire growth on vinyl ester composites, but there was considerable variation in the efficacy of the four commercial coatings they examined. One was very effective in protecting the composite from involvement in the fire but itself contributed substantial fuel initially, yielding a potentially threatening, early surge in heat release. Another coating contributed a relatively small amount of fuel initially and then was also effective in preventing fire growth.

Although not directly related to fire-retardant coatings, Mowrer (2001) examined the effect of blistering on the ignition and flammability of painted gypsum wallboard using a cone calorimeter. He noted that the blistering phenomenon was most pronounced in samples coated with multiple layers of oil-based paint, and that as the number of layers in increased, the blistering was observed at lower imposed heat fluxes. He suggests that there is a relationship between the number of coats of paint on a surface and the potential for upward flame spread. These observations are relevant to the discussion later in this report given current exemptions for paint finishes in the BCA (1996).

8. REVIEW OF FIRE TEST METHODS

The fire test methods discussed here are those considered to be most relevant given the topic under consideration. The list is not necessarily comprehensive, and some methods are not specifically included here because of their similarity to another method.

In general the fire test methods used will be the same, whether or not fire-retardant coatings are used. FCRC Project 2A (FCRC, 1998) is a review of the appropriateness of various methods of test for wall and ceiling linings generally, so this report will not repeat what has already been done. Rather the focus here will be on the recommended test methods (ISO Room Corner and Cone Calorimeter) from that work and on the current method (EFH). With regard to the use of fire retardants this study has considered the appropriateness of pre-treating materials to simulate weathering and in-service degradation prior to carrying out a fire test.

One of the outcomes of FCRC Project 2A was a recommendation that regulatory controls on linings should be based on time to flashover in the ISO 9705 room fire test (ISO, 1993). A small scale test (eg cone calorimeter) that provides data for predicting the time to flashover in the ISO room fire test was also thought to be a suitable method of control.

It also follows that it was recommended that the use of AS1530.3 (SA, 1999) also known as the early fire hazard test be discontinued. Some of the reasons given for abandoning the test longer term included:

- Some materials that are known to ignite and burn when exposed to a gas burner in a corner of a room do not ignite in the early fire hazard test, thus the maximum radiant flux achieved is considered to be too low and for some materials the test does not give a true indication of likely behaviour in a fire.

- Materials are assessed for flame spread, heat evolved and smoke developed under different levels of impressed radiation, because movement of the specimen toward the radiant panel is stopped when ignition occurs.

- The method for measuring smoke is arbitrary and technically flawed. Materials that produce a short burst of smoke prior to ignition are penalised compared to materials that produce smoke continuously following ignition. The measurement of optical density is under conditions where the flow rate of combustion gases is neither measured nor controlled.

AS/NZS 1530.3 (SA, 1999). Early Fire Hazard – Specimens measuring 450 mm x 600 mm are vertically mounted opposite a gas-fired radiant panel, with the specimen advanced toward the heater by a prescribed amount every 30 seconds until the specimen ignites. A radiometer is used to view the specimen surface and record the radiation produced following ignition. Smoke from the specimen is collected in a hood and its optical density is measured as it passes through a vertical duct. The parameters measured during the test are: time to ignition, increase in emitted radiation, total radiation emitted in two minutes after ignition and the average rate of smoke production. They are used to derive the reported Ignitability Index, Spread-of-Flame Index, Heat-Evolved Index and Smoke-Developed Index.

ISO 9705 (ISO, 1993). ISO Room Corner – This test uses a room 3.6 m long x 2.4 m wide x 2.4 m high with a single opening 2.0 m high x 0.8 m wide. The walls, ceiling and floor are constructed of non-combustible material to which the lining materials are fixed. A gas burner is located in a corner opposite the door opening, and outputs 100 kW for the first 10 minutes of the test. If flashover is not reached by 10 minutes the burner output is increased to 300 kW, and the test continued for a further 10 minutes or until flashover occurs. This fire test is generally accepted as being representative of a full-scale end use application applicable to interior wall and ceiling lining materials.

AS/NZS 3837 (SA, 1998). Cone Calorimeter – This apparatus was developed at the National Bureau of Standards, USA in the 1970s. The cone calorimeter uses the principle of oxygen consumption calorimetry to measure the rate of heat release from 100 x 100 mm specimens. Specimens may be exposed to a radiant heat flux from the cone-shaped electrical heater in the range 0-100 kW/m^2. In addition to measurement of the rate of heat release, other parameters measured include: time to ignition, mass loss, smoke production, CO and CO_2 production. It is reported that there are in excess of 100 cone calorimeters in more than 20 countries, thus while the apparatus is widely used for research purposes, it is not yet widely used for building control purposes.

UL 790 (UL, 1995) 10 Year Weathering Test – developed for roofing materials. All products subjected to: intermittent flame test, spread of flame test, and a burning brand test. Fire retardant roofing materials are in addition subjected to a flying brand test, a rain test, and a weathering test. The rain test is designed to try and flush fire retardants out of the treated wood. The roofing material is subjected to 12 weekly cycles of 96 hours of water exposure and 72 hours of drying at 140F. After the rain test the roofing material is again tested to the intermittent flame test, the burning brand test and the flying brand test. Treated wood roofing material is the only product exposed to actual outdoor weather conditions. After one, three, five and ten years, the roofing material is subjected again to the intermittent flame, burning brand and flying brand tests.

9. PERFORMANCE IN SELECTED TEST METHODS

AS1530.3 (EFH) Results for Timber Products

The Timber Development Association (TDA, 1979) published a document summarising EFH indices to AS 1530.3-1976 (SA, 1999) obtained for a large range of timbers. Some of that data is presented in Table 4 to Table 7.

Table 4: TDA – Untreated Timbers

Description	Ignitability Index (0-20)	Spread-of-Flame Index (0-10)	Heat-Evolved Index (0-10)	Smoke-Developed Index (0-10)	Report Reference
Douglas fir	14	9	9	3	EBS 19/9/78 E4221
Hoop pine	14	7	6	2	Beesley et al, 1974
Lauan	14	9	10	4	EBS 19/9/78 E4227
Radiata pine	15	7	6	3	EBS 19/9/78 E4220
Red cedar (western)	14	10	9	4	EBS 19/9/78 E4219
Redwood	14	9	9	4	EBS 26/1/79 E4253
Yellow walnut	14	7	6	1	Beesley et al, 1974

Table 5: TDA – Untreated Plywood

Description	Ignitability Index (0-20)	Spread-of-Flame Index (0-10)	Heat-Evolved Index (0-10)	Smoke-Developed Index (0-10)	Report Reference
Lauan	14	8	10	3	EBS 5/10/78 E4244
Radiata pine	14	8	9	2	EBS 5/10/78 E4237
Radiata pine (scorched and brushed surface)	14	7	7	2	EBS 5/10/78 E4246

Under the exposure conditions of the AS1530.3 fire test (SA, 1999), the pressure-impregnated methods of fire retardant treatment were more successful than the use of coatings (as shown in Table 7). The fire-retardant coating appeared to be ineffective in preventing ignition but was able to achieve a significant reduction in the spread-of-flame and heat-evolved indices in some cases.

Table 6: TDA – CCA Treated Timber

Description	Ignitability Index (0-20)	Spread-of-Flame Index (0-10)	Heat-Evolved Index (0-10)	Smoke-Developed Index (0-10)	Report Reference
Radiata pine S.A. not profiled	14	6	5	3	Beesley et al, 1974
Radiata pine S.A. profiled	14	4	5	3	Beesley et al, 1974
Radiata pine Vic. profiled	14	5	5	3	Beesley et al, 1974
Radiata pine NSW. profiled	15	7	6	3	Beesley et al, 1974
Radiata pine NSW. Profiled (b)	15	5	5	3	Beesley et al, 1974
Radiata pine NZ. profiled	14	6	4	3	Beesley et al, 1974
Hoop pine QLD. Profiled	15	2	5	3	Beesley et al, 1974

(b) CCA loading was 10 kg/m^3, all others were 5.6 kg/m^3

Table 7: TDA - Timbers and Plywood Treated with Fire Retardants

Description	Ignitability Index (0-20)	Spread-of-Flame Index (0-10)	Heat-Evolved Index (0-10)	Smoke-Developed Index (0-10)	Report Reference
Hoop pine, retardant impregnated	0	0	0	2	Beesley et al, 1974
Redwood, coated with 3 coats of fire retardant	14	0	4	5	EBS 23/2/79 E4362
Redwood, coated with 1 coat of fire retardant	14	8	6	4	EBS 23/2/79 E4361
Western red cedar, coated with 3 coats of fire retardant	14	0	5	4	EBS 23/2/79 E4360
Western red cedar, coated with 1 coat of fire retardant	15	8	6	4	EBS 23/2/79 E4359
Yellow walnut, retardant impregnated	0	0	0	1	Beesley et al, 1974

10. EXPERIMENTAL WORK

All types of samples (control and the simulated interior and exterior accelerated weathering samples) were subjected to testing in the cone calorimeter in accordance with AS/NZS 3837 (SA, 1998) and for some samples, the early fire hazard test AS/NZS 1530.3 (SA, 1999).

10.1 Testing Matrix

Table 12 outlines the testing matrix for both the interior and exterior samples. It should be noted that the intumescent-based samples have two coating coverage rates. These two different coverage rates are included to investigate the effect of variation of differing on-site application practices (see also section 3.2).

Three different accelerated weathering methods were used as indicated in the table:

(1) W1- For interior application – humidity chamber, automated humidity – temperature cycles (6 hours at 95% RH and 30^{o}C, then 6 hours at 67% RH and 15^{o}C; 250 cycles).
(2) W2 - For interior application – manual washing procedure using the method of Pettitt and Routley (1978) as described in Section 7 of this report.
(3) W3 - For exterior application – QUV weatherometer (8 hours UV-light on at 60^{o}C, 4 hours UV-light off, at 50^{o}C; 2000 hours)

The exterior intumescent coating system comprised one coat of intumescent plus topseal (with the topseal specified as the topcoat for this exterior intumescent).

Where ½ recommended application rates where used, this was for the base coat only (i.e. topcoat application rate did not change).

In this report, we have used the term 'weathering' to apply to both the interior and exterior systems. While for the interior systems this term is perhaps not entirely correct, it is used with the meaning given above for W1, W2 and W3 as applicable to describe the environmental conditions to which the samples were exposed prior to fire testing.

The coating systems investigated included:

- A clear intumescent coating system on plywood intended for interior use
- An opaque intumescent coating system on plywood intended for interior use
- An opaque intumescent coating system on western red cedar intended for exterior use
- An ablative coating on wood fibre insulation board intended for interior use

Specific details are provided in Table 8 to Table 11.

Table 8: Product Description for the Interior Clear Intumescent Coating

Interior Clear Intumescent Coating	
Description	A clear intumescent coating for internal use designed to protect timber and timber based products from the effects of fire, comprising a base coat and top seal.
Application	Brush, roller or spray. The coating system should be applied to clean surfaces free from any contamination.
Test Data	Application rate 1: one coat of basecoat 200 gm/m^2 one coat of topseal at 85 gm/m^2 Application rate 2: one coat of basecoat 130 gm/m^2 one coat of topseal at 85 gm/m^2 When tested to AS 1530 Part 3, the manufacturer stated the following results were achieved: **Spread of Flame** / **Smoke Developed** Application rate 1 on particle board: 0 / 5 Application rate 1 on timber panels: 0 / 5 Application rate 2 on particle board: 6 / 5

Table 9: Product Description for the Interior Opaque Intumescent Coating

Interior Opaque Intumescent coating	
Description	An intumescent coating designed to protect specific substrates from the effects of heat and fire. An acrylic paint with low flammability characteristics, used as a top seal over the intumescent coating.
Application	Intumescent coat Brush, short nap roller or airless spray. Coverage – two coats at a nominal 5m per litre per coat Top coat – brush, roller or spray. One coat at 12 to 16 m² per litre. Apply a second coat if necessary to achieve full coverage or required colour.
Test Data	Application rate 1: one coat of basecoat 200 gm/m^2 one coat of topseal at 85 gm/m^2 Application rate 1: one coat of basecoat 130 gm/m^2 one coat of topseal at 85 gm/m^2 When tested to AS 1530 Part 3, the manufacturer stated the following results were achieved: **Spread of Flame** / **Smoke Developed** Intumescent Coat On vermiculite panels: 0 / 3 With top seal on plywood: 0 / 5 Over particle board: Previously Painted: 0 / 5 2 coats at 5 m²/litre per coat: 0 / 5 1 coat at 4 m²/litre: 3 / 4 Top Coat When applied to plasterboard: 0 / 3

Table 10: Product Description for the Exterior Opaque Intumescent Coating

External Opaque Intumescent Coating	
Description	Basecoat – latex water base intumescent coating Topseal – water based acrylic gloss
Application	Basecoat Brush, roller or airless spray. Coverage 2.5 m² / litre gives 400 microns wet film thickness which dries to 300 microns dry film thickness. Topseal coverage 16 m² / litre
Test Data	When tested to AS 1530 Part 3, the manufacturer stated the following results were achieved: 500 microns dry film thickness of basecoat on 11mm thick plywood gave:– **Ignitability Index** 1 **Spread-of-Flame Index** 0 **Heat-Evolved Index** 0 **Smoke-Developed Index** 4

Table 11: Product Description for the Interior Factory-Applied Ablative Coating

Factory applied fire-retardant coating	
Description	Cellulose fibre soft board ceiling tile coated on one side with a factory applied flame retardant paint finish
Properties	Size : 600 mm x 400 mm Thickness: 13 mm Density 300 kg/m³
Test Data	When tested to AS 1530 Part 3, the manufacturer stated the following results were achieved: **Spread of Flame** / **Smoke Developed** Panels 0 4

Table 12: System Description with Weathering and Test Regimes

ID	Substrate	Coatings	Weathering	Fire Tests
Interior Applications				
A	radiata pine ply 10 mm thick density 455 kg/m^3	none	none	EFH & cone @ 50 kW/m^2
B	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (½ recommended application rate)	none	cone @ 50 kW/m^2
C	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (½ recommended application rate)	yes (W1)	cone @ 50 kW/m^2
D	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (recommended application rate)	none	cone @ 50 kW/m^2
E	radiata pine ply 10 mm thick density 455 kg/m^3	opaque intumescent system (recommended application rate)	yes (W1)	cone @ 50 kW/m^2
F	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	none	EFH & cone @ 50 kW/m^2
G	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	yes (W1)	cone @ 50 kW/m^2
H	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	none	EFH & cone @ 50 kW/m^2
I	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	yes (W1)	cone @ 50 kW/m^2
J	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (recommended application rate)	yes (W2)	EFH & cone @ 50 kW/m^2
K	radiata pine ply 10 mm thick density 455 kg/m^3	clear varnish intumescent system (½ recommended application rate)	yes (W2)	EFH & cone @ 50 kW/m^2
L	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	factory-applied fire-retardant coating	none	cone @ 50 kW/m^2
M	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	factory-applied fire-retardant coating	yes (W1)	cone @ 50 kW/m^2
S	cellulose fibre insulation board 12 mm thick density 339 kg/m^3	none	none	cone @ 50 kW/m^2
Exterior Applications				
N	western red cedar 18 mm thick density 406 kg/m^3	none	none	cone @ 50 kW/m^2
O	western red cedar 18 mm thick density 406 kg/m^3	opaque intumescent system (½ recommended application rate)	yes (W3)	cone @ 50 kW/m^2
P	western red cedar 18 mm thick density 406 kg/m^3	opaque intumescent system (½ recommended application rate)	none	cone @ 50 kW/m^2
Q	western red cedar 18 mm thick density 406 kg/m^3	opaque intumescent system (recommended application rate)	yes (W3)	cone @ 50 kW/m^2
R	western red cedar 18 mm thick density 406 kg/m^3	opaque intumescent system (recommended application rate)	none	cone @ 50 kW/m^2

Notes:

EFH means fire test to AS/NZS 1530 Part 3 (1999)

Cone means fire test to AS/NZS 3837 (1998)

10.2 Paint Defects after the Weathering Regime

The specimens submitted for testing were inspected before and after the durability/weathering studies. Most of the samples showed no sign of visible defects except the clear coating. After being submitted to weathering processes W1 and W2, the clear intumescent system over plywood showed visible signs of defects. Figure 2 illustrates the plywood samples coated with the clear intumescent system, the sample on the left has been submitted to washing (W2).

The defect may be described as 'milky blushing' (Hess, 1965). The exact cause of this blushing is unknown but may be due to precipitation or hydrolysis of an additive in the coating film. The blushing is occurring at the wood-basecoat interface and it is considered unlikely to adversely affect performance in fire.

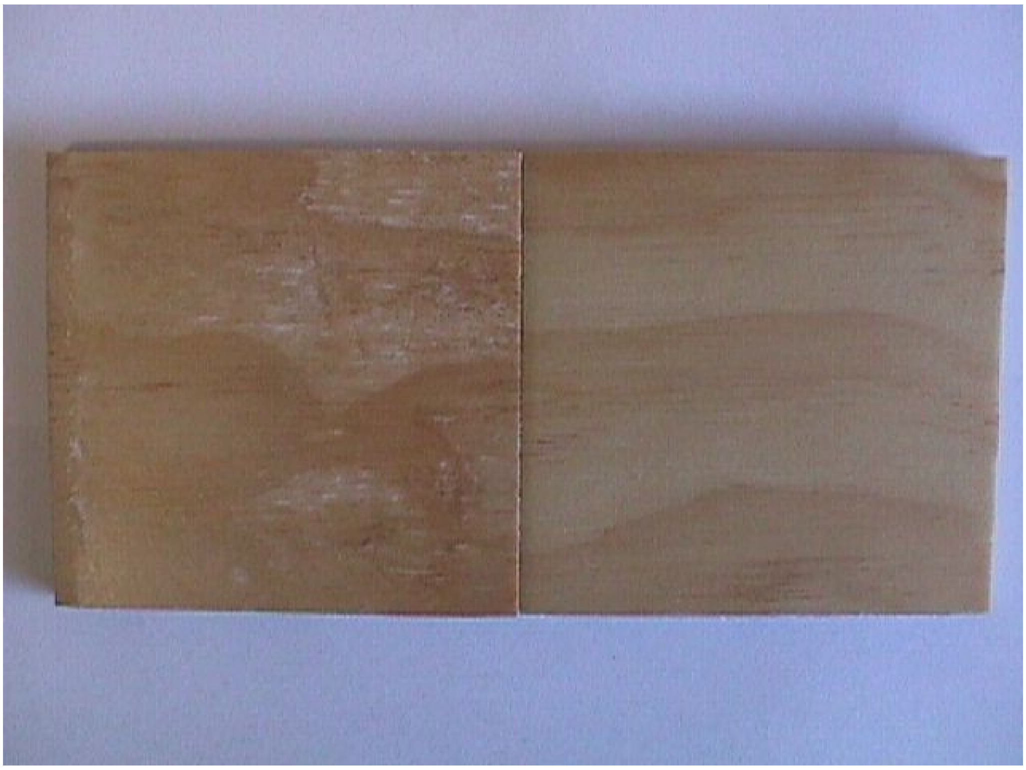

Figure 2: Plywood Samples Coated with a Clear Intumescent System, After Washing Process W2 (left) and Unweathered Sample (right)

10.3 Infra-Red Study on Topcoats

To investigate the effect of weathering on the topcoats, dried samples of topcoats were removed from the exterior coating systems before and after the QUV exposure. The samples were dried in a desiccator and analysed using an infra-red spectrometer with ATR film sample attachment. The results are shown in Figure 3 and Figure 4.

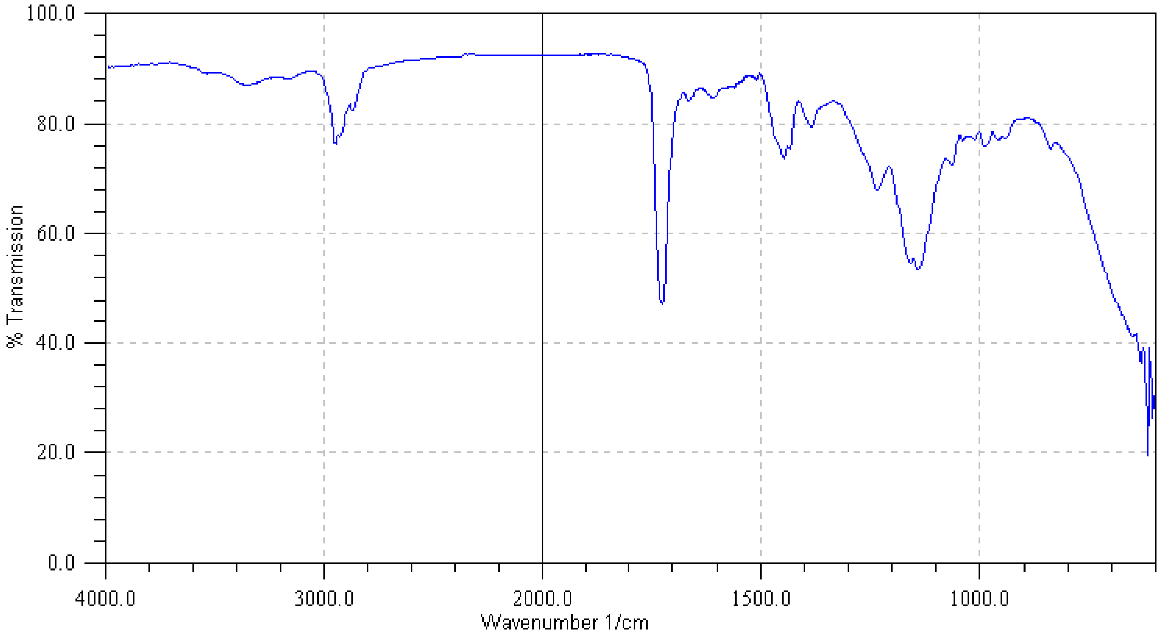

Figure 3: External Intumescent Coating Topseal Before QUV Exposure

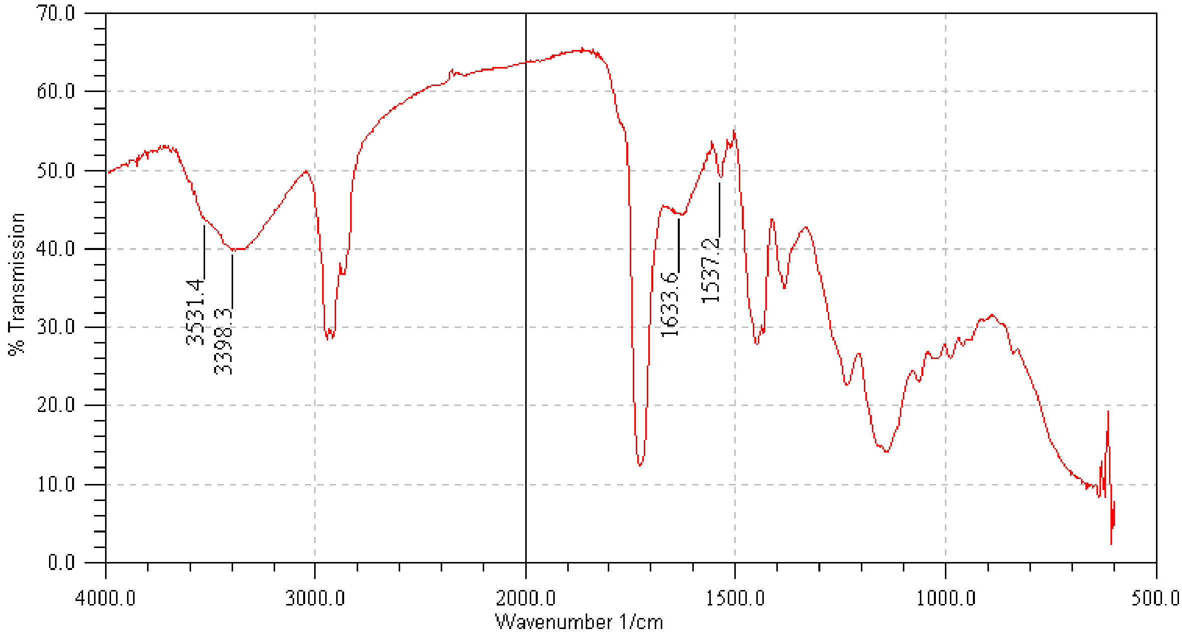

Figure 4: External Intumescent Coating Topseal After QUV Exposure

The samples differ in that the sample subjected to UV light and humidity contains strong peaks at 3531 and 3398 bands. The peaks at 3531 represents water, trapped by hydrogen bonding in the film, the peak at 3398 represents pendant hydroxyl groups on the paint surface.

This suggests that the weathered topseal contains water even after conditioning and that a larger amount of the polymer contains hydroxyl groups at the surface when compared to the unweathered topseal. This may result in an improved performance in fire.

10.4 AS1530 Part 3 Results

The interior plywood with clear intumescent coating was selected for fire testing to AS1530.3. Due to the larger specimen size required for the AS1530.3, it was not practical to test the exterior western red cedar sample because of insufficient room in the QUV weatherometer. The results are shown in Table 13 and Figure 5. The durability test procedure used for these specimens was the manual washing procedure (W2) described in Section 7.

Table 13: Results from AS 1530 Part 3 (Early Fire Hazard Test)[a]

System (refer Table 12)	*Ignitability*		*Spread of flame*		*Heat evolved*		*Smoke developed*	
	Ignition time (min)	*Index (0–20)*	*Flame propagation time (s)*	*Index (0–10)*	*Radiant heat release (kJ)*	*Index (0–10)*	*Max. optical density (m^{-1})*	*Index (0–10)*
A	5.91 ± 0.30	14	28.7 ± 8.8	8	213 ± 19	8	0.061 ± 0.018	3
H	6.33 ± 0.13	14	10.3 ± 3.3	9	216 ± 23	8	0.244 ± 0.049	5
K	5.99 ± 0.48	14	38.2 ± 27.6	8	186 ± 31	7	0.212 ± 0.04	5
F	8.07 ± 0.57	12	165.7 ± 22.1	2	64.7 ± 16.8	2	0.098 ± 0.01	4
J	8.06 ± 1.15	12	147.9 ± 36.4	4	84.2 ± 27.8	3	0.140 ± 0.02	5

[a] All results show mean and 95% confidence interval for 6 replicates.

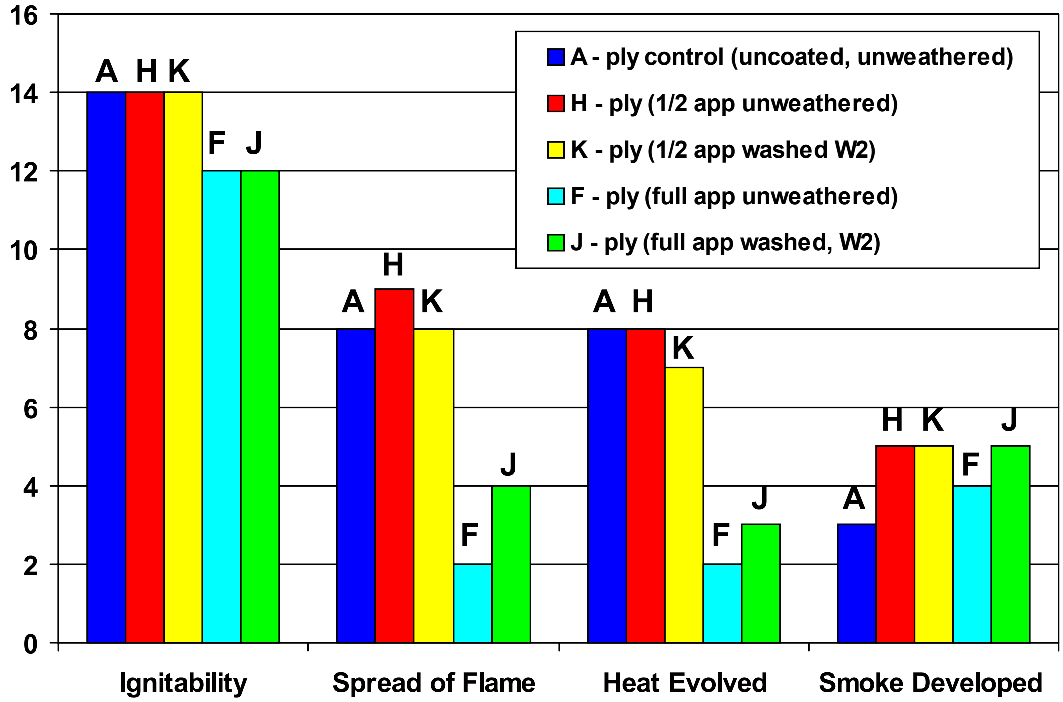

Figure 5: AS 1530 Part 3 Indices

The application of the clear intumescent coating system at the recommended application rate showed a small improvement in the Ignitability Index compared to the uncoated and unwashed samples (12 and 14 respectively for systems J and A); but no improvement where only the half application rate was applied (Index 14 for both systems K and A). More significant improvements were observed for the spread-of-flame index and the heat-evolved index.

For the washed samples, the spread-of-flame, heat-evolved and smoke-developed indices are slightly worse than the comparable unweathered samples where the full recommended application rate was used. However the opposite was observed when only half the recommended application rate was used: the same indices for the washed samples were all slightly better or the same as the unweathered samples.

The improved ignitability index for systems F and J with full application of coatings (compared to the uncoated control, A) is consistent with the cone calorimeter results obtained for these same systems. The mean time to ignition in the cone calorimeter was 86, 84 and 20 seconds respectively for systems F, J and A.

10.5 Cone Calorimeter Results

Testing was carried out in accordance with AS/NZS 3837 (SA, 1998). All testing was carried out at an irradiance of 50 kW/m^2 in a horizontal orientation so that the results could be evaluated using the recommendations of FCRC Project 2A for interior wall and ceiling linings.

The retainer frame was used for all specimens, while the wire grid was used for those specimens with intumescent surface coatings.

Due to an instrumentation problem, the Smoke Extinction Area (SEA) measurements were not recorded for all specimens. This is noted when applicable in the following tables.

A summary of the results for each coating system is given in Table 14 to Table 19. The results are presented as the average of three replicate specimens. Graphs showing the rate of heat release during each test, for each of three specimens, are given in Figure 6 to Figure 24.

As a general observation, a higher variability in the heat release rate behaviour of specimens incorporating fire retardant coatings was noted, compared with the uncoated timber specimens (see Figure 6 and Figure 20). Intumescent coatings in particular present a greater challenge because of the dimensional change occurring in the coating that changes the actual surface area exposed during the test. While the wire grid was used, it is not totally effective in maintaining a flat specimen surface. The intumescent coatings were also more difficult to apply and harder to achieve consistent application rates. These factors contribute to a greater apparent variability in the cone calorimeter results.

Table 14: Cone Calorimeter Results for Uncoated Radiata Pine Plywood*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved [a] (MJ/kg)*	*Peak RHR (kW/m²)*	*60 s average RHR [b] (kW/m²)*	*180 s average RHR [b] (kW/m²)*	*300 s average RHR [b] (kW/m²)*	*Average RHR [c] (kW/m²)*	*Average EHC [a] (MJ/kg)*	*Average SEA [a] (m²/kg)*
A – UW	20 ± 5	447 ± 81	46.3 ± 3.5	216 ± 25	148 ± 10	115 ± 8	131 ± 13	109 ± 20	11.4 ± 0.6	86 ± 13

* All results are mean ± 95% confidence interval for three replicates.
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered

Table 15: Cone Calorimeter Results for Radiata Pine Plywood with Opaque Intumescent Coating*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved [a] (MJ/m²)*	*Peak RHR (kW/m²)*	*60 s average RHR [b] (kW/m²)*	*180 s average RHR [b] (kW/m²)*	*300 s average RHR [b] (kW/m²)*	*Average RHR [c] (kW/m²)*	*Average EHC [a] (MJ/kg)*	*Average SEA [a] (m²/kg)*
B – UW ½ app rate	20 ± 10	450 ± 99	51.3 ± 8.0	236 ± 29	152 ± 4	119 ± 31	141 ± 23	121 ± 32	11.8 ± 1.4	93 ± 41
C – W ½ app rate	37 ± 1	498 ± 108	44.8 ± 4.2	196 ± 63	125 ± 11	104 ± 9	123 ± 24	101 ± 32	10.2 ± 0.8	73 ± 41
D – UW full app rate	24 ± 4	598 ± 185	45.7 ± 5.9	216 ± 34	26 ± 6	59 ± 11	82 ± 26	82 ± 20	10.4 ± 0.1	97 ± 35
E – W full app rate	61 ± 55	478 ± 35	41.7 ± 1.7	242 ± 27	37 ± 58	70 ± 35	96 ± 37	100 ± 10	10.0 ± 0.6	NA

* All results are mean ± 95% confidence interval for three replicates.
[a] From start of test; [b] From ignition; [c] From ignition to end of test

EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W = Weathered: For interior application – humidity chamber, humidity – temperature cycles

Table 16: Cone Calorimeter Results for Radiata Pine Plywood with Clear Varnish Intumescent Coating*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved [a] (MJ/m²)*	*Peak RHR (kW/m²)*	*60 s average RHR [b] (kW/m²)*	*180 s average RHR [b] (kW/m²)*	*300 s average RHR [b] (kW/m²)*	*Average RHR [c] (kW/m²)*	*Average EHC [a] (MJ/kg)*	*Average SEA [a] (m²/kg)*
H – UW ½ app rate	52 ± 7	525 ± 148	43.2 ± 5.4	187 ± 49	110 ± 18	103 ± 5	119 ± 23	95 ± 26	9.9 ± 0.8	NA
I – W1 ½ app rate	34 ± 4	390 ± 17	40.0 ± 1.7	224 ± 60	103 ± 16	102 ± 32	122 ± 9	109 ± 6	9.7 ± 0.5	112 ± 25
K – W2 ½ app rate	51 ± 12	450 ± 46	43.2 ± 3.8	220 ± 76	119 ± 8	105 ± 4	129 ± 17	109 ± 19	9.9 ± 0.5	NA
F – UW full app rate	86 ± 10	490 ± 33	39.2 ± 0.8	178 ± 55	84 ± 12	97 ± 11	115 ± 8	97 ± 9	9.7 ± 0.3	NA
G – W1 full app rate	80 ± 21`	556 ± 118	39.9 ± 2.3	158 ± 53	99 ± 23	102 ± 8	109 ± 13	87 ± 19	9.8 ± 0.6	NA
J – W2 full app rate	84 ± 12	460 ± 26	36.4 ± 1.9	198 ± 42	80 ± 14	91 ± 19	113 ± 10	97 ± 11	8.6 ± 0.5	NA

* All results are mean ± 95% confidence interval for three replicates
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W1 = Weathered: For interior application – humidity chamber, humidity – temperature cycles
W2 = Weathered: For interior application – manual washing procedure
NA = Data not available

Table 17: Cone Calorimeter Results for Cellulose Fibre Insulation Board with Factory Applied Fire-Retardant Coating*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved[a] (MJ/m^2)*	*Peak RHR (kW/m^2)*	*60 s average RHR[b] (kW/m^2)*	*180 s average RHR[b] (kW/m^2)*	*300 s average RHR[b] (kW/m^2)*	*Average RHR[c] (kW/m^2)*	*Average EHC[a] (MJ/kg)*	*Average SEA[a] (m^2/kg)*
L – UW	22 ± 10	520 ± 61	39.1 ± 2.7	115 ± 26	73 ± 8	81 ± 5	82 ± 16	79 ± 12	11.6 ± 0.9	32 ± 34
M – W	25 ± 2	650 ± 124	35.9 ± 1.6	85 ± 3	76 ± 6	78 ± 5	73 ± 5	58 ± 9	10.1 ± 1.3	52 ± 8
S – UW no coating	12 ± 3	513 ± 79	42.8 ± 1.2	133 ± 19	113 ± 8	105 ± 15	100 ± 23	97 ± 11	12.0 ± 0.2	NA

* All results are mean ± 95% confidence interval for three replicates
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W = Weathered: For interior application – humidity chamber, humidity – temperature cycles

Table 18: Cone Calorimeter Results for Uncoated Western Red Cedar*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved [a] (MJ/m²)*	*Peak RHR (kW/m²)*	*60 s average RHR [b] (kW/m²)*	*180 s average RHR [b] (kW/m²)*	*300 s average RHR [b] (kW/m²)*	*Average RHR [c] (kW/m²)*	*Average EHC [a] (MJ/kg)*	*Average SEA [a] (m²/kg)*
N – UW	9 ± 2	1136 ± 62	82.8 ± 3.4	166 ± 10	116 ± 12	87 ± 6	78 ± 3	73 ± 1	12.6 ± 0.4	69 ± 27

* All results are mean ± 95% confidence interval for three replicates.
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W = Weathered: For interior application – humidity chamber, humidity – temperature cycles

Table 19: Cone Calorimeter Results for Western Red Cedar with Opaque Intumescent Coating*

System ID	*Ignition time (s)*	*End of test[a] (s)*	*Total heat evolved[a] (MJ/m²)*	*Peak RHR (kW/m²)*	*60 s average RHR[b] (kW/m²)*	*180 s average RHR[b] (kW/m²)*	*300 s average RHR[b] (kW/m²)*	*Average RHR[c] (kW/m²)*	*Average EHC[a] (MJ/kg)*	*Average SEA[a] (m²/kg)*
P – UW ½ app rate	9 ± 6	1197 ± 16	32.2 ± 21.6	159 ± 21	26 ± 6	14 ± 5	13 ± 8	27 ± 19	5.2 ± 4.4	62.2 ± 17
O – W ½ app rate	101 ± 81	1194 ± 18	56.5 ± 8.1	70 ± 11	58 ± 18	58 ± 14	56 ± 12	52 ± 9	9.5 ± 1.1	40 ± 21
R – UW full app rate	8 ± 3	130 ± 39	2.4 ± 1.8	144 ± 72	30 ± 21	10 ± 7	6 ± 4	17 ± 16	6.7 ± 3.7	288 ± 1
Q – W full app rate	28 ± 5	1276 ± 73	65.2 ± 4.0	103 ± 12	44 ± 7	20 ± 3	26 ± 7	52 ± 1	8.8 ± 3.5	NA

* All results are mean ± 95% confidence interval for three replicates.
[a] From start of test; [b] From ignition; [c] From ignition to end of test
EHC = Effective heat of combustion
RHR = Rate of heat release
SEA = Specific extinction area (a measure of smoke)
UW = Unweathered
W = Weathered: exterior application – QUV weatherometer

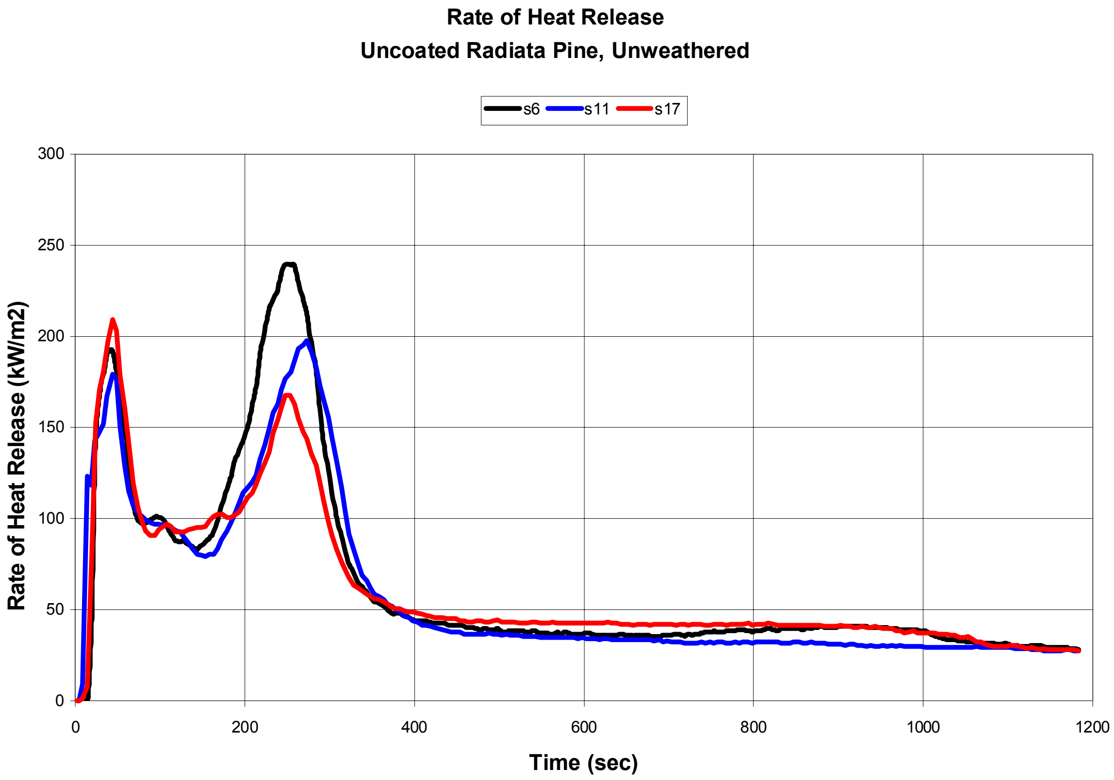

Figure 6: Heat Release Rate – System A

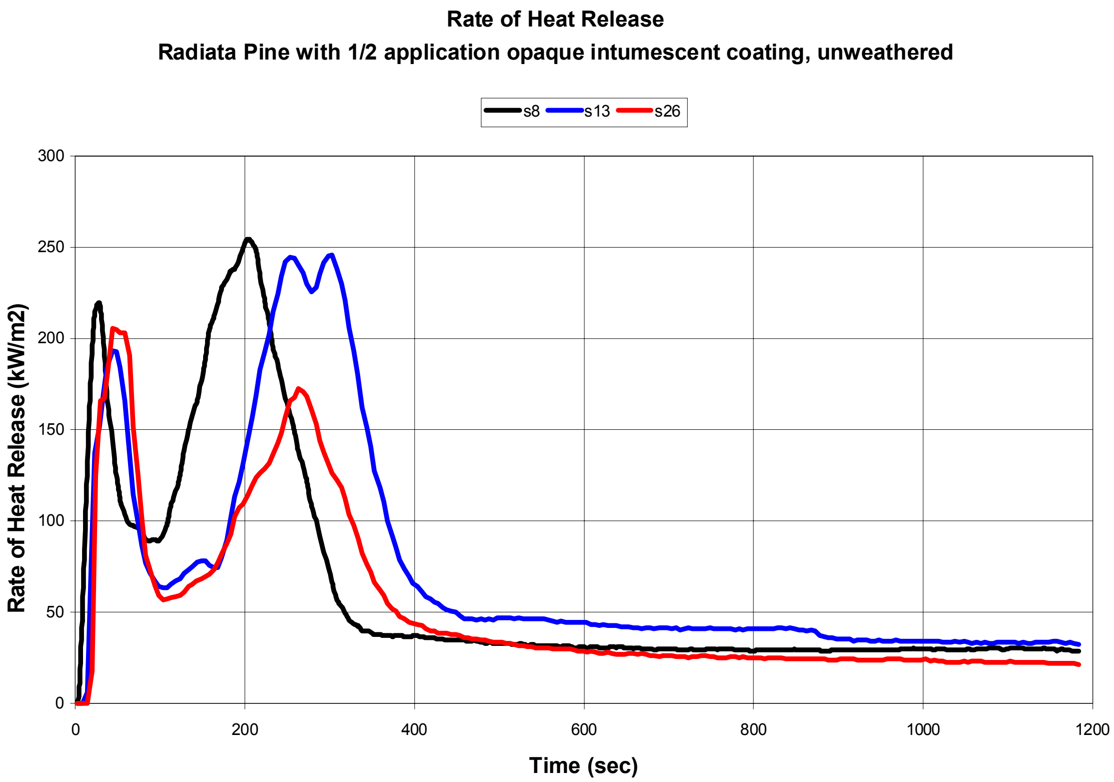

Figure 7: Heat Release Rate – System B

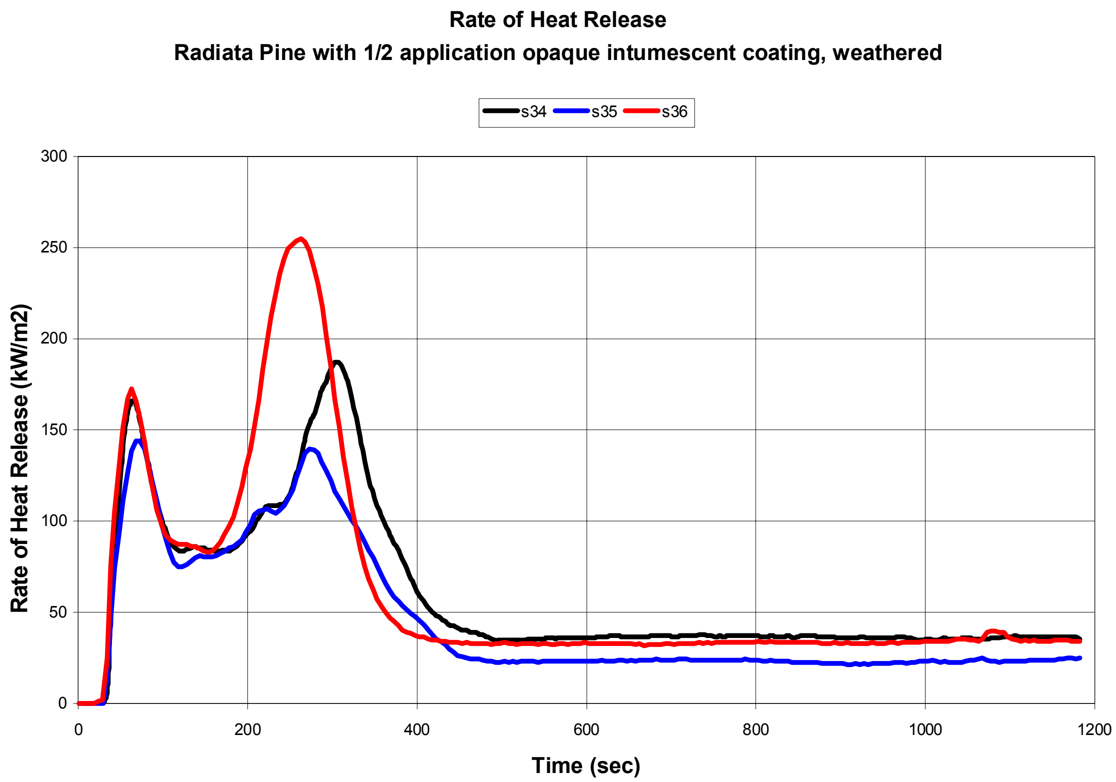

Figure 8: Heat Release Rate – System C

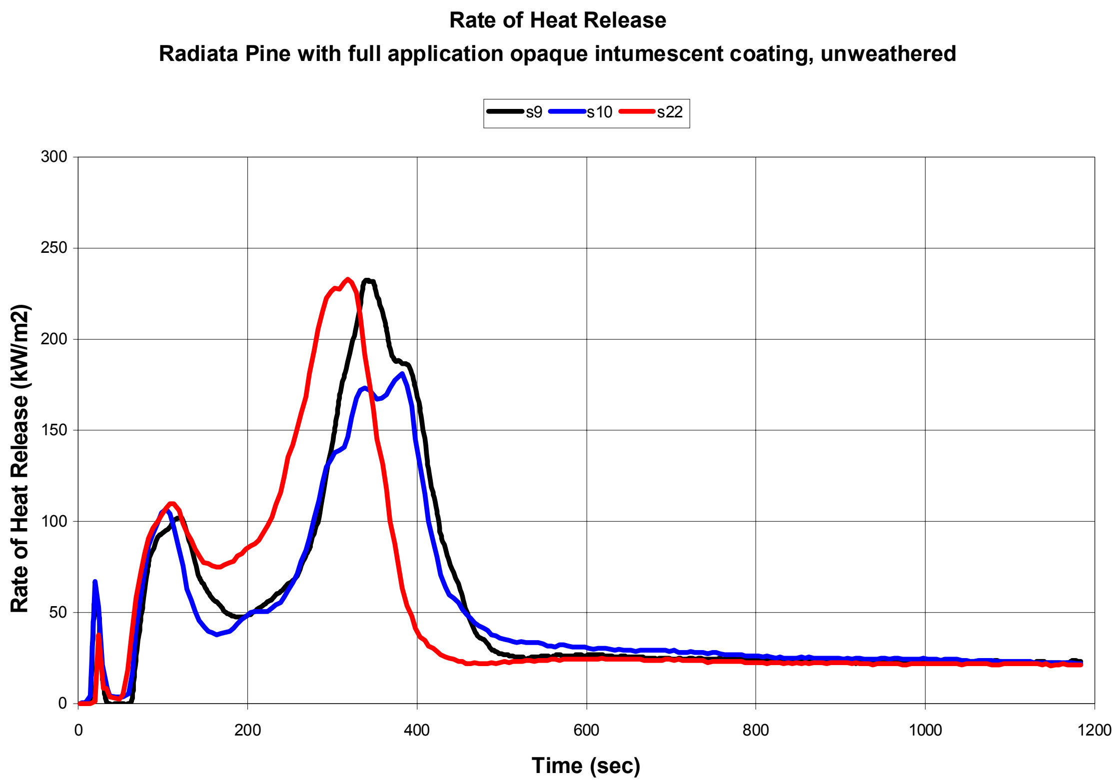

Figure 9: Heat Release Rate – System D

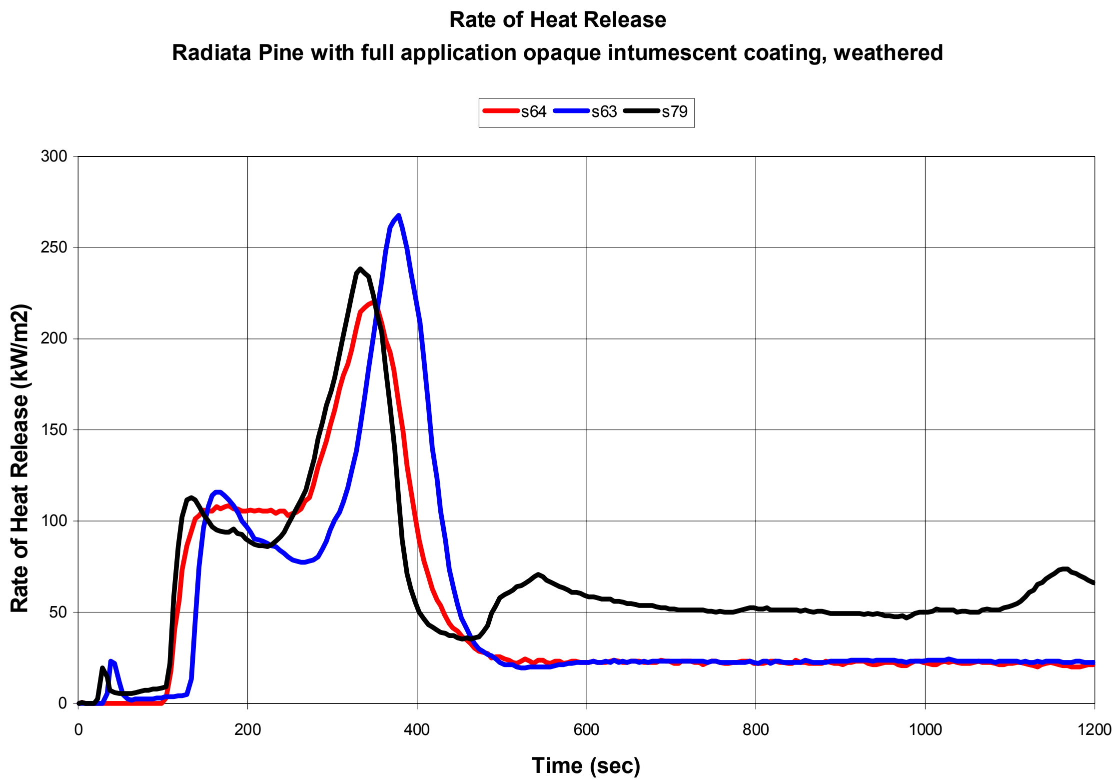

Figure 10: Heat Release Rate – System E

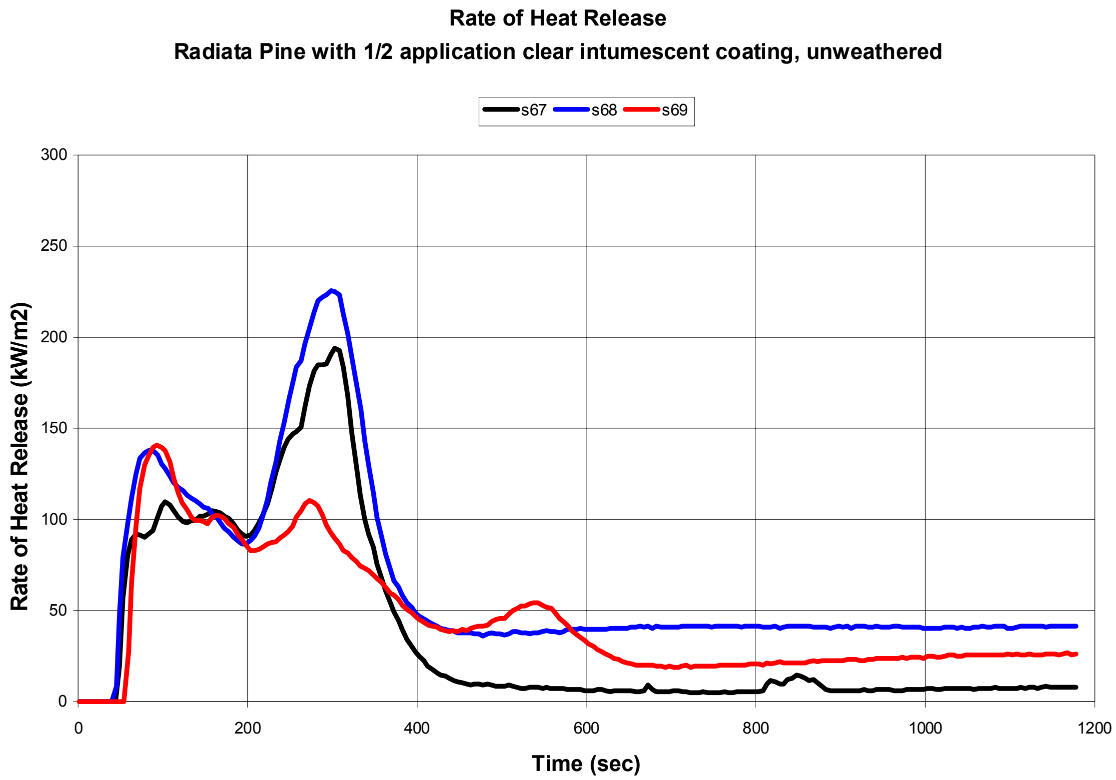

Figure 11: Heat Release Rate – System H

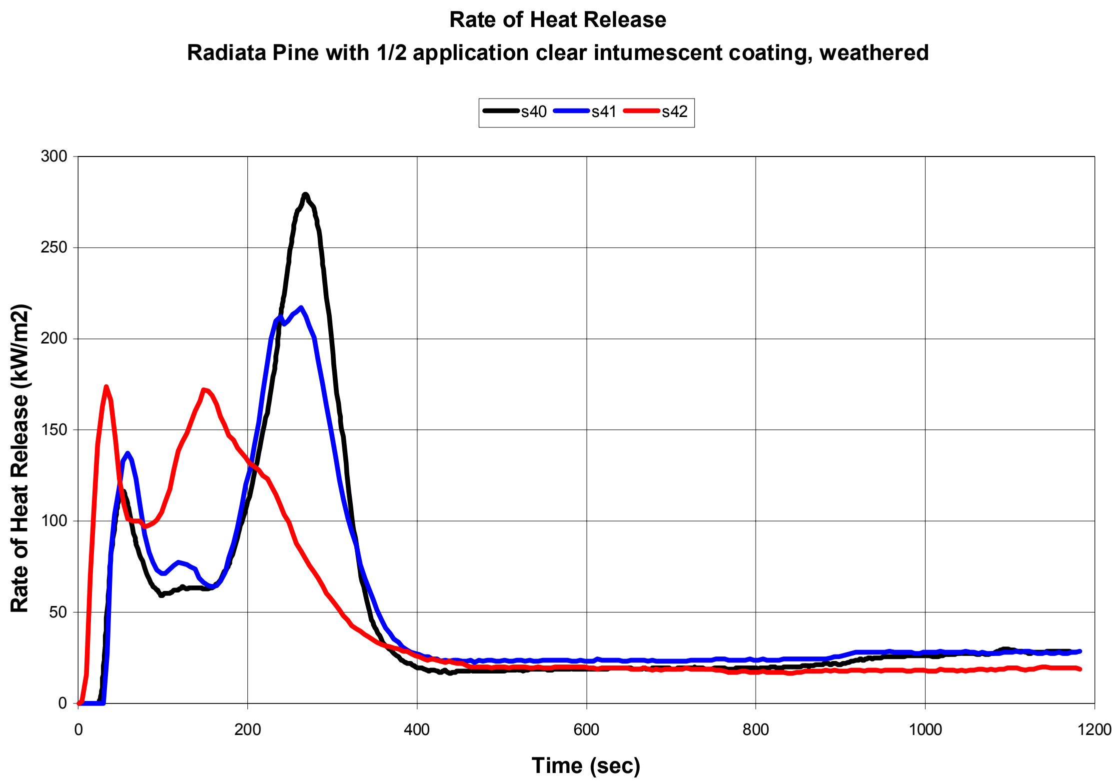

Figure 12: Heat Release Rate – System I

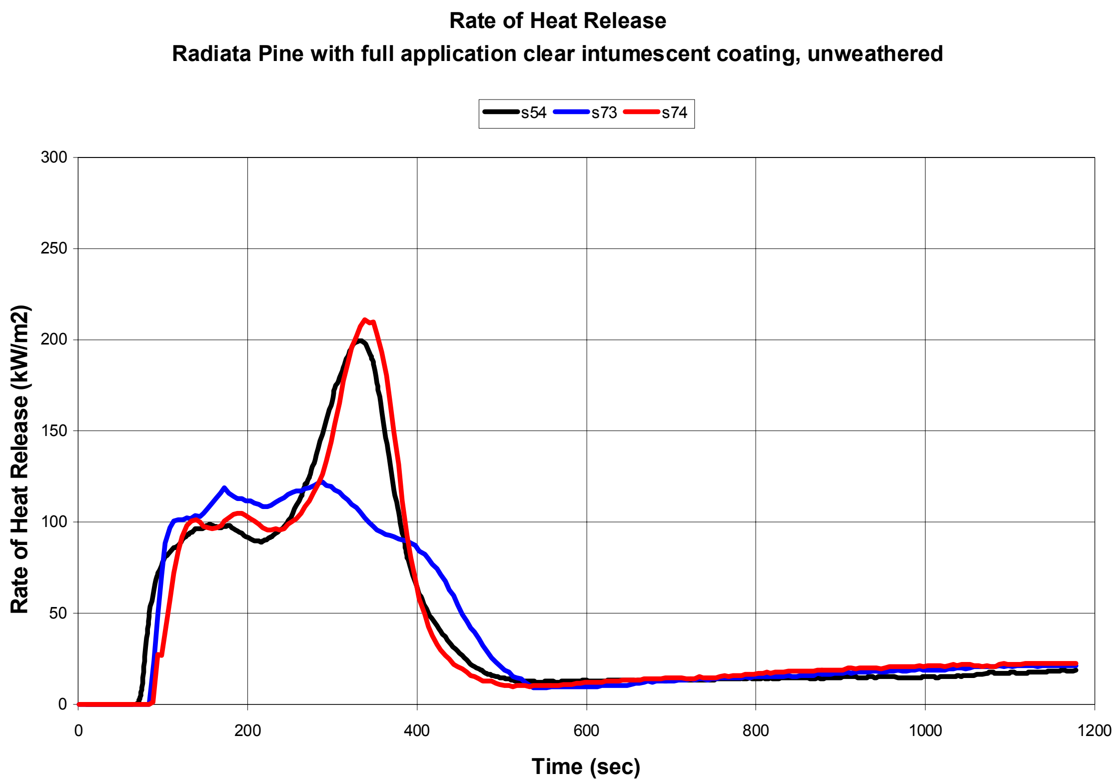

Figure 13: Heat Release Rate – System F

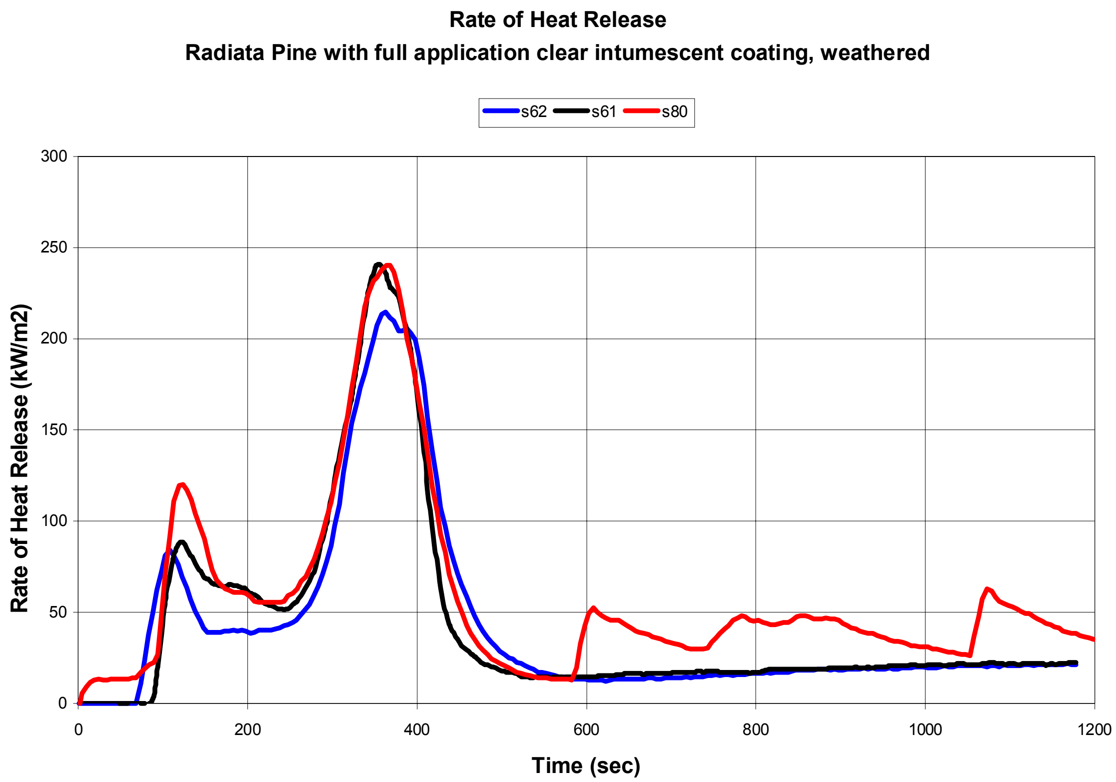

Figure 14: Heat Release Rate – System G

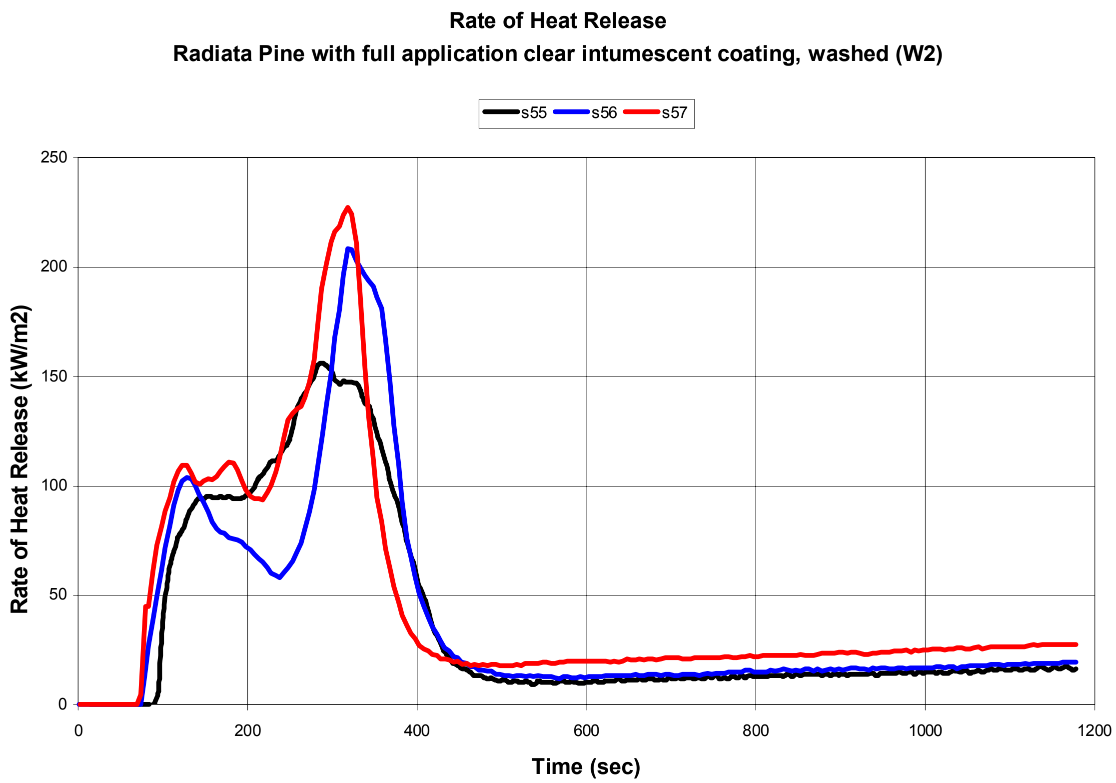

Figure 15: Heat Release Rate – System J

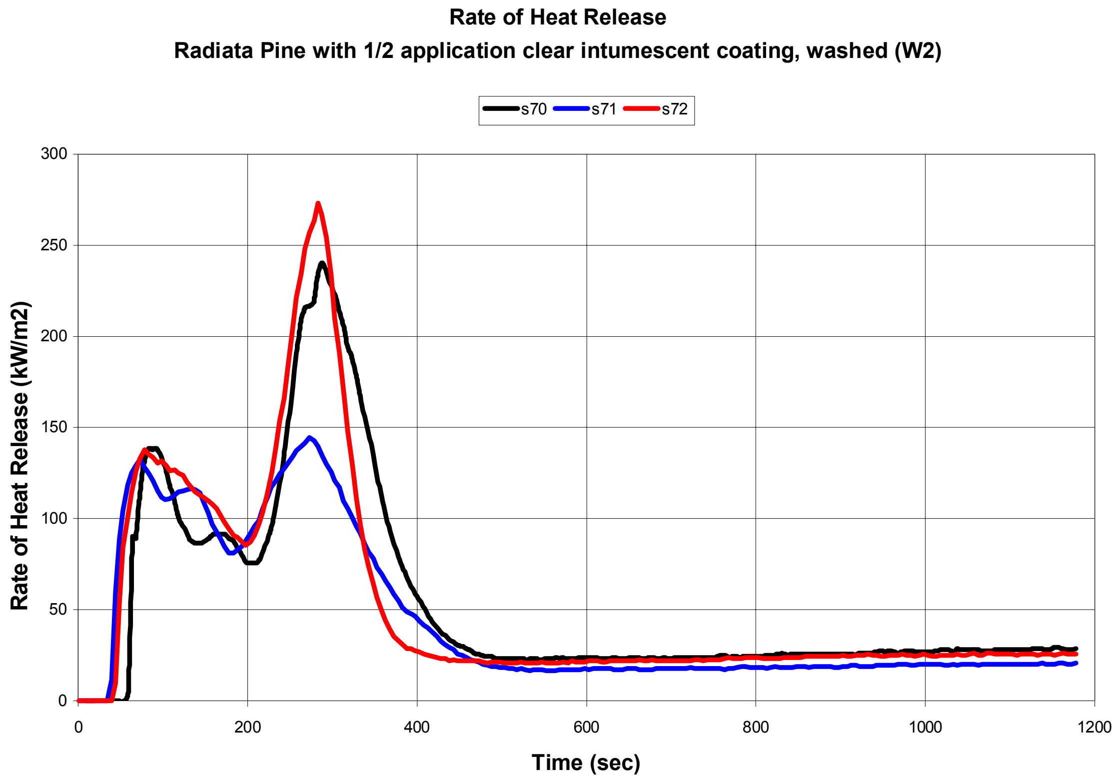

Figure 16: Heat Release Rate – System K

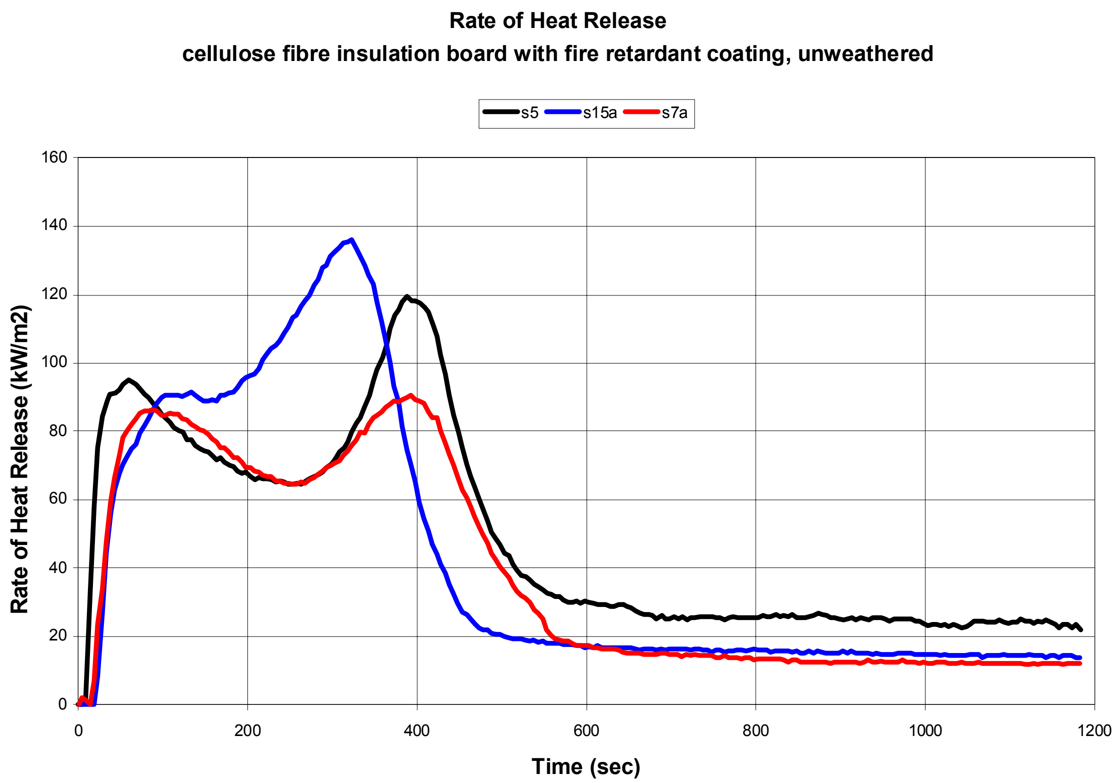

Figure 17: Heat Release Rate – System L

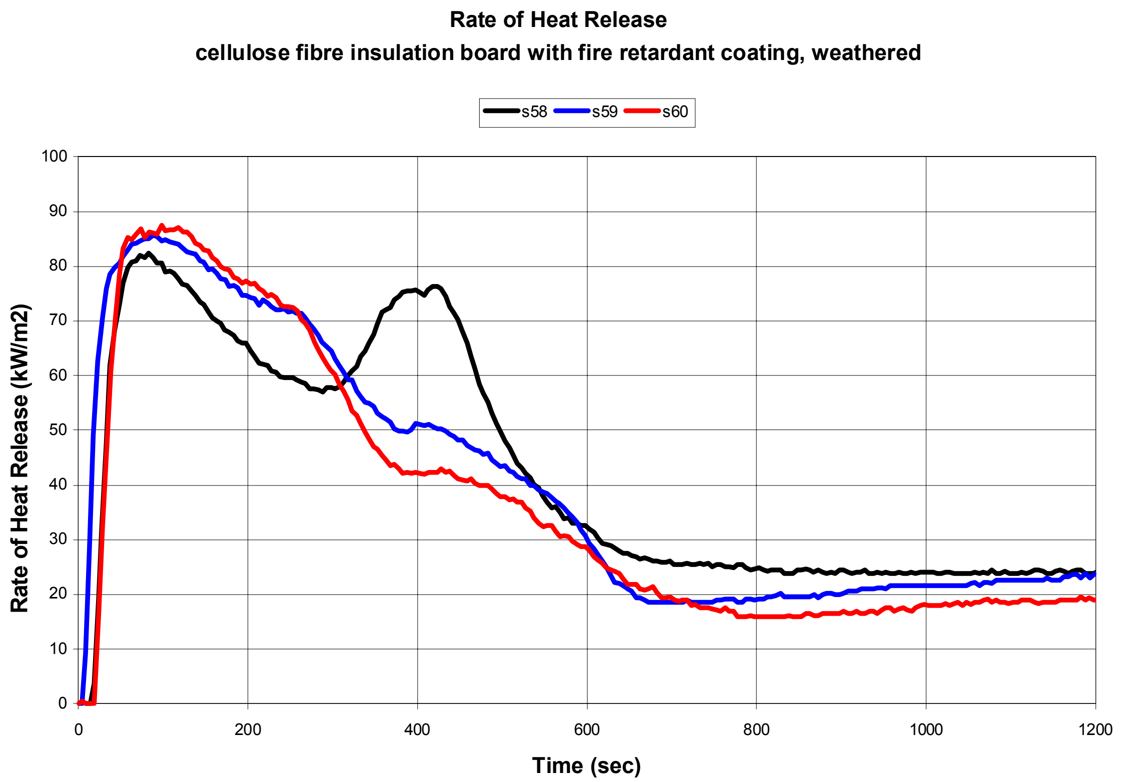

Figure 18: Heat Release Rate – System M

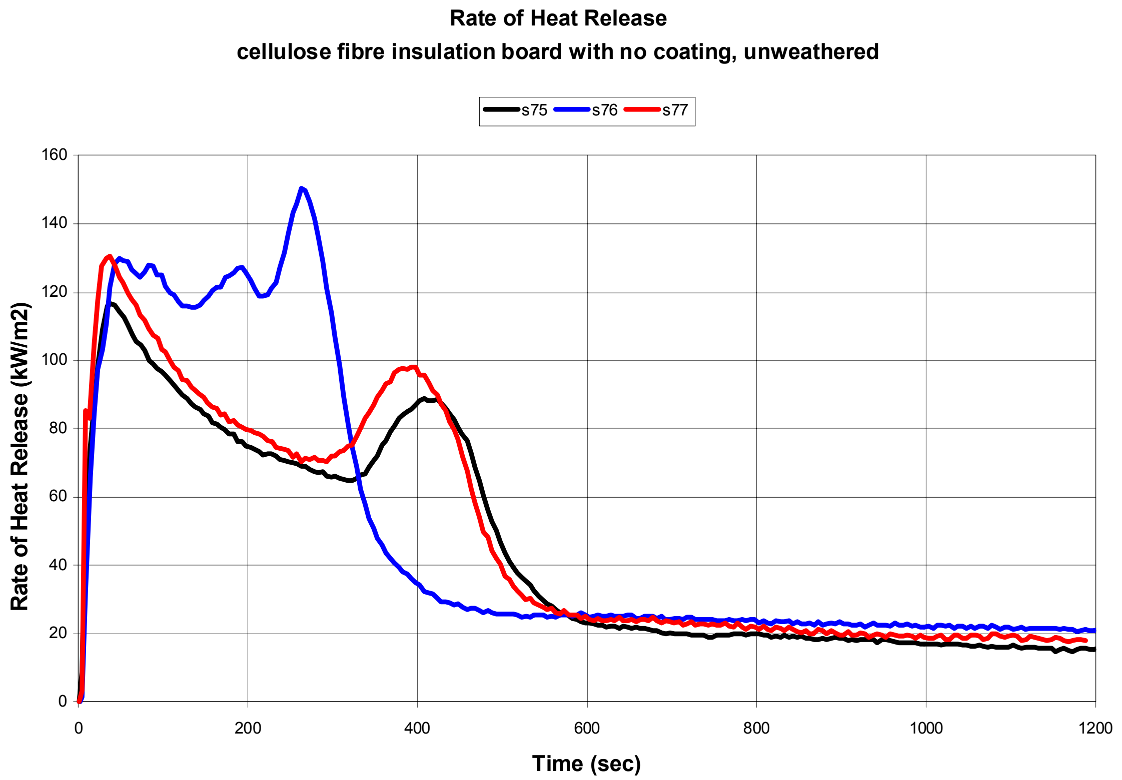

Figure 19: Heat Release Rate – System S

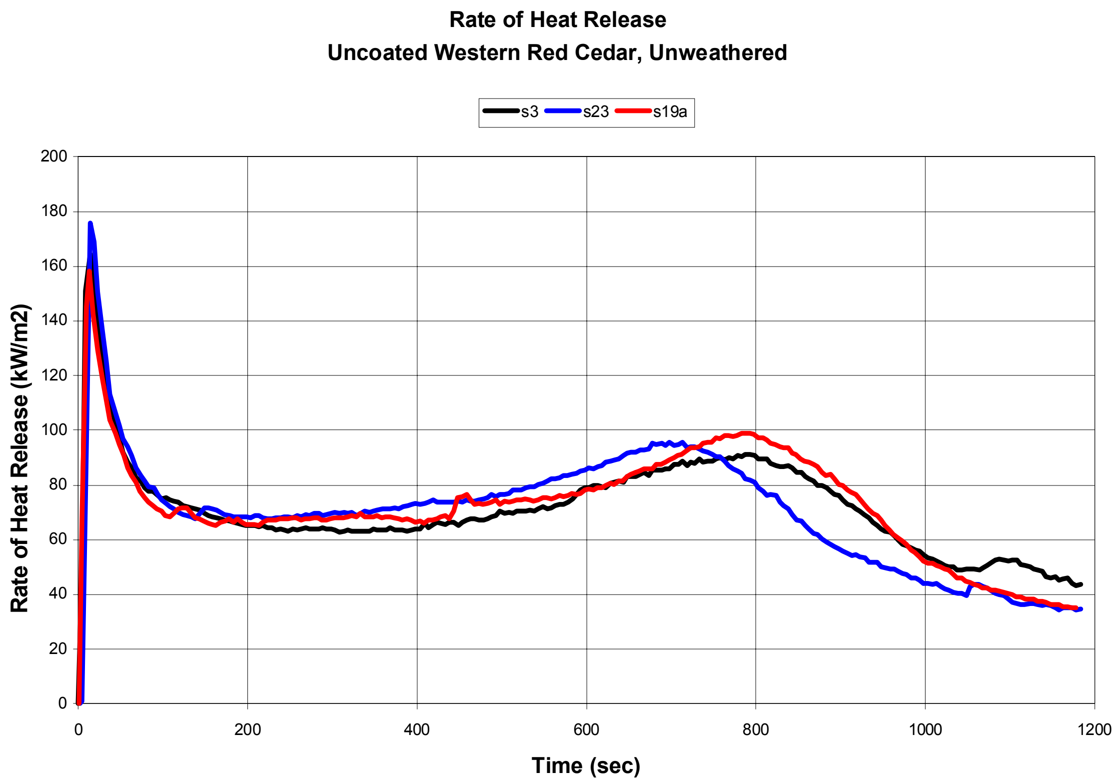

Figure 20: Heat Release Rate – System N

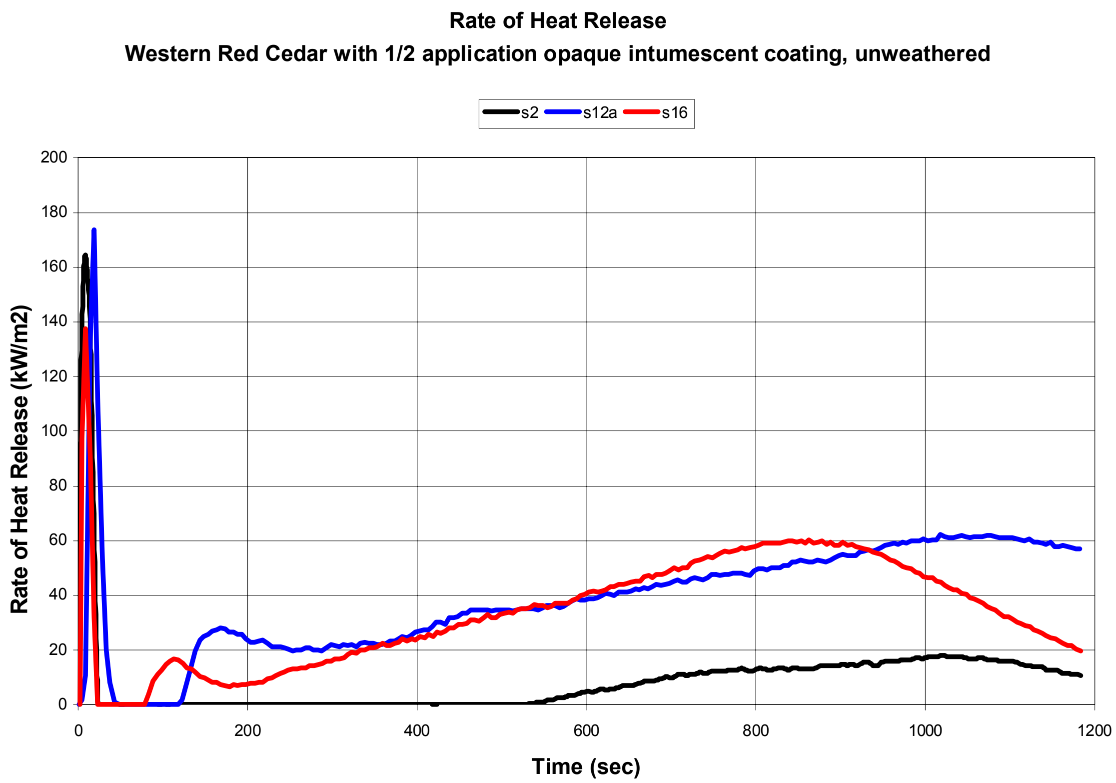

Figure 21: Heat Release Rate – System P

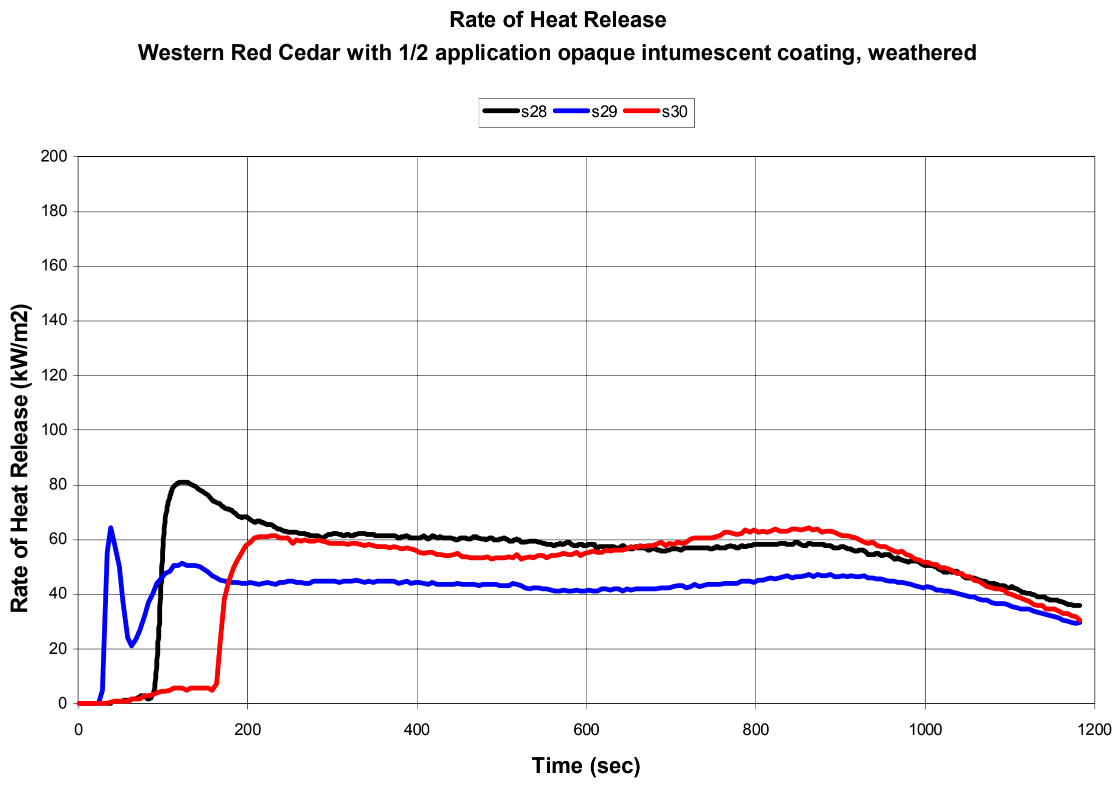

Figure 22: Heat Release Rate – System O

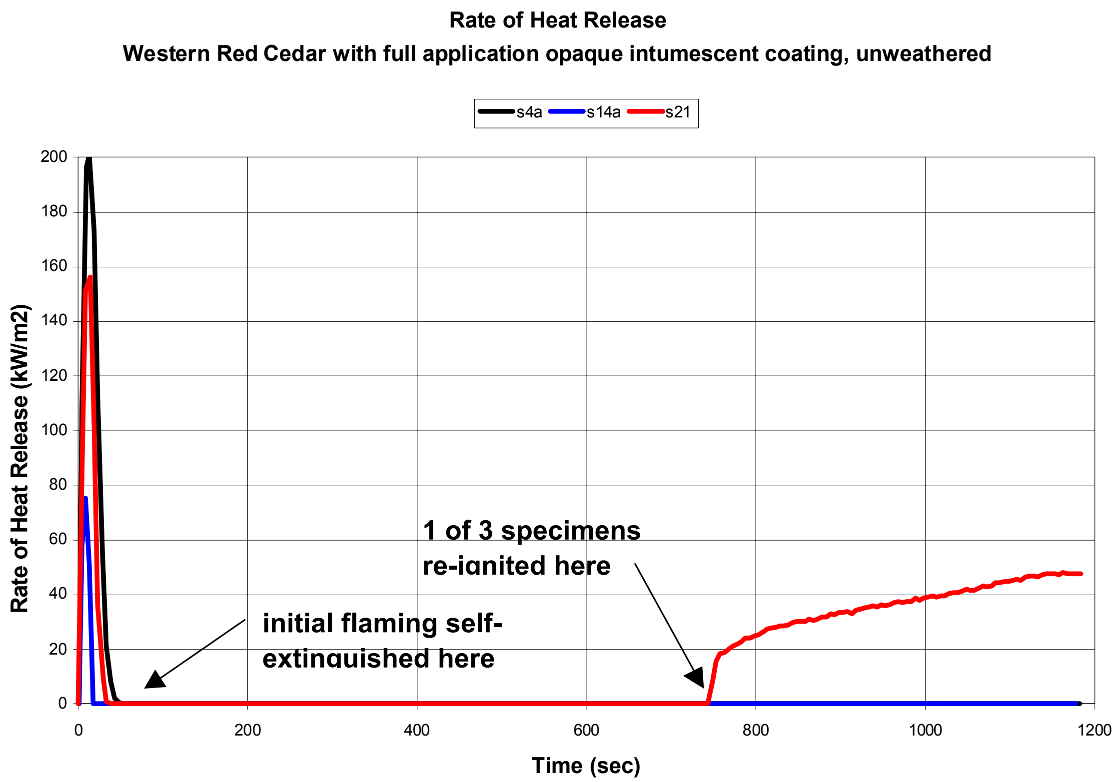

Figure 23: Heat Release Rate – System R

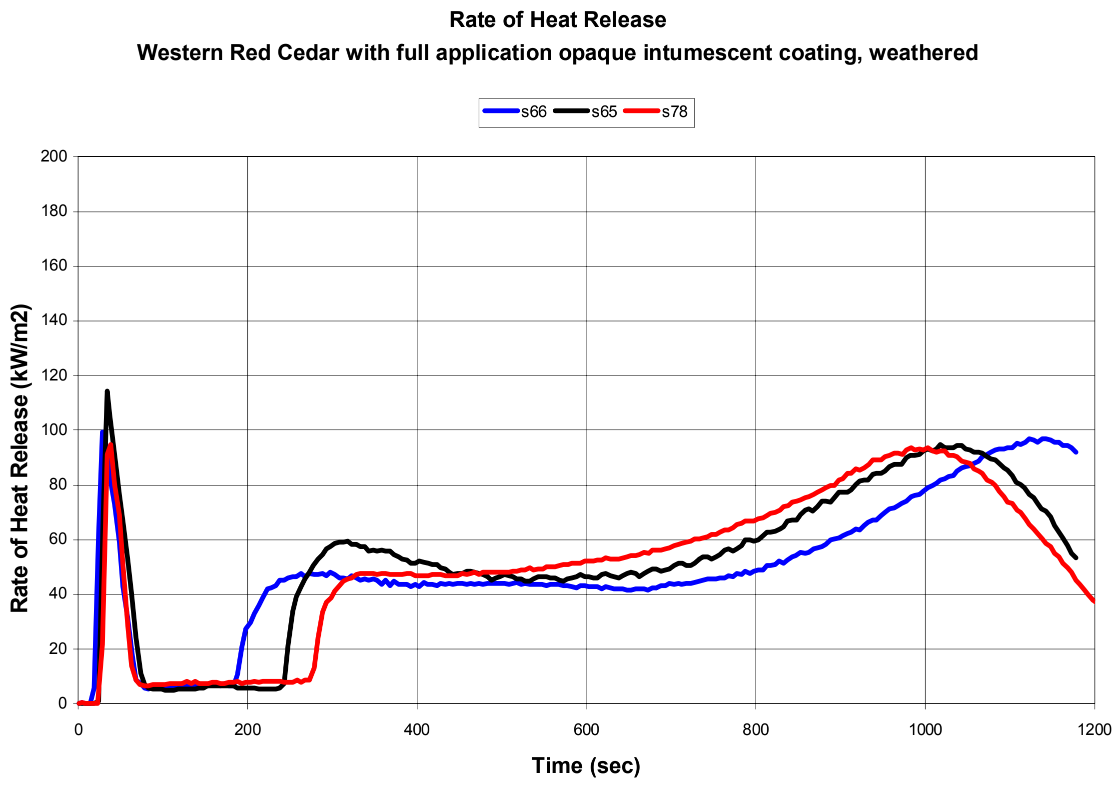

Figure 24: Heat Release Rate – System Q

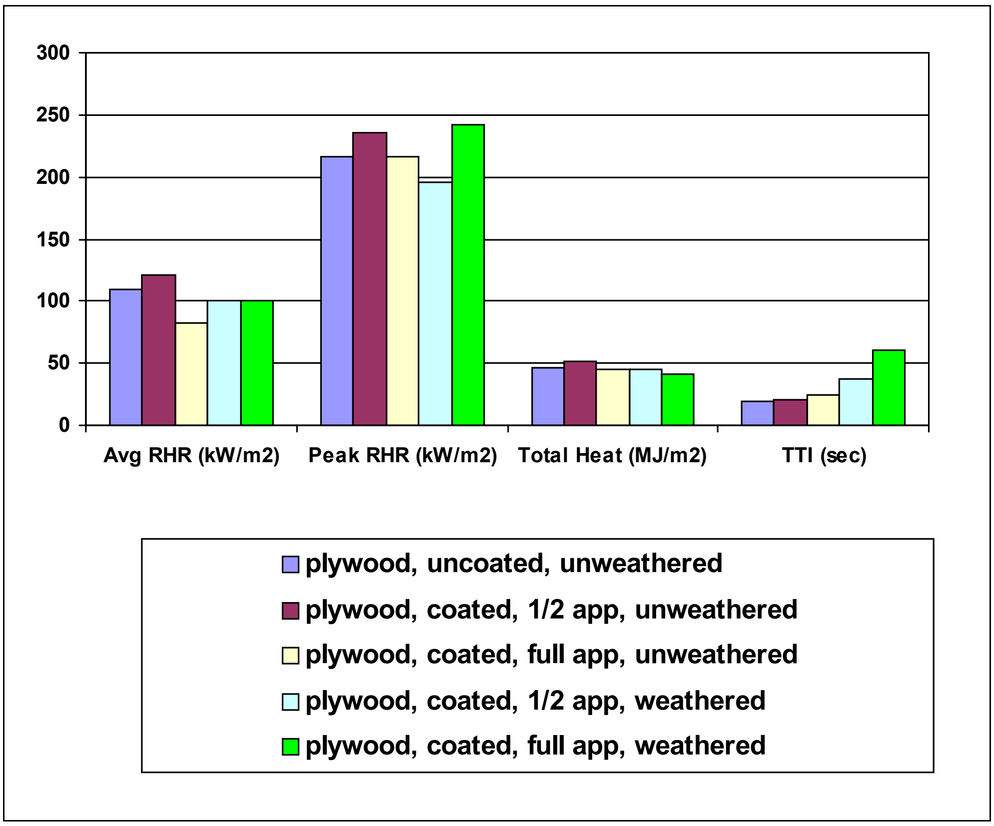

Figure 25: Radiata Pine Plywood, Opaque Intumescent Coating, Interior Use

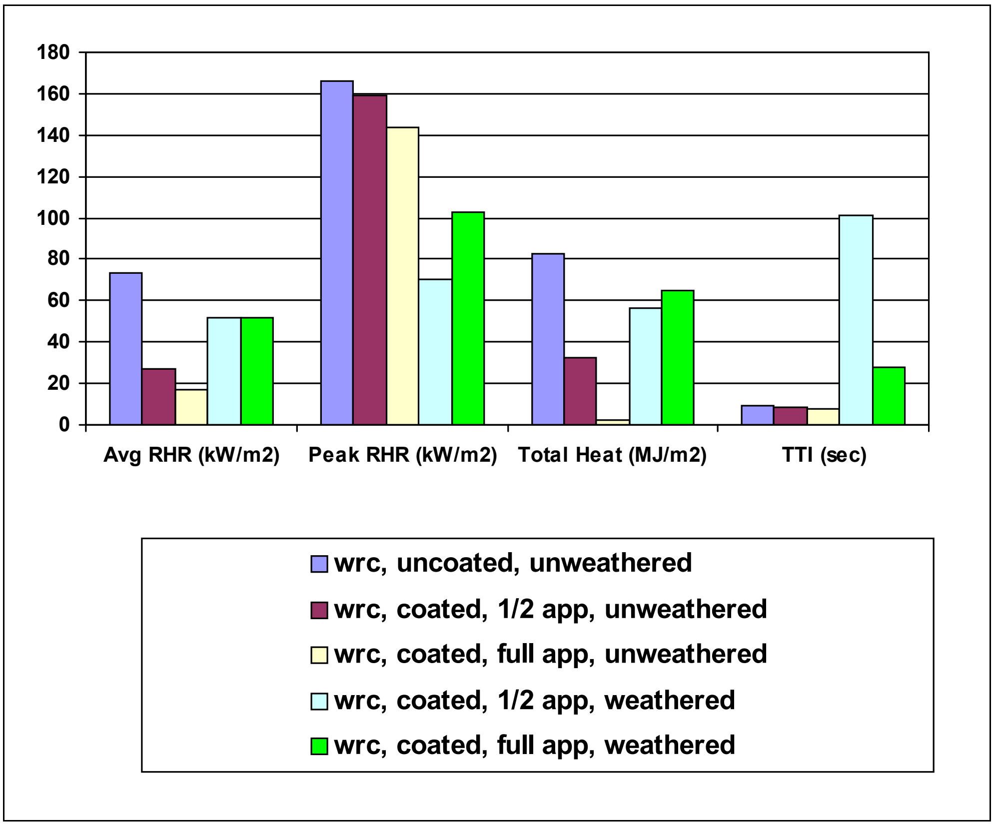

Figure 26: Western Red Cedar, Opaque Intumescent Coating, Exterior Use

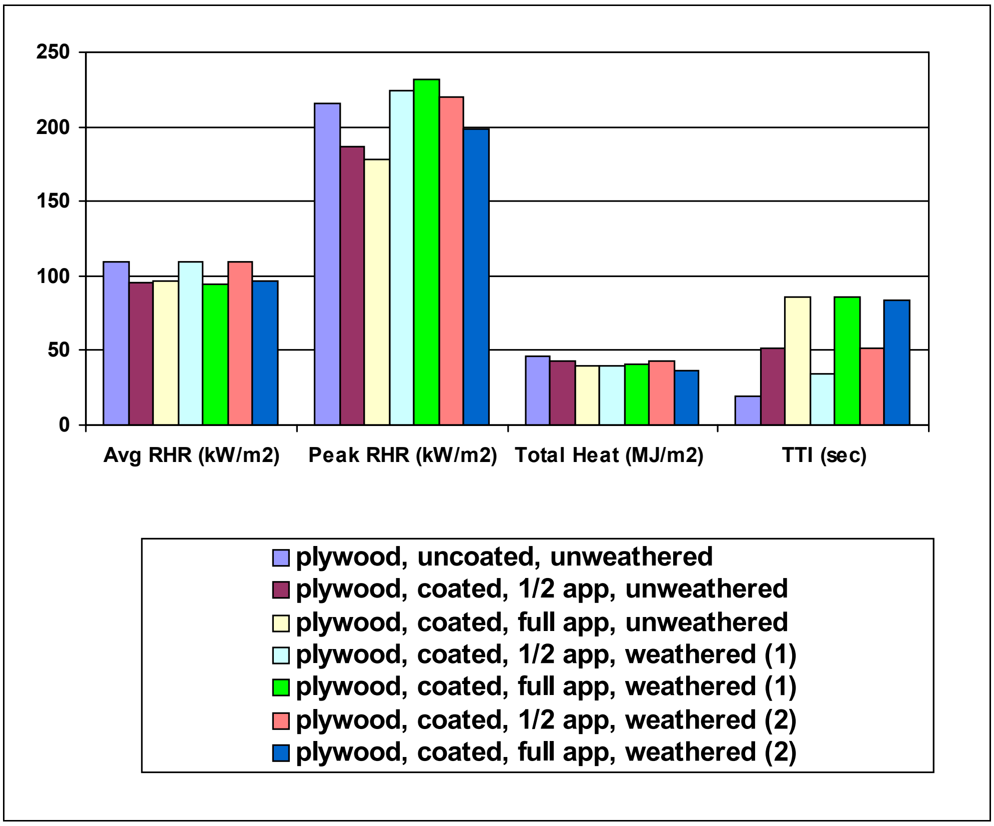

Figure 27: Radiata Pine Plywood, Clear Intumescent Coating, Interior Use

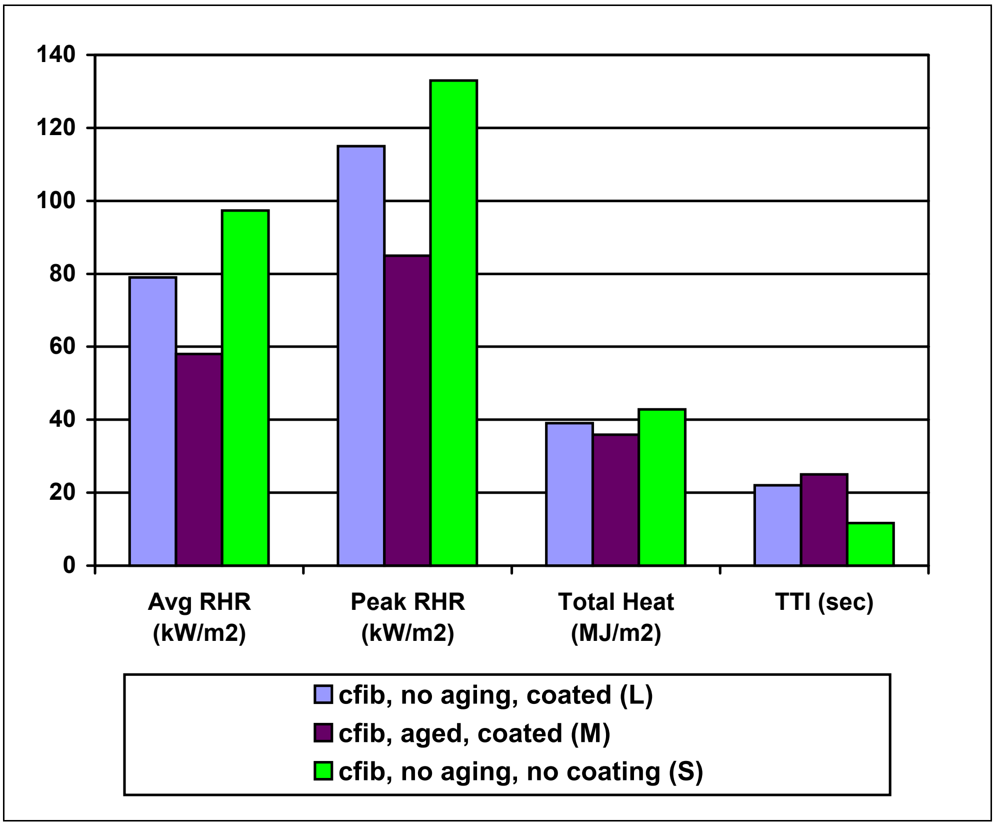

Figure 28: Cellulose Fibre Insulation Board with FR Coating, Interior Use

10.5.1 Time to Ignition

Short time to ignition values are often associated with fast surface flame spread behaviour for a material.

Although one of the opaque intumescent coating systems was designed for exterior use and the other for interior use, both had coating systems that were finished with acrylic-based topcoats. The purpose of the topcoats in both cases was to protect the intumescent base coats.

Ignition times for the exterior systems tended to be shorter than for the interior systems. This may have been due to the effect of the different substrates, with the trend for the western red cedar to ignite more readily than for the radiata pine plywood also being the case for the coated systems. For example, the mean time to ignition for the uncoated western red cedar was only 9 seconds compared to 20 seconds for the uncoated radiata pine plywood. Similar differences occurred for the opaque intumescent coated and weathered systems.

In both exterior systems, for a given substrate, there was very little difference in the time to ignition before weathering, irrespective of the half and full coating application rates of the intumescent base coats. For example, the unweathered half and full application on western red cedar (P and R) recorded a mean time to ignition of 9 and 8 seconds respectively. The unweathered half and full application on radiata pine plywood (B and D) recorded a mean time to ignition of 20 and 24 seconds respectively. Hence, the fact that both these systems showed similar trends both for weathered and unweathered samples implies that the time to ignition properties for these samples was mostly associated with the non-intumescent acrylic topcoat.

Also in both opaque systems, the time to ignition increased with weathering (see Figure 29 below). It is noticeable that the time to ignition for the weathered half coating for the exterior sample (system O – 101 seconds) appears to have increased more significantly than the time to ignition for the other weathered samples (Figure 26). However, the range of ignition times for these samples varied from 33 to 176 seconds, which has possibly inflated the average time to ignition for that sample. Of more interest is that the weathering of both the interior and exterior samples has increased or lengthened the time to ignition. When considering that the purpose of the acrylic topcoat is to protect the intumescent from the leaching effects of undue moisture, then these results reaffirm that the time to ignition and associated flame-spread properties are more reliant on the topcoat properties than they are on the intumescent base coat. Furthermore, as the interior weathering regime involved cyclic heat and moisture and the exterior regime involved heat, moisture and exposure to ultra violet (UV) radiation, this suggests that the UV exposure played a negligible effect on determining the ignition properties of the surface and coating system. This is not highly surprising considering that the exterior acrylic top coat that was used can give up to 12 years resistance to UV radiation and that the entire length of the UV exposure in the laboratory was only 2000 hours (a short time in durability testing terms). The increase in time to ignition may be due to the removal of residual combustible components from the paint film by washing/wetting during the weathering tests. The absorption of water indicated in Figure 4 may also be affecting the time to ignition results.

Figure 29 also suggests that the sample test results can be broken into four quadrants with the uncoated unweathered western red cedar samples displaying worst case scenario of low ignition time (9 seconds) and higher average rate of heat release (73 kW/m²). The unweathered coated samples (P, R) have lower average rate of heat release (27 and 17 kW/m² respectively) but also short ignition times (9 and 8 seconds respectively). Finally the weathered coated samples (O, Q) display longer ignition times (101 and 28 seconds respectively) but with higher average rate of heat release (both 52 kW/m²).

Figure 30 for the interior plywood samples coated with an opaque intumescent are not quite so easily categorised. This graph displays some improvement in the ignition times with weathering but does not suggest any change in average rate of heat release with either base coating thickness or weathering.

The trends in the time to ignition results of the clear interior intumescent paint system are less easy to interpret. The clear intumescent base coat system is known to be more susceptible to moisture degradation than the other opaque intumescent systems. As a corollary to that, it is important that the drying conditions are strictly controlled during application, although it is acknowledged that this would not be feasible in practice.

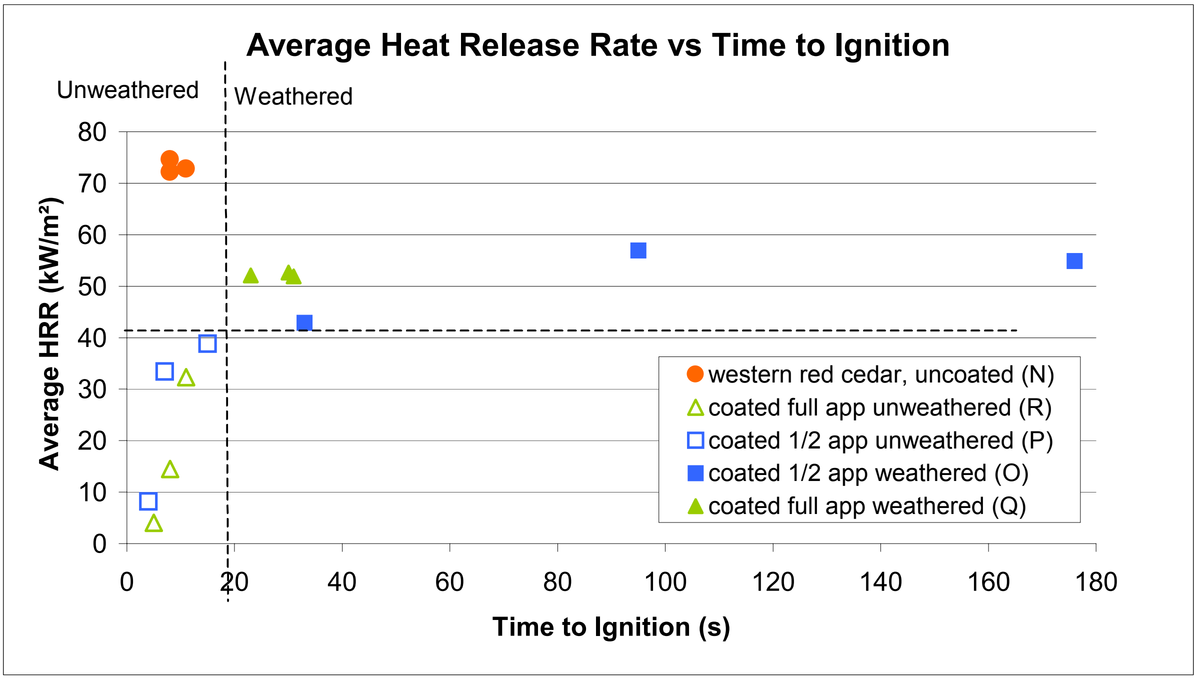

Figure 29: Comparison of Average RHR and Time to Ignition for the Exterior Western Red Cedar with Opaque Intumescent Coating

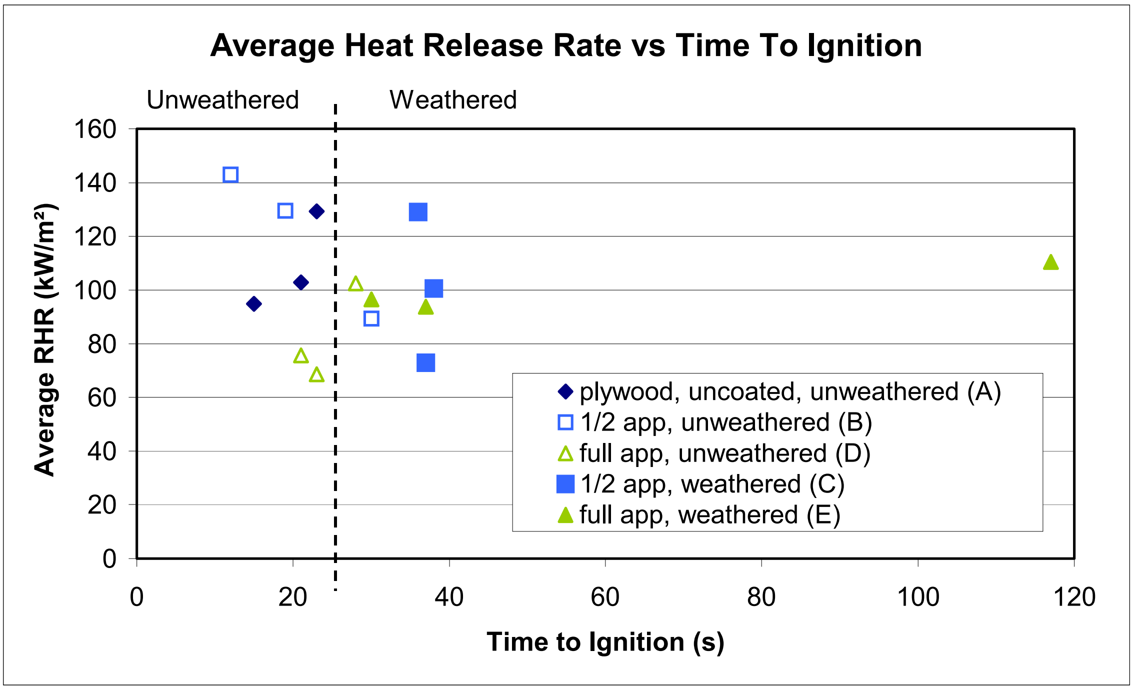

Figure 30: Comparison of Average RHR and Time to Ignition for the Interior Plywood with Opaque Intumescent Coating

All the sample types, weathered and unweathered with a full intumescent base coat applied (systems F, G and J) had time to ignitions (86, 80 and 84 seconds respectively) that were longer than the samples that had only the half application of base coat (systems H, I and K – ignition times were 52, 34 and 51 seconds respectively). Also there appeared to be no significant difference between the mean time to ignition results between the unweathered, weathered (W1) and washed (W2) samples. Similarly the three sample types with a half coating of the intumescent paint all had average ignition times greater than that for the uncoated substrate but significantly less than those for the fully coated samples (Figure 27). This suggests that the intumescent coating system and not the weathering played a greater part in affecting the time to ignition properties of these samples. One explanation for this is that the transparency of this coating system allowed the radiative heat from the cone heater to penetrate through to the intumescent and substrate faster, thereby delaying the rate at which the relatively flammable top layer heated up and ignited. As for the negligible effect of the weathering, the unweathered samples may have been equivalently affected by environmental moisture, during conditioning or drying, as the weathered sample, but the reason is not certain.

It is also interesting to note that similar ignition times were found for both interior weathering regimes, which suggests that the shorter manual washing test may be just as significant as the longer fluctuating humidity test. If this is the case, the durability of such coatings could be established more quickly and cheaply, simply with the washing test rather than with the more traditional cyclic humidity tests. However, more extensive comparisons of these two weathering regimes would be required to confirm this conclusion.

The cellulose fibre insulation board coated with a factory applied ablative coating showed (Figure 28) that both the weathered and unweathered coated samples had ignition times greater than that of the uncoated board. It is not surprising that there was no significant difference in the ignition times for the weathered and unweathered samples as the ablative coating system is not moisture sensitive. However in most cases the time to ignition or protection afforded by this thin layer ablative coating was less than for the intumescent coating systems.

10.5.2 Heat Release Rates

There was little to no difference in the total heat released for the plywood samples (Figure 25 and Figure 27), irrespective of the clear or opaque intumescent coating or the weathering/aging regime used. The coated systems recorded total heat release in the range 36 – 43 MJ/m^2 depending on weathering and application rate, while the total heat evolved for the uncoated control sample was just slightly higher at 46 MJ/m^2. This indicates that once burning had proceeded through to the substrate, the plywood behaved similarly in all cases. While this result is not strictly crucial it does mean that reliance can be placed on the comparison between plywood samples.
No statistically significant difference was found in the average rate of heat release between any of the plywood samples. Similarly no real difference was found between the peak rate of heat release of the plywood samples. The average rate of heat release is determined from the total heat released over the time between ignition and the end of the test, and the peak rate of heat release gives the maximum rate of heat release over this time. This suggests that once ignition has occurred the average rate of heat release is determined by the properties of the substrate and not the coating system used. So aside from delaying ignition, these results would question the effectiveness of using a fire coating system with an acrylic topcoat as a means of improving flame spread

properties for interior substrates. It is also worthy of note that none of the interior intumescent coating systems prevented the substrate from eventually burning.
However, the exterior coating system did appear to afford the western red cedar better protection (Figure 26). Both the unweathered full- and half-coated samples had a significantly lower average rate of heat release (17 and 27 kW/m² respectively) than the uncoated sample (73 kW/m²). However the average rate of heat release did increase for both the full- and half-coated samples after weathering (both 52 kW/m²) which suggests that even though the weathering appeared to delay the ignition times, it still adversely affected heat release rate following ignition. Of particular note are the fully coated unweathered samples in which burning appears to have been halted shortly after ignition although the high smoke extinction value suggests the sample displayed ongoing smouldering. This appears to correlate with the rate of heat release profiles seen in Figure 23.
Even though there is no statistical difference in the total rate of heat release between the cellulose fibre insulation board (CFIB), the weathered CFIB samples have significantly lower average and peak HRR values (see Figure 28). This could be due to the thinness of the factory-applied finish which may have allowed water to be absorbed through the coating and into the board.
Figure 31 compares the results using the different weathering regimes for plywood samples coated with a clear intumescent coating. From a graphical comparison of selected ratios, there appears to be no significant difference between the results from the cone calorimeter obtained with the washing or cyclic humidity/temperature processes (see Figure 31). This implies that the quicker and simpler washing method is able to simulate rapid ageing reasonably well. Some caution should be taken with this result as it has only been tested with one combination of coating and substrate.

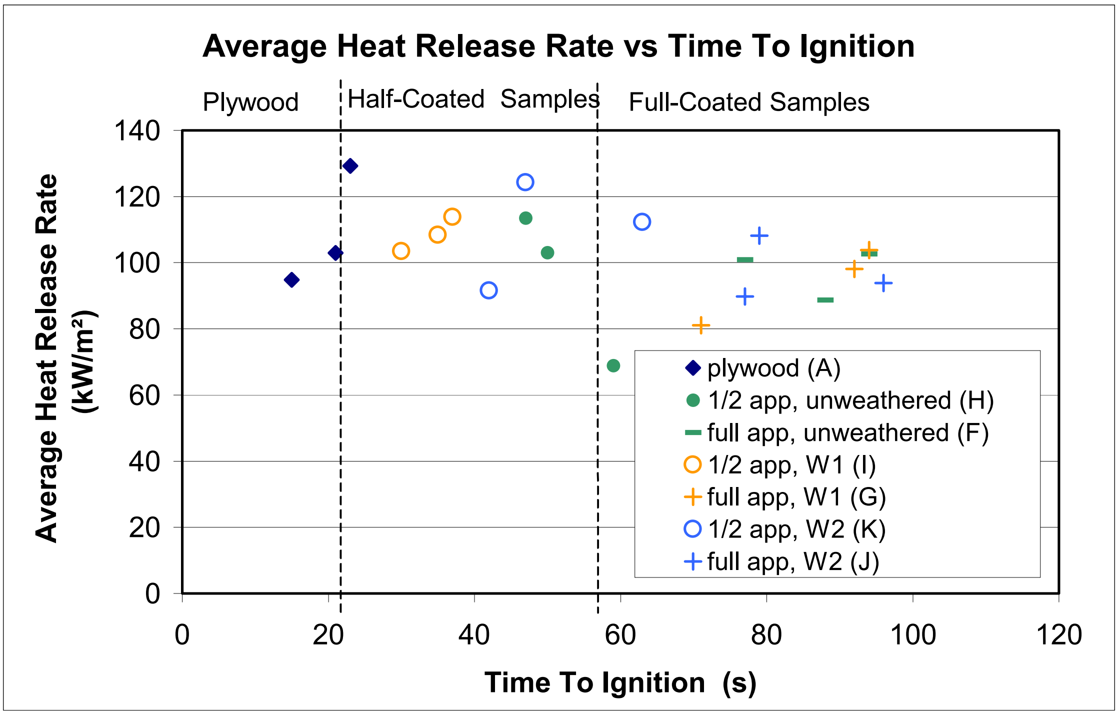

Figure 31: Comparison of Average RHR with Time to Ignition for the Interior Plywood Clear Intumescent Samples

10.6 Physical Effect of Weathering on Topcoat

The above discussion emphasised the importance of the condition of the topcoat layer on the overall fire properties of the intumescent coating. This is not entirely surprising as the topcoat provides the first line of defence for the intumescent basecoats against chemical and physical environmental effects. The performance and durability of topcoats is essential to the long-term performance of substrates coated with intumescent paint systems.

Paint coatings subject to exterior weathering conditions experience weathering effects that cannot necessarily be recreated in a laboratory environment. These weathering effects include physical erosion by wind-blown particles and other climatic effects such as hail. It is well documented that these types of weathering effects cause physical deterioration of the painted topcoats of exterior surfaces. It is expected that exterior claddings should be durable for at least 25-35 years hence it is recommended that exterior surfaces be repainted at regular intervals, usually every 8-10 years. This practice is important to the findings of this report as, if only the acrylic topcoat, proprietary or otherwise is recoated, then this is likely to worsen the protection afforded by the intumescent undercoat due to a build-up of non-fire resistant paint on the surface. As demonstrated in the above results and in previous papers (Alexiou 1986, Saxena and Gupta, 1990) a coating of acrylic topcoat supplies enough fuel for ignition to lead to sustained burning. Therefore additional layers of acrylic topcoat will supply further fuel which could negate the protective effect of any fire-retardant paint. This is based on the assumption that the intumescent paint itself will not suffer any significant ageing/performance effects.

Consequently, this suggests that the entire intumescent system may need to be reapplied at the same regular intervals. Even without considering the other problems associated with the application of intumescent systems, the cost alone may preclude the use of this system as a means of fire protection for exterior wooden substrates. Furthermore the effectiveness of further coatings of intumescent paints may be negated as any additional coatings are adhered onto the previous coats rather than to the substrate. This is likely to lead to the protective coatings prematurely failing in a fire situation.

10.7 Summary

The effect of varying the application rate of an intumescent base coat to half that of the manufacturers recommended rate was mainly to reduce the time at which the substrate material starts to burn and contribute heat release. This effect was most pronounced for the western red cedar with opaque intumescent coating, and least pronounced for the radiata pine with the clear intumescent coating.

The effect of accelerated ageing, using temperature and humidity cycling representative of interior environments, was to slightly reduce the heat release rate and delay ignition. Overall fire performance characteristics were similar or slightly improved after accelerated ageing.

The effect of accelerated weathering, using temperature, humidity and ultra-violet light representative of exterior environments, was mainly to reduce the time at which the substrate material starts to burn and contribute heat release. Overall fire performance characteristics were significantly decreased after weathering.

11. IMPLICATIONS FOR REGULATORY CONTROL

11.1 Interior Linings

Recently, the Fire Code Reform Centre in Project 2A (FCRC, 1998) concluded that time to flashover in the ISO 9705 (ISO, 1993) room was the appropriate parameter to use for regulatory purposes for interior walls and ceilings. Time to flashover was defined as the time taken for the heat release rate to reach 1 MW from the ISO room. The research proposed that wall and ceiling materials be grouped into one of four categories[i] based on this time to flashover parameter (when tested in the ISO 9705 standard room test) as follows (see also Figure 32):

A: materials that result in flashover in less than 120 seconds

B: materials that result in flashover in more than 120 seconds but less than 600 seconds

C: materials that result in flashover in more than 600 seconds

D: materials that do not result in flashover

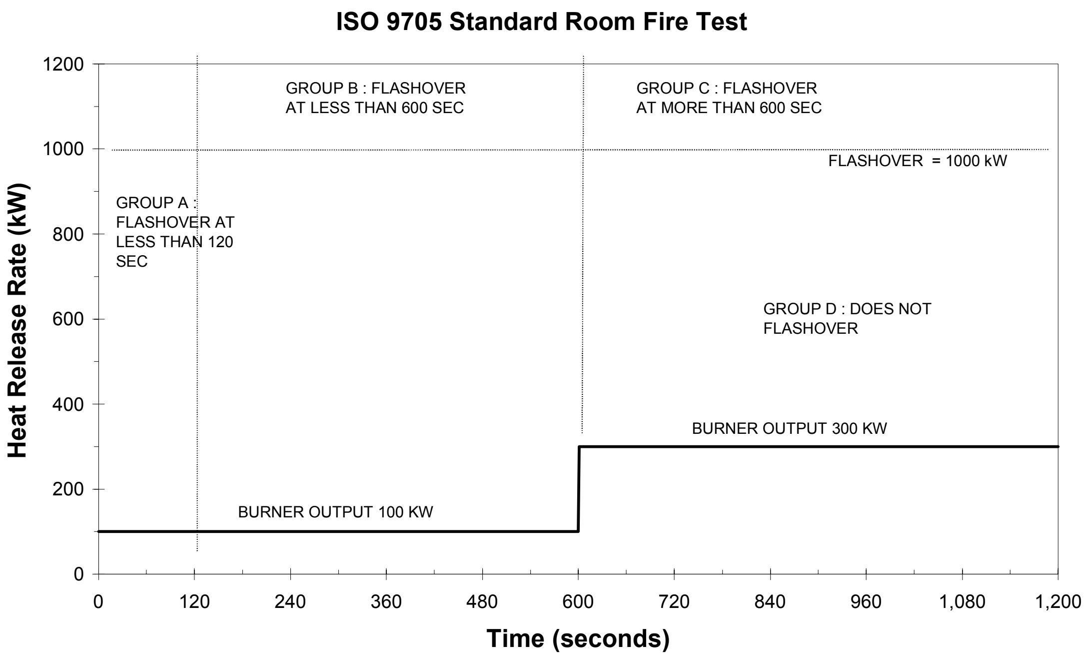

Figure 32: Proposed FCRC Project 2A Classification System

[i] It is understood that a technical working group for FCRC Project 2A has proposed that the A-D classification order be changed to 1–4, such that '1' would be the best performing classification and '4' would be the worst. The classification system as referenced in this report is according to the definition in the text above, i.e. 'A' is the poor performer , while 'D' is the best.

They also concluded that it was acceptable for small-scale test results to be used in conjunction with a mathematical model in order to predict the time to flashover in the ISO room fire test, as an alternative to carrying out the large-scale test.

They identified that the cone calorimeter test was able to provide appropriate small-scale fire test data for predicting time to flashover in the room corner test. They reviewed the SP model (Wickström and Göransson, 1992), the Classification Index proposed by Kokkala et al (1993) and the Östman relationship (Östman and Tsantaridis, 1994) and concluded that the Classification Index of Kokkala was the most suitable method for use with routine testing of many wall and ceiling linings.

Kokkala's classification index uses data from the Cone Calorimeter at an irradiance level of 50 kW/m^2. An ignitability index is determined as the inverse of the time to ignition, $I_{ig} = 1/t_{ig.}$

Time to ignition is defined as the moment when the recorded heat release rate is 50 kW/m^2. This definition is used in preference to the observed/reported time to ignition in the Cone Calorimeter test.

A rate of heat release index, I_Q, is also calculated and is given by the following integral, where t_f is the time at the end of the test, $\dot{q}''(t)$ is the measured rate of heat release as a function of time, and *m* is an exponent taken as either 0.34 or 0.93 as described below.

$$I_Q = \int_{t_{ig}}^{t_f} \left[\frac{\dot{q}''(t)}{\left(t - t_{ig}\right)^m} \right] dt$$

The classification procedure works as follows.

If $I_Q > 6800 - 540\, I_{ig}$ (using $m = 0.34$), and $I_Q > 2475 - 165\, I_{ig}$ (using $m = 0.93$) then a time to flashover in the ISO 9705 test of less than 2 minutes is predicted and the material is classified as – '**A**'.

If $I_Q > 6800 - 540\, I_{ig}$ (using $m = 0.34$), and $I_Q \leq 2475 - 165\, I_{ig}$ (using $m = 0.93$) then a time to flashover in the ISO 9705 test of between 2 and 10 minutes is predicted and the material is classified as – '**B**'.

If $I_Q \leq 6800 - 540\, I_{ig}$ (using $m = 0.34$), and $I_Q > 1650 - 165\, I_{ig}$ (using $m = 0.93$) then a time to flashover in the ISO 9705 test of between 10 and 20 minutes is predicted and the material is classified as – '**C**'.

If $I_Q \leq 6800 - 540\, I_{ig}$ (using $m = 0.34$), and $I_Q \leq 1650 - 165\, I_{ig}$ (using $m = 0.93$) then it is predicted that flashover will not occur in the ISO 9705 test and the material is classified as – '**D**'.

This classification system has been applied to the materials/coatings investigated in this research and the results are shown in Table 20.

The results are somewhat surprising. For both the clear and opaque intumescent coatings on a plywood substrate, the classification using Kokkala's method does not change. Simulated ageing of the coatings, using the controlled humidity/temperature chamber, also does not change the classification. In all cases, including the bare uncoated plywood, a 'B' classification applies indicating a predicted time to flashover of between 2 and 10 minutes in the ISO 9705 room corner test.

The same results applied to the cellulose fibre insulation board with and without the factory-applied fire-retardant coating, and also after simulated ageing of the coating. Again, a 'B' classification applied.

In the case of the western red cedar substrate, adding a fresh intumescent coating either at the recommended application rate or at one-half the recommended rate, did not change the 'A' classification, indicating a predicted time to flashover of less than 2 minutes in the ISO 9705 room corner test. However after simulated weathering in the QUV weatherometer, the classification generally changed (for the better) from an 'A' to a 'B'. It is noted that the classification system was developed for interior wall and ceiling linings, and not exterior claddings, however, we have applied it to external cladding here for interest and for comparison with the other substrates and coatings.

It is not known how well Kokkala's method works with fire-retardant coatings. For example system R achieves the worse classification with flashover in the ISO room expected within 2 minutes. However, Figure 23 shows that although the time to ignition is very quick, the burning duration is also relatively short and that in the main the substrate does not become significantly involved. The total energy release over the test duration was only 2.4 MJ/kg compared to 82.8 for the uncoated western red cedar thus there appears to be a significant improvement in the fire behaviour with the coating but this is not reflected in Kokkala's classification.

Kokkala et al (1993) determined indices for 11 EUREFIC products and 13 Scandinavian products for which full-scale ISO room test data and small-scale cone calorimeter data was available. The products covered a wide range of interior lining materials but none of the materials fall into the category of a fire-retardant coating on a timber substrate. It is concluded here that full-scale ISO 9705 room test data is required for fire-retardant coatings to more clearly establish the adequacy of the Kokkala classification method for these types of products.

Table 20: Kokkala's Classification Index

ID	Substrate	Coating	Project 2A - Kokkala's Classification Index (for each of 3 replicates)
A	radiata pine plywood	none, unweathered	B,B,B
B	radiata pine plywood	opaque intumescent system (½ application rate), unweathered	B,B,B
C	radiata pine plywood	opaque intumescent system (½ application rate), weathered	B,B,B
D	radiata pine plywood	opaque intumescent system (full application rate), unweathered	B,B,B
E	radiata pine plywood	opaque intumescent system (full application rate), weathered	B,B,B
F	radiata pine plywood	clear varnish intumescent system (full application rate), unweathered	B,B,B
G	radiata pine plywood	clear varnish intumescent system (full application rate), weathered	B,B,B
H	radiata pine plywood	clear varnish intumescent system (½ application rate), unweathered	B,B,B
I	radiata pine plywood	clear varnish intumescent system (½ application rate), weathered	B,B,B
J	radiata pine plywood	clear varnish intumescent system (full application rate), weathered	B,B,B
K	radiata pine plywood	clear varnish intumescent system (½ application rate), weathered	B,B,B
L	cellulose fibre insulation board	factory-applied fire-retardant coating, unweathered	B,B,B
M	cellulose fibre insulation board	factory-applied fire-retardant coating, weathered	B,B,B
N	western red cedar	none, unweathered	A,A,B *
O	western red cedar	opaque intumescent system (½ application rate), weathered	B,B,B *
P	western red cedar	opaque intumescent system (½ application rate), unweathered	A,A,B *
Q	western red cedar	opaque intumescent system (full application rate), weathered	B,B,B *
R	western red cedar	opaque intumescent system (full application rate), unweathered	A,A,A *
S	cellulose fibre insulation board	none, unweathered	B,B,B

* classification may not be strictly applicable to external claddings, but shown here for information.

11.2 Alternative Flame-Spread Model

An alternative flame-spread model was developed by Cleary and Quintiere (1991) and then used by McGraw and Mowrer (1999) for assessing the flammability of painted gypsum wallboard subjected to heat fluxes. This may also have applicability to the flammability of fire-retardant coatings. This model produces a flammability parameter defined as:

$$b = k\dot{Q}'' - (t_{ig} / t_b) - 1$$

where: k = characteristic flame length coefficient (~0.01 m^2/kW)

$\dot{Q}'' =$ characteristic heat release rate per unit area [peak] (kW/m^2)

$t_{ig} =$ characteristic ignition time [in the cone] (s)

$t_b =$ characteristic burning duration [$= Q''/\dot{Q}''$] (s)

$Q'' =$ characteristic heat release per unit area from ignition (kJ/m^2)

According to this model, acceleratory flame spread is indicated when the value of the flammability parameter (*b*) is positive, and decay to extinction is expected if the flammability parameter is negative, and steady propagation if the value is close to zero (McGraw and Mowrer, 1999; Mower, 2001).

Table 21: Flammability Parameter for Products at Irradiance of 50 kW/m²

System ID	Peak RHR (kw/m^2) $\dot{Q}''$	Total Heat Release (kJ/m^2) Q''	Time to Ignition (s) t_{ig}	Burning Duration (s) t_b	Flammability Parameter b
A	216	46300	20	214	1.07
B	236	51300	20	217	1.27
C	196	44800	37	229	0.80
D	216	45700	24	212	1.05
E	242	41700	61	172	1.07
F	178	39200	86	220	0.39
G	158	39900	80	253	0.26
H	187	43200	52	231	0.64
I	224	40000	34	179	1.05
J	198	36400	84	184	0.52
K	220	43200	51	196	0.94
L	115	39100	22	340	0.09
M	85	35900	25	422	-0.21
N	166	82800	9	499	0.64
O	70	56500	101	807	-0.43
P	159	32200	9	203	0.55
Q	103	65200	28	633	-0.01
R	144	2400	8	17	-0.04
S	133	42800	12	322	0.29

Therefore, using this model of flame-spread, only systems M, O, Q and R are expected to show little or no flame spread when exposed to an irradiance of 50 kw/m^2. M is the cellulose fibre insulation board with fire-retardant coating <u>after</u> weathering; Q and R are the western red cedar with a full application of an opaque intumescent coating, weathered and unweathered respectively, while O is the western red cedar with one-half the recommended application rate of an opaque intumescent coating, <u>after</u> weathering.

Again, where flammable top coatings are used, there appears to be a tendency for flame spread behaviour to be improved (lesser flame spread) after some weathering has taken place.

However, there are conflicting conclusions when comparing the results from this method with Kokkala's method. For example system R (western red cedar with a full application of an opaque intumescent coating, unweathered) is a good performer with a flammability parameter < 0, but using Kokkala's method it is a bad performer, achieving the lowest 'A' classification (also see discussion on page 60). This reinforces the need for some larger-scale room/corner data to be collected for fire-retardant coatings on combustible substrates.

11.3 Exterior Claddings

Where regulations call up large scale or intermediate scale façade fire tests, it is not practical for cladding materials to be subjected to accelerated weathering using the QUV weatherometer or Xenon arc weatherometers because of the volume of material that would be required to be weathered.

Previous Fire Code Reform Centre research by Wade and Clampett (2000) recommended the use of the 'Vertical Channel Test' for regulatory use in Australia for claddings as being a suitable compromise between the even larger and more expensive full-scale façade tests, and the inherent limitations of small scale tests such as the cone calorimeter. However the 'Vertical Channel Test' still requires a section of wall cladding measuring 7.32 m high x 0.85 m wide.

New Zealand recently adopted the use of cone calorimeter data for evaluating the fire properties of external claddings in the new Acceptable Solution C/AS1 (BIA, 2001). The results of full-scale tests are also acceptable. In the case of the cone calorimeter data two performance levels are identified based on testing specimens to AS/NZS 3837 (SA, 1998) in the horizontal orientation with an irradiance of 50 kW/m^2. They are:

A: Peak rate of heat release not > 100 kW/m^2
Total heat release in 900 seconds not > 25 MJ/m^2

B: Peak rate of heat release not > 150 kW/m^2
Total heat release in 900 seconds not > 50 MJ/m^2

Of the western red cedar samples investigated in this study, only system R (opaque intumescent coating on western red cedar at the full application rate, unweathered) was good enough to achieve either of these performance levels (in this case a 'B'). All the other western red cedar samples fell short either because the peak rate of heat release or the total heat release was too high. Interestingly, the same coating, after simulating weathering (system Q), did not meet these performance levels as a result of the substrate burning and causing the total heat release to be higher than 50 MJ/m^2.

12. INSTALLATION AND QUALITY CONTROL ISSUES

A number of factors could affect the performance of a fire-retardant coating when installed in an actual building, these include:–

- Has the coating been installed or applied in full accordance with the manufacturer’s specifications? (This can be difficult for intumescent coatings as the paint is more viscous and is recommended to be warmed prior to application so that the same properties as a standard paint can be achieved during application.)
- Are the manufacturers specifications adequate? Are they correct?
- Has the coating been applied by approved applicators?
- Has the coating been applied to a similar/same substrate to that tested in the laboratory?
- Will other decorative coatings be installed over the fire protection during the life of the building?
- Does the coating have adequate resistance to chemical or mechanical damage?
- Will any chemical change occur in the coating during its lifetime that will reduce its performance?
- Has the substrate been prepared correctly?
- Is the coating suitable for the environment where it has been applied?
- Does the coating have adequate resistance to mechanical damage?
- Are the manufacturer’s production quality control arrangements adequate?
- Are there arrangements for repair or recoating of the intumescent coating?
- Will the differing paint application properties lead to inadequate coating?

Many of these factors apply to other products in the fire protection industry as well but are often much more clearly defined than with fire protective coatings. As has been identified, the performance of a fire-retardant coating depends on many factors.

A code of practice is needed for the production, testing and use of coatings for fire protection to address such issues as:

- Fire-retardant coatings should be fire tested in a manner that reflects their end use application. If the fire-retardant coating is intended for use on a full range of substrates, a testing regime involving a range of substrates should be developed. If a topcoat is normally specified to be used over the fire-retardant coating it should also be tested in that manner. This report has shown the topcoat to have a strong influence on the fire test results.
- Ensure the product is manufactured using appropriate quality control methods. Because many fire retardant properties of ablative and intumescent coatings rely upon several pigments or additives working synergistically, the exclusion of small amounts of such reagents would strongly reduce the fire protective properties of a coating. A quality control system monitoring the production of such coatings needs to be in place. The fire testing of each batch of fire-retardant coating produced would be costly and impractical, but the monitoring of simple paint properties including percentage solids content and paint viscosity are easily measured and help identify problem batches.

- Adequate product data should be available. Data concerning a fire protective coating should include at least the following information.

    1. The physical paint properties, including at least: paint type, drying time and time to recoat, wet film thickness, dry film thickness, theoretical coverage and topcoat paint to be used.
    2. Test data detailing the type of test and specimens.

- The full effect of ageing by carrying out durability studies in a full range of environmentally adverse conditions.

- The product should be installed by trained contractors who are subject to regular quality control assessment.

- Fire-retardant coatings should be clearly identified to prevent excessive re-coating with multiple applications of coatings, and subsequent degradation in flame spread properties.

- Introduce inspections during the coating life to ensure it is still providing protection.

13. CONCLUSIONS

Based on the fire test results, this study concludes that:

- The effect of varying the application rate of an intumescent base coat to half that of the manufacturers recommended rate, was mainly to reduce the time at which the substrate material starts to burn and contribute heat release. This effect was most pronounced for the western red cedar with opaque intumescent coating, and least pronounced for the radiata pine with the clear intumescent coating.

- The effect of accelerated ageing, using temperature and humidity cycling representative of interior environments, was to slightly reduce the heat release rate and delay ignition. Overall fire performance characteristics were similar or slightly improved after accelerated ageing.

- The effect of accelerated weathering, using temperature, humidity and ultra-violet light representative of exterior environments, was mainly to reduce the time at which the substrate material starts to burn and contribute heat release. Overall fire performance characteristics were significantly decreased after weathering.

There appears to be no compelling reason why fire-retardant coatings should not be used to enhance the reaction to fire properties of building materials, provided suitable steps are taken to ensure the quality of application and the efficacy of the coating over the expected life of the material. This would need to require the introduction of an initial durability assessment into the regulatory regime as well as regulated ongoing inspection schedule. To be of practical benefit, any such fire-retardant coating would, of course, need to result in an improved regulatory classification.

Coatings may be susceptible to deterioration and damage over time, so there is a need for some ongoing programme of maintenance and inspection to identify when repair or reinstatement work may be needed. This can be seen as comparable to the performance of fire separations which are susceptible to installation of penetrations and alterations over their life and which hence also require ongoing inspection and maintenance.

While physical damage to a coating system may have a major effect on the bench-scale fire properties of the wall or ceiling in the region of the damage, it has not been shown that this would necessarily have a major impact on the overall fire growth and hazard in a room, provided that the damage was localised to only a small area of the room.

Durability testing is an important part of ensuring that a wall, ceiling or cladding product is fit for its recommended lifetime. It is normal to expect that any coatings will require re-application at specified intervals to ensure aesthetics, durability and continued functionally of the underlying material. Usually durability testing involves a long simulated weathering procedure that is attempting to both mimic actual service conditions and to condense the worst case of those service conditions in a shortened timeframe. The timeframe chosen is relative to the end lifetime that is to be simulated and could be market-driven in as much as different periods might be identified in manufacturers literature based on the current knowledge, durability assessment and testing carried out for the particular system.

This study concludes that, for interior products, the cone calorimeter results where the washing procedure was used were very similar to the results where the cyclic humidity/temperature procedure was used. It is possible that the interior weathering procedure used in this investigation may be replaced by the washing procedure which is quicker and simpler to carry out. However it is recommended that further comparisons on a wider range of coatings be performed to reaffirm this finding.

The effectiveness of the exterior weathering appeared to rest with the heating and humidity treatment of the samples rather than the direct exposure to ultra-violet light. This is thought mainly to be due to the choice of topcoat recommended for the exterior coating system. The recommended topcoat in this case was rated to be resistant to the degradation effects of ultra-violet (UV) radiation for up to 12 years. Therefore, the exterior weathering procedure used in this study was unlikely to be significantly affected by exposure to UV over the simulated timeframe. This was borne out by the lack of evidence of deterioration of the coating both visually and by FTIR spectroscopy. The Australian Paint Approval Scheme (APAS, 2000) offers one way of assessing the performance of a range of different commercial paint systems. This scheme has been in operation for many years and most of the well-known paint companies would be able to show compliance. APAS specifications include semi-gloss latex paints for exterior use (APAS – 0280/3) which includes a requirement for a four-year exterior weather exposure test. Where a new protective topcoat with unknown performance, or a fire-retardant coating which is to be used without a protective topcoat is developed, then there would appear to be little option but to carry out a full scale weathering test (either laboratory or field-based) which would simulate the performance expected for a standard exterior paint over four years or more.

Where durable protective topcoats are used over a fire resistant coating, the need to use a weathering device which simulates the UV radiation levels at the earth's surface is overcome. The primary weathering agents of heat and moisture fluctuations can be produced in less expensive climatic chambers and over a shorter timeframe. This opens up options for testing much larger specimens such as those proposed in the 'Vertical Channel Test'. Any such weathering test needs to include: changes in temperature, humidity and wetting. Further work would be required to evaluate potential test methodologies but options range from simple heat/rain tests such as that specified in AS/NZS 2908.2 (SA, 2000), with a much greater number of cycles, to a programmable cyclic chamber test similar to that used for the interior products in this report (with a wider temperature range).

It must be noted that the issue of maintenance and recoating (as discussed earlier) raises questions which remain unanswered at this stage. The weathering of decorative and protective paints results in gradual changes to the paint film. These changes will vary depending on the paint type, but most paints will suffer from a gradual loss of film thickness as the paint weathers. With a standard three-coat exterior paint system for timber, recoating should ideally be carried out on a regular basis to replace the film thickness lost by weathering before any damage to the substrate occurs. In theory this results in a cyclical variation in film thickness but no appreciable increase in thickness over time. In reality this is seldom the case because weathering of the paint proceeds at different rates depending on the degree of exposure. For example paint on south faces, under eaves, in porches or in other sheltered locations will erode much more slowly than that on an exposed north face. Also, repainting decisions are typically based on appearance and not film thickness. What this means for a paint system consisting of a fire retardant base layer with a standard exterior topcoat, is that there will be a conflict between trying to avoid a build-up of the more flammable topcoat, and ensuring that there is enough topcoat retained to protect the base coat from deterioration (eg. leaching). The systems tested in this report used a single layer of topcoat. Depending on the colour of the topcoat and base coat and the texture of the base coat, two layers of topcoat may be needed to achieve the desired aesthetic appearance. This will need to be taken into consideration in any future testing or regulatory decision-making.

There is a lack of full-scale fire test data for fire-retardant coatings on combustible substrates. This data is needed to confirm the applicability of Kokkala's Classification Method (or any other method) for fire-retardant coatings on combustible substrates.

If Kokkala's method can be shown to be valid for coatings on timber substrates, then at least for the coating systems investigated in this project, the coatings did not enhance the fire properties of the substrate to a point where a change in the proposed Deemed-To-Satisfy classification would result. For example, the plywood samples gained the same proposed FCRC classification (based on time to flashover in the ISO 9705 room) with and without the various coatings, and with and without simulated ageing/weathering. Similarly, for the factory-applied thin ablative coating applied to wood fibre board, there was no change in classification compared to the uncoated wood fibre board. Thus in these cases, there was no advantage to be gained by requiring a simulated weathering protocol to be adopted prior to fire testing. In fact for the interior systems examined in this study, there was no Deemed-To-Satisfy advantage gained in specifying a fire-retardant coating at all.

However, there was a change in the case of the western red cedar with intumescent coatings. The uncoated timber achieved the worse classification using Kokkala's method (A) and this was able to be improved to the next level (B) by the use of a coating but only after a period of simulated weathering. Thus in this case, it would have achieved a worse result by testing the unweathered material and hence again there would have been no advantage to be gained by requiring a simulated weathering protocol to be adopted prior to fire testing (other than a better outcome for the manufacturer).

The outcome of this investigation is inconclusive as to whether it is essential to require accelerated weathering of any sort prior to reaction-to-fire testing of interior linings. Part of the reason for this is the influence of a flammable topcoat on the reaction to fire properties of the materials. Surface coatings including topcoats do influence the reaction to fire properties of materials. Although convenient, it seems unwise to ignore these influences.

Traditionally in Australia site-applied coatings have been ignored for the purpose of determining reaction to fire properties of wall and ceiling linings; however, this investigation has highlighted the influence that a protective topcoat on a fire-retardant coating system can have on the overall reaction to fire properties. Ideally there needs to be consistency, for if site-applied topcoats are able to be ignored for wall and ceiling linings generally, then why not also for topcoats on fire-retardant coatings? Yet it is misleading to fire test a fire-retardant coating without a topcoat, if it should never be installed that way in a building. From a technical and fire hazard perspective there is no sound reason to ignore the application of a topcoat. It has been more a matter of practical convenience due to difficulties in controlling the application of decorative re-coats throughout the life of the product.

Coatings will generally rely on `maintenance' to prevent damage or degradation of performance over the extended time periods. Fire-retardant coatings (a passive system) should not be treated in a fundamentally different way from active means of fire protection, i.e. alarm systems, sprinklers where it is accepted that periodic checks and maintenance will be carried out at regular time intervals. The same should apply to performance of fire-retardant coatings (as indicated by NFPA 703 for example). Thus the fear of mechanical degradation over long time periods should not be a valid reason on its own for excluding the use of fire-retardant coatings.

14. RECOMMENDATIONS

It is recommended that:

- Several full-scale ISO 9705 room/corner experiments be carried out using fire-retardant coatings on combustible substrates to provide additional data to assess the suitability of Kokkala's classification method for fire-retardant coatings, and to provide data on the fire growth and flame-spread performance of these types of systems in their end-use application.

- The BCA exemption in Paragraph 7 of Specification C1.10 which exempts paint, varnish, lacquer or similar finishes from requirements for spread-of-flame, smoke-developed or flammability indices requires rationalisation. If this exemption is continued to be applied in any future BCA reaction to fire requirements (based on ISO 9705 and/or AS/NZS 3837 for example), then there needs to be consistency in how test requirements for fire-retardant coatings are dealt with, especially where the purpose of a topcoat is solely to protect a fire retardant base coat from the effects of ultra-violet light and moisture. It is noted that in all other countries considered in this study, reaction to fire properties for wall and ceiling linings are determined on materials/substrates including any proposed surface treatments and finishes.

- For interior applications, further comparison between the effects of using the manual washing technique versus the automated temperature/humidity chamber would be valuable to ascertain whether the quicker and less expensive washing procedure would be adequate to simulate interior exposure conditions. This study compared the methods for only one coating-substrate combination and found little difference in the results of the small-scale fire tests using both of these procedures.

- For exterior applications, accelerated weathering testing equivalent to 4-5 years of real weather exposure is desirable. In practice such testing is time consuming (approximately a year with UV weathering machines) and expensive. It is proposed that where protective topcoats with an established durability history are used to protect a fire retardant base coat from the weather, a test which only simulates the effects of cyclic heat and moisture be used.

- Where full scale exterior weathering is required (because a proven durable topcoat is not used), the time frame (for exterior weathering trials) and sample size make the use of intermediate or large scale fire tests (should they be adopted for regulatory control) impractical. In these situations another approach could be to require additional small-scale (eg cone calorimeter fire testing) on weathered and unweathered specimens with a requirement that the product classification achieved (perhaps using Kokkala's method) be no worse for the weathered product when compared with the unweathered product. More work is required to explore these ideas further.

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