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Chapter 3

Regulatory and testing requirements for flame retardant textile applications

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3.1 Introduction

Chapter 1 has presented statistics that have demonstrated that certain types of textiles are more hazardous than others in terms of their ability to ignite and lead to fire injuries and fatalities. However, these alone rarely drive the drafting of legislation and regulation. Within the UK the first textiles requiring levels of defined flame retardancy were children's nightwear and this arose not from statistical data generally but from the work of Bull et al published in 1964 [1] where they had studied the severities of burn casualties from the Birmingham Burns Unit, UK. It must be remembered that during this period most British homes had open coal fires and the incidence and severity of burns to young girls wearing cotton nightdresses was of particular concern. The result was the UK nightdress regulations of 1967 [2] which required all young girls' nightdresses to have a minimum burn rate requirement (*see* below) and these regulations effectively removed cotton flannelette nightdresses from the market. These were amended in 1985 to cover the testing of all nightwear, including pyjamas, and dressing gowns and require adult and children's nightwear to carry a permanent label showing whether or not each item meets the requirements of BS 5722:1984 (revised in 1991 and which uses Test 3 of BS 5438: 1976, amended 1989- *see* **Section 3.3.1** below). Before testing, garments must be washed once in accordance with BS 5651 and adult garments failing the standard, have to be and still must be labelled "Keep away from Fire".

In the USA very similar observations were being made and the 1976 study of Tovey and Vickers [3], which analysed 3087 case histories of textile ignition-caused fire deaths, showed that loose-fitting clothes such as shirts, blouses, trousers and underwear ranked higher as potential hazards than bedding and upholstered furniture; pyjamas, nightgowns, dresses and housecoats presented very similar hazards to these two latter. The hazard of fast burning textiles in clothing had, of course, been recognised in the USA in the 1950s with publication of the US Flammable Fabrics Act 1953 which covers clothing, children‘s nightwear, carpet and rugs, mattresses [4] and is mentioned in **Chapter 1**.

However, in most other UK fire legislative and regulatory examples, these usually follow only when large loss of life or property occurs. Within the UK over the last 30 years, a number of significantly well-publicised fires involving textiles as major fuel and ignition elements has driven the need to create new or review current fire precautionary and preventative regulations and procedures. **Table 3.1** lists these major incidents, all of which were associated with textiles being the first ignited material or being responsible for major loss of life or damage.

Table 3.1

Notable among these is the Woolworth’s fire of 1979 from which the first UK cigarette ignition requirement for upholstered furnishings derived; subsequently, the later more comprehensive legislation of 1990 followed [5] with its demand for match ignition and the mandatory combustion modification of foam filling. Similarly, the Manchester Boeing 737 fire brought forward the planned UK Civil and US Federal Aviation Authorities’ requirement for fire resistant seating materials in all passenger aircraft designed to carry more than 30 passengers [6].

All the fires in **Table 3.1** have the common features that the textiles present at each scene, functioned as the material first ignited by the relevant igniting source. Secondly and subsequently, the speed with which this caused the fire to grow and spread to adjacent materials, was a significant feature in the inability of victims to escape or the fire fighters to bring the fires under control. Therefore, these catastrophic fires serve to demonstrate more obviously the ignitability of textiles in the first place followed by the associated speed with which the resulting fire can grow.

With this last factor in mind, most fire regulations relating to textiles are designed to

- prevent facile ignition of common textiles in the first instance,
- offer potential victims more time to escape, or
- provide protection of the body or parts of the body from fire.

Those responsible for issuing fire regulations fall into a number of categories including:

i. National governments: typically all national governments within the EU issue their own fire regulations which can now fall, if relevant, within an overarching EU directive and its requirements. Related standards may be issued also by national standards organisations such as ASTM, BS and DIN as well as international organisations such as CEN and ISO. In the USA, standards are also issued by the Consumer Product Safety Commission (CPSC) and the National Fire Protection Association (NFPA) and federal regulations may specify them as appropriate.

ii. State or provinces: in the US, states such as California issue their own fire regulations which may differ from national or federal regulations. An example here is the Californian regulation for the flame retardance of upholstered furniture defined in Technical Bulletin 116: 1980 (*see* **Section 3.2.2**).

iii. International organisations responsible for transport systems such as civilian air and marine transport (*see* **Section 3.2.3**).

Examples of all these will become apparent in the foregoing sections of this chapter.

3.2 Textile-related fire regulations

While textile-related fire regulations between different nations may offer an overall confusing picture in terms of the items regulated and the applications covered by them, in general, regulations fall into one a number of categories depending on whether they apply to the normal consumer living in a domestic environment, a member of the public in a public environment such as a hotel, airport, public building including hospitals and prisons, in the workplace for worker protection, for personal protection in the emergency and defence services or in transport where escape by passengers and personal is restricted. Thus regulations generally cover

i. Nightwear (domestic environment)
ii. Upholstered furnishings (domestic and contract or public)
iii. Bedding (domestic and contract or public)
iv. Protective clothing (workplace, civil emergency and defence)
v. Transport (land, marine and air)

It may also be pointed out that when textiles become a part of a building such as a wall- or floor-covering, they may be covered by the normal building fire regulations for that particular country or region.

3.2.1 Nightwear regulations

Table 3.2 lists a selection of nightwear regulations and **Table 3.3** related nightwear fire regulatory tests from different parts of the World [7, 8].

Table 3.2 and Table 3.3

While they have been reviewed comprehensively by the author [8], a summary of their main features will be presented here together with more recent and relevant information. Not all of the test methods in **Table 3.2** are covered by regulations and may not be mandatory. Apart from the UK whose regulations [2] have been discussed above, mandatory regulations exist in Ireland (which are similar to the UK regulations [2, 9]) and the USA [10]. Here the US Consumer Product Safety Commission (CPSC) flammability standards 16 CFR Parts 1615 and 1616 for children's sleepwear are based on flame spread. If the average char length of burning for five specimens exceeds 178 mm (7 inches), the fabric is deemed not to comply with the flammability regulations and garments must pass this test after withstanding 50 launderings. In 1996 the US CPSC voted to amend the children's sleepwear standard under the Flammable Fabrics Act. The amendments permitted the sale of tight-fitting children's sleepwear for infants aged 9 months and under, even if the garments do not meet the flammability standards ordinarily applicable to such sleepwear. The amendments were based on the fact that there were virtually no reported injuries associated with single-point ignition incidents of tight-fitting sleepwear, or from sleepwear worn by infants under one year [8, 11].

Australia and New Zealand have regulations that require labelling of all the children's night-clothes to display an appropriate hazard classification [12]. The Australian philosophy about consumer protection is to inform consumers of the hazard and hence permit them to make their own judgement as to whether the risk is acceptable. The standard AS/NZS 1249:2003 [13] enables nightwear to be classified as 1, 2, 3 or 4 where categories 1, 2 and 3 carry a low fire danger label and category 4 ones, a high fire danger label.

Within the European Community, while a number of countries had regulations which were usually voluntary (*see* **Table 3.2**), in 1997 a mandate from the EU [7] required the European Committee for Standardisation CEN 248 to investigate the feasibility of introducing nightwear flammability regulations. Two task groups reported respectively on the nightwear standards then currently available (*see* **Table 3.3**) and possible toxicological hazards associated with flame retardant treatments available for nightwear [14]. For instance, the Dutch and French standards in **Table 3.3** were derived from an ISO-standard (ISO 6941) on measurement of flame spread properties and ISO 6940 on determination of ease of ignition. The Swedish and Norwegian regulations were based on the American ASTM 1230 standard test-method for flammability of clothing textiles. Most of the national test methods listed in **Table 3.3** were and still are based on existing national standards, which outside of the respective country of origin do not have acceptance. The second task group of the Committee CEN 248 considered the possible toxicological consequences of using a number of most appropriate flame retarded textiles in nightwear. Because of the nature of the end-use involved, the antimony-bromine based flame retardants were excluded from the study [14]. For the established durable phosphorus-containing finishes for cotton-based fibres and inherently flame retardant viscose and synthetic (e.g. polyester, modacrylic) fibre-containing fabrics, respective toxicological hazards were considered to be low and hence toxicological risk negligible. As a consequence of the submitted report [14] this same CEN 248 Committee were tasked with drafting an appropriate test method and standard by September 2003 [15]. In 2007 a new European Standard, EN 14878:2007 [16] was issued and although a voluntary one is currently under review for publication in the Official Journal of the European Union (OJEU) under the General Product Safety Directive (2001/95/EC). The standard covers all types of nightwear, including nightdresses, nightshirts, pyjamas, dressing gowns, and bath robes. It provides requirements for an absence of surface flash and a maximum burn rate acceptable for different categories of nightwear garments. It also places responsibility on the manufacturer to ensure that any flame retardant chemicals used are effective throughout the life of the garment and do not present a health hazard.

The test methods required by EN 14878 are based upon BS EN 1103:2005 [17], but without any prior washing requirement. This standard defines the following classes:

- **Class A – All nightwear (except pyjamas)**: There shall be no surface flash and the 3rd marker thread (520 mm) must not be severed in less than 15 s.
- **Class B – Pyjamas :** There shall be no surface flash and either the 3rd marker thread (529 mm) must not be severed in less than 10 seconds, plus certain design criteria must be met (including hem circumference, sleeve cuff, and bottom trouser width dimension) or the burn rate from Class A is applicable without the design criteria.
- **Class C – Babies' nightwear (up to 6 months):** No criteria

This standard does not override existing legislation in any EU country, which must still be complied with (e.g. UK, Ireland) and which are more stringent with regards to burn rate. For example, in the UK (BS 5722:1984 (revised 1991) requires a minimum burn time of 25s before reaching the second marker thread using and 50 s before reaching the second marker thread using BS 5438:1976:Test 3 (or 30s and 42s respectively using BS 5438:1989:Test3A) (*see* **Section 3.3.1** below) and in the case of flame retardant treated clothing, washing before testing and labelling. However, additional aspects covered by this standard, include no surface flash and requirements for terry towelling bathrobes and pyjamas and children's nightwear from age 13-14.

3.2.2 Upholstered furniture, furnishing and bedding regulations

Table 3.4 lists the current regulations relating to furnishings and furniture in Europe and the USA [18].

Table 3.4

In **Chapter 1**, the UK furnishing regulations have been briefly discussed as well as their known effect on the UK Fire Statistics since their implementation in 1988 [5]. These are the only mandatory regulations that exist for domestic furnishings and cover all forms of upholstered furniture including children's furniture, mattresses, bed-heads, sofa-beds, futons and similar convertible furnishings, garden furniture suitable for use in the home, furniture in caravans, scatter cushions and pads and loose and stretch covers. Excluded are bedding, duvets, pillowcases and curtains. The amendment in 1993 introduced second hand furniture and also included furnishings in rented dwellings and manufactured since 1950 into the regulations. The amendment in 2010 enabled the polyester cover fabrics used in testing of filling materials to be updated given that that defined in the 1988 regulations is no longer commercially available. The UK regulations cover the testing requirements for both fillings (e.g. polyurethane foam) and furnishing fabrics tested over both a commercial filling and standard polyurethane foam. Fabrics are thus tested as a fabric/filling composite (*see* **Section 3.3.2** below). A guide to these regulations has been published by the UK Fire Industries Research Association (FIRA International) [19].

In the USA while the proposed US standard CPSC 16 CFR Part 1634 covers furniture, CPSC 16 CFR Part 1632 and Part 1633 cover mattresses for cigarette and open flame hazards respectively. It should be noted that the US standard CPSC 16 CFR Part 1634 for furniture was proposed in 2008 and is currently a source of much debate regarding current (February 2013) concerns in the USA about introducing flame retardants into the home environment. The proposal seeks to establish performance requirements and certification and labelling requirements for upholstered furniture and manufacturers who would choose one of two possible methods of compliance. Either they could use cover materials that are sufficiently smoulder-resistant to meet a cigarette ignition performance test or they could place fire barriers that meet smouldering and open flame resistance tests between the cover fabric and interior filling materials. The Consumer Product Safety Commission still intend to finalise this proposed regulations but it is probable that these may be modified so that they may be met by non-use of flame retardant chemicals [20]. A similar debate is being undertaken in California where the current 30 year old Technical Bulletin 117: 2002 (Requirements, test procedures and apparatus for testing the flame retardance of resilient filling materials in upholstered furniture (*see* **Table 3.4**) is proposed to be replaced by one which removes the open flame or simulated match test, which requires the need for flame retardant chemicals in both foam and fabric components of furniture [21]. The proposed regulation will require only cigarette ignition resistance of cover or barrier fabric using the procedure outlined in ASTM E1353-08a [22].

All other national regulations for domestic furnishings are not mandatory, only in the public and/or contract sector are respective regulations mandatory because of the need to protect public safety. For instance in the UK, the Regulatory Reform (Fire Safety Order) 2005 (*see* **Table 3.4**), which became law in 2006 replaced over 70 former pieces of UK fire safety regulation were brought together such as the Fire Precautions Act of 1971, the Fire

Precautions (Factories, Offices, Shops and Railway Premises) Regulations 1976 and the Fire Precautions (Workplace) Regulations 1977 for example. While such regulations relate to buildings and their fire safety, textiles are covered if they are a part of that building such as wall and floor-coverings and curtains and blinds. To ensure that textiles comply with the necessary regulations, premises are inspected by the local Fire and Rescue Authority. With regard to furnishings in non-domestic buildings the advisory standard BS 7176:2007 [23] is used by fire authorities. **Table 3.5** summarises the essential features of this standard which identifies the ignition sources to be used for buildings of low to very high hazard.

Table 3.5

For instance, Low Hazard relates to schools and colleges etc., where only cigarette (Source 0) and simulated match (Source 1) ignition resistance are required which is similar for UK domestic furnishings except that tests BS EN 1021-1 and -2 are used instead of BS 5852:2006 Sources 0 and 1. Buildings in which the public are generally admitted or sleep such as hotels, restaurants and places of entertainment are in the Medium Hazard category and these require so-called Crib 5 (BS 5852:2006:Source 5) ignition resistance. The High Hazard rating relates to hospital wards (UK NHS and private) and off-shore accommodation where so-called crib 7 (BS 5852:2006:Source 7) ignition resistance is required. The Very High Hazard is required in prison cells and here the criteria required are at least those required in the previous High Hazard category plus other safety factors at the specifier's discretion. BS 7176 also defines the labelling requirements for items as does the similar standard for bedding, BS 7177 [24] which also falls under the UK Furnishing and Furniture and regulatory Reform requirements (*see* **Table 3.4**). FIRA International has produced a guide to the UK contracts furnishing regulations in which these standards are more fully explained [25]. BS 7177:2006 mirrors BS 7176 exactly in determining low, medium, high and very high hazard environments each of which requires a specific test regime. There are three cited test methods namely BS EN 597-1:1995 (Furniture. Assessment of the ignitability of mattresses and upholstered bed bases. Ignition source: smouldering cigarette), BS EN 597-2:1995 (Furniture. Assessment of the ignitability of mattresses and upholstered bed bases. Ignition source: match flame equivalent) and BS 6807:2006 (Methods of test for the assessment of ignitability of mattresses, divans and upholstered bed bases with flaming types of primary and secondary sources of ignition) (*see* **Section 3.3.2**). For all hazard levels, bedding items should conform to BS EN 597-1 and -2 and in addition, medium hazard areas require a pass to ignition Source 5 (BS 6807), high hazard areas a pass to ignition Source 7 (BS 6807) and for very high hazard there may be additional requirements in addition to the latter.

Other countries such as France and Germany (*see* **Table 3.4**) specify the public places where different but specific regulations apply.

3.2.3 Protective clothing (workplace, civil emergency and defence)

In the UK need for protective clothing is regulated by the Health and Safety at Work Act of 1974. In the main, protective clothing falls into one of two groups [25]:

- Protective clothing for workwear, hazardous industrial occupations, firefighters and defence personnel.
- Extreme hazard protection, e.g. furnace operators' aprons to protect against hot metal splash, fire entry suits, racing car drivers' suits.

Within the EU, the Directive on Personal Protective Equipment (PPE) 89/686/EEC of 1989 belongs to the family of directives under Article 114 of the Treaty on the functioning of the

European Union. In the case of protective clothing, these directives harmonise products to ensure a high level of protection for citizens throughout Europe. National regulations incorporate the requirements of the relevant directive for the various protective clothing types.

Underpinning the directive, are a number of CEN testing methods for heat and fire protective clothing which include

- BS EN 469:2005 - Protective Clothing for Firefighters - Performance requirements for protective clothing for firefighting [27]
- ISO 11613:2000 - Protective Clothing for Firefighters - Laboratory test methods and performance requirements [28]. This is a combination in one document of EN 469:1995 (revised 2006) and NFPA 1971 from a similar date. It is intended to be revised as the basis for all of the PPE items which are required for 'conventional' firefighting and hence issued as an ISO test.
- BS EN IS0 11611:2007 (replacing former BS EN 470-1:1999) - Protective Clothing for Welders [29]. This performance requirements for a weld droplet test and flammability behaviour and also has detailed design criteria (to prevent weld spatter being trapped in turnups, etc). A unique aspect is that it contains a note as to the dangers of UV radiation from welding processes in the context of potential skin cancer.
- BS EN ISO 11612:2008 (replaces BS EN 531:1995) - Protective clothing - Clothing to protect against heat and flame [30]. This is a complex performance specification providing a choice of several main performance levels to a variety of heat sources including molten metal splash protection (as distinct from welding spatter) plus one extreme level of heat protection. It also sets design criteria for garments and seams.

- BS EN ISO 14116:2008 (replacement for BS EN 533:1997- Protective clothing - Protection against heat and flame - Limited flame spread materials, material assemblies and clothing. This is a means of classifying clothing materials subjected to ISO 15025:2000 which is a test to determine the extent of damage to a fabric sample subjected to a small flame. The final index gives a measure of both flame resistance and durability (*see* **Section 3.3.4**).

It is noteworthy that while some of these standards refer to a specific application or hazard (e.g. BS EN ISO 11612 for welders protective clothing), others such as those for firefighters define a set of performance requirements for protective properties such as flame resistance and heat protection as well as setting design criteria. An objective of the 2005 revision of EN 469 is to offer 2 levels of heat protection so as to take account of various ambient conditions and firefighting techniques (*see* **Section 3.3.4**).

IN the USA, there is no federal standard for protective clothing but various USA regulatory agencies such as the Occupational Safety and Health Administration (OSHA) under several of its regulations and the US Departments of Defence (DOD) and of Transportation (DOT), in their regulations where appropriate incorporate by 'reference' a standard vertical flame test such as ASTM D6413 or similar [31]. This requirement is essentially regulated as a mandatory standard, since most regulatory agencies legislative requirements include a 'general duty clause'; for example under OSHA an employer is required to maintain 'a safe and healthful workplace'.

The methodologies underlying some of these regulatory test methods will be further discussed in **Section 3.3** below.

3.2.4 Regulations and tests relating to transport

Textiles in transport are generally associated with seating, floor-coverings and other furnishings within the vehicle or vessel interior. Within the defence, civil emergency and industrial sectors, similar associations may be made although protective clothing and other safety/protection-related equipment will comprise textile components. Textiles are also present in fibre-reinforced composites which form major structural components in vehicles as well as in functional components such as tyres, beltings, wiring harnesses, filters, etc. In most of these transport applications where safety is an issue, there are national or international regulations that govern their fire performance requirements. Automobiles may be included here because of their many textile components only those in internal passenger compartments such as seating, carpet and internal side and roof lining fabrics require a defined level of flame resistance.

In aircraft, all internal textiles such as seatings, internal decor and blankets require defined levels of flame or fire resistance to internationally recognised standard levels. However, higher levels of fire and heat resistant textiles are required in engine insulation (e.g. ceramic fabric structures around combustion chambers), reinforcements for composites (e.g. carbon fibre reinforcements for major structural elements), aramid honeycomb reinforcement for wall and floor structures and fuselage acoustic and fire/heat insulation.

In surface marine vessels, whether commercial, pleasure or naval, similar textile solutions to those seen in aircraft include interior textiles as well as those which are present in metal-replacing composites used in fibre-reinforced composite hulls, bulkheads and superstructures, for example.

3.2.4.1 General testing and performance requirements

National and internationally operating transport systems such as air and marine, are subject to international fire regulations and standards.

Marine regulations fall within the remit of the International Maritime Organisation (IMO) whereas commercial air regulations are effected by national organisations such as the Civil Aviation Authority (CAA) in the UK, the European Aviation Safety Agency (EASA) across Europe and the Federal Aviation Administration (FAA) in the US. These and national authorities belong to the International Civil Aviation Authority (ICAO) and these together define the various fire standards relating to commercial aircraft across the World. However, it must be said that the US FAA and its associated regulations and test methods largely determine the world's commercial regulations and associated test methods [32, 33].

While most national railways recognise the fire hazard posed by rail travel, outside of the EU national standards exist and these will differ from country to country [32]. The same mix of fire standard requirements also existed across the EU member states until 2008 when the European Directive 2008/57/EC was published covering both high speed and conventional rail vehicles as a means of co-ordinating fire requirements across Europe. Two years later, the standards to be implemented across the EU with regard to assessing the performance of materials and components within rail vehicles were published in BS EN 45545 in 2010 with Part 2 being especially relevant to the materials within rail vehicles [34]. This standard will take time to be implemented and in the meantime, respective EU national standards will prevail such as BS 6583 (UK), NF-F 16-101/NF-F-102 (France), UNI CEI 11170:2005 Part 3 (Italy) and PN-K-02511 March 2000 (Poland) in which textile items such as seating materials feature.

A more detailed discussion of these international regulations and standards are beyond the scope of this chapter but examples of test methods and performance requirements can be found from various sources [32-36]. Below is presented an outline of those most significant textile-related fire regulations and test methods for the various transport sectors.

3.2.4.2 Land transport

Regulations extend mainly to public transport such as buses and coaches and trains although as shown below, automobiles with global markets accept the need for some level of textile flame resistance.

Automobiles: The fire risk in the US to vehicle fire losses has been stated to be that 70% of these occur in road vehicles of which over 90% of these are in private cars [37]. **Figure 3.1** shows that total fires in automobiles have reduced considerably by a factor of over four of which deliberate fires form the major part and which in 2010/11 still was of the order of 65% [38].

Figure 3.1

The decrease in deliberate fires has been attributed to a number of factors including an improved UK licensing regime and related success of vehicle removal schemes and the increase in metal prices which makes car abandonment less attractive. While fatal casualties are very few and often zero in any one year, the number of non-fatalities has generally reduced in a fluctuating manner. These figures would suggest that the internal contents of cars are generally safe even with the increasing wiring hazard content, although what fraction of these fires relates to the interior textile content is not known. These statistics might suggest that automobiles do not require international fire regulations. However, while there are no official international regulations for establishing a minimal level of fire safety in cars worldwide, its global character has forced it to adopt the US Federal National Highway Traffic Safety Administration FMVSS 302 standard [39] test developed in 1969 and implemented in 1972. This standard was designed to prevent ignition in the passenger compartment of textile materials to a lighted cigarette by defining a minimum burning rate of 100mm/min of the sample held in a horizontal geometry. This standard is now redesignated in many countries across the World by their respective test organisations, e.g. ISO 3795, BS AU 169 (UK), ST 18-502 (France), DIN 75200 (Germany), JIS D 1201 (Japan) and ASTM D-5132 (US). Typical fabric types occurring in automobiles and which pass these criteria have been described by Fung and Hardcastle [40].

Buses and coaches: These are often determined by national regulations depending on previous fire experiences. Troizsch [32] has summarised the position in the EU following its issuing of a directive in 1995 (EU Council Directive 95/28 EC (10.95)) which defines requirements for the fire behaviour of interior materials in vehicles carrying 22 or more passengers. Textile materials include decorative fabrics used to line the ceilings and walls, those with an acoustic function, curtain and blind materials and those used in seating. A test similar to FMVSS 302 is described to test fabrics for a minimum burning rate of 101 mm/min in the horizontal geometry while the ISO 6941vertical strip test is used to assess blind and curtain flammability and testing for potential flaming drip formation is also required for roof linings.

Trains and rapid transit systems: As stated above, national railways are traditionally required to conform to national fire standards which are typically often quite different from one another [32]. Within the EU standard BS EN 45545 discussed above, the main concerns for materials in a fire are heat release, spread of flame and toxicity and density of smoke which reflect the similar stringent material requirements which have been applied within the aviation sector for many years (*see* below). Hazard levels (HL) are designated to the type of railway vehicle; for instance a standard carriage is given the lowest level, HL1, and a couchette/sleeper carriage, HL3, the highest. Within all carriage vehicles a significant hazard is posed by furnishings and bedding and these are listed in **Table 3.6** which must be tested to protocols described in BS EN 45525-2 [34].

Table 3.6

Other potential textile materials may also be present in curtains, blinds, decorative panels and floorcoverings each of which is covered by a set of defined requirements and hazard-related performance criteria. Readers are advised to consult the actual standard to fully understand the complexity of the test protocol defined for each material type.

Not surprisingly, textile materials which achieve the desired fire performance criteria will be similar to those in aircraft and include FR wool and blends for seatings, FR polyester for curtains, polyamide for floorcoverings with flame retardant back-coatings used as required.

Metropolitan railways, especially those underground, are particularly high fire risk transport systems and within the textile field, only seats are of significance. Again FR wool and blends will feature significantly.

3.2.4.3 Marine transport

Maritime shipping falls into two groups, commercial passenger and cargo vessels and naval surface vessels and submarines. The whole area of the factors determining choice of flame retardant materials for use in this sector has been recently reviewed by Sorathia [41].

Naval vessels: Naval vessel regulations will be defined by each country with respect to its own surface and submarine craft. For example, the primary regulatory body for the fire performance of materials in US Navy ships and submarines is the Naval Sea Systems Command (NAVSEA), also referred to as the Naval Technical Authority (NTA) [41]. However, textile materials rarely feature in regulations from such a body and where they are used, they are subject to separate governmental military specifications. For instance, in the USA, MIL-STD-1623 [42] provides the fire performance requirements and approved specifications for various categories of interior finish materials and furnishings for use on naval surface ships and submarines. This standard identifies the Federal Standard FED-STD-191 (Tests for Textiles) in which, for instance, Method 5903 defines a 45^{o} strip method for determining the flame resistance of clothing and Method 5905 as the method for assessing material behaviour when subjected to a high heat flux contact. This latter involves a larger (Fisher) gas burner as opposed to the simple Bunsen burner defined in 191A Method 5903 and the fabric is suspended vertically. Clearly, different textiles having varying levels of flame retardancy may be assessed using either of these standards and so enable them to be used for naval applications.

Similar methods are used by other navies and in the UK the Ministry of Defence will determine the standards for protective clothing, general uniforms and interior textiles. Outer garments, in particular, must protect against high heat fluxes and these will be based on protective textiles used both in non-defence and other defence applications [26, 43]

Commercial passenger and cargo ships: These have to comply with the fire performance requirements contained in the International Convention for the Safety of Life at Sea (SOLAS) as Codes Safety for High Speed craft of the International Maritime Organisation (IMO/HSC)

[44]. In the main these codes are concerned with fire prevention, detection, containment and control of flame and smoke spread, suppression and escape. The selection of potentially flame resistant textiles including textile-reinforced composites and the associated standard testing methods will be defined within the fire prevention arena defined in Part B (Prevention of Fire and Explosion) [44,45]. The fire tests to be carried out and the acceptance criteria are defined in the International Code for Application of Fire Test Procedures (IMO/FTP), which have been mandatory since 1998 [46].

Textile materials are covered, often indirectly, when part of a structure, for example, (e.g. wall decor, floorcoverings) by FTP Code Part 1- Non combustibility test using the standard ISO 1182;1990, by Part 2- Smoke and toxicity test (using ISO 5659) and by Part 5- Test for surface flammability procedures which applies also to floorcoverings and which are tested in accordance with resolution A.653(16) [47].

Textile materials not part of some other structure are more specifically covered in IMO FTP Parts 7-9 which are:

Part 7- Test for vertically supported textiles and films: here draperies, curtains and other textile materials are required to have qualities of resistance to the propagation of flame not inferior to those of wool of mass 0.8 kg/m^2, they shall comply with this part and be tested in accordance with resolution A.563(14)[48]

Part 8- Test for upholstered furniture: this requires that eligible upholstered furniture shall be tested in accordance with resolution A.652(16) [49]. The test method used is based on the British Standard for upholstered furnishings, BS 5852 for cigarette and simulated match ignition sources and so fabrics conforming to the current UK furnishing regulations [5] will be satisfactory in marine applications.

Part 9- Test for bedding components: bedding components must be tested in accordance with resolution A.688(17) [50]. The test method used is similar to that in Part 8 except that a mock-up of a mattress or pillow of the same size (450 x 450 mm) is subjected to the cigarette and simulated match source.

Fabrics should be tested after a defined wash or durability test and in the case of Part 7 for fabrics treated with a flame retardant, this is a single specified wash cycle which only so-called durable flame retardant finishes will pass. However, furnished cabins comprising a number of different fabrics (e.g. cotton and cellulosic blends, silk- and wool-containing fabrics, etc.) are often aftertreated by spray or roller application of solutions of soluble flame retardants comprising typically ammonium or organic base phosphates sometimes in the presence of ammonium bromide to confer an element of vapour phase activity. These treatments are often semi-durable at best but at the present time are accepted and certified to FTP Code standards if they are durable to dry-cleaning [51]. However, fabrics containing inherently flame retardant fibres such as FR-modified polyester (e.g. Trevira CS®), polyacrylics (e.g. modacrylics such as Kanecaron®) and FR polypropylene do not require a prewash treatment prior to testing.

Not surprisingly all textiles conforming to Parts 7-9 must also comply with Part 2 which relates to smoke and toxicity. For example, **Table 3.7** lists the maximum permissible toxic gas emissions from curtains tested under the Part 2 regulation.

Table 3.7

Regulations for high speed craft in excess of 40 knots require certain additions or modifications to the above regulations. These require that structural materials including textiles do not create a flashover in a fire, have average heat release rates (HHR) not exceeding 100 kW, maximum HRR values over a 30s period not exceeding 500 kW, minimal smoke emissions and flame spread rates, an absence of flaming drops and all seatings conforming to FTP Code Part 8 above.

As cruise ships become ever larger, so fire risk increases. The need to reduce this has been addressed largely in the carpet and upholstered furnishings areas where in the former, for instance IMO/FTP approval is given if the carpet has minimal flame spread under method A.563 (FTP Part 7) and low smoke and toxic gas generation under IMO Resolution MSC 61(67) (FTP Part 2). Carpets, in addition to the resolution A.653(16) method (FTP Part 5) are also often required to pass the reaction to fire test BS EN ISO 9239-1:2010 (*see* **Table 3.8**) which specifies a method for assessing the burning behaviour and spread of flame of horizontally mounted floorings exposed to a heat flux radiant gradient in a test chamber, when ignited with pilot flames.

Table 3.8

It is probably generally true to say that pure wool and wool-rich blends can conform easily to the standards required for carpets although sometimes flame retardant wool (e.g. Zirpro® wool) may be used depending on the carpet structure and weight.

3.2.4.4 Aviation

As stated above, the US Federal Aviation Administration, FAA, is the World's principal regulation-defining body since it influences all other national and international regulators. The FAA materials test procedures are covered comprehensively in their on-line handbook [52] and Lyon [53] has described those test methods in detail as they relate to aerospace and aviation. According to Troitzsch [54], within a modern high capacity jet such as the Boeing

747, there are about 4000 kg of plastics materials of which about half comprises glass- and carbon-fibre-reinforced composites. Within the other half are the textiles that are part of the aircraft itself including decorative features. In addition there will be carpets, blankets and other textile-based equipment.

All textiles such as seating fabrics, carpets, curtains/drapes, blankets, etc., used anywhere in a commercial aircraft flying on national and international flights must pass a simple ignition test defined in the requirements given in US Federal Aviation Regulation FAR 25.853(b) (and its other national/international equivalents) using the test procedures defined in FAR Part 25. This latter defines a series of "Bunsen burner ignition in vertical, 60^o, 45^o or horizontal strip tests" which assess whether or not a given material is self-extinguishing. For instance, vertical strip samples (75 x 305 mm) of textile materials used in blankets and seatings are subjected to a flame at the specimen bottom edge for 12 s and after its removal must experience a burn or damaged length ≤ 152 mm, an afterflame time ≤ 15 s and a flame time of any drippings ≤ 3 s. Typical textiles used in these areas include [52, 54] modacrylics and flame retarded viscose and wool. For textiles used in liners for cargo and baggage compartments the 45^o test is used with similar requirements except that no flame penetration through the fabric should occur.

However, many textiles are used as part of assemblies which pose greater fire risks, for example seating and wall panels, and so require to be additionally tested as part of such an assembly. For instance, textiles which form a decorative or reinforcing element of structures within the passenger cabin must be tested as a composite or assembly according to the requirements of FAA specification FAR 25.853 Part IV Appendix F [53] for their ability not to spread fire using the Ohio State University (OSU) calorimeter. In this test, textiles for use as decorative coverings for wall panels are mounted on an appropriate wallboard material and are subjected to a heat flux of 35 kW m^{-2} yield. To pass, the burning composite must emit a maximum heat flux output below65 kW m^{-2} and generate an average flux over 2 min of less than 65 kW m^{-2}.

In seatings, the external fabrics must be able to prevent ignition of internal filling materials, hence the use of fire blocking fabrics between the outer fabric and the inner seat filling. In specification FAR 25.853(c), a seat assembly mock-up is subjected to a kerosene burner having a heat flux of about 115 kW m^{-2} for 2 min. After extinction of the burner, the assembly must extinguish within 5 min, not burn beyond the seat dimensions and the overall mass loss must be ≤ 10%. To enable seating assemblies to pass this test, it is usual to have an outer fabric (e.g. FR wool or FR wool/polyamide 6.6) that passes FAR 25.853(b) and an underlying fire blocking or barrier layer typically based on high performance fibres such as aramid, oxidized acrylic, glass or blends of these with other each other or with fibres such as FR wool.

Apart from the normally accepted textile products, heat and fire resistant textiles find use in engine insulation (e.g. ceramic structures around combustion chambers), fuselage acoustic insulation (e.g. glass fibre-based battings in FR polymeric film containers), reinforcements for composites (e.g. carbon fibre reinforcements for major structural elements), aramid honeycomb reinforcement for wall and floor structures and fuselage acoustic and fire/heat insulation each of which requires its own fire performance requirements [53, 55]. Associated with all these tests and materials or composites are toxic fire gas and smoke requirements similar to those required by IMO regulations in **Table 3.7** and so the choice of fibre and textile structures will be influenced by the need to pass the minimum emission standards for gases including carbon monoxide, nitrogen oxides, sulphur dioxide, hydrogen chloride and hydrogen cyanide.

3.3 Flammability testing of textiles

It is probably true to state that nearly every developed country has its own set of textile fire testing standard methods which together with those defined by other national and international bodies such as air, land, and sea transport authorities, insurance organisations and governmental departments relating to industry, defence and health, in particular pose a very complex picture. A brief overview of the various and many test methods available up to 1989 is given in reference 56 and a more recent and detailed review of textile fabric flammability tests 2008 in reference 57. **Table 3.8**, however, attempts to give an oversight of the complexity of the range of tests available for textile products at the present time.

The complexity of the burning process for any material such as a textile which, because not only is it a “thermally thin” material, but also has a high specific volume and oxygen accessibility relative to other polymeric materials, proves difficult to quantify and hence rank in terms of its ignition and post-ignition behaviour. Most common textile flammability tests are currently based on ease of ignition and/or burning rate behaviour which can be easily quantified for fabrics and composites in varying geometries. Few, however, yield quantitative and fire science-related data unlike the often maligned oxygen index methods, LOI [56]. LOI, while it proves to be a very effective indicator of ease of ignition, has not achieved the status of an official test within the textile arena. For instance, it is well known that in order to achieve a degree of fabric flame retardancy sufficient to pass a typical vertical strip test (*see* **Section 3.3.1** below), an LOI value of at least 26-27% is required which must be measurable in a reproducible fashion. However, because the sample ignition occurs at the top to give a vertically downward burning geometry, this is considered not to be representative of the most typical ignition geometries. Furthermore, the exact LOI value is influenced by fabric structural variables (*see* above) for the same fibre type and is not single-valued for a given fibre type or blend. However, it finds significant use in developing new flame retardants and optimising levels of application to fibres and textiles.

Based on the seeming complexity of the many tests available, some of which have been alluded to above in **Section 3.2** as well as **Table 3.8**, they may discussed in this chapter in terms of a typography where the many types of test may be more simply categorised as below:

i. Simple fabric strip tests
ii. Textile composite tests
iii. Tests undertaken with the addition of radiant heat (including reaction to fire tests)
iv. Thermal protection (including protective clothing and manikin tests)

These will each be discussed with respect to the sample character and the flammability properties being measured using the previously mentioned (*see* **Section 3.2**) and **Table 3.8** examples. Many of these tests require samples to have undergone some form of durability test [51] especially if flame retardant-treated textiles are present and examples of these tests are also included in **Table 3.8**.

3.3.1 Simple fabric strip tests

Fabric strip testing constitutes the oldest form of reproducibly assessing the burning behaviour of fabrics in terms of such parameters as time to ignite, burning rate, char length, damaged length, nature of debris (including melt dripping) and extinction time for a fabric having specified dimensions, held at a specified angle to the horizontal (0, 45, 60 or 90^o) and subjected to a small flame of standard dimensions. These must be undertaken in an atmosphere having a specified temperature and relative humidity range. Ideally, all practical tests should be based on quite straightforward principles which transform into practically simple and convenient-to-use test methods. **Figure 3.2** shows a schematic representation of a typical vertical strip test such as BS 5438: 1989 test method 2 (and ISO 15025) in which a simple vertically orientated fabric may be subjected to a standard igniting flame source either at the edge or on the face of the fabric for a specified time such as 10 s.

Figure 3.2

For flame retarded fabrics the properties measured after extinction of the ignition source are the damaged (or char) length, size of hole if present, times of after-flame and afterglow and nature of any debris (e.g. molten drips), etc. For slow burning fabrics, such as are required in nightwear, a longer fabric strip is used across which cotton trip wires connected to timers are placed so that times of burning a specified distance and/or burning rates may be assessed. Examples here are BS 5438 test method 2 and BS EN ISO 6941: 2003 (*see* **Sections 3.2.1** and **3.3.1** and below) for use in assessing nightwear, for example.

In the USA a 45^o test was and is still used today to assess whether all clothing fabrics for sale are safe within the General Apparel regulations [4] using the test defined in CFR-2012-16-2 in terms of a maximum burn rate requirement. The previously mentioned automotive standard FMVSS 302 is a horizontal test schematically shown in **Figure 3.4** and again a maximum burn rate of 101 mm/min (4"/min) is the defined pass requirement.

Figure 3.4

For flame retardant fabrics, the more stringent vertical (90^o) test geometries are required and a number are listed in **Table 3.8**. Of these in the USA the often termed "12 inch vertical strip test" is formalised in the standards ASTM D6413 and US Federal Test Method Standard 191, Method 5136(3). The US aviation standard FAR 25. 853(b) demands that most textiles in use in passenger compartments must pass the vertical test version of this requirement after ignition for 12s by a standard gas burner. The damaged length must be less than 152 mm (6") for a pass to be achieved.

In the UK the principles of vertical flame spread on fabrics were discussed over 50 years ago by Lawson et al [58] which led to the development of the now obsolete British standards of 1950-60 period [56]. Subsequently, these were replaced by BS 5438:1976 revised in 1989 which during subsequent normalisation influenced the development of the EU standards BS EN ISO 6940 and 6941:1995 (current revision is 2003) and international standard ISO 15025:2002. Analysis of these respective test standards suggests that BS EN ISO 6940 is comparable to BS 5438 test method 1, BS EN ISO 6941 is similar to BS 5438 test method 3 and ISO 15025, used to assess protective clothing (*see* below), is similar to BS 5438 test method 2. These tests are then used within performance standards relating to given applications such as nightwear, curtains and drapes. For instance BS 5722:1991 uses BS 5438:1976 or 1989 test method 3/3A to test and define performance levels for nightwear fabrics [2] which demands that fabrics having a maximum average burn rate of 12 mm/s pass the requirement for children's nightwear. As stated previously, using BS 5438: 1976 test method 3, on introducing the burner to the lower face of the fabric for 10s, the time of the advancing flame up the fabric to reach the 300 mm marker should not be less than 25 s and to reach the upper 600 mm thread, 50 s if the nightwear is to receive a label that it meets the requirements of BS 5722:1991.

Similarly in the UK curtains and drapes use the same BS 5438:1989 test method 3 within the standard BS 5867: Part 2:1980. In the latest revised version, BS 5867-2:2008 version, the test methods are BS EN ISO 6941:2003 for Type A fabrics and ISO 15025:2002 for Types B and C fabrics is used. ISO 15025:2002 is really a test method for protective clothing (*see* **Table 3.8**) that assumes fabrics are flame retardant or are of limited flame spread. The method is not dissimilar to BS EN ISO 6941 except that a frame size of 150x170 mm is used unlike the longer frame (150x 560 mm) used in BS EN ISO 6941:2003. Part 1 of this standard, BS 5867-1:2004, describes the general requirements including labelling for fabrics to be tested. Using this test method for curtains and drapes used for domestic usage (Type A), the flame application time is typically 10 s whereas for curtains used in contract furnishing Type B), the test is more severe with longer flame application time of 15s. The flammability test is even more stringent for the curtains and drapes used in more hazardous applications such as hospitals, prison etc. (Type C). For these applications the fabric has to be tested with 4 flame application times of, 5, 15, 20 and 30 s.

Within the EU, a simpler test BS EN1102:1996 is defined for curtain and drapes which again uses the test method BS EN ISO 6941 but only with a 10 s ignition time. However, the standard BS EN 13772:2003 also for curtains and drapes is a more stringent standard that uses EN ISO 6941 to which a small radiator is attached to increase the intensity of the ignition source to represent a larger burning source such as a waste paper basket.

For apparel not used for protective clothing, BS EN 1103:2005 defines how flammability may be assessed using the method BS EN ISO 6941: 2003 with a 10 s ignition time.

A variant of these fabric strip test methods are required when testing for surface flash, important not only for high pile toys [59] but also children's nightwear as mentioned above in **Section 3.2.1** (EN 14878:2007 [16, 17]). In such test methods a flame is passed for a short time, typically about 2 s, about 50mm over the surface of the fabric held at a 45° or 90° angle and if ignition occurs, the duration of flaming is measured and the length of specimen damaged by flames is noted. For certain type of toys, the rate of flame spread is also measured through severing of marker threads although for nightwear, any surface flash should not be sufficient to ignite the fabric itself.

3.3.2 Textile composite tests

With the recognition of the hazards posed by upholstered fabrics which comprise both outer fabrics and inner fillings, the development of the small-scale composite test BS 5852 (*see* **Table 3.8**) represented a milestone in the development of realistic model tests which cheaply and accurately indicate the ignition behaviour of full-scale products of complex structure. BS 5852 Parts 1 and 2:1979 and BS EN 1021 Parts 1 and 2 for testing upholstered furnishing fabric/filling composites to simulated cigarette and match ignition sources. These sets of BS and BS EN standards are similar with regard to Source 0, the cigarette ignition source but differ in the time of application of Source 1 in that BS 5852:Part 1: Source 1 has a flame ignition time of 20s and that for BS EN 1021-2, an application time of 15s. Both standards have been reviewed over the years and the latest versions are cited in BS 7176:2007 which advises on test method selection for a given hazard level as shown in **Table 3.5**. However, for UK domestic furnishings BS 5852 Parts 1 and 2:1979 is still valid because it is contained within the current legislation (*see* **Table 3.4**) [5]. **Figure 3.3** shows a schematic diagram of this and the related EN and ISO tests (*see* **Table 3.8**) for undertaking tests with Sources 0 (cigarette) and 1 (simulated match). Again, the test has proved to be a simple to use, cost-effective and reproducible test which may be located in the manufacturing environment as well as formal test laboratory environments. A similar testing methodology is described in the proposed US standard for furnishing fabrics CPSC 16 CFR Part 1634 discussed in **Section 3.2.2** above (*see* **Table 3.4**).

The original BS 5852:1979 Parts 1 and 2 (which were amalgamated into a single test standard in subsequent revisions), describes seven different ignition sources of increasing intensity and these are more fully described in **Table 3.9**.

Table 3.9

BS 7176:2007 defines how they may be used in public and contract environments as shown in **Table 3.5** for upholstered furnishings. This range of sources covers that of a simple smouldering cigarette to a simulation of 4 sheets of newspaper (Source 7).

With regard to bedding in the UK, the standard BS 6807:2006 is used to assess ignitability of mattresses and uses ignition sources specified in BS 5852 while BS 7177:2008 specifies various combinations of ignition sources for four different hazard classifications: low, medium, high and very high based on the standards BS 6807 and BS EN 597-1 and -2. The 0/NS (cigarette plus non-smouldering insulation) ignition source is also described in Annex B of BS 7177:2008 to provide guidance for users on the ignitability behaviour of mattresses when covered with bedding. These test methods are mandatory in contract furnishings.

The US equivalents for bedding with regard to cigarette (CPSC 16 CFR Part 1632) and match (CPSC 16 CFR Part 1633) ignition have been discussed above in **Section 3.2.2** and listed in **Table 3.4.**

Finally for bedding, the latest versions of the international standard for bedding BS EN ISO 12952-1:2010 have been established for smouldering cigarette ignition and BS EN ISO 12952-2:2010 for match flame. Both these standards are quite similar to the UK standard BS 6807.

Other furnishing materials such as carpets have appropriate tests such as BS 6307:1982 which determines the flame spread of a carpet sample in a horizontal orientation in the presence of a simulated match, namely a methenamine pill of 6 mm dia and 150±5 mg weight. The standard test methods for contract curtains described in BS 5867-2:2008 have been discussed in **Section 3.2.2** above.

3.3.3 Tests undertaken with the addition of radiant heat (including reaction to fire tests)

It is well known that when textiles are subjected to elevated temperatures they become more easily flammable and even flame retardant textiles may become flammable at heat fluxes above 25 kW/m^2. Consequently when textiles are required to perform well at elevated temperatures, test methods must be devised that reflect this.

To simulate this scenario, a radiant panel is usually mounted at an angle to the textile sample, which may be vertically or horizontally orientated. The specimen is typically exposed to radiant heat from an air-/gas-fuelled radiant panel and the textile fabric specimen is at an angle typically of 30º to the panel face. The mounted specimen is thus exposed to a gradient of heat flux ranging from a maximum of 10 kW/m^2 immediately under the radiant panel to a minimum of 1 kW/m^2 at the far end of the test specimen, remote from the panel. The specimen closest to the panel is usually subjected to a small flame and the distance burned until flame extinguishes is converted into an equivalent critical radiant flux, in W/m^2 related to the panel intensity at that point. Such a test method has been included by the EU for fire test approval of floorings such as BS EN ISO 9239-1:2010.

For textile materials used as interior wall-coverings in UK buildings including railway carriages, where the fabric could be in a vertical orientation attached to the wall panel, measurement of rate of flame spread under external heat flux is one of the requirements. For such applications, the test method BS 476-7:1997 (Fire tests on building materials and structures. Method of test to determine the classification of the surface spread of flame of products) essentially requires a vertically oriented specimen exposed to gas fired radiant panel with incident heat flux of 32.5 kW/m^2 for 10 min. In addition, a pilot flame is applied at the bottom corner of the specimen for 1 min 30s and rate of flame spread is measured. The same principle is used in the French test for carpets, NF P 92-506.

In the French suite of test methods, NF P 92-501-507, for testing building materials, the presence of a radiant panel is a significant test feature. Only the method NF P 92-503 is relevant to textiles in the main. NF P 92-503 is often known as the Breuleur Electrique, "epiradiateur" or "M" test and is used for flexible textile materials often used in contract seatings, for example. The schematic of the test apparatus is shown in **Figure 3.5**.

Figure 3.5

The fabric sample is inclined at 30^o to the horizontal and is subjected to a radiant heat flux for 5 min and a flaming ignition source is applied to the heated fabric. Time-to-ignition or time to hole formation, presence of burning droplets and length of damaged specimen are recorded in order to classify materials from M1 to M4 where M1 textiles may be classed as non-flammable, M2 as low flammable, M3 as moderately flammable and M4 as being highly flammable. While this test is mainly used in France, Belgium, Spain and Portugal to certify the use of flexible materials in buildings for public use, it affects many UK and other EU manufactures supplying into EU markets.

However, sometimes a textile is required to be tested under simulated fire conditions which usually means heat fluxes in excess of 25 kW/m^2 and this is especially the case for testing textile composites such as textile covered structural items in transport such as aircraft. The best and original example of such a reaction-to-fire test is the Ohio State University calorimeter designed to test such textile composite samples in FAR 25.853 Part 4 Appendix F and ASTM 906:1983. The apparatus is shown schematically in **Figure 3.6** and all decorative panels in commercial aircraft throughout the developed World must pass this standard.

Figure 3.6

The test applies an incident heat flux of 35 kW/m^2 to a vertically orientated sample which on ignition by a small flame burner must not generate a peak heat release rate of 65 kW/m^2 and an average heat release rate of 65 kW/m^2 over a period of 2 min. This test attempts to measure the ease of ignition under a high heat flux and the associated heat release may be used to define both the ignition and fire propagating of textiles in composite structures used in commercial aircraft. The more recently available cone calorimeter [60] has yet to make a significant impact in the assessment of textile fire behaviour apart from in the defence and extreme protective clothing-related sectors. However, the author has attempted to correlate the two techniques with some degree of success [61].

In **Section 3.2.4.4**, another of the aviation fire tests mentioned which could be included in this discussion as examples of extreme heat flux fire performance tests is FAR 25.853(c) which subjects a seat assembly unit to a so-called "kerosene burner" test in which an assembly is subjected to an incident heat flux of 115kW/m^2 for 2 min. There is also a not dissimilar second FAR test for assessing the burn-through resistance of fuselage thermal/acoustic insulation, usually based on glass or ceramic fibre nonwoven structures – FAR 25.856(a) Appendix F Part VI. This describes a test in which a burner having a flame temperature of about 1050ºC and a heat flux of 160 kW/m^2 impinges on the back of a 810x910 mm sample. To pass, none of the specimens must allow the flame to penetrate through the thickness for 4 min or register a heat flux of greater than 23 kW/m^2 at a distance of 31cm behind the sample face. The full details of these and other related FAR tests are given in reference 53.

3.3.4 Thermal protection (including protective clothing and manikin tests)

As textile materials are used in more complex and demanding environments, so the associated test procedures become similarly more complex. This is especially the case for protective clothing where the garment and its components have to function not only as a typical textile material but be resistant to a number of agencies including heat and flame. However, before the mid 1990s most protective clothing tests were simply based on vertical strip burning tests and still today in the USA as discussed in **Section 3.2.3** above [26, 31]. However, during the 1970-80 period the realisation for and development of measures of thermal protection from both radiant and convective (ie flame) heat sources were recognised. Resistance to heat transfer by convective flame, radiant energy or plasma energy sources may be quantified in terms of a Thermal Protective Index (TPI) often related to the time taken for an underlying skin sample with or without an insulating air gap to achieve a minimum temperature or energy condition sufficient to generate a second degree burn [62]. One early authoritative study of the thermal insulative properties of fabrics was that by Perkins [63] who studied a large number of fabrics with an area density range of 85-740 gsm as single layers. He selected an incident radiant source intensity of up to 16.8 kW/m^2 and a convective flame source of 84 kW/m^2, which is considered to be commensurate with the exposure typically experienced by firefighters. Behind each fabric was a heat flux meter which enabled time versus heat flux to be determined. Using a standard burn-injury curve that relates delivered heat to incipient second degree burn threshold level, performance of fabrics could be measured in terms of time to reach the latter. Their results may be summarised as follows:

- For radiant heat fluxes of 8.4 kW/m^2, fabric area density determines protection efficiency with air permeability also influencing performance.
- At heat fluxes of 12.6 and 16.8 kW/m^2, the fibre properties become important and char-forming fibres like FR cotton and FR wool become superior.
- Exposures to the convective flame at 84 kW/m^2, shows the FR wool fabrics to yield significantly higher times than FR cotton and aramid fabrics of similar weight.

An alternative method is to determine the so-called thermal protective performance index (TPP) as described in the ASTM D4108-82 (revised 1987)[64] where TPP for a fabric assembly is the burn threshold time multiplied by the incident heat flux.

A similar bench-scale experimental set-up is used for test methods described in BS EN ISO 6942:2002 (Protective clothing. Protection against heat and fire. Method of test: Evaluation of materials and material assemblies when exposed to a source of radiant heat) and EN 367:1992 (Protective clothing. Protection against heat and fire. Method for determining heat transmission on exposure to flame) (*see* **Table 3.8**) for measuring Radiant Heat Transfer

Index (RHTI) and convective heat transfer index (HTI) respectively. RHTI and HTI are the mean times taken, t_{12} and t_{24}, for the calorimeter at the rear of the assembly away from the flame to rise respectively by 12±0.2 and then by 24±0.2°C.

Based on such developments, as **Table 3.8** shows, a number of tests which has been developed across the EU since 1990 to accommodate the different demands of varying types of protective clothing and the hazards whether open flame, hot surface, molten metal splash or indeed a combination are catered for as defined in both standards for firefighters' (BS EN 469:1995 revised 2005) and general workers' (BS EN ISO 11612:2008) clothing, referred to above in **Section 3.2.3** and which will be more fully discussed below. Furthermore, the whole aspect of design, comfort and durability in addition to performance requirements are defined within BS EN 340:2003 together with the specified labelling requirements of protective clothing sold within the EU under the Directive on Personal Protective Equipment (PPE) 89/686/EEC discussed above in **Section 3.2.3**. A current list of all CEN standards relating to protective clothing valid at 2009 has been published by the UK Health and Safety Executive [65].

Metal splash protection requires further comment and in BS EN ISO 9185:2007 (Protective clothing. Assessment of resistance of materials to molten metal splash) which replaces the earlier BS EN 373:1993, molten drops of metal (e.g. steel, copper, aluminium) impinge up on the upper fabric surfaces orientated at 45° to the horizontal so that droplets during impact have time to thermally degrade the fabric surface and either glance off or stick to and burrow into the fabric. An underlying embossed PVC film (with an area density of 160 gsm) is present as a skin simulant and when heated first loses its embossing and then generates small holes. In this test, shown in **Figure 3.7**, 50 g molten metal (at about 50°C higher than its respective melting point) is dropped on to a supported fabric. If no PVC damage is apparent, the test is repeated with fresh fabric and PVC samples but with an increasing incremental mass of molten metal (10 g) until damage is apparent. Conversely, if 50 g molten metal damages the PVC, incrementally decreasing masses are used until no damage is apparent. The molten mass index for a given fabric is the average of four highest masses that do not give rise to PVC damage.

Figure 3.7

With regard to skin damage more generally, one test not yet standardised is that based on the simulation of a human torso and its reaction to a given fire environment when clothed; the original Du Pont "Thermoman" [66] or instrumented manikin provided the means of recording the temperature profile and simulated burn damage sustained by the torso when clothed in defined garments (usually prototype protective garments) during exposure to an intense fire source. This latter is typically a series of gas burners yielding a heat flux of 84 kWm^{-2}. This method has been made an official standard in the USA since about 2000 as ASTM F 1930 [67]. However, its adoption as either a CEN or ISO standard has occurred only recently and Sorensen [68] has reviewed attempts to establish this and related manikin methods as a standard method during the 1990 period which at that time were impeded by the claimed poor reproducibility of the test and its sensitivity to garment fit. Subsequently the ISO standard test specification was published as BS ISO 13506:2008 [69] and its final development to achieve this is reviewed by Camenzind et al [70]. **Figure 3.8** shows a schematic representation as defined in BS ISO 13506:2008 of a manikin under test in which a clothed manikin is subjected to the heat from six burners, two at each side and two behind, which focus on the jacket and trouser areas.

Figure 3.8 and Figure 3.9

Figures 3.9(a) and **3.9(b)** show images of the BTTG Ltd., RALPH manikin [68] as the undressed torso and a manikin under test respectively. The number of sensors in the torso ranges from 110 to 126 divided across the torso, including the head region, as recommended by the standard in order to produce an effective body map of first, second and third degree potential burn damage. This test is listed as a possible additional test as BS EN 469:2005 (E) within the standard for firefighters' clothing, BS EN 469: 2005 [27] and in Annex C of BS EN ISO 11612:2008 [30] (*see* below). Recommended flame application times at 84 $kWm^{-}2$ heat flux are either 4 or 8s depending on the level of protection requirement. Within the USA, however, to assess the flash-fire resistance of textile materials for both industrial and military applications, the ASTM F 1930 requires exposure of fully dressed manikin to the heat flux of 84 kW/m^2 for 3s and to pass the related performance standard US NFPA 2112 [71], materials used in the tested flame-resistant garments should yield a body burn rating ≤ 50%.

The standard BS EN 469:2005 is a composite standard that attempts to determine all the significant factors that determine the overall protective character of a firefighter's garment for two levels of performance. **Table 3.10** shows the number of tests and required minimum performance requirements at each level within this standard. This standard may be applied to any part of the full garment assembly from the outershell jacket and overtrousers (or a single outer coverall) to the underlying outer and underwear garments. Gloves and hoods are covered by other standards listed in **Table 3.8**.

Table 3.10

The performance specifications specifically relating to thermal protection include ignition and flame spread (BS EN ISO 15025:2002) and heat transfer to radiant (BS EN ISO 6942:2002) and convective (BS EN 367:1992) heat. For instance, the radiant heat transfer index, RTHI, values for a multilayer assembly (to BS EN ISO 6942 Method B) at 40 kW/m^2 rear of the fabric to rise by 24°C ($RHTI_{24}$) should be ≥ 10.0 and ≥ 18.0s for level 1 and 2 performance respectively and the differences, ($RHTI_{24}$- $RHTI_{12}$), ≥3.0 and ≥4.0 s indicating that the initial rise by 12°C usually occurs in a longer period than the time taken to rise another 12°C to a total of 24°C. However, the time limits prescribed ensure that this second stage of the temperature rise is not unduly rapid. A similar set of HTI values for flame exposure (80 kW/m^2), are defined for levels 1 and 2 performance. In addition are tests relevant to the overall performance of firefighters' clothing, including tensile and tear strength, surface wettability and others. Again the reader is referred to the main standard and its component parts for full details of each test.

BS EN ISO 11612:2008 [30] is also a composite standard which as stated in **Section. 3.2.3** defines a number of different performance levels for a variety of industrial protective clothing subjected to convective (flame), radiant, molten metal splash (iron and aluminium) and contact heat sources. All fabric samples (including those used in garment parts such as pockets and seams) are subjected to a prescribed cleansing process prior to testing and like BS EN 469:2005 above, has an option for full garment testing for burn injury protection to BS ISO 13506:2008 as defined in Annex C of the sample. While the full specifications for each level are complex and the standard relates to both textile and leather garments, an outline of those for textile garments is presented in **Table 3.11** which shows the number of tests and required minimum performance requirements at each level within this standard.

Once tested a garment may be labelled according to the provisions in ISO 13688 with the appropriate level of performance e.g. B1/C2/D1, etc.

Table 3.11

Finally a standard which enables a clothing fabric to be indexed in terms of both flame retardancy and durability is BS EN ISO 14116:2008 (a replacement for BS EN 533:1997) mentioned in **Section 3.2.3** above. The standard entitles ‘Protective clothing - Protection against heat and flame - Limited flame spread materials, material assemblies and clothing’ uses ISO 15025:2000, Procedure A, face ignition (*see* **Table 3.8** and **Figure 3.2**). BS EN ISO 14116 defines is a method of classifying the extent of damage to a fabric sample subjected to a small flame using test method BS EN ISO 15025:2000. Fabrics are tested before and after a specified cleansing process for a number of cycles according to ISO 11611:2007 (which is similar to BS 5651:1989). Fabrics are classified in terms of thermal performance as 1 (no flame or damage (e.g. hole or char) to reach the upper or vertical specimen edge, no flaming debris, no afterflame spreading beyond char edge), 2 (as for 1 except no hole formation) or 3 (as for 2 but afterflame should not exceed 2 s). A final index is stated as “x/y/z” where x is the flame spread index, y is the number and type of cleansing process and z is the temperature of that process. For example 3/5I/75 indicates material that meets flammability index 3, five times industrially-washed at 75 °C, 2/5H/60 indicates a material that meets flammability index 2, five times home-washed at 60°C and 3/5C/P indicates a material that meets flammability index 3, five times dry-cleaned with perchlorethylene, Thus the final index gives a measure of both flame resistance and durability and both single layer fabrics, assemblies of fabrics and garments may be labelled as described in the BS EN ISO 14116:2008 standard.

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Table 3.1: Major textile-related fires in the UK and Ireland, 1979-present

Fire	**Cause**	**Consequences**
Rail sleeper fire, Taunton, 6 July 1978	Sacks of soiled and clean laundry adjacent to electric heater.	12 fatalities 15 non-fatal casualties
Woolworths Store Fire, Manchester, 8 May 1979	Ignition by smoker's material of a stack of polypropylene fabric-covered, polyurethane-filled furniture in restaurant area.	10 fatalities 53 non-fatal casualties
Stardust Disco Fire, Dublin, 14 February, 1981	Ignition of PVC-covered, foam-filled furnishings leading to flashover of multi-seating array.	48 fatalities 128 non-fatalities
Boeing 737 Fire, Manchester Airport, 22 August 1985	Punctured fuel tank causing external pool fire which broke through the fuselage into the cabin. Cabin engulfed in toxic fumes and smoke from burning seating materials.	55 fatalities 15 serious non-fatalities
Windsor Castle, 1992	Flood lighting ignition of upper region of large curtain funnelling growing fire into the wooden ceiling and structure.	No casualties £40 million damage and loss of heritage.

Table 3.2: Selected National and International Nightwear Fire Regulations

Country	Regulation	Mandatory/voluntary
UK	The Nightdress (Safety) Regulation, S. I. 839:1967 and The Nightwear (Safety) Regulations S.I. 2043:1985, HMSO, London, UK.	Mandatory
Ireland	I.S. 148 Flammability and Labelling Requirements of Fabrics and Fabric Assemblies Used in Children's Nightwear. Covered by S.I. 215/1979 Industrial Research and Standards (Section 44) (Children's Nightdresses) (Amendment) Order, 1979	Mandatory
Netherlands	The Nightwear (Safety) Regulations 1985; from 2008 all clothing must meet minimum burning requirements	Mandatory
EU	General Product Safety Directive (2001/95/EC**); EN 14878:2007. Textiles – Burning Behaviour of Children's Nightwear – Specification, 2007**	Mandatory
Norway, Sweden and Switzerland	No specific nightwear regulations but have general clothing flammability regulations	
USA	Standard for the flammability of children's sleepwear, Title 16, Code of Federal Regulations, 16 CFR Parts 1615 and 1616 (recodified from Department of Commerce to Consumer Product Safety Commission at 40 FR 59917, December 30, 1975). Standard for the flammability of clothing textiles, 16 CFR 1610, February 2007	Mandatory
Australia/New Zealand	Australian Government: Trade Practices (Consumer Product Safety Standards) (Children's Nightwear and Paper Patterns for Children's Nightwear) Regulations 2007. Product Safety Standards (Children's Nightwear & Limited Daywear Having Reduced Fire Hazard) Regulations, 2008 (declares AS/NZS 1249:2003 as the standard with variations stated in Amendment A 2008)	Mandatory

Table 3.3: Selected test standards for nightwear (safety) regulations prior to 2000[7]

Country	Test standard	Testing					
		Face (F)/ Edge (E)	Flame height, mm	Type of test	Ignition time, s	Frame V= vertical	Label
Germany & France,	EN ISO 6940	F-E	40	Ignitability	0-20	ISO V	-
	EN ISO 6941	F-E	40	Flame spread	10	ISO V	-
	EN1103	F	40	Flame spread Flash Flaming debris	10	ISO V	-
Netherlands	NEM 1722 (based on EN/ISO 6941	F-E	40	Flame spread		ISO V	Yes
Ireland	IS 148	F	45	Flame spread	10	BS V	Yes
United Kingdom	BS 5722 (using BS 5438:1976 Test 3 or BS 5438:1989:Test 3A*)	F	45/40*	Flame spread	10	BS V	Yes

Australia & New Zealand	AS 2755/2 Now replaced by AS/NZS 1249:2003	F-E	40	Flame spread	5-15	ISO V	Yes
Denmark, Finland, Norway, Sweden	NT FIRE 029 ASTM 1230 KOVFS 1985:8 /ASTM 1320	F	16 40 40	Flame spread Flame spread Flame spread	1-20 1 1	45º 45º 45º	-
Germany	DUTCH CONVENANT	F	40	Flame spread Flash Flaming debris	5 spread 1 flash	ISO	Yes
United States of America (and Norway & Sweden)	ASTM D1230	F	16	Flame spread	1	45º	-

Table 3.4: Selected National and International Furniture and Furnishing Fire Regulations [18]

Country	Regulation	Test method	Domestic/ contract or public
UK	*Consumer Protection Act (1987), the Furniture and Furnishings (Fire) (Safety) Regulations, 1988*, SI1324 (1988), London, HMSO, 1988; revised 1993 Regulatory Reform (Fire Safety Order) 2005 [Fire safety of furniture and furnishings in non-domestic environments]	BS 5852:1979:Part 1 BS5852:1979:Part 2 and BS 7176:1995 revised 2007 (seating) and BS 7177:2008 (bedding)	Domestic Contract/public
France	No.200-164 - Bedding U 23 (Health) – Bedding - Mattress AM 18 (Public) – Seat GPEMD1-90 (Prison)	EN ISO 12953- and -2 EN ISO 12953- and -2 EN 597 F D 60013N & NFP 92501 and NFP 92507 EN 597-1 and -2 & GPEM D1-90	Domestic Public Public Public
Italy	DM26/06/1984 (seat and mattress fillings)	CSE RF/4/83	Public
Finland	No.743/1990 & No.479/96 Finnish fire safety guidelines for furnishings; A-56.1988	EN 1021-1 EN 1202-1 and -2	Domestic Public
Sweden	No regulations only recommendations from the consumer agency: Seating Mattresess	 EN 1021-1 EN 1202-1 and EN	Domestic and public

		597-1	
Norway	Crown Prince Regent's Decree 07/09/1990: Seating Mattresses	 EN 1021-1 EN 1202-1 and EN 597-1	Domestic and public
Spain and Portugal	Same as French regulations		
Germany	Requirements for seating in cinemas	DIN 4102 (classification B2 required)	
USA California Federal	 Technical Bulletin 116: 1980-Requirements, test procedures and apparatus for testing the flame retardance of upholstered furniture Technical Bulletin 117: 2002-Requirements, test procedures and apparatus for testing the flame retardance of resilient filling materials in upholstered furniture Technical Bulletin 603: 2005-California open flame standard for mattresses CPSC 16 CFR Part 1634. Proposed standard for the flammability of residential upholstered furniture; proposed rule, US Consumer Protection Safety Commission, March 4, 2008. CPSC 16 CFR Part 1632: Standard for the flammability of mattresses and mattress pads (FF 4-72, AMENDED), US Consumer Protection Safety Commission (cigarette ignition) CPSC 16 CFR Part 1633: Standard for the flammability (open flame) of mattress sets, US Consumer Protection Safety Commission, March 15, 2006.	 Tech Bull 116:1980 Tech Bull 117:2002: test method No. 191 Method 5903.2 or FF 3-71 CPSC 16 CFR Part 1634 CPSC 16 CFR Part 1632 CPSC 16 CFR Part 1633	 Domestic

Table 3.5: Ignition Source/Hazard combinations – BS 7176: 1995 revised in 2007 (for full details, see the actual standard)

	Low Hazard	**Medium Hazard**	**High Hazard**	**Very High Hazard**
Requirements	Resistance to ignition source: smouldering cigarette of BS EN 1021-1: 2006 and the match flame of BS EN1021-2: 2006	Resistance to ignition source: smouldering cigarette of BS EN 1021-1: 2006 and the match flame of BS EN1021-2: 2006. Resistance to ignition Source 5 in BS5852: 2006	Resistance to ignition source: smouldering cigarette of BS EN 1021-1: 2006 and the match flame of BS EN1021-2: 2006 Resistance to ignition Source 7 in BS5852: 1990	Resistance to ignition source: smouldering cigarette of BS EN 1021-1: 2006and the match flame of BS EN1021-2: 2006. At discretion of the specifier but at least high hazard requirements
Typical examples	Offices Schools Colleges Universities Museums Exhibitions Day centres	Hotel bedrooms Public buildings Public (boarding) schools Restaurants Places of public entertainment Public baths Public houses & bars Casinos Hospitals Hostels	Sleeping accommodation in certain hospital wards and hostels Off-shore installations	Prison cells

Table 3.6: Furnishing items identified in BS EN 45545-2 together with their test protocol requirements [28]

Item	Description
Complete passenger seat	Complete passenger seat including arm and head rests, separate pillows, tip up seats and driver seat accessible to the passenger
Upholstery for passenger seats and head rest	Upholstery for seats and head rest
Armrest passenger seats – Upwards facing surface	Armrest – Surface on which the arm rests R21
Armrest passenger seats – Vertical surface	Armrest – Inside surface (or outside surface on transverse seating) which is against the body of the seat occupant
Armrest passenger seats – Downwards facing surface	Armrest – Underside surface of the arm rest
Back shell; base shell of passenger seats	Back shell; base shell of passenger seats
Seats in staff areas	Tested as an assembled product from upholstery, back and base shell side
Mattresses	Mattresses
Bed clothes for couchettes and beds (blanket, duvets, pillows, sleeping bags and sheets)	Bed clothes for couchettes and beds (blanket, duvets, pillows)
Underside surface of couchettes and beds	Underside surface of couchettes and beds

Table 3.7: Maximum concentrations of toxic gas emissions allowed for curtains for use in commercial shipping and tested to IMO FTP Part 2 method, ISO 5659:1994 Part 2

CO	1450 ppm	HBr	600 ppm
HC1	600 ppm	HCN	140 ppm
HF	600 ppm	SO_2	120 ppm
NO_x	350 ppm		

Table 3.8: Selected test methods for textiles

Test Type	Nature of test	Textile type	Standard	Ignition source
i). Simple fabric strip tests	British Standard based vertical strip method BS 5438:1989	Curtains and drapes	BS 5867:Part 2:1980(1990)	Small flame
		Nightwear	BS 5722:1991	Small flame
	ISO vertical strip similar to Tests 1 and 2 in BS 5438	Vertical fabrics	BS EN ISO 6940/1:1995	Small flame
	US strip tests	Vertical fabrics	ASTM D6413	Small flame
			US Federal Test Method Standard 191, Method 5136(3)	Sample size 305 x 70mm, Small flame impinging for 20s
		Horizontal	FMVSS 302	Small flame
		0, 45, 60, 90^o	FAR 25. 853(b)	Small flame, 12 s ignition
		45^o	CFR-2012-16-2.	Small flame
ii).Textile composite tests	Small-scale composite test for furnishing fabric/fillings. See also Table 3.4 for non-UK countries	Furnishing fabrics	BS 5852: Pts 1 and 2:1979 (retained pending changes in legislation [2])	Cigarette and simulated match flame(20s ignition)
		Furnishing fabrics	BS 5852:1990(1998) replaces BS 5852: Pt 2	Small flames and wooden cribs applied to small and full scale tests
			ISO 8191:Pts 1 and 2 (same as BS 5852:1990)	
			BS EN 1021-1:1994	Cigarette
			BS EN 1021-2:1994	Simulated match flame (15s

				ignition)
			BS 7176:2007	Advises on test selection (BS 5852 vs BS EN 1021/2) versus hazard (see table 3.5)
		Bedding (mattresses)	BS 6807:1996	Specifies sources from BS 5852.
			BS 7177:2008	Advises on which test method/source to use for specified hazard levels
		Carpets	BS 6307:1982	Methenamine pill ignition source
		Curtains	BS EN 13772:2003	Uses EN ISO 6941
			BS 5867:Part 2:1980(revised 1990)	Uses BS 5438 Test Method 3
iii).Tests undertaken with the addition of radiant heat including reaction to fire tests.	Use of radiant flux plus specified ignition	Carpets	prEN ISO 9239 and BS ISO 4589-1.	Irradiate with
		All fabrics/composites often for use in seatings	NF P 92503, French “M test”	Irradiate with small burner
		Aircraft seat assemblies, so-called “Boeing” test	ASTM E906: 1983 and FAR 25.853 Part 4, App F uses Ohio State University heat release calorimeter	Irradiate under 35 kW m^{-2} with small flame igniter
iv).Thermal protection (including	Protective Clothing: General requirements		EN 340:2003	

protective clothing and Mannikin tests) [Protective Clothing]			
	Resistance to radiant heat	BS EN ISO 6942:2002 (formerly BS EN366:1993 which replaced BS 3791:1970)	Exposure to radiant source
	Resistance to radiant and? convective heat (flame)	BS EN 367:1992	Determine heat transfer index
	Resistance to molten metal splash	BS EN 373:1993	Molten metal
	Gloves	BS EN 407:1994*	Composite standard (including firefighters' and welders' gloves)
	Firefighters clothing	BS EN 469:1995 revised 2005	Composite standard
	Welders' and allied industrial clothing	BS EN 470-1:1995/ISO 11611	Composite standard
	Classification of degree of fabric damage	BS EN ISO 15025:2000 (formerly BS EN 532:1995 which replaced BS 5438)	Small flame
	Protection to industrial workers exposed to heat	BS EN 531:1995/ISO 11612	Composite standard
	Protective clothing – protection from limited flame spread	BS EN ISO 14116:2008 (replaces BS EN 533:1997)	Small flame
	Contact heat transmission	BS EN 702:1995	Contact temps. 100-

				500^oC
	Firefighters' hoods		EN 131911	
Durability tests	Cleansing and wetting procedures for use in flammability tests	All fabrics	BS 5651:1989	Used on fabrics prior to submitting for standard ignition tests
		Commercial laundering	BS EN ISO 10528: 1995	
		Domestic laundering	BS EN ISO 12138: 1997	
		Domestic laundering & dry cleaning	EN ISO 6330 ISO 11611:2007	

Note: * Test methods presently under review

Table 3.9: Ignition sources described in BS 5852

Source	**Ignition source**	**Gas flow rate or mass**	**Energy output, kWh**	**Time of application**
0	Cigarette	-	-	Throughout the test
1	Burner	45 ml/min	0.001	20 s
2	Burner	160 ml/min	0.004	40 s
3	Burner	350 ml/min	0.016	70 s
4	Crib	8.5 g	0.04	Throughout the test
5	Crib	17 g	0.08	Throughout the test
6	Crib	60 g	0.28	Throughout the test
7	Crib	126 g	0.59	Throughout the test

Table 3.10 Test methods within the composite standard for firefighters' clothing, BS EN 469: 2005 [27]

Property tested	**Standard**	**Principal performance specifications**	
		Level 1	**Level 2**
Flame spread (material and seams)	BS EN ISO 15025:2002 (replaces BS EN 532:1995)	No flame extending to top or edge, no hole formation and afterflaming and afterglow times ≤ 2s; flame spread index 3	
Heat transfer (flame)	BS EN 367:1992 (ISO 9151)	$HTI_{24} \geq 9.0s$ $HTI_{24}- HTI_{12} \geq 3.0$	$HTI_{24} \geq 13.0s$ $HTI_{24}- HTI_{12} \geq 4.0$
Heat transfer (radiant)	BS EN ISO 6942:2002 at 40 kW/m^2	$RHTI_{24} \geq 10.0s$ $RHTI_{24}- RHTI_{12} \geq 3.0$	$RHTI_{24} \geq 18.0s$ $RHTI_{24}- RHTI_{12} \geq 4.0$
Residual strength when exposed to heat	EN ISO 13934-1 or EN ISO 1421:1998, method 1 after pre-treatment to EN ISO 6942:2002, method A at 10 kWm^2	Tensile strength ≥ 450 N	
Heat resistance	ISO 17493 at 180±5ºC for 5min	No shrinking (≤5%), melting, dripping or ignition	
Tensile strength	EN ISO 13934-1 or EN ISO 1421:1998	Tensile strength ≥ 450 N	
Tear strength	ISO 4674-1:2003, method B (coated); EN ISO 13937-2:2000 (uncoated)	Tear strength ≥ 25 N	
Surface wetting (after washing and drying)	BS EN 24920:1992 (ISO 4920:1981)	Spray rating ≥ 4	
Dimensional change	ISO 5077	≤ 3%	
Penetration by liquid chemicals	EN ISO 6530 (for 40% NaOH, 36% HCl, 36% H_2SO_4 and o-xylene at 20ºC)	≥ 80% run off	
Water resistance (pressure for water entry)	BS EN 20811:1992 (ISO 811:1981)	<20kPa (without moisture barrier)	≥20kPa (with moisture barrier)
Breathability	BS EN 31092:1994 (ISO 11092:1993)	>30m^{2}Pa/W	≤30m^{2}Pa/W
Ergonomic performance	BS EN ISO 469:2005 Annex D	Defined by manufacturer/customer	
Visibility (optional)	EN 471:2003	Defined by manufacturer/customer	
Manikin (optional)	BS EN ISO 469:2005 Annex E (method BS ISO 13506:2008)	Defined by manufacturer/customer	

Table 3.11 Test methods within the composite standard for industrial heat protective textile clothing, BS EN ISO 11612:2008 [30]

Property tested	**Standard**	**Principal performance specifications**			
		Level 1	**Level 2**	**Level 3**	**Level 4**
Heat resistance	ISO 17493:2000				
	180±5ºC	No ignition, melting or shrinking (≤5%)			
	260±5ºC	No ignition, melting or shrinking (≤10%)			
Flame spread (material and seams)	<u>BS EN ISO 15025:2002</u>	No flame extending to top or edge, no hole formation and afterflaming and afterglow times ≤ 2s			
Heat transmission:					
Convective heat (Code B)	ISO 9151:1995	B1/ 4.0min≥HTI_{24}≤10min	B2/ 10.0min≥HTI_{24}≤20min	B3/ B1/ 20.0min≥HTI_{24}	
Radiant heat (Code C)	BS EN ISO 6942:2002 at 20 kW/m^2	C1/ 7min≥HTI_{24}≤20min	C2/ 20min≥HTI_{24}≤50min	C3/ 50min≥HTI_{24}≤95min	C4/ HTI_{24} ≥ 13.0s
Molten metal splash	ISO 9185:2007				
Aluminium (Code D)		D1/ 100g≥Al mass≤200g	D2/ 200g≥Al mass≤350g	D3/350g≥Al mass	
Iron (Code E)		E1/ 60g≥Fe mass≤120g	E2/ 120g≥Fe mass≤200g	E1/ 200g≥Fe mass	
Contact heat (Code F)	ISO 12127-2:2007 at 250ºC	F1/ 5s≥threshold time≤10s	F2/ 10s≥threshold time≤15s	F2/ 15s≥threshold time	
Tensile strength	EN ISO 13934-1	Tensile strength ≥ 300 N			
Tear strength	EN ISO 13937-2	Tear strength ≥ 15 N			
Burst strength	ISO 13938-1	Burst strength ≥200kPa			
Seam strength	ISO 13925-2	Seam strength ≥225N			
Resistance to water penetration (optional)	EN 343	Requirements within EN 343			
Resistance to water vapour penetration (optional)	EN 343	Requirements within EN 343			
Ergonomic performance	BS EN ISO 11612:2008 Annex D	Defined by manufacturer/customer			
Innocuousness/pH	ISO 3071	3.5≥pH≤9.5			
Manikin (optional)	BS EN ISO 11612:2008 Annex C (method ISO BS 13506:2007)	Defined by manufacturer/customer			

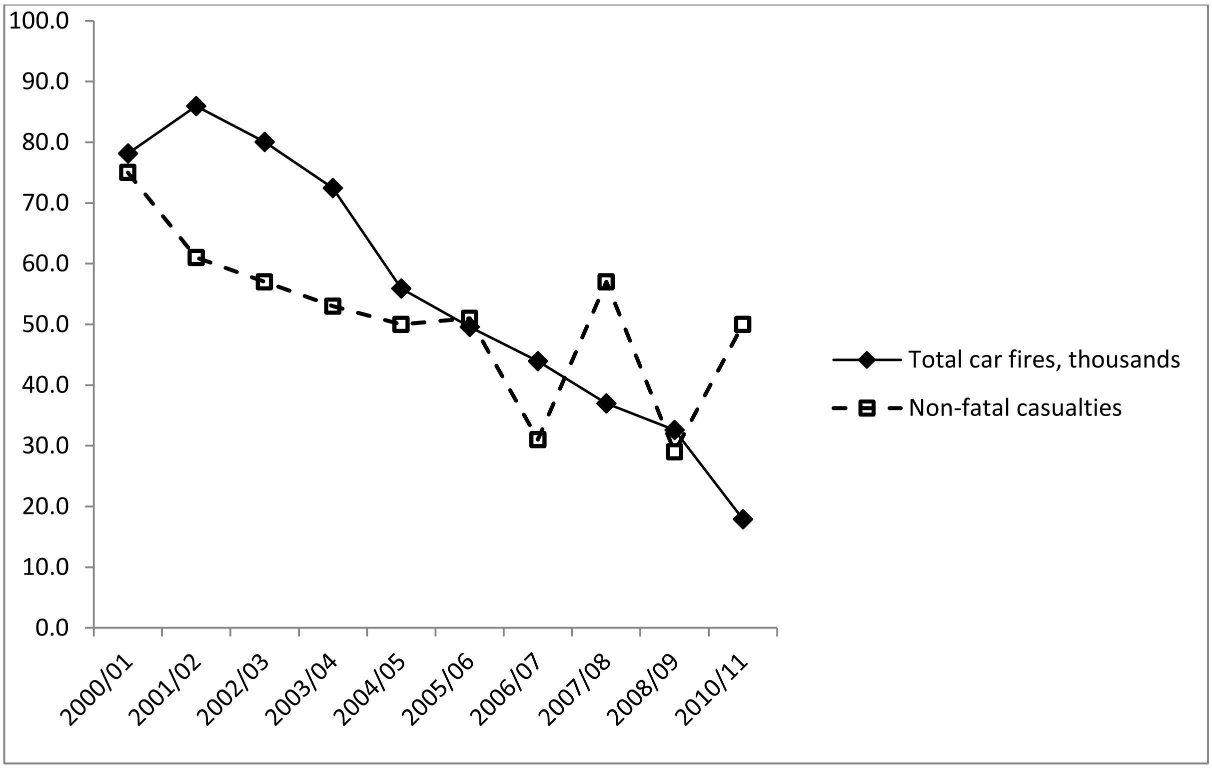


Figure 3.1. UK car fire and non-fatal casualty incidence, 2000-2011 [7]

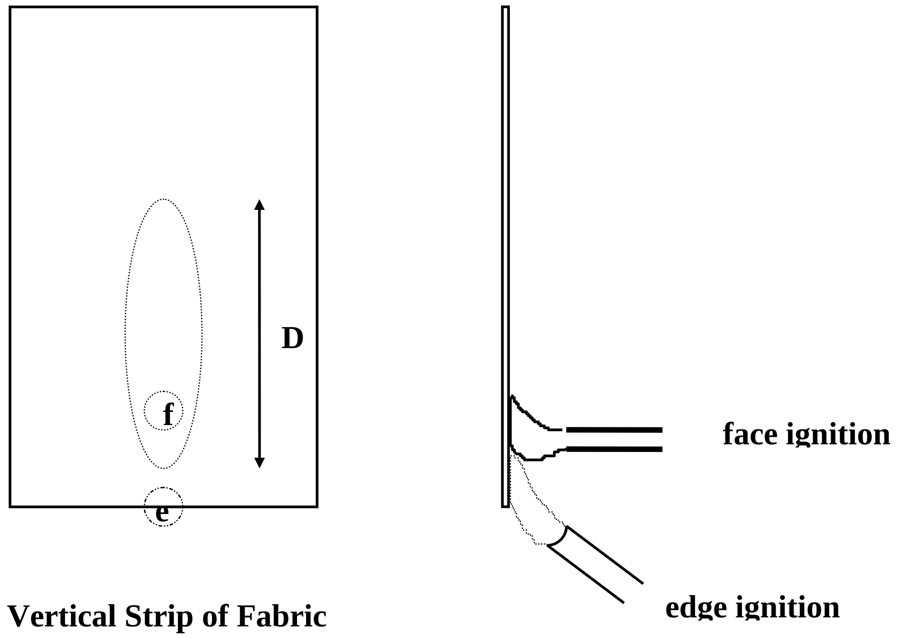
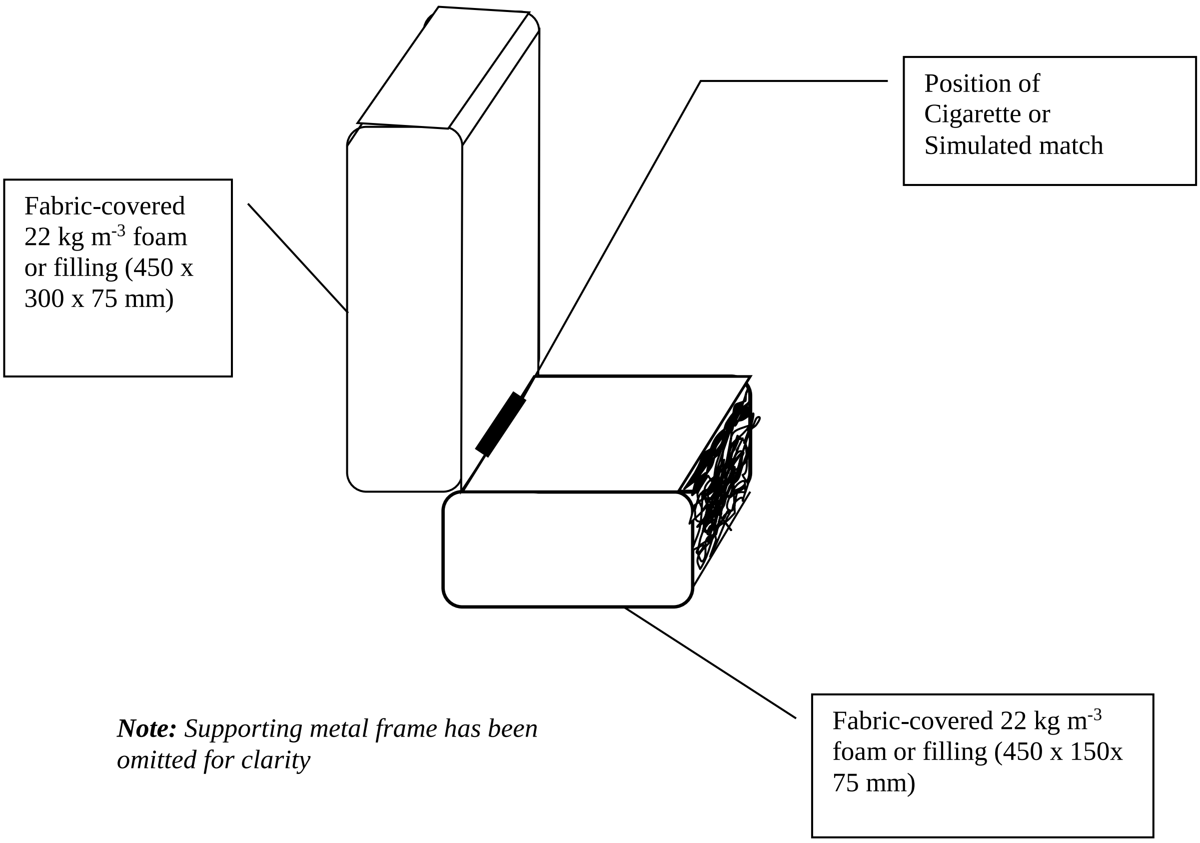


Figure 3.2. A schematic representation of the vertical strip test in BS 5438:1989 test method 2A (face) and 2B edge)

Figure 3.3. Schematic diagram of the filling and fabric geometry in BS5852:Part 1:1979 and subsequent revisions



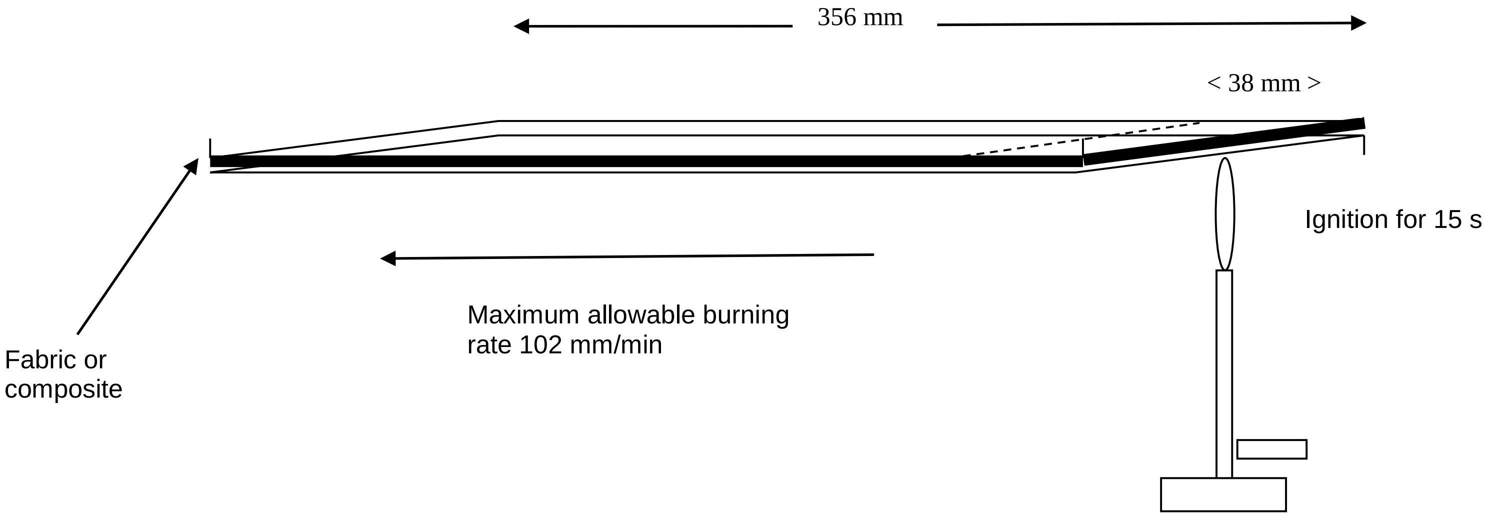
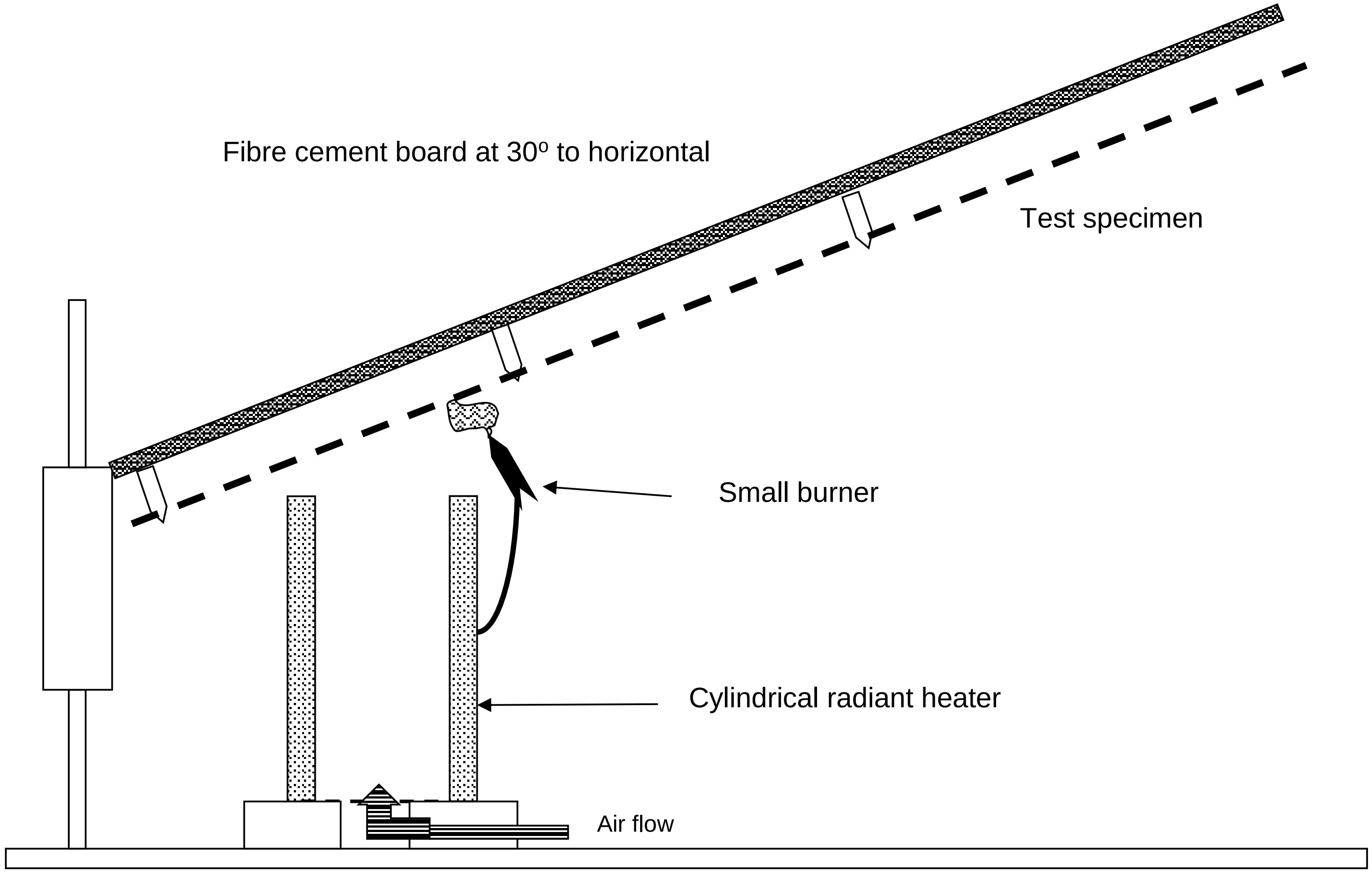


Figure 3.4. Schematic of the automobile interior textile test FMVSS 302 (also ISO 3795, BS AU 169 (UK), ST 18-502 (France), DIN 75200 (Germany), JIS D 1201 (Japan) and ASTM D-5132 (US)



Fibre cement board at 30º to horizontal
Test specimen
Small burner
Cylindrical radiant heater
Air flow

Figure 3.5. The French "Epiradiateur" or "M" test NF P 92-503

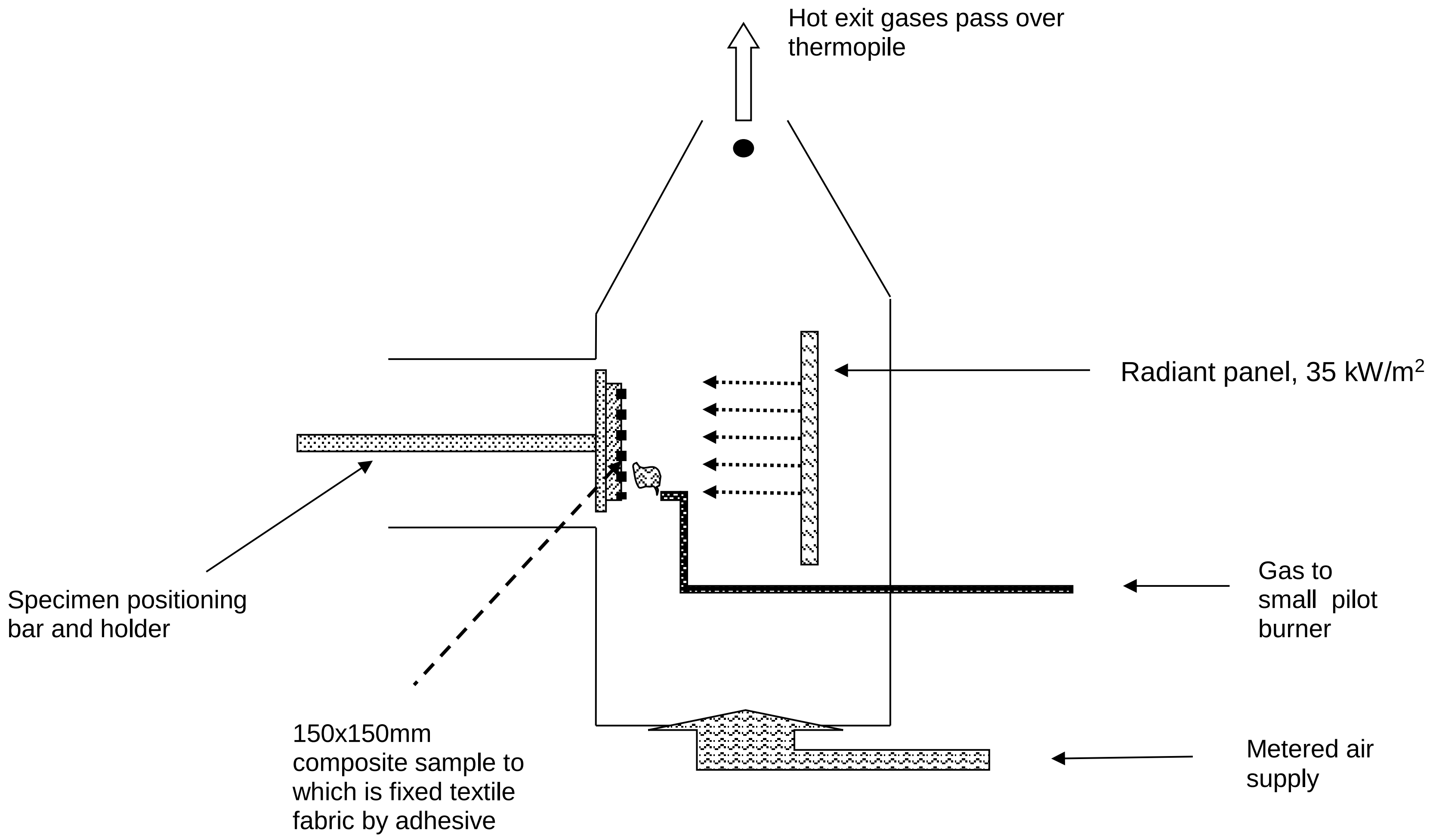


Figure 3.6. Schematic diagram of the Ohio State University (OSU) calorimeter designed to test textile composite samples in FAR 25.853 Part 4 Appendix F

Figure 3.7. The hot metal splash test, BS EN ISO 9185:2007 (replaces BS EN 373:1993) (courtesy of BTTG Fire Testing Laboratory, Altrincham, UK)

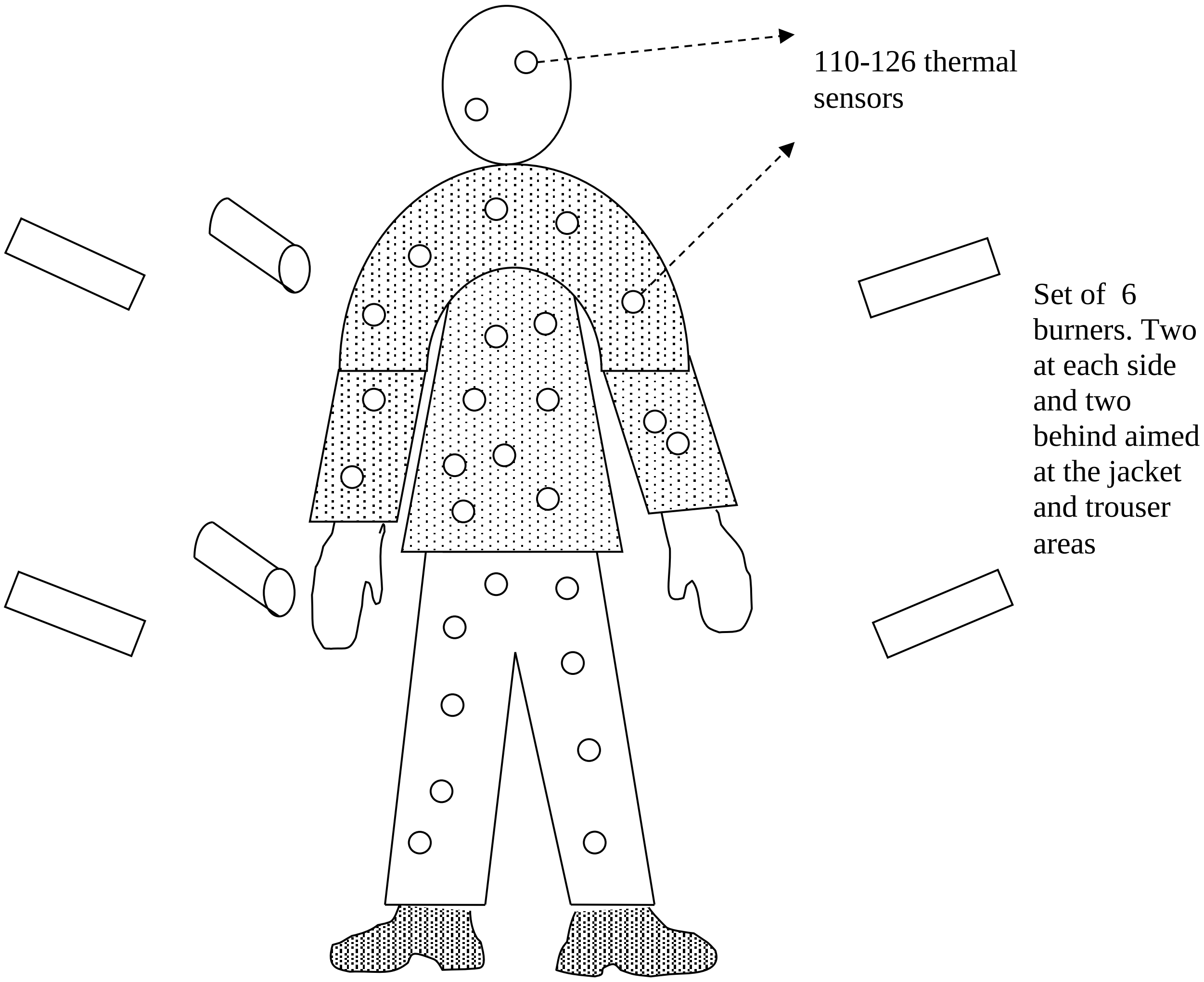


Figure 3.8. Schematic diagram of a manikin under test according to BS ISO 13506:2008 showing the position of six gas burners and the sensors

(a)

(b)

Figure 3.9. Images of the BTTG Ltd., manikin RALPH [68] as (a) the undressed torso and (b) as a manikin under test. (courtesy of BTTG Fire Testing Laboratory, Altrincham, UK)

A.R. Horrocks. Regulatory and testing requirements for flame retardant textile applications, in: *Update on Flame Retardant Textiles: State of the Art, Environmental Issues and Innovative Solutions*, J. Alongi, A.R Horrocks, F. Carosio and G. Malucelli (Eds.), pp 53-122, Smithers Rapra, Shawbury, UK (2013)