April 2001

C/SNCF/01001

Contract SMT4 – CT 97 - 2164

Final report

FINAL REPORT

1 - ABSTRACT

The FIRESTARR project is a 3 year research programme jointly funded by the European Commission and Industry. It was established in 1997 to assist the work of CEN/TC256/WG1 and CENELEC/TC9X/WG3 in drafting a Part 2 (Requirements for the fire behaviour of materials and components) for a 7-part European Standard prEN 45545 [1] "Fire protection on railway vehicles". The main objectives of the 11 partners of the FIRESTARR Consortium are as follows:

1 To identify the fire risks in European trains and to define the most relevant fire scenarios which frequently occur
2 To select the most suitable test methods for the assessment of reaction-to-fire behaviour as defined by key fire critical effects such as fire initiation, time to an uncontrolled state (flashover), time to loss of visibility and time to lethal conditions for passengers.
3 To obtain test results on three representative ranges of railway products (i.e. structural, furniture and electrotechnical) and to compare them with known values from national tests.
4 To propose a classification system for these ranges of products and to validate these proposals with real-scale tests on parts of European trains.

The statistical analysis of fires occurring in European trains indicated that arson involving vandalised seats was the main fire risk and hence, the selection of test methods for furniture and structural products was governed by this fact. Small-scale tests were selected based mainly on existing ISO and CEN Standards. Large-scale and real-scale tests were developed in relation to the above high risk fire scenario. The real-scale tests involved developing test procedures for seats and structural products in a small train compartment. Electrotechnical products (except cables, which are not within the scope of this project) were evaluated in a similar way to seats and structural products using other tests.

All the test results were statistically analysed to relate reaction-to-fire parameters such as ignitability (I), flame spread (F), rate of heat release (R), smoke opacity (S) and toxicity of fire effluents (T) to the key fire critical effects.

Based on the CEN/TC256 definitions of 4 railway operation categories, which are associated with different hazard levels (HL), the FIRESTARR Consortium have developed principles for a classification system to be used for specifying the reaction-to-fire performance levels of products in future European trains. Proposals for this classification system as it applies to structural, furniture and electrotechnical products have been made so that they may be developed further by the CEN and CENELEC Committees.

2 - ACKNOWLEDGEMENT

Contributions of the FIRESTARR partners are summarised in this final report. SNCF was responsible for compiling the final report with the assistance of the experts from the participating institutes. The principal authors of the chapters describing the work performed are the following :

Peter Briggs, WFRC
Serge Métral, Patricia Gil, SNCF
Yannick Le Tallec, Véronique Le Sant LNE
Domenico Troïano, Stefano Marrucci, FS
Silvio Messa, Claudio Baiocchi, LSF
Hervé Breulet, ISSeP.

The Commission of the European Communities contributed to the FIRESTARR project through the SMT research programme. The remaining funding was raised nationally by the partners of the Consortium.

3 - ABBREVIATIONS

ABS	acrylonitrile butadiene styrene
ANOVA	ANalysis Of VAriance
CEN	European Committee for Standardisation
CENELEC	European Committee for Electrical Standardisation
CFE	critical flux at extinguishment
CHF	critical heat flux
C_i	concentration of gas i in ppm
CO	carbon monoxide
CO_2	carbon dioxide
D_{max}	max smoke density
D_s 10	smoke density after 10 minutes
EHC	effective heat of combustion
EN	European standard
FED	fractional effective dose
FIPEC	European fire research programme : “Fire Performance of Electric Cables”
GRP	glass reinforced polyester
HBr	hydrogen bromide
HCA	Hierarchical Clustering Analysis
HCl	hydrogen chloride
HCN	hydrogen cyanide
HF	hydrogen fluoride
HF-30	heat flux at 30 minutes
HR_{peak}	heat release peak
HRR	heat release rate
IEC	International Electrotechnical Commission
IMO	International Maritime Organisation
ISO	International Standardization Organisation
k_{max}	max extinction coefficient
LC_{50}	lethal concentration 50
NOx	nitrogen oxide
PCA	Principal Component Analysis
PML	percentage of total mass loss
PVC	polyvinyl chloride
qmax	max heat release rate
QSB	heat of sustained burning
RSP	smoke production rate
S“	smoke extinction area normalized to the specimen area
SBI	single burning item (fire test method)
SEA	specific extinction area
SO2	sulphur dioxide
THR	total heat release
Ti	Toxicity Index from UITP E6
tig	time to ignition
TML	total mass loss from ISO 5660 test
TSP	total smoke production
VL	vandalism level
VOF4 index	rate of smoke generation in the first 4 minutes
WP	Work Package
NR	not reached
FR	flame retarded
Xmax	max flame spread distance
FR GRUP	flame retarded glass reinforced unsaturated polyester
GRUP	glass reinforced polyester
PA	polyamide
GWFI	glow wire flammability index
MIT	minimum ignition time
FIGRA	fire growth rate
FCE	fire critical effect
SPR	smoke production rate
JWG	Joint Working Group
SMOGRA	smoke growth rate

4 - INTRODUCTION

This report presents the work performed in the FIRESTARR (Fire Standardisation Research in Railways) project within the European Standards, Measurement and Testing programme under Contract n°SMT4-CT97-2164. The project was initiated in October 1997 by the Commission of the European Communities in the SMT research programme.

The objectives of the FIRESTARR project were :

- to select the criteria for the fire behaviour performance levels of the materials and the components based on their reaction to fire measurements and in relation to the identified risks ;
- to select the relevant test methods to measure them ;
- to obtain test results on representative railway materials and to compare them with known national values ;
- to validate these proposals with real scale tests on parts of vehicles.

The project included the following tasks :

- Risk and scenario selection ;
- Selection of materials ;
- Choice of small and large scale test methods ;
- Small scale tests on a range of representative railway materials ;
- Statistical analysis ;
- Classification proposal ;
- Large scale tests ;
- Real scale tests ;
- Data processing.

The partner organisations and responsible contact persons of the FIRESTARR Consortium were :

SNCF	Société Nationale des Chemins de Fer Français (administrative co-ordinator) Serge Métral, Patricia Gil	France
LNE	Laboratoire National d'Essais (technical co-ordinator) Alain Sainrat, Yannick Le Tallec, Véronique Le Sant	France
BASF	BASF Aktiengesellschaft Ulrich Werther, Axel Ebenau	Germany
BAYER	BAYER AG Leverkusen Friedrich-Wilhelm Wittbecker, Berthold Mueller	Germany
DB	Deutsche Bahn Hans-Jürgen Fischer	Germany
DIFT	Danish Institute of Fire Technology Tom Nisted	Denmark
FS	Ferrovie dello Stato Domenico Troiano, Stefano Marucci	Italy
ISSeP	Institut Scientifique du Service Public Hervé Breulet	Belgium
LSF	Laboratorio di Studi e Ricerche sul Fuoco Silvio Messa, Claudio Baiocchi	Italy
SP	Swedisch National Testing and Research Institute Jesper Axelsson	Sweden
WFRC	Warrington Fire Research Centre Peter Briggs, Janet Murrell	United Kingdom

5 - DESCRIPTION OF THE STUDY

The major aim of the project is to develop the most representative and comprehensive test methods giving results significant enough to classify the constituent products of railway vehicles taking into account the acceptable risks for users, the vehicle design, the shape and use of the products, the functional equipment, the ventilation system and all relevant combinations of these items.

A methodology has been elaborated to ensure that all effects and parameters related to fire behaviour should be understood as part of the complex system.

DEFINITION OF THE MAIN CHARACTERISTICS OF FIRE BEHAVIOUR RELATED TO PRODUCTS OR VEHICLE PARTS INCLUDED IN THE RAILWAY MATERIALS

These characteristics are inferred from measurements of five reaction-to-fire parameters.
A database has been set up with the results obtained from the measurements performed by test methods on the most representative sampling of products included in the railway materials.

A statistical data process has been drawn out from the results the main characteristics of fire behaviour such as level of ignitability, spread of flame, heat release, smoke opacity and toxicity.

The tests methods to measure reaction-to-fire parameters have been selected from standardised and international methods, taking into account the best economic ratio.

Small-scale tests [1] and large-scale tests[2] have been carried out.

VALIDATION OF FIRE BEHAVIOUR CRITERIA FOR PRODUCTS BY MEANS OF TESTS CARRIED OUT ON CRITICAL PARTS OF VEHICLES

The real-scale tests [3]have been carried out on a scenario basis. The scenarios have been previously fixed and reproduced various conditions and types of risks representative of the real use of railway materials.

As these tests are expensive, only a few products have been tested. These have been selected taking into account the results obtained from the statistical data process on the small scale tests.

Fire behaviour criteria have been drawn from the results taking into account the different types of risks.

SELECTION OF THE MOST SUITABLE TEST METHODS FOR THE ASSESSMENT OF FIRE BEHAVIOUR CRITERIA RELATED TO PRODUCTS INCLUDED IN THE RAILWAY MATERIALS.

The selection of the test methods has been based on the accuracy of the measurement of the reaction-to-fire parameters and on the correlation level between laboratory test results and real-scale test results.

Thus, from all these data and conclusions, a classification system has been developed and proposed as a technical contribution to the European standardisation bodies.

The FIRESTARR project was divided into nine work packages :

[1] Small-scale test : test performed on an item of small dimensions.
[2] Large-scale test :conventional test which cannot be carried out in a typical laboratory chamber, preformed on an item of large dimensions
[3] Real-scale test :test which simulates a given application, taking into account the real scale, the real way of working or installation and the environment.

WP1 : Risks and scenario selection

The objective of this work package was to collect relevant information about fires in railways to determine the principal risks of fire and the reference scenarios related to the operation categories of vehicles, their design, etc. It included a review of studies done in Europe, in Japan and in USA, an analysis of fire statistics in railways and a review of fire requirements in European countries for railway materials and products.

From this study, the basis for a real scale test has been defined :
- which critical part of the vehicle has to be simulated ;
- the conditions which have to be reproduced ;
- which scenarios have to be reproduced ...

The output is :
- the definition of the most relevant scenarios of fires in railway vehicles, including ventilation conditions and level of fire sources ;
- the types of risks and hazards ;
- the definition of the basis for a real scale test ;
- the essential regulatory requirements in each European country, the fire conditions used and the parameters measured.

WP2 : Product selection and procurement

The objective of this work package was the selection, the procurement and the distribution of products or materials which were tested in this programme. The selection was based on three criteria :
- all selected materials or products were representative of those used in railways ;
- national test results, in terms of fire behaviour were available, using existing databases in each country ;
- materials or products of different levels were selected.

Three types of materials and products have been distinguished :
- structural materials and products which include wall, floor and ceiling coverings, insulation materials ;
- furniture materials and products which include foams, fabrics used as components of seats, pillows, mattresses, curtains...
- electrotechnical materials and products which do not include electrical cables.

WP3 : Choice of small and large scale test methods

The objective of this work package was to select the small and large scale test methods.

The test methods have been selected taking into account the following parameters :
- ability to simulate the required fire scenario conditions as identified in WP1 ;
- ability to test material in end-use conditions ;
- repeatability and reproducibility ;
- economic aspects.

WP4 :Small-scale tests on a range of representative railway materials

The objective of this work package was to obtain data on the reaction to fire parameters (ignitability, spread of flame, rate of heat release, smoke generation and toxic gas species generation), for each type of material or products (structural, furniture and electrotechnical).

WP5 : Statistical analysis

The objective of this analysis was to determine the different fire-test-response characteristics of materials or products with the independent reaction to fire parameters measured with small scale test methods, according to the scenarios and risks which have been identified in WP1.
From the different fire test-response characteristics which have been identified, the most representative materials, products or assemblies have been selected for the large and real scale tests.

WP6 : Classification proposal

The objective of this work package was to propose selection criteria based on all independent reaction to fire parameters defined in WP5 for the fire behaviour performance levels of the materials and components. From these criteria, a classification system according to the fire safety objectives defined in the pr EN 45545 has been proposed by taking into account the fire test response characteristics of materials which have been determined with small and large scale test results.

WP7 : Large-scale tests

Large scale tests representing the defined scenarios (WP1) have been performed. Tests have been done on products which have been selected by WP5 from the materials and products provided in WP2.
The results obtained have been used to validate the proposals of WP5 and the selection of the test methods proposed in WP3 to achieve the defined fire safety objectives.

WP8 :Real-scale tests

These tests served as a main validation procedure in verifying the predictions and proposals of the previous steps and as a second validation of the choice of test methods.

Real-scale tests have been carried out on structural, furniture and electrotechnical materials or products, using the same materials or products as in WP7. The end-use conditions of materials or products in a carriage have been taken into consideration.
Ignitability, spread of flame, rate of heat release, smoke generation and toxic gas species generation have been evaluated.

WP9 : Data processing

The objective of this work package was to maintain a data base for all data from the tests performed in this study. The results have been transferred between the work packages in a convenient and reliable way.

6 - SELECTION OF FIRE SCENARIOS

6.1 - STATISTICS OF MOST RELEVANT FIRES WHICH HAVE OCCURRED WITHIN EUROPEAN RAILWAY COMPANIES

The most probable «fire scenario» must be defined directly through the statistics of the most relevant fires which have occurred within the European Railways Companies. To such end, the investigation has involved almost the whole of the Railway Companies in the EU and also involved networks in Eastern Europe and some Metropolitan Companies (e.g. Madrid Metro, London Underground).

The analysis of the most important reported fires which have happened in the last ten years show without doubt that in recent years significant fires in railway vehicles have fortunately decreased in a substantial way. This is often due to the renewal of the railway vehicles with materials in conformity with more severe Standards about Fire Safety.
If sporadic cases of fires with remarkable consequences are excluded and those with numerous dead (e.g. the fire that occurred in a passenger train in Canada on the 21st November 1994 was caused by the ignition of the diesel oil that had escaped from a tank damaged from a vandal action and resulted in the death of 60 passengers, or the fire in a underground train in Baku-Azerbaidjan on the 29th October 1995 from an electrical defect caused the death of 300 people), fires of modest importance only have occurred and these have been mainly caused from actions of vandalism.

With respect to the statistical data above, the following conclusions should be noted:

- Except in particular cases, the causes of fire and the most probable ignition sources have had to be deduced from partially or totally destroyed vehicles. The description of arson is understood to be generically an act of vandalism.
- In some cases of fires that have happened in U.K. and in Canada, a certain frequency of ignition is deduced to have occurred externally to the vehicle, (e.g. fuel); also these may be connected with other catastrophic events (derailment, collisions of trains with diesel locomotives with the fire involving the fuel contained in the tank). In each case such fires have less importance in statistical terms compared to those where the ignition source is inside the vehicle.
- Many cases of fire are due to the bad reaction-to-fire characteristics of materials used in the vehicles (especially old vehicles).

LOCALIZATION OF THE PRINCIPAL SOURCES OF IGNITION AND SURROUNDING CONDITIONS IN REAL FIRES

The above conclusions based on the statistical analysis of real fires that have occurred within the main European railway networks were supported by an external investigation undertaken by the various partners of the FIRESTARR Consortium as well as by the experts of the railway companies represented on CEN/TC256/WG1. This external investigation has enabled the specialist fire experience of railway experts to be added to the knowledge obtained from the railway statistics.

Through a questionnaire, it has been possible to collect other information concerning:

- the most probable ignition source
- which ignition source is appropriate to evaluate ignition hazard with an indication of their features (e.g. duration, heat intensity)
- the probability to have a post ignition hazard and what type of ignition source should be used to evaluate it.
- what kind of environment is involved.

From the analysis of the completed questionnaires, it is possible to draw the conclusions reported in the next section.

SUMMARY OF ADDITIONAL INFORMATION ABOUT THE DEFINITION OF THE MOST LIKELY FIRE SCENARIO

Based on the questionnaire to the European railway companies, two main scenarios should be considered. The first scenario takes into account fire originating in the interior of the railway vehicle and the other a fire that originates outside the railway vehicle.

However, the most probable «interior fire scenarios» that occur in modern trains are due to arson, inattention or electrical defect. Those which originate externally, above all under the floor (e.g. by sparks from brakes or by combustion of fuel after a major collision) are very rare both because modern trains are protected against sparks and because major collisions are extremely rare in railways. This last conclusion is confirmed by the statistical analysis of real fires (i.e. only small fires occurred due to sparks from brakes in very old vehicles and there is no data regarding fires that have occurred from fuel combustion).

Due the above evidence the FIRESTARR Group have not considered fire scenarios caused by exterior ignition sources.

For the first main scenario there are many possible sub-fire scenarios depending on the type of the most probable ignition source and on the location of the initiation of the fire.

Additional important evidence shows that luggage is involved in only a few fires (e.g. in UK, about 20-30% fire incidents) and the contribution of luggage occurs in developed fire conditions; that is, luggage is seldom the primary cause of fires in railways.

6.2 - FIRE SCENARIOS

From the statistical analysis of the fires occurring in European trains and from the other additional information it is possible to identify the following real relevant fire scenarios in the interior of railway vehicles.
In real fires that have occurred in railways, structural materials (e.g. insulation materials, plywood for floor or wall, etc.,) are hardly ever the first item ignited but are usually the second ignited item. Nevertheless some fire scenarios do involve structural materials such as walls and ceiling linings.

FIRE SCENARIO 1 – Arson on a seat due to a cigarette lighter or burning newspaper

- **General**

From the statistical analysis of the actual fires, this scenario is the most probable.
The scenario has been described schematically to highlight the development of the fire in a compartment of a railway vehicle, from the primary ignited item until post flashover.
The intention is to indicate those ignition sources which should be taken into account when designing tests for the evaluation of the reaction-to-fire behaviour of the materials and components inside the railway compartment.
The description provides useful indications about the surrounding conditions (such as volume, compartment ventilation, position of the primary ignited item etc.,).

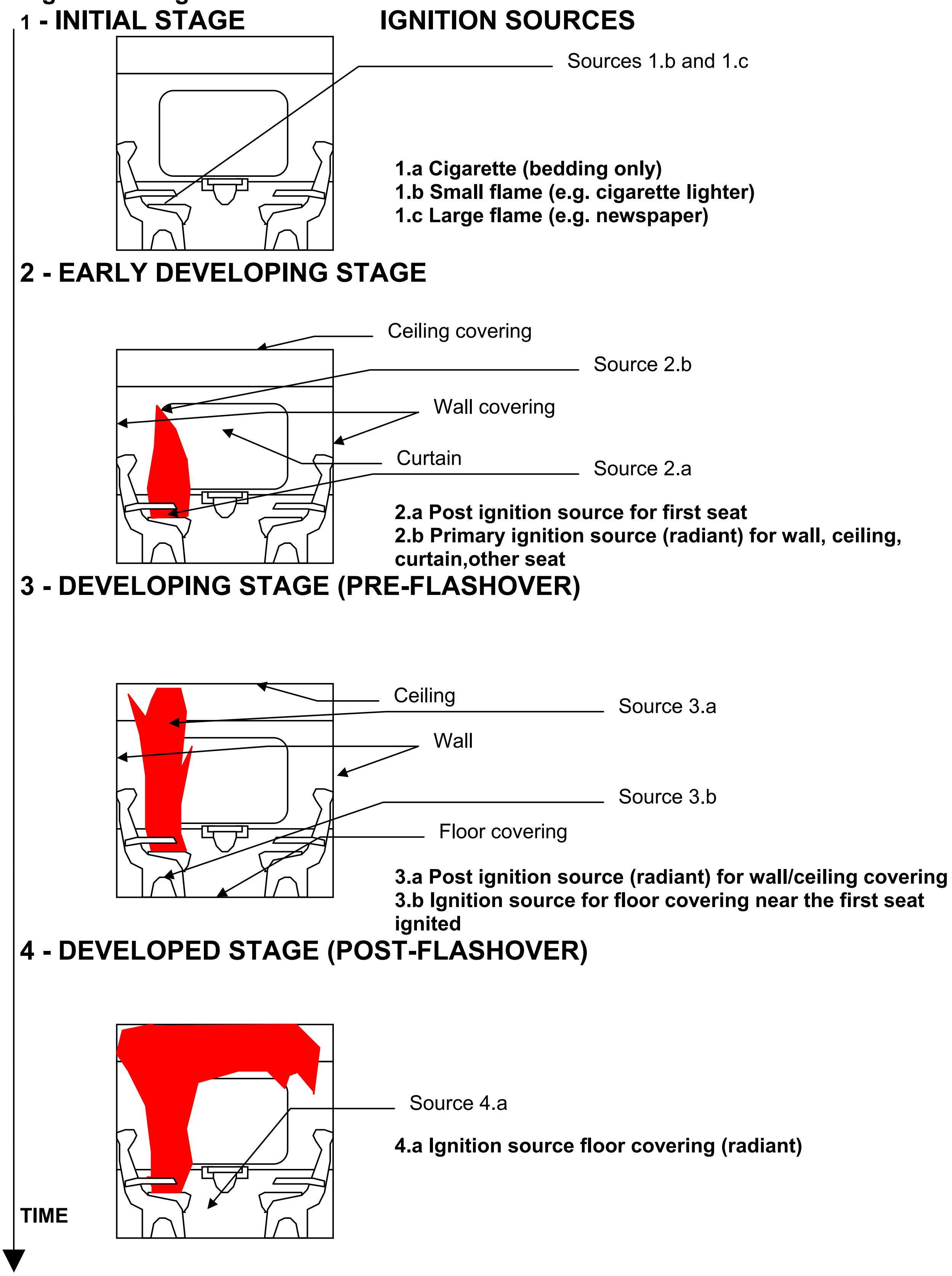
The fire starts on a seat from an arson attack and within a few minutes the fire spreads to adjacent seats, walls and curtains. Smoke and toxic gases begin to be generated. As the fire develops, other interior components become involved and all the passenger areas are invaded by smoke and toxic gases. The compartment may flashover resulting in total or partial destruction of the vehicle.

Final Consequences : Vehicle totally or partially destroyed
Fire Hazard Category Involved : All vehicles involved but information only for 1N,1S,1D, 3N,3S, (*)

(*) For the definition of Fire Hazard Category involved see prEN45545 «Fire protection in railway vehicles» Part 1 -General

The fire is ventilation-controlled whilst the windows are sealed but when the windows are broken, the fire becomes fuel-controlled. For testing purposes, the FIRESTARR Group assumed the fire is fuel-controlled.
The worst case position of seat is against a bulkhead.

Figure 1 : Stages of Fire Scenario 1



Through the statistical analysis of the most relevant fires that have occurred in recent years in European trains, the FIRESTARR Group have identified the following three most common fire scenarios:
- FIRE SCENARIO 1 - Arson on seat due to a cigarette lighter or burning newspaper
- FIRE SCENARIO 2 - High temperature in electrical equipment due to electrical defect
- FIRE SCENARIO 3 - Fire in toilet due to a cigarette lighter or burning newspaper.

The conditions that occur in fire scenario 3 are similar to those of fire scenario 1.

7 - PRODUCT SELECTION PRINCIPLES

The selection is based on three criteria :
- all selected materials or products are representative of those used in railways ;
- national test results, in terms of fire behaviour (ignitability, flame spread, smoke generation, toxic gas species evaluation...) are also available, using existing data bases in each country ;
- materials or products of different levels of performance are selected by reference to the national classifications in each country.

Three main types of materials and products are distinguished :
- structural materials, products or assemblies which include wall, floor and ceiling coverings, insulation materials ;
- furniture materials, products or assemblies used as components of seats and mattresses, pillows, curtains.. ;
- electrotechnical materials and products which include moulded compounds used in electrical insulation and connectors but does not include electrical cables : prior to December 1996, all materials and components in rollingstock were involved in the FIRESTARR research project, but, after the European Commission signed the contract of this study, CENELEC TC 20 WG 12 sent a draft of European standard prEN 50264 for ballot. In this standard the test methods for ignitability, spread of flame, smoke opacity and toxic potency have been chosen and the performance requirements set. The FIRESTARR consortium decided to leave out cables to avoid an overlap with the current EC project whose acronym is FIPEC (Fire Performance of Electric Cables).

In each field, it is important to have products with different fire behaviours and different countries to provide them. These products and components have to be often used in new vehicles and their national fire behaviour classifications have to be known. As a matter of fact, it would be useless to get a classification of products that are not used in recent vehicles anymore, because they could not be used by the railway companies.
A pre-selection of products was made taking into account the different generic families that they belong to and the defined fire scenario.

8 - SELECTION OF TEST METHOD PRINCIPLES

The materials selected are evaluated under three conditions :
- small scale (mainly bench scale test methods)
- large scale test methods
- real scale test.

The test methods can be applicable for the three families of materials and/or specific for one type (e.g. seats, electrotechnical..) The main keys of the selection are :
- The method has to be representative of at least one of the fire stages described in the fire scenario considered for the FIRESTARR study,
- The test method has to be an international standard (EN or ISO/IEC). National methods could be selected when no international method has been found as relevant regarding fire scenario,
- The repeatability and the reproducibility of the test method,
- The safety of the method,
- When necessary, other factors such as : interlaboratory trial results and/or number of countries using the method in Europe were considered.

The set of test methods must be able to cover the following measurements identified as FIRST (**F**lame spread, **I**gnitability, **R**ate of heat release, **S**moke opacity and **T**oxicity)

- Ignitability (**I**): ignition (Y/N), time afterflame, time to ignition
- Fire growth (F & R) : Flame spread, damage length/area, heat release, total heat release, mass loss, flaming droplets, critical flux at extinguishment,
- Visibility (S): smoke density (maximum and curve versus time), smoke produced using specific extinction area, smoke production rate (maximum and curve versus time)
- Toxicity (T) : concentration of gases, total yield for each gas, toxicity index / fractional effective dose.

For small scale test methods to measure the same parameter, several test methods could be chosen. The most relevant one, according to the statistical analysis in terms of correlation with real scale tests, repeatability and discrimination, will be retained for the classification proposal to CEN TC 256 /WG1.

The large scale tests must give a suitable way to test materials in "end use condition". The surrounding conditions are conventional (heat source characteristics, air flow, size of specimen…).

The real scale test method is defined regarding the fire scenario selected. The test rig and also the surrounding conditions must be as similar as the ones found in a railway carriage.

8.1 - Toxicity evaluation : selection of test methods

Toxicity of fire effluents can be evaluated in two ways :

- Incapacitation of passenger,
- And/or lethality effect.

The incapacitation data are not world-wide validated compared to lethality values for which a consensus exists. In order to evaluate the toxicity effect of fire effluents in a railway carriage two parts have been considered.

- The choice of test methods in small, large and real scale tests,
- The calculation mode to quantify the fire critical effect toxicity.

The toxicity test methods were chosen considering their ability to simulate one stage of a fire (ISO TR 9122-4) [2].

Calculation for toxicity evaluation.

The calculation mode for toxicity evaluation in small, large and real scale test are presented in the ISO 13344 [3] document. The FIRESTARR consortium recommended to consider lethality rather than incapacitation because validated incapacitation values are not available at the moment.
The calculation modes are :

- **Small scale**

$$TI = \frac{[CO]}{LC_{50,CO}} + \frac{[HCN]}{LC_{50,HCN}} + \frac{[HCl]}{LC_{50,HCl}} + \frac{[C_i]}{LC_{50,i}}$$

Where
TI is Toxicity Index
[Ci] is the concentration in mg/g of gas i
$LC_{50,i}$ is LC_{50} for gas i, in ppm

- **Large and real scale test**

$$FED = \frac{[CO]}{LC_{50,CO}} + \frac{[HCN]}{LC_{50,HCN}} + \frac{[HCl]}{LC_{50,HCl}} + \frac{[C_i]}{LC_{50,i}}$$

Where :
FED is Fractional Effective Dose
[Ci] is the concentration gas of i in ppm
$LC_{50,i}$ is LC_{50} for gas i, in ppm

The concentrations of gas are the results of C*t integrated values taken respectively on curves concentration/time for a 10 min or 30 min period of test divided by 10 or 30.

In order to propose guidance for the toxicity of fire effluents in the other parts of a railway carriage the dispersion of gases in a 40 m^3 corridor.
The evaluation of the toxicity will also be done considering that the gases travel from the compartment to the 40 m^3 corridor.
The airflow of gases from the compartment to the corridor is 300 m^3/h (5 m^3/min). The maximum concentration will be obtained in 8 min (time to replace fresh air in the corridor with vitiated air coming from the burning compartment (in the hypothesis of no "renewing of air).

$$[C]_{corridor} = [C] \times (V_a/40)$$

The FED corridor is calculated using the value of $[C]_{corridor}$.

8.2 - Design of fire model for large scale tests

Inquiry on the thermal attack to be used in order to evaluate the reaction to fire of structural products – walls and ceiling – in FIRESTARR programme

To reproduce realistic conditions, since the JWG and the railways have precisely indicated the fire model (a burning seat) and the scenario (a train compartment of about 10 m^3), it was necessary:

- To measure the fire potency of a seat, when set on fire (RHR curve, kW versus time).
- To measure the thermal attack produced by the burning seat on walls and ceiling (kW/m^2)
- To carry out the measurements in a space with the exact dimensions of the compartment, in order to get the real room geometry
- To work in a real ventilation condition, i.e. with the real ventilation of the compartment as quantity of air introduced, as portion of the air flux entrance, as grid size and as exit position

On this subject, two conditions have been considered:
- the first with the compartment door closed (situation where the smoke evacuation occurs, as in reality, through an exit of known size, under the seat, next to the door)
- the second, with the same real ventilation, but with the door open (in the train corridor)

The vandalisation of the seat.
The seat has been cut (to simulate vandalism) on the seat and on the back
Not vandalised: tested in the conditions as supplied by SNCF
Vandalised level 1: a crossed cut, deep, but not detaching the interliner from the foam (when specified, only on the back, otherwise, on back and seat)
Vandalised level 2: cut having the same characteristics, but the interliner has been detached from the foam and slightly removed, in order to let the foam, in some points, to be directly hit by the flames

The first series of preliminary tests

The first series of preliminary tests was carried out in the compartment placed under the room corner test hood, so that the smoke and the gases produced by the fire (with the door closed), after having been conveyed in a duct, through a chimney that releases the smokes at about 1 metre from the collecting cube placed at the top of the hood could be evacuated by the room corner test hood.
The 'draught' was the natural one, i.e. produced by ventilation (air introduced by the conditioning system) that forced the smoke to get out through the only possible way, that is the way having size, and placed in the point indicated by Railways, to flow to the chimney.
The internal pressure of the compartment was checked with the door closed, and a pressure of only 6mm of water has been measured.

Ignition source for seats

It consists of the Belfagor burner, fed by propane, leant on the seat surface with a pressure of about 100 gr, (in order to sink in the burning item), applied for 180 sec, with 4 Nl/min flow of propane in such way to represent, more or less, the 100gr paper cushion (the gas flow is controlled by mass flow control).

The opening of 3 holes addressing their flame towards the seat, should be sufficient to reach the same result as the paper cushion.

Description of the potential fire scenario

There are 3 different real scale tests:

- A room having the dimensions of a real railway compartment (about 9 m^3). The room is placed under the hood of Room Corner Test ISO 9705 [4].
  - Ventilation is made with air introduced in a well-known and controlled quantity (0,07 m^3/sec) through the real distribution and conditioning system for the whole test duration
  - Smokes collection by a chimney to which they are naturally conveyed by the ventilation (real compartment grid + chimney, hood and measurement system of the Room Corner Test)
- SBI – (in a chimney placed in a corner)
  - Smoke collection: in the duct of SBI
  - Ventilation: 0.6 m^3/sec sucked through the room of about 20 m^3 and conveyed to the hood
- A dihedral of panels class 0, having the same dimensions as SBI, placed under the Roland hood
  - Smokes collection: in the exhaust duct of Roland
  - Ventilation: 0.33 m^3/sec sucked by the Roland hood

Conclusions of design tests

If not heavily vandalised, the TGV seat cannot be accidentally set on fire by the ignition of the paper cushion (or equivalent), in the compartment with door closed.
With TGV vandalised level 2, there is a bigger RHR peak and thermal attack when the door is open, compared to that with the door closed.
The experimental reality leads us to the following conclusions:
The condition of open door, in the compartment ventilated as in reality, allows the seat to produce a fire of bigger power. Then, this is the fire to be considered to reproduce the thermal attack and the real conditions to attack walls and ceilings.
So, observing also the curves behaviour, we suggest to use a burner able to reach 180 kW in 5 minutes, producing on the walls a thermal attack of 40, or maximum 50 kW/m^2.
Actually, only for a very short period, 60 kW/m^2 are reached; when, because of the lateral fall of the back, the flames touch the radiometer. On the other hand, even the tests with closed door show 50 kW/m^2 is reached 2 times out of 3.
The behaviour of temperature from the series of thermocouples placed on the ceiling shows that the thermal attack on the ceiling is NEVER bigger than the attack on the wall. So, the decision should be taken choosing between 40 and 50 kW/m^2 also for the ceiling.
The behaviour of the fire growth in the 2 semiscale test methods – SBI and Roland – leads us to the following conclusions:
SBI The rate of heat release measured in the duct with SBI ventilation conditions is far from that obtained in the real compartment, even with door open and ventilation 255 m^3 maintained for all the test. The thermal attack is much influenced by the fire power.
ROLAND The results are nearer to the results obtained in the compartment with the door open, but the method has the limitation that it cannot be used at an imposed flux greater than 50 kW/m^2 with the present radiant panel.

9 - DATA ANALYSIS PRINCIPLES

The statistical analysis was performed in two main steps :

- the first, on results from small scale methods,
- the second, on results from large and real scale methods.

The objective of the first analysis was to determine the different reaction-to-fire characteristics of materials or products and the independent parameters measured with small scale test methods and to select for large and real scale tests the most representative materials/products.

As a first step, in order to assess the validity of all tests performed in small scale, calibration exercises between laboratories for each selected fire test method were performed.

The statistical analysis performed is an analysis of variance ANOVA. It is used to determine the repeatability and the reproducibility for each test method.

After adjustment of some test protocols when necessary, a green light was given for all laboratories.

The statistical analysis for small scale tests was performed on all test methods for each type of product (structural, furniture, electrotechnical).

A preliminary statistical analysis using Principal Component Analysis (PCA) and Hierarchical Clustering Analysis (HCA) was carried out on the results for each test method and for each type of materials/products.
PCA analysis permits to see correlation between parameters and HCA permits to cluster the materials in different homogeneous classes. These two complementary analyses permit to determine the most discriminatory methods on the found classes of materials.
The selection of products for large and real scale tests was performed with regard to the different reaction-to-fire characteristics of materials and the parameters which are representative of the Fire critical effects (ignitability, flashover, loss of visibility).

The objective of the second analysis on results from large and real scale method is

- to define in real scale, criteria to represent the fire critical effects,
- to link the different reaction-to-fire characteristics of materials/products and the fire critical effects i.e. to find a relationship between the data from real scale test data and small or large scale test data which allows to predict fire risks.

As the first step, for each type of parameter related to the fire effects (i.e. Fire growth, loss of visibility, flame spread, ignitability), a statistical analysis was carried out with scalar data from each scale test (real, large and small). This analysis using PCA analysis was performed to find the best correlation between the different scale tests.
The second analysis was performed on vector data. New parameters were defined from the vector data in small and real scale to take into account the shape of the curves. The aim was to find a robust relationship between the data from the real scale test and those from small scale tests.

10 - STRUCTURAL PRODUCTS

10.1 - Products selected

Table 2 gives all the structural products selected for the small tests.

TABLE 2

CODE	PRODUCT	LOCATION	COUNTRY
PS03	Polyester GRP (good fire performance)	ceiling	France
PS04	Sandwich plywood - decorative laminate	wall	France
PS05	Polyester GRP (low fire performance)	wall	U. K.
PS06	Melamine formaldehyde phenol formaldehyde laminate	wall and ceiling	U. K.
PS07	Plywood (flame retardant)	wall and ceiling	Italy
PS08	Plywood (flame retardant)	floor	Italy
PS09	Plywood	wall and ceiling	France
PS10	Plywood	floor	France
PS11	Melamine formaldehyde resin on Al sheet	wall and ceiling	Germany
PS12	Melamine formaldehyde resin laminate bonded to Al honeycomb core	wall	U.K.
PS13	Phenolic - GRP painted	wall	Italy
PS14	Sound insulation compound on steel plate	non reachable	Germany
PS15	Insulation synthetic fibre (polyester)	wall and ceiling	Italy
PS16	Glass wool + polyester bonded to Al sheet	non reachable	Germany
PS17	Phenolic foam	wall and ceiling	U.K.
PS18	Decorative laminate	wall and ceiling	Germany
PS19	Film self adhesive bonded to Al sheet	wall and ceiling	U.K.
PS20	Aluminium painted	wall and ceiling	U.K.
PS21	Wall carpet (polyester)	wall	France
PS22	Ceiling carpet (polyester)	ceiling	France
PS23	Polycarbonate	light diffusers	Germany
PS24	Acrylic	light diffusers	U.K.
PS25	Polycarbonate (good fire performance)	frame of seat	U.K.
PS26	Polycarbonate (low fire performance)	frame of seat	U.K.
PS27	ABS	frame of seat	U.K.
PS28	PVC/aluminium sandwich	floor	Italy
PS29	Rubber floor covering (high fire growth)	floor	Italy
PS30	Wool nylon carpet	floor	U.K.
PS31	Polypropylene needle felt carpet	floor	U.K.
PS32	Polychloroprene rubber	seal for inside door	France
PS 33	Profiled rubber (on aluminium profile)	front of luggage rack	Italy

10.2 - Tests Selected

The main objective of WP3 was to select small and large-scale test methods which would relate to the fire scenario 1; i.e. arson on a seat in a passenger compartment. Tests were selected so that fire conditions were appropriate to the initial stage, early developing stage and developing stage (pre-flashover) within a small compartment.

Small-Scale Tests

The following small-scale tests and conditions were selected for use in WP4.1:

- **Ignitability:**

I.1 prEN ISO 11925 Part 2 Small Burner Test

This test was included to simulate a vandal applying a match or cigarette lighter to a vertical surface and edge of structural products. Application time was 30s.

The key parameters for analysis from the prEN ISO 11925-2 [5] test are:

- Ignition or Non-ignition
- Time for a sustained flame to reach 150mm mark.

I.2 UIC 564-2 Part 11 Small Flame Test

The key parameters for analysis from the UIC 564-2 Part 11 [6] small flame test applied to face of specimen for 180s are:
- Time to Ignition
- Afterflame time
- Area of surface damaged

I.3 ISO 5660 Part 1 Cone Calorimeter

This test was included to simulate heat fluxes at the early developing stage (35kW/m^2) and at the developing stage (50kW/m^2).

The key parameter for ignitability analysis from the ISO 5660 Part 1 [7] test is time to ignition (t_{ig}).

I.4 IEC 60695-2-2 Needle Flame (for light diffuser panels)

The key parameters for analysis from the IEC 60695-2-2 [8] needle flame applied to the upper surface of light diffusers are:-

- Minimum flame application time to give sustained flaming.
- Flaming drips or not.

The use of the IEC 60695-2-2 needle flame by this procedure simulates an electrical fault condition in the light assembly above the light diffuser panel.

- **Fire Growth**

F.1 ISO 5658 Part 2 Lateral Flame Spread under radiant heat conditions (50kW/m^2 exposure at hot end of specimen).

The key parameters for analysis from the ISO 5658 Part 2 [9] test are:

- Heat for sustained burning (QSB), which provides a measure of flame-spread rate.
- Max flame spread distance (Xmax) and critical flux at extinguishment (CFE)

F.2 ISO 5660 Part 1 Cone Calorimeter

This test provides data on rate of heat release and total heat released at both 35kW/m^2 and 50 kW/m^2.

The key parameters for analysis concerning heat release are:-

- Max heat release rate (q max)
- Heat release rate (q) as mean over t_{ig} to t_{ig} + 180s (q_{180}) and t_{ig} + 300s (q_{300}).
- Total heat release (THR).

F.3 prEN ISO 9239 Part 1 Radiant Panel Test

This test was used specifically for floorings. It provides data on extent of flame spread and total smoke generated over 30 minutes.

The key parameters for analysis from the prEN ISO 9239 Part 1 [10] test are:-

- Heat flux at 30 minutes (HF-30) or Critical heat flux (CHF) if the flames extinguish within the 30-minute test period.
- Total smoke generated over the 30-minute test.

- **Smoke Opacity**

S.1 ISO 5660 Part 2 Cone Calorimeter (Dynamic Test)

This test provides data on rate of smoke generation and total smoke released over 32 minutes. It was operated at both 35kW/m^2 and 50 kW/m^2 heat flux levels.

The key parameters for analysis from the ISO 5660 Part 2 [11] test are:-

- Total smoke produced using specific extinction area (SEA).
- Max extinction coefficient (k_{max}).

S.2 ISO 5659 Part 2 Smoke Chamber (Cumulative test)

This test was used under IMO conditions (25 and 50kW/m^2) to obtain data on smoke generation over 10 minutes.

The key parameters for analysis from the ISO 5659 Part 2 [12] test are:

- Smoke Density after 10 minutes (D_s10) and D_{max} for all 3 heat flux conditions.
- Smoke Density/time graphs.
- VOF4 index, which takes into account the rate of smoke generation in the first 4 minutes.

- **Toxic Potency**

T.1 NFX 70-100 [13] Tubular Furnace Test (UITP E6)

- This test was used under the conditions listed below:2 temperatures: 400 and 600 °C
- air flow: 2 l/min.

T.2 DIN 53436 [14] Travelling Furnace Test

This test was used under the following conditions:
- 2 temperatures: 400 and 600 °C
- air flow: 2 l/min for primary air flow and 8l/min for secondary air flow.

For both methods the gases analysed were: CO, CO_2, HCN, HCl, HBr, HF, NOx, SO_2, Formaldehyde and acrolein. The analytical methods used are specific ones (e.g. NDIR, ILC, titrimetry,, chemiluminescence…) or FTIR (according to the SAFIR project proposal).

Large-Scale Tests

A large-scale corner test was selected for evaluation of wall and ceiling products in WP7.1; i.e. an assembly of two walls and a ceiling simulating a corner of a railway compartment was burnt under an ISO 9705 [15] hood and duct measuring system (Figure 2). The test specimen was mounted on the upper part of the walls and on the ceiling with the lower part of the walls constructed from steel sheets since in a railway compartment the lower part of the walls is often covered by the seats. The test specimen was assembled on a steel framework.

The fire source was a laboratory propane burner which was designed to simulate the heat output and heat flux on the compartment walls caused by a typical burning vandalised railway seat. The net heat output was 75kW for the 10 minutes test period after ignition of the burner. The ventilation conditions were the same as those used for the furniture calorimeter and essentially represent a well-ventilated compartment with the door open.

The method provides data for the specified ignition source for the early stages of a fire from ignition up to potentially full involvement of the walls and ceiling. Measurements of heat release, smoke opacity and concentrations of toxic gases are made in the ISO 9705 ducting.

Real-Scale Tests

A real-scale compartment test was designed to validate the WP4.1 small-scale tests and the WP7.1 large-scale tests.

Based on the WP1 conclusions, SNCF identified a railway carriage Voiture VU78 with 11 compartments served by a side corridor. Each compartment contains eight seats, a 1200mm x 950mm window and a 1930mm high x 600mm wide door opening to the corridor. The compartment was 2300mm high, 1900mm wide and 2040mm long (see Figure 3). The ceiling of the compartment was curved from a height of 1940mm above floor level. This compartment may be assumed to have a volume of approximately $9m^3$, i.e. only 43% size of ISO 9705 room but ideally comparable to the small compartment size of $<10m^3$, which CEN/TC 256 JWG specified in their materials requirements document prEN 45545 Part 2.

The ventilation conditions into the Voiture VU78 compartment were precisely defined by SNCF. Since SNCF were able to supply the exact ventilation grids used in their compartment to the FIRESTARR laboratories, this was a critical requirement in the selection of this compartment for the WP8.1 and WP8.2 tests.

ISO 9705 Part 2 extends the scope of the ISO 9705 small room test methodology since non-lining products may be evaluated inside the room, or other products may be evaluated under the 3m x 3m hood. This means that the same measurement system for fire effluents may be applied to these other test conditions. It was concluded that a real-scale Voiture VU78 compartment could be sited underneath the standard ISO 9705 hood/duct system.

A design exercise was introduced into the WP8.1 programme to ensure that the ignition source to be used in the compartment tests corresponded to the vandalised seat scenario identified in WP1. The requirements of this exercise were identified as follows:

- to measure the heat output of an ignited train seat (in kW versus time)
- to measure the thermal attack (in kW/m^2) of a burning train seat on the walls and ceiling of a Voiture VU78 compartment.
- to carry out the tests with the same ventilation conditions found in real Voiture VU78 compartments. Initially these tests would run with the compartment door closed, and then, be repeated with the door open to the train corridor.
- to design a propane burner, which would reproduce the burning conditions and thermal attack of a typical train seat.

The LSF laboratory, as leader of the FIRESTARR furniture products group, carried out a series of tests with both SNCF and FS seats. The results of relevance to the WP8.1 requirements were performed with FIRESTARR Burner A (i.e. a Belfagor propane burner equivalent to burning 100g paper) on a vandalised TGV seat located in the corner of the reconstructed Voiture VU78 compartment. The seat was vandalised by cutting a cross deep into both back and seat so that the interliner could be locally detached from the upholstery foam. Analysis of the test-data gave the following mean values:-

Peak Rate of Heat Release	177 kW
Total Heat Release	63 MJ
Max thermal attack on walls	40 kW/m^2
Duration of combustion	19 minutes

It was concluded that a propane burner (FIRESTARR Burner B) should be designed for WP8.1 tests to simulate the above described burning seat. The specification for this burner was agreed to be 75kW for 2 minutes followed by 150kW for 8 minutes. In addition, the burner should be located in a corner position of the compartment so that the maximum thermal attack to the walls was $40kW/m^2$.

10.3 - Test Results

Small-Scale Tests

31 structural products were tested in WP4.1. These products were distributed across the following 6 application areas; i.e.

a)	Wall and ceiling linings	(16 products)
b)	Floorings	(6 products)
c)	Light diffusers	(2 products)
d)	Seat frames	(3 products)
e)	Insulation products	(2 products)
f)	Linear products	(2 products)

Products were tested at end-use thickness and if appropriate, with realistic substrates such as 2mm thick aluminium sheet (for wall linings) or 15mm plywood (for floorings).

The complete results for the WP4.1 tests are stored in the FIRESTARR database and reported in document WP4/WFRC/01001 [16].

The small flame tests prEN 11925-2 and UIC 564-2 Annex 1 were not able to discriminate ignition performance satisfactorily whereas the cone calorimeter did allow products to be separated into categories of non-ignitable, difficult to ignite or easy to ignite according to the ignition times.

The cone calorimeter also proved to be a valuable method for assessing heat release and dynamic smoke generation. Examples of the test results for products evaluated in the cone calorimeter are shown in Figures 4 and 5.

Flame spread was characterised well with the ISO 5658-2 lateral spread across a vertically-oriented specimen for wall linings and with the prEN ISO 9239-2 horizontal test for floorings. Examples of results for products tested by these methods are given Table 3 and 4.

Table 3. Fire Growth of Wall & Ceiling Linings: Flame Spread Tests With ISO 5658-2

Product	**ISO 5658-2**		
	QSB (MJ/m2)	CFE (kW/m2)	Xmax (mm)
PS03	3.0	37.7	180
PS04	6.7	30.3	180
PS05	1.8	7.7	513
PS06	10.6	33.0	283
PS07	2.9	14.8	433
PS12	4.1	36.7	247
PS13	2.8	30.7	300
PS15	0.9	1.5	750
PS18	4.1	24.1	350
PS19	4.0	24.1	350
PS20	2.5	48.3	53
PS21	1.8	26.3	330
PS22	4.0	30.8	300

Table 4 : Fire Growth of Flooring Products : Flame Spread Tests with prEN ISO 9239-1

Product	prEN ISO 9239-1	
	RF-10 (kW/m^2)	CHF or RF-30 (kW/m^2)
PS08	11.1	11.1
PS10	5.0	4.7
PS28	11.0	11.0
PS29	11.0	11.0
PS30	11.0	9.25
PS31	10.1	3.7

The single chamber smoke test ISO 5659-2 was shown to be a useful cumulative method for evaluating a variety of products under different fire conditions. Examples of smoke opacity data for 9 miscellaneous products are given in Table 5.

Table 5 : Smoke Opacity Data for Miscellaneous Products with the Cumulative Method ISO 5659-2

Product		25kW/m^2 + pilot flame			25kW/m^2 – pilot flame			50kW/m^2 – pilot flame		
		Dmax	Ds10	VOF4	Dmax	Ds10	VOF4	Dmax	Ds10	VOF4
Insulations	PS14	120	69	16	256	124	31	467	451	243
	PS16	5	4	15	7	5	20	9	3	18
Light Diffusers	PS23	127	47	1	132	45	2	932	883	1275
	PS24	188	157	118	83	71	2	215	178	374
Seat Frames	PS25	175	67	3	74	40	2	485	451	1024
	PS26	284	153	65	102	51	2	921	807	1159
	PS27	962	829	31	367	141	28	642	620	1436
Linear Products	PS32	501	476	631	741	678	574	439	408	1132
	PS33	490	421	888	276	152	187	887	798	1736

Large-Scale tests

Eleven structural products were selected for test in WP7.1 based on the statistical analysis of the test data obtained on 31 structural products in WP4.1. These products were all wall and ceiling linings. They were chosen with the objective that correlations would be sought between the WP7.1 large-scale test-data and the WP4.1 small-scale test-data. The details of the products tested in WP7.1 are shown in Table 6.

The testing of the 11 wall and ceiling products was divided between the BAYER (Germany) and WFRC (UK) laboratories, who constructed identical test rigs onto which the products were mounted.

Warrington Fire Research Centre carried out tests with the FIRESTARR B burner in the corner rig fitted with calcium silicate boards on the walls and ceiling. The objective of these tests was to determine the optimum position of the 75kW burner so that a similar thermal attack of 35 – 40kW/m^2 could be achieved in the corner tests to that obtained in the WP8.1 railway compartment tests.

TABLE 6 Wall & Ceiling Linings tested in WP7.1 and WP8.1

Product Reference	Description of the Product	Substrate	Thickness (mm)
PS03	Polyester GRP (good fire performance)	None	3
PS04	Sandwich plywood-decorative laminate	None	15
PS05	Polyester GRP (low fire performance)	None	4
PS06	Melamine formaldehyde, phenol formaldehyde laminate	None	3
PS09	Plywood	None	9.5
PS11	Melamine formaldehyde resin	Bonded to 2mm Aluminium Sheet	2.5
PS12	Melamine formaldehyde resin laminate bonded to aluminium honeycomb core	None	14.5
PS13	Phenolic – GRP painted	None	4
PS18	Decorative laminate	None	22.5
PS20	Aluminium sheet painted	None	3.1
PS21*	Polyester ceiling carpet (600g/m^2)	Bonded to 2mm aluminium sheet	3
PS22	Polyester ceiling carpet (350g/m^2)	Bonded to 2mm aluminium sheet	2.5

* tested in real scale only.

Five products were not ignited by the 75kW burner under these corner conditions and it may be concluded that the 75kW FIRESTARR burner B is not sufficiently discriminatory for use as a classification test in its present form. This burner provides 2.5 times the thermal input as the prEN 13823 [17] (SBI) burner and gave a thermal attack of about 40kW/m^2 onto the walls of the corner rig.

Six products gave maximum rates of heat release (HRR max) in the range 80 – 100kW but only 1 product (PS05) gave a HRR max greater than 1000kW. The measurement of heat release, smoke and gaseous effluents under the ISO 9705 hood was satisfactory. Examples of the test results obtained on HRR and smoke opacity are shown in Figures 6 and 7.

Real-scale Compartment Tests

Twelve structural products (see Table 4) were tested in WP8.1 in the railway compartment described in Section 1. The test procedure was carried out using the FIRESTARR burner B (75kW/2 minutes plus 150kW/10 minutes) in the corner of the compartment with the door open.

All the testing of the 12 wall and ceiling products in this railway compartment was carried out at Warrington Fire Research Centre, (UK). It should be noted that the test compartment constructed for these WP8.1 structural products tests was identical to the test compartment constructed at LSF (Italy) for evaluation of railway seats in the WP8.2 programme. Both test compartments were fitted with SNCF ventilation ducts and were installed underneath ISO 9705 hoods for measurement of smoke and toxic gases.

Only 1 of the 12 products (i.e. PS06) did not ignite under these test conditions. 6 products went to flashover, where the time to flashover was assessed by determining the following criteria:

- Time when the rate of heat release reaches 600 kW (which includes the 150 kW contribution from the burner.
- Time when the heat flux on the floor reaches 20 kW/m^2.
- Time when sustained flames are observed to spread out of the compartment door.

The time to flashover is taken as the time when the first of any of the above criteria is reached. In practice, it is found that, for those products which proceed to a flashover state, the above times are often close together.

The evaluation of heat release, dynamic smoke opacity and toxic effluents in the ISO 9705 hood/ducting system was satisfactory. Examples of the test results obtained on HRR and Smoke opacity are shown in Figures 8 and 9.

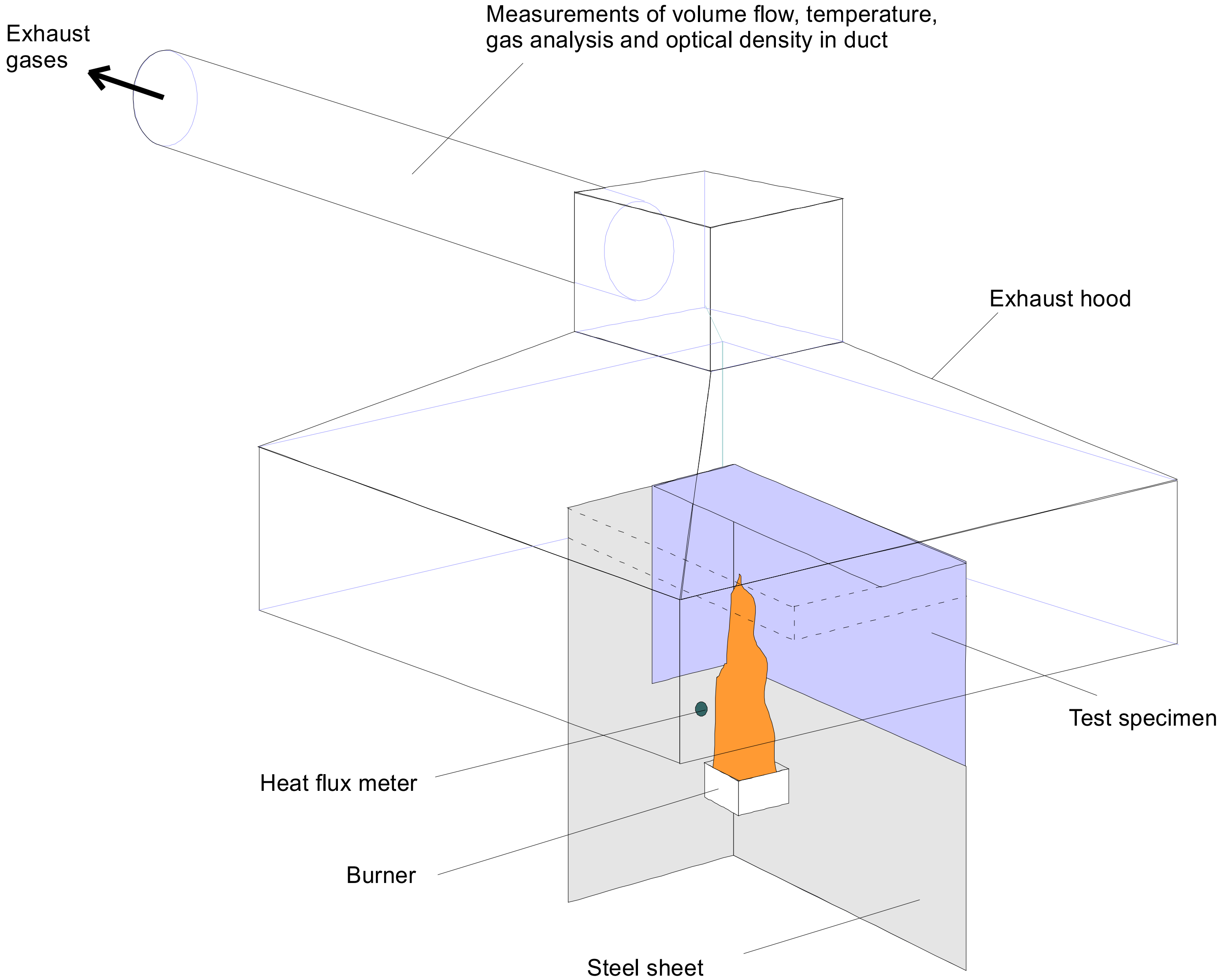


Figure 2 – Principle of corner test

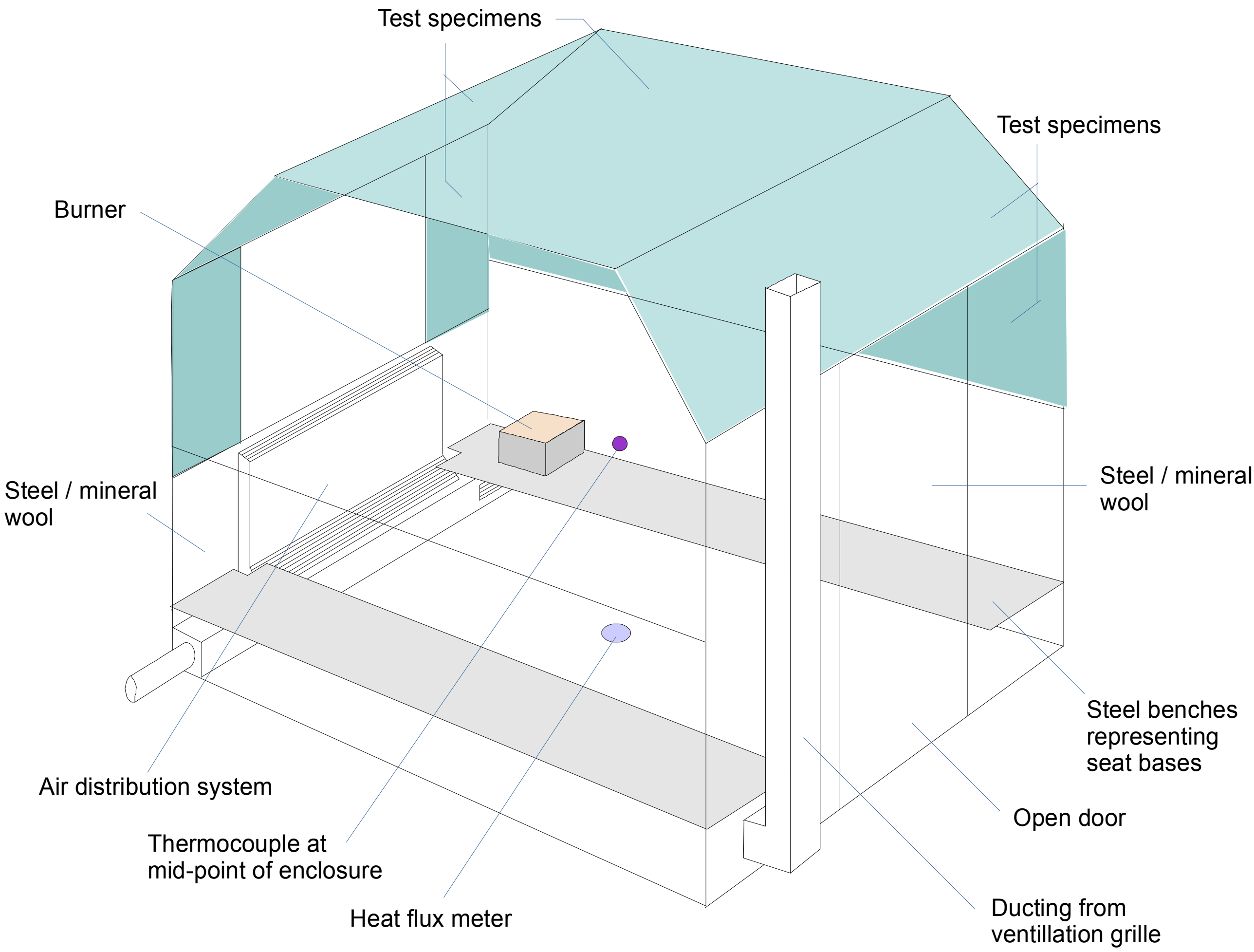


Figure 3 – Schematic view of compartment

Figure 4 : Typical HRR results from Small-Scale ISO 5660-2 Tests (50 kW/m²)

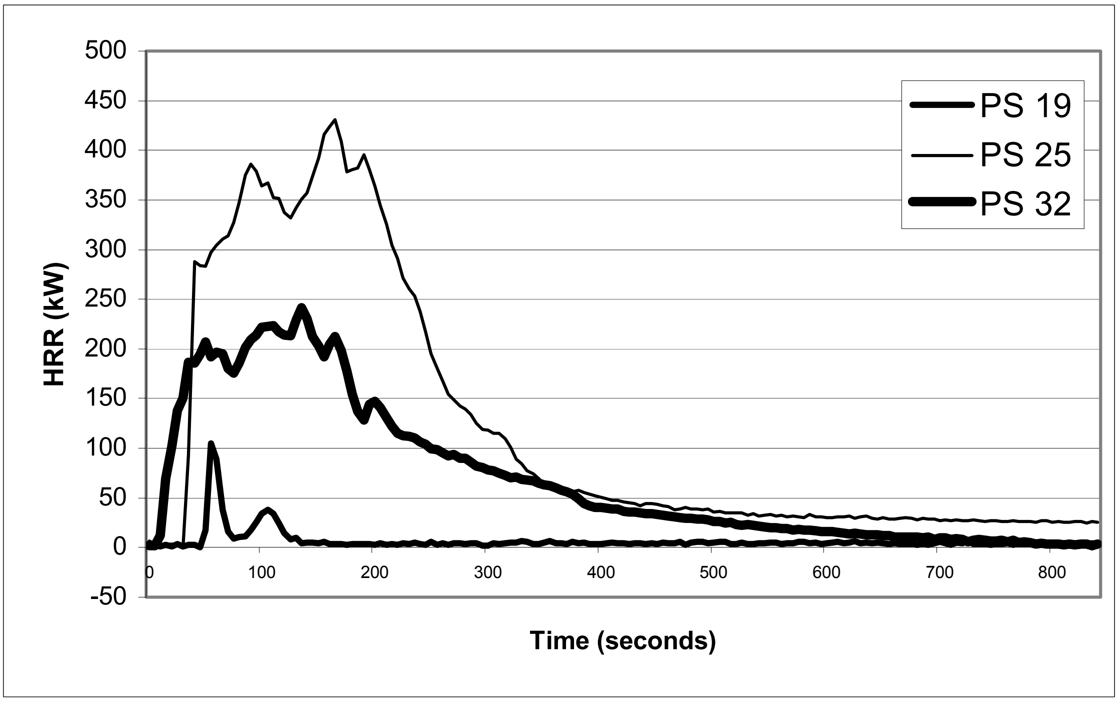


Figure 5 : Typical Smoke Production Rate results from Small-Scale ISO 5660-2 Tests (50 kW/m²)

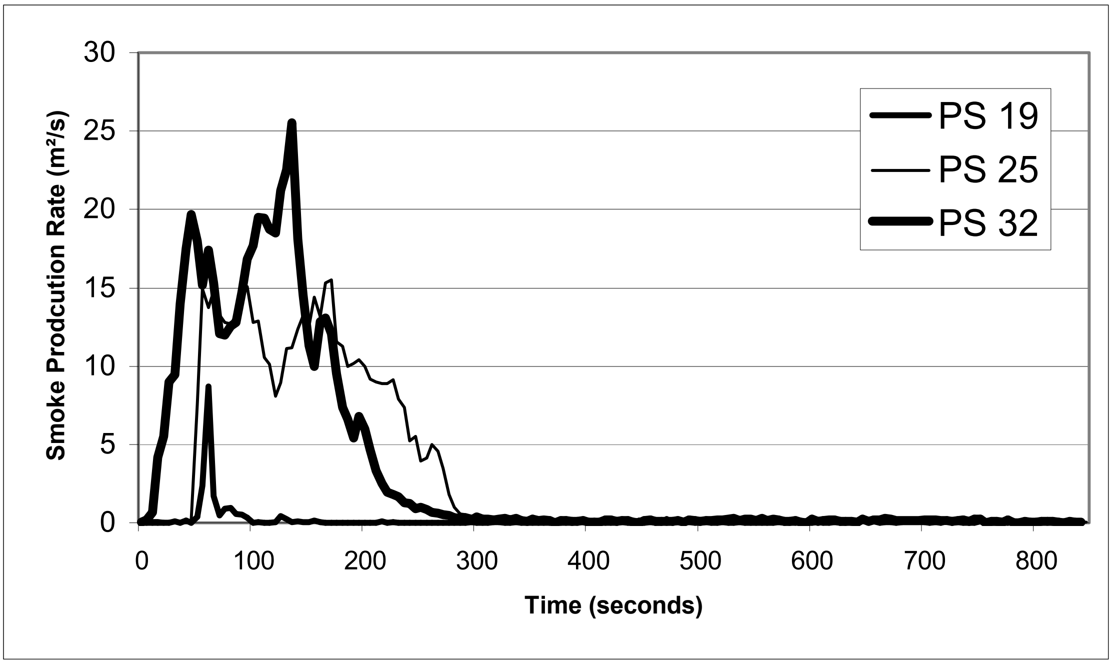


Figure 6 : Typical HRR results from Large-Scale Corner Tests

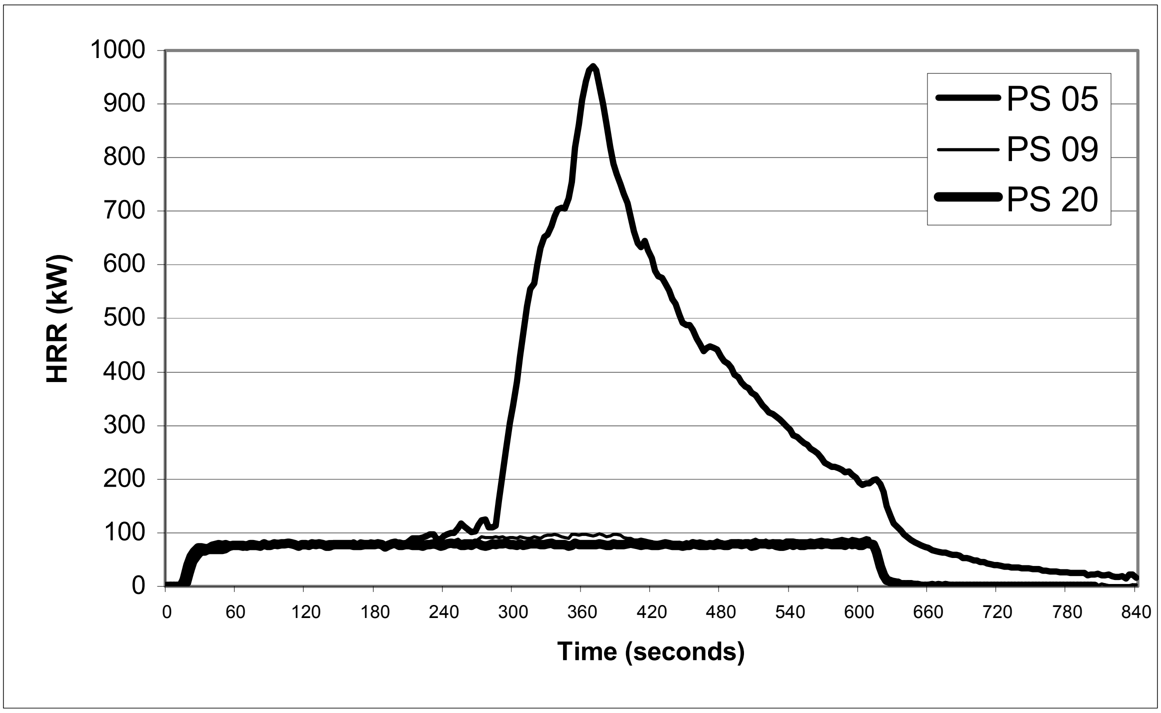


Figure 7 : Typical Smoke Production Rate results from Large-Scale Corner Tests

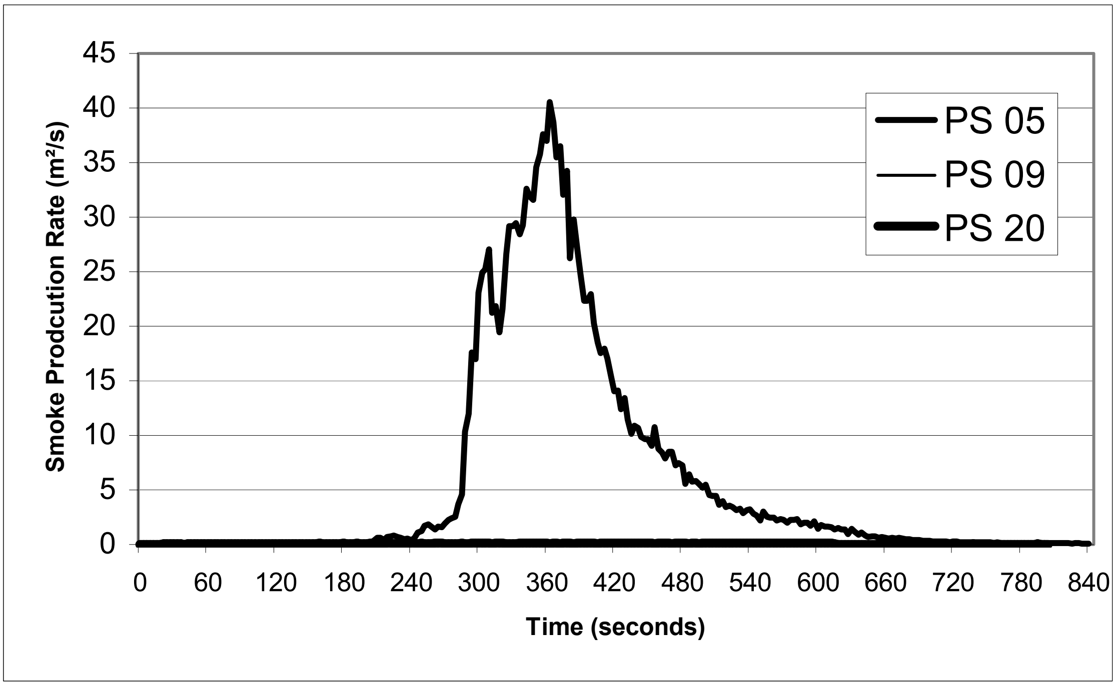


Figure 8 : Typical HRR results from Real-Scale Train Compartment Tests

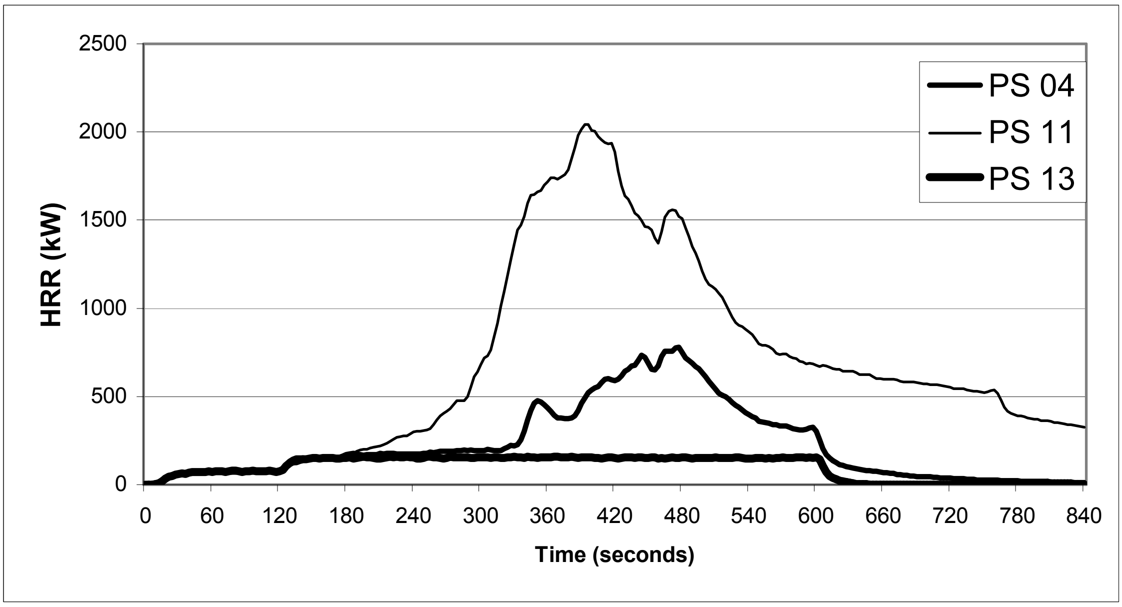
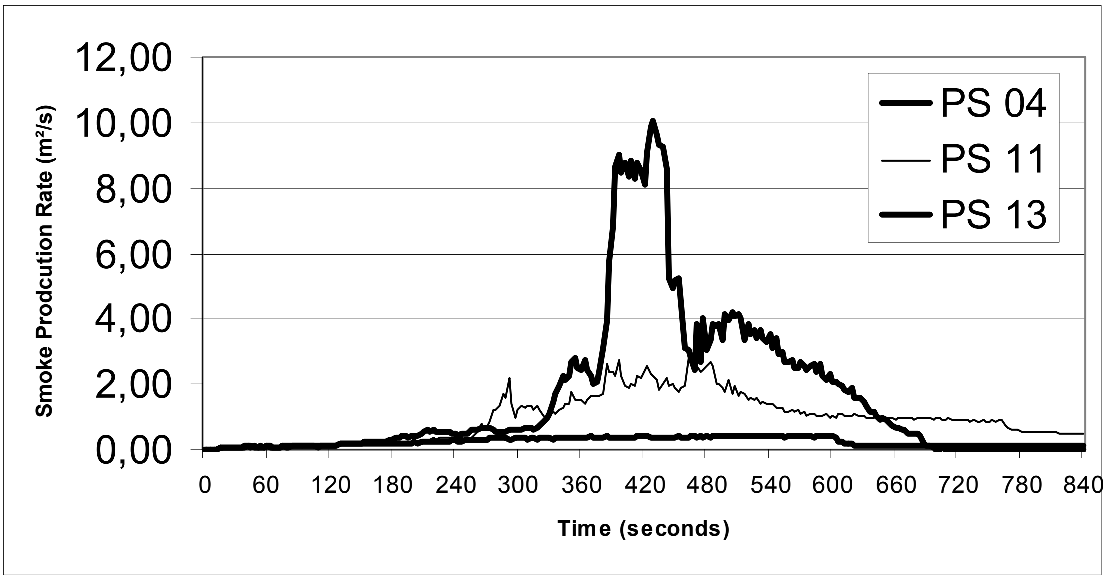


Figure 9 : Typical Smoke Production Rate results from Real-Scale Train Compartment Tests



10.4 - Main conclusions on correlation

To answer to the objective of the FIRESTARR project, which is to develop a classification proposal, the first study was performed on the critical effects in real scale (ignitability, fire growth, loss of visibility, toxicity). This resulted in the definition of the criteria and analysis of the time to reach the critical effects according to essential requirements based on safety of passengers.
The second study, statistical analysis on scalar data and on vector data, was performed on the results from the three scales: research of correlation and research of models for the prediction of critical effects. This second study has allowed to select small scale tests for the classification.

For the structural products, all the critical effects are reached during real scale tests.
Nearly half of the structural products went to flashover, half the products reached the toxicity limit (FED=1) and all products provide the loss of visibility effect.
The loss of visibility effect is the first effect that occurs with structural products.

For furniture products, one critical effect for any product was never reached during the real scale tests: that is flashover. But the loss of visibility and the toxicity effect were reached for all products except two. Contrary to structural results, the time to reach the toxicity limit occurs before the loss of visibility effect.

After that, a first statistical analysis was carried out. According to the critical effect results, it is very important to try to find correlation between small and real scale or at least if there is no correlation found, between large and real scale.
This first analysis was performed on scalar data for each type of product and for each type of critical effects.
The results of this analysis must be considered very carefully because some materials give a great contribution to results. Sometimes, when these particular materials are eliminated from the calculation, the correlation disappears!

For structural products, the correlation changes with the type of materials taken into account
(e.g. a) materials which provide flashover, b) those which do not provide flashover, c) all materials).
The principal results are summarised below.

- **Ignitability:**

In small scale and in real scale, all materials/products ignite except one. In large scale, several products/materials do not ignite.
Then there is no correlation between large and real scale for the time to ignition but only a correlation for materials which provide flashover between real scale and small scale according to ISO 5660 at 50kW/m².

- **Fire growth**

The results are much influenced by the type of materials taken into account.
Moreover, some materials provide great values in one scale but not in another scale as PS05 for HRR and THR in real and large scale and PS18 for HRR and THR in real scale.
Some correlation were found between real scale and small scale :

- HRR (real scale) and q180 or q300 (ISO 5660 at 35 and 50kW/m²),
- THR (real scale) and THR (ISO 5660 at 35 kW/m²) only for materials with flashover.

- **Loss of visibility**

The results are also much influenced by the type of materials taken into account. PS05 gives a great contribution for the parameters RSP in real and in large scale, for VOF4 and kmax in small scale. PS03 which is a material that does not provide flashover in real scale is also particular.
There is no robust correlation between the real scale and the small scale for the kinetic parameters (RSP, kmax) and for cumulative parameters (TSP,VOF4, Dmax, SEA). But there is a correlation between RSP in real scale and VOF4 in small scale (ISO 5659 at 25kW/m² with pilot flame and 50kW/m² without pilot flame).

- **Toxicity**

There is correlation between FED in real scale and a combination of parameters in small scale that is, Ti*TML (with Ti the index toxicity from UITP E6 test at 400°C or 600°C and TML the total mass loss from ISO 5660 test at 35 or 50kW/m²). But there is no correlation between the FED in real scale and parameters from the DIN 53436 test in small scale. There is also no correlation between the FED in real scale and the FED in large scale.

In conclusion, statistical analysis of scalar data does not give a robust result. It is influenced by the behaviour of particular products and sometimes by the low number of products taken into account. Then, a more elaborate analysis was performed on vector data, which allows to take into account the shape of the curve.

The results for structural products are very interesting. It has been shown that the Fire Critical Effects for Fire growth, smoke opacity and smoke lethality may be predicted from small scale test data.

It should be noted that the relationships found are available on a limited number of materials tested in the FIRESTARR project and for the range of parameter values analysed for correlation purposes. The results used in small scale tests are the average of three repetities whereas in real scale, no test repetition were done.

The good correlation found permits optimum small scale test selection and the results from predictive models using derived parameters permit a classification system for the materials to be proposed.

These predictive models allow to predict the following Fire Critical Effects:

- Whether a product will cause a flashover, two models are proposed :

  $$HRR = 1608.67 – 102.70\, y_{tg} + 1.72\, y^2_{tg} – 0.006\, y^3_{tg} \qquad \{1\}$$

  $$HRR = -2544 + 50y_{tg} \qquad \{2\}$$

  Both of the models for y_{tg} included in the range [20 kW/m² - 140 kW/m²]
  where y_{tg} = ($\int t.q(t)dt$) / ($\int q(t)dt$) integral between t=0 to time for end of test
  NB:**The test-data for this prediction are provided by ISO 5660-1 at 50kW/m^2.**

- The time when a flashover will occur,

  $$t_{FO}= 138.52 + 1.39\,(tmax – tig) \qquad \{3\}$$

  for (tmax – tig) included in the range [50 – 140]
  Where t_{FO} is the time to reach flashover, tmax is the time when the maximum of heat release is reached, tig is the time to ignition during the ISO 5660 1 at 50 kW/m^2.

- The time when the visibility in a 40m^3 compartment and corridor space will be obscured by smoke,

  $$t_{VL} = 459 – 0.345\,(VOF4) \qquad \{4\}$$

  for VOF4 included in the range [16 – 1000]
  where VOF4 is determined from the ISO 5659-2 test using the 50kW/m^2 exposure mode without pilot flame.

  NB: The visibility limit in this calculation is based on a requirement for people to be able to see at least 10m. According to Jin's work, the extinction coefficient k for this condition is 0.8.

- The time when the toxicity limit is reached in a 40m^3 compartment and corridor space,

  $$FED = 2.84\,(TML)Ti \qquad \{5\}$$

  for TML*Ti included in the range [0.0008 – 4.5]
  where FED is the fractional effective dose, TML is the total mass loss (based on the ISO 5660-1 test at 35kW/m^2) and Ti is obtained from the UITP E6 test at 400°C.

  NB: t_{TL} (or time to toxicity limit) is reached when the effluent gas levels yield FED = 1.

In conclusion, the small scale tests used for the evaluation of predictive models are:

- for ignitability parameter: ISO 5660-1 with test condition heat flux of 50kW/m²
- for fire growth parameters: ISO 5660-1 with test condition heat flux of 50kW/m²
- for smoke parameters: ISO 5659-2 with test condition heat flux of 50kW/m² without pilot flame
- for toxicity parameters: ISO 5660-1 with test condition heat flux of 35 kW/m² for the total mass loss measurement and UITP E6 with test condition 400°C for the toxic index measurement

11 - FURNITURE PRODUCTS

11.1 - Products selected

Table 7 gives all the furniture products selected for the small scale tests.

TABLE 7

CODE	PRODUCT	LOCATION IN TRAIN	COUNTRY SUPPLYING PRODUCT
PF01	Sunblind in glass and PVC	Wall	France
PF02	Curtains in PVC fibre	Wall	France
PF03	Curtains in preoxydate fibre	Wall	Italy
PF04	Curtains in polyester	Wall	Germany
PF05a	Mattress foam	Bedding	U.K.
PF05b	Mattress covering	Bedding	France
PF06	Sheet	Bedding	France
PF07	Blanket	Bedding	France
PF08a	Pillow (stuffing)	Bedding	France
PF08b	Pillow (covering)	Bedding	France
PF09	Silicone unlacerable fabric	Seat	France
PF10	Polyurethane foam	Seat	France
PF11	Seat covering knitted velvet	Seat	France
PF12	Seat covering « en drap »	Seat	France
PF13	Seat covering in simulated leather	Seat	France
PF14	Seat interlayer polyacrylate-aramide fibre	Seat	France
PF15	Polyurethane foam	Seat	Italy
PF16	Seat covering wool / synthetic fibre	Seat	Italy
PF17	Seat covering synthetic fibre	Seat	Italy
PF18	Seat covering wool / acrylic fibre	Seat	Italy
PF19	Seat covering texoïd	Seat	Italy
PF20	Seat interlayer polyacrylate-aramide fibre	Seat	Italy
PF21	Polyurethane foam	Seat	Germany
PF22	Seat covering polyester fibre	Seat	Germany
PF23	Seat covering wool / polyester fibre	Seat	Germany
PF24	Seat interlayer skin polyester	Seat	Germany
PF25	Integral skin polyurethane foam	Seat	U.K.
PF26	Polyurethane foam	Seat	U.K.
PF27	Seat covering woollen spun cloth	Seat	U.K.
PF28	Seat covering double plush seating moquette, untreated	Seat	U.K.
PF29	Seat covering double plush seating moquette, Zirpro treated	Seat	U.K.
PF30	Seat covering cut and uncut seating moquette, untreated	Seat	U.K.
PF31	Seat interlayer fibrous glass substrate with polymeric treatment and special coating	Seat	U.K.
PF32	Seat interlayer polyacrylate-aramide fibre	Seat	U.K.

For seats, which are probably the part of vehicles most frequently involved in fires, it was decided to test different combinations from 4 countries. Table 8 gives the combination selected.

TABLE 8

	Foam	Interlayer	covering	
C01	PF10	PF14	PF11	France
C02	PF10	PF14	PF12	France
C03	PF10	PF14	PF13	France
C04	PF15	PF20	PF16	Italy
C05	PF15	PF20	PF17	Italy
C06	PF15	PF20	PF18	Italy
C07	PF15	PF20	PF19	Italy
C08	PF21	-	PF22	Germany
C09	PF21	-	PF23	Germany
C10	PF26	PF32	PF27	U.K.
C11	PF26	PF32	PF29	U.K.
C12	PF26	PF32	PF30	U.K.
C13	PF26	PF31	PF28	U.K.
PF09	Silicone unlacerable fabric			France
PF25	Integral skin polyurethane foam			U.K.

11.2 - Tests selected

The main objective of WP 3 was to select small and large scale test methods which would relate to the fire scenario 1.

Small scale tests

The following small-scale tests and conditions were selected for use in WP 4.2 :

- **Ignitability**

I.1 : pr EN ISO 11925-2 : Small burner test

This test simulates an application of a match or cigarette lighter to the edge of a lining or covered textile. Application time was 15 and 30 s.
This key parameters for analysis from the pr EN ISO 11925-2 test are :
- ignition or non-ignition.
- time for a sustained flame to reach 150 mm mark.

I.2 : EN 597 part 1,2

This test simulates an accidental application of a small thermal energy source on to the surface of mattress.
This key parameters for analysis from the EN 597 part 1,2 [18] [19] test is the damaged distance after combustion.

I.3 : pr EN ISO 32952 part 2,4

This test simulates a smouldering and flaming small ignition source on bedding sheets and blanket.
This key parameters for analysis from the pr EN ISO 32952 [20] [21] are :
- damaged area

- time to reach distance

I.4 : UIC 564-2 Annex 5

This test simulates a casual or an arson application of a match or lighter flame to the edge of a lining or covered textile.
The key parameters for analysis from UIC 564-2 Annex 5 [22] are :

- time to extinction
- mass loss
- damaged distance

I.5 - ISO 5660 part 1

This test simulates the effect of the heat flux produced by an existing external fire of limited size. The irradiance level is 25 kW/m^2.
The key parameter for ignitability analysis from the ISO 5660-1 test is time to ignition (t_{ig}).

I.6 - UIC 564-2 Annex 13 [23]

This test simulates the presence of a large flame caused by a fire at the early developing stage. The key parameter for ignition analysis is time to ignition for seat and back.

I.7 - pr EN 1021 parts 3 and 4 [24] [25]

This test simulates the effect produced by 20 g and 100 g of burning newspaper. The key parameter for ignition analysis is time to ignition.

- **Fire growth**

F.1 - ISO 5660 part 1

This test provides data on rate of heat release and total heat release at 25 and 35 kW/m^2.

The key parameters for analysis concerning heat release are :

- max heat release rate (qmax) ;
- heat release rate as mean over t_{ig} to t_{ig} + 180 s (q_{180}) and over t_{ig} to t_{ig} + 300 s (q_{300}) ;
- total heat release

F.2 - UIC 564-2 Annex 13

This test simulates the presence of a large flame caused by a fire at the early developing stage.
The key parameters concerning fire growth are :

- flaming time ;
- damaged volume ;
- total mass loss.

F.3 - pr EN 1021 parts 3 and 4

This test simulates the effects produced by 20 g and 100 g of burning newspaper. The key parameters for analysis concerning fire growth are the same as UIC 564-2 Annex 13.

F.4 - ISO 5658 part 2

This test provides the spread of flame measurement of an ignited curtain.
The key parameter for fire growth analysis are :
- heat for sustained burning (QSB) ;*
- max flame spread distance (Xmax) ;
- critical flux at extinguishment (CFE).

- **Smoke opacity**

S.1 - ISO 5660 part 2 (dynamic test)

This test provides data on rate of smoke generation and the smoke released over 32 minutes. It was operated at 25 and 35 kW/m^2.
The key parameters for analysis are :
- Total smoke produced using specific extinction area (SEA) ;
- max extinction coefficient (k_{max}).

S.2 - ISO 5659 part 2 (cumulative test)

This test provides data on smoke generation over 10 minutes. It was operated at 25 kW/m^2 with and without pilot flame and 50 kW/m^2 without pilot flame.
The key parameters for analysis from the ISO 5659-2 test are :
- smoke density after 10 minutes (Ds 10) and Dmax ;
- VOF4 which takes into account the rate of smoke generation in the first 4 minutes.

- **Toxic potency**

T.1 - NF X 70-100 (Tubular Furnace test) (UITP E6)

This test was used under the conditions listed below :
- 2 temperatures : 400 °C and 600 °C ;
- air flow : 2 l/min.

T.2 - DIN 53436 (Travelling Furnace test)

This test was used under the following conditions :
- 2 temperatures : 400 °C and 600 °C ;
- air flow : 2 l/min for primary air flow and 8 l/min for secondary air flow.

For both methods the gases analysed were : CO, CO_2, HCN, HCl, HBr, HF, NOx, SO_2, formaldehyde and acrolein (Same analytical as the one used for structural products).

Large scale test

The large scale test method for furniture products was selected for seats that are the main furniture products found in a railway carriage.

The test method carried out in large scale for a furniture product was the NT FIRE 032 [26] (furniture calorimeter). The ignition source consisted of a square burner which simulated the same thermal attack on a seat as that given by a 100 g burning paper cushion.
To improve the seats and their behaviour regarding possibility of vandalism, three vandalised levels were defined to test the seats :

- vandalised level 0 : not vandalised at all ;
- vandalised level 1 : a cut (cross shape) on the back and on the seat ;
- vandalised level 2 : vandalised level 1 and the fabric (cover and interliner) pulled away from the foam.

The ventilation conditions essentially represented a well-ventilated railway compartment with door open.

Measurements of time to ignition, heat release, smoke opacity and concentrations of toxic gases were made.

Real scale test

Referring to the WP1 conclusion [27], a railway carriage Voiture VU78 with 11 compartments served by a side corridor was identified by SNCF. A small compartment was reproduced in the laboratory.
The compartment may be assumed to have a volume of approximately 9 m^3. The ventilation conditions in the compartment essentially represented a real ventilated railway compartment with door firstly closed for 3 minutes and then open. The compartment was sited underneath the standard ISO 9705 hood/duct system. During all the tests, the flow rate in the exhaust duct system was fixed at 3,5 m^3/s.
2 seats were placed edge to edge inside the compartment and positioned on the right wall in the corner next to the window.

Measurements of time to ignition, heat release, smoke opacity and concentrations of toxic gases were made.

11.3 - Test results

Small-Scale Tests

32 furniture products were tested in WP4.2. These products were distributed across the following 4 application areas; i.e.

a)	Wall / Curtain	(4 products)
b)	Bedding	(4 products)
c)	Seat	(24 products)
d)	Others (e.g. sheet)	(2 products)

Concerning the seat application area, the materials were then subdivided in two separate parts due to a different evaluation as single components of seats and as combination of them, related to the type of fire reaction parameter measured:

- Fabrics
- Assemblies

For assembly, a combination of a block of foam covered first with a piece of an interlayer and second with a piece of fabric covering was put together.
Under the indication of different railway companies the components of seat presented for each assembly were one foam, one or two interlayers, several coverings.

In all or most of cases, the combinations for each country were equal to the number of coverings because the foam and interlayer were the same.
So, this system combining all materials and components of seats has permitted to determine 13 different combinations or assemblies which are described in Table 8.
Every assembly is intended to simulate or represent the full seat article used in real compartments but having a smaller size to be suitable for bench scale testing.
The complete results for the WP4.2 tests are stored in the FIRESTARR database and reported in document WP4.2/LSF/00001 [28].

Concerning wall / curtains application area, the small flame test is less discriminating than Cone calorimeter method in terms of Ignitability and especially at 35 kW/m^2.
In "Fire Growth" results, all products show a similar good spread of flame performance in ISO 5658-2 testing. Concerning the smoke opacity performance under dynamic conditions, the ISO 5660-2 method defines 3 potential different levels for S" data at 25 kW/m^2, while a small difference between products was detected in the measurements from single chamber smoke test for cumulative system only at lower irradiance level.
The main conclusion is however that the small number of products tested does not allow to obtain a significant range of results for assessing different reaction to fire performance levels.

As already for Wall/Curtain products, in the Bedding application area only 4 different materials were tested and this does not permit to give reliable results for use in their classification.

The analysis of results concerning the covering fabrics of seats shows that the damaged area data is not useful for a determination of Ignitability performance levels because of the particular difficulty to obtain an accurate measurement.

The ignitability of assemblies gives more significant results only in ISO 5660 at 25 kW/m^2 .

TABLE 9 : "Ease of ignition". Results for assemblies products tested according to ISO 5660-1 at 25 and 35 kW/m^2

	Imposed heat flux: 25 kW/m^2	Imposed heat flux: 35 kW/m^2
Products	Time to Ignition (s)	Time to Ignition (s)
PF 09	131	73
PF 25	10	1
C 01	50	88
C 02	37	23
C 03	79	21
C 04	52	28
C 05	53	23
C 06	35	20
C 07	45	34
C 08	35	15
C 09	n.d.	n.d.
C 10	24	17
C 11	71	16
C 12	57	14
C 13	83	16

Concerning the other test methods (pr EN 1021 Parts 3 and 4, UIC 564.2 Annex 13) for evaluation of "ease of ignition", the results are affected by an imprecise determination of the "ignition times" for seats and backs because the measurement is extremely dependant on the operator (presence of burner.with a flame that can hide the ignition of the product).

TABLE 10 : Small scale tests on furniture products (assemblies) – "Fire growth" results according to ISO 5660 part 1 Standard

Products	25 kw/m^2 of imposed heat flux				35 kw/m^2 of imposed heat flux			
	q_{180} (kW/m^2)	q_{300} (kW/m^2)	q_{max} (kW/m^2)	THR (MJ/m^2)	q_{180} (kW/m^2)	q_{300} (kW/m^2)	q_{max} (kW/m^2)	THR (MJ/m^2)
PF 09	24.2	20.8	117.3	48.3	52.5	58.1	137.0	48.1
PF 25	51.4	38.0	117.0	10.7	63.5	49.1	125.2	16.1
C 01	15.9	12.7	130.3	53.3	31.3	38.7	159.7	62.9
C 02	16.2	11.5	114.7	17.4	79.3	61.6	170.0	88.2
C 03	42.8	31.1	98.3	43.5	62.8	47.7	132.3	82.2
C 04	35.7	22.9	159.6	8.0	81.9	66.4	283.3	80.1
C 05	49.6	51.9	165.7	83.1	75.9	68.2	182.0	88.9
C 06	30.2	20.8	204.7	33.3	67.3	52.1	279.0	86.7
C 07	28.5	17.1	128.0	4.3	91.2	62.5	167.1	15.9
C 08	98.0	59.2	226.6	17.7	111.0	72.2	265.6	64.6
C 09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C 10	35.9	29.5	213.9	8.76	56.0	46.0	246.9	15.3
C 11	79.9	63.1	206.2	74.4	104.0	93.2	281.4	87.0
C 12	129.1	98.7	439.0	77.0	173.4	147.8	524.8	92.1
C 13	118.5	87.4	321.8	37.0	133.2	110.4	328.8	53.9

The cone calorimeter results for "fire growth" highlight that q_{max} and THR data better summarise the peak of combustion and total heat contribution from a single product burning.

TABLE 11 : Small scale tests on furniture products (assemblies) – "Fire growth" results

Products	**UIC 564.2 annex 13**				**Pr EN 1021 part 4**			
	Flaming time (s)	**Damaged volume for seat (cm^3)**	**Damaged volume for back (cm^3)**	**Total Mass Loss (g)**	**Flaming time (s)**	**Damaged Volume for seat (cm^3)**	**Damaged volume for back (cm^3)**	**Total mass loss (g)**
PF 09	166.7	52.8	56.9	6	8	25.8	123.4	8.8
PF 25	1273	3754.0	6666.7	2090.0	30	538.3	2304.7	54.7
C 01	260	1673.0	2050.0	36.5	1	165.8	524.4	18.5
C 02	1335	4963.5	5762.5	112.5	6	63.6	233.3	17.0
C 03	280	2380.0	1752	47.0	22	149.3	286.7	22.1
C 04	448	4249.0	4393.3	127.0	20	258.0	591.3	31.5
C 05	860	6711.0	8600.0	201.7	177	1532.5	3723.8	36.5
C 06	225	3149.0	2424.3	127.0	10	531.0	1598.3	21.5
C 07	498	3415.0	6000.0	147.0	n.d.	620.0	2042.5	39.0
C 08	270	5635.0	9511.0	44.0	125	1865.0	7025.0	34.0
C 09	239	2799.0	11616.0	68.7	239	2799.0	6.0	68.7
C 10	327	86.6	299.1	23.2	125	368.1	1213.0	21.0
C 11	663	350.6	482.3	69.5	154	198.7	456.4	12.3
C 12	830	206.0	622.0	116.8	152	234.6	796.4	19.7
C 13	295	752.0	932.3	2483.3	70	33.4	233.3	24.6

The "fire growth" was studied also by pr EN 1021.4 and UIC 564.2 annex 13 methods.
Looking to "Damaged volume" for seat and back data and "total mass loss", it may be pointed out that the paper cushion test appears to be more severe and gives a very large range of results. At same time pr EN 1021 Part 4 method can be used for the same purpose but with a smaller range of absolute values for consideration.

TABLE 12 : Small scale tests on furniture products (assemblies) – "Loss of visibility" results in well-ventilated and cumulative conditions

Product	ISO 5660-2 at 25 kW/m²		ISO 5660-2 at 35 kW/m²		ISO 5659-2 at 25 kW/m² no pilot flame			ISO 5659.2 at 25 kW/m² with pilot flame			ISO 5659.2 at 50 kW/m² no pilot flame		
	S" (m^2/m^2)	k_{max} (m^{-1})	S" (m^2/m^2)	k_{max} (m^{-1})	Max. level of smoke density (Dmax)	Smoke density value at 10 min (D_{10})	Index of smoke growth for the first 4 min. (V0F4)	Max. level of smoke density (Dmax)	Smoke Density value at 10 min (D_{10})	Index of smoke growth for the first 4 min. (V0F4)	Max. level of smoke density (Dmax)	Smoke density value at 10 min (D_{10})	Index of smoke growth for the first 4 min. (V0F4)
PF 09	930.7	1.40	729.7	1.76	197	135	76	86	52	22	368	353	448
PF 25	56.6	0.79	79.5	0.49	174	162	463	48	48	31	68	65	176
C 01	1505.3	5.71	1655.7	7.15	221	216	378	169	151	440	419	359	800
C 02	413.3	4.85	822.7	6.37	n.d.	n.d.	n.d.	75	75	211	442	412	1066
C 03	1443.7	5.81	1881.7	10.32	404	397	947	257	175	751	435	352	1370
C 04	162.7	1.06	214.3	1.32	173	167	319	40	38	75	99	91	244
C 05	685	3.25	953.0	1.81	227	224	468	114	92	73	343	268	672
C 06	370.8	0.64	533.7	1.18	125	122	236	n.d.	n.d.	n.d.	201	113	275
C 07	893.8	4.71	768.5	6.68	633	625	1404	413	317	1168	687	665	2135
C 08	656.3	4.9	1150.5	5.80	458	435	234	625	493	1076	719	660	1809
C 09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
C 10	72.0	0.41	49.2	0.96	201	198	295	108	106	75	95	89	219
C 11	199.4	0.61	175.4	0.86	265	254	207	150	140	82	182	125	583
C 12	231.4	1.21	320.4	1.52	271	254	326	180	169	239	173	119	509
C 13	212.3	1.40	186.3	1.40	313	312	381	205	196	293	174	147	487

In the analysis of "smoke opacity" under well-ventilated conditions as summarised by Cone calorimeter results, S" and k_{max} allow a stratification of data, specially for the first parameter.
Under cumulative conditions, smoke opacity is determined by the ISO 5659-2 test method, where the most representative key parameters are D_{max} and V0F4.
A stratification of these results may be pointed out particularly at 25 kW/m² (with and without pilot flame) and their ranges are respectively: D_{max} 40-625, V0F4 22-1168 for flaming condition and D_{max} 125-633, V0F4 76-1404 for smouldering condition.

Large-Scale tests

Eight seats were selected for test in WP7.2 based on the statistical analysis of the test data obtained on 13 combinations/assemblies in WP4.2. They were chosen with the objective that correlations would be sought between the WP7.2 large-scale test-data and the WP4.2 small-scale test-data. The details of the products tested in WP7.2 are shown in annex 1 of WP7.2/LSF/00002 [29].

The testing of the 8 seats was divided between the LSF (ITALY) and SP(SWEDEN) laboratories, who followed an identical test protocol and used the same new ignition source designed by LSF and named FIRESTARR "A" burner (see WP7.2/LSF/00002).

"Ease of ignition" results firstly show that 3 seats out of 8 do not ignite when tested at level 2 of vandalism. Only one combination reaches ignition also at level 1 and no seats burn under normal conditions (vandalism level "0").
Secondly, comparing the times to reach ignition for VL2 testing, it observed that only one has an average value around 5-6 minutes, while the other seats ignite between 1.5 and 2.5 minutes (3 products).
Finally, it means that, generally, all tested seats have a good ignitability performance under normal conditions so they do not permit a discrimination until forcibly ignited by vandalism which then show 4 categories of performance.

Analysing the "Fire growth" data, it is confirmed that there is similar good level of performance for all seats when tested at Vandalism level "0" – "1" and all parameters evaluated are in the same low range. Among all seats where ignition has occurred at the same vandalism level, it is observed that: HR_{peak} data show one product as the best and the others at same level of performance; the "times to reach" these peaks have a range between 207 to 558 seconds and could permit a division into two main groups.
"THR" results, "mass loss" and "EHC" data show a similar response and the same performance ranking already obtained by " HR_{peak}" data analysis.

In conclusion, the evaluation of “fire growth” data does not give discriminating results for seats tested under normal conditions (i.e. not vandalised) but it seems to define rankings for all the products that burn at vandalism level “2”.
A further classification system should anyway consider this step always after the “ignitability” response.

The results on “Loss of visibility” show a general range of low values for each parameter everywhere ignition is not reached.
A significant discrimination of results and products is obtained for ignited seats. Two main groups of results are found taking into account “RSP_{peak}” and “TSP” data at the same time.
The time for RSPpeak results do not rank the seats in the same order of smoke emission performance.
Also for this reaction to fire parameter, a category performance system should take into account the “ignitability” response.

All scalar results and an example of vector data of WP 7.2 testing are shown in table 13 and figure 10.

Real-scale Tests

Eight seats were tested in WP8.2 in the railway compartment described in Section 1. The test procedure was carried out using the FIRESTARR burner A (7 kW 3 minutes) applied on seat with the door closed in the first 3 minutes and then open until the end of test.

All the testing of the eight seat products in this railway compartment was carried out at LSF, (Italy).
It should be noted that the test compartment constructed for these WP8.2 railway seats tests was identical to the test compartment constructed at WFRC (UK) for evaluation of structural products in the WP8.1 programme. Both test compartments were fitted with SNCF ventilation ducts and were installed underneath ISO 9705 hoods for measurement of smoke and toxic gases.
For simulating the different and most probable real situations with the seats positioned in a train compartment, 3 different stages have been defined. These are intended to reproduce the effect of a burning seat on adjacent seats:

- **Stage1:**
  The seat that will be ignited is not vandalised. The objective is to observe if there is a flame spread to the adjacent seat and facing seat measuring all reaction to fire parameters which may be related to the identified risks.
- **Stage2:**
  The seat that will be ignited is vandalised. The objective is the same of the first stage.
- **Stage3:**
  The seat that will be ignited is vandalised. The objective is to observe if there is a flame spread to the adjacent seat and the effect to the back side of a third seat placed before the first one with the same sense of direction. All reaction to fire parameters which may be related to the identified risks are measured.

The ignitability results show that 4 seats have reached the ignition in both not-vandalised and vandalised conditions but they do not seem to discriminate them looking to “time to reach the ignition” data.

Fire growth results gave 2 or 3 different groups of performance for HRR and THR data.
The same response is identified looking RSP measurements for “Loss of visibility” parameter.

All scalar results and an example of vector data of WP 8.2 testing are shown in table 14 and figure 10.

TABLE 13 : WP 7.2 Large scale tests on railway seats

Combination nr. / Test nr.		VL (1)	REACTION TO FIRE PARAMETERS										
			Ease of ignition		**Fire growth**						**Loss of visibility**		
			Ignition (2) (yes / no)	Time to reach the Ignition (2) (s)	HRR peak (3) (kW)	Time to HRR peak (s)	THR (MJ)	TML (kg)	PML (%)	EHC (MJ/kg)	RSP peak (m^2/s)	Time to RSP peak (s)	TSP (m^2)
C01	Seat 1	0	No	NR	6.7	108	0.6	0.10	0.5	6.5	0.117	93	18.1
	Seat 2	1	No	NR	9.9	162	1.0	0.10	0.5	10.7	0.163	150	23.0
	Seat 3	2	Yes	150	100.2	207	18.9	1.45	6.9	13.1	1.568	192	606.4
	Seat 4	2	Yes	153	90.5	270	20.1	1.45	6.9	13.8	1.698	219	528.4
C02	Seat 1	0	No	NR	9.6	192	0.5	0.07	0.2	6.6	0.414	168	38.4
	Seat 2	1	No	NR	8.4	195	0.8	0.10	0.3	8.4	0.510	219	49.3
	Seat 3	2	Yes	99	198.9	414	74.9	4.38	13.9	17.1	4.675	150	1266
	Seat 4	2	Yes	99	211.1	234	85.3	4.90	15.7	17.4	5.528	153	1456
C03	Seat 1	0	No	NR	10.1	177	0.8	0.10	0.7	8.0	0.892	156	80.3
	Seat 2	1	Yes	1323	40.7	1353	17.7	1.10	7.5	16.1	1.038	1347	628.2
	Seat 3	1	Yes	675	68.4	705	21.8	1.94	13.3	11.2	1.847	693	923.1
C04	Seat 1	0	No	NR	4.7	93	0.4	0.05	0.2	8.6	0.044	183	8.1
	Seat 2	1	No	NR	4.6	138	0.3	0.06	0.2	5.2	0.036	132	3.9
	Seat 3	2	Yes	192	148.9	525	45.6	2.70	8.2	16.9	1.468	507	561.4
	Seat 4	2	Yes	492	199.4	558	57.8	3.24	9.8	17.9	1.898	546	694.2
C05	Seat 1	0	No	NR	18.8	180	1.8	0.05	0.4	35.2	0.519	165	51.4
	Seat 2	1	No	NR	13.8	200	2.1	0.05	0.4	41.8	0.525	170	59.8
	Seat 3	2	No	NR	20.1	235	14.1	0.77	6.9	18.3	0.532	195	73.0
	Seat 4	2	No	NR	19.0	275	2.2	0.15	0.8	14.9	0.524	235	63.0
C07	Seat 1	0	No	NR	8.7	235	0.3	0.05	0.4	5.4	0.987	55	109.5
	Seat 2	1	No	NR	18.3	225	2.75	0.06	0.4	45.8	1.260	70	131.9
	Seat 3	2	Yes	135	341.2	385	82.07	3.06	21.6	26.8	10.63	310	2601
	Seat 4	2	Yes	130	256.8	350	53.56	2.39	16.5	22.4	10.16	320	2257
C08	Seat 1	0	No	NR	19.2	225	2.68	0.17	0.7	15.8	0.500	195	52.7
	Seat 2	1	No	NR	18.1	215	2.02	0.14	0.6	14.4	0.577	215	63.4
	Seat 3	2	No	NR	19.0	250	2.64	0.08	0.3	33.0	0.569	200	54.8
	Seat 4	0	No	NR	19.0	250	2.64	0.09	0.4	29.3	0.569	200	54.8
C09	Seat 1	0	No	NR	25.2	210	4.42	0.12	0.5	36.8	0.509	200	59.7
	Seat 2	1	No	NR	21.8	160	3.81	0.12	0.5	31.8	0.497	155	66.8
	Seat 3	2	No	NR	15.1	235	1.82	0.06	0.2	30.3	0.316	220	30.0
	Seat 4	0	No	NR	22.9	170	3.74	0.13	0.5	28.8	0.653	215	55.4

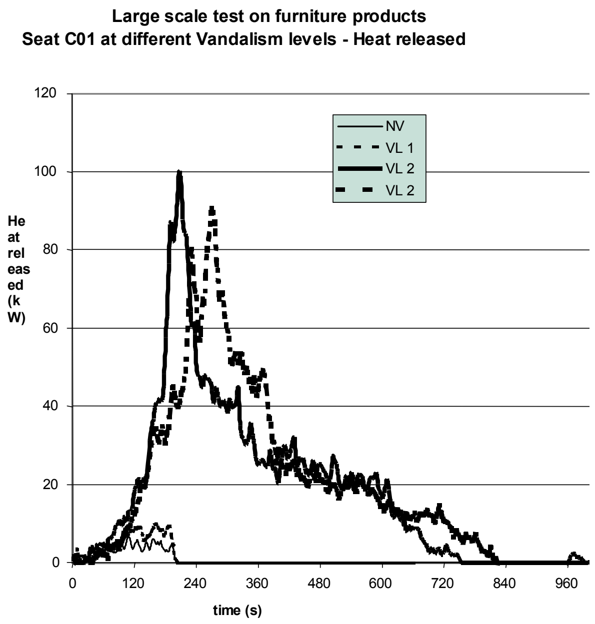
(1) : VL = Vandalism level on the seat
(2) : Ignition of the seat is indicated when the Heat release peak reach at least the value of 30 kW excluding the burner contribution.
(3) : All Heat release data are reported excluding the burner contribution.
HRR_{peak} :Heat release peak; t HR_{peak} : time to Heat release peak (s); THR : Total Heat released.
TML :Total mass loss; $PML_{\%}$: Percentage of Total mass loss (%).
EHC : Effective heat of combustion determined from the quotient between the total heat release and the mass loss (MJ/kg).
RSP_{peak} : Rate of Smoke Production peak (m^2/s); t RSP_{peak} : time to Rate of Smoke Production peak (s);
TSP : Total production of light obscuring smoke (m^2); NR : Not reached.

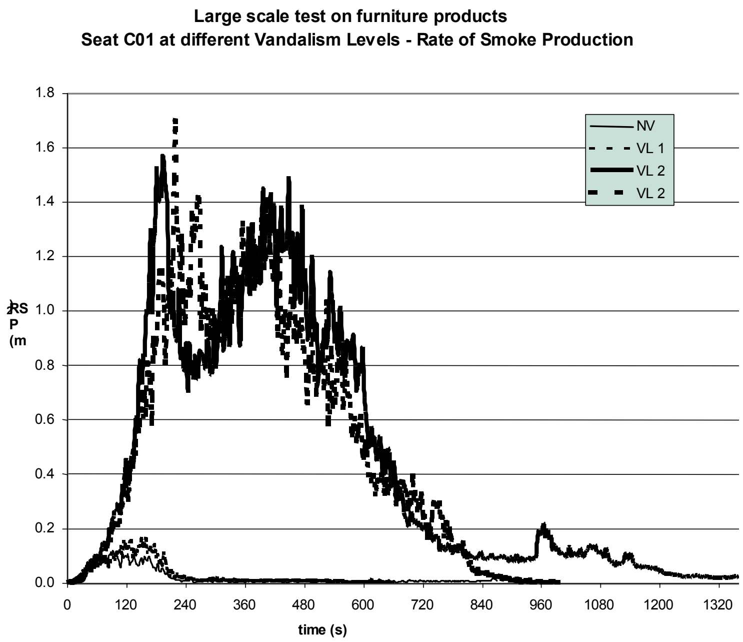
Table 14 : WP 8.2 - Real scale tests on railway seats

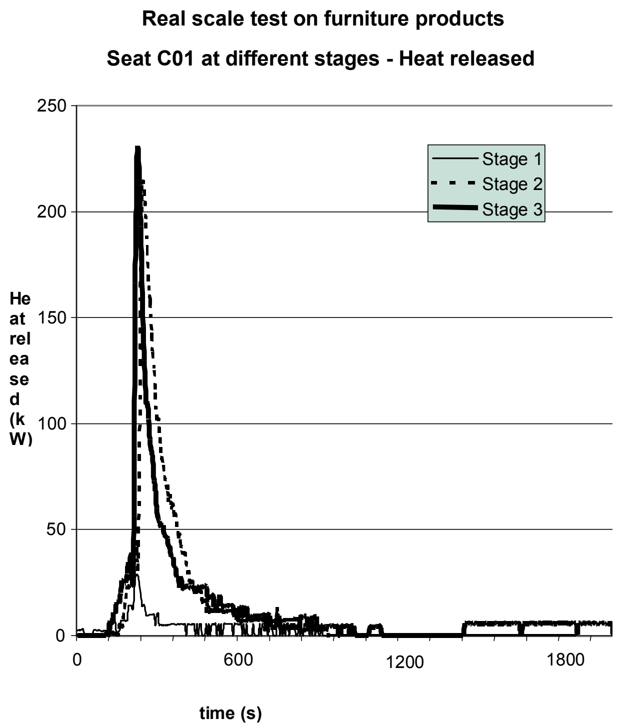
Combination	Stage	REACTION TO FIRE PARAMETERS								
		Ease of ignition		Fire growth				Loss of visibility		
		Ignition (1) (yes / no)	Time to reach the Ignition (1) (s)	HRR peak (2) (kW)	Time to HRR peak (s)	THR (MJ)	DM (3) (%)	RSP peak (m^2/s)	Time to RSP peak (s)	TSP (m^2)
C01	1	No	NR	28.6	230	4.4	0.9	0.74	195	53
	2	Yes	205	214.2	250	24.6	10.8	5.30	215	1196
	3	Yes	195	231.0	230	27.8	12.0	7.44	200	1229
C02	1	Yes	245	327.6	880	87.7	16.8	7.41	860	2381
	2	Yes	150	321.8	325	197.1	18.8	7.97	300	6928
	3	Yes	135	317.5	255	108.2	16.8	11.16	195	2508
C03	1	Yes	240	40.5	255	1.7	0.7	3.77	220	241
	2	Yes	140	341.8	365	85.0	21.1	11.38	340	2855
C04	1	No	NR	29.6	260	2.8	0.2	0.14	225	16
	2	Yes	130	229.5	370	97.8	25.1	3.45	240	1481
	3	Yes	150	249.4	325	79.7	25.1	4.09	285	1312
C05	1	No	NR	20.3	260	4.6	1.0	0.21	225	30
	2	Yes	220	273.4	715	80.2	25.8	5.80	605	1706
C07	1	No	NR	23.6	235	1.3	5.1	1.67	200	162
	2	Yes	200	222.8	465	78.3	25.6	11.06	200	4055
C08	1	Yes	255	35.2	270	4.0	1.2	1.03	235	61
	2	No	NR	29.0	480	1.6	0.7	0.92	445	53
	4	Yes	205	67.0	210	3.2	ND	1.63	185	51
C09	1	Yes	245	80.3	260	4.6	1.7	2.32	225	150
	2	Yes	205	91.9	215	5.3	1.1	2.65	185	73
	4	Yes	240	37.6	250	2.1	ND	1.16	220	80

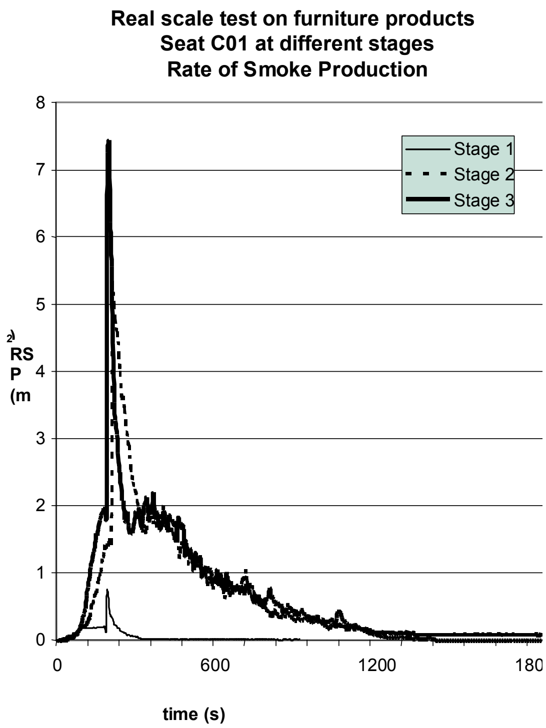
(1) : Ignition of the seat is indicated when the Heat release peak reach at least the value of 30 kW excluding the burner contribution.
(2) : All Heat release data are reported excluding the burner contribution.
(3) : Percentage of Total mass loss of ignited seat(%).
HR_{peak} :Heat release peak; t HR_{peak} : time to Heat release peak (s); THR : Total Heat released.
RSP_{peak} : Rate of Smoke Production peak (m^2/s); t RSP_{peak} : time to Rate of Smoke Production peak (s);
TSP : Total production of light obscuring smoke (m^2).
NR : Not reached; ND : No data available.

FIGURE 10 : Examples of Vector data for Large and Real scale tests results on railway seats:









11.4 - Main conclusions on correlation of furniture products

For furniture products, the statistical analysis was carried out with small large and real scale test results (except for toxicity) effects because the products tested in large or in real scale are the whole seat even though in small scale only one part of the seat (a constituent) was tested.

The principal results are presented below.

- **Ignitability**
  In large scale, no seat which is not vandalised ignites; only half of those that are vandalised ignite. In real scale, half of the seats which are not vandalised ignite whereas all seats, (except two), ignite when they are vandalised. Then there is no correlation between these two scales.
- **Fire growth**
  The correlation found for this type of parameter are not robust because only four seats were taken into account in the analysis (seats which ignite in large scale).
  Moreover, two products give great contribution in the analysis, C2 is a great producer of heat in real scale and in large scale, and C7 gives a great HRR in large scale.
- **Loss of visibility**
  This analysis was performed on vandalised seats, which provide a loss of visibility effect in real scale. Some correlation were found between RSP in real scale and cumulative parameters in small scale such as VOF4 and Dmax. Correlation between RSP in real scale and RSP in large scale was found. But the seats C2 and C7 are also particular as for fire growth parameters since they are also great producers of smoke in real scale.
- **Toxicity**
  For seats vandalised level 2, two seats have a particular behaviour C2 and C3 and then have a high weight on the research of correlation. No correlation can be proposed between large and real scale tests for all the seats or for all the seats (except C2) tested wherever the measurements of toxic gases are performed.

The correlation between small and real scale and between large and real scale, for furniture products are poor due to the low number of seats ignited in real scale tests. This is mainly related to the fact that the seats available in European railways are good fire behaviour products.

For furniture products, only one predictive model is available, that is, for the loss of visibility effect. This model was established with results from the ISO 5659-2 test method as for the structural products but it is not robust because it was established only with four seats.

The time when the visibility in a 40m^3 compartment and corridor space will be obscured by smoke is given by the formula :

$t_{VL} = 5.525 – 0.0015\ (VOF4)$ where VOF4 is in the range [240 – 1370]

This prediction is possible only for the 10 m^3 compartment, which has been used. It is considered as the worst case but it is impossible from these results to predict the critical effects in bigger compartments with different ventilation. For that it is necessary to use fire safety engineering tools. Actually the knowledge about these tools is not sufficient. This is why we have chosen a pragmatic approach in trying to find a relation between the small-scale tests and the critical effects in a worst case Real Scale compartment.

12 - ELECTROTECHNICAL PRODUCTS

12.1 - Products selected

Table 15 gives all the electrotechnical products selected for the small tests.

Table 15

Code	Material	Location / use	Country (supply)
PE01	FR GRUP	Sparks screen	UK
PE02	PA 6 or 6.6	Cable tie	Fr
PE03	Glass mat	Equipment support and connectors parts	Fr
PE04	GRUP	Relay	Fr
PE05	Polycarbonate (10 % glass fibre)	Connectors cover	Fr
PE06	Copper/double layer insulation/adhesive	Bus Bar	Be
PE07	Pultruded GRUP	Cable tray	UK
PE08	PVC	Cable tray	UK
PE09	GRUP	Driver's desk, cupboard wall	It
PE10	Mica paper on silicon resin	Chimney isolator; isolator panel for rheostat	It
PE11	Cotton textile and epoxy resin	Cam switch, supporting panel for electrical switch	It
PE12	Copper/polyester1/adhesive	Bus bar	Be

GRUP : Glass Reinforced Unsaturated Polyester

At this stage, one has to realise that the selected products must be considered as "high fire performance" ones, in part since they meet present tough fire requirements for electrotechnical products used for railway rolling stock.

12.2 - Tests Selected

The main objective of WP3 was to select small and large-scale test methods, taking into account the following criteria :

- The selection of tests should permit to obtain data for the 5 reaction-to-fire parameters (FIRST),
- The test methods would mainly relate to the fire scenario 2; i.e. « high temperature in an electrical equipment due to electrical defect » (see WP1 report),
- The tests were selected so that fire conditions were appropriate to the different stages (i.e. initial stage, early developing stage and developing stage (pre-flashover), and usually within an electrical enclosure.

Small-Scale Tests

The following small-scale tests and conditions were selected for use in WP4.3:

- **Ignitability:**

I.1 IEC 60695-2-1/2 Glow Wire (GWFI) [30]

Amongst common standard tests, this is probably the single one able to simulate to some extent the occurrence of a hot contact, which can be subsequent to an electrical fault such as a loose connection.

It is normally used to determine the **Glow Wire Flammability Index** (GWFI), i.e. the maximum temperature of the wire for which no flame persistence longer than 30 s is observed. In addition, the possible occurrence of flaming particles is noted.

I.2 IEC 60695-2-2 Needle Flame

With this test is associated a very low power, short duration, flame attack, as it could be caused by some intermittent electrical fault, e.g. arcing. Such a test can be seen as a screening test, with the lowest level of requirement.

According to the procedure developed in FIRESTARR[4], the key parameter to be measured is the **Minimum Ignition Time** (MIT), i.e. the minimum duration of application of the burner required to get a flame persistence.
In addition, the possible occurrence of flaming particles is noted.

I.3 IEC 60695-2-4/2 500 W burner [31]

This test was selected to simulate a medium power ignition source in the initial stage.

The obtained parameters are as follows :
- Flame persistence
- Maximum flame height
- Burnt / damaged height
- Flaming drips or not

I.4 IEC 60695-2-4/1 1 kW burner [32]

This test was selected to simulate a higher power ignition source in the initial stage.

The obtained parameters are as follows :
- Flame persistence
- Maximum flame height
- Burnt / damaged height
- Flaming drips or not

[4] Internal FIRESTARR document titled « Needle flame test according to IEC 60695-2-2 (1994) - Additional information about the procedure”

I.5 ISO 5660 Part 1 Cone Calorimeter

This test was included to simulate heat fluxes at the early developing stage (25kW/m^2) and at the developing stage (50kW/m^2).

The key parameter for ignitability analysis from the ISO 5660 Part 1 test is time to ignition (t_{ig}).

- **Fire Growth**

F.1 ISO 5658 Part 2 Lateral Flame Spread under radiant heat conditions (50kW/m^2 exposure at hot end of specimen).

The key parameters for analysis from the ISO 5658 Part 2 test are:

- Heat for sustained burning (QSB), which provides a measure of flame-spread rate.
- Max flame spread distance (Xmax) and critical flux at extinguishment (CFE)

F.2 ISO 5660 Part 1 Cone Calorimeter

This test provides data on rate of heat release and total heat released at both 25kW/m^2 and 50 kW/m^2.

The key parameters for analysis concerning heat release are:

- Max heat release rate (q max),
- Heat release rate (q) as mean over t_{ig} to t_{ig} + 180s (q_{180}) and t_{ig} + 300s (q_{300}),
- Total heat release (THR).

- **Smoke Opacity**

S.1 ISO 5660 Part 2 Cone Calorimeter (Dynamic Test)

This test provides data on rate of smoke generation and total smoke released over maximum 32 minutes. It was operated at both 25kW/m^2 and 50 kW/m^2 heat flux levels.

The key parameters for analysis from the ISO 5660 Part 2 test are:

- Total smoke produced using specific extinction area (SEA),
- Max extinction coefficient (k_{max}).

S.2 ISO 5659 Part 2 Smoke Chamber (Cumulative test)

This test was used under IMO conditions (25 and 50kW/m^2) to obtain data on smoke generation over 10 minutes.

The key parameters for analysis from the ISO 5659 Part 2 test are:-

- Smoke Density after 10 minutes (D_s10) and D_{max} for all 3 heat flux conditions.
- Smoke Density/time graphs.
- VOF4 index, which takes into account the rate of smoke generation in the first 4 minutes.

- Toxic Potency

T.1 NFX 70-100 Tubular Furnace Test (UITP E6)

This test was used under the conditions listed below:
- 2 temperatures: 400 and 600 °C
- air flow: 2 l/min.

T.2 DIN 53436 Travelling Furnace Test

This test was used under the following conditions:
- 2 temperatures: 400 and 600 °C
- air flow: 2 l/min for primary air flow and 8l/min for secondary air flow.

For both methods the gases analysed were: CO, CO_2, HCN, HCl, HBr, HF, NOx, SO_2, Formaldehyde and acrolein (Same analytical methods as the one used for structural products).

Large-Scale Tests

Prior to the choice and design of large-scale tests for electrotechnical products, it was decided to split these products in two sub-groups : linear products and the others.

The linear products have to be considered apart from other electrotechnical products due to their size and geometry, their location (normally not, or only partially, in an electrical cabinet) and the fire hazard possibly associated with them.

This part of the work has been restricted to linear products since, for other electrotechnical products (i.e. products mainly mounted in electrical cabinets), the differentiation between large and real-scale is meaningless.

For linear products, a large-scale, a ladder test was designed based upon PrEN standards (prEN 50264 [33] and prEN 50266-2-4 [34]) and appendix 5 of the FIPEC book [35].
The test method was modified and improved mainly as follows :
- Fire source : a heating program has been defined, with 3 steps (1 kW – 10 kW – 30 kW). At each step corresponds a level of fire source. The latter have been chosen to simulate the early stages of a fire due to an electrical fault and a starting fire of cables installed in the tray (values obtained from the WP7 report of the FIPEC project),
- Measurement of HRR and smoke release, according to measurement procedure developed in FIPEC,
- Mounting of the specimen,

(see figure 11).

In addition, the concentrations of a few gases were measured via sampling probes attached onto the exhaust duct.

Real-Scale Tests

RS1 Real scale test for linear products

The real-scale tests must permit to test some of the selected products in end-use conditions (as far as possible). Their results should be used to validate the results of small-scale and large-scale tests.

The developed test method is close to the one used for large-scale test, with consideration given here to the actual mounting conditions. The cable tray was mounted between calcium silicate boards, in order to simulate a cable tray installed between walls or under floor, above ceiling. The possible presence of an air gap was also considered (see figure 12)

RS2 Real scale test for non linear products

For these products, the initial objectives were considered as difficult, if not impossible, to meet since any correlation study requires that the same material / product is tested at the different scales. For the considered products, any fire (even at early stages) would rapidly involve a few components and, therefore, real-scale tests performed on a single material would be meaningless.
In addition, the real-scale tests should be designed to test a complete product and/or composite or to simulate a critical part of a vehicle.

Therefore, a mock-up of an actual electrical cabinet was designed according to the drawings of one type of equipment found on high speed French trains.
A few tests were performed, each time with a number of one type of component including, as one of its parts, a selected FIRESTARR material. Those tests provided data on fire start and growth as well as possible fire effluents for one selected electrotechnical products. In addition, the tests permitted to determine, for the selected mounting conditions, which combination ventilation / fire location and orientation can lead to a fire spread, when the latter was observed.

Two different fire sources were used :
- a high temperature, one spot, flame simulating a electrical fault;
- a diffusion flame simulating neighbouring components in fire,

each time with a different location and/or direction (considering possible location of electrical faults and the results of a few preliminary tests).

The figure 13 gives the layout of these tests.

12.3 - Test Results

Small-Scale Tests

12 electrotechnical products were tested in WP4.3.

The complete results for the WP4.3 tests are stored in the FIRESTARR database and reported in WP4.3 report [36].

- **Ignitability:**

The needle flame tests did not enable to discriminate ignition performance for the selected products. A similar conclusion was found for the Glow wire. However, the latter can be more appropriate, if the GWTI (Glow Wire Temperature Index)[5] would be considered instead of the GWFI.

The 500 W and 1 kW burner tests can be severe enough to discriminate some products.
The most pertinent criteria is probably the occurrence of flame persistence.

The Cone Calorimeter was found also to be a valuable tool for assessing the ignitability of electrotechnical products but simpler methods could be sufficient when only ignitability data are needed.

Table 16 gives an example of a possible classification (pass/fail)[6] with the 500 W burner test.

Table 16

Product	Flame height mm	Flame persistence (s)	Flaming droplets	**Pass/Fail**
PE01	80	1	No	Pass
PE05	125	2	No	Fail
PE10	0	-	No	Pass
PE11	115	2	No	Pass

- **Fire growth**

For flame spread, the ISO 5658-2 method can provide data for some electrotechnical products ; i.e. those products with a flat area wide enough to render such a test meaningful.

The Cone Calorimeter proved to provide valuable data for most electrotechnical products, in terms of Heat release. The selected products being rather « high fire performance » ones, it is suggested that the higher the external heat flux, the better the repeatability (and the discrimination of the materials).

The table 17 gives typical values obtained at 50 kW/m² with the Cone Calorimeter.

[5] Acc. to IEC 60695-2-1/3
[6] with the following requirements : the flames may not reach the 125 mm mark and the flame persistence is not longer than 2 s.

Table 17

	Code	q_{max} (kW/m²)	q_{180} (kW/m²)	q_{300} (kW/m²)	THR (MJ/m²)
Non linear products	PE01	85	58	58	23.6
	PE03	182	110	90	39.7
	PE04	141	98	95	39.1
	PE05	243	197	179	98
	PE10	9.4 (1)	0.9 (1)	1.5 (1)	12.5 (1)
	PE11	212	122	129	138
Linear products	PE07	284	198	146	56
	PE08	163	68.5	67.8	52.4
	PE09	159	88	89	35.5

(1) For 2 specimens out of 3, HRR values = 0

- **Smoke**

For the selected test methods, the Cone Calorimeter is an appropriate tool to discriminate the products in terms of smoke release in a dynamic mode, while the single chamber smoke test ISO 5659-2 corresponds to a cumulative measurement. The latter permits to evaluate the products under different fire conditions. Examples of results are given in Table 18.

Table 18 : Smoke (static) results according to ISO 5659-2

	Code	**25 kW/m² with pilot flame**			**25 kW/m² without pilot flame**			**50 kW/m² without pilot flame**		
		Ds_{10}	D_{max}	VOF_4	Ds_{10}	D_{max}	VOF_4	Ds_{10}	D_{max}	VOF_4
Non linear products	PE01	42	50	10	59	71	10.3	100	107	328
	PE03	165	173	87	378	407	49	217	276	313
	PE04	196	473	61	234	324	78	549	583	394
	PE05	73	73	3.7	41.3	41.3	5	818	803	759
	PE10	1	0.7	2	1	0.7	1.3	3.3	2.7	1.7
	PE11	166	163	19.5	156	156	13.0	577	564	524
Linear products	PE07	630	714	13.7	240	522	17	846	913	1322
	PE08	741	903	163	501	531	188	619	786	1595
	PE09	123	252	20.3	126	128	12.3	252	282	389

Large-Scale tests

Two linear electrotechnical products (cable trays) were selected for test in WP7.3, after a brief analysis of the small-scale test results.
Due to the very limited number of products tested at large-scale, no extensive correlation study (small-scale versus large-scale) was possible. Nonetheless, the large-scale tests were needed to obtain data to validate, for the complete products or composites, the fire-test response-characteristics based on the small-scale test results analysis.

For the two products, the specimen had a size LxWxH = 2000x300x50 mm.

Table 19 gives some of the most significant measured parameters.

Table 19 : scalar results obtained at large-scale tests

Test	Tig (s)	RHR Peak kW	RHR Time to Peak (s)	FIGRA (SBI) W/s	THR MJ	SPR Peak m^2/s	SPR time to Peak (s)	TSP m^2	Burnt height mm
PE07/2	237	157.2	543	228.1	43.1	0.443	573	127.5	2000
PE08/1	267	35.9	522	9.9	15.4	0.645	351	156.9	500

It should be noted that the two tested products performed definitively at different levels, as opposed to what was measured at small-scale tests. This is explained by the inability of the latter to simulate the actual behaviour of the end-use products under fire conditions.

None of the products exhibited fire growth for the first step of the heating programme, i.e. a premixed 1 kW flame. For PE07, the fire spread was obtained even with the 10 kW burner.

Examples of the test results obtained on HRR and smoke production are shown in Figures 14 and 15.

Real-scale Tests

RS1 Linear products

The same two products were tested at real-scale test, in similar conditions, with consideration to the actual mounting conditions of this type of products. Tests were performed in a “void” configuration, i.e. with the products mounted between two boards simulating walls or bulkheads (or ceiling/roof, floors), with and without an air gap.

Table 20 gives a summary of important results.

Table 20

Test Nr	Air Gap (Y/N)	Tig (s)	RHR Peak kW	RHR Time to Peak (s)	FIGRA SBI kW/s	THR MJ	SPR Peak m^2/s	SPR time to Peak (s)	TSP m^2	Burnt height (mm)
PE07/1	N	225	86.3	620	86.4	28.9	0.397	761	64.3	2000
PE07/3	Y	195	159.3	465	257.5	45.2	0.35	501	48.4	2000
PE08/2	N	222	62.5	738	40.73	21.6	2.177	699	551	2000
PE08/1	Y	225	35.4	582	44.44	17.8	1.151	360	201.3	N.D.

N.D. : Not Determined (due to melting)

These results confirm the difference of fire performance observed between the two products when tested at large-scale. The presence of boards simulating walls renders the test more sensitive, but not very significantly.

The presence of an air gap has opposite effect on the two tested products : the peak of HRR is higher and comes sooner with an air gap for PE07; some flame spread is observed for PE08 only without air gap.

The real-scale tests gave a confirmation that for such products, only large-scale (or real-scale) tests permit to take the flame spread and the actual behaviour of the end-use product into account.

Examples of the test results obtained on HRR are shown in Figure 16.

RS2 Other products (electrical cabinets)

A number of tests were performed in the mock-up of an electrical enclosure, with a few relays mounted[7]. Each test was defined by a set of conditions including the type and power of fire source, the number and mounting of the components and the ventilation through the cabinet.
The table 21 gives a summary of the test conditions.

Table 21 : Test conditions

Test Nr	Burner		Components (relays)	Ventilation (m/s)
	Type	Power (kW)		
Cab/1	Premixed	1	4x4	< 0.05
Cab/2	Premixed	1	2x7	< 0.05
Cab/3	Premixed	1	2x7	≅ 0.5
Cab/4	Premixed	1	2x7	≅ 0.5
Cab/5	Diffusion	2.5	4x4	≅ 0.5
Cab/6	Diffusion	2.5	4x4	< 0.05

Prior to any comment or conclusion, it matters to highlight some important limitations of the tests, which were performed.

- The cabinet itself (the enclosure) was built only with non-combustible materials whereas this actual cabinet normally includes 2 “combustible” walls.
- For the tests, the cabinet was filled only with a few specimens of one single type of component (a relay). As a consequence, the potential fire load was probably less that one tenth of the one of an actual electrical cabinet.
- Only a few combinations of fire source and locations, together with given levels of ventilation, have been checked.

In the conditions of the tests, no real fire growth was observed. Only for the test NR 5 and 6, i.e. with the diffusion burner, a limited flame spread occurred, with subsequent low values of heat release. This was expected, for the op cit. reasons.

Table 22 : main results for the tests for which limited fire spread was observed

Table 22

Test nr	Tig (s) (1)	Flame persistence (s)	Max. Flame height (cm)	Nb of relays involved (2)	RHR Peak kW	RHR Time to Peak (s)	THR MJ	SPR Peak m²/s	SPR time to Peak (s)	TSP m²	Max T° °C
Cab/5	N.D.	420	57.5	12	4	452	1.5	0.107	443	32.3	164.5
Cab/6	N.D.	426	57.5	12	6.9	491	2.8	0.16	485	40.8	170

[7] One main combustible constituting part of this relay was one of the selected Firestarr materials.

While real-scale tests on electrotechnical products including a single type of component have proved to be of only limited value, it was confirmed that no real-scale test on electrotechnical products can involve a single material, even at the early stages.
Further study is certainly required to gain better knowledge of the phenomena leading to the fire initiation and growth in an electrical cabinet.

Considering the FIRESTARR work for electrical cabinets, and in order to give some basis to CEN to introduce a fire classification of such products, a process in two steps is suggested :

- A classification of electrotechnical products upon basis of small-scale tests performed on their constituting materials. The most appropriate tests would be selected considering the conclusions given in WP 4.3 report. A possible classification system is detailed in WP 6 report.
- At a later stage, such a classification would be further validated. For this validation, a standard mock-up cabinet is used (e.g. the one used in FIRESTARR). In this cabinet are mounted actual components build with materials meeting the fire requirements expressed in the future EN 45545 part 2. The mock-up in installed in an “intermediate” scale hood (e.g. SBI one) permitting to measure HRR and SPR. In those conditions, and with an appropriate fire source, it is checked that the fire growth does not reach unacceptable levels. The choice of the scenario (e.g. fire source, ventilation,..) must be related to the hazard level, i.e. the category of vehicle in which those components are normally installed.

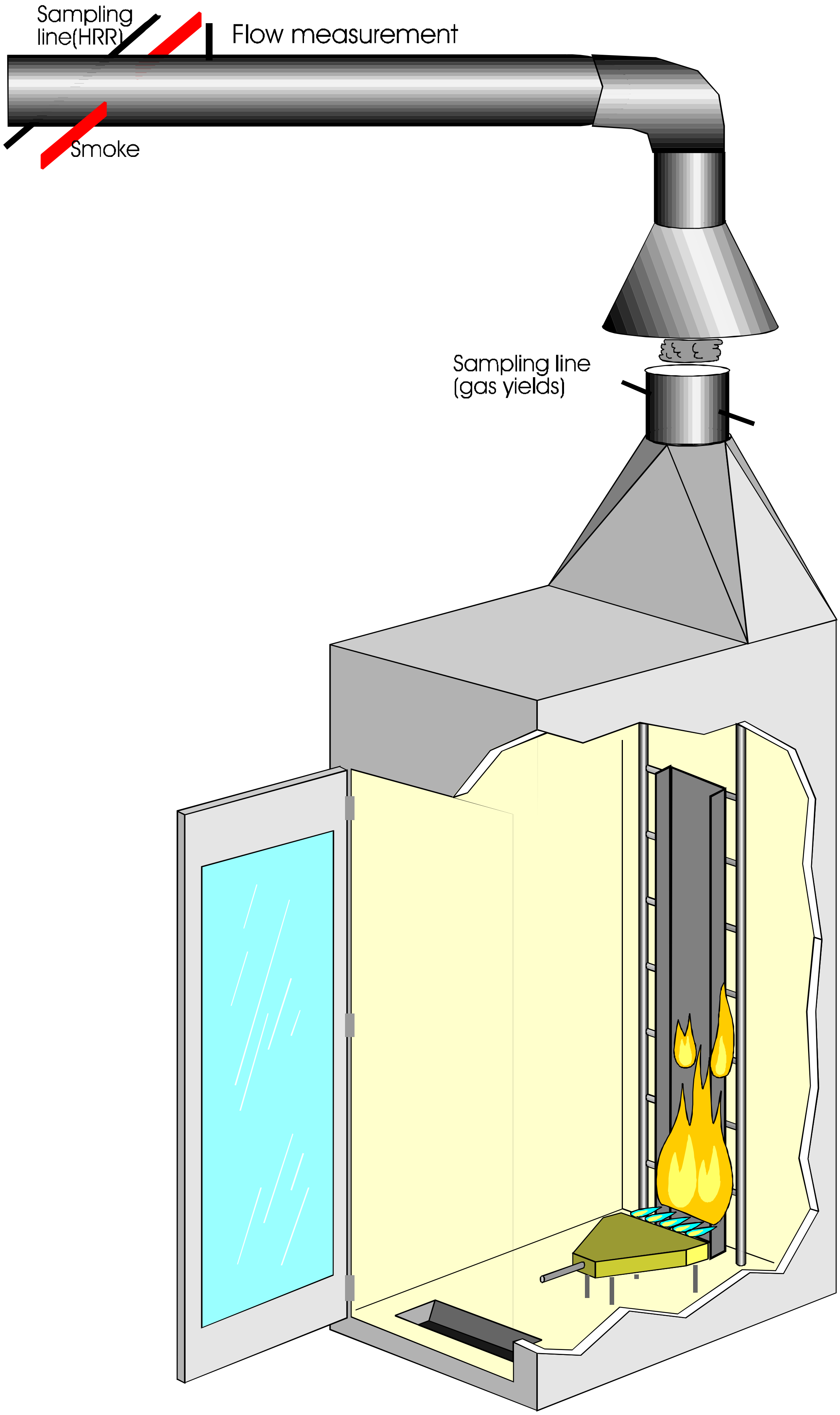


Figure 11 : Large-scale test for linear products

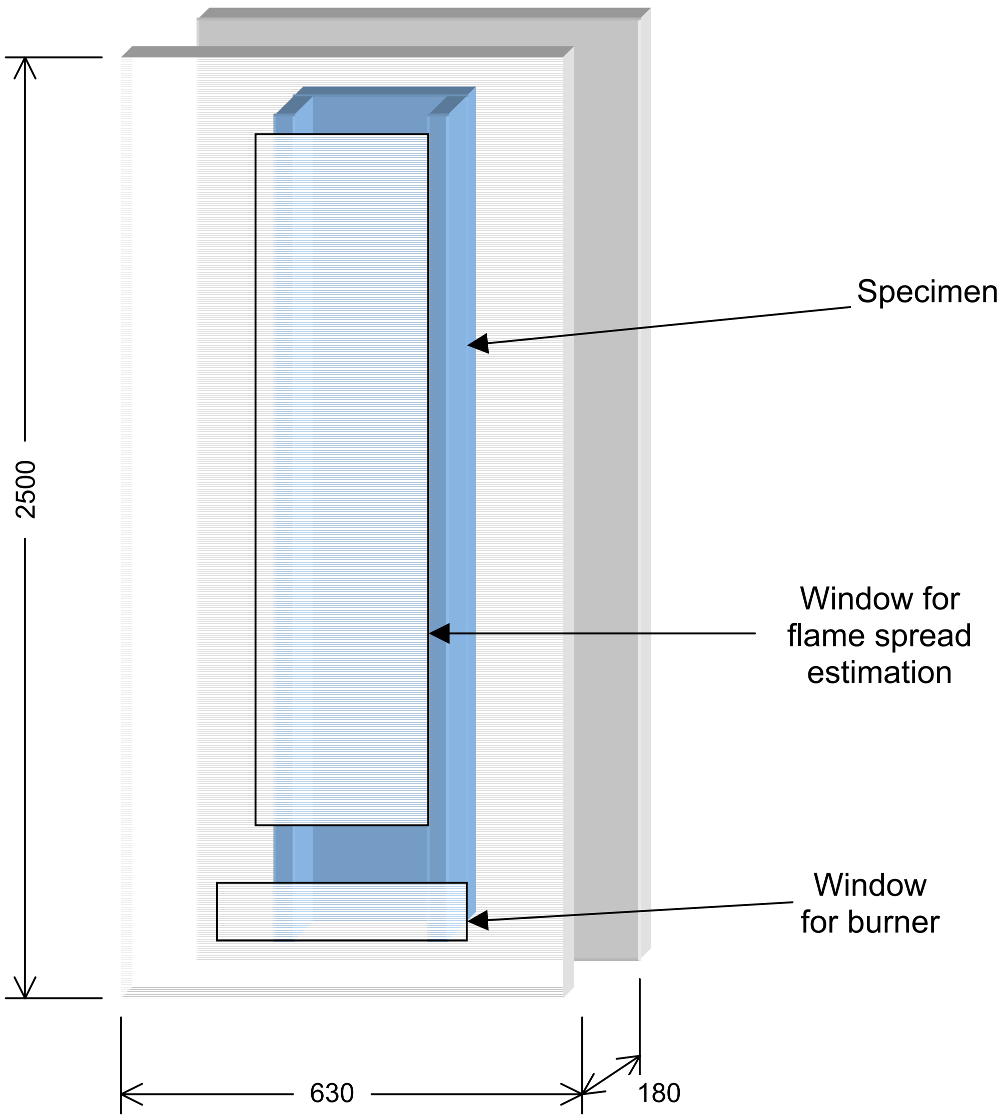


Figure 12 : layout of specimen mounting for real-scale tests on linear products

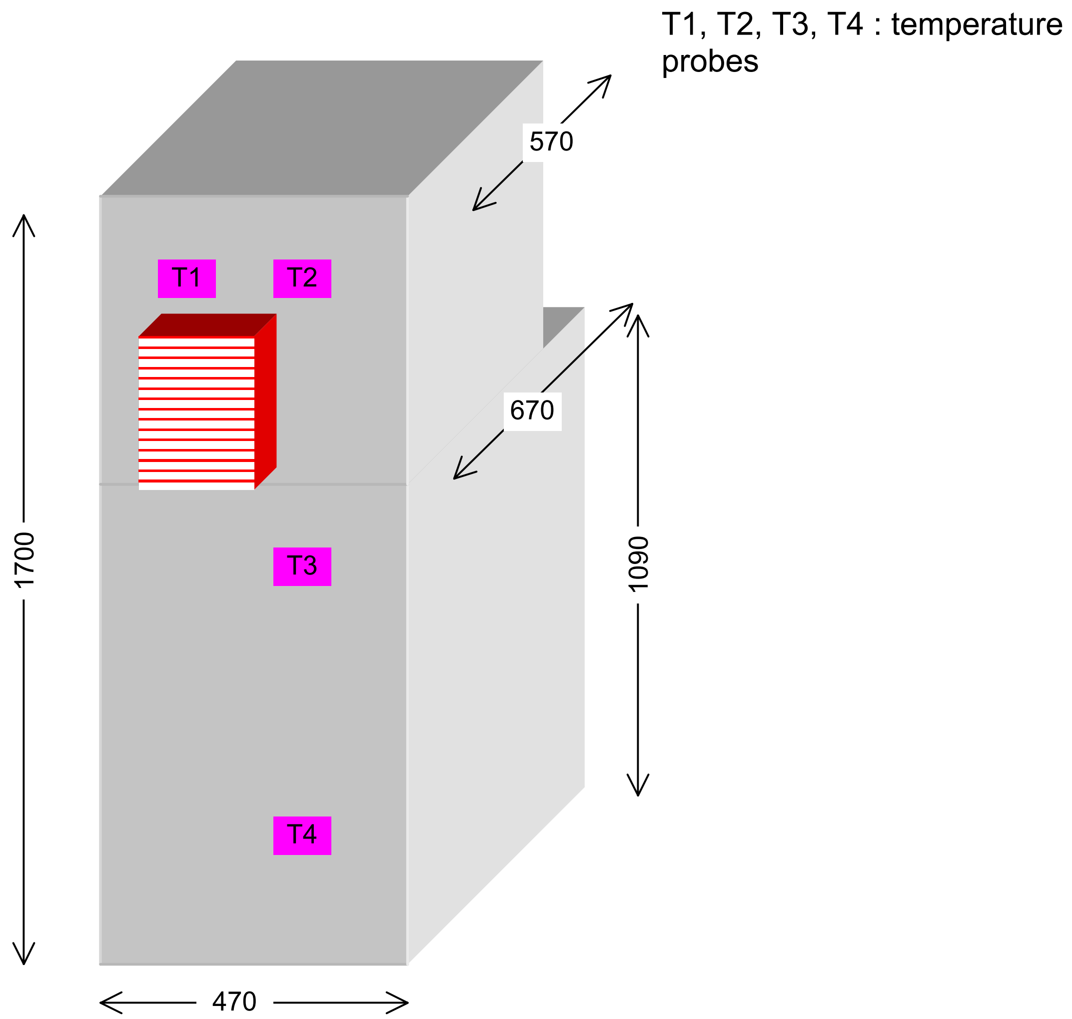


Figure 13 : Mock-up of the electrical cabinet for the real-scale tests

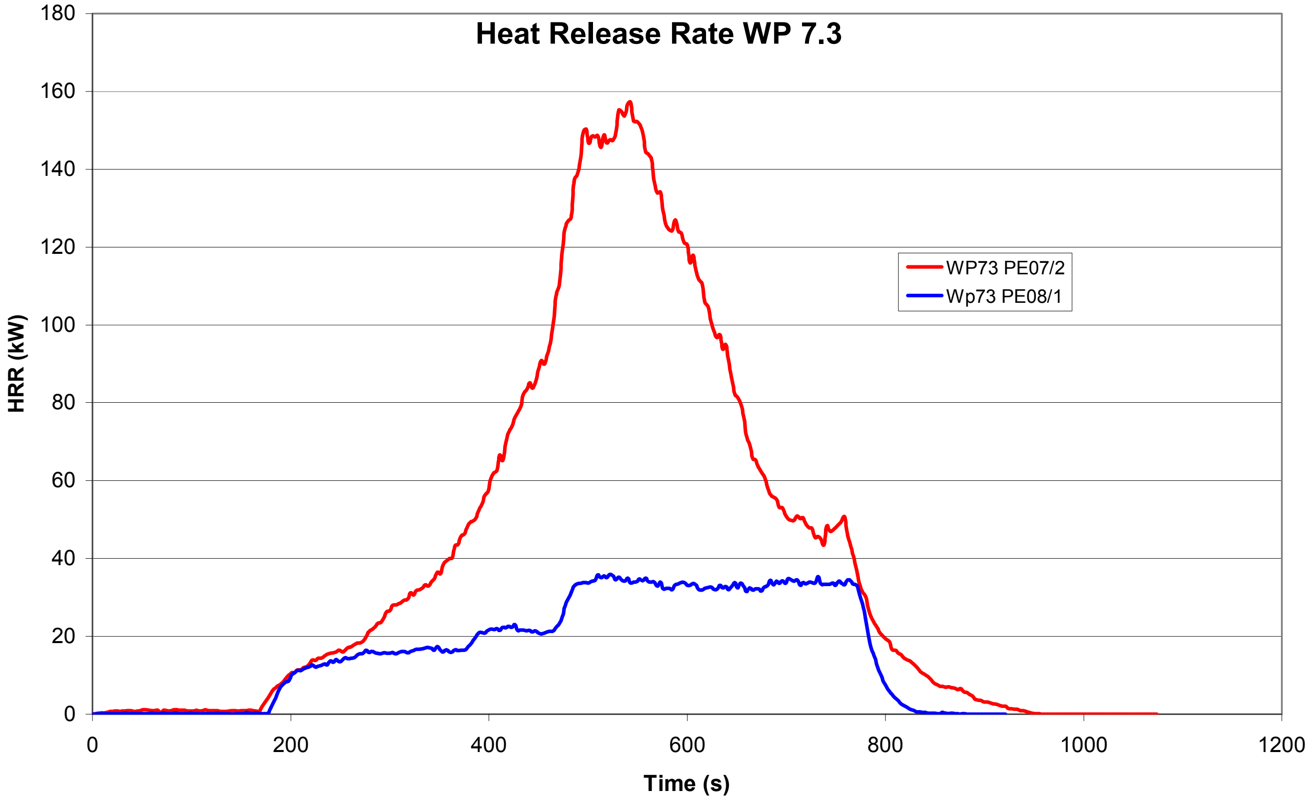


Figure 14 : examples of HRR measured for linear products in large-scale tests

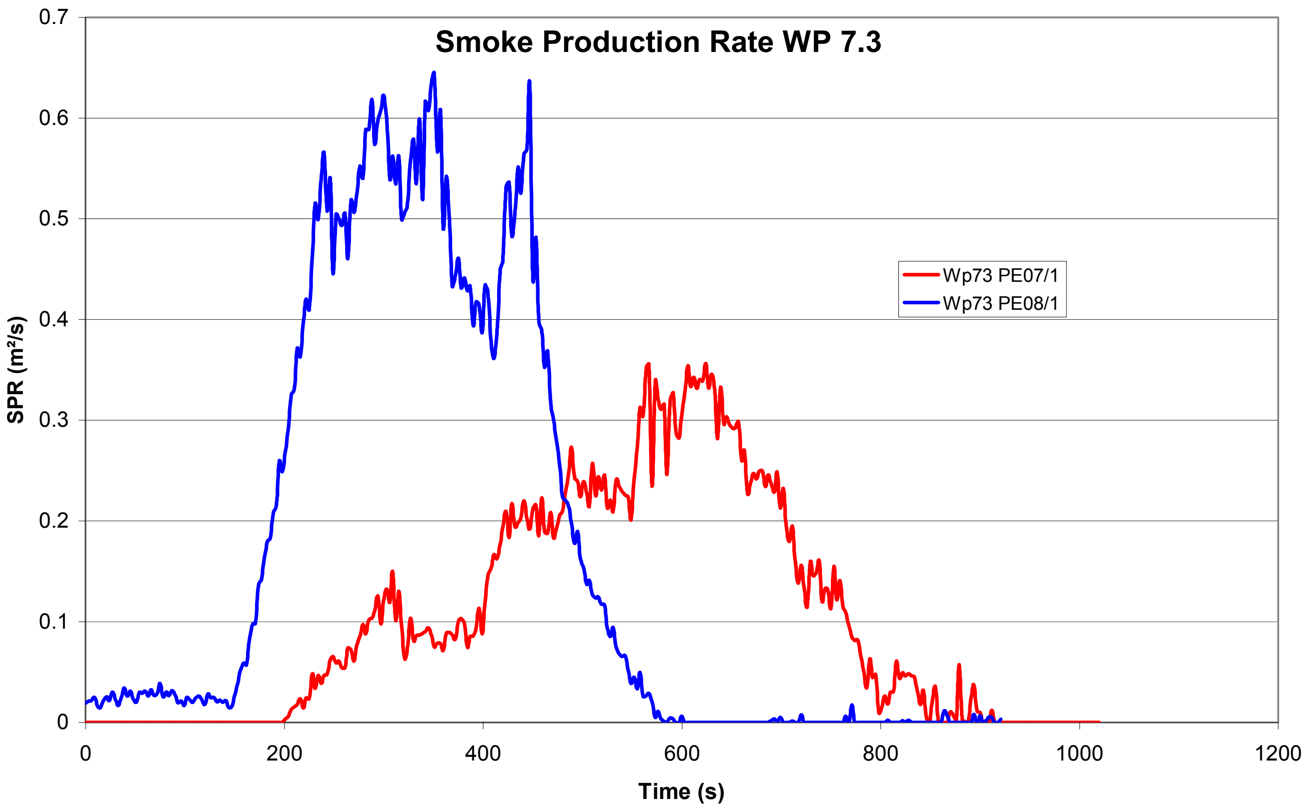


Figure 15 : examples of SPR measured for linear products in large-scale tests

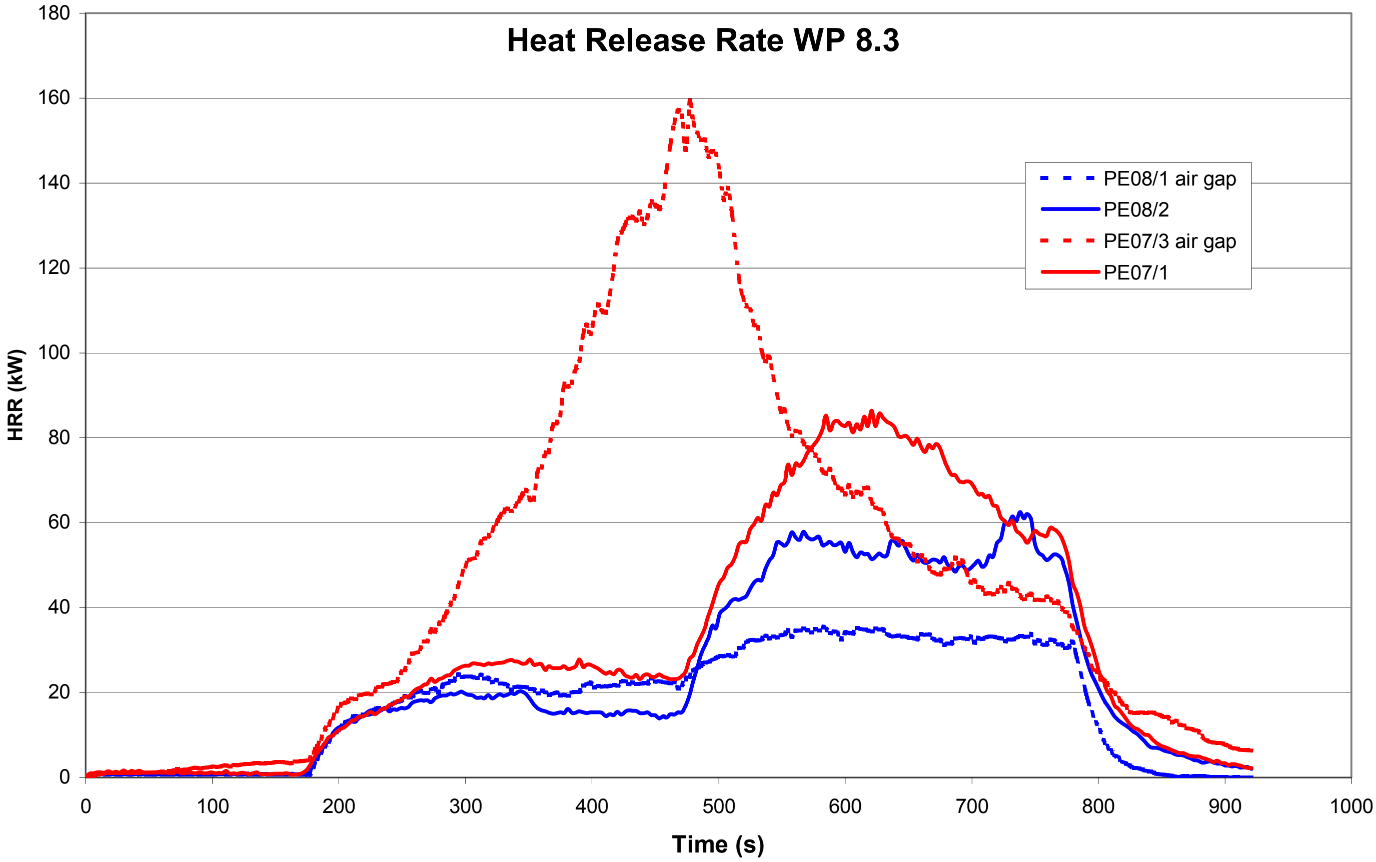
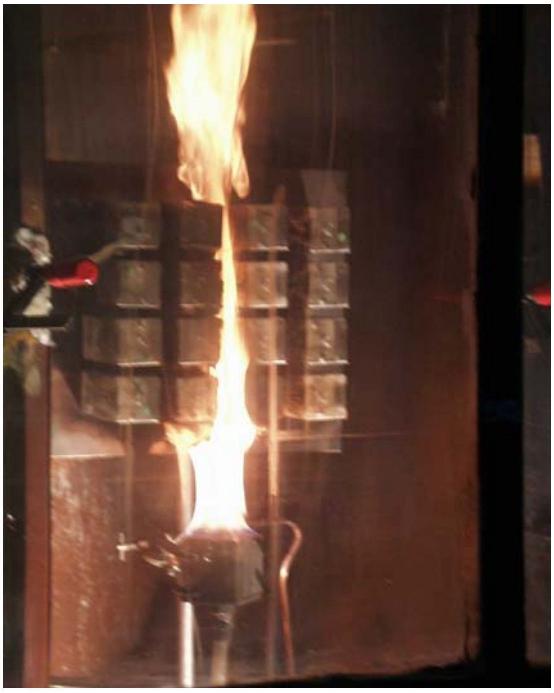


Figure 16 : examples of HRR measured for linear products in real-scale tests



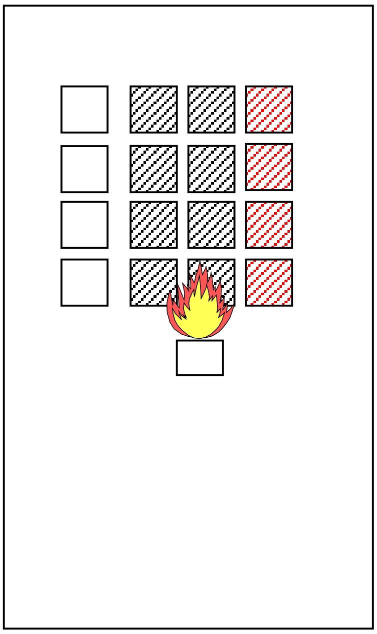


Figure 17 : test nr 6 (electrical cabinet)

Figure 18 : result of test nr 6 (electrical cabinet)

12.4 - Main conclusions on correlation

There is not enough results for electrotechnical materials in real scale to deal with them.

13 – Toxic potency in small scale

The statistical analysis carried out in order to compare the two small scale test methods does not allow defining strong correlation between them. The analysis has been performed in two steps : all materials together and per type of material.

Classification trees have been drawn and the following limits of classes have been defined :

- UITP test method : 4 classes
- Class 1 : number of material 25 – limits : [0.00227 - 0.04433]
- Class 2: number of material 28 – limits : [0.04757 - 0.12135]
- Class 3 : number of material 7 – limits : [0.13868 - 0.18931]
- Class 4 : number of material 3 – limits : [0.30120 - 0.35720]

- DIN test method : 4 classes
- Class 1 : number of material 36 – limits : [0.0025 - 0.03326]
- Class 2 : number of material 19 – limits : [0.03906 - 0.09535]
- Class 3 : number of material 6 – limits : [0.13329 - 0.25024]
- Class 4 : number of material 2 – limits : [0.37275 - 0.39602]

Note : The statistical analysis on repeatability of the test methods has been carried out only on the UTIP test method as the DIN method considers only one combustion. It was decided in the test protocol that for a deviation in the results of more than 20% compared to the mean a new combustion has been realised. The statistical analysis allow to conclude of a satisfactory repeatability for the UITP test method.

14 - PRINCIPLE FOR A CLASSIFICATION PROPOSAL

The objective of WP6 was to propose a classification system to categorise the fire performance of railway products (structural, furniture and electrotechnical). This system based mainly on small-scale tests needs to be correlated with the requirements of CEN/TC256 and the fire hazard levels (HL) in prEN 45545-1 and also needs to be validated by the FIRESTARR Group using real-scale tests.

It is possible to address the fire safety objectives of CEN/TC256 and the European railway industries by identifying certain fire critical effects (FCE), which are related to these main parameters. A fire critical effect may be interpreted as a criterion to establish a classification system. Products which contribute in fires so that they cause these fire critical effects should be down-graded in the classification. When considering individual fire critical effects, it should be understood that test data about more than one parameter has often to be considered in order to assess satisfactorily a fire critical effect. The following fire critical effects may be considered as important for the development of a reaction to fire classification system for railway products; the relevant fire parameters are marked against each FCE:-

- Initiation of fire (FI).
- Uncontrolled fire growth (represented by a substantial increase in heat release and area burning), which is usually termed the Flashover point, occurring within a railway compartment (FIR).
- Loss in Visibility (relatable to smoke opacity) as assessed by the inability of passengers to find an escape route in and outside a railway compartment (FIRS).
- Lethality effects on passengers within and outside a railway compartment where the fire has started due to toxic effluents (FIRT).

It was the intention of WP6.1 to link the fire performance measured in small-scale tests to a specification proposed by the JWG for the above FCEs in a small compartment (≤ $10m^3$). It is not possible within the scope of the present WP6.1 to directly link the fire performance of small-scale tests to FCEs in larger compartments (i.e. > $10m^3$); however, the small compartment of $10m^3$ may be regarded as a worst case scenario and hence, it may serve as the model for a classification proposal to be extended to larger volume compartments.

Based on the CEN/TC 256 definitions of 4 railway operation categories, which are associated with different hazard levels, the following principles of a classification system were developed:

- A classification matrix can be specified to recognise the different risks associated with these applications: i.e. Class A could be used for HL2, 3 and 4 (with underground or tunnel operations), Class B for HL1 (non-underground or non-tunnel operations) and Class C for low risk, limited use applications only. Different suffixes would be associated with these according to the application, e.g.
  - Classes A(S), B(S), and C(S) for structural products
  - Classes A(Fl), B(Fl) and C(Fl) for Flooring products
- Acceptable levels of performance would be represented by reference to the above fire critical effects (FCE) determined from:
  - intermediate–scale or large-scale tests
  - real-scale tests

The level of fire critical effects (FCE) which are considered to be hazardous to passengers and their connection to dwell times (i.e. escape times to places of relative and ultimate safety) have been defined by CEN JWG and by modelling studies.

The selection of classification criteria for the FCE's has been based on the correlation studies carried out in the FIRESTARR project for the three main areas of the products; i.e. walls and ceilings, seats and electrotechnical products. The four key FCEs for each range of products were examined against the most discriminating test parameters so that the best choice of criteria could be introduced into the classification proposals.

Initial proposals for classification of test parameter data for structural products (wall and ceilings), floorings, furniture (seats) and electrotechnical products are given in Tables 23 to 27.

15 - RECOMMENDATION FOR CLASSIFICATION SYSTEM

15.1 - Structural products

For structural (walls and ceilings) products, the recommendations concern the selection of test methods and the test conditions are given in Table 23.

Table 23: Test methods and conditions used for classifying structural products (walls and ceilings)

Parameter	Test Method	Test Conditions
FI	ISO 5658-2 ISO 5660-1	Heat flux gradient 50 to 1.5kW/m^2 Heat flux of 50kW/m^2
R	ISO 5660-1	Heat flux of 50 kW/m^2.
S	ISO 5659-2	Heat flux of 50 kW/m^2 (without pilot flame)
T	ISO 5660-1 UITP E6	Mass loss measurement at 35 kW/m² 400ºC

The criteria to use with these test methods are detailed in the annex A (see also WP 6.1 report)

For structural (flooring) products, the recommendations concern the selection of test methods and the test conditions are given in Table 24.

Table 24: Test methods and conditions used for classifying flooring

Parameter	Test method	Test conditions
FI	Pr EN ISO 9239-1 ISO 5660-1	Heat flux gradient 11 to 1 kW/m² 25 kW/m²
R	ISO 5660-1	25 kW/m²
S	ISO 5659-2	25 kW/m²
T	UITP E6	400 °C or 600°C

For floorings, the proposal for test methods are based on the analysis of results obtained in small scale and also information coming from the EN work for building products. The proposed criteria are given in annex A.

15.2 - Furniture products

For furniture products, the test recommendations are listed in Table 25. The proposal includes the small scale test ISO 5659-2 as an option for measuring cumulative smoke opacity. However, for composite products such as seats, the large scale furniture calorimeter is the preferred test since it allows the measurement of all FIRST parameters and especially permits the products to be tested under its end-use conditions. The proposed criteria are given in annex B.

Table 25: Test methods and conditions used for classifying furniture products (seats and mattresses)

Parameter	Test method	Test conditions
FIRST	NT Fire 32 Furniture calorimeter	Burner according to prEN 1021-4 (equivalent to 100g paper) with and without vandalism Gas analysis in the duct
S	ISO 5659 – 2 *	25 kW/m² with and without pilot flame and 50 kW/m² without pilot flame

* Optional

15.3 - Electrotechnical products

For electrotechnical products , the tests proposed are given in Tables 26 and 27. Since only a small number of electrotechnical products could be examined in this project there can be little validation of the proposals. The proposed criteria are given in annex C.

Table 26: Test methods and conditions used for classifying linear electrotechnical products

Parameter	Test method	Test conditions
FIRS	Modified Pr EN 50266-2-4	Burner at 1, 10 and 30 kW/m²
T	UITP E6	600 °C

Table 27: Test methods and conditions used for classifying other electrotechnical products

Parameter	Test method	Test conditions
FI	IEC 60695-2-1/2 IEC 60695-2-4/2	Glow wire 500 W flame
R	ISO 5660 –1	50 kW/m²
S	ISO 5659-2	25 kW/m² with and without pilot flame and 50 kW/m² without pilot flame
T	UITP E6	600°C

16 - COMPARISON WITH NATIONAL CLASSIFICATION

16.1 - FIRESTARR classification

According to the requirements given by CEN TC 256 JWG, the proposal classification defined in the FIRESTARR research is shown in WP 6.1 Report [37].
Test methods and conditions listed in the above Report derive from the selection in WP3 (see WP3.1; Wp3.2 and WP3.3).
The FIRESTARR classification divides the materials into three important categories:

- structural materials
- furniture materials
- electrical materials

and for each category (and in some cases for each type of component) it provides the test method to evaluate all the parameters of the fire behaviour. Afterwards on the basis of the determined values it classifies the material/component in three categories (A,B,C,).

16.2 - French classification

The actual classification used by French regulations for the classification of fire behaviour of materials/component is described in:

- NF F 16101: “Rolling stock – Fire behaviour – Materials selection” [38].
- NF F 16102: “ Rolling stock – Fire behaviour – Materials selection – Application for electrical equipment” [39].

This classification regards substantially three vehicles categories.

The standard provides the classification of the material by “reaction to fire” and “smoke” (combination of smoke emission and toxicity). The product of the above parameters gives the “risk index” .
For the reaction to fire performance the parameters taken into account are:

- flammability
- flame spread
- max flame length
- combustibility

“The reaction to fire tests” classify the material/product into one of six categories: from M0 to M5 and are obtained from combination of the parameters measured.
The principal test used in this standard is the “epiradiateur”. According to NF P 92501 [40] both for rigid and flexible materials more than 5 mm thickness are evaluated. NF P 92503 [41] is used for flexible materials with thickness up to 5 mm. If dripping is noted in the above tests, NF P 92504 [42] and NF P 92505 [43] test (rate of flame speed) are used.
A complementary test for floor covering is the radiant panel test NF P 92506 [44] which is used only if in the primary test (NF P 92501 and NFP 92503) the material does not obtain the M1 or M2 classification. The NF P 92510 [45] test (calorific potential) is used to give materials classified in M1 class (below NF P 92501) the M0 class (if the heat of combustion is less than 2500 kJ/kg).
The complete seat are evaluated using the test method in UIC 564-2. Components of the seats are also evaluated (separately) for toxicity and smoke opacity.

For small specimens, two tests are used : Oxygen index (NF EN ISO 4589-2) [46] and glow wire test . These tests classify the materials into five classes: from I0 to NC (I5). The same tests are used for the electrical materials as described in NF F 16 102.

Concerning “smoke” parameter, as described in the standard, this is obtained from the combination of “smoke emission” and “toxicity index”. The first one is evaluated by the NF X 10 702 [47] (Smoke Density Chamber) and the second one with NF X 70100.
According to NF 16101, the combination of these two parameters gives the “smoke value” with classes from F0 to F5.
The French standard gives a complete set of allowable pass criteria by using 18 matrices. Each grid is available for a specific material/component with three classes:

- acceptable
- acceptable with agreement of user
- not acceptable.

16.3 - German classification

The German Standard for the test procedures and classification of materials and components for the fire behaviour and fire effluents is DIN 5510 Part 2 [48].

The following parameters are defined to classify the fire behaviour of materials and components (both for external parts of car body and for internal materials):

- Combustibility
- Smoke development

Test specimens have to meet end-use requirements.

For the combustibility classification there are five categories defined from S1 (only for small item) and S2 to S5 (all materials and components) and from SF1 to SF3 for floor coverings.

Category S1 is determined by DIN 53 438 (part 1-3) [49] " Testing of combustible materials; reaction to a flame of a burner; edge and surface flame action". The combustibility category from S2 to S5 is obtained using DIN 54837 [50] "gas burner test". By this test smoke development and dripping will be evaluated too.
The categories SF1 to SF3 for floor coverings are obtained using the test DIN 4102 [51] with evaluation of "critical radiation intensity" and smoke emission.

There are two "smoke development" categories: SR1 and SR2 by evaluating the integral of light attenuation.

For "dripping" category there are only two levels: ST1 and ST2

The seats (original seats with complete equipment) are submitted to a paper cushion test according to the DIN 54 341 [52] test and the supplementary conditions given in DIN 5510-2 and TL 918433 [53] (similar to UIC 564-2 annex 13). Seats which are used in operation category 2 (see prEN 45545-1) have to be tested slashed additionally (vandalism).

The DIN standard gives in a complete table the minimum requirements of the three parameters for each material and component depending on 4 operation categories .

16.4 - British classification

The British classification is in accordance with BS 6853 [54] "Code of practice for fire precautions in the design and construction of passenger carrying trains".
This classification regards essentially three vehicles categories:

- Category Ia and Ib (underground)
- Category II (surface)

In this Standard each material (except mass loss materials and seat components) is classified by their position on the vehicle.

The most important classification regards all the materials/item with important surface (both interior and exterior of vehicle). For these are provided 3 positions:

- Horizontal prone "ceiling-like" (HP surface)
- Horizontal supine "floor-like" (HS surface)
- Vertical "wall-like" (V surface)

Further types of material which cannot be incorporated into the surfaces classification are classified as follows:

- minor usage materials(L surface)
- textiles and mattresses
- seats (seat trim and seat shell)
- cables

The fire behaviour parameters evaluated by the British Standard are:

- ignitability (not for all materials)
- spread of flame
- heat release (using BS476 part6)
- smoke opacity
- smoke toxicity

For the exterior and interior horizontal (supine) surfaces the above parameters are evaluated by BS 476-7 [55] (surface spread of flame); smoke density by a 3 meter cube chamber according to Annex D of the standard and smoke toxicity by the test method described in the Annex B of the above Standard.
The determination of the weighted summation of toxic gas is obtained by two different methods:

- The first one is available for the "minor use material" and is based on the mass of the material using NF X 70-100,
- The second one is available to the "surfaces" materials, seat and mattress using prEN 2825 [56] and 2826 [57] (using the cone calorimeter ISO 5659-2 apparatus at 25kW/m²).

Moreover the standard gives in annex C some information about heat release evaluation without giving any limit.

16.5 - Italian classification

The actual classification used for Italian regulations for the fire behaviour of materials/component is described in the standard UNIFER PrE10.02.977.3 [58] "Guidelines for fire protection of railway, tramway and guided path vehicles – Part 3 Evaluation of fire behaviour of materials – threshold values"
This classification regards essentially three vehicles categories.
Similar to the French Standard, the Italian Standard provides the classification of the material/item by "reaction to fire" and "smoke" (combination of smoke emission and toxicity).
For the reaction to fire performance, the following parameters are taken into account :

- flammability
- flame spread
- max burned length
- dripping.

For the "smoke" parameter as described in the Standard, this is obtained from the combination of "smoke emission" and "toxicity index".
For the parameter "reaction to fire" (FI parameters) are provided six categories:

- Class 0 is evaluated by ISO 1182 [59] "non combustibility test";
- Class1 to Class 5 are determined by the combination the above parameters evaluated with two tests:
    1. UNI 8456 [60] "reaction to fire by applying a small flame on both surfaces" and UNI 9174 [61] "reaction to fire of material attacked by flame with radiant heating"
    2. UNI 8457 [62] "reaction to fire of material attacked by flame on one surface" and UNI 9174 [63] (where the sample is positioned as on the end use e.g. horizontal supine for floor materials, horizontal prone for ceiling materials or vertical for wall materials).

For small items (also for same electrical items) is provided the test according to EN ISO 11925-2 .
For seat padding, mattress and pillow is provided the UNI 9175. Moreover the complete seat is submitted to Fiche UIC 564-2 Annex13 (paper cushion test).
Heat release (without giving any limit) is evaluated by ISO 5660-1"Cone calorimeter test".

The “smoke” parameter is obtained identically to the French Standard, namely from combination of “smoke emission” and “toxicity index” (F value). The first one is evaluated by NF X 10702 (Smoke density Chamber) and the second one with NF X 70100 (toxicity test). There are three acceptable classes from F1 to F3.
For electrical materials smoke emission and smoke toxicity are separately evaluated with NF X 10 702 and IEC EN 50267 part 1 and 2 [64].
The classification system is done by a “threshold value” for “reaction to fire” and “smoke” for each listed item described in two summary tables in the standard (one for electrical components the second for all other materials/item).
A dynamic evaluation of combustion effluents (using FTIR methods) is also provided but without giving a limit.

16.6 – Conclusions concerning transposition of national classifications

No one parameter of the fire behaviour (FI, R, S, T) is directly comparable when comparing each parameter in FIRESTARR and various National classifications.
Therefor, report of WP6.2 gives tables with comparison between known national classification and proposal classification.

17 - CONCLUSIONS

The scenario considered in the FIRESTARR study is a fire starting in a small 10 m^3 compartment. The first ignited item is a seat: ignited by a smoker source or arson (higher source), then the different stages of the fire are identified: developing stage, pre and post flashover stages. During the different stages all the items found in the rail carriage catch fire and participate to the development of the fire. Other scenarios were considered but only this one was simulated for real scale test experiments as it is considered as the worst case.

The materials tested in the project have been selected from products used on European trains. Three types of products are selected:
- structural products,
- furniture products,
- electrotechnical products (cables were not included in the project).

For the selected materials national classifications were requested (when available). The products were chosen in order to cover a large range of fire behaviour (from low performance to high performance).

The tests have been carried out according three scales: small, large and real scale. The test methods retained for the FIRESTARR project are chosen in regard of their ability to give information on at least one of the fire critical effects (FIRST).

According to the results obtained in the project, recommendations for a classification are proposed in order to help the CEN TC256 JWG1 and CENELEX / TC9X to develop the part 2 of the prEN 45 545 standard. The classification proposal is based on the statistical analysis carried out on the test results. Three levels of fire behaviour are proposed :
- A for high performance product,
- B for medium performance product,
- C for low performance product.

  - For structural products (mainly wall and ceiling) correlation have been found between small and real scale tests. The criteria and limits are based on a correlation between the bench scale tests and the real scale test.
  - For furniture products poor correlation have been found between small and real scale and/or large and real scale tests. The criteria are arbitrary based on selective consideration and information on safety of upholstered furniture.
  - For electrotechnical products due to the small number of products available for test in large and real scale, correlation have not been looked for.

The “smoke” parameter is obtained identically to the French Standard, namely from combination of “smoke emission” and “toxicity index” (F value). The first one is evaluated by NF X 10702 (Smoke density Chamber) and the second one with NF X 70100 (toxicity test). There are three acceptable classes from F1 to F3.
For electrical materials smoke emission and smoke toxicity are separately evaluated with NF X 10 702 and IEC EN 50267 part 1 and 2 [64].
The classification system is done by a “threshold value” for “reaction to fire” and “smoke” for each listed item described in two summary tables in the standard (one for electrical components the second for all other materials/item).
A dynamic evaluation of combustion effluents (using FTIR methods) is also provided but without giving a limit.

This classification system is based on a reference real scale (10m^3 compartment with a specific ventilation) which is considered as the worst case situation. It is not based on an engineering concept. Therefore, it can give information only about a prescriptive approach. (The product satisfying the requirements according to the classification approach do not reach the critical effect in the considered circumstances). The requirements covered a large range of safety. It will not be possible to predict exactly the critical effect according to design and type of railway carriage or to adjust precisely the specification according to this requirement.

18 - PERSPECTIVES

Some aspect could be usefully validated in complementary studies. They are :
- consideration of bigger railway compartments,
- development of tests on components for seats.

In the FIRESTARR project the real scale tests were carried out using a 10 m^3 compartment considered as the worst case. In European trains other types of compartments are encountered. Tests on higher sizes of compartment could be proposed to complete the study. The objective is to develop an engineering tool to allow the prediction of fire behaviour of products in different type of railway carriages taking into account the fire critical effects.

The FIRESTARR conclusions for furniture products and more precisely on seats are to use large scale tests (in order to also consider the shape of the seat). This type of test could be considered as not easily applicable when substitution of the cover fabric is needed. An alternative or complementary test method on components could be useful for Railways companies (and also fabric producers) for replacement considerations. A proposal could be to define a small-scale test method for components “qualification”. The tests can be performed using reference materials: reference foam and fabric reference. The tests on components could be carried out using EN 1021 part 3 and/or ISO 5660 – 1. The protocol needs to be described and improved. Reference materials must also be identified for the specific use of seats used in railway carriage.

19 - REFERENCES

[1] prEN 45-545 : Railway applications - Fire safety on railway vehicles.
[2] ISO TR 9122-4 : Toxicity testing of Fire effluents – part 4 – The Fire model (furnace and combustion apparatus used in small-scale testing).
[3] ISO TR 13344 : Determination of the lethal toxic potency of fire effluents.
[4] ISO 9705 : Fire tests - Full-scale room test for surface products.
[5] pr EN ISO 11925-2 : Reaction to fire tests for building products – part 2 : Ignitability when subjected to direct impingement of flame.
[6] UIC 546-2 Appendix 11 : Regulations relating to fire protection and fire-fighting measures in passenger-carrying railway vehicles or assimilated vehicles used on international services. Appendix 11. Test method for determining the fire-resistance of rigid thermoplastic materials.
[7] ISO 5660-1 : Fire tests – Reaction to fire. Part 1.: Heat release (cone calorimeter method).

[8] IEC 60695-2-2 : Fire hazard testing for electrotechnical products. Part 2 : Test methods. section 2.2 : Needle-flame test.
[9] ISO 5658-2 : Reaction to fire tests – Spread of flame – Part 2 : Lateral spread on building products in vertical configuration.
[10] pr EN ISO 9239-1 : Reaction to fire tests for floorings – Part 1 : Determination of the burning behaviour using a radiant heat source.
[11] ISO DIS 5660-2 : Fire tests – Reaction to fire. Part 2 : Smoke production rate (dynamic measurement).
[12] ISO 5659–2 : Plastics – Smoke generation – Determination of optical density by a single chamber test.
[13] NF X 70-100 : Fire tests – Analysis of pyrolysis and combustion gases – Tube furnace method.
[14] DIN 53436 : Producing thermal decomposition products from materials in an air stream and their toxicological testing.
[15] ISO 9705 : Fire tests – Full scale room test for surface products.
[16] FIRESTARR WP4.1 Report WP4/WFRC/01001 : Small-scale reaction to fire tests on a range of structural products used on European Trains.
[17] pr EN 13823 : Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item (SBI test).
[18] EN 597-1 : Furniture – Assessment of the ignitability of mattresses and upholstered bed bases – Part 1 : Ignition source – Smouldering cigarette
[19] EN 597-2 : Furniture – Assessment of the ignitability of mattresses and upholstered bed bases – Part 2 : Ignition source – Match flame equivalent.
[20] pr EN 32952 - Parts 1 and 2 : Textiles – Burning behaviour of bedding items – Parts 1 and 2 – Ignitability by smouldering cigarette.
[21] pr EN 32952 – Parts 3 and 4 : Textiles – Burning behaviour of bedding items. Parts 3 and 4 – Ignitability by a small open flame.
[22] UIC 564-2 Annex 5 : Regulations relating to fire protection and fire-fighting measures in passenger-carrying railway vehicles or assimilated vehicles used on international services. Appendix 5 : Test method to measure the reaction to fire of covered textiles.
[23] UIC 564-2 Annex 13 : Regulations relating to fire protection and fire-fighting measures in passenger-carrying railway vehicles or assimilated vehicles used on international services. Appendix 13 : Test method to measure the ignitability of seats.
[24] pr EN 1021 Part 3: Furniture – Assessment of the ignitability of upholstered furniture – Part 3 : Ignition source : Flame equivalent to the flame from 20 g of newspaper.
[25] pr EN 1021 Part 4 : : Furniture – Assessment of the ignitability of upholstered furniture – Part 3 : Ignition source : Flame equivalent to the flame from 100 g of newspaper.
[26] NT FIRE 032 – Furniture calorimeter tests : Upholstered furniture : burning behaviour – Full scale.
[27] FIRESTARR WP1 Report WP1/FS/98002 : Statistical analysis of fires which have occurred in European Railways.
[28] FIRESTARR WP4.2 Report WP4.2/LSF/00001 : Small scale tests on furniture products.
[29] FIRESTARR WP7.2 Report WP7.2/LSF/00002 : Large scale tests on furniture products.
[30] IEC 60695-2-1/2 : Fire hazard testing – Part 2-1 Section 2 – Glow-wire flammability test method for materials.
[31] IEC 60695-2-4/2 : Fire hazard testing – Part 2 Test Methods – Section 4 sheet 2 : 500 W nominal pre-mixed test flame and guidance.
[32] IEC 60695-2-4/1 : Fire hazard testing – Part 2 Test Methods – Section 4 sheet 1 : 1 kW nominal pre-mixed test flame and guidance.
[33] pr EN 50264 : Railway applications – Railway rolling stock cables having special fire performance – Standard wall.
[34] pr EN 50266-2-4 : Cable calorimeter tests.
[35] FIPEC book : Fire Performance of Electric Cables – new test methods and measurement techniques – Final Report.
[36] FIRESTARR WP 4.3 Report WP4/ISSeP/00001 : Small-scale reaction to fire tests on a range of electrotechnical products used on European trains.
[37] FIRESTARR WP 6.1 Report WP6/WFRC/01008 : Classification proposal for Structural, Furniture and Electrotechnical Products.
[38] NF F 16-101 : Rolling stock – Fire behaviour – Materials selection.

[39] NF F 16-102 : Rolling stock – Fire behaviour – Materials selection – Application for electrical equipment.
[40] NF P 92-501 : Safety against fire – Building materials – Reaction to fire tests – Radiation test used for rigid materials, or for materials on rigid substrates (flooring and finishes) of all thicknesses, and for flexible materials thicker that 5 mm.
[41] NF P 92-503 : Safety against fire – Building materials – Reaction to fire tests – Electrical burner test used for flexible materials.
[42] NF P 92-504 : Safety against fire – Building materials – Reaction to fire tests – Flame persistence test and speed of flame spread.
[43] NF P 92-505 : Safety against fire – Building materials – Reaction to fire tests – Test used for thermoplastic materials – Dripping test.
[44] NF P 92-506 : Safety against fire – Building materials – Reaction to fire tests – Radiant panel test for flooring.
[45] NF P 92-510 : Safety against fire – Building materials – Reaction to fire tests – Determination of upper calorific value.
[46] NF EN ISO 4589-2 : Plastics – Determination of burning behaviour by oxygen index – Part 2 : Ambient-temperature test.
[47] NF X 10-702 : Fire test methods – Determination of the opacity of the fumes in an atmosphere without air renewal.
[48] DIN 5510 : Preventive Fire Protection in railway vehicles.
Part 1: Levels of protection, fire preventive measures and certification
Part 2: Fire behaviour and fire side effects of materials and parts; Classifications, Demands and test methods
Part 4: Vehicle design; Safety requirements
Part 5: Electrical equipment; Safety requirements
Part 6: Auxiliary measures, emergency brake operation function; Information systems, fire alarms, fire fighting equipment; Safety requirements
[49] DIN 53438 : Testing of combustible materials; reaction against a flame of burner
Part 1: General remarks
Part 2: Edgeing flame action
Part 3:Surface flame action
[50] DIN 54837 : Testing of materials, small components and component sections for rail vehicles; Determination of burning behaviour using a gas burner.
[51] DIN 4102 : Behaviour of building materials and components in fire – Part 1: Building materials, terminology, requirements and tests - Part 14: Floor coverings and floor coatings; determination of rate of flame spread using a radiant heat source.
[52] DIN 54431 : Testing of seats in railways for public traffic; determination of burning behaviour with a paper pillow ignition source.
[53] TL 918433 : Technical specifications for delivery; material combinations, passenger seats; particular demands against burning behaviour.
[54] BS 6853 : Code of practice for fire precautions in the design and construction of passenger carrying trains.
[55] BS 476-7 : Fire tests on building materials and structures – Part 7 : Method of test to determine the classification of the surface spread of flame of products.
[56] pr EN 2825 : Aerospace series – Burning behaviour, determination of smoke density and gas components in the smoke of materials under the influence of radiating heat and flames – Determination of smoke density.
[57] pr EN 2826 : Aerospace series – Burning behaviour, determination of smoke density and gas components in the smoke of materials under the influence of radiating heat and flames – Determination of gas components in the smoke.
[58] UNIFER pr E10.02.977.3 : Guidelines for fire protection of railway, tramway and guided path vehicles – Part 3 : Evaluation of fire behaviour of materials – threshold values.
[59] ISO DIS 1182-2 : Fire tests. Building materials. Non –combustibility test.
[60] UNI 8456 : Combustible materials which can be hit by flame on both surfaces. Reaction to fire by applying a small flame.
[61] UNI 9174 : Reaction to fire of material which can be hit by flame with radiant heating.
[62] UNI 8457 : Combustible materials which can be hit by flame on one surface. Reaction to fire by applying a small flame.

[63] UNI 9175 : Reaction to fire of upholstered furnitures by applying a small flame.
[64] IEC EN 50267 : Common test methods for cables under fire conditions – Test on gases evolved during combustion of materials from cables
[64] IEC EN 50267 : Common test methods for cables under fire conditions – Test on gases evolved during combustion of materials from cables

Annex A - Classification Criteria for Structural products

Classification criteria for walls and ceilings products

Table A.1: Classification criteria for structural products (wall and ceilings)

Fire Critical Effect	Test Reference	Classification Criteria		
		Class As	Class Bs	Class Cs
Ease of Fire Initiation	1	CFE $\geq$ 37kW/m^2	CFE $\geq$ 30kW/m^2	CFE $\geq$ 10kW/m^2
	2	NI	I	I
Fire Growth	2	No FO or $t_{FO} \geq$ 390s	$t_{FO} \geq$ 240s	n/r
Smoke Opacity	3	$t_{vL} \geq$ 390s	$t_{VL} \geq$ 240s	n/r
Smoke Lethality	2 & 4	FED<1.0	FED< 10.0	n/r

Key:
(a) Test references are given in annex D
(b) CFE is Critical Flux at Extinguishment
(c) NI is no ignition; I is ignition (i.e. time to sustained flaming > 10s)
(d) FO is Flashover in 10m^3 Compartment as calculated from ISO 5660-1 data at 50kW/m^2 heat flux
(e) t_{FO} is time to flashover in 10m^3 Compartment as calculated from ISO 5660-1 data at 50kW/m^2 data
(f) t_{VL} is time to loss of visibility in 40m^3 corridor as calculated from ISO 5659-2 data
(g) FED is fractional effective dose calculated from UITP E6 data and ISO 5660-1 data at 35kW/m^2 flux
(h) n/r is not required.

NOTE 1: the classification criteria which are introduced in this table are linked to the 10m^3 compartment which is considered as the worst case but they may not be transposable to other larger compartments.

NOTE 2: tFO, tVL, and FED are calculated with mathematical models from the results of small scale tests which are indicated in Table 1 or directly measured from 10m^3 compartment tests, which may be used in an appeals situation if the results of small-scale tests are considered to be inappropriate.

NOTE 3:

- **Class As:** products which are not ignited during the ISO 5660-1 test at $50kW/m^2$ and which reach a CFE more than $37kW/m^2$. If one of these criteria are not respected these products can be classified as if there is no flashover or if tFO, and tVL, are more than 390s, and FED is less than 1.0. The three types of risks which are represented by these three parameters are considered at the same level. If one of these conditions is not respected the product is not classified As.

- **Class Bs:** products which are ignited during the ISO 5660-1 test at $50kW/m^2$ and of which CFE $\geq 30kW/m^2$ and tFO, and tVL are more than 240s, and FED is less than 10.0.

- **Class Cs:** product of which CFE $\geq 10kW/m^2$ (but less than $30kW/m^2$).

Classification criteria for floorings

Table A.2: Classification criteria for floorings

Fire Critical Effect	Test Reference	Classification Criteria		
		Class A_{fl}	Class B_{fl}	Class C_{fl}
Ease of Fire Initiation	6	CF $\geq 8.0kW/m^2$	CF $\geq 4.5\ kW/m^2$	CF $\geq 3.0kW/m^2$
	2	NI	I	I
Fire Growth	2	THR $\leq 75MJ/m^2$	THR $\leq 120MJ/m^2$	n/r
Smoke Opacity	3 (+ pf)	VOF4 $\leq$ 100	VOF4 $\leq$ 1000	n/r
	3 (– pf)	VOF4 $\leq$ 100	VOF4 $\leq$ 200	n/r
Smoke Lethality	2 & 4	FED < 1.0	FED < 10.0	n/r

Key:

(a) Test references are given in annex D
(b) CF is the critical flux defined as the radiant flux at which the flame extinguishes or the radiant flux after a test period of 30 minutes, whichever is the lower (i.e. the flux corresponding with the furthest extent of flame spread).
(c) THR is total heat release
(d) VOF4 is smoke rate index in the first 4 minutes

NOTES:

(1) The above CF classifications are the same as those to be used for floorings to meet the essential requirements of the EC Construction Products Directive;

i.e.	A_{fl}	=	Euroclass B_{fl}
	B_{fl}	=	Euroclass C_{fl}
	C_{fl}	=	Euroclass D_{fl}

(2) Test references 2, 3 and 4 with the proposed test conditions are optional for measurements on parameters RST and are only required if specified by Regulators.

(3) No real-scale compartment/corridor tests were carried out on floorings in the FIRESTARR Project and hence, no heat release or smoke criteria can be validated. The criteria for CF have been validated by room/corner tests at NIST, USA.

Annex B - Classification Criteria for furniture products

Classification criteria for seats and mattresses

Table B.1: Classification criteria for furniture (seats and mattresses)

Fire Critical Effect	Test Reference	Classification Criteria		
		Class Af	Class Bf	Class Cf
Ease of Fire Initiation	8	With v = 0, NI and with v = 2, NI	With v = 0, NI or $t_{ig} \geq$ 10 min and With v = 2, NI or $t_{ig} \geq$ 2 mins)	n/r n/r
Fire Growth		t_{max} HRR ≥ 10 min and THR < 5MJ	t_{max} HRR ≥ 6 – 10 min and THR 5 – 70MJ	t_{max} HRR ≥ 6 min and THR > 70MJ
Smoke Opacity		t_{max} RSP ≥ 10 min and TSP < 60m^2	t_{max} RSP 6 -10 min and TSP 60 – 700m^2	t_{max} RSP < 6 min and TSP > 700m^2
Smoke Lethality		FED < 1.0	FED < 5.0	n/r

Key:

(a) Test references are given in annex D.
(b) V=0 is no vandalism on specimen
V=2 is vandalism to level 2 on specimen
(c) HRR is heat release rate
(d) RSP is smoke production rate
(e) TSP is total smoke production

NOTE:

(1) Ignition is deemed to have occurred if the seat or mattress release 30kW (or more) heat after the burner has been removed.
(2) Class Af may also be satisfied for the fire growth parameters FIR if no flashover occurs in a 10m^3 compartment test performed according to the principles of FIRESTARR Project WP8.2.

Classification criteria for curtains

Table B.2 : Classification criteria for curtains

Fire Critical Effect	Test Reference	Classification Criteria		
		Class Ac	Class Bc	Class Cc
Ease of Fire Initiation	11	Fs < 150mm	$t_{150mm} \geq 60s$	n/r
	1	CFE ≥ 37kW/m^2 QSB ≥ 2.5MJ/m^2	CFE ≥ 20kW/m^2 QSB ≥ 1.5MJ/m^2	CFE ≥ 10kW/m^2 QSB < 1.5MJ/m^2
Fire Growth	2	$q_{max} < 75kW/m^2$	$q_{max} < 150kW/m^2$	$q_{max} \geq 150kW/m^2$
Smoke Opacity	3	a) D_{max} <100 VOF4 < 100 b) D_{max} <100 VOF4 < 100 c) D_{max} <100 VOF4 < 100	a) D_{max} <400 VOF4 <200 b) D_{max} <400 VOF4 < 600 a) D_{max} <400 VOF4 < 600	a) D_{max} ≥400 VOF4 ≥200 b) D_{max} ≥400 VOF4 ≥ 600 c) D_{max} ≥400 VOF4 ≥ 600
Smoke Lethality	4	FED < 1.0	FED < 10.0	n/r

Key:

(a) Test references are given in annex D.
(b) Fs is vertical flame spread
(c) t_{150mm} is time for flame tip to reach 150mm height above application point
(d) QSB is heat for sustained burning
(e) q_{max} is maximum heat release rate
(f) D_{max} is maximum optical density

Annex C - Classification Criteria for electrotechnical products

Classification criteria for linear electrotechnical products (excluding cables)

Table C.1 : Classification criteria for linear electrotechnical products (excluding cables)

Fire Critical Effect	Test Reference	Classification Criteria		
		Class A_{el}	Class B_{el}	Class C_{el}
Ease of Fire Initiation	13	$t_{ig} \geq 600s$	$t_{ig} \geq 480s$	$t_{ig} \geq 180s$
Fire Growth		FS ≤ 500mm THR ≤ 15MJ $RHR_{peak} \leq 40kW$	FS ≤ 1200mm THR ≤ 40MJ $RHR_{peak} \leq 80kW$	FS ≤ 2000mm THR ≤ 70MJ $RHR_{peak} \leq 150kW$
Smoke Opacity		$TSP \leq 40m^2$ $RSP_{peak} \leq 0.2m^2/s$	$TSP \leq 200m^2$ $RSP_{peak} \leq 0.8m^2/s$	$TSP \leq 500m^2$ $RSP_{peak} \leq 2m^2/s$
Smoke Lethality		FED < 1.0	FED < 10.0	n/r

Test references are given in Annex D.

Notes:

1. For the ease of ignition, the limits are chosen so that no “ignition” can occur for the first stage (i.e. 1kW burner) for Class C_{el}, during the 2nd stage (10kW burner) for Class B_{el} or within the first 2 minutes of the last stage (i.e. 30kW burner) for Class A_{el}.
2. FS (Flame Spread) is defined by the burnt height of the specimen
3. For fire growth, the limits of RHR and THR are given including the burner output.

Classification criteria for other electrotechnical products

Table C.2 : Classification criteria for other electrotechnical products

Fire Critical Effect	Test Reference	Classification Criteria		
		Class A_{et}	Class B_{et}	Class C_{et}
Ease of Fire Initiation	10	No flame persistence No flaming drips	No flame persistence No flaming drips	n/r
	9	GWIT $\geq$ 960°C	GWIT $\geq$ 850°C	GWIT $\geq$ 700°C
Fire Growth	2	$q_{max} \leq$ 100 kW/m^2 THR $\leq$ 40 MJ/m^2	$q_{max} \leq$ 250 kW/m^2 THR $\leq$ 100 MJ/m^2	n/r
Smoke Opacity	3	$VOF4_{25pf} \leq$ 20 $Dmax_{25pf} \leq$200 $VOF4_{25} \leq$20 $Dmax_{25} \leq$150	$VOF4_{25pf} \leq$ 50 $Dmax_{25pf} \leq$400 $VOF4_{25} \leq$ 50 $Dmax_{25} \leq$300	$VOF4_{25pf} \leq$ 200 $Dmax_{25pf} \leq$ 750 $VOF4_{25} \leq$ 200 $Dmax_{25} \leq$ 500
Smoke Lethality	4 & 5	FED < 1.0	FED < 10.0	n/r

Key:

(a) Test references are given in annex D.
(b) GWIT is the glow wire ignition temperature

NOTE:

1 The 500W burner test must be considered as a Pass/Fail test on materials (not products)

2 The GWIT is determined according to IEC 60695-2-1/3.

3 The smoke criteria have been selected with regard to the statistical analysis of the results. The considered parameters are shown above as follows:

VOF4 measured at 25kW/m^2 with pilot flame
Dmax measured at 25kW/m^2 with pilot flame
VOF4 measured at 25kW/m^2 without pilot flame
Dmax measured at 25kW/m^2 without pilot flame

Annex D - Test references

<u>Test References</u>

1	ISO 5658-2	Lateral flame spread test with radiant panel source
2	ISO 5660-1	Cone calorimeter test for ignition time and heat release rate.
3	ISO 5659-2	Single chamber smoke test (cumulative conditions)
4	UITP E6	Static furnace test for fire effluents
5	DIN 53436	Moving furnace test for fire effluents
6	prEN ISO 9239-1	Radiant panel test for horizontal flame spread on floorings
7	prEN 1021-4	Ignitability test for seats using burner equivalent to 100g paper
8	NT FIRE 032	Furniture Calorimeter Tests. Upholstered furniture : Burning behaviour – Full Scale Test
9	IEC 60695-2-11	Glow wire test
10	IEC 60695-2-4/2	Ignitability and flammability test with 500W flame source
11	prEN ISO 11925-2	Small flame test
12	IEC 60695-2-30	Ignitability and flammability test with 1kW flame source.
13	prEN 50266/2/4	Cable Calorimeter Tests