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Work package 7.2 :

Large scale tests on furniture products

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1 ABSTRACT

The aim of the FIRESTARR project is to support CEN TC 256 WG1 and CENELEC TC9X WG3 in the drafting of part 2 (requirements for the fire behaviour of materials and components) of a seven part European standard pr EN 45545 (ref. 3).
The programme includes a series of tests to evaluate in large scale the fire behaviour of a representative range of furniture products used on European trains (ref. 2).
The scenario that should be simulated has been defined by WP1 (ref.1), which also determined that statistically the most hazardous part of a railway compartment is a seat.

The choice of the method, conditions and procedure for testing was justified in WP 3.2 part 2 and are detailed in WP3/LSF/00001 document (ref. 3).
The seats, which are tested in their final shaped size, were selected by WP5 from the materials/products provided in WP2 and after the completion of statistical analysis on the small scale tests results (ref. 6).
The test results obtained in this working programme are to be used for validation of proposals of WP5, to confirm the right selection of methods made in WP3 to achieve the fire safety objectives and for a further extension of classification of single materials to larger components and/or complete parts, eg. seats.
This report describes the data obtained by large scale testing carried out on a range of different seats actually used in European railway vehicles.

2 OBJECTIVES OF WP 7.2

The objectives of WP 7.2 are as follows:

I) To obtain data on relevant fire reaction parameters (ignitability, spread of flame, heat release, smoke opacity, toxic gas species generation) for a selected range of seats, which come from railway vehicles and which are tested in their full end-use size.

Using this data and taking into account the defined fire safety objectives of the project, it will be possible to:

II) Validate the statistical analysis and the selection of products performed by WP5 for real scale tests (ref. 6).
III) Support the selection of the test methods and parameters proposed in WP3.2 (ref. 5 and ref. 7)
IV) If required, extend the classification and selection criteria for larger components or complete parts of furniture
V) Complete the data bank of WP10.

The method for testing was chosen with the first aim to simulate as closely as possible the conditions described by the reference scenario of WP 1 (ref. 1) and to reproduce the end-use conditions of the railway products selected in WP 2 (ref.2).
It also takes into account the sampling of the products, the accuracy of the measurements and economic aspects.
Amongst the 3 categories (seats, curtains and bedding) of furniture products evaluated in small scale tests, only seats were tested in large and real scale tests since they represent the most dangerous part of the compartment and will reproduce the probable primary ignited item in the interior of the railway vehicle.
In small scale tests some assemblies were defined which are intended as a combination of a block of foam covered first with a piece of an interlayer and second with a piece of fabric.
From the indication of different railway companies and taking into account the list of furniture products selected in WP 2 (ref. 2), the selected seats are intended to represent the corresponding full seats actually used in European trains.

These full size seats have been evaluated in large scale tests.
Following the same principles adopted for small scale test results, all data on the main 5 reaction to fire parameters may be collected into 4 different "families" of results:

- Ease of ignition (Ignitability)
- Fire growth (spread of flame and heat release)
- Loss of visibility (smoke opacity)
- Lethality of smoke (toxic gas species generation)

These type of results can give information to define the following Fire Critical Effects (FCE), which may lead to the human death:

- Irritation and narcosis (toxicity)
- Loss of visibility to find the way-out (opacity of smoke)
- Hyperthermia, burned skin, damage to respiratory tract (heat)

All data obtained in large scale tests will be compared with small scale test data using the same parameters. The selection criteria for fire behaviour performance levels will be validated in real scale tests.
After this analysis, a classification system will be defined and proposed to categorise the constituent products of railway vehicles taking into account the acceptable risks for users, the design of the vehicle, the shape and use of the product, the functional requirements, the ventilation system and all relevant combinations between these factors.

3 PARTICIPANTS

The two partners of working group 7.2 who carried out the large scale tests on seats were :

LSF (leader)	ITALY
SP	SWEDEN

4 DESCRIPTION OF THE PRODUCTS TESTED

The selection of the furniture products to be tested in WP7.2 was made by statistical analysis of small scale data performed in WP5 (ref. 6) and included 13 combinations/assemblies and 2 single products; hence, they represent 15 different types of seat.
A maximum of 8 seats has been selected using the Principal Component Analysis and Hierarchical Clustering Analysis technique for deleting outliers, to judge the repeatability of several tests and to observe the correlation between small scale parameters according to the different Fire Critical Effects.
It has permitted the comparison of the test methods and the discrimination of products.
The complete list of assemblies evaluated in small scale tests is described in the WP2 report (ref. 2) and the WP4.2 report (ref. 8).

The 8 seats tested in WP7.2 and WP8.2 and representing the real full size products with combinations listed in WP 4.2 are as follows:

C01
C02
C03
C04

C05
C07
C08
C09

A full and detailed description of the seats tested is given in Annex 1.

5 DESCRIPTION OF TEST METHOD AND CONDITIONS USED

Concerning the furniture products and particularly for seats, only one method was selected for use in Working Programme 7.2: the Furniture calorimeter test (NT Fire 032).
In making this selection, all relevant international standards which simulate the reference scenario were considered. In addition, the selected test had to be capable of testing seats in their final shaped form since small-scale tests are not sufficiently representative.

The NT FIRE 032 standard (ref. 4) is the reference method for a new protocol which has been developed to meet the requirements of the FIRESTARR project and so it was used for WP 7.2 testing.
A detailed description of the main reasons for the selection of the method and all technical aspects related to the new procedure are reported in the WP 3.2 part 2 report (ref. 5).

5.1 General description of test method

The method is intended to be used for the fire behaviour evaluation of full-size seats used in the railway vehicles.
A representative specimen of the product, such as a sofa or a single seat, is placed on a weighing platform.
The platform is located under a hood that extracts all the combustion gases.
Probes for sampling of gas and for measurement of volume flow rate are placed in the exhaust duct leading from the hood. A photocell lamp system for measurement of light obscuration is installed across the exhaust duct.
The specimen is ignited by a specified ignition source (Firestarr “A” burner – ref. 5) and burns freely under well ventilated conditions.
A general scheme of the test and set-up of measurement system is shown in Figure 1.
During the test, concentrations of carbon monoxide and carbon dioxide are measured by NDIR, and other toxic gas species by FTIR analyser. Oxygen depletion, light obscuration and volume flow rate are measured in the exhaust duct.
Mass loss rate of the burning specimen is measured by means of a weight measuring device.

From these measurements the rate of heat release, the production of gas species and light obscuration of smoke are calculated.

5.2 Vandalism on seats

In the FIRESTARR objectives, the scope of the method is to simulate the best fire scenario defined by WP1, which means to reproduce an arson attack by a primary ignition source on a seat. This represents the probable primary ignited item in the interior of railway vehicles.

The method is intended to evaluate the contribution to fire growth and smoke generation from a seat which is deliberately ignited using a square burner applied onto 3 different levels of vandalised seat.
The procedure for laceration of seats for reproducing different vandalism levels is described in Annex A of WP 3.2 part 2 report (ref. 5).

5.3 Ignition source

The ignition source was developed by LSF and consists of a square burner which simulates the same thermal attack on seat given by 100gr of burning paper cushion.
This new burner was named “Firestarr A” and described in the WP 3.2 part 2 report (ref. 5).

5.4 Toxic gases measurement

The analysis of all toxic gas species was performed by the FTIR technique.
The smoke gas samples were taken from the sampling line connected to the exhaust duct and drawn continuously through a heated sampling line and the IR absorption cell of a FTIR spectrometer.
All the requirements for the use of this technique are described on annex A of WP 3.2 part 2 report (ref. 5) and follow the specifications coming from SAFIR project (ref. 9).
The gases to be detected are: CO, CO_2, HCN, HCl, HBr, NOx, Acrolein, Formahldyde, HF.

6 TEST RESULTS

The parameters (FIRST) have been identified earlier in the FIRESTARR project and are listed below:
F for Flame Spread
I for Ignitability
R for Rate of heat release
S for Smoke Opacity
T for Smoke Toxicity

Concerning the Furniture calorimeter test, the following 4 groups of results connecting the Fire Critical Effects include one or more of the above parameters:

- **Ease of ignition (FI) :**

Ign	Ignition [(1)] (yes/not),
t ign	time to reach the Ignition (s)

- **Fire Growth (FIR) :**

HRR_{peak}	Heat release peak (kW),
t HRR_{peak}	time to Heat release peak (s),
THR	Total Heat released (MJ),
TML	Total mass loss (kg),
δm	Percentage of Total mass loss (%),
EHC	Effective heat of combustion determinated from the quotient between the total heat release and the mass loss (MJ/kg)

- **Loss of visibility (FIRS):**

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 obstruction smoke (m^2)

- **Toxicity of smoke (FIRST):**

TQ	Total amount of gas produced (g),
Yield	Yield of gases produced referred to initial mass of specimen (g/kg)

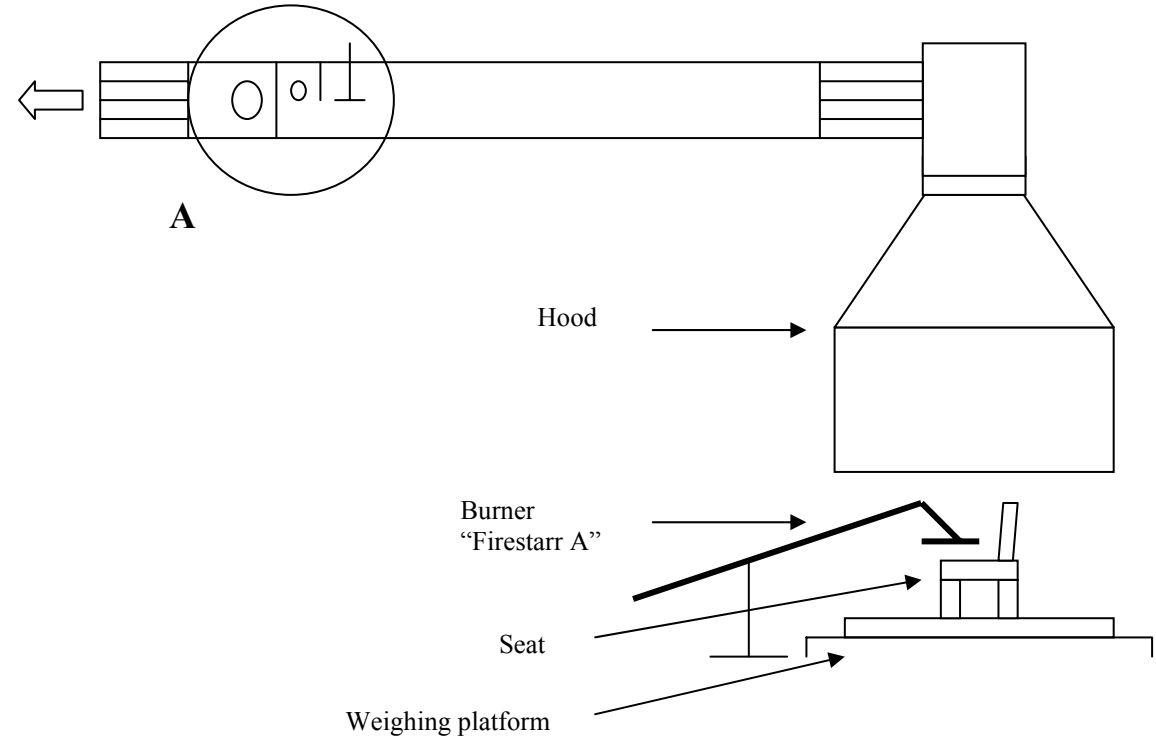
The tables 1, 2, 3 and 4 show all data for each single test carried out on 8 different types of seat.
The vector data on heat released and smoke production from these tests is shown in Annex 2.

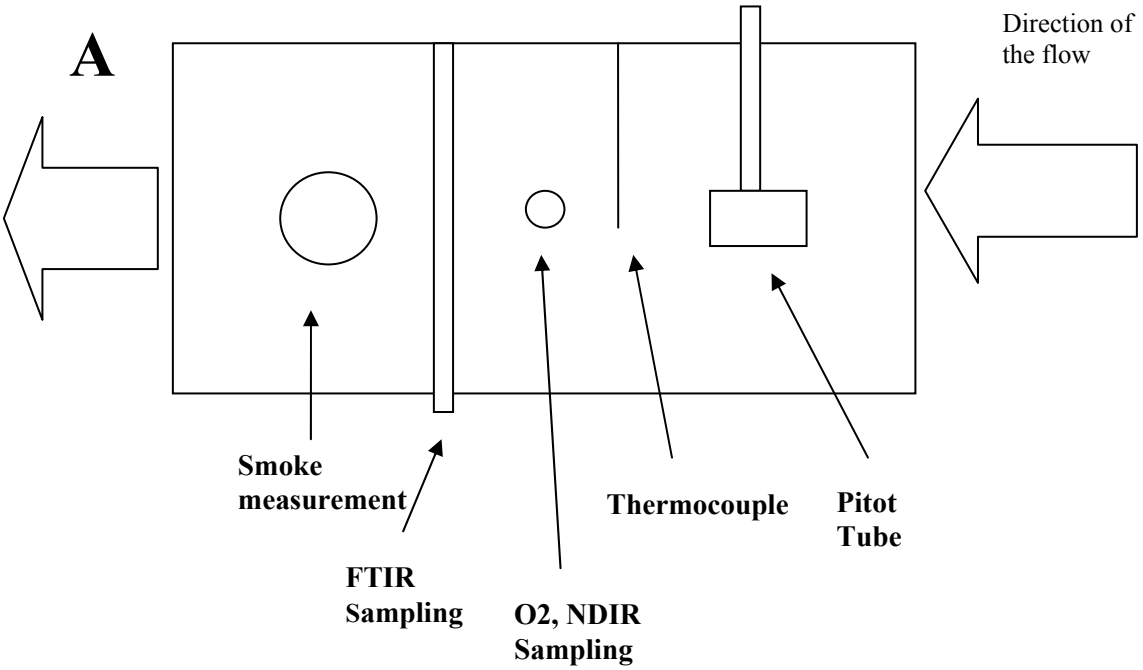
(1) : Ignition of the seat has occurred when the heat release peak reaches at least the value of 30 kW excluding the burner contribution.

FIGURE 1

FIRESTARR WP 7.2 - FURNITURE CALORIMETER TEST METHOD FOR SEATS USED IN RAILWAY VEHICLES

Scheme of test and set-up of measurement systems in ISO 9705 exhaust duct (ref. 10):





6.1 Tables of results

TABLE 1 : EASE OF IGNITION

Combination nr. / Test nr.		Vandalism level on the seat	Ignition[(1)] (yes / no)	Time to reach the Ignition [(1)] (s)
C01	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	Yes	150
	Seat 4	2	Yes	153
C02	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	Yes	99
	Seat 4	2	Yes	99
C03	Seat 1	0	No	NR
	Seat 2	1	Yes	1323
	Seat 3	1	Yes	675
C04	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	Yes	192
	Seat 4	2	Yes	492
C05	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	No	NR
	Seat 4	2	No	NR
C07	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	Yes	135
	Seat 4	2	Yes	130
C08	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	No	NR
	Seat 4	0	No	NR
C09	Seat 1	0	No	NR
	Seat 2	1	No	NR
	Seat 3	2	No	NR
	Seat 4	0	No	NR

NR : Not reached
(1) : Ignition of the seat is intended when the heat release peak reaches at least the value of 30 kW excluding the burner contribution.

TABLE 2 : FIRE GROWTH

Combination nr. / Test nr.		Vandalism level on the seat	HRR peak (2) (kW)	Time to HRR_{peak} (s)	THR (MJ)	TML (kg)	δm (%)	EHC (MJ/kg)
C01	Seat 1	0	6.7	108	0.7	0.10	0.5	6.5
	Seat 2	1	9.9	162	1.1	0.10	0.5	10.7
	Seat 3	2	100.2	207	18.9	1.45	6.9	13.1
	Seat 4	2	90.5	270	20.1	1.45	6.9	13.8
C02	Seat 1	0	9.6	192	0.5	0.07	0.2	6.6
	Seat 2	1	8.4	195	0.8	0.10	0.3	8.4
	Seat 3	2	198.9	414	74.9	4.38	13.9	17.1
	Seat 4	2	211.1	234	85.3	4.90	15.7	17.4
C03	Seat 1	0	10.1	177	0.8	0.10	0.7	8.0
	Seat 2	1	40.7	1353	17.7	1.10	7.5	16.1
	Seat 3	1	68.4	705	21.8	1.94	13.3	11.2
C04	Seat 1	0	4.7	93	0.4	0.05	0.2	8.6
	Seat 2	1	4.6	138	0.3	0.06	0.2	5.2
	Seat 3	2	148.9	525	45.6	2.70	8.2	16.9
	Seat 4	2	199.4	558	57.8	3.24	9.8	17.9
C05	Seat 1	0	18.8	180	1.8	0.05	0.4	35.2
	Seat 2	1	13.8	200	2.1	0.05	0.4	41.8
	Seat 3	2	20.1	235	14.1	0.77	6.9	18.3
	Seat 4	2	19.0	275	2.2	0.15	0.8	14.9
C07	Seat 1	0	8.7	235	0.3	0.05	0.4	5.4
	Seat 2	1	18.3	225	2.8	0.06	0.4	45.8
	Seat 3	2	341.2	385	82.1	3.06	21.6	26.8
	Seat 4	2	256.8	350	53.6	2.39	16.5	22.4
C08	Seat 1	0	19.2	225	2.7	0.17	0.7	15.8
	Seat 2	1	18.1	215	2.0	0.14	0.6	14.4
	Seat 3	2	19.0	250	2.6	0.08	0.3	33.0
	Seat 4	0	19.0	250	2.6	0.09	0.4	29.3
C09	Seat 1	0	25.2	210	4.4	0.12	0.5	36.8
	Seat 2	1	21.8	160	3.8	0.12	0.5	31.8
	Seat 3	2	15.1	235	1.8	0.06	0.2	30.3
	Seat 4	0	22.9	170	3.7	0.13	0.5	28.8

HRR_{peak} Heat release peak
t HRR_{peak} time to Heat release rate peak (s),
THR Total Heat released
TML Total mass loss
δm 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)
(2) : All Heat release data are reported excluding the burner contribution.

TABLE 3 : LOSS OF VISIBILITY

Combination nr. / Test nr.		**Vandalism level on the seat**	RSP_{peak} (m^2/s)	Time to RSP_{peak} (s)	**TSP (m^2)**
C01	Seat 1	0	0.117	93	18.1
	Seat 2	1	0.163	150	23.0
	Seat 3	2	1.568	192	606.4
	Seat 4	2	1.698	219	528.4
C02	Seat 1	0	0.414	168	38.4
	Seat 2	1	0.510	219	49.3
	Seat 3	2	4.675	150	1265.6
	Seat 4	2	5.528	153	1455.7
C03	Seat 1	0	0.892	156	80.3
	Seat 2	1	1.038	1347	628.2
	Seat 3	1	1.847	693	923.1
C04	Seat 1	0	0.044	183	8.1
	Seat 2	1	0.036	132	3.9
	Seat 3	2	1.468	507	561.4
	Seat 4	2	1.898	546	694.2
C05	Seat 1	0	0.519	165	51.4
	Seat 2	1	0.525	170	59.8
	Seat 3	2	0.532	195	73.0
	Seat 4	2	0.524	235	63.0
C07	Seat 1	0	0.987	55	109.5
	Seat 2	1	1.260	70	131.9
	Seat 3	2	10.631	310	2601.3
	Seat 4	2	10.164	320	2257.2
C08	Seat 1	0	0.500	195	52.7
	Seat 2	1	0.577	215	63.4
	Seat 3	2	0.569	200	54.8
	Seat 4	0	0.569	200	54.8
C09	Seat 1	0	0.509	200	59.7
	Seat 2	1	0.497	155	66.8
	Seat 3	2	0.316	220	30.0
	Seat 4	0	0.653	215	55.4

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)

TABLE 4 : TOXICITY OF SMOKE

Quantitative analysis of toxic gases measured by FTIR in the duct sampling point.

Combination nr. / Test nr.		Vandalism level on the seat	CO		CO_2		HCN		HCl		HBr		SO_2		NOx		C_3H_4O		HCOH	
			TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg	TQ g	Yield g/Kg
C01	Seat 1	0	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**112**	**5.266**	**2470**	**116.13**	**10.2**	**0.479**	**11.7**	**0.550**	**ND**	**ND**	**20.3**	**0.954**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 4	2	**102**	**4.795**	**2580**	**121.30**	**10.0**	**0.470**	**14.3**	**0.672**	**ND**	**ND**	**18.1**	**0.851**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
C02	Seat 1	0	**1.9**	**0.060**	**ND**	**ND**	**ND**	**ND**	**4.5**	**0.143**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**3.7**	**0.118**	**ND**	**ND**	**ND**	**ND**	**9.6**	**0.305**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**260**	**8.272**	**6760**	**215.08**	**22.5**	**5.1**	**248**	**7.891**	**ND**	**ND**	**46.5**	**1.479**	**26.0**	**0.827**	**ND**	**ND**	**ND**	**ND**
	Seat 4	2	**340**	**10.82**	**7940**	**252.62**	**27.2**	**5.5**	**255**	**8.113**	**ND**	**ND**	**41.3**	**1.314**	**30.4**	**0.967**	**ND**	**ND**	**ND**	**ND**
C03	Seat 1	0	**7.7**	**0.535**	**ND**	**ND**	**ND**	**ND**	**13.5**	**0.938**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**58.7**	**4.080**	**1510**	**104.9**	**3.6**	**0.250**	**105**	**7.300**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	1	**134**	**9.310**	**2960**	**205.7**	**5.8**	**0.403**	**188**	**13.06**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
C04	Seat 1	0	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**126**	**7.604**	**5290**	**319.2**	**6.2**	**0.374**	**14.6**	**0.881**	**ND**	**ND**	**21.1**	**1.270**	**12.9**	**0.778**	**ND**	**ND**	**ND**	**ND**
	Seat 4	2	**147**	**8.871**	**5970**	**360.3**	**7.6**	**0.459**	**18.5**	**1.116**	**ND**	**ND**	**22.0**	**1.328**	**19.8**	**1.195**	**ND**	**ND**	**ND**	**ND**
C05	Seat 1	0	**2.6**	**0.142**	**108.4**	**5.964**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**1.4**	**0.127**	**91.6**	**8.079**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**0.4**	**0.038**	**160.6**	**14.387**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 4	2	**25.8**	**1.397**	**186.3**	**10.097**	**ND**	**ND**	**0.0013**	**7 E-6**	**0.0001**	**5 E-6**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
C07	Seat 1	0	**4.4**	**0.310**	**91.3**	**6.497**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**4.4**	**0.308**	**137.1**	**9.657**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**296.6**	**20.949**	**3524.8**	**248.93**	**14.8**	**1.046**	**194.6**	**13.746**	**0.0003**	**2 E-5**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 4	2	**238.0**	**16.413**	**3219.4**	**222.02**	**12.4**	**0.855**	**106.7**	**7.356**	**0.0002**	**1 E-5**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
C08	Seat 1	0	**0.3**	**0.012**	**96.6**	**3.783**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**3.1**	**0.125**	**176.3**	**7.013**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**1.7**	**0.072**	**163.9**	**6.883**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 4	0	**4.1**	**0.170**	**110.2**	**4.569**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
C09	Seat 1	0	**3.5**	**0.138**	**210.7**	**8.441**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 2	1	**17.1**	**0.694**	**179.1**	**7.251**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 3	2	**ND**	**ND**	**90.2**	**3.663**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
	Seat 4	0	**6.0**	**0.241**	**144.7**	**5.846**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**

TQ : Total amount (quantity) of gas produced ; **Yield** : Yield of gases produced referred to initial mass of specimen; **ND** : No detected or below the minimum detection limits.

7 Discussion of test results

7.1 Ease of ignition

"Ease of ignition" results firstly show that 3 seats out of 8 do not ignite when tested at level 2 of vandalism. Only the C03 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 was observed that only C04 has an average value around 5-6 minutes, while the other seats ignite between 1.5 and 2.5 minutes (C01, C02, C07).
Generally all tested seats have good ignitability performance under normal conditions so they do not permit a discrimination until forcibly ignited by vandalism which then shows 4 categories of performance. The best one includes C05 C08 and C09 seats, the second one is represented by C04, the following one contains C01 C02 and C07, so the worst product seems to be proven to be the C03 seat.

7.2 Fire growth

Analysing the "Fire growth" data, a similar good level of performance for all seats was confirmed 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: HRR_{peak} data show C01 as a better product and the others at same level of performance are C02 – C04 and C07; the "times to reach" these peaks have a range between 207 to 558 seconds and could permit a division into two main groups. One group would include C04 as the best product and the second group C01- C02 - C07, which are all around 250 - 300s.
"THR" results, "mass loss" and "EHC" data show a similar response and the same performance ranking already obtained by " HRR_{peak}" data analysis.
In conclusion, "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".
It is recommended that a classification system should consider the fire growth parameter always after evaluating the "ignitability" response.

7.3 Loss of visibility

The results on "Loss of visibility" show a general range of low values for each parameter wherever 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 best one includes C01- C04 and the worst one includes C02 and C07.
The time for RSP_{peak} results does not rank the seats in the same order of smoke emission performance.
It is recommended that a category performance system should take smoke emission into account after determining the "ignitability" response.

8 Conclusion

The statistical analysis on results large and real scale methods made by WP5 will permit to define criteria in real scale to represent the fire critical effects.
Furthermore, it will join the different fire-test-response characteristics of material/products and the fire critical effects i.e. to find relationships between the data from real scale test data and large scale test data which allow to predict fire risks.
Looking just to data results obtained carried out the tests on furniture in Large scale, we can propose three levels of performance for seats based essentially on the first parameter of risk: "ignitability" or "easy of ignition".

For each family of parameter 3 levels of risk were identified:

I = Low level of risk and high performance of furniture
II = Medium level of risk and medium performance
III = High level of risk and low performance

EASE OF IGNITION

LEVEL	EASE OF IGNITION PARAMETERS	
	Ignition requirements	**"Time to reach the ignition " requirements**
I	▪ No ignition for "0" vandalism level of seat And ▪ No ignition for "1" vandalism level of seat And ▪ No ignition for "2" vandalism level of seat	
II	▪ No ignition for "0" vandalism level of seat or if ignition occur…….. And ▪ No ignition for "1" vandalism level of seat And ▪ No ignition for "2" vandalism level of seat or if ignition occur ……..	▪ Time to reach the ignition > 600 ▪ Time to reach the ignition > 120s
III	▪ No ignition for "0" vandalism level of seat or if ignition occur…….. And ▪ No Ignition for "1" vandalism level of seat And ▪ Ignition for "2" vandalism level of seat with OR ▪ No ignition for "0" vandalism level of seat or if ignition occur…….. And ▪ Ignition for "1" vandalism level of seat And ▪ Ignition for "2" vandalism level of seat	▪ Time to reach the ignition < 600 ▪ Time to reach the ignition < 120s ▪ Time to reach the ignition < 600

The main parameter is "IGNITION".
Whenever IGNITION occurs, FIRE GROWTH and LOSS OF VISIBILITY levels of performance will be determinated in accordance with following criteria:

FIRE GROWTH

LEVEL	FIRE GROWTH		
	Time to RHR peak	**THR**	**TML**
I	>600s	<5 MJ	<0.2 kg
II	360÷600s	5÷70 MJ	0.2÷3.5 kg
III	<360s	> 70 MJ	> 3.5 kg

LOSS OF VISIBILITY

LEVEL	LOSS OF VISIBILITY PARAMETER	
	Time to RSP peak	**T S P**
I	>600s	<60 m^2
II	360÷600s	60÷700 m^2
III	<360s	>700 m^2

Performance levels in Large scale test:

REFERENCE PRODUCTS	Performance levels					
	EASE OF IGNITION	FIRE GROWTH			LOSS OF VISIBILITY	
		tRHRp	THR	TML	tRSPp	TSP
C01	II	III	II	II	III	II
C02	III	III	III	III	III	III
C03	III	I	II	II	I	III
C04	II	II	II	II	II	II
C05	I	NO IGNITION				
C07	II	II	II	II	III	III
C08	I	NO IGNITION				
C09	I	NO IGNITION				

The proposal above give a good discrimination products in terms of fire reaction performance which taking into account all parameters of risk.
The proposal before its use for calssification purpose (WP 6) will be verified and validated by the study of WP5 that will link it to the real scale data and the identified fire critical effects.

9 REFERENCES

1. FIRESTARR WP1 Report. WP1/FS/98002
   Statistical analysis of fires which have occurred in European Railways

2. FIRESTARR WP2 Report. WP2/SNCF/98004
   Selection of products for small-scale tests

3. prEN 45545 Part 2 Draft document WGS 2006 : 2000
   Material requirements : Classification for Fire Protection

4. FURNITURE CALORIMETER TESTS - NT FIRE 032. Upholstered furniture: Burning behaviour – Full scale test

5. FIRESTARR WP3/LSF/00001: Work package 3.2 Part 2 report – Selection of large and real scale test methods for furniture products for WP 7.2 and 8.2.

6. FIRESTARR WP5/LNE/TYPE26: Analysis of small scale tests data for assemblies.

7. FIRESTARR WP3/LSF/99001: Work package 3.2 Part 1 report – Selection of small scale test methods for furniture products for WP4.2

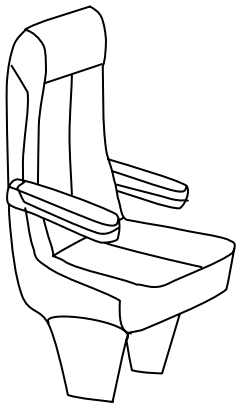
8. FIRESTARR WP4.2/LSF/00001: Work package 4.2 – Small scale test on furniture products

9. SAFIR Final report: 1999 Smoke gas analysis by Fourier transform infrared spectroscopy

10. ISO 9705 : 1993 Fire Tests – Full-scale room test for surface products

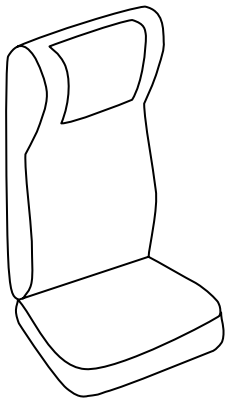
ANNEX 1 : Description of seats tested

Description of the seats tested in WP 7.2:



Seat "C01"

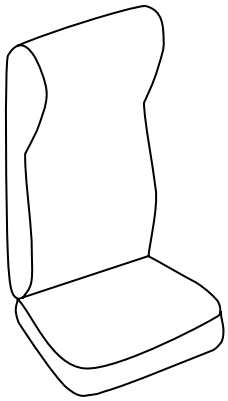
	Colour	Thickness (mm)	Density
Fabric	Blue with light blue vertical lines and sometimes a short light green horizontal line	1.5 mm	700g/m^2 fabric+interliner glued 550g/m^2 fabric and glue
Foam	Very light yellow	Seat+back max 9 cm	0.07g/cm^3
Interliner	Gray-green cloth (glued to fabric)	0.5 mm	150g/m^2
Under the seat	White plastic with large mesh	0.6 mm	575g/m^2
Shell	metallic		



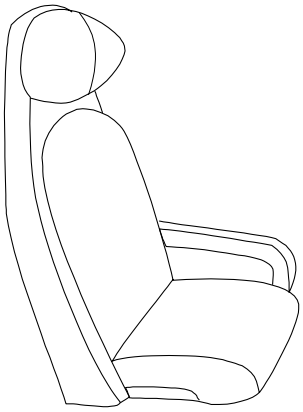
Seat "C02"

	Colour	Thickness (mm)	Density
Fabric	Pink and purple, diagonal lines (~45°), width ~3 mm	1.0 mm	450g/m^2
Foam	Yellow with outside more orange	Seat: max 10 cm Back: max 8 cm	Seat: 0.12g/cm^3 Back: 0.13g/cm^3
Interliner	Large white mesh tied to the foam	0.8 mm	320g/m^2
Under the seat	White plastic with large mesh	0.6 mm	575g/m^2
Shell	metallic		

Seat “C03”



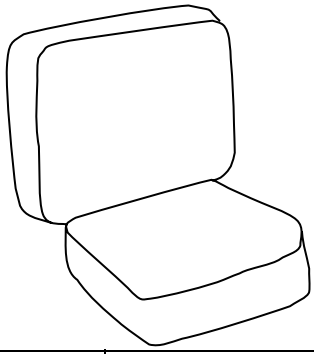
	Colour	Thickness (mm	Density
Fabric	Light brown false skin	0.8 mm	710g/m^2
Foam	Yellow	Seat: max 11 cm Back: max 7 cm Behind the back: max 3 cm	Seat+back: 0.10g/cm^3 Behind the back: 0.18g/cm^3
Interliner	Large white mesh, tied to the foam	0.9 mm	Seat (glue): 275g/m^2 Back (glue): 475g/m^2
Under the seat	White plastic with large mesh, tied to the foam	0.7 mm	550g/m^2
Shell	metallic		



Seat “C04”

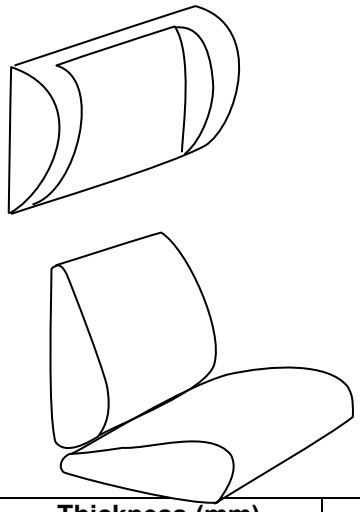
	Colour	Thickness (mm)	Density
Fabric	Blue with random green lines (hard to cut)	1.7 mm	9.5g/m^2
Foam	Light yellow. Metallic structure inside		Impossible to establish
Interliner	Grey cloth (glued to foam)		
Shell	metallic		

Seat "C05"



	Colour	Thickness (mm)	Density
Fabric	Orange with lighter vertical lines	3.4 – 1.1 mm	600g/m^2
Foam	White – light yellow	Seat: max 9.5 Back: max 13.0	0.18g/cm^3
Interliner	Seat: black cloth (glued to fabric) Back: nothing	Seat: 4 mm	Seat: 240g/m^2
Shell	Metallic under the seat and 2mm plastic board under the back		

Seat "C07"

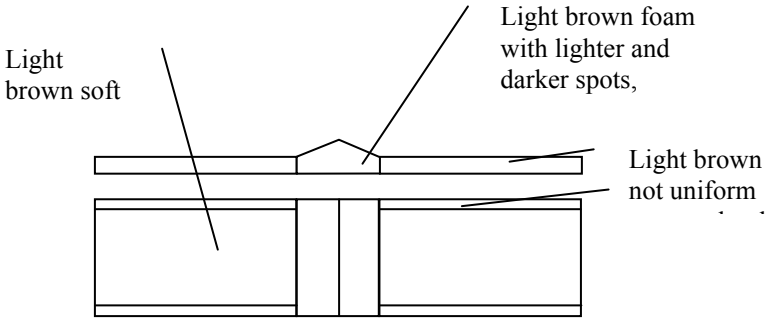


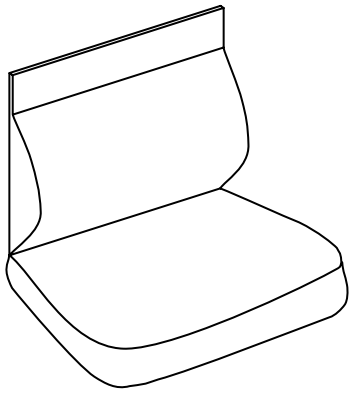
	Colour	**Thickness (mm)**	**Density**
Fabric	Dark brown false skin	1.2 mm	875g/m^2
Foam	Seat: white Back: yellow	Seat: max 13 cm Back: max 8 cm	Seat: 0.12g/cm^3 Back: 0.09g/cm^3
Interliner	Seat: grey-green felt with lighter and darker spots glued to foam Back: white glued to foam	Seat: 2.0 mm Back: 5.0 – 2.25 cm	Seat: 710g/m^2 Back: 1190g/m^2

Arm	Dark brown false skin (no interliner) Foam: White – light yellow	Fabric: 1.2 mm	Fabric: 875g/m^2 Foam: 0.19g/cm
Headrest	Dark brown false skin (no interliner) Foam: White – light yellow	Fabric: 1.2 mm	Fabric: 875g/m^2 Foam: 0.14g/cm^3
Shell	metallic		

Light brown foam with lighter and darker spots, harder 0.74g/cm^3
Light brown not uniform foam, harder 0.25g/cm^3

Seat "C08" / "C09"





Seat "C08"

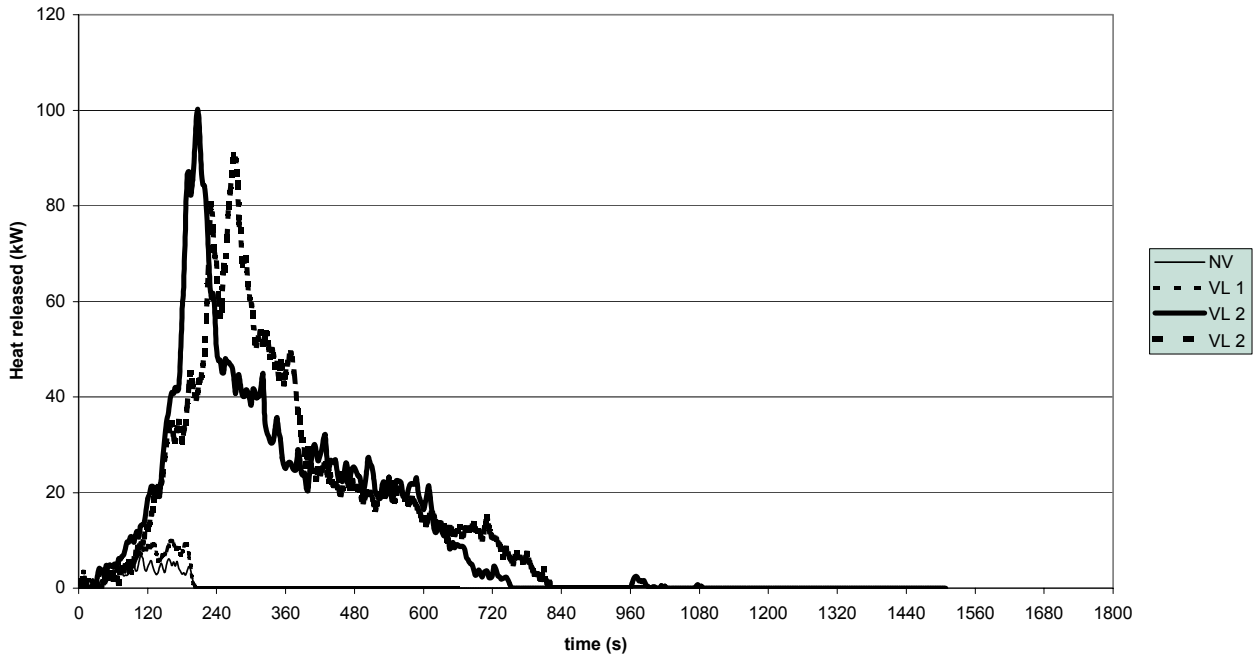
	Colour	Thickness (mm)	Density
Fabric	Pink velvet with diagonal blue lines	1.1 mm	380g/m^2
Foam	Seat+back: grey Upper part of the back: black.	Seat: max 12 cm Back: max 11 cm Upper part of the back:13 mm	Seat+back:0.09g/cm^3 Upper part of the back: 0.07g/cm^3
Interliner	Nothing		
Headrest	Fabric: grey plastic with diagonal lines of pink dots Foam: light brown soft.	Fabric: 0.9 mm Foam: 3 cm	Fabric: 800g/m^2 Foam: 0.14g/cm^3
Shell	Plywood		

Seat "C09"

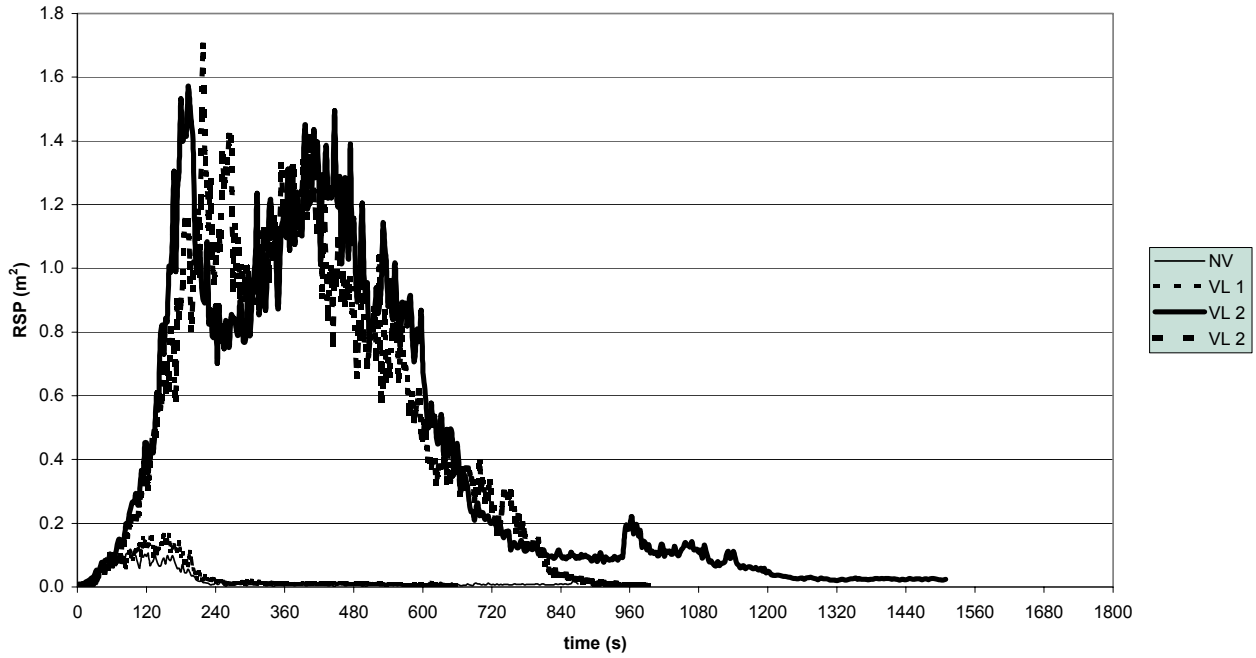
	Colour	Thickness (mm)	Density
Fabric	Blue velvet with yellow, green, violet and orange dots		550g/m^2
Foam	Grey	Seat: 11-12 cm Back: 11 cm	0.09g/cm^3
Interliner	nothing		
Headrest	Fabric: dark grey plastic Foam: light brown soft foam	Fabric: 0.9 mm Foam: 3 cm	Fabric: 800g/m^2 Foam: 0.14g/cm^3
Shell	Plywood		

ANNEX 2 : Vector data on heat released and smoke production

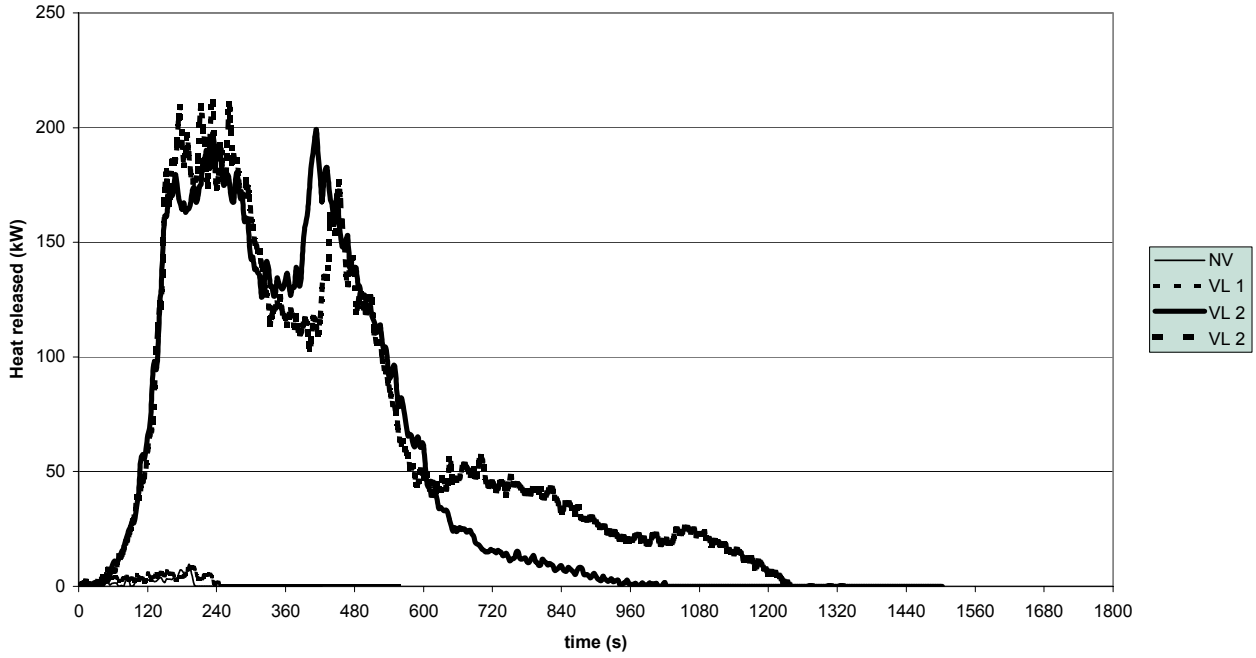
Firestarr WP7.2 - Large scale test on furniture products
Seat C01 at different Vandalism levels - Heat released



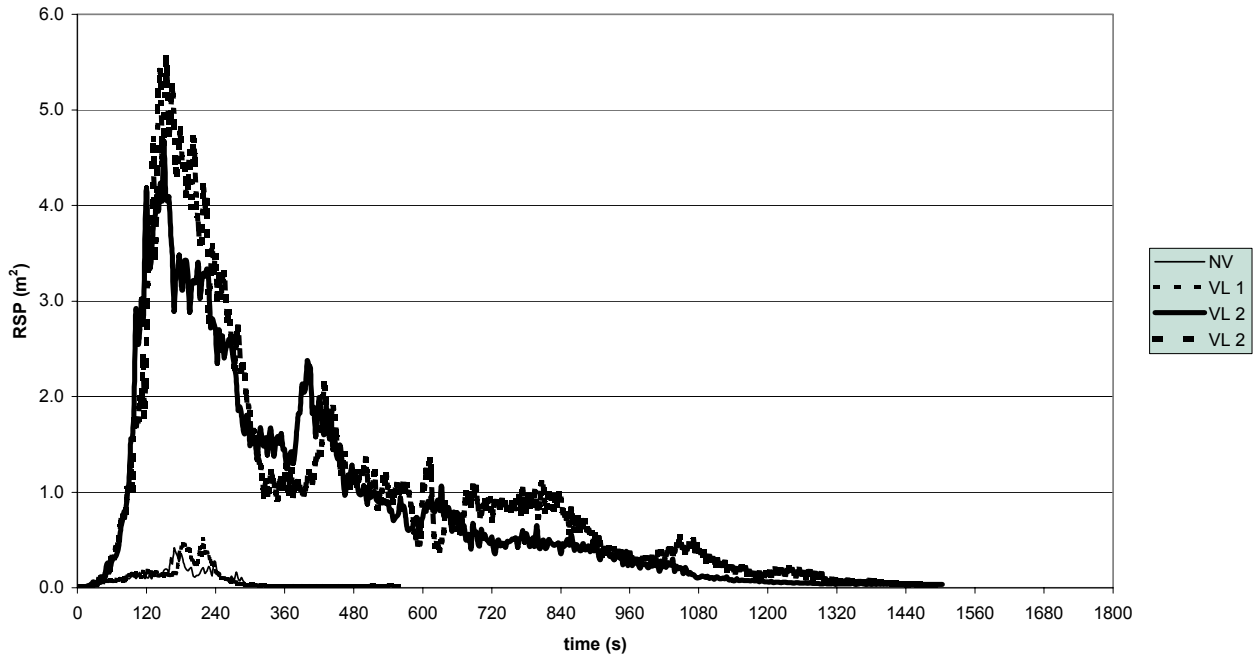
Firestarr WP7.2 - Large scale test on furniture products
Seat C01 at different Vandalism Levels - Rate of Smoke Production



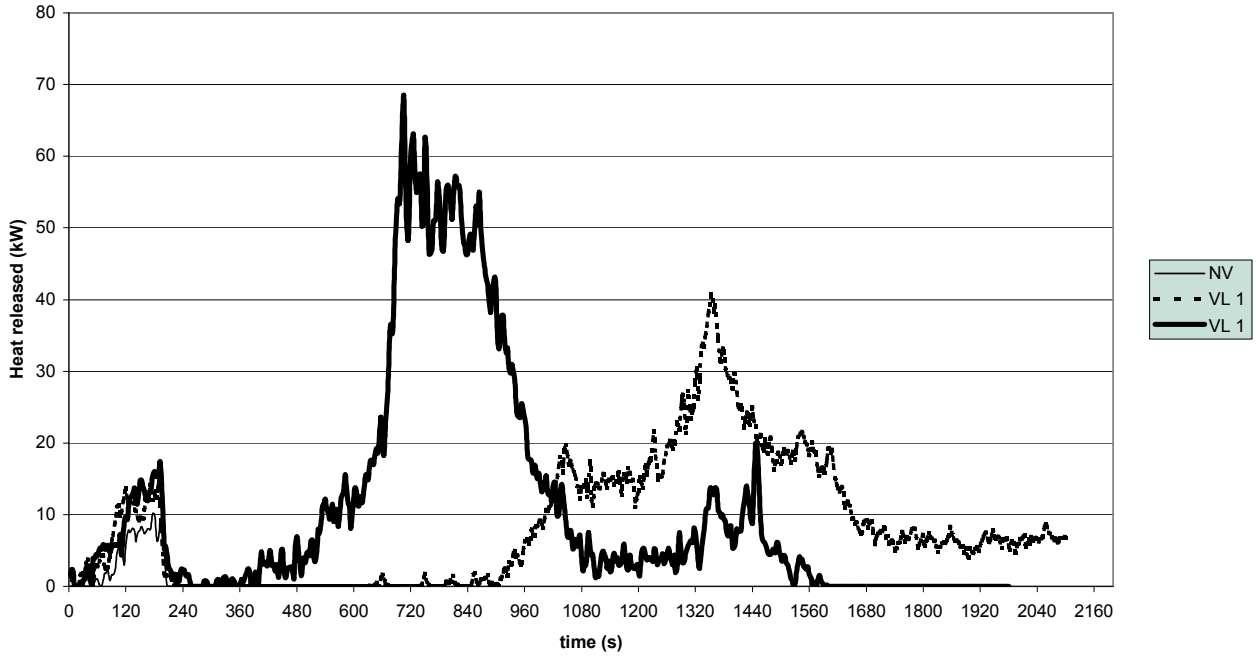
Firestarr WP7.2 - Large scale test on furniture products
Seat C02 at different Vandalism levels - Heat released



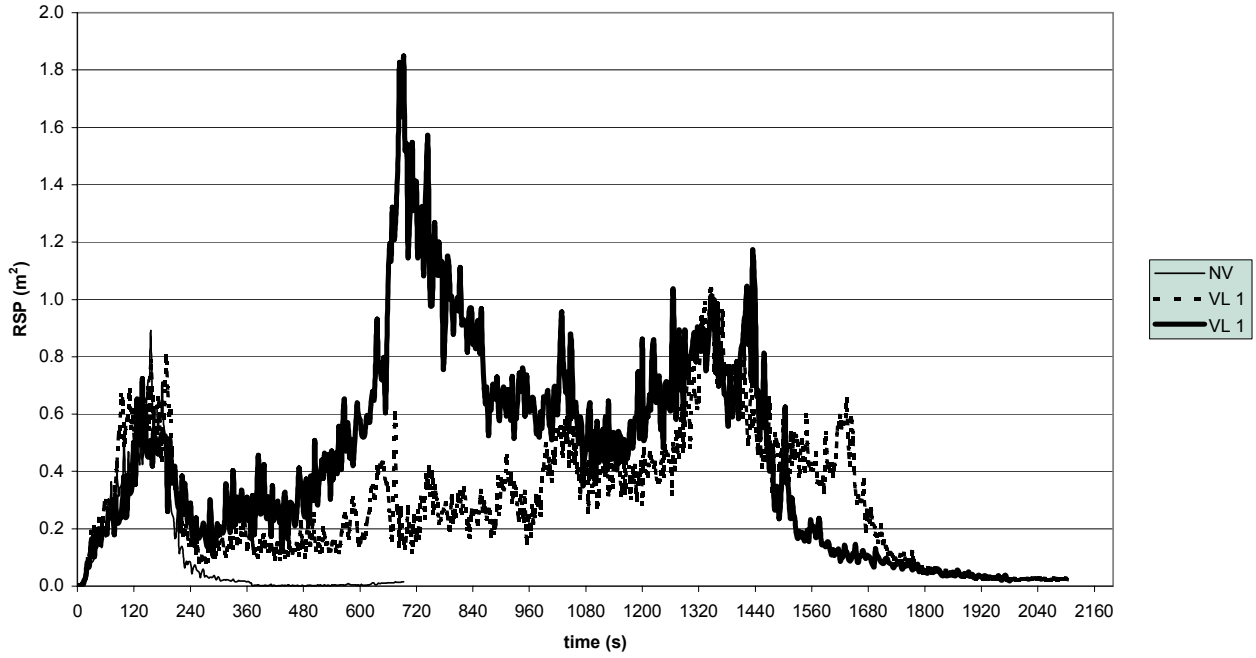
Firestarr WP7.2 - Large scale test on furniture products
Seat C02 at different Vandalism Levels - Rate of Smoke Production



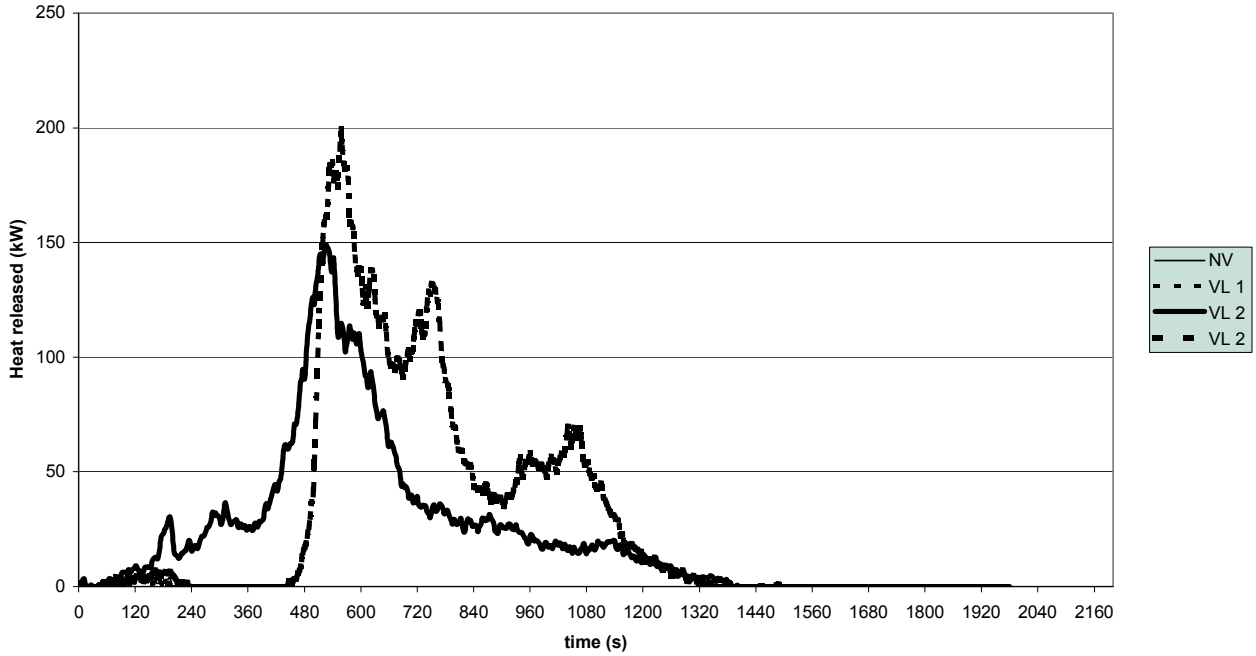
Firestarr WP7.2 - Large scale test on furniture products
Seat C03 at different Vandalism levels - Heat released



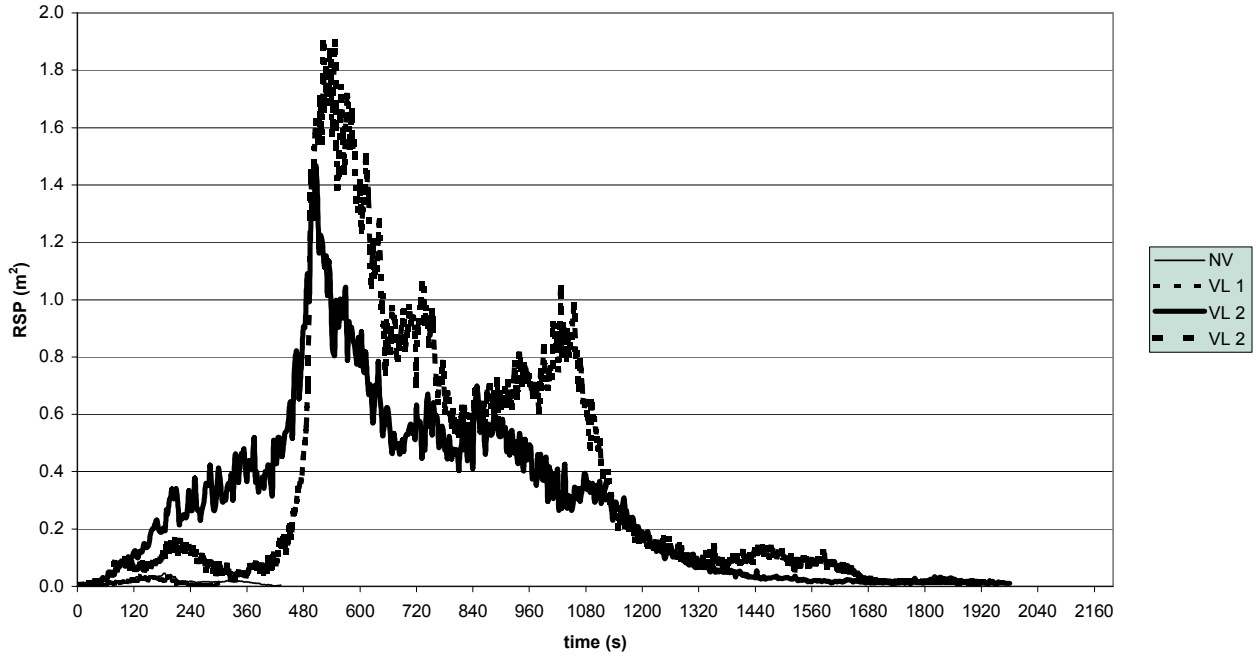
Firestarr WP7.2 - Large scale test on furniture products
Seat C03 at different Vandalism Levels - Rate of Smoke Production



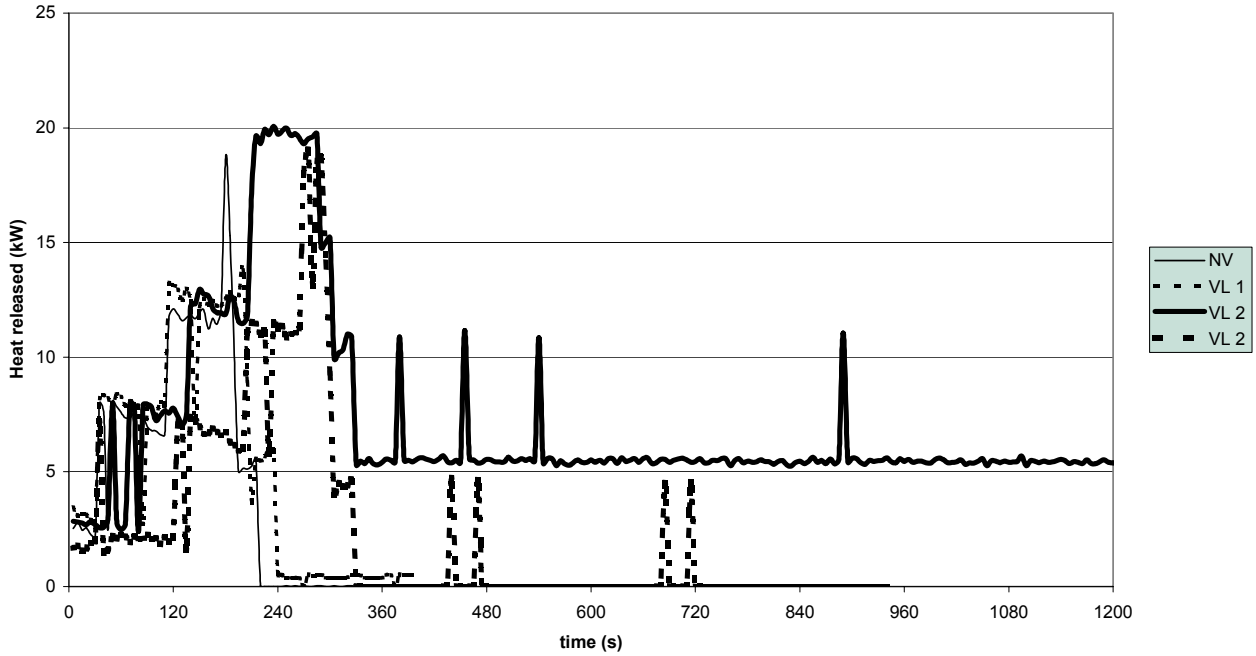
Firestarr WP7.2 - Large scale test on furniture products
Seat C04 at different Vandalism levels - Heat released



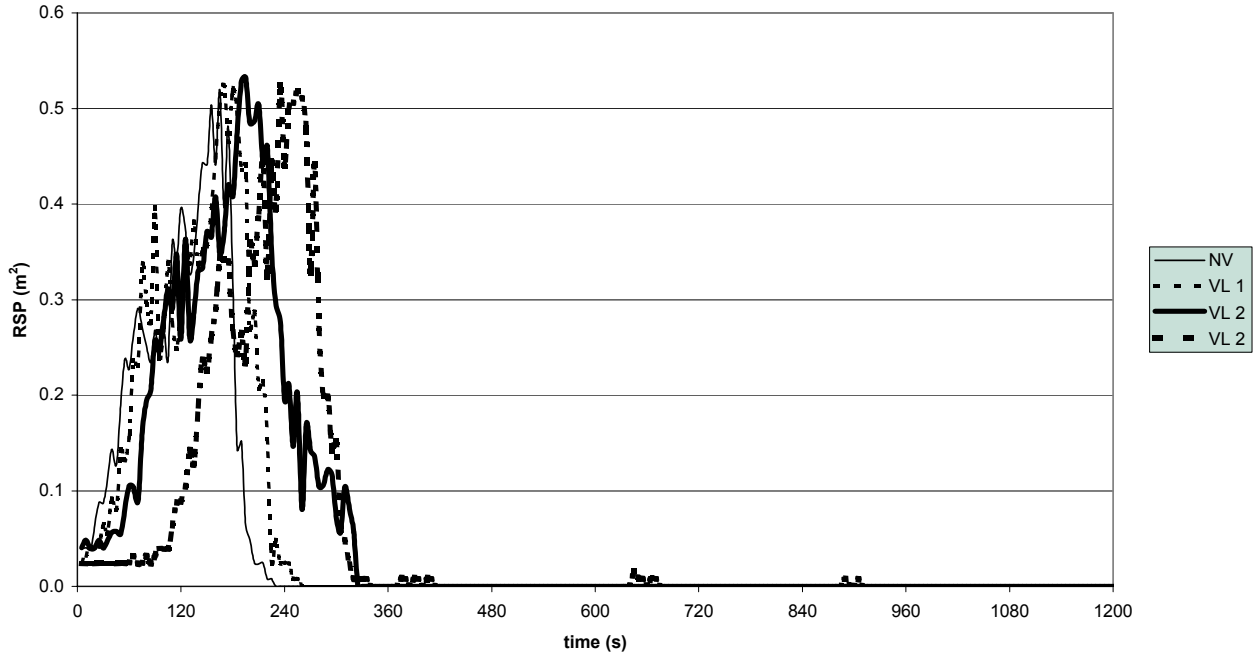
Firestarr WP7.2 - Large scale test on furniture products
Seat C04 at different Vandalism Levels - Rate of Smoke Production



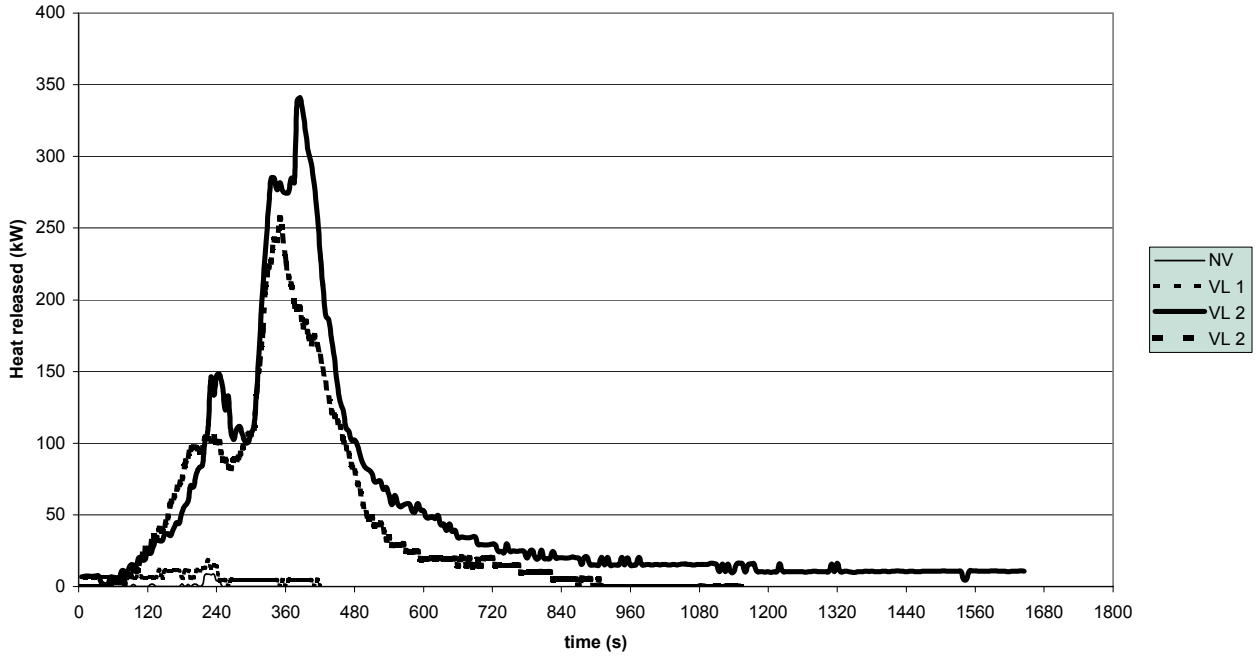
Firestarr WP7.2 - Large scale test on furniture products
Seat C05 at different Vandalism levels - Heat released



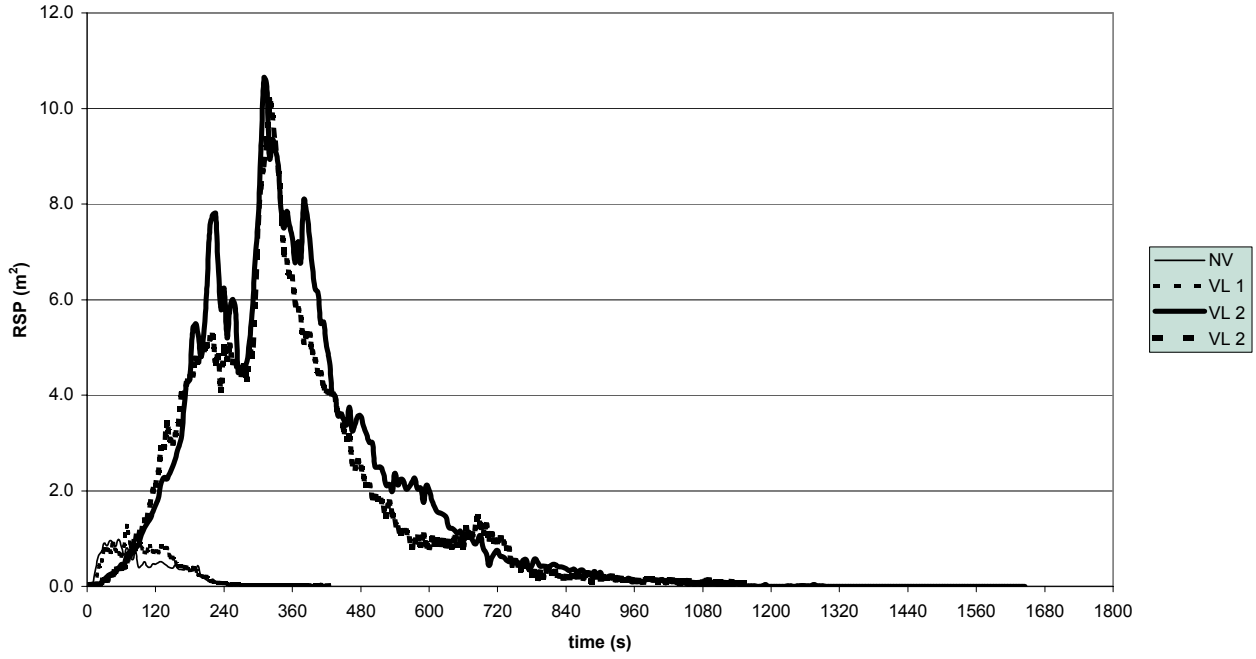
Firestarr WP7.2 - Large scale test on furniture products
Seat C05 at different Vandalism Levels - Rate of Smoke Production



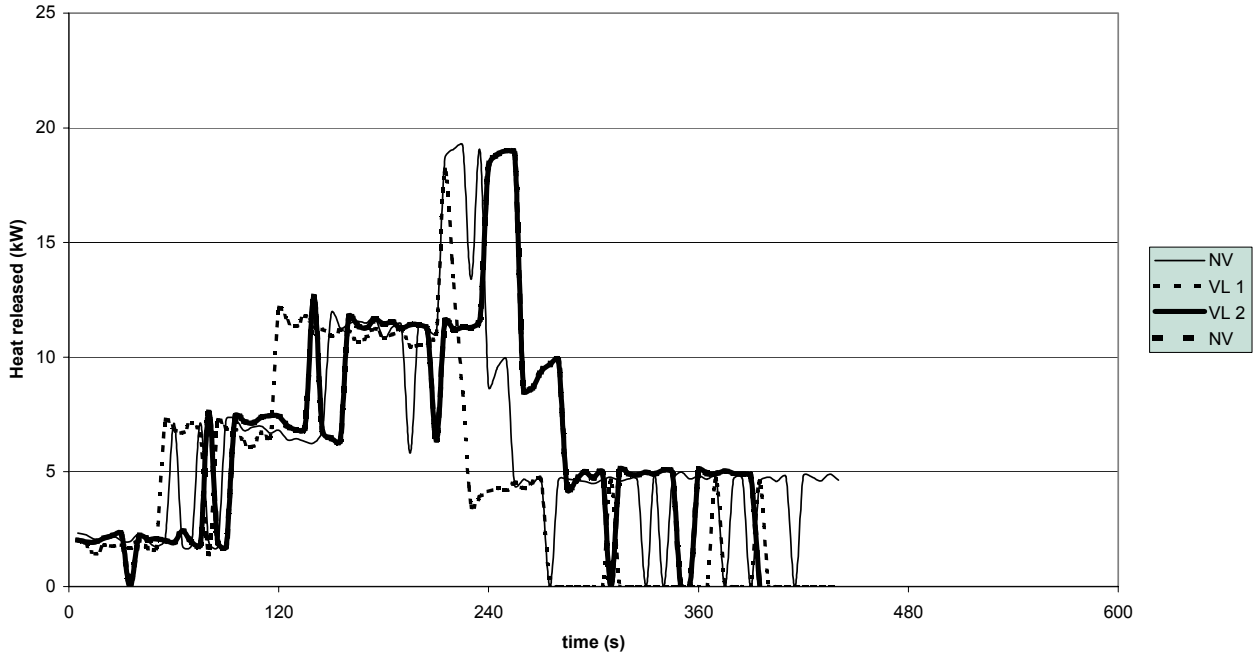
Firestarr WP7.2 - Large scale test on furniture products
Seat C07 at different Vandalism levels - Heat released



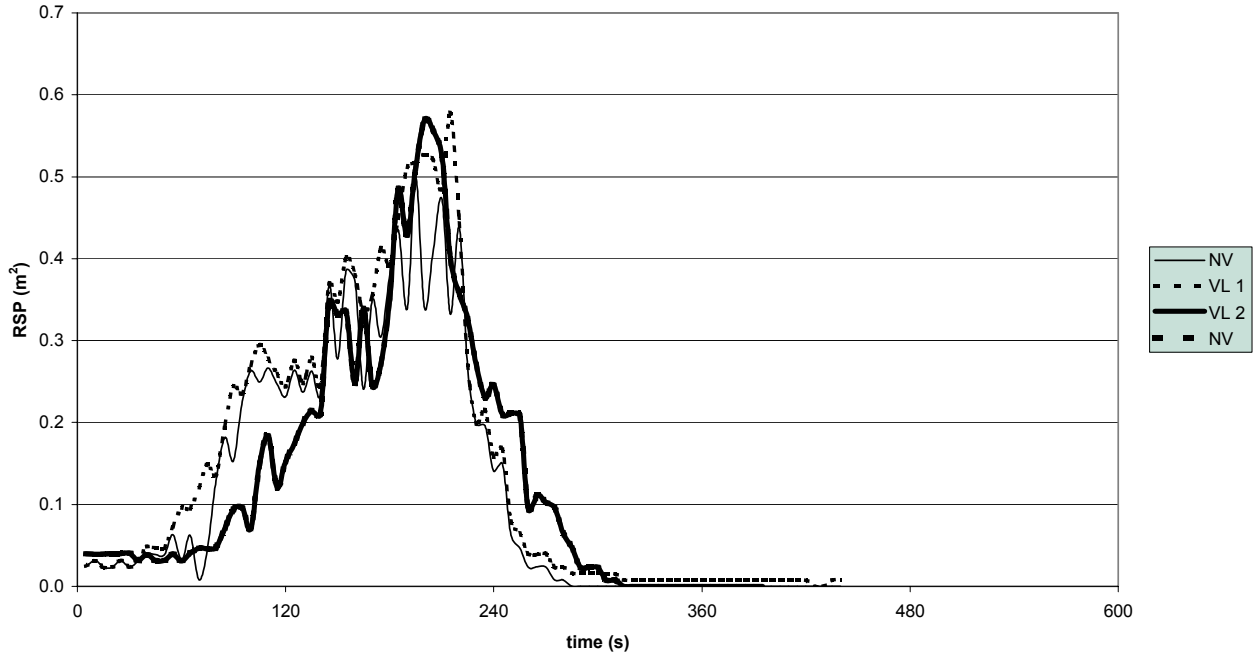
Firestarr WP7.2 - Large scale test on furniture products
Seat C07 at different Vandalism Levels - Rate of Smoke Production



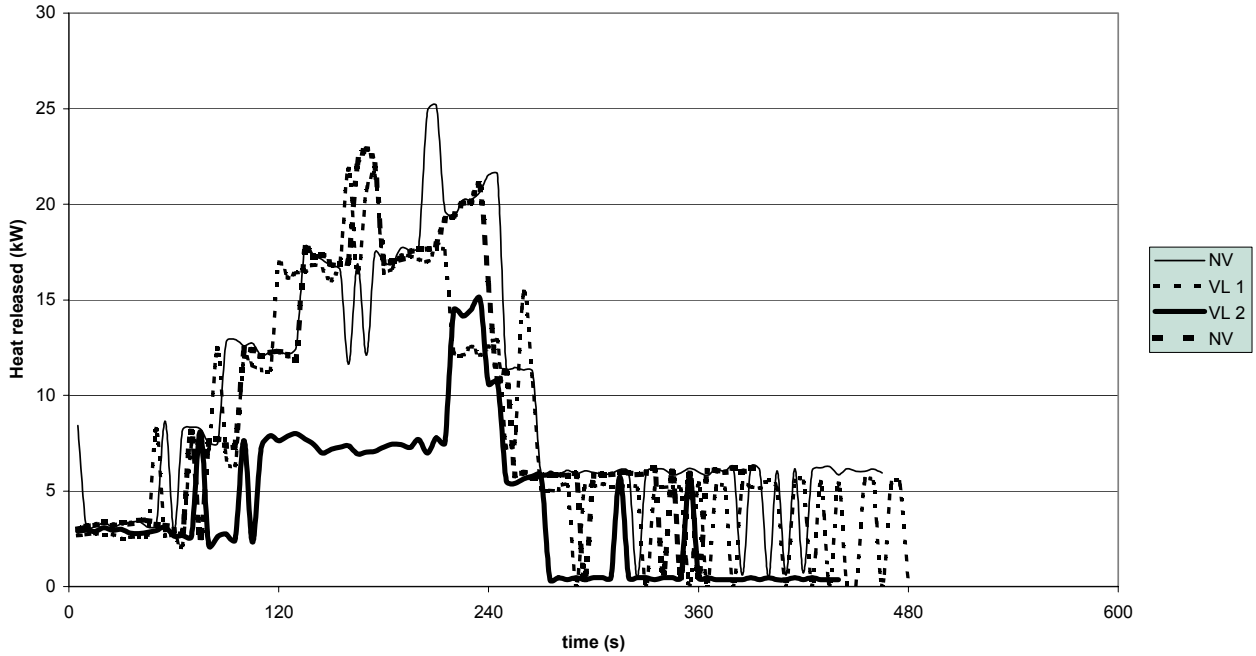
Firestarr WP7.2 - Large scale test on furniture products
Seat C08 at different Vandalism levels - Heat released



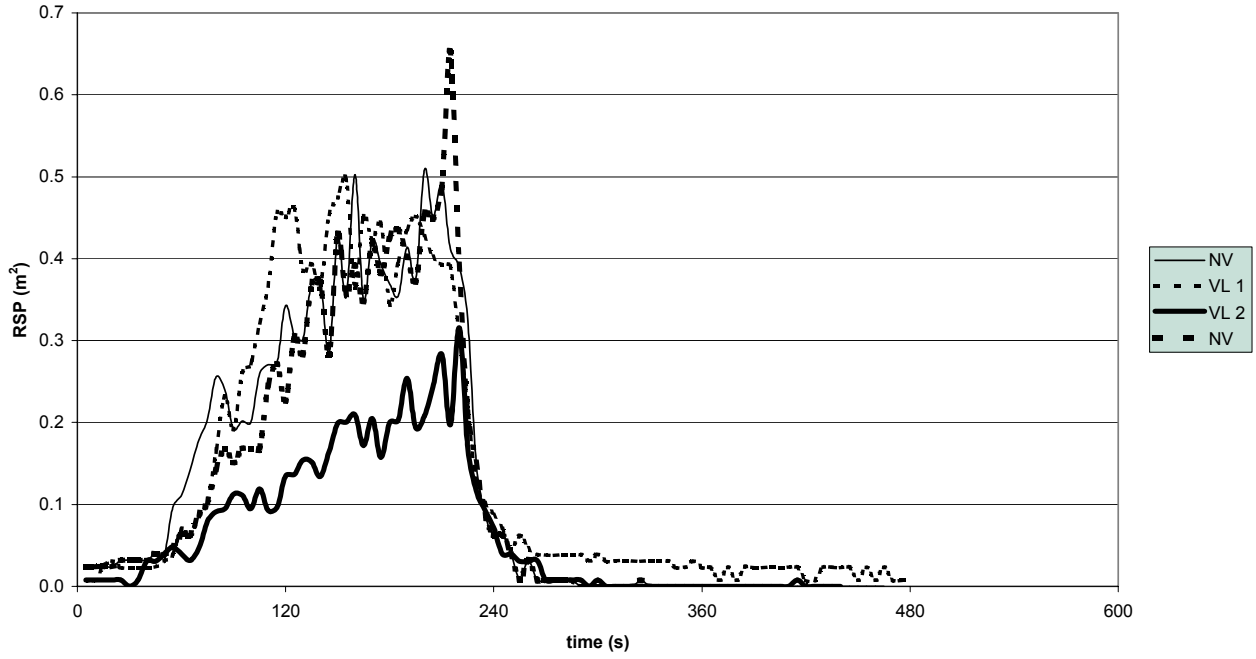
Firestarr WP7.2 - Large scale test on furniture products
Seat C08 at different Vandalism Levels - Rate of Smoke Production



Firestarr WP7.2 - Large scale test on furniture products
Seat C09 at different Vandalism levels - Heat released



Firestarr WP7.2 - Large scale test on furniture products
Seat C09 at different Vandalism Levels - Rate of Smoke Production



ANNEX 3 : Toxicity

Annex A

Toxicity : Analysis of fire effluents

A3.1 Test procedure

A3.1.1 Sampling procedure

In large scale test experiments the fire effluents are collected in the exhaust duct and driven through a sampling line to the analysers. The principle of the sampling in the exhaust duct is shown in figure A3.1.

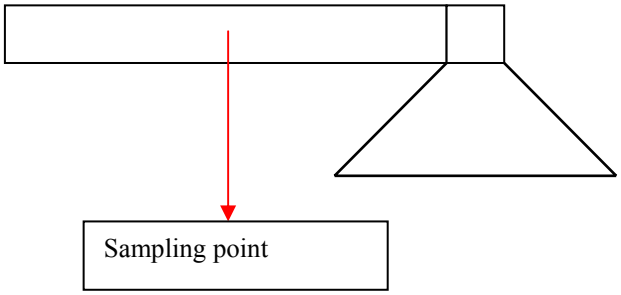


FIGURE A3.1 : SAMPLING OF FIRE EFFLUENT IN LARGE SCALE.

The sampling point is positioned in the exhaust duct at a sufficient distance from the fire to avoid the heterogeneity of the gas mixture and also to restrict the possibility of turbulence near the sampling point. The figure A3.1 of the present report detailed the sampling conditions for gas analysis.

The probe is positioned in the geometric centre of the exhaust duct and the holes (when relevant) are positioned down stream to avoid clogging. The probe could be a multi hole one or a “end hole” probe.

The fire effluents are driven to the analytical part through a heated sampling line to avoid condensation of gases. The line has to be kept as short as possible to minimise sample looses. The air flow in the sampling line is 6 to 8 L/min.

A3.1.2 Analytical methods

Two laboratories where involved in the WP7.2. The WP3 toxicity recommended different analytical methods. They have been compared in the first stage of the project (calibration trial).

The two laboratories carried out the sampling and the analysis of gases using FTIR (Fourrier Transformed Infra Red). The two laboratories applied the recommendation of the SAFIR project. The gases analysed for the first laboratory are : CO, CO_2, HCl, HCN, HF HBr, NOx, and SO_2. The FTIR calibration for the other gases (analysed in small scale) was not available at the time of analysis then only semi qualitative analysis are available.

Gases	Detection limit
CO	10 ppm
HCl	5 ppm
HBr	10 ppm
HCN	2 ppm
HF	2 ppm
NOx	10 ppm
SO_2	3 ppm

TABLE A3.1 : FTIR detection limit (used in WP7.2)

The sampling line and the filter(s) are washed in order to analyse the total amount of gases. The analysis of gases are performed with titration methods.

The WP3 – toxicity evaluation part 2 report gives detailed on the analytical methods and their uses.

A3.2 Test results

The results for the 8 seats tested in WP 7.2 are summarised in tables A3.2 and A3.3. The FED versus time curves is also shown in figure A3.2.

When components were tested in small scale tests, only complete seats are tested in large scale : the seat shells are involved in the combustion process.

Remark :
- C1, C2, C3, C4 and C7 have metallic external shell
- C4 has also plastic armrests and headrests (both of them melted during the test.)
- C5 has a metallic shell under the seat and 2 mm plastic board under the back.(during tests the plastic sheet was not involved in fire).
- C8 and C9 have plywood shell for back and seat (not reached by fire).

Test	C 1_1	C 1_2	C 1_3	C 2_1	C 2_2	C 2_3	C 3_1	C 3_2	C 4_1	C 4_2	C 4_3
$CO_{2\ (amount\ in\ g)}$	0	0	2525.0	0	0	7350	0	2235	0	0	5630
CO (amount in g)	0	0	107.00	2.8	0	300	0	96.35	0	0	136.5
HCN (amount in g)	0	0	10.100	0	0	5.3	0	4.7	0	0	6.9
HCl (amount in g)	0	0	13.00	7.05	0	251.5	0	146.5	0	0	16.55
HF (amount in g)	0	0	0	0	0	0	0	0	0	0	0
HBr (amount in g)	0	0	0	0	0	0	0	0	0	0	0
$SO_{2\ (amount\ in\ g)}$	0	0	19.20	0	0	43.9	0	0	0	0	21.55
NOx (amount in g)	0	0	0	0	0	28.2	0	0	0	0	16.35
Acrolein (amount in g)	0	0	0	0	0	0	0	0	0	0	0
Formaldehyde (in g)	0	0	0	0	0	0	0	0	0	0	0

Test	C 5_1	C 5_2	C 5_3	C 7_1	C 7_2	C 7_3	C 8_1	C 8_2	C 8_3	C 9_1	C 9_2	C 9_3
$CO_{2\ (amount\ in\ g)}$	108.4	91.6	173.4	91.3	137.1	3372.1	96.6	176.3	137.1	210.7	179.1	117.4
CO (amount in g)	2.58	1.44	13.10	4.36	4.37	267.31	0.30	3.14	2.91	3.45	17.15	2.98
HCN (amount in g)	0	0	0	0	0	13.60	0	0	0	0	0	0
HCl (amount in g)	0	0	0.00065	0	0	150.66	0	0	0	0	0	0
HF (amount in g)	0	0	0	0	0	0	0	0	0	0	0	0
HBr (amount in g)	0	0	0.00005	0	0	0.00025	0	0	0	0	0	0
$SO_{2\ (amount\ in\ g)}$	0	0	0	0	0	0	0	0	0	0	0	0
NOx (amount in g)	0	0	0	0	0	0	0	0	0	0	0	0
Acrolein (amount in g)	0	0	0	0	0	0	0	0	0	0	0	0
Formaldehyde (in g)	0	0	0	0	0	0	0	0	0	0	0	0

TABLE A3.2 : Seats in large scale - Total amount of gases in g.

Test	FED	FED corridor	time to FED = 1 (corridor)	CO/CO2
C 1_1	0.0000	0.0000		/
C 1_2	0.0000	0.0000		/
C 1_3	0.0190	0.4790		0.35
C 1_4	0.0180	0.4670		0.35
C 2_1	0.0000	0.0000		0.00
C 2_2	0.0000	0.0000		0.00
C 2_3	0.0850	2.1420	5 min	0.42
C 2_4	0.0997	2.5120	4 min 30	0.49
C 3_1	0.0008	0.0210		/
C 3_2	0.0109	0.2759		0.18
C 3_3	0.0201	0.0507		0.31
C 4_1	0.0000	0.0000		/
C 4_2	0.0000	0.0000		/
C 4_3	0.0297	0.7470		0.21
C 4_4	0.0411	1.0350	18 min 40	0.23
C 5_1	0.0001	0.0021		0.37
C 5_2	0.0001	0.0012		0.25
C 5_3	0.0000	0.0003		0.03
C 5_4	0.0009	0.0217		1.86
C 7_1	0.0002	0.0038		0.74
C 7_2	0.0002	0.0039		0.50
C 7_3	0.0399	1.0065	21 min 40	1.30
C 7_4	0.0290	0.7310		1.16
C 8_1	0.0000	0.0002		0.06
C 8_2	0.0001	0.0026		0.28
C 8_3	0.0001	0.0015		0.17
C 8_4	0.0001	0.0036		0.03
C 9_1	0.0001	0.0033		0.30
C 9_2	0.0006	0.0155		1.75
C 9_3	0.0000	0.0000		/
C 9_4	0.0002	0.0056		0.73

TABLE A3.3 : FED , time to reach FED =1 and CO/CO_2 ratio.

The FED (fractional effective dose) is calculated according to ISO 13 344 standard. The calculated values and the CO/CO2 ratio are listed in table A3.3.
FED in corridor is calculated for a 40 m^3 volume which represent a corridor and 2 compartments (10 m^3) in a railway carriage. The hypothesis of a non ventilated “corridor is considered in order to simplify the calculation. (The measurement of gases used for the estimation in a corridor are performed in the duct of the NT FIRE 032 – furniture calorimeter)

The fire critical effect (FCE) on lethality is reached when FED = 1. The FED = 1 is reached only for PS05 in duct condition measurement. In the hypothesis of gases going through the corridor the lethality FCE is reached for 4 tests :

- Combination 2 : vandalised level 2 (back of the seat cut and fabric taken out of the foam)
- Combination 4 : vandalised level 2
- Combination 7 : vandalised level 2

The participation of each gas to the FED is estimated with the representative percentage of ratio $Ci/LC_{50,Ci}$ to the FED.

The figure A3.2 presented the participation in % to FED for the seats tested in WP7.2.

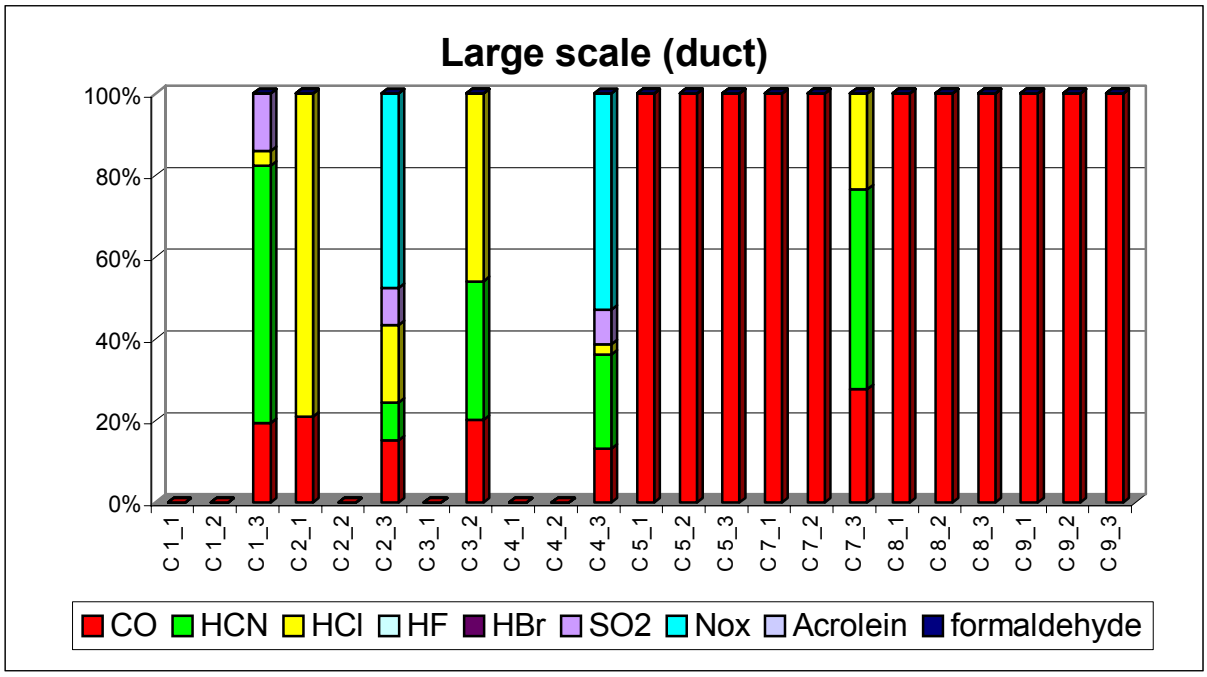


Figure A3.2 : Participation to FED in % (when two replicates for one condition results given for the mean)

A3.3 Conclusion

The lethality fire critical effect can be reached for seats tested in large scale test for the hypothesis of gases going through the corridor.

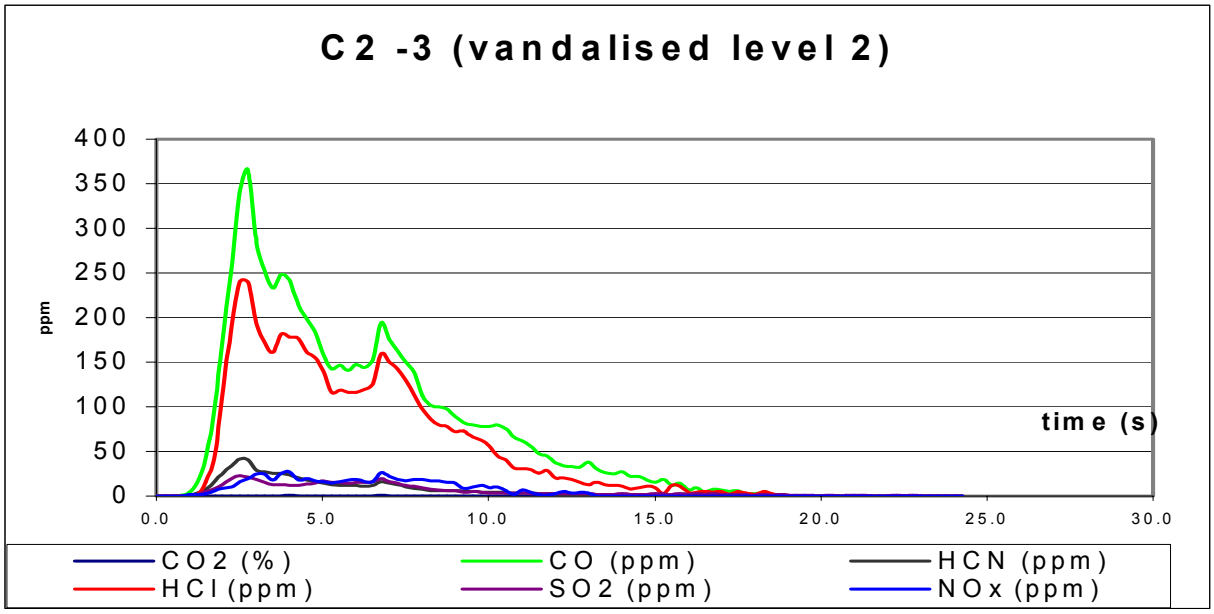
The main conclusion is that in large scale FED =1 can be obtained for burning seats. The toxicity must be evaluated and considered for a classification of product used on railway.

For seats that conducted to FED =1, the figure A3.2 shows that CO is not the main contribution to the FED value. These results confirm the necessity to analyse not only CO and CO_2 but also the main toxicants: HCl, HBr, HF,HCN, SO_2, NOx (when analytical methods are available aldehyde must also be analysed because of their low LC50 values).

The FTIR method used for the purpose of this work package has been proved relevant for toxic gases analysis. The SAFIR protocol (also described in a DRAFT ISO standard) allows the direct analysis of gases and gives important information on the kinetic of evolved gases.

ANNEXE :

FIGURE A3.3 : example of kinetic curves- production of gases from burning seats.



Ranking of materials – FED increasing

Rank	Material
1	**C 1_1**
2	**C 1_2**
3	**C 2_1**
4	**C 2_2**
5	**C 4_1**
6	**C 4_2**
7	**C 9_3**
8	**C 8_1**
9	**C 5_3**
10	**C 5_2**
11	**C 8_3**
12	**C 5_1**
13	**C 8_2**
14	**C 8_4**
15	**C 9_1**
16	**C 7_1**
17	**C 7_2**
18	**C 9_4**
19	**C 9_2**
20	**C 3_1**
21	**C 5_4**
22	**C 3_2**
23	**C 1_4**
24	**C 1_3**
25	**C 3_3**
26	**C 7_4**
27	**C 4_3**
28	**C 7_3**
29	**C 4_4**
30	**C 2_3**
31	**C 2_4**

Yellow cells means FED =0