Assessment of the adequacy of fire behaviour tests for cables

Programme d'appui scientifique à la normalisation et aux réglementations techniques

Rapport final

N° NM/G7/38

Politique scientifique fédérale

Hervé BREULET & Thibaut STEENHUIZEN

INSTITUT SCIENTIFIQUE DE SERVICE PUBLIC
Rue du Chéra 200
B-4000 LIÈGE

Table of contents

1. Executive Summary

Résumé: Evaluation de la Pertinence d'Essais de tenue au Feu de Câbles

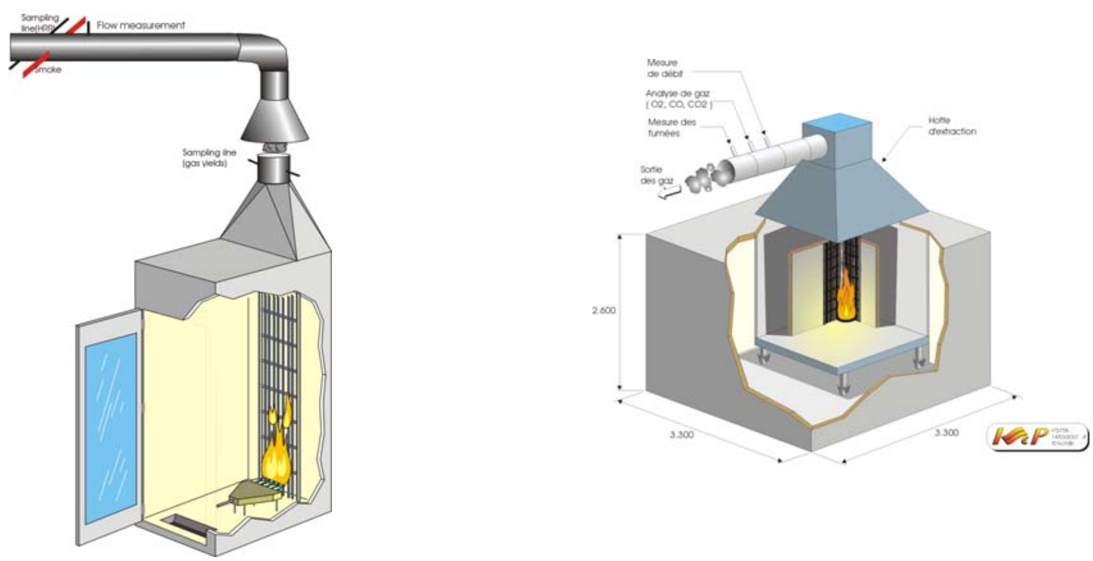
A. Contexte

Il est maintenant acquis que les câbles électriques (et les câbles à fibres optiques) doivent être inclus dans l'ensemble des directives « Produits de Construction » (89/106/EC). Par conséquent, il est nécessaire de disposer d'un système Euroclasses adéquat. Le système défini pour les produits communs de construction est basé principalement sur l'essai SBI (Single Burning Item – Objet Isolé en Feu, décision 2000/147/EC).
Ce test est il adapté aux « produits longs », la question reste ouverte.

Deux propositions concurrentes relatives aux câbles ont étés déposées :

1. Europacable[1] a suggéré un système inspiré du test EN 50266-2 (équivalent à la CEI 60332-3), amélioré grâce aux innovations issues du projet FIPEC[2]. Deux scénarios différents ont été proposés afin d'autoriser une meilleure discrimination des câbles à hautes performances feu (i.e. câbles recommandés pour des gaines inaccessibles ou masquées).
2. La préférence du CFRA[3] va au SBI, moyennant des adaptations liées aux essais câble. Ils considèrent ce test comme étant plus pertinent pour l'évaluation des câbles « plénum ».

Bien que chaque méthode a été testée individuellement dans des programmes spécifiques de recherche (initialement dans FIPEC et ensuite dans PIT[4] et PII[5], il n'existait pas de comparaison plus approfondie.



IEC / FIPEC full-scale test and SBI for cables

---

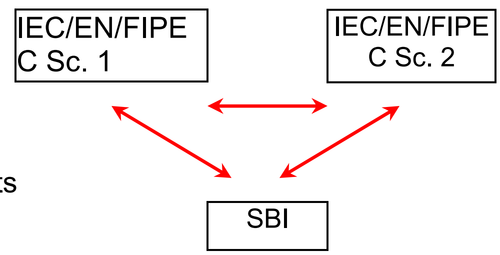
[1] European Confederation of Cables Manufactures
[2] FIPEC : Fire Performance of Electric Cables – New tests methods and measurement techniques
[3] Cable Fire Research Association
[4] Partners in Technology – Study of Cables Insulation in Hidden Voids
[5] Partners in innovation, Harmonization of Reaction to Fire Tests for an "Exotic Product" – Communication Cable

B. Objectifs

La Section Risque Incendie de l'ISSeP a mené à bien une étude plus large, ayant entre autres pour objectifs de comparer les deux méthodes sur un échantillonnage incluant des câbles hautes performances (câbles plénum: LC – Low Combustible, FEP – Fluorinated Ethylene Propylene). Les deux méthodes ont été comparées sur les aspects suivants:

- Capacité à mesurer des paramètres essentiels comme Hauteur de Flamme (Flame Spread), Energie totale dégagée (Total Heat Release), FIGRA[6], Fumées …
- La capacité à discriminer les différents câbles en fonction de leur niveau de performances feu.

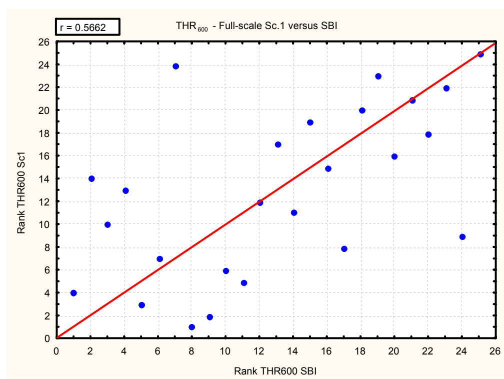
Mesure des fumées : deux familles d'essais ont étés comparées, d'une part les essais « dynamiques » (Full Scale & SBI) et d'autre part les essais « statique » (3 meter cube).



Nous avons également étudié comment ces différents tests peuvent corréler entre eux, grâce à :

- Des corrélations de rang
- Des corrélations linéaires entre les paramètres obtenus

Example of correlation: Spearmann correlation between SBI and Europacable Sc. 1 tests for THR_{600}



Quoique des différences majeures ont été soulevées, chaque méthode a donné des résultats probants pour la majorité des câbles testés, aussi bien en terme de capacité à mesurer les principaux paramètres qu'en terme de discrimination et/ou de classification des câbles. Cela est probablement dû aux conditions d'essai différentes : ventilation, environnement, montage des câbles (il a déjà été démontré précédemment que le montage est un paramètre critique), type de brûleur (brûleur à diffusion contre prémélange)…

C. Conclusions

Des essais à grande échelle éprouvés sont maintenant disponible pour les câbles. Basés sur des techniques de mesure scientifiques, ils offrent assez de sensibilité pour permettre un classement fiable des différents câbles disponibles sur le marché où pourtant leur type de construction et leurs matériaux peuvent être très variés.

---

[6] Fire Growth Rates index

Concernant les mesures de fumées, les mesures dynamiques offrent des améliorations par rapport à l'essais « 3 meter cube ». Néanmoins toutes avouent leur limite pour les câbles « low smoke ».

Pour la plupart des paramètres, il n'y a pas de corrélation bien établie, sauf entre les essais Full Scale Scenario 2 et SBI. L'emploi de paramètres pondérés a amélioré lesdites corrélations.

D. Apport du projet dans un contexte d'appui aux processus de normalisation et de réglementations techniques

Quelques points critiques essentiels ont été soulignés en vue du futur développement des Euroclasses pour les câbles:

- SBI n'autorise pas la mesure de la Hauteur de Flamme (Flame Spread).
- Pour les autres paramètres (THR_{600s}, HRR_{peak}, FIGRA, TSP), les deux méthodes conviennent.
- L'emploi du FIGRA pour la classification peut conduire à des résultats absurdes, i.e. des câbles hautes performances sont relégués dans des mauvaises classes.
- En utilisant les deux scénarios Europacables, il peut être difficile de hiérarchiser les différents classements.

E. Mots clés

Full Scale Test – SBI – Heat Release – FIGRA – Flame Spread - EUROCLASSES – Cables Fire Testing – Smoke Measurements – Correlations – Cable Classification

Samenvatting : Beoordeling van de Geschiktheid van Vuurbestendigheidstests voor Kabels

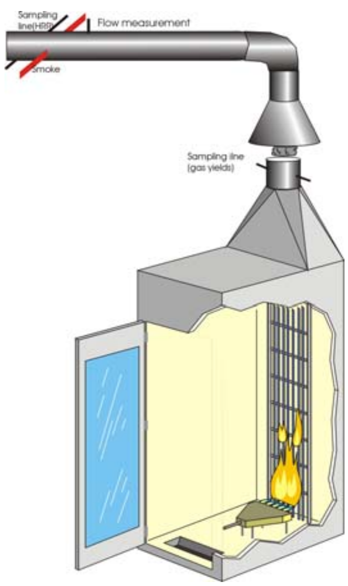
A. Context

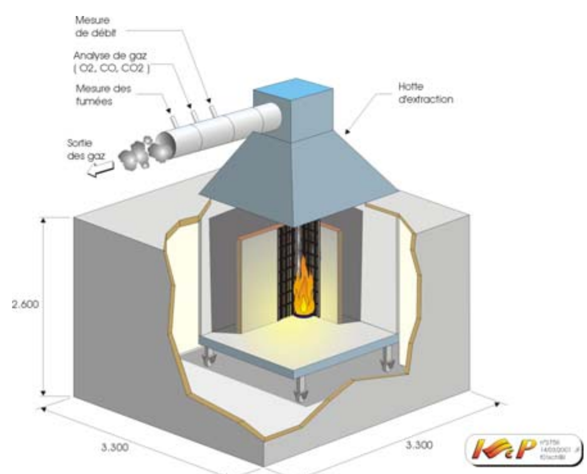
Het is nu erkend dat elektrische kabels (en optische vezelkabels) beschouwd moeten worden binnen het vlak van de Richtlijn Bouwproducten (89/106/EC). Bijgevolg, is een Euroclass systeem geschikt voor kabels vereist. Het systeem dat uitgewerkt werd voor gewone bouwproducten, is gebaseerd op de Single Burning Item (SBI) als hoofdtest (beslissing 2000/147/EC). Het blijft de vraag of een dergelijke test geldig is voor lineaire producten.

Er werden twee voorstellen in mededinging ingediend betreffende kabels:

1. Europacable[7] heeft een systeem gesuggereerd dat berust op de EN 50266-2 (gelijkwwaardig aan IEC 60332-3) test, met verbeteringen zoals ontwikkeld in het FIPEC[8] project. Er werden twee verschillende scenarii voorgesteld, om het onderscheid mogelijk te maken van kabels met hoge brandprestatie (bijv. zoals vereist voor installatie in bepaalde verborgen lege ruimtes).
2. CFRA[9] gaf de voorkeur aan de SBI, aangepast om het testen van kabels mogelijk te maken. Zij beschouwen een dergelijke test als pertinenter voor de evaluatie van "plenum" kabels[10].

Hoewel elke testmethode individueel beoordeeld werd in specifieke onderzoeksprogramma's (de eerste in FIPEC, de laatste in PIT[11] en PII[12]), was er geen uitgebreide vergelijking van beide tests beschikbaar.





IEC / FIPEC full-scale test   *SBI for cables*

---

[7] European Confederation of Cables Manufacturers
[8] FIPEC: Fire Performance of Electric Cables – New test methods and measurement techniques
[9] Cable Fire Research Association
[10] Het CFRA-voorstel suggereerde in een bepaald stadium SBI enkel te gebruiken voor communicatiekabels
[11] Partners in Technology – Study of cable Insulation Fires in Hidden Voids.
[12] Partners in Innovation, Harmonisation of Reaction to Fire Tests for an "Exotic Product" - Communication Cable

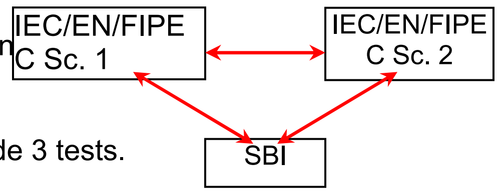
B. Doelstellingen

Ons laboratorium heeft recent een uitgebreide studie[13] afgewerkt, waarvan de doelstellingen, onder andere, waren deze 2 testmethodes te vergelijken, voor een staal van kabels met inbegrip van hoge prestatiekabels (plenum kabels: LC –Low Combustible, FEP – Fluorinated Ethylene Propylene).
De methodes werden vergeleken in termen van:

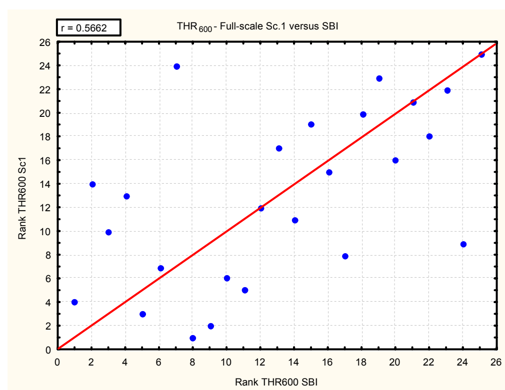
- Geschiktheid om de essentiële parameters te meten: Flame Spread (FS), Total Heat Release (THR), FIGRA, Total Smoke Production (TSP)
- Onderscheiding (d.w.z. geschiktheid om kabels te onderscheiden, welk ook hun brandprestatieniveau is)

Wij hebben ook onderzocht of de tests onderling konden correleren, door middel van:

- Correlaties van orde van classificering
- Lineaire correlaties tussen parameters bekomen bij de 3 tests.



Voorbeeld van correlatie: Spearmann correlatie tussen SBI en Europacable Sc. 1 tests voor THR_{600}



Hoewel elke methode toepasselijk werd bevonden voor de meeste geselecteerde kabels, werden verschillende verschillen duidelijk gemaakt, zowel in termen van geschiktheid voor de meting van de voornaamste parameters en de onderscheiding en / of kwalificering van de kabels. Dit was te verwachten, vermits de testomstandigheden niet vergelijkbaar zijn : ventilatie, omgeving, opstelling van de kabels (er werd eerder aangetoond dat de opstellingsprocedure de invloedrijkste parameter is t.o.v. de testresultaten), type van brander (voorgemengd t.o.v. diffusievlam),…

C. Besluiten

Er zijn nu bewezen ruimschalige kalorimetrietests beschikbaar voor kabels. Gebaseerd op wetenschappelijk stevige meettechnieken, bieden ze voldoende gevoeligheid om een sterke classificering mogelijk te maken van de verschillende op de markt verkrijgbare kabeltypes, waar hun opbouw en gebruikte materialen grote verschillen kunnen vertonen.

---

[13] *Assessment of the Adequacy of Fire Behaviour Tests for Cables, Belgian Science Policy project, 2000-2003*

Voor de meeste parameters, werd er geen stevige correlatie gevonden tussen de methodes. Het wegen van de parameters (bijv. THR per lengte-eenheid kabel) zou de correlatie kunnen verbeteren.

D. Bijdrage van het project in een context van ondersteuning aan het proces inzake normalisatie en technische regelgeving

Er werden enkele kritische vaststellingen aangewezen, die essentieel zijn t.o.v. de ontwikkeling van toekomstige Euroclasses voor kabels:

- SBI maakt het niet mogelijk de kabels te classificeren in termen van FS.
- Voor andere parameters (THR_{600s}, HRR_{peak}, FIGRA, TSP), kunnen beide methodes geschikt zijn.
- Het gebruik van FIGRA voor classificering kan tot nonsensicale resultaten leiden, d.w.z. kabels met topprestaties kunnen naar lagere klassen verwezen worden.
- Met de 2 "Europacable" scenarii, kan op moeilijkheden gestoten worden inzake de hiërarchie tussen klassen.

E. Trefwoorden

Full Scale Test – SBI – Heat Release – FIGRA – Flame Spread - EUROCLASSES – Cables Fire Testing – Smoke Measurements – Correlations – Cable Classification

Abstract : Assessment of the Adequacy of Fire Behaviour Tests for Cables.

.

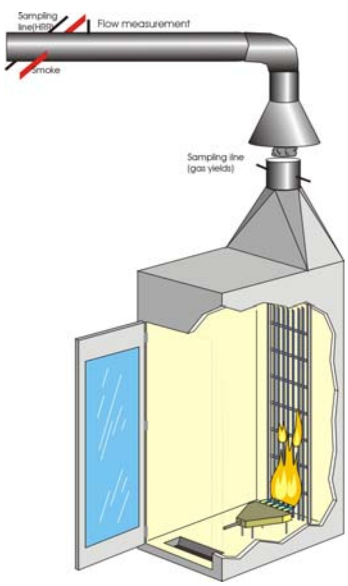
A. Context

It is now acknowledged that electric cables (and optical fibre cables) must be considered within the scope of the Construction Product Directive (89/106/EC). Consequently, a Euroclass system appropriate for cables is required. The system built for common building products is based upon the Single Burning Item (SBI) as main test (decision 2000/147/EC). Whether such a test is valid for linear products remains questionable.

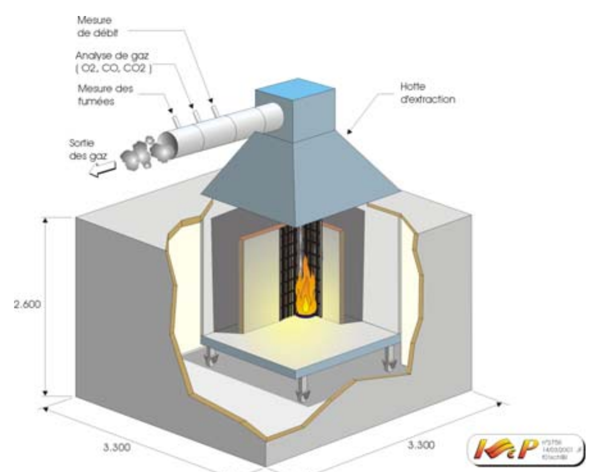
Two competing proposals have been introduced in relation to cables:

1. Europacable[14] has suggested a system built upon the EN 50266-2 (equivalent to IEC 60332-3) test, with improvements as developed in the FIPEC[15] project. Two different scenarios were proposed, in order to permit the discrimination of cables with high fire performance (e.g. as required for installation in some hidden voids).
2. CFRA[16] preferred the SBI, adapted to enable testing of cables. They consider such a test to be more pertinent for the evaluation of “plenum” cables[17].

While each test method has been assessed individually in specific research programmes (the former in FIPEC, the latter in PIT[18] and PII[19]), no extensive comparison of both tests was available.



IEC / FIPEC full-scale test



SBI for cables

---

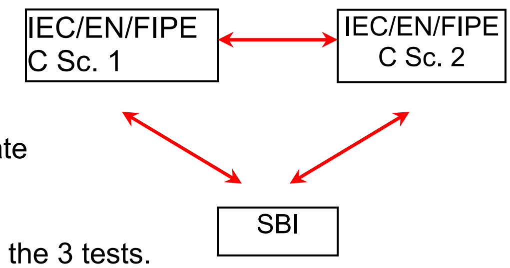
[14] European Confederation of Cables Manufacturers
[15] FIPEC: Fire Performance of Electric Cables – New test methods and measurement techniques
[16] Cable Fire Research Association
[17] The CFRA proposal suggested at some stage to use SBI only for communication cables
[18] Partners in Technology – Study of cable Insulation Fires in Hidden Voids.
[19] Partners in Innovation, Harmonisation of Reaction to Fire Tests for an “Exotic Product” - Communication Cable

B. Objectives

Our laboratory has just completed an extensive study[20], the objectives of which were, amongst others, to compare those 2 test methods, for a sample of cables including high performance ones (plenum cables: LC –Low Combustible, FEP – Fluorinated Ethylene Propylene).
The methods were compared in terms of:

- Ability to measure the essential parameters: Flame Spread (FS), Total Heat Release (THR), FIGRA, Total Smoke Production (TSP)
- Discrimination (i.e. ability to discriminate cables, whatever their level of fire performance)

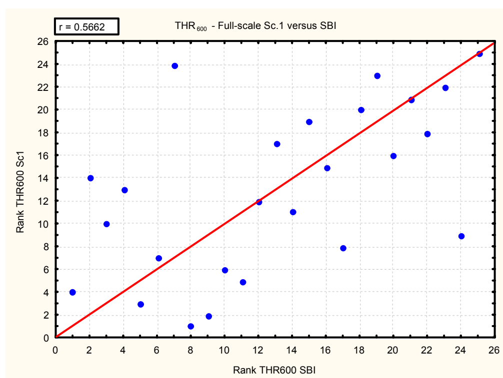
Smoke measurements: two families of tests were performed and compared, dynamic (Full Scale & SBI) and static (3meter cube)



We have also investigated whether the tests could correlate with each other, by means of:

- Ranking order correlations
- Linear correlations between parameters obtained at the 3 tests.

Example of correlation: Spearmann correlation between SBI and Europacable Sc. 1 tests for THR_{600}



While each method has been found to be applicable for most selected cables, significant differences have been highlighted, both in terms of ability to measure the main parameters and to discriminate and/or rank the cables. This could have been expected since tests conditions are not comparable: Ventilation, environment, mounting of the cables (it has been demonstrated previously that the mounting procedure is the parameter with the most influence on the test results), type of burner (premixed against diffusion flame),…

C. Conclusions

Proved large-scale calorimetry tests are now available for cables. Based on scientifically sound measurement techniques, they offer enough sensitivity to allow a robust classification of the different types of cables available in the market place, where their construction and used materials can vary greatly.

---

[20] *Assessment of the Adequacy of Fire Behaviour Tests for Cables, Belgian Science Policy project, 2000-2003*

About smoke measurements, dynamic tests offer some improvements with regard to 3 meter cube test. None of the method permits a reliable discrimination of low smoke cables.
For most parameters, no robust correlation has been found between the methods, except between the Full Scale Scenario 2 and the SBI. Weighting the parameters (e.g. THR per unit length of cable) might improve the correlation.

D. Contribution of the project in a context of support to the processes of standardisation and technical regulations

A few critical findings have been pointed out, that are essential with regard to the development of future Euroclasses for cables:

- SBI does not enable to rank the cables in term of FS.
- For other parameters (THR_{600s}, HRR_{peak}, FIGRA, TSP), both methods can be adequate.
- Using FIGRA for classification may lead to nonsensical results, i.e. top performance cables can be relegated in lower classes.
- With the 2 “Europacable” scenarios, difficulties in maintaining the hierarchy between classes can be encountered.

E. Keywords

Full Scale Test – SBI – Heat Release – FIGRA – Flame Spread - EUROCLASSES – Cables Fire Testing – Smoke Measurements – Correlations – Cable Classification

2. Introduction

This 3-year project is funded by the Belgian Science Policy in the framework of his scientific support to a federal policy concerning the whole of activities relating to standardisation and technical regulations.

This project should give support to the Belgian Cable industry and the Belgian authorities involved with fire safety requirements for cables. Both will have to face an important challenge in the next year, i.e. to move from a mainly “voluntary” system to a mandatory one based upon an European Directive.

Indeed, so far the fire behaviour requirements for electric cables have been mainly expressed in the General Regulation for Electric Installations (RGIE), in regulations dedicated to some buildings, in technical specifications and requirements, and in standards, especially NBN C 30-004.

Such a situation is going to change, one reason being the translation in the Belgian Law of the European Construction Products Directive (89/106/EC) together with some willingness to use the Euroclasses (fire behaviour classes for building products, which were first published in the Official Journal of the European Communities in September 94) for electric cables.

Sooner or later, one needs harmonized standards including parameters used in Euroclasses, i.e. heat release rate, flame spread and smoke release rate.

Experts of the Commission CEB (Belgian Electrical Committee) 20 C "burning characteristics of electric cables", following the example of the European cable industry, were considering the following options:

1. To adopt the large-scale test method developed in the European project FIPEC “Fire Performance of Electric Cables”.
2. The Single Burning Item (SBI) test, which is one of the selected fire test methods for the Euroclasses.

In that context, the objectives initially proposed for the project were as follows:

- To compare the two test methods mentioned above by means of tests performed on a meaningful sampling of the Belgian production of cables;
- From the detailed analysis of the so-obtained data, to determine the most appropriate test method;
- To propose a classification system based upon the selected test method;
- To analyse the present Belgian regulations with regard to the obtained results and the proposed classification system.

From the moment when the proposal has been elaborated and the project has actually started, Europacable has introduced a proposal for the Euroclasses of cables. The DG III of the EC - (European Commission) seems to be in favour of the principles of this proposal. As a

consequence, the “full-scale” test as developed in FIPEC would become a major test method for the cables within the scope of the CPD (Construction Product Directive).
For this reason, the Promoter of the project suggested to amend the objectives. This has been agreed by the Follow-up Committee during its first meeting.

The amended objectives can be summarized as follows:

- To assess the fire performance of a set of cables by means of the major test procedures proposed for the Euroclasses of cables. This means testing each selected cable with 2 scenarios at the « FIPEC » full-scale test. The chosen set of cables shall be representative of the cables produced in Belgium, as far as possible.
- To test the same cables by means of the SBI, with a single scenario. These results will be compared with the results obtained at the full-scale test.
- To measure the smoke released by the selected cables when tested according to IEC 61034-1/2 (so-called 3 meter cube test) since such a test is used world-wide for many applications. The so obtained values (static measurement) will be compared to the ones recorded at the full-scale tests (dynamic measurement).
- To apply the most up-to-date proposals of classifications[21] to the results obtained from the selected test methods and to compare the so-obtained classification for the set of cables.
- To analyse the present Belgian regulations with regard to the obtained results and the classification system proposed in the project and / or the one of the Euroclasses.
- From our analysis, to suggest recommendations in relation with the elaboration of the classification table for cables for the CPD.

Follow-up Committee

From the elaboration of the proposal, it was decided to have a Committee playing as a link between the Laboratory and the Industry.

Function:

The members of this Committee must act as representative of the concerned industry, i.e. the Belgian Cable Industry (and its confederation, Cablebel). As such, they have the opportunity:

- To give their opinion and suggestion on the project and its objectives;
- To help for the redefinition of the objectives, as required by the work under progress at the Commission;
- To help for the selection of the cables to be included in the study;
- To circulate the information to whom might be concerned.

Members:

Representatives of the Belgian Cable Industry.
The follow-up Committee has agreed to include an additional member during the second year,

[21] Available during the project.

representing a small Belgian cable manufacturer. The list of members is given below.

For ISSeP :	Hervé BREULET Thibaut STEENHUIZEN
For EUPEN KABELWERK :	Edgar HANSEN Bernd ZEIMERS
For NEXANS Belgium:	Daniel GUERY Frédéric BECHARD
For OPTICABLE:	Luigi ALESSI Real HELVENSTEIN
For CABLERIES LUCAS:	Eric LUCAS

3. Methodology

3.1 Cables selection and procurement

The main criteria used for selection were the following:
1. The cables should be commercially available ones;
2. The selection must be relevant with regards to the Belgian market;
3. The selected cables shall cover the range of possible fire performances.

The following Belgian cable Manufacturers were involved in the project; NEXANS Belgium, Opticable and Eupen Kabelwerk.

Consequently, the cables were selected at first from their usual production.

The follow-up Committee also agreed that additional aspects should be considered:

- The cables are constructed with a variety of common materials (for the sheath and the insulation) to exhibit a full range of expected fire performance (including smoke release). It matters to include so-called low smoke (LS) cables, as well as “zero halogen” (ZH or NH) ones.
- It is now usually admitted that, for given construction of cable, its size (i.e. the section of copper, or the amount of copper) can dramatically affect its fire behaviour. Therefore, for a given type of cable, 2 or 3 different sizes were selected.
- Cables have been grouped according to the usual “classification”, i.e.
    - Low voltage (power cables) → P1, P1´, P2, P3, P3´, P4, P5, P6, P7, P9
    - Telephone cables → T1, T2, T3, T4
    - Coax cables → C1, C2
    - Data cables → D1, D2, D3, D4
    - Optical fibre cables → O2, O3, O5

For the selected cables, the main used materials are:

Sheath:

- PVC (Polyvinyl chloride)
- ZH TP (Zero Halogen Thermoplastic)
- FRNH TP (Flame Retarded Non Halogen ThermoPlastic)
- FEP (Fluorinated Ethylene Propylene)

Insulation:

- PVC (Polyvinyl chloride)
- PE (Polyethylene)
- XLPE (Cross-linked polyethylene)
- ZH TP (Zero Halogen ThermoPlastic)
- EVA (Ethylene vinyl acetate)

It has also been decided to add a few “very high” fire performance data cables, e.g. plenum cables. Such cables are unfortunately neither produced by Belgian cables manufacturers nor used in Belgium. Nonetheless, they were required in order to permit to check the ability of the selected test methods or scenarios to discriminate cables covering the whole range of possible fire performance levels.

As the whole, twenty-five cables have been selected as shown in the table I.

Table I: Selected cables

Nr.	Cable type	Size	Materials				
			Cond.	Sheath	Insul.	Other	Comb.Vol.
P1	XVB	3x2,5 mm²	Cu	PVC	PE		0.071 l/m
P1´	XVB	3x2,5 mm²	Cu	PVC	PE		0.08 l/m
P2	XVB	4x10 mm²	Cu	PVC	PE		0.144 l/m
P3	XVB	19x1,5 mm²	Cu	PVC	PE		0.227 l/m
P3´	XVB	19x1,5 mm²	Cu	PVC	PE		0.250 l/m
P4	XGB	3x2,5 mm²	Cu	ZH TP	PE		0.074 l/m
P5	XGB	5x10 mm²	Cu	ZH TP	PE		0.156 l/m
P6	XFVB	3x2,5 mm²	Cu	PVC	PE		0.112 l/m
P7	XFVB	3x10 mm²	Cu	PVC	PE		0.149 l/m
P9	XVB	5x10 mm²	Cu	PVC	PE		0.156 l/m

T1	Telephone	10x2x0,6 mm²	Cu	PVC	PVC		0.041 l/m
T2	Telephone	50x2x0,6 mm²	Cu	PVC	PVC		0.146 l/m
T3	Telephone	10x2x0,6 mm²	Cu	ZH TP	ZH TP		0.074 l/m
T4	Telephone	50x2x0,6 mm²	Cu	ZH TP	ZH TP		0.146 l/m
C1	Coaxial	50 Ω	Cu	FRNH TP	PE		0.494 l/m
C2	Coaxial	75 Ω	Cu	PVC	PE		0.024 l/m
D1	Data	2x2x0,5 mm²	Cu	PVC	PVC		0.064 l/m
D2	Data	25x2x0,5 mm²	Cu	LSHF	PE	Screen	0.060 l/m
D3	Data		Cu	PVC			0.096 l/m
D4	Data		Cu	FEP			0.007 l/m
W1	Wire	2,5 mm²	Cu		PVC		0.006 l/m
W2	Wire	2,5 mm²	Cu		XLPE		0.009 l/m
O2	Optical Fibre	Multiple	Glass		EVA	Polyamide	0.032 l/m
O3	Optical Fibre	Single	Glass	PVC		Polyamide	0.031 l/m
O5	Optical Fibre	Multiple	Glass	PVC		Polyamide	0.017 l/m

3.2 Choice and/or definition of the test procedures

3.2.1 Full-Scale test

The Full-Scale test is based upon the series of standards EN 50266-2-4 and IEC 60332-3 and the FIPEC Full-Scale test (see Figure 1).
Appendix A6 of the FIPEC book describes the test protocol. It includes two different "scenarios". The main differences are related to the level of the burner (power) and the mounting of the cables.
The follow-up committee has decided that it was appropriate to work according to the protocols associated to the latest Europacable proposal for Euroclasses for cables at the time the tests began (see them Minutes of the 3rd Follow-up Committee) and thus not to use the Fipec

scenarios for the cables mounting.
At the end of this project, the latest official available Europacable proposal was described in the document " EUROPACABLE Proposal 22 May 2002 ".
The associated tests methods for mid classes are fully described in the following documents (again, latest issue available at the time the first full-scale tests started) :

- PrEN CPD-1 draft 10 describing the apparatus
- PrEN CPD-2-1 draft 4 for Euroclasses Cc and Dc
- PrEN CPD-2-2 draft 6 for Euroclasses Bc

Tests conditions, which can vary depending on the procedures, are mainly:

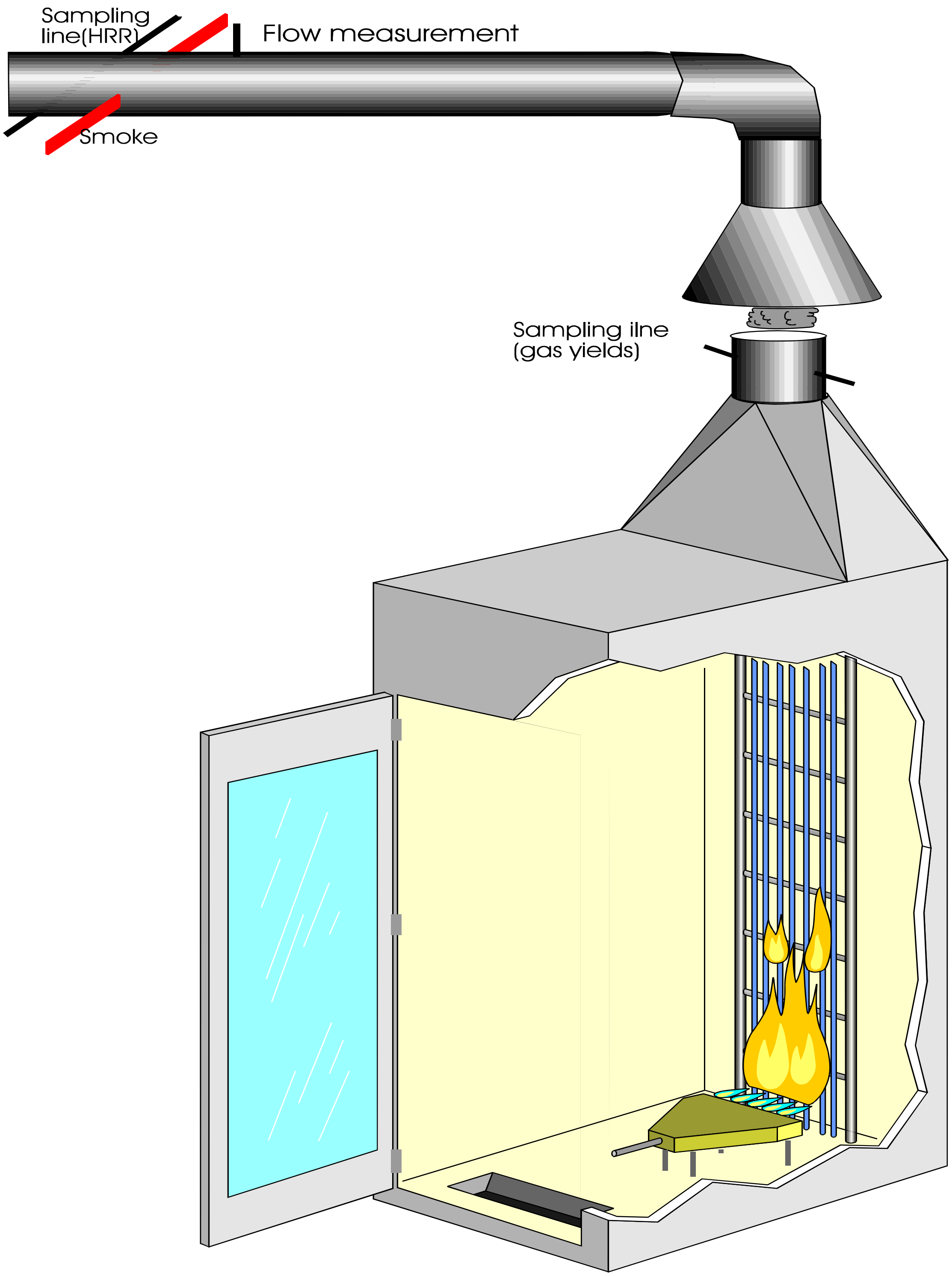
- Burner output
- Duration of burner application
- Mounting of the cables (amount of cable, spacing or not, number of layers, presence of a refractory backing board,…)
- Air supply through the chamber.

The used scenarios in this project can be summarized as follows in Table II:

Table II: Comparison of the both scenarios

	Euroclass Cc - Dc (prEN CPD 2-1)	**Euroclass Bc (prEN CPD 2-2)**
Heat output of the Burner	20.5 kW	30 kW
Nb of cables	1.5 l/m	1.5 l/m, max 1 layer
Cable mounting	Joined if $S \leq 35^2$ Spaced if $S > 35^2$	Joined if $S \leq 35^2$ Spaced if $S > 35^2$
Air flow through the chamber	5 m^3/mn	8 m^3/mn
Duration of burner application	20 min	40 min
Backing board	No	Yes

Figure 1: Full-Scale (FIPEC) test



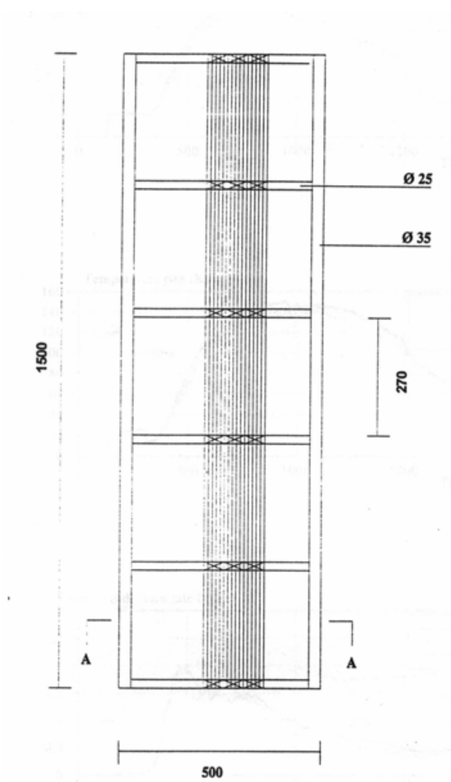
3.2.2 Single Burning Item (SBI)

According to all information about testing of cables with SBI (see Figure 3) we were able to collect during the first part of the project, it seems that all previous studies were conducted each time using a single set of test conditions. Once more, it was decided to perform the tests according to the latest available procedure, as proposed by CFRA (Annex 1 of the CFRA Sponsored Research report, September 2001). This procedure is based upon EN 13823 modified with regard to the mounting of the specimen (in order to take into account the specificity of the product to be tested, i.e. cables):

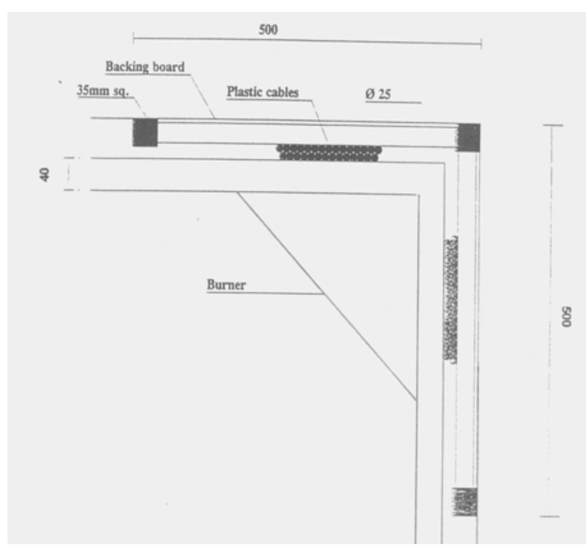
- *Test pieces shall be attached longitudinally to the front of each of the two ladders in a single layer up to a maximum width of 150 mm per ladder. The test pieces shall have a length so that they can be attached individually to each rung of the ladder by means of a metal wire (steel or copper wire, 0.5 to 1.5 mm in diameter). The test pieces shall be laid straight with adjacent pieces touching.*
- *When mounting the test pieces, the first piece shall be positioned approximately 120 mm from one edge of the ladder, and further pieces added in touching formation to form an array extending towards the centre of the ladder to a maximum width of 150 mm. Mounting on the left and right wing ladders should be such that the inner edge of each array is approximately 120 mm from the corner when the ladders are positioned in the test chamber. Test pieces shall be conditioned as specified in EN 13823.*

The cables are mounted on 2 ladders, in a corner set-up, as show in the next Figures 2.

Figure 2: Mounting cables on SBI ladders

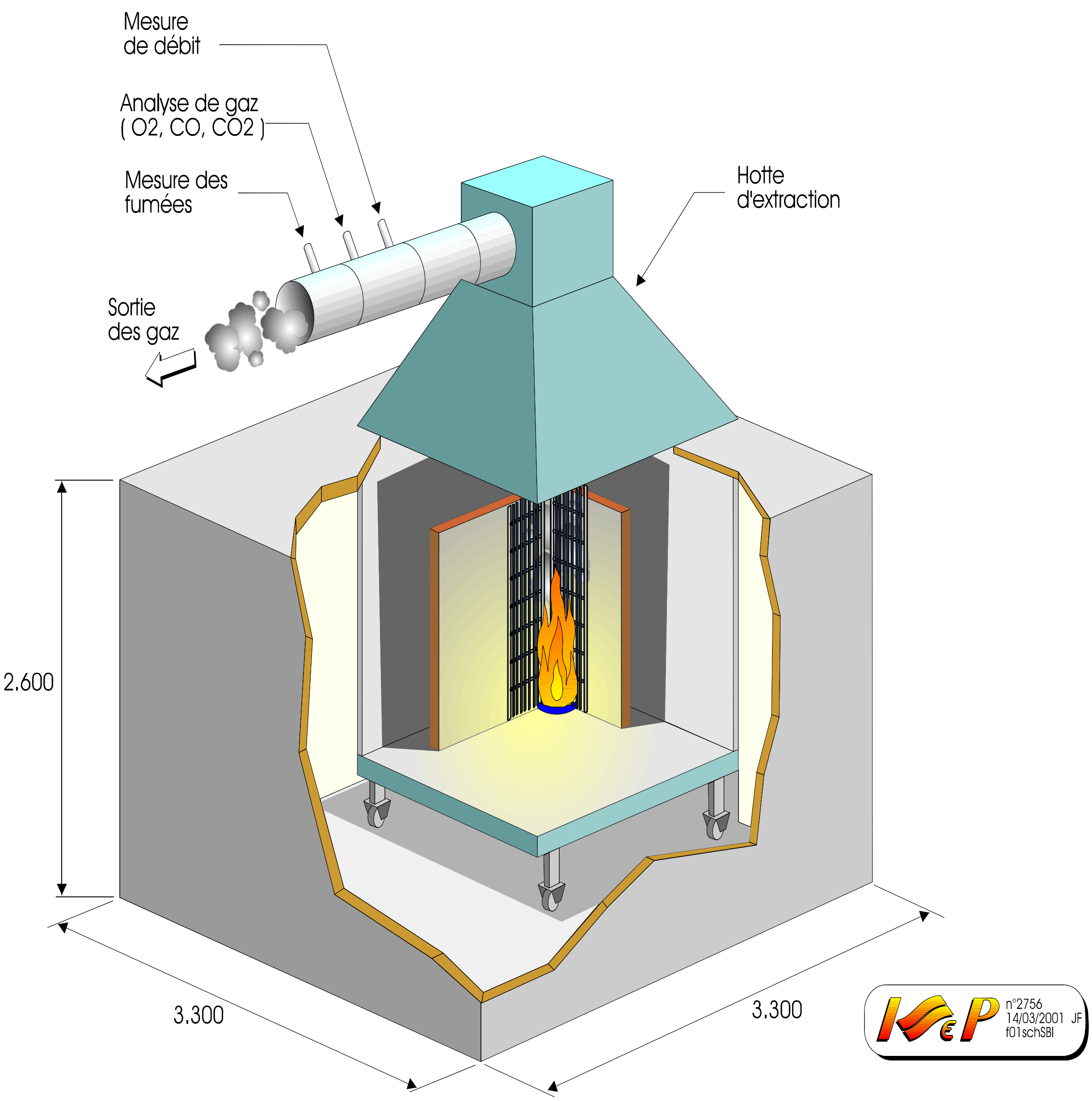


Ladder with mounted cables (front view)



2 ladders in the corner + burner (plan view)

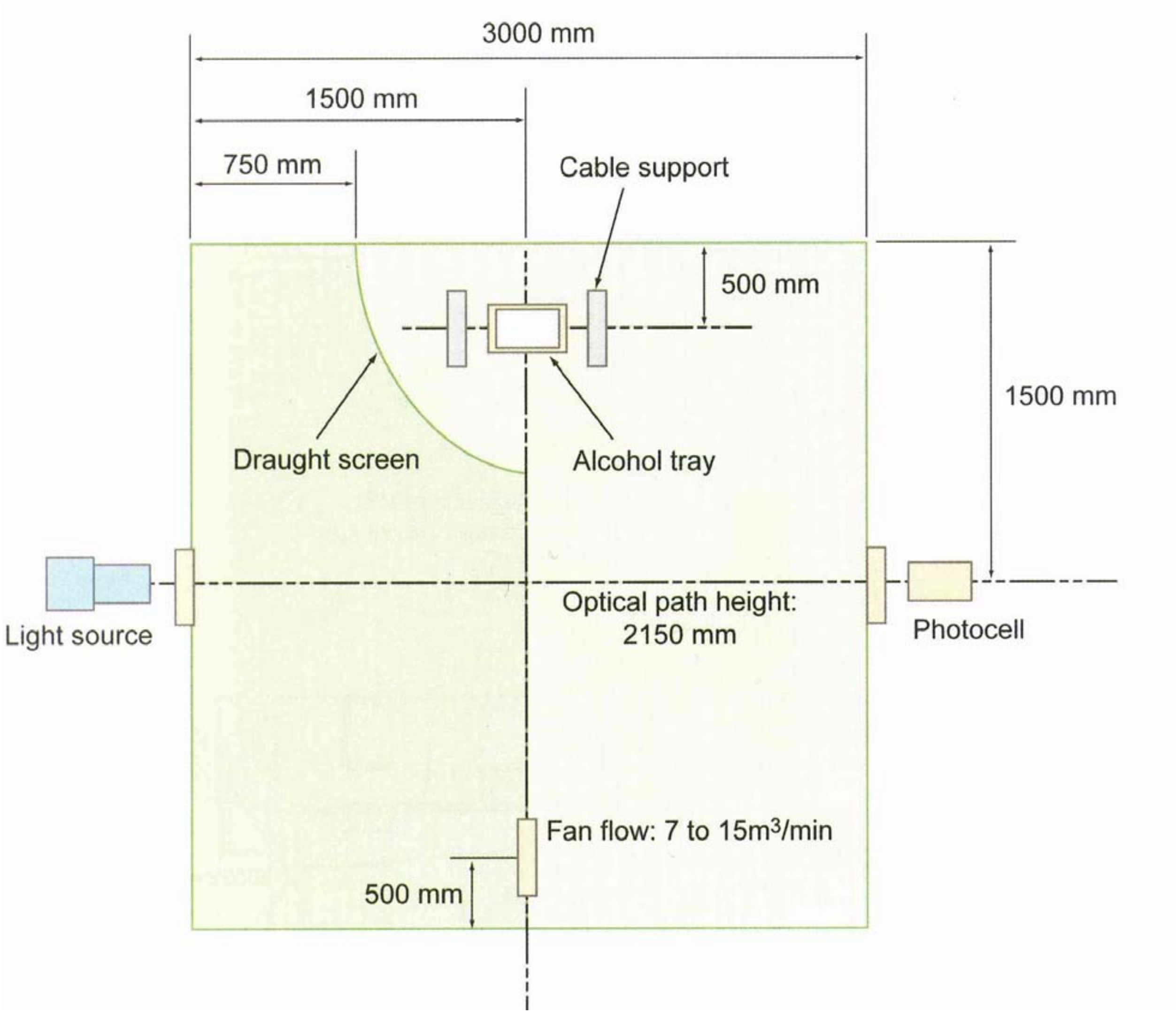
Figure 3: SBI (Single Burning Item) test for cables



3.2.3 3-meter cube test

This test (see Figure 4) permits the measurement of the production of smoke in a static mode (by contrast with the full-scale test and SBI both using a dynamic measurement).
The chosen procedure is strictly according to IEC 61034-1/2. However, in addition to the prescriptions given by the standard, raw data have been processed in order to get results (parameters) comparable to the ones given by dynamic methods.
Each cable has been tested in duplicate.

Figure 4: 3-meter cube chamber



3.3 Data management and results exploitation

3.3.1 Dynamics measurements

The Full-Scale test and SBI test are based on oxygen consumption technique for the heat release and measurement of the absorption of a light beam for the smoke release. The output from these tests is vector data. Therefore, they give dynamic information on the variables. In order to be able to get as much information as possible from the raw data given by the test, it is important to export these raw data in usual spreadsheet.

The number of possible derive parameters, which can be calculated form the data obtained with one test, is rather large, e.g. in combining “primary” parameters.
In a first stage, it was decided to look at a limited number of these parameters, taking into account the FIPEC work and the provisional table defining the Euroclasses for cables.
According the latest draft procedures, HRR and SPR results will be averaged

In order to damp the variability caused by point measurement, the measurement to be taken into account shall be the average of measurement points during a period of 30 s for heat release and 60 s for smoke production. FIGRA and SMOGRA are calculated according EN13823. Times are taken in account at the lightening of burner.

For the Heat Release:

- HRR peak, i.e. Peak of Heat release (in kW)
- THR_{600}, i.e. the Total Heat Release for the 10 first minutes (in MJ)
- THR_{1200}, i.e. Total Heat Release for the 20 first minutes (in MJ)
- FIGRA, i.e. the Fire Growth Rate (in W/s), defined as:

$$FIGRA = 1000 * Max \frac{HRR_{av}}{t\text{-}300}$$

For the Smoke Release:

- SPR peak, i.e. Peak of Smoke Production (in m^2/s)
- TSP_{600}, i.e. the Total Smoke Production for the 10 first minutes (in m^2)
- TSP_{1200}, i.e. Total Smoke Production for the 20 first minutes (in m^2)
- SMOGRA, i.e. the SMOke Growth Rate (in m^2/s)
- kmax, i.e. the maximum extinction coefficient (in m^{-1})

Others:

- Flame spread: the damaged height at the end of the test
- Flaming droplet and/or particles

3.3.2 Static measurements

The IEC 61034-2 standards related to this test only consider the minimum level of transmission recorded throughout the test. They also include recommendations for the evaluation of the test results: when no limit is given in the relevant cable specification, the standards recommend to put as requirement a minimum value of 60 % of light transmittance.

In order to permit some comparison with the 2 other test methods, it was decided to determine, in addition to the minimum light transmittance:

- Kmax, i.e. the maximum extinction coefficient (in m^{-1})
- tmax, i.e. the time to reach the minimum light transmittance (in s)

as a reminder, smoke measurement is usually based upon the Bouger's law:

$$k = \frac{1}{L}\ln\left(\frac{I_0}{I}\right) \quad \text{or} \quad I/I_0 = e^{-kL}$$

Formula 1

Where I_0 : light intensity without smoke
I : light intensity with smoke
k : extinction coefficient
L : optical path length

For a dynamic measurement (e.g. full-scale test, SBI) :

$$SPR = k\dot{V}$$

Formula 2

Where *SPR:* Smoke Production Rate
V : volume flow in the exhaust duct)

3.4 Test protocols and classification : trends

Although the situation is still evolving, a summary of opinion expressed by main groups, as well as the latest proposals are presented here. Further information can be found in the Second Annual Report (Hervé Breulet, March 2002).

3.4.1 Europacable proposal

The previous second annual report included the proposal elaborated by Europacable and transmitted to the European bodies in charge of setting the Euroclass system dedicated to cables, in the framework of the CPD.

At the time the report was issued, the table included in the proposal gave the structure, i.e.

- The different classes (from A to E)
- The different tests associated to each class
- The parameters to be considered for each specific test

The next table (Table III) corresponds to this last proposal of Europacable.

Table III: last Europacable classification and test conditions

EUROPACABLE **Euroclass Table** **22 May2002**

Class	**Test method(s)**	**Classification criteria** (1)	**Additional classification**
A_C	EN ISO 1716	PCS ≤ 2.0 $MJ.kg^{-1}$ (2) 2.4.1.1.1	-
B_{1C}	EN 50266-2-x (3) *And*	FS ≤ **1.75** m; *and* THR_{600s} ≤ **6.0** MJ; *and* Peak RHR ≤ **15** kW; *and* FIGRA ≤ 120 ** $W.s^{-1}$	Smoke production (5) *and* Flaming droplets/ particles (6); *And* Acidity/ Corrosivity (7)
	EN 50265-2-1	H ≤ 425 mm	
B_{2C}	EN 50266-2-x (3) *And*	FS ≤ **1.75** m; *and* THR_{600s} ≤ **17,5** MJ; *and* Peak RHR ≤ **50** kW; *and* FIGRA ≤ **150** ** $W.s^{-1}$	Smoke production (5) *and* Flaming droplets/ particles (6); *And* Acidity/ Corrosivity (7)
	EN 50265-2-1	H ≤ 425 mm	
C_C	EN 50266-2-y (4) 600s *And*	FS ≤ **2.0** m; *and* THR_{600s} ≤ **15** MJ; *and* Peak RHR ≤ **60** kW; *and* FIGRA ≤ **150**** $W.s^{-1}$ 2.4.1.1.2	Smoke production (5) *and* Flaming droplets/ particles (6); *And* Acidity/ Corrosivity (7)
	EN 50265-2-1	H ≤ 425 mm	
D_C	EN 50266-2-y (4) 600s *And*	FS ≤ **2.5** m; *and* THR_{600s} ≤ **35** MJ; *and* Peak RHR ≤ **200** kW; *and* FIGRA ≤ **250** ** $W.s^{-1}$ 2.4.1.1.3	Smoke production (5) *and* Flaming droplets/ particles (6); *and* Acidity/ Corrosivity (7)
	EN 50265-2-1	H ≤ 425 mm	
E_C	EN 50265-2-1	H ≤ 425 mm	Flaming droplets/ particles (6); *and* Acidity/ Corrosivity (7)
F_C	No performance determined		

(1) Symbols used: PCS - gross calorific potential; FS - flame spread; THR - total heat release; RHR - rate of heat release; FIGRA - fire growth rate; TSP - total smoke production; SPR - smoke production rate; H - flame spread. (2) Mineral insulated cables without a polymeric sheath, as defined in EN 60702-1, are deemed to satisfy the Class A_C requirement without the need for testing. (3) EN 50266-2-4 modified on the basis of FIPEC scenario 2 and to include heat release and smoke measurements. (4) EN 50266-2-4 modified to include heat release and smoke measurements. (5) **EN 50266-2-x and EN 50266-2-y**: **s1** = TSP_{600s} ≤ 50 m^2 *and* Peak SPR ≤ 0.25 m^2/s; **s2** = TSP_{600s} ≤ 100 m^2 *and* Peak SPR ≤ 0.5 m^2/s; **s3** = not s1 or s2. (6) **EN 50265-2-1 (mod.)**: **d0** = No flaming droplets/ particles; **d1** = No flaming droplets/ particles persisting longer than 10 s (**); **d2** = not d0 or d1. (7) **EN 50267-2-3**: **a1** = conductivity < 2.5 μS/mm *and* pH > 4.3; **a2** = conductivity < 10 μS/mm *and* pH > 4.3; **a3** = not a1 or a2. No declaration = No Performance Determined.

Fire testing conditions

Euroclasses	**B_1 and B_2**	**C and D**
Fire scenario	**EN 50266-2-x**	**EN 50266-2-y**
Testing apparatus	EN 50266-2-1 modified according to Fipec Final Report Annex 5 for HRR and SPR measurements	
Burner	30 kW	20.5 kW
« Back-board »	Yes	No
Air flow	8000 l/min	5000 l/min
Test duration	20 min	20 min

3.4.2 Miscellaneous

3.4.2.1 CFRA proposal

CFRA is an international coalition for the promotion of the fire safety of communication cables installed in buildings. Their members mainly come from the material manufacturing industries, including some huge American based companies.
They suggest working with the standard Euroclass system (decision 200/147/EC), i.e. the one set up for "common" building products (but excluding floorings). This would imply using the so-called "klein brenner" EN 11925-2 test for class E and SBI for class D to A2. For this test, parameters to be considered are : THR_{600s} and FIGRA (the Lateral Flame Spread LFS is not meaningful for communication cables). According to CFRA, using the SBI offers a number of advantages :

- The test has been correlated to the ISO 9705 Room Corner Test and, to some extent, to real-scale "plenum" scenario,
- As a test rig, it is readily available in a number of European Laboratories,
- It permits a good discrimination of enhanced fire performance (EFP) products, which might be required to take into account the specific fire hazard presented by communication cable networks in modern buildings.

Eventually, they have come with a proposal (Proposal dated from25 April 2002, CFRA/C/250402) closer to Europacable one, i.e. referring to the full-scale modified EN 50266-2 test (or modified Fipec full-scale test), in an attempt to find a compromise for the industry.

3.4.2.2 CE opinion

The Fire Regulatory Group (FRG) concludes by giving a clear message to industry. They invited the cable industry to work together to formulate a single classification table on which everybody could agree, based upon a single testing regime for mid-classes, B to D in the current proposal. The classification must be suitable for all cable types and have a sufficient number of classes to allow differentiation between cable performance and allow for technical progress. A test method allowing must be defined to discriminate the fire and smoke performances of all the cables and using a single test (and as possible a single scenario) for mid classes. Repeatability and reproducibility must also be ensured. Actually this large-scale

tool should be flexible and reliable enough to provide data for fire engineering.
More recently (May 2002), the FRG has given a mandate to Mr B. Sundström to revue the FIPEC scenario and present the conclusions back to the FRG. A first opinion was given end of last year (RG 293: Principles for testing and classification of cables based on typical hazard scenarios).

4. Results

4.1 3-meter cube tests

Each cable has been tested at least twice according to the standard IEC 61034-1/2. Whenever the deviation was found too high, a third test was carried out. An average value of the coefficient transmission and Kmax (the maximum extinction coefficient, see 2.3.2) are calculated for each case. The next table (Table IV) gives a summary of these results:

Table IV : Smoke density (3-meter cube) results

Cable n°	% transm.	Kmax (m-1)	Time to max. (s)
P1	40,42%	0,303	639
P1'	41,11%	0,301	693
P2	36,11%	0,340	1610
P3	22,99%	0,493	1048
P3'	21,99%	0,505	690
P4	88,20%	0,042	2184
P5	66,25%	0,144	2276
P6	31,30%	0,390	678
P7	35,08%	0,349	1580
P9	32,18%	0,381	779
T1	15,33%	0,626	469
T2	16,01%	0,613	951
T3	92,19%	0,027	2070
T4	58,04%	0,181	2387
C1	44,75%	0,268	1544
C2	33,62%	0,365	261
D1	3,67%	1,102	237
D2	91,91%	0,028	1170
D3	56,46%	0,191	835
D4	94,84%	0,018	1808
W1	29,89%	0,403	407
W2	83,14%	0,062	890
O2	92,86%	0,025	1008
O3	73,25%	0,105	690
O5	62,03%	0,160	2183

It is worth noting that, considering the usual requirement, i.e. a minimum transmission ≥ 60 %, most cables would not comply. Only nine samples on the twenty fives cables succeed the test (shaded cells). The repeatability seems acceptable for the majority of the cables. Only three further tests had to be performed because the deviation was found too high.

4.2 Full-Scale tests

4.2.1 Scenario 1 (Euroclasses Cc - Dc)

HRR and SPR results are summarized in Tables V and VI. Tests were performed on all cable set. Heat Release parameters are calculated excluding burner output and averaged on 30 seconds, SPR ones are averaged on 60 s (as described in EN 13823 and prEN CPD-2-1). Origin of time (t_0) is taken when the burner is turned on.

Table V: HRR results for scenario 1

Cable n°	HRR peak (kW)	Time to peak (s)	THR at 600 s (MJ)	FIGRA acc. EN13823 (W/s)	Damaged length (cm)
P1	64,8	577	16,4	144,3	225
P1'	42,6	650	7,8	67,0	> 250
P2	7,0	1192	0,6	45,4	58
P3	22,7	1567	1,9	44,6	135
P3'	19,1	1128	1,2	32,2	88
P4	45,8	571	10,8	68,1	124
P5	3,9	151	0,9	33,6	55
P6	41,6	484	10,4	86,6	126
P7	23,6	940	2,5	43,8	108
P9	26,2	1123	2,9	56,1	122
T1	36,3	232	10,9	209,2	138
T2	19,3	1418	1,2	40,2	90
T3	7,4	807	1,9	30,4	75
T4	6,7	1206	0,6	36,6	60
C1	26,4	1363	2,0	22,5	> 250
C2	671,7	337	155,1	2015,3	> 250
D1	149,9	778	20,0	207,0	> 250
D2	70,2	822	8,5	98,1	140
D3	10,3	114	3,6	129,6	100
D4	3,5	351	1,0	33,4	48
W1	514,6	166	94,1	3225,3	> 250
W2	255,0	681	59,0	389,1	> 250
O2	18,7	654	7,3	116,0	72
O3	9,9	87	2,3	66,2	55
O5	10,4	102	3,5	67	72

The HRR peak results range from 3.5 to 671kW and THR_{600} from 1 to 155 MJ. This gives a first rough indication that the method permits to differentiate the fire performance of the selected cables. However we must be aware that he lowest values must be considered

with care since they are obtained from measurements to which a rather high uncertainty could be associated, as demonstrated recently for SBI and Room Corner Test (Nordtest Technical Report 477).
Six cables would not meet the requirements of the standard cat. C according to IEC 60332-3-24 (or F2 ac. to NBN C30-004), i.e. the burnt height < 2.5 m.
Contrary to all expectations the high performance cables (i.e. plenum one) do not always exhibit the lowest FIGRA.

Table VI: SPR results for scenario 1

Cable n°	SPR peak (m²/s)	Time to peak (s) (s)	TSP 600s (m²)	SMOGRA acc. EN13823 (m²/s²)
P1	1,21	715	371,6	94,32
P1'	0,96	764	406,9	94,94
P2	0,28	386	67,5	45,64
P3	0,22	469	53,9	22,62
P3'	0,22	435	48,3	23,96
P4	0,05	1373	10,5	1,02
P5	0,03	1675	7,8	4,14
P6	1,36	760	378,4	32,09
P7	0,40	1093	89,6	31,03
P9	0,25	439	53,4	19,01
T1	1,86	433	443,9	159,51
T2	0,46	368	73,1	73,12
T3	0,04	1539	1,9	0,35
T4	0,05	1584	1,5	0,42
C1	0,08	2249	19,3	10,89
C2	5,05	598	907,5	173,24
D1	4,38	895	1382,4	120,70
D2	0,09	1356	4,2	1,58
D3	0,34	417	99,9	41,20
D4	0,03	402	6,5	4,72
W1	5,37	508	932,3	285,18
W2	0,18	1056	4,4	2,51
O2	0,05	1212	6,2	4,92
O3	0,25	375	29,9	45,92
O5	0,26	402	51,1	46,05

SPR peak measurements ranges from 0.03 to 5.37 m²/s and TSP_{600} from 1.5 to 1382.4 m². As expected, PVC cables release smoke in another order of magnitude than halogen free cables.
One must not take for granted that this method is appropriate to discriminate Low Smoke cables since, for a number of them, measurements are close to the noise level,(i.e cables P4, P5, T3, T4, D4 and O2, SPR peak< 0.05 m²/s,here again, reference values can be found for SBI and Room Corner test in the Nordtest Technical Report 477).

4.2.2 Scenario 2 (Euroclasses Bc)

In the Table VII and VIII a summary of the HRR and SPR results for the data is given.

Table VII: HRR results for scenario 2

(excluding burner output, parameters calculated on 30 s. avg.)

Cable n°	HRR peak (kW)	Time to peak (s) (s)	THR at 600 s (MJ)	FIGRA acc. EN13823 (W/s)	Damaged length (cm)
P1	48,3	721	16,3	201,4	300
P1'	43,8	721	15,9	158,6	300
P2	37,3	784	9,2	167,0	300
P3	43,9	799	9,9	100,8	300
P3'	43,5	849	6,5	76,8	300
P4	31,9	1036	9,9	139,8	300
P5	33,2	1210	5,2	96,8	188
P6	62,5	634	18,9	155,2	300
P7	58,9	636	12,2	134,1	205
P9	53,4	750	13,4	127,8	300
T1	36,7	204	10,6	287,9	108
T2	24,4	390	10,1	188,5	135
T3	49,3	1296	10,6	100,9	300
T4	51,8	978	7,5	89,9	173
C1	60,9	682	14,5	91,9	300
C2	268,9	498	92,8	672,4	300
D1	44,5	273	12,4	254,5	168
D2	66,2	729	10,3	96,0	180
D3	10,4	126	2,8	214,5	135
D4	5,5	75	0,5	92,0	60
W1	270,0	96	19,8	3068,3	300
W2	116,6	264	31,7	621,3	300
O2	26,9	738	8,1	102,5	116
O3	12,0	105	3,9	302,5	100
O5	14,8	54	3,5	362,4	82

The HRR peak results range from 5,5 to 270 kW and THR_{600} from 0.5 to 92.8 MJ. These ranges are lower that the one obtained with scenario 1. This is probably explained by the lower amount of cable (and thus of combustible material) with the 2nd scenario.
While this scenario seems to enable a better discrimination of very high performance cables, the opposite is observed for most other cables (especially for the FS).
The previous observation made on FIGRA is emphasised with this scenario.

Table VIII: SPR results for scenario 2

(parameters calculated on 60 s avg.)

Cable n°	SPR peak (m²/s)	Time to peak (s) (s)	TSP 600 s (m²)	SMOGRA EN13823 (m²/s²)
P1	0,86	388	289,21	115,61
P1'	1,09	427	508,13	99,23
P2	0,44	391	101,68	65,40
P3	0,35	436	106,39	27,85
P3'	0,59	435	166,57	51,69
P4	0,04	2929	13,29	7,86
P5	0,00	1954	0,38	0,20
P6	1,63	649	590,43	86,81
P7	1,10	903	349,35	39,62
P9	0,70	732	280,61	47,55
T1	2,81	426	630,92	396,62
T2	1,18	654	518,82	147,22
T3	0,08	3201	3,57	0,89
T4	0,05	1089	5,17	1,03
C1	0,04	361	16,11	10,02
C2	0,94	468	241,87	63,71
D1	2,58	468	843,59	236,34
D2	0,07	1029	6,31	1,11
D3	0,67	360	76,66	145,15
D4	0,14	354	9,75	34,66
W1	2,16	384	240,32	430,13
W2	0,11	396	10,00	13,86
O2	0,06	1014	7,28	0,89
O3	0,17	495	46,16	19,00
O5	0,80	384	105,13	123,93

SPR peak measurements ranges from 0 to 2.81 m²/s and TSP_{600} from 0.38 to 843.54 m².
For a number of samples measurements are close to the noise level and the discrimination ability is very low. The SPR peak range is lower than in scenario 1 but TSP_{600} range is wider.

4.2.3 Comparison between Scenario 1 and Scenario 2

All the values are submitted without the burner contribution, i.e. heat release rate, fire growth rate and total heat release. Results including burner would falsify the comparison because the burner contribution (level and duration) is different according to the test or to the scenario chosen.
The general trend is that Scenario 2 is more severe than Scenario 1. It could be explained by several factors like the duration and the output level of the burner, the mounting of the cables on the ladders…

Flame spread: Scenario 2 clearly leads to a higher flame spread for all the tested cables except for cable T1 as shown in Table IX. With Scenario 2 more than half the cables burnt up to the top.

Table IX: flame spread scenarios 1 and 2 comparison (cm)

F.S.	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	225	> 250	58	135	88	124	55	126	108	122	138	90	75
Sc 2	> 250	> 250	> 250	> 250	> 250	> 250	188	> 250	205	> 250	108	135	> 250

F.S.	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	60	> 250	> 250	> 250	140	100	48	> 250	> 250	72	55	72
Sc 2	173	> 250	> 250	168	180	135	60	> 250	> 250	116	100	82

Heat release: the conclusions for HRR must be drawn with some caution. Scenario 2 gives higher peak of heat release and THR_{600} for most of cables, but a few of them present an opposite behaviour (shaded cells in Table X). Note than Cable T4 has a higher THR_{600} in scenario 1 than in Scenario 2. For most cables the Scenario 2 (CPD Bc) is more severe than Scenario 1 (CPD Cc). Cable P2 has been chosen as example (Figure 5).
However, it is worth noting that the hierarchy is reversed for a number of cables, e.g. cable C2 (see figure 6).

Table X: heat release rate scenarios 1 and 2 comparison (kW)

HRR	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	64.8	42.7	7	22.8	19.1	45.9	4	41.6	23.6	26.2	36.3	19.3	7.4
Sc 2	48,3	43,8	37,3	43,9	43,5	31,9	33,2	62,5	59,0	53,4	36,7	24,4	49,3

HRR	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	6,7	26,4	671,7	149,9	70,2	10,3	3,5	514,6	255,0	18,7	9,9	10,4
Sc 2	51,77	60,91	269,8	44,52	66,17	10,35	5,48	270	116,6	26,87	12	14,8

Figure 5: comparison of scenarios 1 (CPD Cc) & 2 (CPD Bc), usual trend

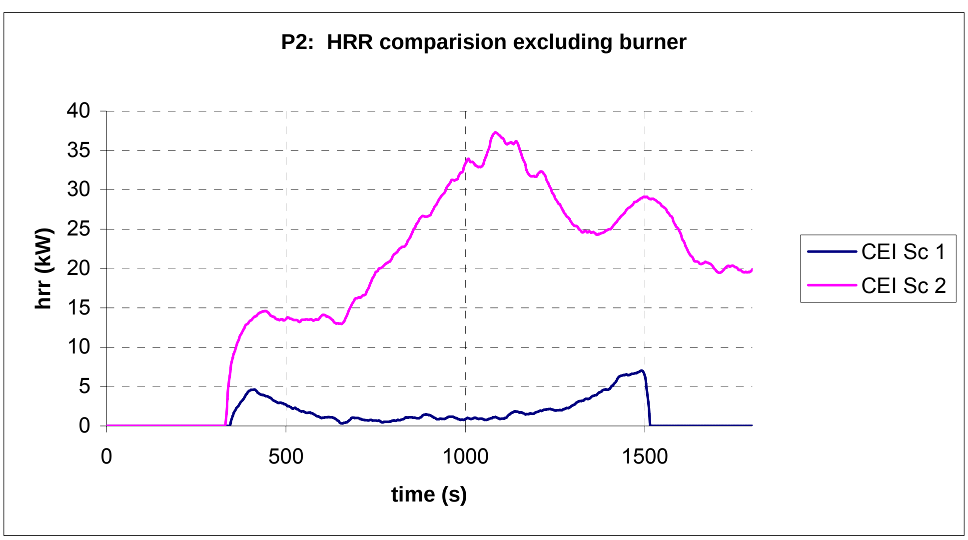
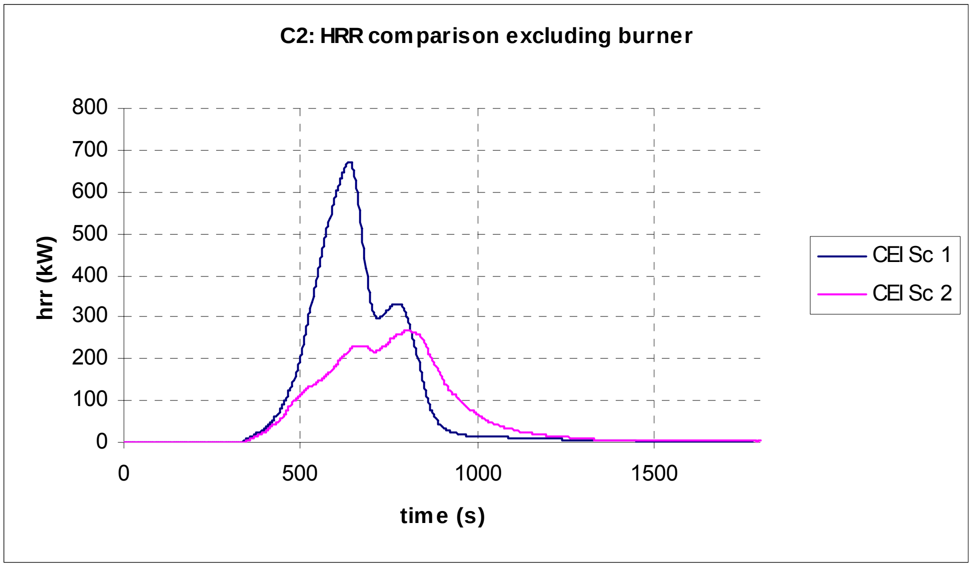


Figure 6: comparison of Scenarios 1 & 2, « abnormal » trend



FIGRA: The Fire Growth Rate gives a measure of the size and growth rate of a fire and expresses a big and fast growing fire as the most dangerous. Initially the ratio *Time to ignition/peak rate of heat release* was used as an indicator of overall fire hazard because this parameter is proportional to the time to flashover (Comparison of Large- and Small-scale Heat Release Tests with Electrical Cables, M. M. Hirschler, 1994). The FIGRA has been defined as the inverse (*HRR peak/ time to peak*). Higher values are supposed to indicate large fire hazard. All the FIGRA indexes in this project are calculated according the standard EN 13823, which are calculated in another way than the original FIGRA. As a consequence, it must no be considered as granted that the so-obtained FIGRA would correlate with the time to flashover.
Scenario 2 (CPD Bc) is clearly more severe. FIGRA comparison (Table XI) strengthens the idea than scenario 2 (CPD Bc) is tougher than scenario 1 (CPD Cc).

Table XI: FIGRA index for Scenarios 1 & 2 (W/s)

figra	**P1**	**P1'**	**P2**	**P3**	**P3'**	**P4**	**P5**	**P6**	**P7**	**P9**	**T1**	**T2**	**T3**
Sc 1	144	67	45	45	32	68	34	87	44	56	209	40	30
Sc 2	201	159	167	101	77	140	97	155	134	128	288	189	101

figra	**T4**	**C1**	**C2**	**D1**	**D2**	**D3**	**D4**	**W1**	**W2**	**O2**	**O3**	**O5**
Sc 1	37	23	2015	207	98	130	33	3225	389	116	66	67
Sc 2	90	92	672	255	96	214	92	3068	621	103	303	362

THR_{600}: the THR_{600} is lower in Scenario 1 than in Scenario 2 for most cables as shown in Table XII.

Table XII: full-scale test THR_{600} comparison (MJ)

thr600	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	16,43	7,78	0,59	1,92	1,19	10,79	0,90	10,39	2,49	2,91	10,86	1,18	1,90
Sc 2	16,34	15,95	9,25	9,90	6,52	9,89	5,23	18,90	12,22	13,39	10,64	10,08	10,64

thr600	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	0,58	1,98	155,1	20,04	8,51	3,60	1,00	94,15	59,02	7,27	2,35	3,54
Sc 2	7,48	14,50	92,80	12,44	10,28	2,77	0,49	19,79	31,72	8,07	3,95	3,52

4.3 Single Burning Item (SBI)

All the cables have been tested twice except P1 and D4 for technical reasons. An example is shown in Figure 7.
The data results are the average values of these both tests. Whenever the deviation was found too high, a third test was carried out. Additional tests were performed only on three cables.
In the Table XIII and Table XIV, a summary of the HRR and SPR measurements is given.

Table XIII: HRR results for SBI
(excluding burner output, parameters calculated on 30 s. avg.)

Cable n°	HRR Peak (kW)	Time to peak (s)	THR at 600 s (MJ)	FIGRA acc. EN13823 (W/s)	FS (cm)
P1	89,4	753	21,9	341	150
P1'	77,9	742,5	19,2	131,8	150
P2	62,4	904,5	10,6	77,9	150
P3	164,9	895,5	14,8	147,1	150
P3'	107,8	1012,5	10,9	453,6	150
P4	82,1	1150,5	14,5	100,3	150
P5	65	1066,5	7	68,4	150
P6	102,1	1111,5	23,5	163,3	150
P7	84,4	1156,5	13,6	109,1	150
P9	94,8	996	12,7	170,9	150
T1	43,4	1039,5	16,4	171,5	150
T2	41,1	1101	12,4	109,2	150
T3	127	858	9,8	133,7	150
T4	139	700,5	10,5	126,8	150
C1	158,9	810	29,1	217,3	150
C2	245,8	1042,5	42,8	1251,2	150
D1	86,1	954	26,8	223,2	150
D2	107	880,5	12,9	137,1	150
D3	2,9	1000,5	1,1	63,5	150
D4	1,2	690	0,3	5,2	150
W1	137,4	339	10,1	2097	150
W2	86,1	441	18,9	503	150
O2	58,2	775,5	14,7	98	150
O3	4,3	931,5	1,9	46,1	150
O5	5,2	970,5	2,1	56,2	150

HRR peak ranges from 1,2 to 246 kW and THR_{600} from 0.3 to 42.8 MJ., i.e. a range not as wide as the full-scale test (scenario 1 or scenario 2). This is probably due to the lower amount of cable (and thus of combustible materials) in case of the SBI mounting.
No Flame Spread measurement is possible because the SBI cable bunch burns completely.

Figure 7: repeatability of SBI tests (HRR including burner)

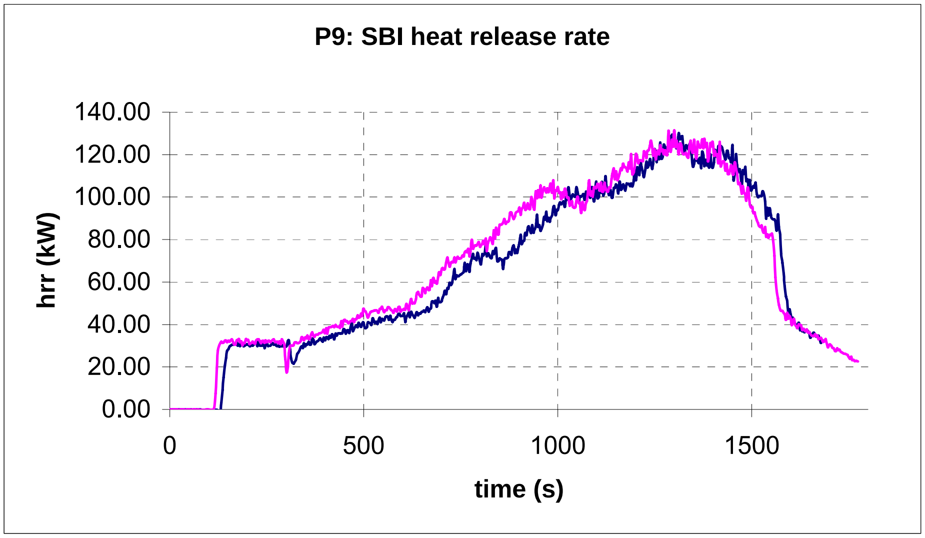


Table XIV: SPR results for SBI (parameters calculated on 60 s avg.)

Cable n°	SPR peak m²/s	Time to peak (s) (s)	TSP 600s (m²)	SMOGRA acc. EN13823 (m²/s²)
P1	1,06	279	398,00	62,06
P1'	1,48	432	558,82	49,64
P2	0,63	450	227,60	39,87
P3	1,43	533	390,81	39,10
P3'	1,16	603	288,99	35,25
P4	0,15	645	46,16	22,32
P5	0,11	1101	33,20	17,97
P6	2,01	545	683,59	53,08
P7	1,44	481	390,56	31,75
P9	1,01	551	332,79	95,59
T1	1,44	221	567,90	79,23
T2	1,13	761	382,36	41,43
T3	0,25	986	56,43	31,99
T4	0,27	1135	50,76	23,98
C1	0,21	440	58,56	26,17
C2	1,65	168	318,28	111,46
D1	2,46	363	786,21	74,92
D2	0,22	1014	59,11	26,96

D3	0,17	98	73,00	50,97
D4	0,06	1200	25,23	15,73
W1	1,24	79	152,98	197,68
W2	0,14	186	49,72	42,14
O2	0,12	864	43,61	25,95
O3	0,20	308	97,37	25,57
O5	0,24	186	103,11	36,74

SPR peak ranges from 0.06 to 2.46 m²/s and TSP_{600} from 33.2 to 684 m². As observed in the others tests , the PVC cables give off much more smoke. The SMOGRA range (15.7 to 198 m²/s²) is smaller than in the other kind of tests (full scale tests SC1 &2).

4.4 HRR parameters: Comparison between Full scale tests and SBI

Flame spread: It seems difficult to consider the flame spread as a selection criterion for the SBI test because for all the cables, the jacket burns up to the top. This could be expected since the cable specimens are only 1.5 m high while the flames of the burner alone reaches about 0.8 m high.
Comparison of the damaged length with the full-scale test is meaningless. This a key drawback for SBI since flame spread is probably the main fire hazard associated to bunched cables.

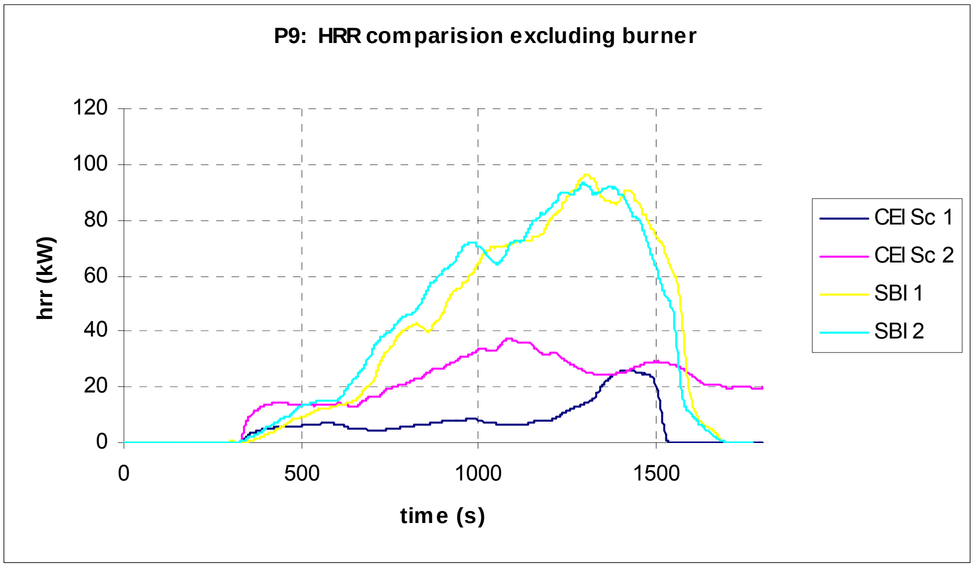
Peak of Heat release rate: For the peak, the SBI gives off higher values for all power and telephone cables, and lower values for most other cables (data, optical, coaxial) (Table XV). An example is shown in Figure 8. The shaded cells in the following Table XV highlight the highest HRR value between the three kinds of tests.

Table XV: comparison of peak of heat release (kW)

HRR	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	26,6	21,5	21,5	23,7	47,5	22,1	25,0	27,3	26,1	26,7	30,1	22,6	65,8
Sc 2	48,3	43,8	37,3	43,9	43,5	31,9	33,2	62,5	59,0	53,4	36,7	24,4	49,3
SBI	89,4	77,9	62,4	165,0	107,9	82,1	65,0	102,2	84,4	94,8	43,5	41,1	127,0

HRR	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	6,7	26,4	671,7	149,9	70,2	10,3	3,5	514,6	255,0	18,7	9,9	10,4
Sc 2	51,77	60,91	268,9	44,52	66,17	10,35	5,48	270	116,6	26,87	12	14,8
SBI	138,9	159	245,8	86,06	107	2,841	1,236	137,4	86,16	58,21	4,262	5,198

Figure 8: behaviour of cable P4 for each test



FIGRA: All the FIGRA indexes in this project are calculated as described in the standard EN13823. It is different from the original FIGRA (*HRR peak/time to peak*), this FIGRA gives the more severe slope of the HRR curve. That doesn't necessarily correspond to the original FIGRA(i.e. HRR curve with several peaks). Higher values are mixed between SBI and scenario 2 Full-Scale test (CPD Cc). Here the comparison does not lead to obvious trends. Shaded cells show the top values.

Table XVI: FIGRA index comparison (W/s)

figra	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	144	67	45	45	32	68	34	87	44	56	209	40	30
Sc 2	201	159	167	101	77	140	97	155	134	128	288	189	101
SBI	341	132	78	147	454	100	68	163	109	171	172	109	134

figra	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	37	23	2015	207	98	130	33	3225	389	116	66	67
Sc 2	90	92	672	255	96	214	92	3068	621	103	303	362
SBI	127	217	1251	223	137	64	5	2097	503	98	46	56

THR_{600}: Conclusions are similar to the ones drawn for HRR_{peak}. Surprisingly enough, THR_{600} as measured by SBI for the highest performance cables (i.e. D3, D4, O3, O5) are lower than for both Full-scale scenarios (Table XVII).

Table XVIII: THR_{600} comparison (MJ)

thr600	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	16,43	7,78	0,59	1,92	1,19	10,79	0,90	10,39	2,49	2,91	10,86	1,18	1,90
Sc 2	16,34	15,95	9,25	9,90	6,52	9,89	5,23	18,90	12,22	13,39	10,64	10,08	10,64
SBI	21,97	19,22	10,66	14,83	10,92	14,55	7,01	23,55	13,63	12,69	16,45	12,45	9,82

thr600	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	0,58	1,98	155,1	20,04	8,51	3,60	1,00	94,15	59,02	7,27	2,35	3,54
Sc 2	7,48	14,50	92,80	12,44	10,28	2,77	0,49	19,79	31,72	8,07	3,95	3,52
SBI	10,54	29,13	42,83	26,82	12,89	1,08	0,26	10,10	18,94	14,67	1,92	2,08

Discrimination ability: A major criterion in comparing different test methods is their ability to discriminate the products to be tested, here a selection of cables more or less covering the range of possible fire performances . We do not take into account the cables that exhibit an “exotic” behaviour when trying to draw a trend. No simple mathematical parameter permits to actually quantify the discriminating ability of a test method. Therefore we provide a graphical approach, which has to be taken with caution because it can be tricky.
The next three Diagrams 9, 10, 11 and 12 allow some comparison of the discrimination between the three test methods for the HRR peak, the THR_{600} and the FIGRA. For the FS, only the Full-Scale tests are compared.

Figure 9: Discrimination ability for the HRR peak between Full Scale and SBI

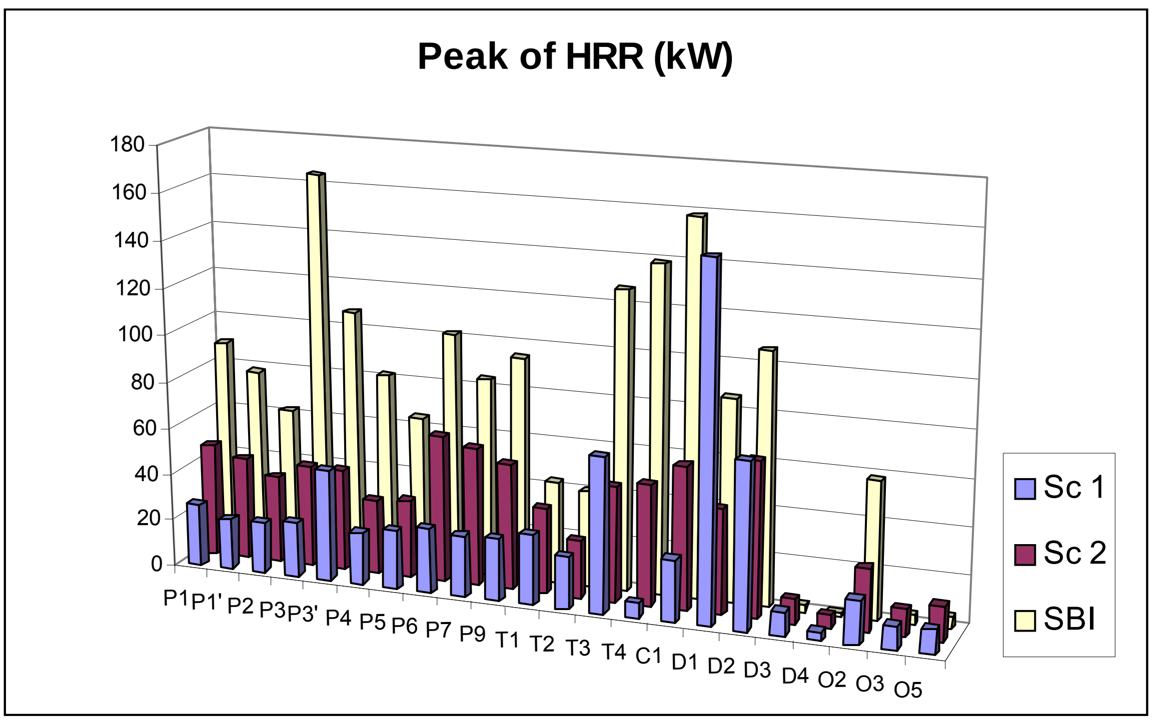


Figure 10: Discrimination ability for the THR_{600} between Full Scale and SBI

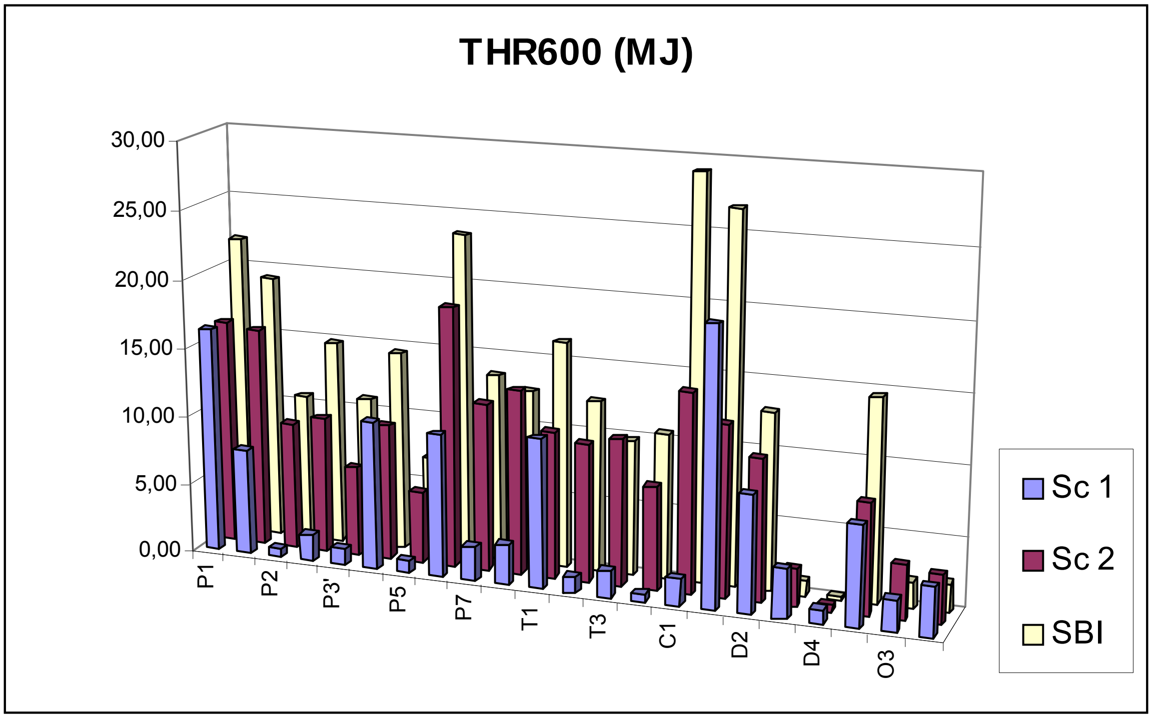


Figure 11 : Discrimination ability for the FIGRA index between Full Scale and SBI

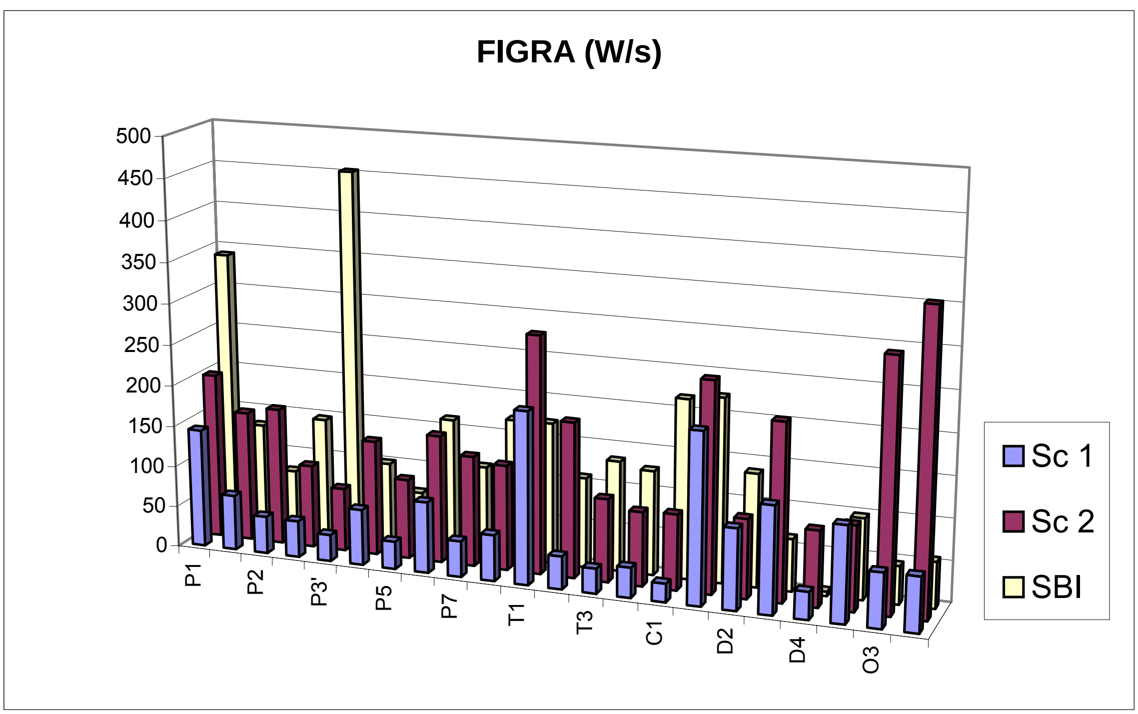
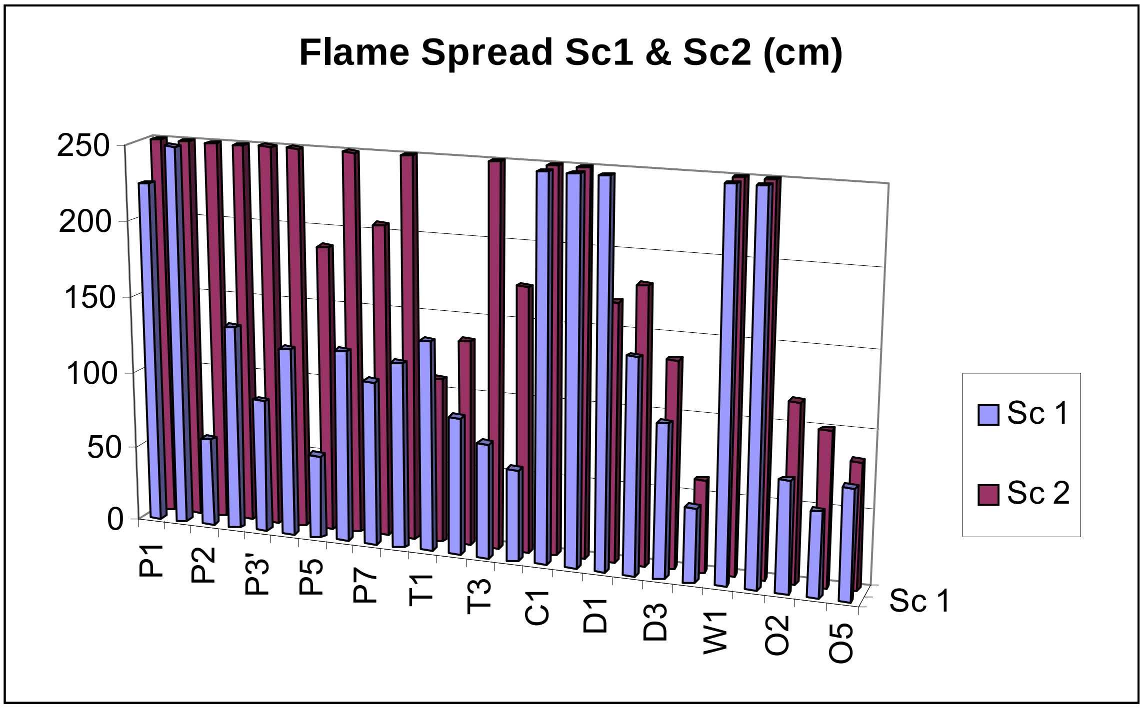


Figure 12 : Discrimination ability for the Flame Spread between Full Scale test Sc1 and Sc2



The Scenario 1 offers an acceptable discrimination ability except for cables with the highest fire performance.
The Scenario 2 and the SBI actually offer a higher discrimination but it remains questionable whether they actually permit to correctly discriminate “common” cables, i.e. cables with a standard fire rating (e.g. usual F2 cables).
It is interesting to note that severity does not mean a higher discrimination ability. Considering flame spread alone, i.e. the single criterion to be considered at present in regulation and/or specifications of cables, the Full Scale Scenario 1 test, which is less severe, give a good discrimination.

4.5 SMOKE parameters: Comparison between Full Scale and SBI

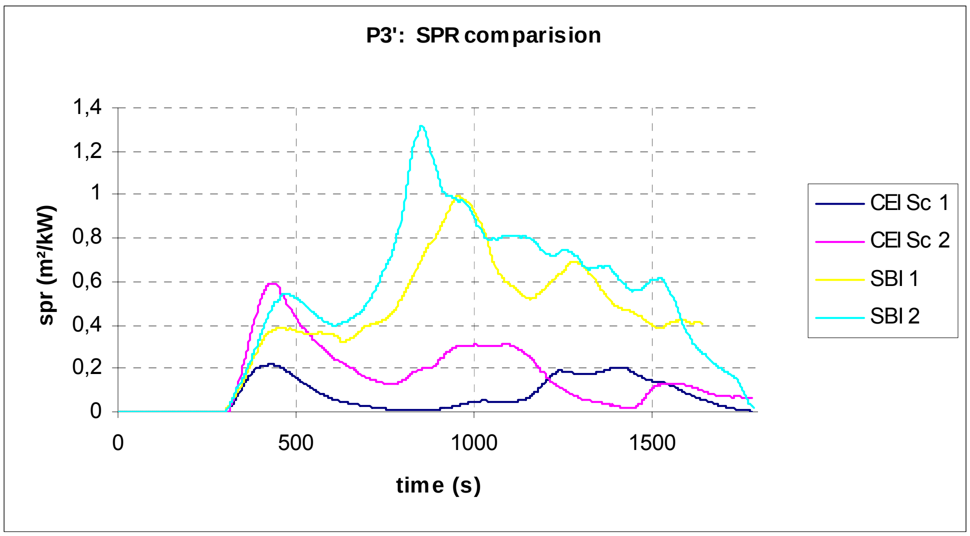
SPR peaks: For all power cables except P1, SBI test presents an upper rate of smoke production. For the rest of the cables no obvious trend is noted.
Shaded cells in Table XIX illustrate the highest values so the worse cables. Figure 13 illustrates the behaviour of power cable P3’. At full scale scenarios (CPD Cc & Bc) the cable gives off a first peak at the ignition of the burner while for SBI tests the smoke production is slower first and get its main peak later and higher.

Table XIX: SPR peaks comparison (m²/s)

SPR	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	1,213	0,963	0,281	0,219	0,218	0,045	0,027	1,357	0,395	0,249	1,858	0,461	0,043
Sc 2	0,858	1,087	0,444	0,353	0,591	0,036	0,002	1,633	1,098	0,699	2,806	1,178	0,081
SBI	1,059	1,48	0,629	1,428	1,158	0,149	0,105	2,009	1,439	1,015	1,436	1,13	0,249

SPR	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	0,054	0,081	5,046	4,38	0,085	0,342	0,027	5,374	0,175	0,053	0,253	0,256
Sc 2	0,046	0,038	0,939	2,584	0,071	0,67	0,137	2,162	0,107	0,063	0,168	0,795
SBI	0,271	0,214	1,652	2,462	0,219	0,173	0,057	1,239	0,143	0,118	0,199	0,243

Figure 13: smoke production rate of cable P3'



SMOGRA: The smoke growth rate is calculated in a similar way than FIGRA index. No clear trend can be pointed out (Table XX).

Table XX: smoke growth rate index comparison (cm²/s²)

Smog.	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	94,32	94,94	45,64	22,62	23,96	1,023	4,138	32,09	31,03	19,01	159,5	73,12	0,347
Sc 2	115,6	99,23	65,4	27,85	51,69	7,862	0,202	86,81	39,62	47,55	396,6	147,2	0,889
SBI	62,06	49,64	39,87	39,1	35,25	22,32	17,97	53,08	31,75	95,59	79,23	41,43	31,99

Smog.	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	0,418	10,89	173,2	120,7	1,579	41,2	4,719	285,2	2,515	4,924	45,92	46,05
Sc 2	1,032	10,02	63,71	236,3	1,111	145,2	34,66	430,1	13,86	0,891	19	123,9
SBI	23,98	26,17	111,5	74,92	26,96	50,97	15,73	197,7	42,14	25,95	25,57	36,74

TSP_{600}: the comments expressed for SPR_{peak} remain valid. The shaded cells in Table XXI highlight the type of test, which produces the most of smoke.

Table XXI: TSP_{600} comparison (m²)

tsp600	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	371,6	406,9	67,52	53,89	48,33	10,52	7,817	378,4	89,6	53,39	443,9	73,08	1,881
Sc 2	289,2	508,1	101,7	106,4	166,6	13,29	0,385	590,4	349,3	280,6	630,9	518,8	3,566
SBI	398	558,8	227,6	390,8	289	46,16	33,2	683,6	390,6	332,8	567,9	382,4	56,43

tsp600	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	1,507	19,32	907,5	1382	4,225	99,88	6,528	932,3	4,421	6,232	29,87	51,1
Sc 2	5,165	16,11	241,9	843,6	6,306	76,66	9,747	240,3	10	7,279	46,16	105,1
SBI	50,76	58,56	318,3	786,2	59,11	73	25,23	153	49,72	43,61	97,37	103,1

Discrimination ability: The same graphical approach has been applied to the following smoke results: SPR peak, TSP_{600} and SMOGRA index. The graphs 14, 15 and show the discrimination ability between the three tests levels.

Figure 14: Discrimination ability for the SPR peak between Full Scale and SBI

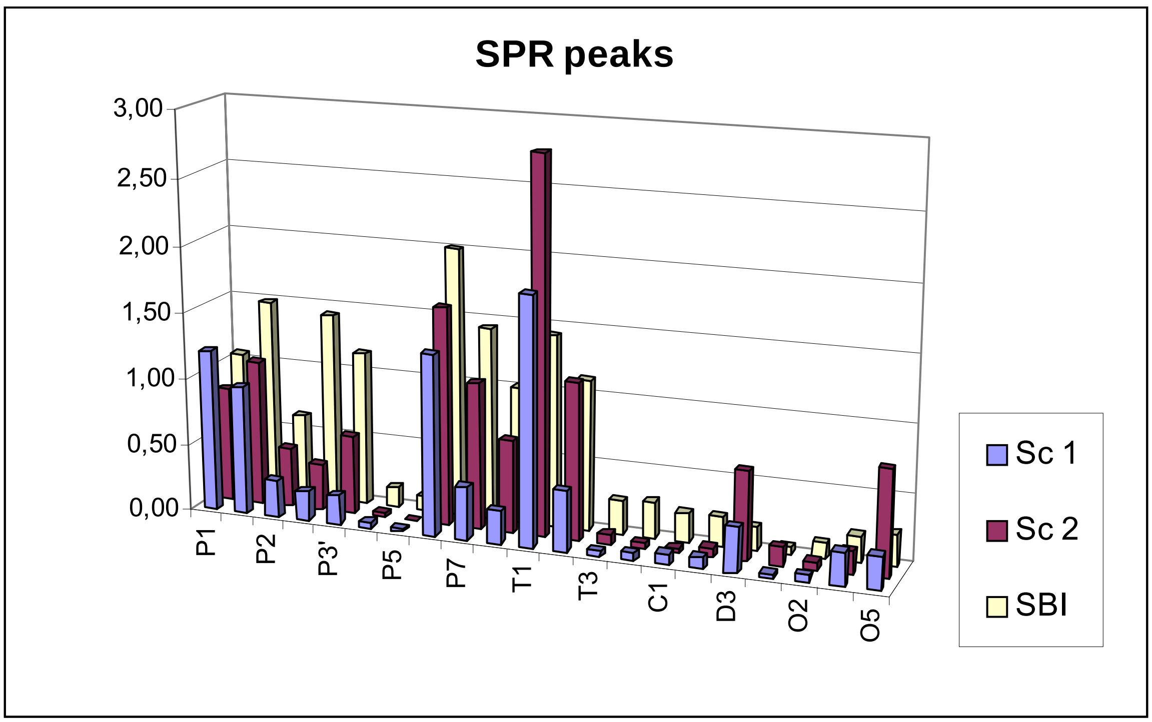


Figure 15: TSP_{600} discrimination ability between Full Scale and SBI

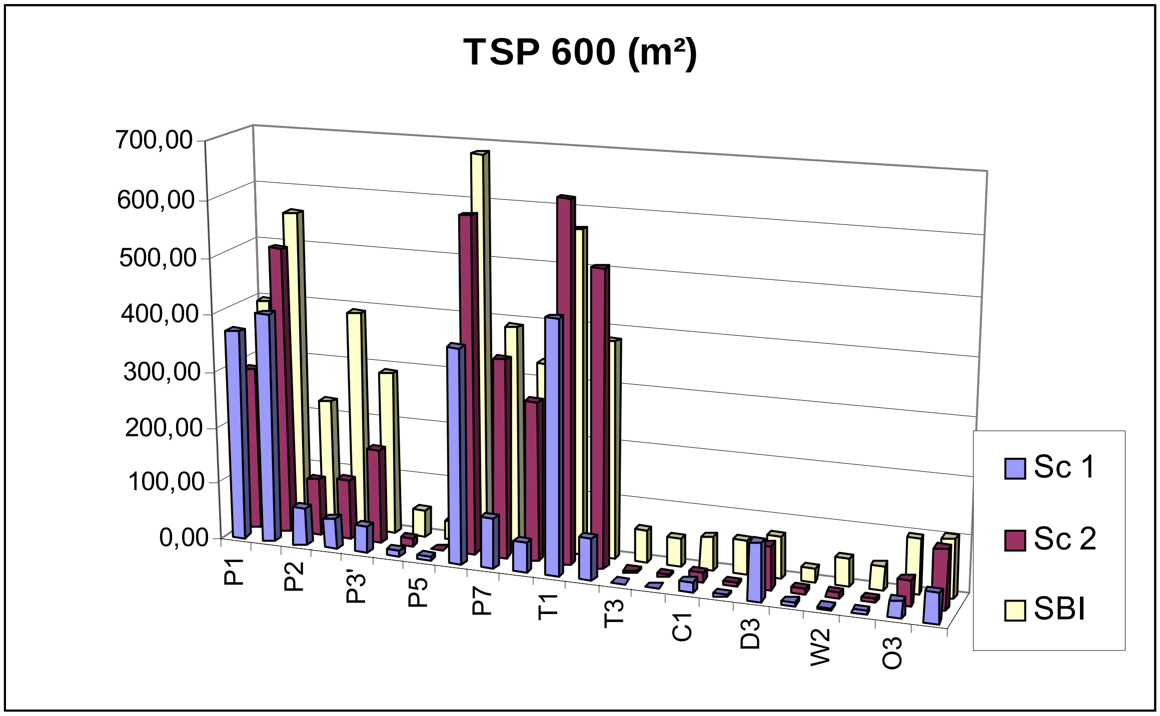
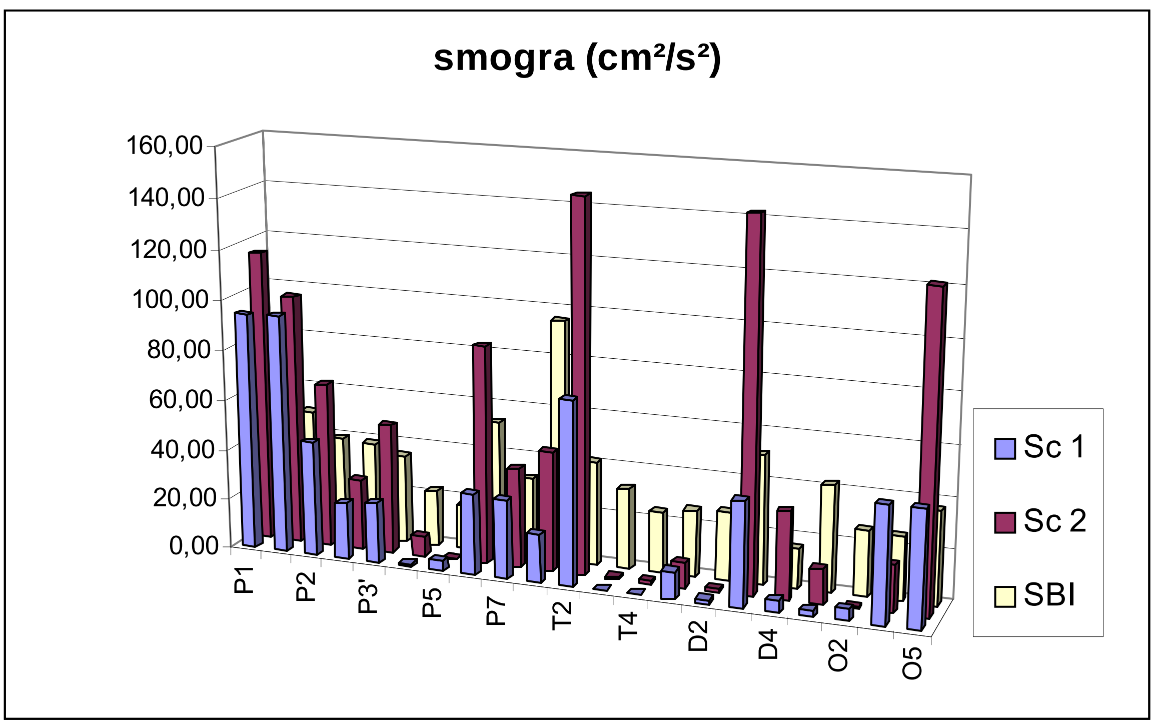


Figure 16: Discrimination ability for the SMOGRA index between Full Scale and SBI



The three tests offer a good smoke discrimination level. The Scenario 1 and the SBI present again higher values due to a usually higher rate of combustion.

4.6 SMOKE parameters: Comparison with 3-meter cube test

When comparing these test methods, one must keep in mind that the former test is based upon a static measurement while the new ones (Full-Scale and SBI) use dynamic measurement .It was decided to compare first the maximum extinction coefficient Kmax (1/m) This coefficient can be calculated from ***Formula 1*** (static measurement) or ***Formula 2*** (dynamic measurement). Kmax corresponds to the peak of smoke production. The Table XXII compares the Kmax values. Since Kmax remains apparatus-dependant, a direct comparison of its values would be meaningless.
We will check further if it exists a statistical correlation between the different tests (see § 3.8).

Table XXII: Kmax comparison

kmax	P1	P1'	P2	P3	P3'	P4	P5	P6	P7	P9	T1	T2	T3
Sc 1	1,283	1,133	0,39	0,295	0,27	0,092	0,063	1,557	0,519	0,332	2,254	0,59	0,064
Sc 2	1,082	1,255	0,514	0,413	0,808	0,093	0,014	1,757	1,226	0,779	3,27	1,337	0,116
SBI	1,865	2,45	1,065	2,217	1,892	0,237	0,18	3,284	2,496	1,708	2,433	1,893	0,379
27m³	0,303	0,301	0,34	0,493	0,505	0,042	0,144	0,39	0,349	0,381	0,626	0,613	0,027

kmax	T4	C1	C2	D1	D2	D3	D4	W1	W2	O2	O3	O5
Sc 1	0,078	0,139	3,69	4,492	0,155	0,361	0,038	4,404	0,254	0,067	0,285	0,258
Sc 2	0,095	0,066	1,014	2,897	0,125	0,88	0,226	2,469	0,136	0,125	0,187	0,928
SBI	0,426	0,377	2,743	3,952	0,365	0,345	0,102	2,216	0,267	0,192	0,342	0,412
27m³	0,181	0,268	0,365	1,102	0,028	0,191	0,018	0,403	0,062	0,025	0,105	0,16

4.7 Classification

In addition to the usual pass/fail criterion associated with the standard Full-Scale test (IEC 60332-3-24 and/or EN 50266-2-4, NBN C 30-004 F2), i.e. a maximum burnt height < 2.5 m, the improved method enables a continuous measurement and thus a classification with a number of levels.

4.7.1 Heat Release Classification

The reader will find enclosed several proposal of classifications:

- Belgian classification F2 (NBN C30-004)
- Last Europacable proposal (EUROCLASS, 22 may 2002) for Full-Scale tests
- EN 13501-1 for SBI tests

The **Belgian classification F2** in force only uses the flame spread as result. This is a pass/fail criterion, the cable is classed F2 if the flame spread doesn't reach 2,5 m. The test conditions are the same than in Scenario 1 (CPD Cc). The Table XXIII shows the cables that meet the requirement of the F2 category.

Table XXIII: Cables succeeding in F2 test (scenario 1)

Nr.	P1	P2	P3	P3’	P4	P5	P6	P7	P9	T1	T2	T3	T4	D2	D3	D4	O2	O3	O5
FS (cm)	225	58	135	88	124	55	126	108	122	138	90	75	60	140	100	48	72	55	72

Cables P1’, C1, C2, D1, W1, W2 burnt over 2,5 m and fail the test.

The last proposal of Europacable **EUROCLASS classification for cables** is more complex and more sensitive to specific performance level. The Table III lists the different levels and their associated requirements.
The scenario 1 has the same fire testing conditions than the class Cc and Dc.

The Table XXIV shows how the cables would perform according to the mid classes (i.e. Dc to Cc), consequently upon basis of the results obtained with scenario 1. The bold-faced types highlight the criteria, which possibly causes the cable to fall in the lower class.

Table XXIV: **Cc** & **Dc** classification according to EUROPACABLE proposal of 22 May 2002

Cable n°	HRR_{peak} (kW)	$THR_{600\ s}$ (MJ)	FIGRA (W/s)	Damaged length (cm)	Class
P1	**64.84**	**16.43**	144.30	**225**	**Dc**
P1'	42.66	7.78	67.0	**> 250**	**Out of class**
P2	7.02	0.59	45.4	58	**Cc**
P3	22.78	1.92	44.6	135	**Cc**
P3’	19.1	1.19	32.20	88	**Cc**
P4	45.87	10.79	68.1	124	**Cc**
P5	3.96	0.90	33.6	55	**Cc**
P6	41.63	10.39	86.57	126	**Cc**
P7	23.65	2.49	43.8	108	**Cc**
P9	26.19	2.91	56.1	122	**Cc**
T1	36.33	10.86	**209.2**	138	**Dc**
T2	19.34	1.18	40.2	90	**Cc**
T3	7.40	1.90	30.40	75	**Cc**
T4	6.67	0.58	36.60	60	**Cc**
C1	26.40	1.98	22.5	**> 250**	**Out of class**
C2	**671.70**	**115.10**	**2015.3**	**> 250**	**Out of class**
D1	149.90	20.00	207.0	**> 250**	**Out of class**

D2	**70.20**	8.50	100.0	140	**Dc**
D3	10.3	3.60	129.60	100	**Cc**
D4	3.5	1.00	33.40	48	**Cc**
W1	**514.6**	**94.10**	**3225.3**	**> 250**	**Out of class**
W2	**255.00**	**59.00**	**389.10**	**> 250**	**Out of class**
O2	18.7	7.30	116.00	72	**Cc**
O3	9.90	2.30	66.20	55	**Cc**
O5	10.40	3.50	67.00	72	**Cc**

Six cables are out of classes and 2 cables belong to class Dc. The main parameters causing the cable to fall in class Dc or lower are the FIGRA (FIGRA>150 W/s) and the Flame Spread (F.S.>250 cm).

The same exercise can be performed for the Scenario 2 in order to determine which cables would meet the requirements of the Euroclass Bc. This is summarized in the Table XXV.

Table XXV: HRR classification **B_{1C}** & **B_{2C}** EUROPACABLE to Scenario 1

Cable n°	HRR_{peak} (kW)	$THR_{600\ s}$ (MJ)	FIGRA (W/s)	Damaged length (cm)	Class
P1	48.29	16.34	**201.41**	**>250**	Out of class
P1'	43.77	15.95	**158.63**	**>250**	Out of class
P2	37.31	9.25	**166.99**	**>250**	Out of class
P3	43.86	9.90	100.82	**>250**	Out of class
P3’	43.46	6.52	76.82	**>250**	Out of class
P4	31.89	9.89	**139.78**	**>250**	Out of class
P5	33.17	5.23	96.85	**188**	Out of class
P6	**62.51**	**18.90**	**155.16**	**>250**	Out of class
P7	58.97	12.22	134.13	**205**	Out of class
P9	**53.43**	13.39	127.77	**>250**	Out of class
T1	36.70	10.64	**287.96**	108	Out of class
T2	24.37	10.08	**188.51**	135	Out of class
T3	49.28	10.64	100.89	**>250**	Out of class
T4	**51.77**	7.48	89.99	173	Out of class
C1	**60.91**	14.50	91.86	**>250**	Out of class
C2	**268.92**	**92.80**	**672.38**	**>250**	Out of class
D1	44.52	12.44	**254.55**	168	Out of class

D2	**66.17**	10.28	96.00	**180**	Out of class
D3	10.35	2.77	**214.49**	135	Out of class
D4	5.48	0.49	92.01	60	**Bc2**
W1	**269.97**	**19.79**	**3068.28**	**>250**	Out of class
W2	**116.59**	**31.72**	**621.32**	**>250**	Out of class
O2	26.87	8.07	102.52	116	**Bc2**
O3	12.00	3.95	**302.52**	100	Out of class
O5	14.80	3.52	**362.44**	82	**Out of class**

Only 2 cables would belong to class Bc2, none to class Bc1.
The Flame Spread is the main parameters causing the cables to be downgraded.
FIGRA requirement might cause some very high performance cable to be relegated in lower classes (e.g. D3, O3, O5)

Concerning the SBI tests we propose to refer to **the fire classification of construction products and building elements** as described in the standard **EN 13501-1**. Such a classification system was also suggested by CFRA (document RG N 255).
So the class that are of interest here are A2, B, C and D. It must be kept in mind that the classification is obtained on the single basis of the SBI tests. An actual classification would need additional testing. For example the distinction between class A2 and B would need further tests according to ISO 1716 and/or ISO 1182, which were not carried out in the framework of this study.
The FS criteria were found not to be applicable.

This classification applied to our results is given in Table XXVI.

Table XXVI: classification according to EN 13501-1 (based upon SBI results)

Cable n°	$THR_{600\ s}$ (MJ)	FIGRA (W/s)	Class
P1	**21.97**	341.00	**D**
P1'	**19.22**	131.78	**D**
P2	10.66	77.93	**C**
P3	14.83	147.06	**C**
P3’	10.92	**453.58**	**D**
P4	14.55	100.31	**C**
P5	7.01	68.47	**B or A2**
P6	**23.55**	163.31	**D**
P7	13.63	109.14	**C**
P9	12.69	170.94	**C**

T1	16.45	171.53	**C**
T2	12.45	109.23	**C**
T3	9.82	133.97	**C**
T4	10.54	126.80	**C**
C1	**29.13**	217.33	**D**
C2	42.83	**1251.21**	Out of class
D1	**26.82**	223.20	**D**
D2	12.89	137.15	**C**
D3	1.10	63.53	**B or A2**
D4	0.26	5.18	**B or A2**
W1	10.10	**2097.04**	Out of class
W2	**18.94**	502.90	**D**
O2	14.67	98.01	**C**
O3	1.92	46.17	**B or A2**
O5	2.08	56.21	**B or A2**

Only 2 parameters are considered for classification (instead of 4 for the “Europacable” proposal): THR_{600} and FIGRA.
Flame Spread is not considered, THR_{600} is the critical parameter in term of classification.
Five cables could reach the upper classes B or A2. Two cables fall out of class, i.e. ranked lower than class D.

4.7.2 Smoke classification

For the smoke, 3 test methods were used. A classification can be set for each of them and are described in :

- IEC 61034-2 for the 3 meter cube
- Last Europacable proposal (EUROCLASS, 22 may 2002) for Full Scale tests
- EN 13501-1 for SBI tests

4.7.2.1 IEC 61034-2 (3-meter cube)

The 3-meter cube criterion is a pass/fail one. The IEC 61034-2 recommends putting as requirement a minimum value of 60 % of light transmittance. Results are shown in Table IV in § 3.1.

4.7.2.2 Europacable proposal

We have submitted the smoke results of Full-Scale tests (Scenario 1& 2) to the Europacable proposal classification. The classification criteria are the SPR peak and the total smoke production at 600 seconds. The Table XXVII and Table XXVIII give the classification of the cables.

Table XXVII: Smoke classification according Europacable proposal for Full Scale Scenario 1

Cable n°	SPR peak (m^2/s)	TSP600 (m^2)	Class
P1	1,21	371,6	**S3**
P1'	0,96	406,9	**S3**
P2	0,28	67,5	**S2**
P3	0,22	53,9	**S2**
P3’	0,22	48,3	**S1**
P4	0,05	10,5	**S1**
P5	0,03	7,8	**S1**
P6	1,36	378,4	**S3**
P7	0,40	89,6	**S2**
P9	0,25	53,4	**S2**
T1	1,86	443,9	**S3**
T2	0,46	73,1	**S2**
T3	0,04	1,9	**S1**
T4	0,05	1,5	**S1**
C1	0,08	19,3	**S1**
C2	5,05	907,5	**S3**
D1	4,38	1382,4	**S3**
D2	0,09	4,2	**S1**
D3	0,34	99,9	**S2**
D4	0,03	6,5	**S1**
W1	5,37	932,3	**S3**
W2	0,18	4,4	**S1**
O2	0,05	6,2	**S1**
O3	0,25	29,9	**S1**
O5	0,26	51,1	**S2**

Table XXVIII: Smoke classification according Europacable proposal for Full Scale Scenario 2

Cable n°	SPR peak (m²/s)	TSP600 (m²)	Class
P1	0,86	289,21	**S3**
P1'	1,09	508,13	**S3**
P2	0,44	101,68	**S3**
P3	0,35	106,39	**S3**
P3’	0,59	166,57	**S3**
P4	0,04	13,29	**S1**
P5	0,00	0,38	**S1**
P6	1,63	590,43	**S3**
P7	1,10	349,35	**S3**
P9	0,70	280,61	**S3**
T1	2,81	630,92	**S3**
T2	1,18	518,82	**S3**
T3	0,08	3,57	**S1**
T4	0,05	5,17	**S1**
C1	0,04	16,11	**S1**
C2	0,94	241,87	**S3**
D1	2,58	843,59	**S3**
D2	0,07	6,31	**S1**
D3	0,67	76,66	**S3**
D4	0,14	9,75	**S1**
W1	2,16	240,32	**S3**
W2	0,11	10,00	**S1**
O2	0,06	7,28	**S1**
O3	0,17	46,16	**S1**
O5	0,80	105,13	**S3**

PVC cables get the lowest (S3) rank, whatever their level of fire performance is.
Some distortion is noted between the 2 sets of results, i.e. some cables obtain a different classification depending on the scenario.

4.7.2.3 EN 13501-1 (SBI tests)

Although the designation of the classes is the same than in the previous classification, this classification system does not use exactly the same parameters. The criteria are here the SMOGRA and the TSP_{600}. The Table XXIX illustrates the smoke classification.

Table XXIX: Smoke classification according EN 13501-1 for SBI

Cable n°	SMOGRA (m^2/s^2)	TSP600 (m^2)	Class
P1	62,06	398,00	**S3**
P1'	49,64	558,82	**S3**
P2	39,87	227,60	**S3**
P3	39,10	390,81	**S3**
P3’	35,25	288,99	**S3**
P4	22,32	46,16	**S1**
P5	17,97	33,20	**S2**
P6	53,08	683,59	**S3**
P7	31,75	390,56	**S3**
P9	95,59	332,79	**S3**
T1	79,23	567,90	**S3**
T2	41,43	382,36	**S3**
T3	31,99	56,43	**S2**
T4	23,98	50,76	**S2**
C1	26,17	58,56	**S2**
C2	111,46	318,28	**S3**
D1	74,92	786,21	**S3**
D2	26,96	59,11	**S2**
D3	50,97	73,00	**S2**
D4	15,73	25,23	**S1**
W1	197,68	152,98	**S3**
W2	42,14	49,72	**S2**
O2	25,95	43,61	**S1**
O3	25,57	97,37	**S2**
O5	36,74	103,11	**S2**

The classification according EN13501-1 presents the same trends than the previous classification of the Scenario 2 (Table XXVIII, § 3.7.2.2). PVC cables confirm their classification in lowest smoke class.

4.8 Correlations study

This project involved four methods of testing:

- 3-meter cube
- Full Scale testing Scenario 1
- Full Scale testing Scenario 2

- SBI testing

One major aim of the project is to compare the SBI method with the Full-Scale test.
The links between these levels are investigated by means of :

1. First, ranking order correlations. These are the simplest way to check whether specific types of tests correlate which each other. Using a statistical package the degree of correlation can be investigated for a specific parameter.
   The ranking order correlations are determined by means of the Spearman ranking order correlation coefficient.
2. In a second step, correlations between parameters obtained in the different test. The simplest analysis investigates curve fitting between the parameters by simple linear regression (Pearson coefficient).

4.8.1 Ranking Order Correlations between Full Scale testing Sc1, SC2 and SBI

The Ranking Order Correlations of peak of HRR, THR_{600}, FIGRA, peak of SPR, TSP_{600} and SMOGRA are evaluated and summarized in Table XXX.

Table XXX: summary of Spearman Ranking Order Correlation between SBI, Full Scale Sc1 and Sc2 tests

Ranking parameters	SC1 & Sc2	Sc1 & SBI	Sc2 & SBI
Peak HRR	0.65	0.44	0.83
THR600	0.65	0.57	0.76
FIGRA	0.78	0.39	0.19
Peak SPR	0.92	0.78	0.77
TSP600	0.9	0.80	0.91
SMOGRA	0.88	0.76	0.77

The correlation between Sc1 and Sc2 are poor for heat release but very good for the smoke measurements. Between Full Scale Scenario 2 and SBI are usually found acceptable to good, except for FIGRA (no correlation). Surprisingly enough, correlations are better for smoke.
Correlation between Scenario 2 and SBI is better than Scenario 1 and SBI correlation.
The HRR peak and TSP_{600} correlations can be seen as examples in Figure 17 and 18.

Figure 17: Ranking order correlation between Full Scale Sc2 and SBI for HRR peak

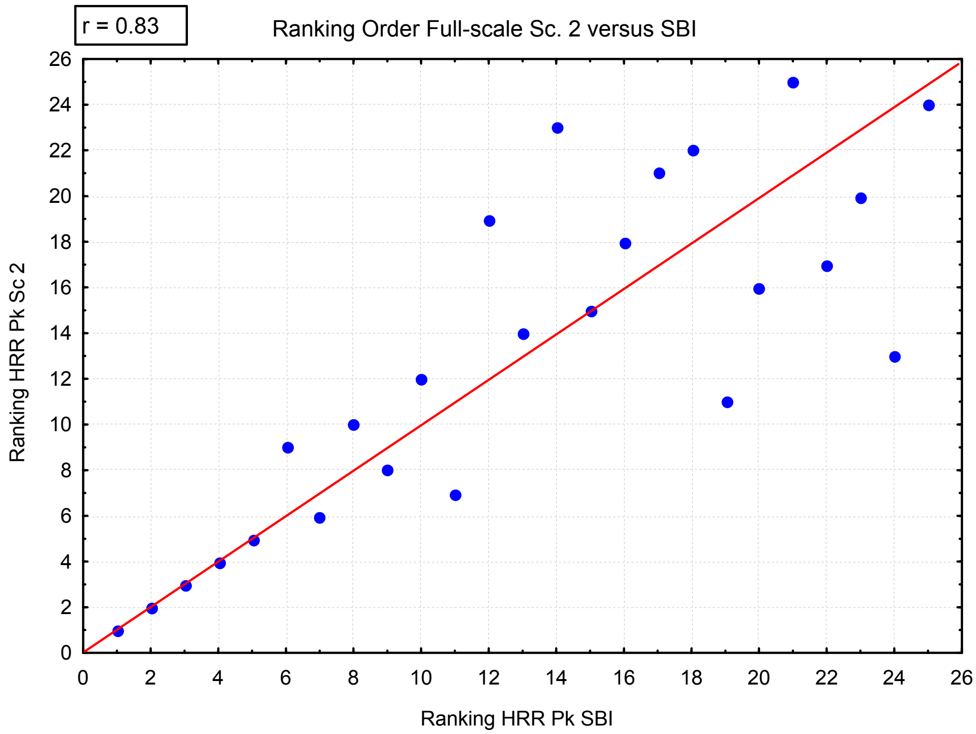
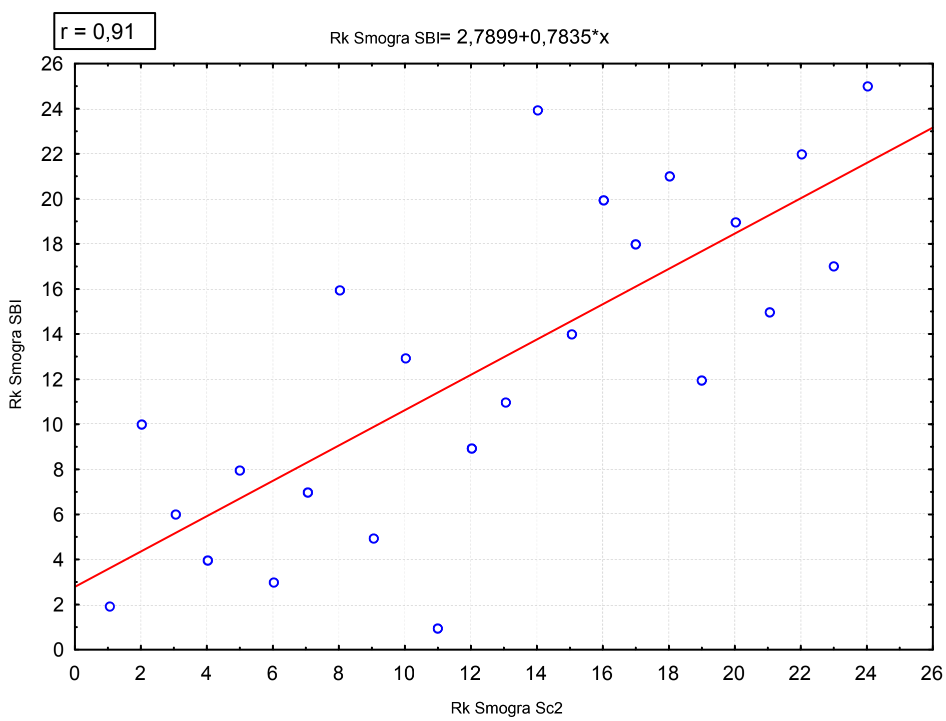


Figure 18: Ranking order correlation between Full Scale Sc2 and SBI for SMOGRA



4.8.2 Pearson Linear correlation

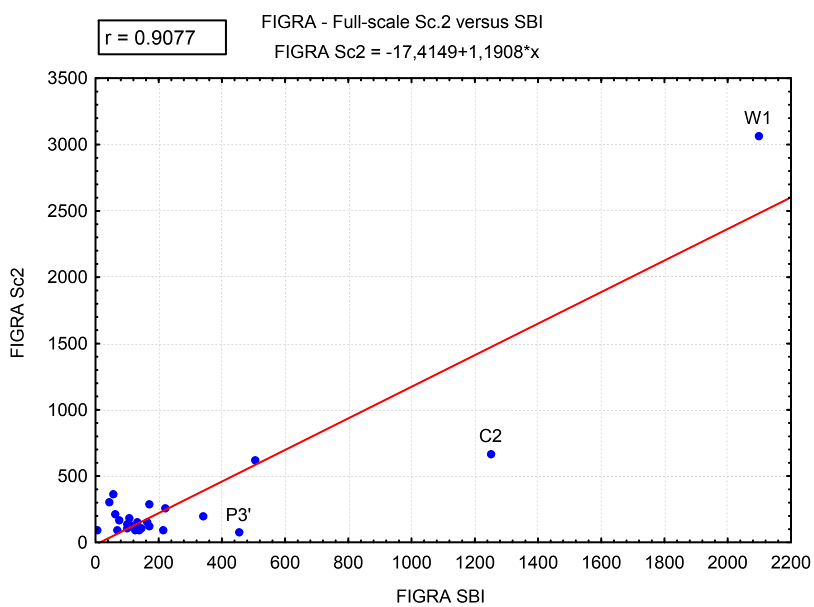
At this stage we are going to check if this trends between Full Scale Sc2 and SBI is confirmed by means of a linear correlation between the different parameters. The summary of Pearson correlation coefficients of HRR peak, THR_{600}, FIGRA, SPR peak TSP_{600} and SMOGRA is given below in Table XXXI.

Table XXXI: Summary of linear correlation coefficients between Full Scale Sc1, Sc2 and SBI

Correlation parameters	Sc 1& Sc2	Sc1 & SBI	Sc2 & SBI
Peak HRR	0.96	0.59	0.69
THR600	0.9	0.57	0.77
FIGRA	0.91	0.97	0.91
Peak SPR	0.71	0.79	0.79
TSP600	0.7	0.64	0.94
SMOGRA	0.85	0.95	0.79

As seen in the ranking correlation, the Full Scale Scenario 2 and the SBI show reasonable to good linear correlation, depending on the considered parameter. The reason is probably that Scenario 2 and SBI are rather close in terms of severity.
Pearson linear correlations between Sc1 and Sc2 are better than the previous ranking order correlations.
Note that FIGRA index obtains here a very good linear correlation coefficient in comparison with the ranking order correlation one. However one must remain cautious with this finding. This good coefficient is obtained thanks to an outlier (cable W1) having "to much weigh" as shown in Figure 19.

Figure 19: Pearson linear correlation between Full Scale Sc2 and SBI for FIGRA index



When these outliers are not included in the statistical analysis, the result can dramatically change, for example, to remove the spots W1 and C2 decreases the correlation coefficient to 0,39.

4.8.3 Correlations between Full Scale, SBI and 3-meter cube tests

As said in section 3.6, the maximum extinction coefficient Kmax will be used in a ranking correlation to detect a potential link between the dynamic (Full Scale & SBI) and the static (3 meter cube) tests. Table XXXII illustrates the Spearman Ranking Order correlation coefficients.

Table XXXII: Spearman Ranking Order correlation coefficients for Kmax parameter

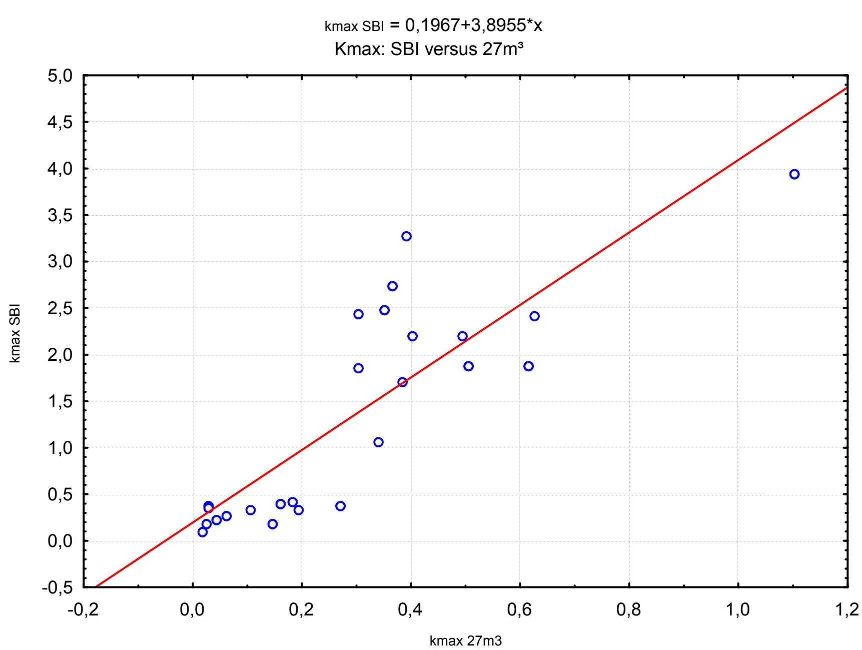
Ranking parameter	Sc1 & 3 m³	Sc2 & 3 m³	SBI & 3 m³
Kmax	0.80	0.74	0.84

In this case the correlation is good and the best is between SBI and 3-meter cube.
This trend is confirmed by the linear correlations analysis (Table XXXIII and Figure 20).

Table XXXIII: Linear Coefficient correlation for Kmax

Correlation parameter	Sc1 & 3 m³	Sc2 & 3 m³	SBI & 3 m³
Kmax	0.65	0.78	0.84

Figure 20: Kmax: Linear correlation between SBI and 3-meter cube chamber



Another type of correlation has been investigated: correlation between 3-meter cube and TSP_{600} of other tests. That correlation doesn't give more information, it is less good than the Kmax correlation.

4.8.4 Further correlation investigations

In an attempt to improve the correlations, a number a derived parameters were calculated :

- HRR peak, THR_{600} and FIGRA per unit length of cable
- SPR peak and TSP_{600} per unit length of cable
- HRR peak, THR_{600} and FIGRA per unit width of bunched cables
- SPR peak and TSP_{600} per unit width of bunched cables

The linear correlation coefficients for all these cases are available in the Table XXXIV and Table XXXV.

Table XXXIV: Pearson Linear correlations for the parameters per length unit

Correlation parameters	Sc1 & Sc2	Sc1 & SBI	Sc2 & SBI
Peak HRR per length unit	0.60	0.59	0.93
THR600 per length unit	0.32	0.40	0.96
Peak SPR per unit length	0.69	0.72	0.94
TSP600 per length unit	0.58	0.67	0.93
FIGRA per length unit	0.30	0.70	0.48

Table XXXV: Pearson Linear correlations for the parameters per bunch width unit

Correlation parameters	Sc1 & Sc2	Sc1 & SBI	Sc2 & SBI
Peak HRR per bunch width unit	0.81	0.64	0.82
THR600 per bunch width unit	0.75	0.60	0.86
Peak SPR per bunch width unit	0.66	0.73	0.89
TSP600 per bunch width unit	0.62	0.70	0.95
FIGRA per bunch width unit	0.91	0.98	0.91

The derived parameters calculated per unit length enables a significant improvement of the correlation between Sc 2 and SBI. The gain is also observed for the second series of derived

parameters (per unit width of cable) but in a lesser extent, except for the FIGRA value.
Correlation between SC1 and Sc2 are not improved by a significant way.
Oddly enough, no comparable conclusion can be drawn for Sc1 against SBI : the derived parameters do not lead to better correlation. No obvious reason for such a finding can be pointed out. It is suggested that difference in the mounting of the cable could be a part of the explanation : in Scenario 1, a number of cable are mounted in multiple layers (in order to have 1.5 l/m of combustible material), with such a mounting, it is questionable whether calculating the parameters per unit length of per unit width is meaningful.

5. Conclusions

This report gives an overview of all the work that has been performed in the framework of this project. Due to format requirements, it cannot cover every aspect. Further details on the results, analysis and conclusions can be found in appendixes, which are not part of this report. Additional information can be obtained from the authors.

While it is now acknowledged that special attention must be paid to the fire safety of cables, one notices that fire requirements for cables (whenever they exist) are still based upon prescriptive methods, usually with simple pass/fail criteria. The Fire Science Community is aware of the need for more sensitive test methods based on sound engineering principles. Major research projects, such as FIPEC and PII, have permitted significant progress in that way. For instance, FIPEC has permitted to overcome the 2 major limitation of the vertical tray test as identified in NIST Technical Note 1291 : its lack of HRR and smoke measurement functions, and its validation against real-scale.
The outputs of this study provide support and/or amendment of some conclusions drawn in the two aforementioned projects. In addition, the study presents an actual detailed comparison between two test methods in part developed in those projects and proposed as main test for the Euroclasses for cables.

Major findings and conclusions may be split up in 4 parts:
1. Extensive comparison of Full-Scale test methods (FIPEC, modified according to Europacable proposal) - with SBI (protocol modified according to CFRA and PII proposals);
2. Possible implications for the definition of Euroclasses for cables;
3. Recommendations for the measurement of smoke production;
4. Possible consequences for Belgium (regulations, standards, cables production).

Comparison Full-Scale test – SBI

The Full-Scale test method has been developed in FIPEC, with two different scenarios (often referred as FIPEC 1 and FIPEC 2). From these scenarios, Europacable suggested modified protocols, Scenario 1 (to be related to FIPEC 1) for mid Euroclasses (Cc and Dc) and Scenario 2 (to be related to FIPEC 2) for the top Euroclass (Bc).
The SBI test method is described in the standard EN 13823. The mounting procedure (dedicated to cables) was set up in PII.

Each test method has been evaluated chiefly in term of ability to measured essential fire parameters and capacity to discriminate the cables over a large range of existing fire performance.

- One may conclude that both methods permit a reliable measurement of most parameters, i.e. RHR_{peak}, THR, FIGRA. However, the SBI has shown a critical limitation since no FS (Flame Spread) can be measured with this method. This is a dramatic drawback since flame spread is a major hazard for bunched cables. In addition, most present regulations (including Belgian F2 – see § 0) include a single requirement that is flame spread.

- The statistical analysis highlights the robust correlation between Full Scale - Scenario 2 and SBI for RHR_{peak}, THR, FIGRA, especially when using derive parameters (i.e. weighted per unit length).

- In term of discrimination, no significant superiority of a method against another is observed. As expected, the Full-Scale Scenario 1 permits to better differentiate cables with low or medium level of fire performance (i.e. cables used nowadays in Europe). For cables with very high fire performance, SBI or Full-Scale Scenario 2 is more appropriate.

- The SBI calibration procedure is very interesting to determine the burner output level. It increases the accuracy of HRR calculations. The determination of all delay and response times as described in SBI standard should be applied to the Full-Scale (FIPEC) equipment. In this case the use of massflow controller would be mandatory.

Implications for future Euroclasses

The Euroclass table as described in EN 13501-1 is applicable to most construction products (e.g. wall linings, ceiling, insulation) except floor coverings and cables (for other linear products, the question is still open). It is built upon the SBI as the main test method. It was one goal of this study to assess to which extent the SBI (modified regarding specimen preparation and -mounting) could be valid for cables.

The alternative is the Full-Scale test method, as developed in FIPEC. In this study, the scenarios as modified by Europacable have been used.

In relation with a possible use as main test for the Euroclasses, both choices would present assets and limitations, as demonstrated by our project:

- No measurement of FS is possible with SBI, and FS in one main criterion of classification for Euroclasses. Full-Scale test enables FS measurement.
- Both test methods permit to measure other parameters (RHR_{peak}, THR, FIGRA). SBI and Full-Scale Scenario 2 seems to be appropriate for higher rank, i.e. class Bc. However, it remains questionable whether they are meaningful for cables with lower fire performance, which represent by far the major part of the European market today. For those cables, the Full-scale scenario 1 looks more convenient.
- The use of FIGRA for classification may lead to illogical results, i.e. some highest performance cables being relegated in lower ranks. The suitability of FIGRA would need further investigations. It is suggested to use a THR for a short duration instead (e.g. THR_{300}).
- At this stage, the smoke classification system should not include more than 3 classes, whatever the chosen method is (see also § 0).

At the time of the choice, it must be stated again that a single test method is preferable and, as far as possible, a single scenario. Taking into account the wide range of cables constructions, used materials and fire performance, it does not seem realistic to achieve the second objective.

Measurement of smoke production

A reliable method to measure the smoke production is needed. So far, the reference method is the 3-meter cube, which is used worldwide. SBI and Full-Scale test offer some improvement for the smoke measurement, in part thanks to their dynamic system, although the correlation between the 3-meter cube and the other method is not as poor as expected.
It must be acknowledged that none of the method permits a reliable discrimination of low smoke cables.

Consequences for Belgium

As stated a few times in this report, the fire classification of cables in Belgium is described in the standard NBN C 30-004. At present, most of the cables sold on the Belgian market meet the F2 requirement, i.e. a flame spread < 2.5 m when tested according to EN 50266-2-4 (or IEC 60332-3-24).
Except for HRR and SPR measurement, the test method is identical to the Full-Scale Scenario 1. Most cables with a F2 rating would be classified Cc or Dc according to the Europacable proposal. None of the selected Belgian cable could reach the Bc class. This could have been expected since such a level of requirement is not considered at present in our country.
When tested with SBI, most Belgian cables achieve a Cc or Dc rating. Surprisingly, one power cable is classified Bc or A2c.

Taking into account the wide and long experience of the Belgian Cable industry with the F2 classification, the choice of a test method close to F2 test (i.e. based upon the Full-Scale test) would facilitate the move towards the new harmonised European system.

All the data and their analysis gathered in the framework of this project will prove to be absolutely required when one will have to adapt the Belgian regulation (e.g. Royal Decree of 19/12/97) and to fix the level of requirements for each application.

In addition, the Belgian cable industry has used most of the results top check how their products perform with regard to the different proposals of classification for the future harmonized system. The findings of the project have also helped the representatives of the industry in the technical meetings during which the criteria of classification and the levels of requirements are discussed. To have an enlightened opinion about this topic requires first to know how the Belgian production performs in the considered system.

Concerning the smoke, no requirement is normally included in the Belgian regulations. The Cable industry has gained a long experience with the 3-meter cube. It is expected that the Euroclasses will include a smoke classification (with compulsory requirements). The Belgian regulator will have to chose whether he wants to apply smoke requirements and where. Here again, all the information gained in this project will be helpful.

6. Publicity

- A detailed status of the work progress was presented at each meeting of the follow-up Committee.
- An overview of the project and the progress of the work have been presented at several meetings of the CEB TC 20C (23rd March 2001, 15th June 2001, 24th October 2001, 24th May 2002, 04th September 2002).
- A meeting dedicated to the Belgian position with regard to the Euroclass proposals for cables was held on the 15th January 2002, in presence of representatives of Cablebel, the Belgian fire regulators (Belgian delegates at FRG) the Belgian representative at SCC and the promoter of this study. During the meeting; the objectives and the progress of the project were reviewed.
- During the last meeting of FRG held in Brussels on the 30th January 2002, at which the promoter was invited as the Belgian technical expert, the Belgian delegates informed FRG members and Chairman about the existence of the Belgian Science Policy project.
- The 2nd annual progress report was circulated to the sponsors, CFRA, Head of Unit Construction DG Enterprise of the European Commission, to the members of the Fire Regulatory Group, to the experts of the Belgian Ministry of Interior.
- During the next European Meeting on Fire Retardancy on Fire and Protection of Materials meeting which will be held on 17 and 19 September 2003 in Lille, an oral presentation of the project and his conclusions will be presented.
- An amended version of this report will be edited and circulated to concerned Belgian and European experts.

7. Acknowledgements

This project has been made feasible thanks to the funding of The Belgian Science Policy.

In addition, the authors would like to thank all the scientists, the laboratory's technicians, and the cable manufacturers who were involved in this project. In particular:

Nexans Belgium
Kabelwerk Eupen
Opticable
CFRA
Cablebel
CEB TC 20C

8. References

- J. Axelsson , P. Andersson, A. Lônnermark, P. Van Hees, I. Wetterlund, (2001), “Uncertainties in Measuring Heat and Smoke Release Rates in the Room/Corner test and SBI”, Nordtest Technical Report 477, SP (Sweden).
- H. Breulet , (2000), “Assessment of the adequacy of fire behaviour tests for cables: Second Annual Report, ProjectNM/G7/38”.
- H. Breulet, (2001), “ Assessment of the adequacy of fire behaviour tests for cables: First Annual Report, ProjectNM/G7/38”.
- Cable Fire Research Association, (25 April 2002), “CFRA Single Table Compromise Proposal : CFRA/C/C250402”.
- Cable Fire Research Association, (September 2001), “Cables and EU construction product directives – SBI – based on cable test proposal to the European Commission (EC) and fire Regulatory Group (FRG)”.
- Europacable, (22 May 2002), Europacable Proposal Classification: Euroclasses table .
- P. Fardell, E. Colwell D. Hoare, “Communication cable fire – A study to assist the development of improved fire tests”, Interflam 2001 Proceedings
- S.J. Grayson, P. Van Hees, U. Vercellotti, H. Breulet, A. Green, (2000), ” FIPEC Book: Fire Performances of Electric Cables – new methods and measurements techniques, Final Report on the European Commission, SMT Programme Sponsored Research Project, SMT4-CT96-2059”, (Interscience communications Ltd, London).
- S.J. Grayson, P. Van Hees, A. Green, H. Breulet, U. Vercellotti, “Assessing the Fire Performance of Electric Cables (FIPEC)”, Fire and Materials 25, 49-60, April 2001
- M. M. Hirschler, (1994),“ Comparison of Large- and Small-scale Heat Release Tests with Electrical Cables”, Fire and Materials, Vol. 18.
- M. M. Hirschler (1990), Electrical Cables Fire Hazard Assessment with the Cone Calorimeter, in Fire Hazard and Fire Risk Assessment, ASTM STP 1150.

Standard References:

- Règlement Général sur les Installations Electriques, Arrêté Royal du 10 mars 1981.
- EN 50266-2-4: Common tests methods for cables under fire conditions – Tests for vertical flame spread of vertically-mounted bunched wires or cables – Procedures – Category C, CENELEC (Bruxelles, 1999).
- EN 13501-1: Fire classification of construction products and building elements – Part 1: Classification using test data from reaction to fire tests, CEN (Bruxelles, 2000).
- EN 13823: Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item, CEN (Bruxelles, 2002).
- IEC 61034-1/2: Measurement of smoke density of cables burning under defined conditions, Part 1 – Test apparatus, Part 2 – Test procedure and requirements (International Electrotechnical Commission, Geneva, 1997).

- IEC 60332-3-10: Tests on electric cables under fire conditions - Part 3-10: Test for vertical flame spread of vertically-mounted bunched wires or cables - Apparatus, International Electrotechnical Commission (Geneva, 2000).
- IEC 60332-3-24: Tests on electric cables under fire conditions - Part 3-24: Test for vertical flame spread of vertically-mounted bunched wires or cables - Category C, International Electrotechnical Commission (Geneva, 2000).
- NBN C 30-004: Fire resistance of electrical cables – Classification and test methods, CEB & IBN (Bruxelles, 1993).
- PrEN CPD-1 draft 10: Common test methods for cables under fire conditions - Heat release and smoke production measurement on cables during flame spread test – Part 1: apparatus, CENELEC (Bruxelles, 2001).
- PrEN CPD-2-1 (Cc and Dc) draft 4: Common test methods for cables under fire conditions - Heat release and smoke production measurement on cables during flame spread test – Part 2: Procedure for classification in Euroclasses C and D, CENELEC (Bruxelles, 2001).
- PrEN CPD-2-2 (Bc) draft 6: Common test methods for cables under fire conditions - Heat release and smoke production measurement on cables during flame spread test – Part 2-2: Procedure for classification in Euroclasses B, CENELEC (Bruxelles, 2001).

Publié en 2005 par la Politique scientifique fédérale

La responsabilité scientifique de ce rapport est assumée par les auteurs.

POLITIQUE
SCIENTIFIQUE FEDERALE

rue de la Science 8 ▪ B-1000 BRUXELLES
Tél. 02 238 34 11 ▪ Fax 02 230 59 12
www.belspo.be