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Experimental Approach of the Fire Hazard in Closed Spaces : Laboratory and Full-scale Tests

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Summary

This presentation is intended to open technical discussions at the workshop devoted to fire testing and modelling with regard to the specificity of the fire hazard in various enclosures that are liable to drive the fire scenario (tunnels, warehouses, technical rooms, underground structures).
More particularly, the paper outlines INERIS views on the role that can be played by fire tests, from lab-scale to real scale, at the light of a brief historical review and from its own experience. The purpose is illustrated by a number of examples where INERIS has contributed to analyse or solve fire problems, evaluate fire protection systems or potential consequences to the environment or more generally understand related phenomena that can be encountered in closed structures. Eventually, the paper stresses the opportunity and advantages from conjugated use of testing and modelling techniques.

Large scale and small scale tests : some historical issues

From a general point of view, it is worth to notice that major fundamental progress in the past decades in the understanding of the fire physics have been obtained through experimentations of various kinds. In comparison, the development of mathematical models and related computer codes, although started as early as in the 70's, have only gained substantial interest together with the sharp increase in the power of microprocessors, related decrease of computation time and with the delivery of user-friendly softwares dedicated to fire engineering and fire hazard analysis, say, since the mid 80's.
As stated very clearly by Hirano et al[1] iterative experiments and related observations are fundamental steps of any scientific research, in order to generate ideas, validate first order analysis of fire problems like fire spread. Eventually, the experimental approach support mathematical development of the expected final operational tools that one wish to use to make accurate or conservative predictions of confined structures at the design level.

In France, we often refer to the fire disaster of the *Bazar de la Charité* that occurred in Paris at the end of last century (where 129 people died) as being the starting point for the implementation of reaction-to fire tests to evaluate the fire performance of linings, floor and ceilings coverings that are allowed to be used in places of public assembly. A more comprehensive review performed by V. Babrauskas has identified the first " recognized " fire

test (e.g. being supported by accurate specifications) to be the one in use in the US Marine to evaluate fire performance of wood used in ship construction[2] . The most common use devoted in the early times to small-scale fire tests was the ranking of test materials from the empirical appraisal of one single or a few criteria that relate to the global fire behaviour (for instance ignitability, fire spread, smoke index, time to ignition…).
In parallel, the very severe risk of fire and explosion and related potential damage in coal mines have been studied by all concerned industrial countries through extensive large-scale experiments, generally performed in wind tunnels or other experimental galleries. Basically, large-scale tests have been used in the field to learn the consequences of a fire scenario from a real simulation, or verify by observation and measurements major fire safety issues whereas current knowledge was unable to understand, even less predict, on a scientific basis all the results obtained and analyse them in terms of physical laws or models.
Later, other large-scale multipurpose facilities were built or retrofitted for fire testing use by various fire research or technical centres such as FMRC, BFRL (a division of the NIST), or Underwriters Laboratories in the USA, FRS in the UK, SP in Sweden. More specific equipment of that kind also exist in France, for instance to study the fire hazard in the nuclear industry[3] or for the certification of fire extinguishers. They often present the configuration of large burn halls where for instance storage commodities may be tested and are generally provided with large-scale heat release rate measurement tools. Extensive use of such facilities have resulted in a basic classification of storage commodities and have also greatly contributed to the improvement of sprinkler systems. Recent experimental investigations using such burn halls deal with the interaction of sprinkler systems with other fire protection devices such as smoke vents and draft curtains[4]. In France, IPSN is operating specific concrete enclosures for fire safety studies regarding the French nuclear power plants[3].
Historically speaking, the major advantage of the large-scale experimental approach was the ability of observing the fire phenomena (smoke movement for instance) and measuring basic parameters characterising the overall fire behaviour (or fire suppression process) at a realistic scale in such a condition that no extrapolation step is needed, because the interaction with the structure or the confinement involved in the fire scenario studied was reproduced at 1:1 scale.

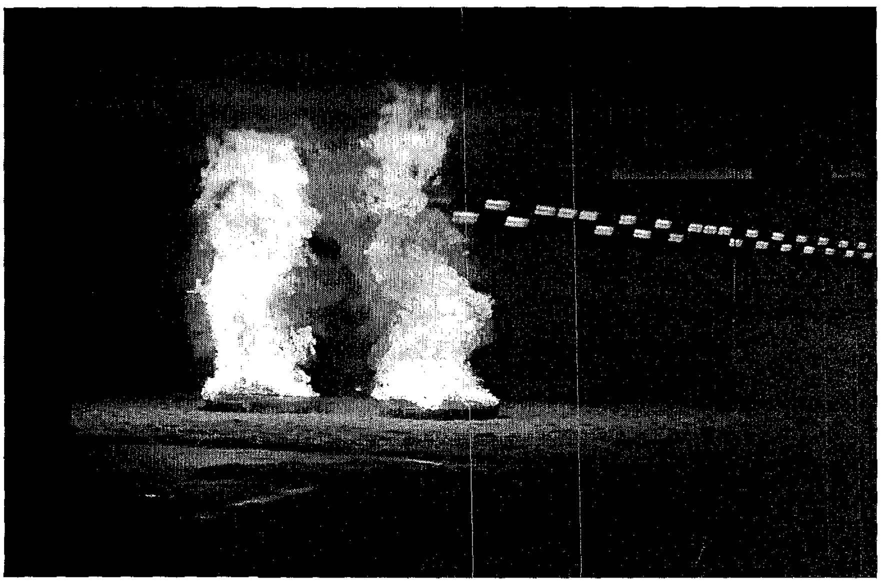

figure 1 : in-situ evaluation of the fire plume interaction with the smoke venting system in an underground roadway (source term : twin pools of heptane, heat release around 5.2 MW)

It shall be stated that fire dynamics which relates to uncontrolled combustion process, remains until now a very complex topic that will justify for still many years the use of pertinent experiments in a number of cases in spite of the progress accomplished by fire zone and CFD models. This will be true in particular, when the fire problem to be coped with relates to complex enclosures or when the main fire hazard deals with chemical issues (e.g. source terms characterisation of toxicants or pollutants produced in fire plumes, that is often a basic requirement for adequate introduction of input data in computer codes).

At the time, due to such considerations, the assessment of the overall performance of smoke venting systems in heavy traffic underground structures is generally performed or at least checked by in-situ calibrated fire tests. Figure 1 illustrates a fire test recently performed by INERIS which took place in a complex underground roadway located in Paris aiming at such a goal.

In the field, interactive processes between pertinent use of CFD and experimental validations at various scales become more and more efficient.

As an example of this, a recent thesis work has outlined the mutual interest of CFD calculations and use of pertinent 1:20 scale tunnel section mock-up designed adequately to perform investigation on the same subject [5].

A further example of a complex confinement where the experimental approach was considered a fundamental step of the risk assessment process was the Channel Tunnel. Coping with the fire hazard inside the single and double deck carriages of *the Shuttle* to be in use in the Trans-Manche fix link had led to the building and operation at INERIS of a full scale mock-up of a wagon carrying real cars. The mock-up was used to perform real fire scenarios[6] for the evaluation of emergency procedures and related fire protection systems performance.

More recently, a collaborative study involving contributions of CETu, Scetauroute, SAPRR and INERIS focused on system under development to drain safely flammable accidental spills for use in road tunnels[7]. The work has comprised a validation step performed by use of a full scale prototype of the drainage system tested with real fire scenarios in the *Mont-la-ville* explosion and fire testing field also belonging to the institute.

Although less directly informative in comparison to large-scale, small-scale fire tests have been developed extensively from early times for purposes such as quality control, fire performance evaluation or approval of various materials (by reference to a standard or a specification in some designated areas e.g. building construction, electrical devices, transportation systems...). Low costs remain the major advantage of these series of tests[8], very numerous, but however very often suffering from empirical design and use. Indeed, many of them have capabilities basically limited to ranking of materials in terms of fire performance regarding a single criteria (e.g. ignitability, flammability, smoke obscuration, fire toxicity, flame spread,...).

However, with the emergence of modern techniques for the measurement of heat release, a very important fire parameter, some new lab-scale tests have emerged, with much more potential for powerful applications such as the cone calorimeter (ISO 5660), the OSU calorimeter (ASTM E906 ; FAR part 21 and 121 ; NFPA 263) and the FMRC Lab-Scale Flammability Apparatus (proposed standards ASTM E5 Z6880Z and NFPA 278). Scientific publications of works based on the use of those apparatuses have largely confirmed that statement. The Single Burning Item (SBI) apparatus newly proposed to serve as the main fire test in the European will also allow the measurement of the rate of heat release.

Eventually, adequate validation work of lab-scale testing protocols by comparison with large-scale tests results is very often a requirement to promote technological breakthroughs in fire problem evaluations at lab-scale[9].

INERIS fire testing facilities and related instructive experimental works

Similarly to the general trend mentioned in the historical review, INERIS started to learn the explosion and related fire risk in mines preferably by use of large testing galleries and wind tunnels.

In particular, the Institute has studied a variety of fire problems related to confined fires by use of its 600 m^3 fire gallery (see figure 2) commissioned in 1982, still in operation today in parallel with more recently built experimental facilities such as the 80 m^3 enclosure and the INERIS lab-scale fire calorimeter, based on the FMRC lab-scale flammability apparatus. The potential applications of the whole set of test equipment are very numerous, and current applications do not restrict any longer to the mine safety background.

In 1996, INERIS has overviewed the use of its fire gallery to qualify well ventilated chemical fires that may occur in warehouses where free burning quickly becomes the dominating process[10]. Thanks to funds coming from the French Ministry of the Environment and some other international technical and financial supports (International Isocyanate Institute, EU DGXII[11]), the characterisation of the thermal and chemical parameters of the fire behaviour of a series of products, such as pesticides, fertilizers, or some commercially-important chemicals. like TDI or MDI has been achieved. Some fire safety issues of a high rise warehouse containing pharmaceutical products and related materials were also determined[12].

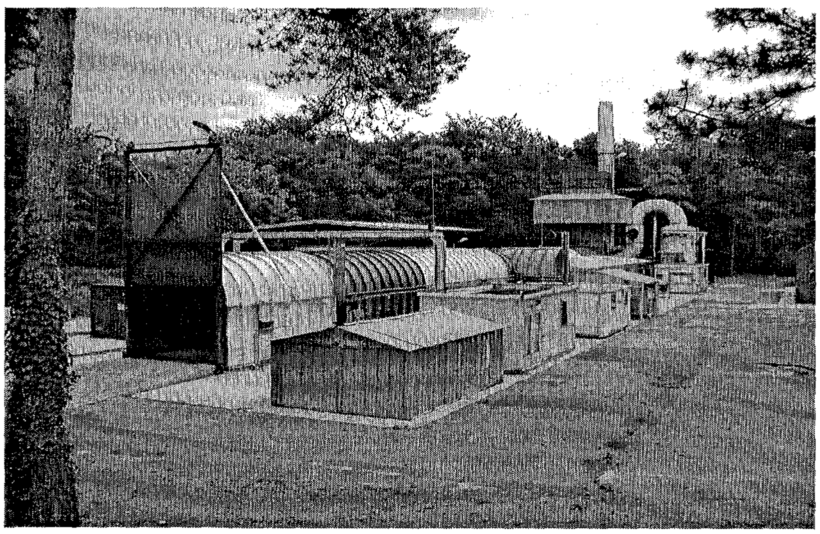

figure 2 : picture of the INERIS fire gallery and related equipment

Other major examples of pertinent applications of the equipment was the experimental work carried out in support of the revision of the ventilation equipment of the RATP, the company operating the Underground in Paris[13], or a customised fire resistance test carried out in collaboration with CTICM to qualify the fire resistance properties of a newly designed irrigated curtain made of mineral woven fabric. The system had proven to perform like an unusual but efficient movable fire door now in operation in a very large exhibition hall in Paris[14].

Other example of use in relation with the fire problem in closed spaces deal with the sizing of the pressure conditions that should prevail for the suitable operation of a safety refuge in the French tunnel of Puymorens[15] or the experimental approach at full-scale of the fire behaviour of Christmas trees decorated with artificial snow in confined areas such as town halls, schools (see figure 3).

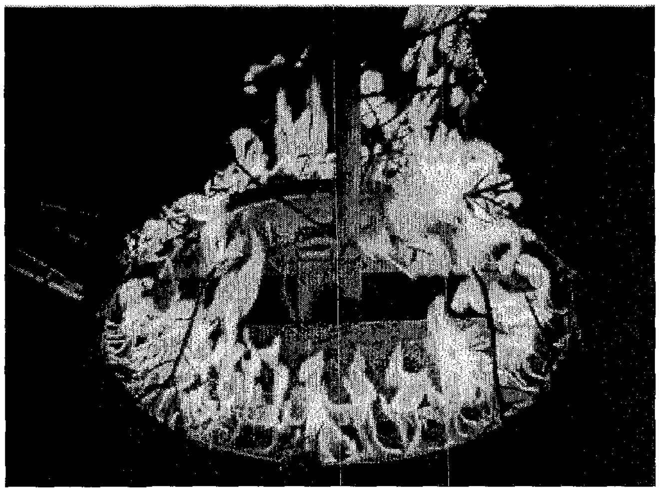

figure 3 : Annular ignition source (alcohol) used in a series of full scale fire tests on Christmas trees (1998) performed in the INERIS fire gallery, vertical section

All those examples have drawn advantage from different capabilities of the INERIS fire gallery, in terms of on-line chemical measurements facilities, adequation of shape of test sections of the equipment or opportunities for real time visualisation of expected or feared events bound to fire dynamics.
Large-scale tests in the INERIS fire gallery have also helped in the recent past the implementation of well calibrated fires associated to the Eureka 499 Firetun research programme performed in 1992. In this programme another series of tests carried out in the Repparfjord tunnel (Norway) have contributed to the development of design fires[16/17]as required in closed spaces for the fire performance based approach in fire safety engineering.

INERIS is also using a 80 m^3 (movable to a 100 m^3) enclosure (4 m x 4.5 m x 4 m) to perform tests involving fire scenarios under control of ventilation, which may be a common situation in some closed spaces depending on the fire spread rate and the size of burning items. The initial use of this concrete building was the validation at 1:1 scale (enclosure + combustible materials) of a non propagating fire scenario from one cable tray (catching a fire) to another cable tray located on the opposite wall, a configuration representative of a cable room of a nuclear power plant.

At the lab-scale, INERIS commissioned in 1997 a fire calorimeter based on the *FMRC* Flammability apparatus, according to fruitful collaborations initiated in the early 90's with the inventor of the equipment still working at *FMRC* and the French user of the equipment *Rhône-Poulenc Industries*. The equipment has been implemented at the Institute as a major step of an on-going research programme aiming at learning and assessing the associated risks of chemical fires controlled by ventilation.

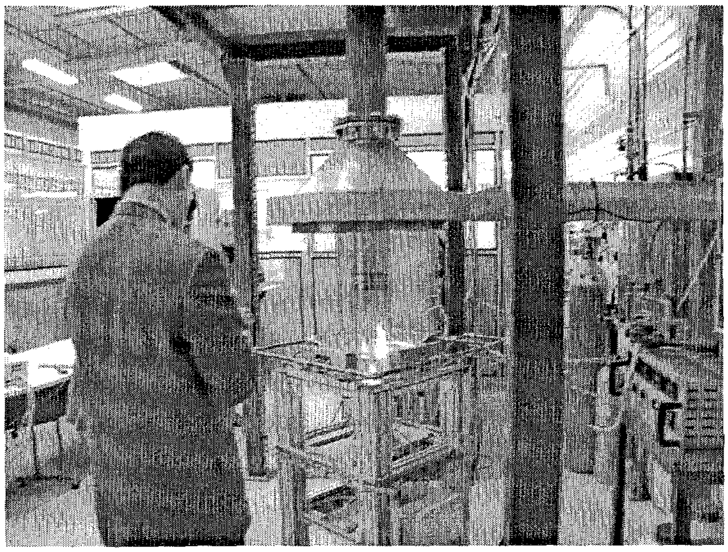

figure 4 : view of a fire test by use of the INERIS lab-scale calorimeter (plastic sample)

However, this equipment is in fact capable of testing materials and products on the full range of ventilation conditions, by adjusting the airflow rate coming in the quartz tube physically delimiting the combustion area. Various scaling techniques involving the external heat flux and the O_2 content of the inlet flow as controlling parameters are in use to simulate large-scale fires or develop predictions applying for large-scale.
Tables 1 and 2 list some a few characteristics of this test rig and figure 3 gives of picture of it.

Apparatus design	*Main features*
basic design features	FMRC lab-scale flammability apparatus
test sample, physical state	solid (even powders), liquid or gas
test sample size	in the order of 10 cm or 50 g
inlet flow (usual range : 0- 200 l/min)	air, any mixture of O_2/N_2, mixture O_2/Ar
outlet flow	usual range : 50 to 300 Nm^3/h
external heat flux	0-65 kW/m^2 by infrared heaters with quartz lamps
ignition device	Pilot flame and spark ignitor

table 1 : Some characteristics of the INERIS lab-scale fire calorimeter (Tewarson Apparatus).

Basic measurements and related calculations	
weight loss rate	weighing sensor range 0 –125 g
heat release rate	both O_2 consumption and CDG techniques[18]
on-line gas analysis capabilities	O_2, CO, CO2, NO, NO_2, HCt, SO_2, HCN, HCl, H_2O_{vap}, NH_3
other (optional) chemical measurements	e.g. NH_3, aldehydes, ketones, nitriles
smoke density	optical measurement of extinction coefficient at 3 different wavelengths
flame temperature	thermocouple K
combustion gases temperature and convected heat	thermocouple K
yields of combustion products	for all measured product, as a function of the equivalence ratio (e.g. ventilation factor)
outlet gas flow	averaging Pitot tube
flammability parameters[19]	Thermal Response Parameter (TRP), Fire Propagation Index (FPI), Critical Heat Flux (CHF) according to FM standards

table 2 : measurements and related calculated data on the INERIS fire calorimeter

The equipment has already revealed very relevant for the identification of specific confined fire phenomenology such as drastic enhancement of non thermal damage in case studies of storage of cellulose nitrate films, or when organophosphorous compounds undergo decomposition in fire conditions[20]. It may also serve as a screening method for ranking the materials with respect to their ability to produce dioxines in fire conditions[21]. Repeatability of experimental data obtained by use of this apparatus is really excellent in all cases.

Eventually, INERIS will soon commission a cold modular mock-up able to address fire problems by use of similarity laws. Thanks to appropriate construction, the new cold mock-up will have the ability to treat fire dispersion problems in both conventional enclosures (rooms) or tunnel configurations at different scales. The design and construction of the equipment are important milestones of a research project regarding the simulation of fires in complex underground structures.

Discussion and conclusive comments

Technical progress in fire science and computer technology, conjugated to new requirements in matter of fire safety levels have now led to new trends in the design and use of fire test equipment and related use.
Small–scale testing have achieved new capabilities in the field of certification and characterisation of the fire behaviour of products and materials, although scaling laws required to extrapolate the results to real fire scenario are still under development for many applications.
Among them, the so-called Tewarson Apparatus in France (Lab-scale *FMRC* Flammability Apparatus) seems to our opinion the one presenting the more versatile capabilities, particularly with regard to underventilation of fires which often prevail in closed structures[22/23].

It looks however surprising that use of CFD calculations seems to be until now very rarely used to understand more finely what happens in well established lab-scale fire testing equipment or in the design phase of new ones. INERIS is currently exploring this technique to increase the detailed knowledge of the operation conditions of the Tewarson apparatus in the framework of the ADELFI project, a European 'ESPRIT' programme.
Large-scale tests using fixed equipment such wind tunnels, large burn halls or room fire tests, as well as in-situ experimentation are very important tools, although leading to more expensive procedures in comparison to lab-scale. Today, they are keeping their interest in a variety of cases, and will remain of high added value for the supply of validation sets of data for the development of the models and related codes running on computers as well as for the engineering of fire safety devices. They may also support conveniently the analysis of special fire hazards in closed spaces.
New series of adequately conducted tests are also required to validate new physical sub-models that still have to be introduced in CFD models to treat major fire related phenomena (e.g. near field air entrainment, smoke production, emission factors of fire products, fuel mass flowrates…) in a suitable manner for accurate prediction of the fire threat in close spaces.
In that field, pertinent lab-scale mock-ups developed in agreement with similitude laws may help also in the extent that boundary conditions are more easily monitored at small scale than at large-scale.

Due to this background, the existing set of fire testing facilities at INERIS seems to be very competitive with regard to the fire hazard assessment in closed spaces. At large-scale, the fire gallery will address adequately well ventilated fire scenarios in tunnels and the 80 m^3 enclosure will be more appropriate when fuel rich conditions are liable to occur in closed spaces. Besides, the INERIS fire calorimeter (of Tewarson type) is suitable to bring valuable contribution to the study of both cases by simple modification of the controlling parameters.
In addition, INERIS has been increasing its capabilities in fire modelling. The expected issue is improved efficiency in the use of the mentioned testing devices as well as the development and the improvement of modelling tools suitable for the evaluation of fire scenarios pertaining to confined hazardous spaces[24].
The French Ministry of the Environment has recently supported that general policy by bringing his financial support to the development of a comprehensive 3-years programme aiming at developing a comprehensive methodology for the study of fires and related environmental impacts in warehouses. The programme will largely rely on computational simulations associated to pertinent testing.
Experimental investigation by use of a cold mock-up and numerical simulation are also very tightly associated in another on-going project conducted at INERIS. The main aim of the project deals with the development of a coupling technique between 1D numerical computation of fluid flows in complex networks (with many branches, ventilators...) and 3D computation (by means of CFD codes) in some particular areas of the network where a fire takes place for instance. This latter project is also granted by National fund.

Literature

[1] T.Hirano & K. Saito, "Fire spread phenomena : the role of observation in experiment", Progress in Energy and Combustion Science, vol 20 # 6 1994.
[2] V. Babrauskas, "From Bunsen burner to heat release rate calorimeter", in *Heat Release in Fires*, Edited by V. Babrauskas, Elsevier Applied Science,London & New-York, 1992.
[3] JC. Malet, C. Casselman, JM Such, and R. Rzekiecki, "Fire Fighting Procedures and Estimation of Fire Consequences in Nuclear Plants", 3rd International Symposium for Fire Safety Science, Edingurgh, 8-12 July 1991.
[4] K. Mac Grattan, "Large-scale tests of sprinkler, vent, draft curtain interaction", Interflam'99, Edinburgh, Scotland, 29th June- 1st July 1999, Confererence Proceedings, vol 1 p 685-695.
[5] O. Megret, rapport de thèse : "Etude expérimentale de la propagation des fumées d'incendie en tunnels pour différents systèmes de ventilation", Valenciennes, 20 octobre 1999.
[6] F. Marlière, C. Cwiklinski, JP. Houeix, G. Marlair, "Approche en grandeur réelle de la sécurité incendie : le cas des navettes de tourisme transmanche", *Recherche-Transport-Sécurité*, n°49, décembre 1995.
[7] D. Lacroix, E. Casalé, C. Cwiklinski, A. Thiboud, "Full-Size Testing of Drainage Systems for Burning Liquids in Road Tunnels", Congrès mondial des tunnels et Journées Stuva, 6-11 mai 1995, p 230-236.
[8] Anonymous, "small-Scale Testing Saves Time Material and Money, FMRC update, A progress report from FMRC, vol 7 #1, April 1993.
[9] J. Newman, "Technological Breakthroughs in Material Flammability Evaluations", technical note, Fire Technology, 4th quarter, 1994.
[10] G. Marlair, C. Cwiklinski, F. Marlière, C. Costa and H. Breulet, "A Review of Large-scale Fire Testing Focusing on the Fire Behaviour of Chemicals", Proceedings of the Seventh International Fire Science and Engineering Conference (Interflam'96 - Cambridge, March 1996), pp 371-382.
[11] G. Marlair, F.H. Prager, H. Sand, "The Commercially Important Di-Isocyanates in Fire Conditions.", Part 1 : Toluene Di-isocyanate (TDI), Fire and Materials, vol 17, 91-102 (1993).
[12] C. Cwiklinski, "L'essai en grand : une méthode réaliste d'évaluation du risque incendie. Cas d'un entrepôt pharmaceutique des laboratoires Sandoz, 6e Congrès National du Service Santé des Sapeurs-Pompiers, Versailles, 14-16 juin 1990.
[13] R. Lodel et D. Gabay, "Le Cerchar étudie le comportement au feu d'une installation de ventilation de la RATP", Revue Générale de Thermique, n°315-316, mars-avril 1988.

[14] D. Ben Mohamed, "Le mur coupe-feu irrigué et le système d'évacuation du public et entrée d'air", Allo Dix-Huit, mars 1998.

[15] E. Casale, J. Broz, "Dimensionnement aéraulique des refuges incendie du tunnel de Puymorens, revue Tunnels et Ouvrages Souterrains, janvier-février 1993, p 389-397.

[16] Haukur Ingason, "Design fires in tunnels", Asiaflam'95.

[17] E. Casale & G. Marlair, "Heptane fire tests with forced ventilation", Proceeding s of the International Conference on Fires in Tunnels", Boras, October 10-11 1994.

[18] S. Brohez, C. Delvosalle, G. Marlair, A. Tewarson, "Accurate Calculations of the Heat Release in Fires", Chisa'98, Pragues, 23-28 August 1998.

[19] A. Tewarson, "Flammability Parameters of Materials : Ignition, Combustion and Fire Propagation", Journal of Fire Sciences, vol 12 – July/August 1994.

[20] G. Marlair, F. Marlière, S. Desmet, C. Costa, M. Leck, W. Siegfried, "Experimental Evaluation of the Fire Hazard of Organophosphorous Insecticides by Use of Various Test Methods", Proceedings of Industrial Fires III, Workshop Proceedings, Riso, Denmark, 17-18 March 1996, EUR 17477 EN.

[21] Karin Adam, private discussions in relation with an on-going research programme performed at INERIS

[22] S. Brohez, C. Delvosalle, G. Marlair, A. Tewarson, "Soot Generation in Fires : An important Parameter for Accurate Calculation of Heat Release", 6th International Symposium on Fire Safety Science, Poitiers, 5-9 July. 1999 (Proceedings to be published).

[23] G. Marlair, C. Costa, B. Gautier, H.Ledoux, S. Brohez, "On-going experimental fire research and testing in France using tests rigs derived from the 'Tewarson' apparatus", 6th International Symposium on Fire Safety Science, Poster session # C75, Poitiers 5-9 July 1999 (Proceedings to be published).

[24] E. Ruffin, A. Carrau, C. Cwiklinski, "Numerical simulation of locomotive fires in the Lyon-Turin tunnel", 5-7 mai 1999, Tunnel fires and Escape from tunnels
Independent Technical Conference, Lyon, 5-7 May 1999.