ZONE MODEL VALIDATION OF ROOM FIRE SCENARIOS

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ABSTRACT

Part of tre results of the Scenario B of the CIB W14 Round Robin for computer fire code assessment are presented. The scenario consisted of three subscenarios. Each of them was a single room with natural ventilation and a wood material fire source. Sixteen participants from ten countries using eleven different computer codes demonstrated the calculation of scenario B. The participants used two CFD-codes and nine two-zone models from 1997 to 1998. In this short report calculation results using codes developed at NIST are compared with measurements and discussed in general.

INTRODUCTION

Zone and field models describing fire development and smoke movement are commonly used as a part of advanced design or fire safety evaluation of buildings. Although numerous efforts to compare fire models with experiments have been published, systematic validation of the plethora of existing fire codes is lacking. This deficiency has become critical due to the introduction of performance based building codes, which often encourage the use of numerical simulations. Designers and authorities, which may not be knowledgeable about fire simulation, should be given guidance on which codes to use and on the limits of the models. VTT organized a round robin of fire simulation within the auspices of CIB W14. Two rounds of calculations were arranged. In the first, scenario A, users, programs, and their technology were studied simultaneously. The main result was, that the user is the most critical component. No further details are given here on scenario A. In scenario B the major objective was to test the performance of the technology although also it revealed a lot from the user contribution. This presentation summarizes the most important findings from that round concentrating on technology contained in CFAST and FIRST model codes originating from NIST.

OVERVIEW OF SCENARIO B

Scenario B consisted of three subscenarios B1, B2 and B3. The experiments corresponding to the subscenarios were conducted during the years 1983, 1985 and 1986 in the VTT testing hall, shown in Figure 1, jointly by VTT and Technische Universität Braunschweig (Hagen & Haksever 1985). Originally, the aim of the test series was to study full compartment fires. Subscenarios B1 and B2 shown in Figures 2 and 3, consisted of a single room with a door/window open to ambient. The names of the tests during the test programme and the room sizes are shown in Table 1.

Table 1 - The subscenarios. Test times were actually longer than the times mentioned here, but the given times were chosen for the Round Robin.

	Test label	Room size (m^3)	Fire load (kg)	Fire load density (MJ/m^2)	Peak RHR (MW)	Test time (min)
B1	SF83-3	$15 \times 7.2 \times 3.5$	1989	330	11	100
B2	SF85-10	$20 \times 7.2 \times 3.6$	1815	220	14	180
B3	SF86-10	$7.4 \times 7.2 \times 3.6$	2×500	330	5.2	120

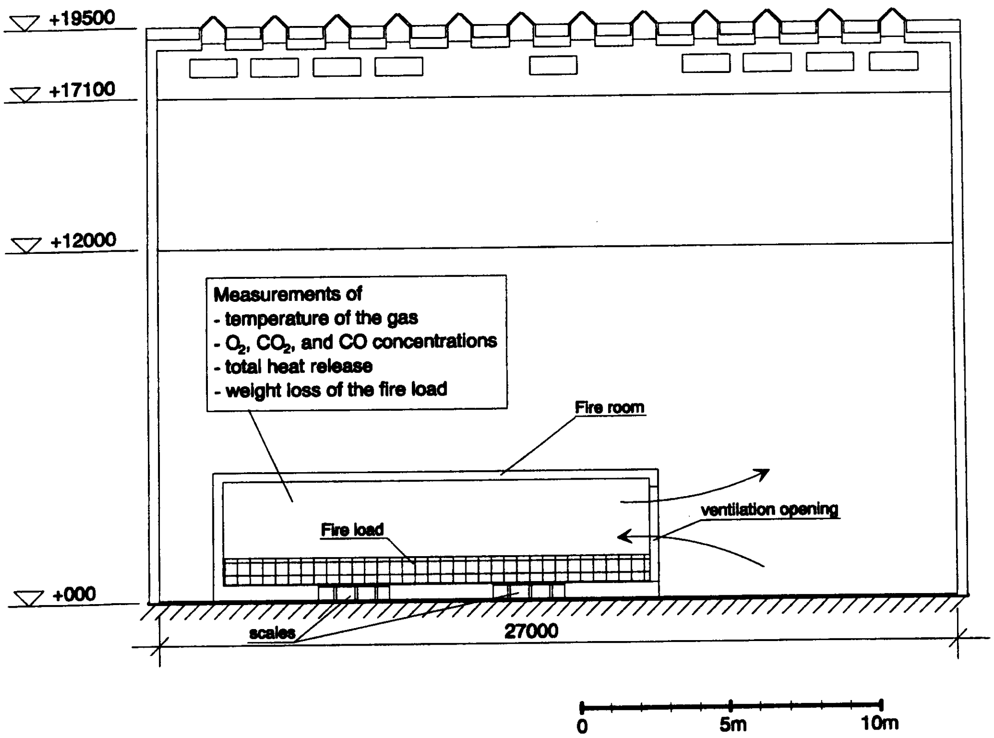

Figure 1. Schematic longitudinal cut of the testing hall. Dimensions are in mm.

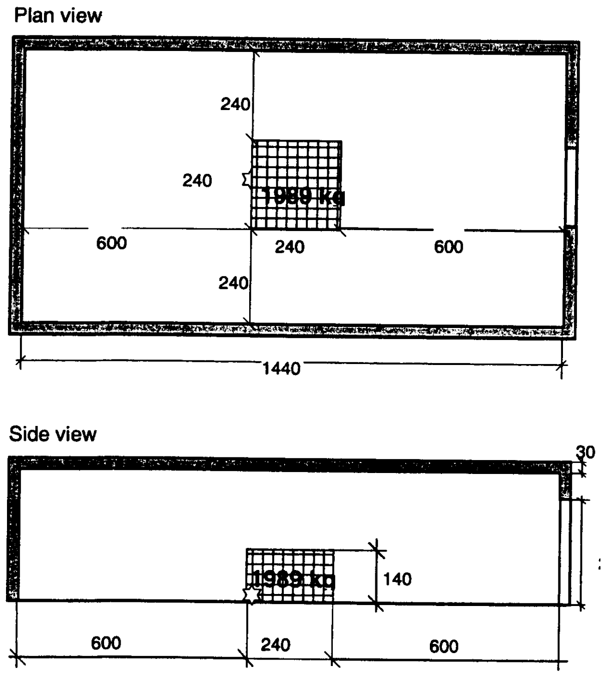

Figure 2. Subscenario B1.

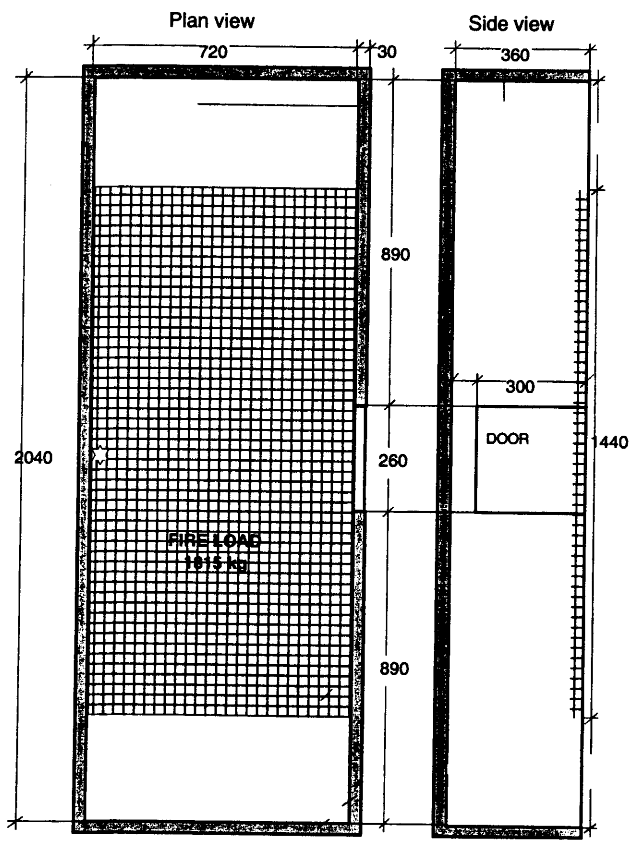

Figure 3. Subscenario B2.

EXPERIMENTAL DATA REDUCTION FOR FIRE MODEL VALIDATION

Here only data reduction of calculation of interface height and layer temperatures is treated. The height of the smoke layer interface is one of the key variables studied during the fire safety analysis of the buildings. It is a natural output variable for two zone model fire codes where the assumed existence of the interface is part of the model. However, when the question is about experimental or CFD data, where temperature is measured/calculated in discrete number of points, there is no general consensus about the correct calculation method for the interface height.

Kawagoe (1958) presented a one-zone model for a post flashover fire with ventilation to ambient and discovered that the flow rate was proportional to the vent factor $A\sqrt{H}$. The two-layer concept was introduced by Thomas *et al.* (1963) who presented the relationships of the layer heights, temperatures and the flow rates. Prahl and Emmons (1975) and Rockett (1976) further studied the hydrodynamic vent flows and presented the relationships between the interface and neutral plane heights and the mass flows in/out of the vent. A careful presentation of the flow equations in the vent has been given by Tanaka (1978), later included in zone model code BRI2 (Tanaka & Nakamura 1989). More recent reviews about the subject have been given by Thomas (1992) and Cox (1995).

In principle, when the fire is sufficiently small compared to the size of the compartment two layers will form. The height of the layer interface can be found by determing the inflection point of the vertical temperature profile. However, in the case of a relatively strong fire, as is the situation in the present scenarios, a single layer may form, with very small vertical temperature gradients. This is demonstrated in Figure 4 showing the development of the vertical temperature profiles inside the compartment in B3. Each line represents one time point. The absolute level of the temperature has been removed for linear presentation by transformation using:

$$T(z_i,t) = T(z_{\min},t) + t\,, \qquad (1)$$

where T is in °C and t in minutes. It can be seen that the development of the hot layer is clear up to the 20 minutes or flashover, after which the difference between the uppermost and lowest measurement is small and no large gradient exists, not to mention a true discontinuity assumed in the papers of Thomas et al. (1963) and Rockett (1976).

One of the most common methods to determine the interface height is to use the so-called *N* percent rule, suggested by Cooper *et al.* (1982). The interface height at time *t* is defined to be the elevation z_i at which the temperature first satisfies

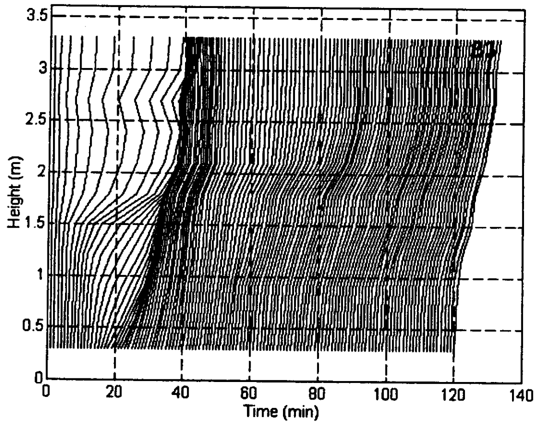

Figure 4 . Mean temperature profiles during the experiment B3.

$$\frac{T(z_i,t)-T_{amb}}{T(z_{top},t)-T_{amb}}=\frac{N}{100}. \qquad (2)$$

In the literature the values suggested for *N* range from 10 to 20. The method was applied to the current scenarios with a value of *N* = 15. The average temperatures in the upper and lower layers were then calculated as mean values of the measurements in the upper and lower sides of z_i, respectively. In cases where $z_i = 0$ the lower layer temperatures are meaningless.

Mathematically the question is: "How to calculate three unknown variables, z_i, T_U and T_L, from the series of temperature measurements at discrete number of heights?" Quintiere *et al.* (1984) introduced a method to calculate the upper layer temperature T_U as an arithmetic average of the upper thermocouple readings. One then solves z_i and T_L from integral equations

$$\int_0^H T(z)dz=(H-z_i)T_U+z_iT_L, \qquad (3)$$

$$\int_0^H \frac{dz}{T(z)}=(H-z_i)\frac{1}{T_U}+z_i\frac{1}{T_L}. \qquad (4)$$

where *H* is the ceiling height. Equation (3) describes the mathematical averaging procedure of the zone model, but has no physical meaning, although it is quite close to the requirement for enthalpy equivalency. Equation (4) is a requirement for mass equivalency.

The goal of this experimental data reduction is to produce data that can be directly compared with the zone model results. The applied calculation method should therefore be able to give interface height and average temperatures that produce the same hydraulic flows as the zone models. Janssens and Tran (1992) introduced a method that combined the mass flow equations of Prahl and Emmons (1975) and Rockett (1976) with the mass integral (4). The problem of this method was that at high temperatures, the mass flow out of the vent is very insensitive to small changes of temperature and the mathematical solution of the system became difficult. They also presented an alternative method where the interface height was taken from the inflection point of the temperature profile. As their example cases had clear layer structures they had good results but here this method can not be applied.

For the round robin comparison the following procedure was used:

1. The lower layer temperature T_L is taken to be the average of the thermocouple readings of the lowest measurement points.
2. The interface height and upper layer temperature were solved from the integral equations (3) and (4). Combining these equations gave expression for the interface height
3.

$$z_i = \frac{T_L\left(I_1 \cdot I_2 - H^2\right)}{I_1 + I_2 T_L^2 - 2T_L H} \quad (5)$$

where

$$I_1 = \int_0^H T(z)dz \text{ and } I_2 = \int_0^H \frac{dz}{T(z)} \quad (6)$$

The problem of this method is the calculation of integrals (6) using relatively few measurement points. Interface heights calculated by this method will be presented together with those calculated with the N-percent rule with N =15.

Shortly after these analyses were made He at al. (1998) treated the problem in a through way. They also concluded the N-percent rule results deviated from the two, methods to define the layer height: integral ratio method (given by equations (3) and (4)) and a more refined least squares method. The algorithm of CFAST produced data close to integral ratio and least squares methods.

PARTICIPANTS

CFAST

The model code CFAST comes from the package HAZARD I, developed at NIST (Peacock et al. 1997). CFAST was used by Jason D. Averill from NIST, Petra Büttner from Hosser, Hass & Partner (HHP) and Daniel Joyeux from Centre Technique Industriel de la Construction Metallique (CTI).
Version: 2.21 (HHP and CTI) and 3.1 (NIST)
Physical models:

- Multi-room two layer model
- McCaffrey entrainment law
- Pyrolysis / Heat release rate given by user
- Maintained carbon-hydrogen-oxygen balance
- Ceiling-floor and inter compartment heat transfer

FIRST

The model code FIRST (FIRe Simulation Technique) was developed at the National Bureau of Standards (NBS), (Mitler & Rockett 1987). During the round robin it was used by Daniel Joyeux from CTI.
Version: September 1987
Physical models:

- One compartment two zone model

Several plume models: Morton-Taylor-Turner (virtual and fire base source points), McCaffrey, Zukoski, Delichatsios and Kawagoe

RESULTS

For shortness in this paper only subscenario B1 is presented. Results are similar from other scenarios described in the full paper (Hostikka & Keski-Rahkonen 2002).

Comparisons of the measured and calculated interface heights are shown in Figure 5. Calculation results for two different methods are presented: the 15 %-rule in Equation (3) and the density integral method in Equation (5). The quality of the agreement between the measurements and the calculations depends on the method used. As mentioned before, in this subscenario, the existence of an interface is questionable due to the very small vertical temperature gradients. The following observations can be made:

There is a lot of deviation between both the different CFAST curves and between the CFAST simulations and the measurements. Only NIST and HHP's open round simulations are close to each other during the first 60 minutes.

CFAST show very high interface heights where the height of the base of the flame was assumed by the modellers to be 1.4 m.

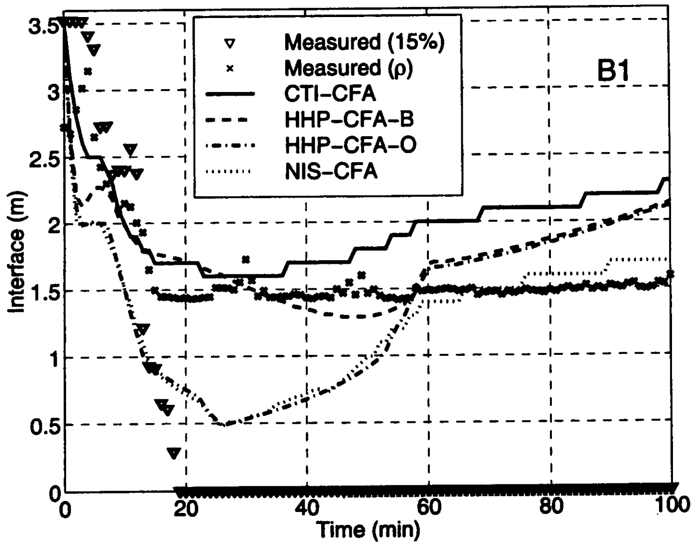

Figure5. Comparison of interface heights given by CFAST zone model and measurements in subscenario B1. The major change in the HHP-simulations was the different base of the flame height.

CFAST

CTI

The comparison between calculations with CFAST and experimental results indicates in a first approach rather bad calculations results. This is the results of the fact that a lower (cold) zone has to exist during calculations while the experimental data do not imply that. The calculation results of the upper layer temperature are always higher than the measured, with 300 or 400 °C. According to author, this result is a good result because such codes have to be used for fire safety calculations, their results have to be in a safe side. According to the author a more convenient comparison could be made by calculating a mean temperature of the whole compartment, ie. by using a one zone model. However, a two zone model as CFAST can also be used and can give good temperature results as an envelop of the experimental results.

HHP

There is a great deviation between experimental and measured data especially concerning the interface height and the species concentrations. While the experiments show a room which remains nearly completely filled with the smoke layer, the code calculates an increasing interface height after the burning peaks. In B1 the interface height calculation results were enhanced when the height of the flame basis was decreased. The deviation may also be caused by the 15%-rule used for the experimental determination of the interface height.

The maximum temperatures of the upper layer show a good agreement with the measured values. In this field the code shows a sufficient accuracy. The calculated upper layer temperatures are somewhat higher than the measured ones but this is consistent to the fact, that, according to the calculations, a part of the room (the lower layer) has only temperatures between 200 and 400 °C.

The measured O_2 concentration is well approximated by the calculation, whereas there are some differences concerning the concentrations of CO and CO_2. Especially the CO production is strongly depending of the course of the fire and difficult to predict.

FIRST

Simulation of the scenario B was not possible with the Delitchatsios and Kawagoe air entrainment models. The run with Zukoski model did not converge. The Morton-Taylor models and the McCaffrey models gave results and converged all along the simulations. The results obtained with the three models were rather similar. The reported results were given using the McCaffrey model.

The comparison between calculations with FIRST (Figure 6) and experimental results indicated very bad results as the scenarios were not very good applications for a two zone model. In terms of interface height, as the two zone model needs a lower zone, the lower zone had to exits in all three subscenarios. The upper layer temperatures were always lower than the experimental ones. A difference of about 200°C between measured and calculated temperature was generally obtained in the upper layer temperature comparison.
The oxygen concentration calculations are rather closed to experiments but the carbon dioxide calculations under-estimate the experimental results. This happened partially because the calculation results were given in mass fractions but the experimental data in mole (volume) fractions.

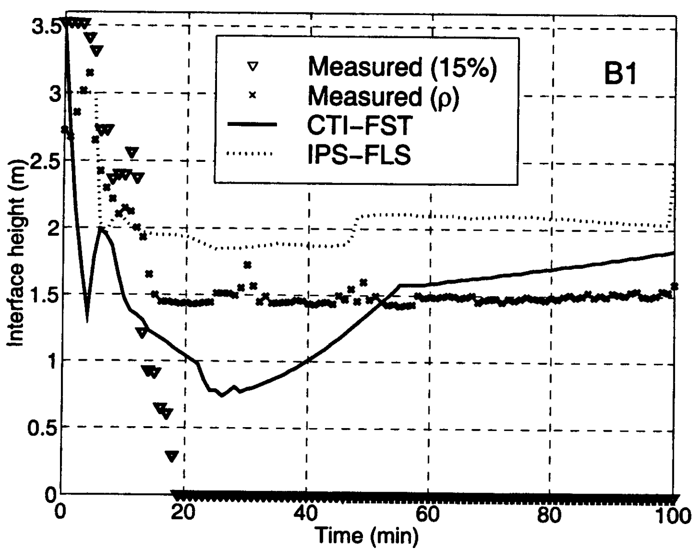

Figure 6. Comparison of interface heights given by FIRST and FLAMME-S zone models and measurements in subscenario B1.

Comparison of the measured and calculated upper layer temperatures are shown in Figures 7 and 8. The limits of the temperature averaging are based on the interface heights calculated by the 15%-rule. However, the method used for the interface calculation had very little effect on the averaged temperatures. Effects of the radiation on the operation of thermocouples were not considered. Below are listed the visual observations concerning the comparison.

CFAST calculations by HHP show a very good agreement with the measured temperature during the first 50 minutes. CTI and NIST in turn achieved considerable over- and underestimations of the maximum temperatures, respectively.
FIRST show good agreement during the first 25 minutes. After that FIRST starts to underpredict.

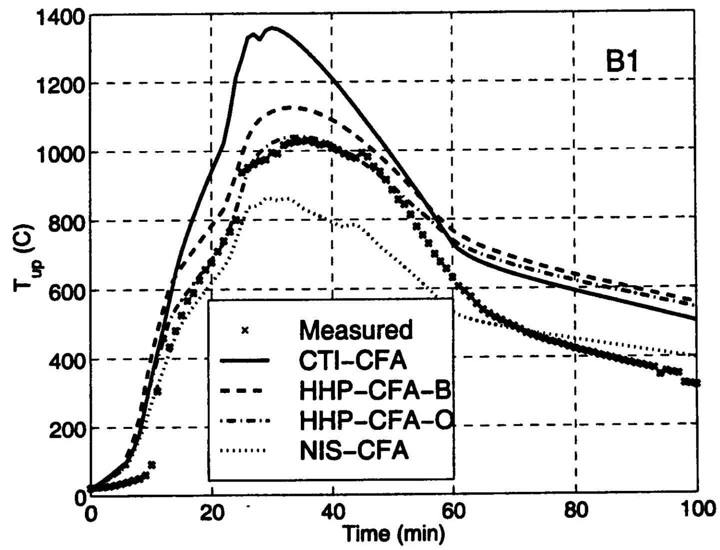

Figure 7. Comparison of upper layer temperatures given by CFAST zone model and measurements in subscenario B1.

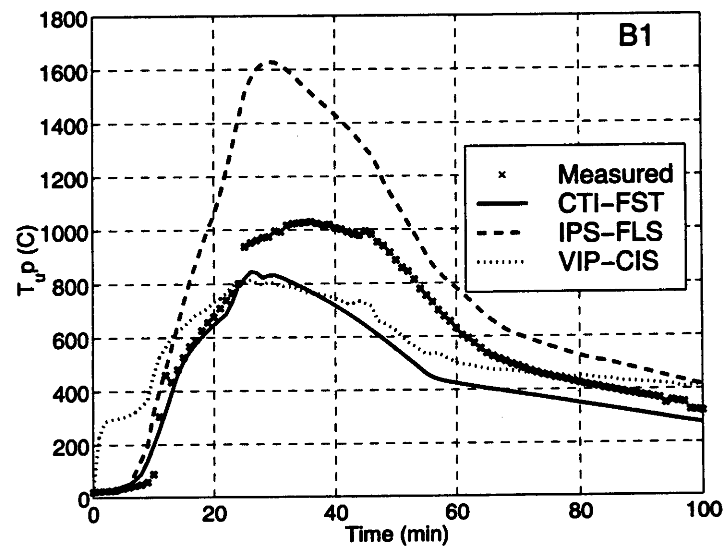

Figure 8. Comparison of upper layer temperatures given by FIRST, FLAMME_S and CISNV zone models and measurements in subscenario B1.

GODNESS DETERMINATION OF THE RESULTS

Based on the previous sections one can say, that each of the codes reproduces the qualitative behaviour of the layer height and upper layer gas temperature. It is not easy to see from the tens of plots, which of the codes performed better than the other ones. A summary of the calculation results of the two-zone models is here given to facilitate making conclusions. The purpose of the summary is not to judge or rank the codes, but to estimate the state of the art of the technology. Since the user seems to be the biggest source of error, it is reasonable to try to decouple the effects due to the user and due to the code itself. Therefore, only the simulation, that seemed to have the best overall agreement with the measurements, was selected for the summary. Here no distinction was made between the blind and open calculations. The summary cannot be complete, because some of the codes were used by only one participant. In these cases the comments of the participants should be taken into account to decide whether the simulation is representative or not.

Goodness of fit by formal methods like least squares analysis of multivariable functional relationships or any alternative test is not yet worthwhile. Pearson has shown (Cramér 1946) squares of differences in the form

$$\sum_i c_i(f_i - g_i)^2 \qquad (7)$$

where f is the normalized function in points i to be compared against function g in the corresponding points, become χ^2-distributed with N-1 degrees of freedom, if the weights are chosen as inverse square roots of functions g

$$\chi^2 = \sum_{i=1}^{N} \frac{(f_i - g_i)^2}{g_i} \qquad (8)$$

Formula (8) is a starting point for nonlinear curve fitting by χ^2 minimum method (Abramowitz & Stegun 1972). A successful application of this method in a noisy environment is described in Routti & Prussin (1969).

If we cannot be sure, that the difference $f_i - g_i$ is not totally random and normally distributes, there is not much point of using χ^2-distributions for comparison. To get a simple quantitative measure for the goodness of predictions in ad hoc manner, relative error indicators were calculated. For the upper layer temperature the variable to consider is the temperature rise from the initial value $\theta(t) = T(t) - T(0)$. The thickness of the smoke layer h_{smoke} and the depletion in the oxygen concentration ΔO_2 were used to measure the goodness of the interface height and species predictions, respectively. Interface height was here calculated using the density integral method.

The simplest way would be to calculate the average of the relative value of absolute deviation

$$E = \frac{100\%}{t_0} \cdot \int_0^{t_0} \frac{|\theta_s(t) - \theta_m(t)|}{\theta_m(t)} dt \qquad (9)$$

where t_o is the simulation time, θ_s is the simulation result and θ_m is the measured value. For applications in fire safety engineering this indicator alone would be rather misleading, since errors at irrelevant times would gain much weight. For evaluating the suitability of the technology for design purposes indicators are needed which give weight for those values indicative for dimensioning. As for the selected variables the large values are important, a weighted average E_{max} is defined, where the relative error weighted by the measured value.

$$E_{max} = 100\% \cdot \frac{\frac{1}{t_0}\int_0^{t_0} \frac{|\theta_s(t)-\theta_m(t)|}{\theta_m(t)} \cdot \theta_m(t)dt}{\frac{1}{t_0}\int_0^{t_0} \theta_m(t)dt} = 100\% \cdot \frac{\int_0^{t_0} |\theta_s(t)-\theta_m(t)|dt}{\int_0^{t_0} \theta_m(t)dt} \qquad (10)$$

If low values are important for design, then the weighting by small values, like the inverse of the measured value, would be appropriate.

The results are given in Table 2 for each code-scenario combination calculated. The accuracy of the upper layer temperature predictions ranges from 17 to 42 %. Smoke layer heights vary from 20 to 65%, and oxygen depletion from 7 to 76%. It is possible to make some conclusions of the mutual order of the codes, but the order of best codes varies from scenario to scenario. Based on the experience from these simulations we could conclude that two-zone models predict e.g. heating of structures for these types of fire scenarios at best at 20 % level of accuracy, if used properly. The technology on smoke layer height and oxygen depletion prediction is, on the average, slightly more inaccurate than for temperatures. CFAST and FIRST performe better than average.

Table 2. Mean relative errors E_{max} (%) of the two-zone model results. ARG = Argos, CFA = CFAST, MRF = MRFC, FIG = FIGARO, FW = FIREWIND, FST = FIRST, FLS = FLAMME-S, FIS = FISBA.

Code Variable	ARG	CFA	MRF	FIG	FW	FST	FLS	FIS	Average
T_{up} B1	25	13	14	14	21	21	48	26	23
T_{up} B2	27	27	25	26	NA	15	36	33	27
T_{up} B3	32	10	20	12	NA	NA	41	35	25
Average	28	17	20	17	21	18	42	32	24
h_{smoke} B1	72	23	14	27	20	19	25	19	27
h_{smoke} B2	69	62	81	88	NA	86	70	65	74
h_{smoke} B3	54	36	10	28	NA	NA	51	32	35
Average	65	40	35	48	20	52	49	39	43
ΔO_2 B1 [a]	3.3	2.7	2.0	3.0	7.4	1.7	1.1	1.8	3
ΔO_2 B2	37	38	36	31	NA	54	53	38	41
ΔO_2 B3	31	34	42	43	NA	NA	175	67	65
Average	24	25	27	26	7	28	76	36	31

[a] Only the first 20 minutes are taken into account.

CONCLUSIONS

A group of fire models was evaluated in the compartment fire scenario by comparing the simulations against the experimental results. The main limitations of the evaluation are due to the type of the fires, that were not well suited for the zone models, and due to the limited resources of both the participants and the organisers of the round robin. This report should not be considered as a thorough validation or ranking of the codes or the users.

All of the codes had features that indicated a discrepancy with the experimental data in the blind simulations, but which could be improved during the open round by choosing alternate submodels and/or changing some optional parameters. According to the summary of the quantitative error estimates the deviations from the experimental data range from ±10 % up to a factor of 2. These deviations are of the same order with the uncertainties related to the experimental measurements and input data, especially the burning rate. The conclusion is that, for this kind of fire scenarios, the expected uncertainty of the zone models is about 25 % in temperature and smoke layer height predictions, if the codes are used properly. Where several persons used the same code, the dependence of the results on the user was demonstrated (not detailed here). It was indicated very clearly, that the user is the most critical link in the chain of using computer fire simulation models for fire safety engineering. This was true even though this group represented code developers, and other well educated fire science and engineering practitioners. The effect is expected to be much more pronounced when the whole group of computer fire code users is considered.

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Introduction

- Performance based code usage
- Zone model technology evaluation
- Round robin within CIB W14
- NIST codes considered here
    - CFAST
    - FIRST
- Excerpt of a full report

VTT

Scenarios

	Test label	Room size (m^3)	Fire load (kg)	Fire load density (MJ/m^2)	Peak RHR (MW)	Test time (min)
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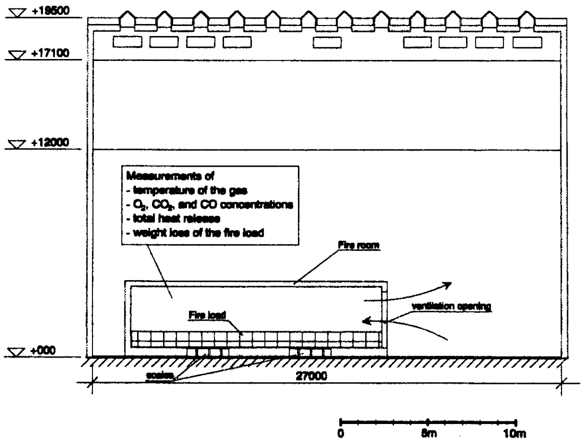
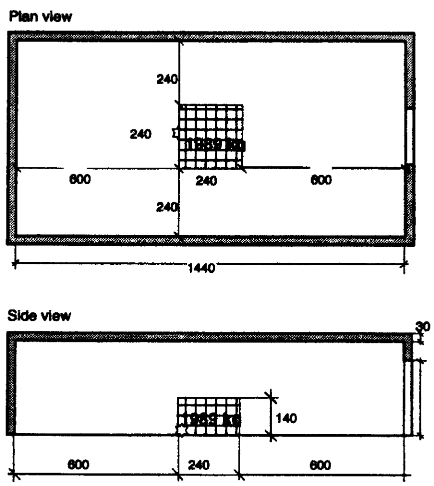
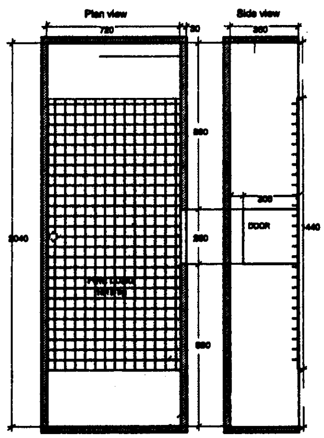
Testing hall



Subscenario B1



Subscenario B2



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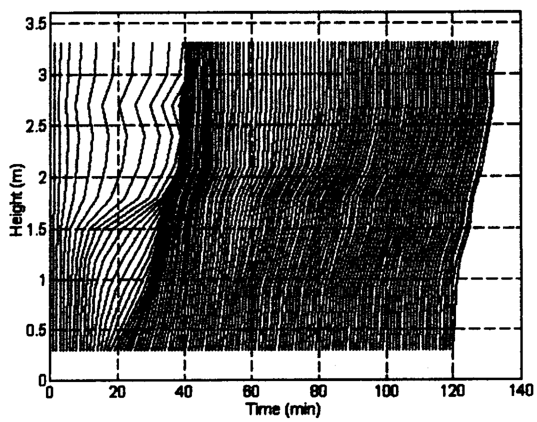
Temperature profiles



$$T(z_i,t) = T(z_{min},t) + t$$

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Layer definitions

$$\frac{T(z_i,t)-T_{amb}}{T(z_{top},t)-T_{amb}}=\frac{N}{100}$$

N-percent rule

$$\int_0^H T(z)dz=(H-z_i)T_U+z_iT_L$$

$$\int_0^H \frac{dz}{T(z)}=(H-z_i)\frac{1}{T_U}+z_i\frac{1}{T_L}$$

Quintiere et al. 1984 (DIM)

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Density integral method (DIM)

$$z_i=\frac{T_L\left(I_1\cdot I_2-H^2\right)}{I_1+I_2T_L^2-2T_LH}$$

$$I_1=\int_0^H T(z)dz$$

$$I_2=\int_0^H \frac{dz}{T(z)}$$

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Layer height

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Temperatures

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'Goddness of fit'

$$E = \frac{100\%}{t_0} \cdot \int_0^{t_0} \frac{|\theta_s(t) - \theta_m(t)|}{\theta_m(t)} dt$$

$$E_{max} = 100\% \cdot \frac{\frac{1}{t_0} \int_0^{t_0} \frac{|\theta_s(t) - \theta_m(t)|}{\theta_m(t)} \cdot \theta_m(t) dt}{\frac{1}{t_0} \int_0^{t_0} \theta_m(t) dt}$$

$$= 100\% \cdot \frac{\int_0^{t_0} |\theta_s(t) - \theta_m(t)| dt}{\int_0^{t_0} \theta_m(t) dt}$$

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Mean relative errors

Code Variable	ARG	CFA	MRF	FIG	FW	FST	FLS	FIS	Average
T_{up} B1	25	13	14	14	21	21	48	26	23
T_{up} B2	27	27	25	26	NA	15	36	33	27
T_{up} B3	32	10	20	12	NA	NA	41	35	25
Average	28	17	20	17	21	18	42	32	24
h_{smoke} B1	72	23	14	27	20	19	25	19	27
h_{smoke} B2	69	62	81	88	NA	86	70	65	74
h_{smoke} B3	54	36	10	28	NA	NA	51	32	35
Average	65	40	35	48	20	52	49	39	43
ΔO_2 B1 [a]	3.3	2.7	2.0	3.0	7.4	1.7	1.1	1.8	3
ΔO_2 B2	37	38	36	31	NA	54	53	38	41
ΔO_2 B3	31	34	42	43	NA	NA	175	67	65
Average	24	25	27	26	7	28	76	36	31

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Conclusions

- Results improved from blind to open simulations
- Selection of alternative submodels important
- Deviations from experimental data 10% ... factor of 2
- The user the most critical factor
- CFD calculations was not superior to zone models

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Fire models for NPP Applications

Fire zone model MAGIC : The validation and verification principles

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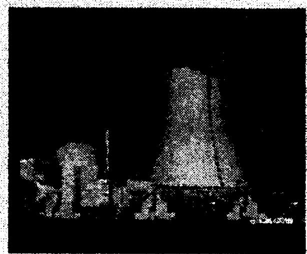

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SUMARY

- Discussion on the zone model validation :
  - » Validation of the submodels (classic laws, empirical correlation,..)
  - » Validation of the global model
- Short presentation of the MAGIC validation :
  - » principles
  - » list of references
  - » examples
  - » future prospects

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Zone model approach of fire

A zonal model results from the association of various sub-models :

- Integration of classical physics laws
  - energy and mass balance on different layers (homogeneous T and concentrations, hydrostatic P, Perfect Gas assumption , etc..
  - simplified conduction in walls (1, 2 or 3D) or some targets
  - simplified radiation (semi-transparent assumptions in concave rooms)
- Semi-empirical models
  - fire source
  - Plume, ceiling jet
  - Convection heat exchange coefficient
  - Openings and vent
  - Detection, suppression etc..

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Validation of the sub-models

General laws are accepted by the scientific community.

Empirical models have most of the time been directly obtained from specific experiment, and have been qualified according to it.

Both have shown a certain accuracy and validity domain.

ex: Alpert correlation for ceiling-jet was studied for r/H<3.

The control of the right use of it must be done inside the code (for instance : produce "warnings" when getting out of a validity domain).

The sub-model validation is so considered during the zone-model conception, but :

- A sub-model used outside of its validity domain does not necessarily mean that the global code results will not be acceptable.
- Deduce the accuracy of a code from its component ones is not possible.

The validation of the global model remains always a necessity.

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Validation of the global zone-model

The objectives of the Zone model validation are the accuracy of the result data and the validity domain. Both are linked : the acceptable accuracy domain is the validity domain.

Accuracy of the code seems impossible to determine theorically, but it can be displayed by confrontation to experimental fire, and estimated by this means.

The accuracy of a fire model, observed by comparison to experimental fires, remains quite rough :

- too many parameters are involved in the fire process
- some complex phenomena (combustion, mass flow, etc..) cannot be completely described.

Furthermore, when using the model in a real life risk study, the input control will be much worse and will interfere with accuracy.

So, it is not necessary to seek a very high level of accuracy when confronting experimental and numerical results.

.../...

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Aims of the validation

.../...

> The most important is to show that the code:
>
> 1- gives realistics quantitative results in its current application field
>
> 2- respects the qualitative tendancies in the fire dynamics and the effect of input variations

The validation process is demonstrative : it has to proove that, when the input parameters are efficiently controlled, the code results are sufficiently realistic, in the range of the code current application field.

The way of using the code in this process must be similar to the way it is used for typical fire risk studies.

Validation "code of ethic"

Quality of the reference tests :

To be demonstrative, the tests must be well known, approved and accepted by the scientist community. Of course, the quality of the experiment is the main factor of this acceptance, and has been discussed a lot (ex: ASTM e603)

Conditions of the code use:

To enhance the confidence and decrease the user effect, the input of the code during the test must be clearly identified.

Any user modeling choice (fixed exchange coeff., plume model,etc..) specific to the calculation must be identified, or, as much as possible, avoided.

Field covered by the tests :

The tests should cover the field of application of the code. First building configuration : mall to medium scale compartment configuration, multi-compartment and large scale tests, opened or confined condition for instance. Also, fire parameters: kinds of combustible, heat release rates, etc..

The validation File of MAGIC

- Validation of Magic is based on comparison to real scale fires. About 60 real scale fire tests are available in the base.
- The file is used to define the validation domain of the code:
  - Volumes from 10 to 1300 m^3 (200 000 m^3 case at work)
  - Heat release from 100 kW to 2.5 MW (50 MW case at work)
  - Ventilated and post-flashover fires
  - Mono-compartment and multi-compartment varied configurations
  - Liquid fires, solid fires
  - Pool fires, linear fires

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MAGIC : A large validation file

- **Main data available :**

Semi-natural fires in a room: Hognon B. CSTB/ DGRST-CSTB 1980 and Carmier, Curtat, Hognon, Bertin - CNRS - CSTB 1984

Semi-natural fire in a commercial hall corridor : N. C. Markatox, M.R. Malin "Int J Heat transfer" Vol. 25 n° 1 p. 63-75 BRE/FRS 1986

Fires in ventilated room: (Alvares N.J., Hasegawa H.K., Lipska.Quin A.E.) Report UCRL-53179, LLNL, Univ. of California, Livermore 1982

Fire in a compartimented building (Cooper L.Y& al.) J. of Heat Transfer vol. 104 pp 714-749 NBS (1982)

Real-size tests in multi-compartimented buildings : R.D Peacock, S. Davis, V. Babrauskas "Data for room Model Comparisons", Journal of research of the NIST, vol 96, N°4, 1991.

Control-room tests FM/SNL : S. Newlen NUREG/CR-4681 1987

20-foot separation tests UL/SNL : NUREG/CR-3192 1983

Large cable fire tests (2 compartments) EDF-CNPP : CNPP TR 96 5045 P1-1997

CTICM Hotel-room : H. Lebotgne Test reprt 96S511 (1996) **Linen-room (2 compartments, post-flashover):** H. Leborgne TR 97S031 (97) **Large hall tests :** TR 98-x-406 (97) ; TR 94-R-242 (94)

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Code quality assurance

- The validation file is used systematically to **guarantee no regression** of new versions (~20 selected tests). Any difference between versions must be justified.
- The code is **always in standard conditions** when launching the reference tests (Quality Assurance Process). The validation file is part of the documentation and can be easily re-played by the user.

<u>note: Verification of code Specification :</u>

Verification of code specification (respect of sub-modle specifications, running of the different part of the code, etc..) is a different task than validation, which is done through an Assurance Quality process.

This aspect must not be neglected because the validation tests are not necessary covering all the code functionalities.

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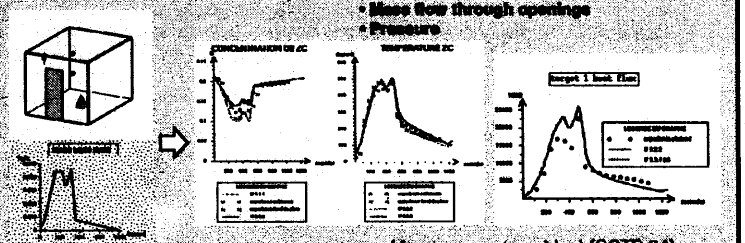
Direct comparison of num. and exp. data

Model necessary input :
- Building materials and configuration, boundary conditions
- Combustible properties and location
- Mass loss rate scenario

Commonly available data for comparison :
- Local temperatures, average temperatures
- Heat exchanges on targets (fluxmeters)
- Interface height
- Gaz velocities
- Species concentrations (O2, CO2, CO, CnHm NOx, SOx,...)
- Mass flow through openings
- Pressure



Mono-compartment test (CSTB 84)

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What and how to compare ?

What :

The first comparison is generally done on gaz temperature and fluxes, considering at less the range and delay of the peaks.

Those variable represent the thermal boundary condition for the materials to protect. Nevertheless, they are not easy to obtain, being very unstable, linked to mass flows and radiation. In somecases it seem that internal temperature of targets could be an interesting alternative to develop.

The other measurements are less frequent, some like pressure or mass flows are rarely provided.

How:

The comparison is first a "visual" analysis of differences.

Numerical analyse can be done, based on relative difference :

ex: (Tmes-Tcalc)/ (Tmes-To) as a error percentage.

Sensitivity to input variation has been done in the process of qualifying the physic model adjustments.

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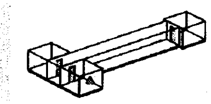
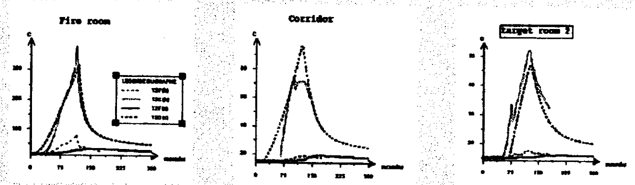
Multi-compartment validation : example

- Thermal conditions in the fire room
- Propagation of smoke and hot gas to the secondary compartments





exc test n°30 from NIST 4 room series , 210 m³, 1 MW (in 120 s)

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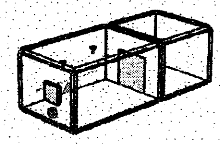
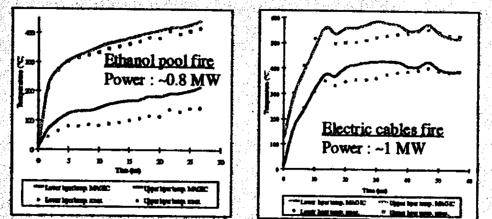
Large cable fire (CNPP 1997)

- 2 room "NPP-like" configuration
  - 7 superposed PVC cable tray fire (~300kg burnt)
  - Pool fire





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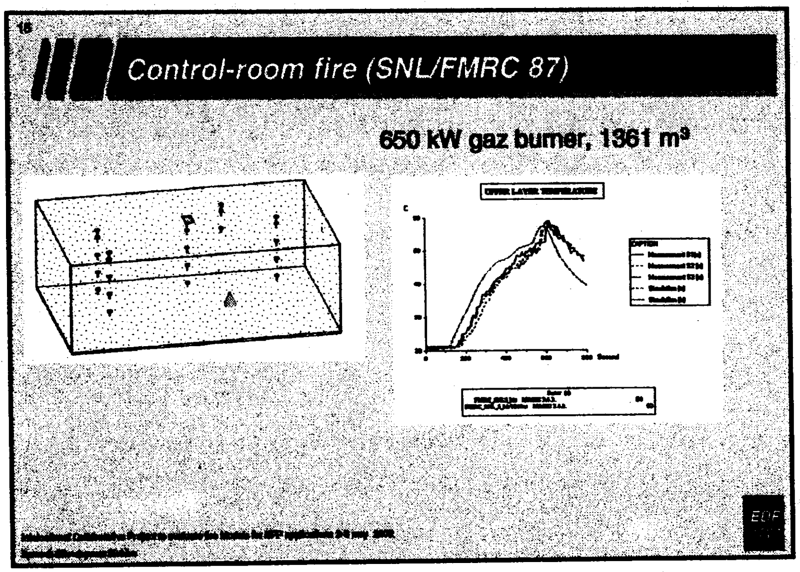
Control-room fire (SNL/FMRC 87)
650 kW gaz burner, 1361 m³
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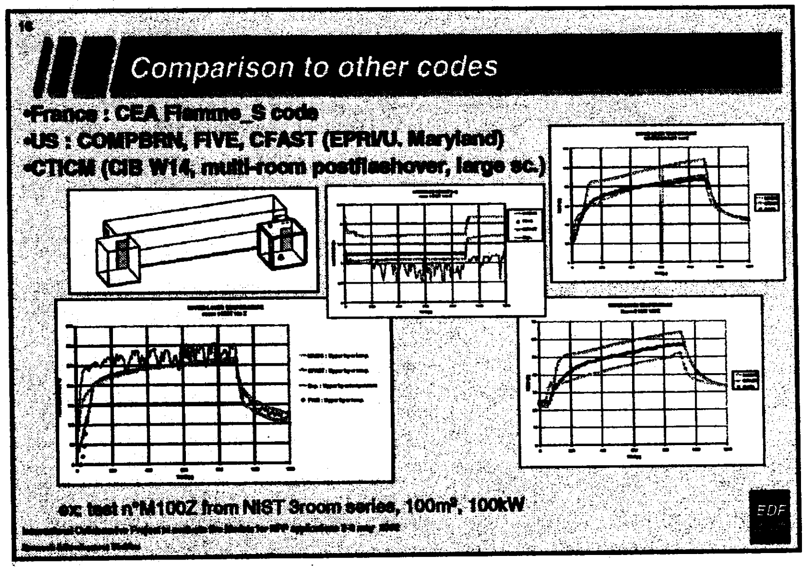
Comparison to other codes
•France : CEA Flamme_S code
•US : COMPBRN, FIVE, CFAST (EPRI/U. Maryland)
•CTICM (CIB W14, multi-room postflashover, large sc.)
ex: test n°M100Z from NIST 3room series, 100m², 100kW
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Future prospects

Enhancement of the validation file :

- Targets temperature : fluctuate less than gas temp. and more relevant for risk studies (dysfunction, ignition) (2002).
- Pressure measurment and interaction with ventilation system (2002)
- Fire suppression effect
- Complex multi -room configurations : horizontal openings and duck-board.

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Conclusion of EDF experience

- The validation File is the key of code acceptance
- Real-size and a large field of experiment data is important.
- Tests must be of good quality, available and accepted by the scientific community.
- The process of code validation must be independent of modeling choices and available to the final user.
- The results obtained with MAGIC on a selection of experimental data has allowed us to get confident for its use in a large range of volumes, heat release and configurations.

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