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International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications: Summary of 2nd Meeting

Held at
Institute for Protection and Nuclear Safety
Fontenay-aux-Roses, France

June 19-20, 2000

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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Abstract

The 2nd meeting of the International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications was hosted by the Institute for Protection and Nuclear Safety (IPSN) and held in the IPSN offices at Fontenay-aux-Roses, France on June 19 and 20, 2000. The Organizing Committee for the meeting included Remy Bertrand from the IPSN (France), and Moni Dey from the U.S. NRC. Eighteen experts from five countries attended this international meeting.

The purpose of the 2nd meeting was mainly to finalize the definition of a benchmark exercise to evaluate zone and computational fluid dynamics (CFD) fire models for application in nuclear power plants. This exercise was identified as the first task of the project and was aimed at evaluating the capability of fire models for simulating cable tray fires of redundant safety trains in nuclear power plants. The discussions at the meeting resulted in three main issues regarding input parameters for the scenarios in the benchmark exercise: (1) specification of the fire source; (2) modeling of the target; and (3) value for the lower oxygen limit. The specification of the fire source is fundamental to the input for fire models, and can significantly affect the predicted thermal environment. A consensus was reached on the characterization of the HRRs for the scenarios in the benchmark exercise. Although agreement was reached on the specification and values for the target model and lower oxygen limit to be used for the benchmark exercise, participants did not reach a consensus on the most appropriate specification that could be recommended for model users. The specification of the above three parameters could lead to "user effects," and are the largest sources of uncertainty in the predicted results from the input parameter specification process for the types of scenarios examined in the benchmark exercise.

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Acronyms and Initialisms

BRE	Building Research Establishment
CIB	International Council for Research and Innovation in Building and Construction
CFAST	Consolidated Model for Fire and Smoke Transport
CFD	Computational Fluid Dynamics
COCOSYS	Containment Code System
EdF	Electricite de France
EPRI	Electric Power Research Institute
FDS	Fire Dynamics Simulator
GRS	Gesellschaft fuer Anlagen-und Reaktorsicherheit
HRR	Heat Release Rate
iBMB	Institut fuer Baustoffe, Massivbau und Brandschutz
IPSN	Institute for Protection and Nuclear Safety
JASMINE	Analysis of Smoke Movement in Enclosures
LOL	Lower Oxygen Limit
NII	H. M. Nuclear Installations Inspectorate
NIST	National Institute of Standards and Technology
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk Analysis
PWR	Pressurized Water Reactor
VTT	Valtion Teknillinen Tutkimuskeskus
WPI	Worcester Polytechnic University

1 Introduction

The objective of the International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications is to share the knowledge and resources of various organizations to evaluate and improve the state of the art of fire models for use in nuclear power plant (NPP) fire risk assessment. The project is divided into two phases. The objective of the first phase is to evaluate the capabilities of current state-of-the-art fire models (zone and CFD) for fire risk assessment in NPPs. The second phase will implement beneficial improvements to current fire models that are identified in the first phase, and extend the validation database of those models.

The 1st planning meeting of the project was held at the University of Maryland at College Park, USA, on October 25-26, 1999. The summary of the 1st meeting and the details of the objectives established for the project can be found in NUREG/CP-0170 (April 2000). The 2nd meeting of the collaborative project was hosted by the Institute for Protection and Nuclear Safety (IPSN) and held at the IPSN offices at Fontenay-aux-Roses, France on June 19 and 20, 2000. The organizing committee for the 2nd meeting included Remy Bertrand from the IPSN (France), and Moni Dey from the U.S. NRC. The experts attending the meeting were:

1. Marina ROEWEKAMP, GRS, Germany
2. Bernd SCHWINGES, GRS, Germany
3. Juergen WILL, iBMB, of Braunschweig Tech. Univ., Germany
4. Olavi KESKI-RAHKONEN, VTT, Finland
5. Stewart MILES, BRE, UK
6. Peter REW, W S Atkins, UK
7. Moni DEY, NRC, USA
8. Jonathan BARNETT, WPI, USA
9. Jean-Pierre SURSOCK, EPRI, USA
10. Maurice KAERCHER, EDF, France
11. Bernard GAUTIER, EDF, France
12. Olivier PAGES, EDF, France

13. Joel KRUPPA, CTICM, France

14. Remy BERTRAND, IPSN, France

15. Jean-Marc SUCH, IPSN, France

16. Chantal, CASSELMAN, IPSN, France

17. Jocelyne LACOUE, IPSN, France

18. Alberto ALVAREZ, IPSN, France

The following organizations sponsored or collaborated with the organizations directly represented at the meeting:

1. H. M. Nuclear Installations Inspectorate, UK
2. Industry Management Committee, UK
3. National Institute of Standards and Technology, USA

The purpose of the 2nd meeting was mainly to finalize the definition of a benchmark exercise to evaluate capabilities of current zone and CFD models. This exercise was identified as the first task of the collaborative project and was aimed at evaluating the capability of fire models for simulating cable tray fires of redundant safety trains. A definition of the problem for the benchmark exercise had been proposed prior to the meeting, and this served as the starting point for comments and discussions at the meeting. This definition is included in Attachment A. The objective, background, and procedure proposed for the exercise is presented in the next section.

The agenda of the 2nd meeting included the following objectives:

- Present proposals and comments for the benchmark exercise, including a description of the fire models participants intended to use in the benchmark exercise;
- Finalize the formulation of the benchmark exercise, and plan the milestones and a schedule for the completion of analyses for the benchmark exercise;
- Formulate future tasks, including opportunities for collaborative experimental research for fire modeling development and validation; and
- Present tasks conducted in national programs for fire modeling (e.g., test results pertinent to the issue under examination).

The full agenda of the 2nd meeting is included in Attachment B.

2 Background

The objective, background, and procedure proposed for the benchmark exercise that was the main subject for the 2nd collaborative project meeting is presented below.

The benchmark exercise was developed to evaluate the capability of fire modeling analyses to provide results for a probabilistic risk analysis (PRA). In a PRA study, fire models are used to estimate the conditional probability of safe-shutdown equipment damage given a postulated fire. The main fire protection features that effect the development of a fire are:

1. Automatic fire detection (detection by operators is also important).
2. Automatic or manual isolation of the fire rooms by the closure of fire doors and dampers.
3. Fire suppression (automatic and manual) with gaseous suppression systems (Halon or CO_2), and nongaseous water-based suppression (sprinkler) systems.

In a PRA study, the target damage time is compared with the duration of a specific fire scenario identified in an event tree formulated to model the possible combinations of the above events. The conditional probability of the safe shutdown equipment damage is the probability of that fire scenario, if the damage time is less than the duration of the fire scenario.

Given the state of the art of fire modeling, the adequacy of fire detection and suppression is normally not included in fire modeling analyses to support a PRA. Therefore, the benchmark exercise proposed did not include the evaluation of these systems or events.

The benchmark exercise is intended to be for a simple fire scenario for a NPP defined in sufficient detail to allow evaluation of the physics modeled in the fire computer codes. This approach is similar to that adopted by the CIB W14 effort for fire code assessment. An assessment of appropriate input parameters and assumptions, interpretation of results, and determining the adequacy of the physical models in the codes for specific scenarios will establish useful technical information regarding the capabilities and limitations of the codes. This valuable information will be documented in a technical reference manual for NPP fire model users. Generic insights regarding the capabilities of the models will also be developed in this process and documented in the final technical reference guide.

The comparisons between fire codes can be used to understand the modeling of the physics in them, i.e., if all the codes produce similar results over a range of fire scenarios then the physics modeled in the codes is probably adequate for the proposed scenario. However, the compounding effects of different phenomena will also need to be evaluated. Some variations in the results may be acceptable depending on how the results will be used. Uncertainties in the predictions of the fire models based on validations of each fire code will be discussed and provide a basis for the confidence on the set of results developed in the proposed benchmark exercise.

The following procedure was proposed to be adopted for the benchmark exercise:

1. Analysts should discuss and agree on the input data for the various fire codes that will be used in the benchmark exercise. The goal is for participants to analyze the same problem and minimize the variation of results due to differing input data. User effects will be examined at a later stage.
2. The form of the results to be compared should be agreed upon by participants prior to the commencement of the exercise.
3. Developers of the fire codes, and those not involved in the development of the codes, can conduct the code analyses for the benchmark exercise.
4. Blind simulations will be conducted, i.e., each analyst will independently conduct his or her analyses. The results will be shared between participants when all the analyses by participants have been completed and results are available. The results will be simultaneously posted on the collaborative project web portal prior to a meeting of the participants.
5. If desired, the same code (e.g., CFAST) can be used by different organizations since this will provide useful information on whether the results vary with different users. However, the same version of the code should be used (for CFAST, use Version 3.1.6).
6. A series of benchmark exercises will be defined and conducted in this project. This will allow the evaluation of the full spectrum of fire model features and applications, and facilitate formulation of a comprehensive technical reference for users on the capabilities and limitations of the current state-of-the-art fire models.

The details of the postulated fire scenarios and data proposed to be used in the benchmark exercise is included in Attachment A. In summary, the simulation of fires inside a representative Pressurized Water Reactor (PWR) emergency switchgear room was selected for the benchmark exercise. This room contains electrical cables associated with safe shutdown equipment of two redundant trains which are separated horizontally by a distance, D. The value of D is varied in the fire simulations.
The postulated ignition source is a transient combustible fire that ignites cables. Several configurations of the compartment ventilation conditions are to be analyzed with the mechanical or forced ventilation system on or off, and the compartment door open or closed.

3 Meeting Summary

3.1 Session 1: Comments on Benchmark Exercise, and Description of Fire Codes

In the 1st session, participants provided comments on the proposed definition of the benchmark exercise. Participants also presented a description of the models that they intended to use for the exercise. The view graphs used for the presentations are included in Attachment C. The codes participants proposed to use in the benchmark exercise were:

1. COCOSYS, CFX - *GRS*
2. CFAST - *IBMB/GRS*
3. JASMINE, CFAST - *BRE/NII*
4. FLAMME-S, *IPSN*
5. MAGIC, *EdF*
6. CFAST, FDS - *NRC/NIST*

The major remarks related to the definition of the benchmark exercise that were made by participants and recorded (on a flip chart) at the session are presented below in Section 3.2.

3.2 Session 2: Finalization of Benchmark Exercise

The following comments on the benchmark exercise were discussed and resolutions developed at the meeting. As proposed in the procedure for the benchmark exercise, efforts were made by the participants to arrive at a consensus on values for all input parameters needed for the various codes to be used in the exercise. Following a summary of the main issues regarding input parameters for the scenarios in the exercise, the discussion at the meeting is presented in the format of issues raised, and the disposition of the issues agreed to by the participants.

<u>Summary</u>

The discussions at the 2nd meeting resulted in three main issues regarding input parameters for the fire scenarios in the benchmark exercise:

A. Specification of the fire source;
B. Modeling of the target in the compartment; and
C. Value for the lower oxygen limit (LOL).

The specification of the fire source is fundamental to the input for fire models, and can significantly affect the predicted compartment thermal environment. A consensus was reached on the characterization of the heat release rate (HRR) for the fire scenarios for the benchmark exercise. Although agreement was reached on the specification and values for the target model and LOL to be used for the benchmark exercise, participants did not reach a consensus on the most appropriate specification that could be recommended for model users. The specification of the above three parameters could lead to "user effects," and are the largest sources of uncertainty in the predicted results from the input parameter specification process for the types of fire scenarios examined in the benchmark exercise. These three issues are summarized below at the beginning of the list of issues.

Main Issues

1. Issue: The HRR curves of cable tray fires should be realistic and based on experiments.

   Disposition: The modeling of and predicting the HRR of a burning cable tray stack is extremely complex, and current models are not capable of realistically predicting such phenomena. Therefore, the HRRs of the burning cable tray stack will be defined as input in the problem. The consecutive ignition and burning of all three cable trays (trays A, C2, and C1) will be modeled as one fire. The analyses will assume peak HRRs for the whole cable tray stack between 1 and 3 MW[1]. A t-squared growth will be assumed with t_o = 600 s, and Q_o = 1 MW[2], where:

   $$\dot{Q} = Q_0(t / t_0)^2$$

   A fire duration of 60 minutes at peak HRRs will be assumed, followed by a t-squared decay with similar constants as for growth. Experiments conducted by EdF have shown that peak HRRs for cable tray fires generally do not last more than 60 minutes.

2. Issue: The type and dimensions (diameter) of the cables need to be specified in more detail to allow more detailed modeling of heat transfer to the cables. What temperature in the cable should be used to establish the criterion for cable failure or damage?

   Disposition: Simulations should be conducted for power cables (50 mm diameter),

[1] The 1 – 3 MW range was chosen as bounding values for a stack of 3 cable trays. Considering a heat of combustion of 25 MJ/Kg and a surface controlled specific mass loss rate of about 3 g/m^2-sec for cables that pass the IEEE tests, a cable tray 15 m long and 0.6 m wide will have an effective HRR of 0.9 MW. An earlier study (NUREG/CR-4230), and fire tests reported in EPRI NP-2660 and EPRI NP-2751 also concluded that the peak HRR for a cable tray is limited from 0.8 to 2 MW for a well ventilated room.

[2] EdF CNPP tests (1997)

and instrumentation cables (15 mm diameter). For models in which targets are represented as rectangular slabs, the slabs should be assumed to be oriented horizontally with a thickness of 50 mm and 15 mm correspondingly. Some participants expressed concern regarding the adequacy of a one-dimensional target model since the incident radiative flux would vary with the orientation of the slab. Also, the specification of the slab thickness, and selection of the criterion for cable damage (surface temperature versus centerline temperature) would be key to the success of a one-dimensional target model. The cable surface temperature is not indicative of the effects of the thermal environment on cable functionality. IPSN experiments indicate that the temperature of the PVC insulation of the electrical conductors reaches about 200 ^{0}C when cable malfunctions occur. Based on experience from experiments conducted at VTT, it was decided that the centerline temperature of a target slab, with a thickness equal to the diameter of the cable, would best approximate the temperature on the inside of the outer cable jacket. However, some participants felt that the slab dimensions specified for the benchmark exercise may be too thick and result in the simulation of a larger thermal inertia of the target than exists in reality.

3. Issue: What value should be used for the LOL for the cases in the benchmark exercise?

   Disposition: At the meeting, it was decided that in order to be conservative a value of zero should be used for the LOL in the base case, and that one case should be evaluated with LOL set at 12% if the model allowed this parameter to be varied. This proposal was put forth based on experimental observations which indicated that it was difficult to determine an LOL value because of the complexity of the combustion phenomena, and effects of ventilation on combustion. Some participants felt that setting LOL at 0 % for cases which were developed to examine the effects of ventilation will be contradictory, and for other cases would not yield best-estimate results. Therefore, it was suggested that the LOL be set at 12% in order to examine these effects.

<u>Other Issues</u>

4. Issue: Should user effects be addressed in this benchmark exercise?

   Disposition: As proposed in the procedure for the benchmark exercise, analysts should discuss and agree on the input data for the various codes that will be used in the benchmark exercise. The goal is for participants to analyze the same problem and minimize the variation of results due to differing input data. User effects will be examined at a later stage.

5. Issue: The mechanical ventilation rate of 9.5 m^3/s supply and exhaust of the compartment in the proposed definition is too high. Zone models would not be valid

for such high ventilation rates because there would be significant local effects due ventilation.

Disposition: Typically, nuclear power plant compartments have mechanical ventilation systems with volumetric flow rates of two to five volume changes per hour. It was decided that a constant volumetric flow rate of five volume changes/hour would be used for all the cases in the benchmark exercise.

6. Issue: The content and dimensions (including floor area) of the trash bag fire source should be specified because some plume correlations require the fire area, and the knowledge of the contents is necessary to determine the species yielded in the combustion process.

   Disposition: Assume the contents of the trash bag are: (1) straw and grass cuttings = 1.55 kg; (2) eucalyptus duff = 2.47 kg; and (3) polyethylene bag = 0.04 kg. The contents were thoroughly mixed, and then placed in the bag in a loose manner. Assume the trash bag is a cylinder with a diameter = 0.492 m, and height = 0.615 m^3.

7. Issue: The curve for the HRR of the trash bag fire should be specified so that there are no errors in the heat input to the fire simulation.

   Disposition: Assume a linear fit between the points provided for the fire curve. Specifying the best curve to go through the data points from the experiments may introduce more error than assuming a linear interpolation between the points.

8. Issue: Should corner/wall effects be examined in this benchmark exercise? In practice, cable trays are installed nearer than 0.9 m's from walls as specified in the proposed benchmark exercise. Should transient combustibles in the corner or along walls be considered?

   Disposition: In order to minimize the number of cases for the benchmark exercise, corner/wall effects will not be examined now but at a later stage. However, model users may run additional cases to examine the issue, and present the results to other participants.

9. Issue: What value should be used for the constriction or orifice coefficient for the vents in the simulation?

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[3] Lee, B. T., "Heat Release Rate Characteristics of Some Combustible Fuel Sources in Nuclear Power Plants," NBSIR 85-3195, National Bureau of Standards, 1985; and
Van Volkinburg, D. R. et al, "Toward a Standard Ignition Source," Paper No. 78-64, Lawrence Berkeley Laboratory, University of California, Berkeley, California, 1978

Disposition: Based on expert opinion of the participants, it was decided that a value of 0.68 would be used for the benchmark exercise.

10. Issue: What value should be used for the convective heat transfer coefficient?

    Disposition: Based on expert opinion of the participants, it was decided that the convective heat transfer coefficient would be set value at 15 $Wm^{-2}K^{-1}$ for the benchmark exercise.

11. Issue: Should the structures securing cable trays be evaluated as targets in the problem?

    Disposition: In order to limit the scope of the current benchmark exercise, the fire modeling of cable tray structures will not be included in the analyses. However, model users may include this analysis and share the results with the other participants.

12. Issue: Should the door be open to ambient conditions outside, or to another compartment? In NPPs, doors in most compartments typically open to another compartment.

    Disposition: In order to simplify and make feasible the evaluation of model effects, multi compartment analysis will not be included at this stage since that would include additional considerations and effects on the results. However, modelers may evaluate the effect of this important assumption on the results and share the information with other participants.

13. Issue: Intermediate results other than cable temperature should be presented to allow a full evaluation of results, and for generating statistics of the results.

    Disposition: In addition to the cable centerline temperature, it was decided that the following parameters would be reported in the benchmark exercise:

    a. Upper layer temperature
    b. Lower layer temperature
    c. Depth of the hot gas layer
    d. Heat release rate
    e. Oxygen content (upper and lower layer)
    f. Flow rates through the door and vents
    g. Radiation flux on the target
    h. Target surface temperature
    i. Total heat loss to boundaries
    j. Chemical species (CO, HCL, soot (C)) in the upper layer

For CFD and lumped-parameter models, the profile at the midpoint of the room should be presented.

14. Issue: The physical properties (heat conductivity, density, and specific heat) and the thickness of the fire door are needed.

    Disposition: Assume the fire door is a metal-clad door with a wood core and insulating panels between wood core and metal clad (on both sides of the wood core). Assume the metal clad, wood core, and insulating panels are 0.6, 40, and 3 mm thick respectively.

Properties of Fire Door

	Thermal Conductivity (W/m°C)	Density (kg/m^3)	Specific Heat (kJ/kg °C)
Carbon Steel	43	7801	0.473
Yellow Pine	0.147	640	2.8
Fiber, insulating panels	0.048	240	

15. Issue: The chemical properties of the cables (C, CL, O, and H amounts), the necessary amounts of oxygen, and the yields of CO, CO_2, H_2O vapor and soot should be given.

    Disposition: Assume the cable insulation is PVC – polyvinyl chloride. Chemical formula is C_2H_3Cl. The oxygen-fuel mass ratio = 1.408. Yields (mass of species/mass of fuel) are CO_2 = 0.46, CO = 0.063, HCL = 0.5, soot = 0.172.

16. Issue: The location of the doors and vents are necessary for use in CFD and lumped parameter models.

    Disposition: Assume the door is located at the center of the front wall, and the vents are at the center of the side walls.

17. Issue: Some fire codes require the specification of a large leakage opening (when doors and vents are closed) to prevent numerical instability in the computer model and successful execution of the code (e.g., HARVARD 6).

    Disposition: The leakage value specified in the proposed problem definition should be maintained. Users of codes with the limitation should adjust the value as needed, and document the value used.

3.3 Session 3: Fire Modeling Research in National Programs

The 3rd session was dedicated to the presentation of fire modeling research conducted in national programs. The view graphs used for the presentations are included in Attachment D. The presentations included research on:

- fire tests performed to determine the performance of electrical cables
- determining the burning behavior of electrical cables using different experimental methods
- cable tunnel fire experiments
- estimation of the probability distribution of secondary target ignition
- application of fire models to address fire protection issues
- blind simulations using a CFD code
- simulation of turbine-generator fires

Meeting Conclusion

The meeting concluded with discussion of actions participants volunteered to take, and the schedule for the project, future tasks, and meetings. Moni Dey, NRC and Jonathan Barnett, WPI volunteered to develop the first draft of the outline of the technical reference document which would be sent to other participants for comments. It was decided that the results of benchmark exercise would be discussed at the next meeting of the project in January 2001. A draft of the outline of the technical reference document would be developed by March 2001, and the final report issued by December 2001. Regarding the second phase of the project, new experiments for validating fire models will be defined by March 2001. A program for validating fire computer codes with new tests, and implementing improvements to the fire models is planned between October 2001 and September 2004. The NRC indicated its interest in international collaboration in this phase of the project, and suggested the international collaborative efforts for developing severe accident codes as a model. In this program, each country conducted fire tests which were offered for an international standard problem exercise.

Bob Kassawara of EPRI offered to host the 3rd meeting at its offices in Palo Alto, California, USA on January 15 and 16th, 2001 (after United Engineering Foundation meeting on January 7-12, 2001 in San Diego, USA). Marina Roewekamp of GRS offered to host the 4th meeting at its offices in Berlin, Germany on September 24-25, 2001.

The meeting was concluded by Remy Bertrand of IPSN.

Attachment A: Definition of Standard Problem

Room Size and Geometry

A representative PWR emergency switchgear room is selected for this standard problem. The room is 15.2 m (50 ft) deep x 9.1 m (30 ft) wide and 4.6 m (15 ft) high. The room contains the power and instrumentation cables for the pumps and valves associated with redundant motor-driven auxiliary feedwater, high-pressure injection, and low-pressure injection cooling system trains for the reactor. The power and instrument cable trays associated with the redundant safe-shutdown equipment run the entire depth of the room, and are arranged in separate divisions and separated horizontally by a distance, D. The value of D, the safe separation distance, is examined in this problem. The cable trays are 0.6 m (~24 in.) wide and 0.08 m (~3 in.) deep full with cables.

A simplified elevation of the room, illustrating critical cable tray locations, is shown in the attached figure. The postulated fire scenario is the initial ignition of the cable tray labeled as «A», located at 0.9 m (~3 ft) from the right wall of the room at an elevation of 2.3 m (7.5 ft) above the floor, by a trash bag fire on the floor. Cables for the redundant train are contained in another tray, labeled «B,» the target. A horizontal distance,D, as shown in the attached figure separates tray B from tray A. The room has a door, 2.4 m x 2.4 m (8 ft x 8 ft), in one of the walls, which leads to the outside. The room has mechanical ventilation of 9.5 m^3/s in and out of the room. The midpoint of the vertical vents for the supply and exhaust air are located at an elevation of 2.4 m and have area of 0.3 m^2 each. Assume air is supplied from and exhausted to the outside.

The effects of the fire door being open or closed, and the mechanical ventilation on and off will be examined.

It is also assumed that:

- Other cable trays (C1 and C2) containing critical and non-critical cables are located directly above tray A.
- No combustible material intervenes between trays A and B.

Analyses

There are two parts to the analyses.

The objective of Part I is to determine the maximum horizontal distance between a specified transient fire and tray A that results in the ignition of tray A. This information is of use in a fire PRA to calculate the area reduction factor for the transient source fire frequency which are derived to be applicable to the total area of the rooms. Analyses of this part of the problem will also provide insights regarding the capabilities of the models to predict simpler fire scenarios for risk analyses than those associated with safe separation distance.

Part II will determine the damage time of the target cable tray B for several heat release rates of the cable tray stack (A, C2, and C1), and horizontal distance, D. The effects of target elevation and ventilation will also be examined.

Thermophysical Data for Walls, Floor, and Ceiling (Concrete, Normal Weight (6»))

Specific Heat	1000 J/KgK
Conductivity	1.75 W/mK
Density	2200 Kg/m3
Emissivity	0.94

Ambient Conditions (Internal and External)

Temperature	300 K
Relative Humidity	50
Pressure	101300 Pa
Elevation	0
Wind Speed	0

<u>Input Data for Part I</u>

Heat Release Rates

Assume heat release rate for a trash fire as characterized in the following Table (assume linear growth between points).

32 Gallon Trash Bag Fire

Time (minutes)	Heat Release Rate (kW)
1	200
2	350
3	340
4	200
5	150
6	100
7	100
8	80
9	75
10	100

Ignition Temperature of tray A = 773 K

Assume the trash bag and the target (tray A) are at the center of the cable tray lengths. Assume the cables in the target tray can be characterized by a mass of cable insulation material 0.6 m wide and 0.08 m deep that is directly exposed to the fire.

Variation of Parameters

To facilitate comparisons of code results, simulations for horizontal distances between the trash bag and tray A of 0.3, 0.9, 1.5, 2.2 m (~1,~ 3,~ 5, and ~7 ft) should be conducted with the door closed and mechanical ventilation system off. Simulations should be conducted at a horizontal distance of 1.5 m with: (a) the door is open and mechanical system off; and (b) mechanical ventilation system on and door closed. The resulting temperature of tray A should be presented in SI units for these simulations.

The maximum horizontal distance between the trash bag and tray A, that results in the ignition of tray A, should be determined by extrapolation of results for the simulations with the door closed and mechanical ventilation system off.

For simulations with the door closed, assume a crack (2.4 m x 0.005 m) at the bottom of the doorway.

<u>Input Data for Part II</u>

Heat Release Rates

The modeling of and predicting the heat release rate of a burning cable tray stack is extremely complex, and I don't believe any of the current zone models are capable of realistically predicting such phenomena. Therefore, it is proposed that the heat release rates of the burning cable tray stack should be defined as input in the problem. This issue could be investigated later with field models to evaluate the capability of that methodology to predict such phenomena. I am not sure whether field models can adequately predict such phenomena either. If we agree on these statements, this would identify the first area in which experimental research may be valuable and that could be conducted in this collaborative program. However, we should examine the need and value of additional data based on the analyses of this problem. Conservative estimates through bounding analyses can also be made to determine the maximum number of cable trays in a cluster that will not damage a redundant cable tray separated by a safe separation distance, D, in a specified time. The specified time can be determined from a goal established for the core damage frequency contribution of the fire area scenario, and the probability of failure to suppress the fire (which is a function of time). Discussion of this issue should lead to the formulation of guidance for modeling the burning of cable tray stacks.

Assume Heat Release Rate for cable tray stack = 1 MW, 2 MW, and 3 MW reaching peak heat-release rate through a linear growth taking 3, 6, and 10 minutes, respectively.

Geometry

Assume the heat source (tray A, C2, and C1) is at the center of the cable tray lengths and at the elevation of tray C2, and the target (tray B) is at the center of the cable tray lengths. Assume the cables in the target tray can be characterized by a mass of cable insulation material 0.6 m wide and 0.08 m deep that is directly exposed to the fire.

Thermophysical Data for Cables

Heat of combustion of insulation	26.5 MJ/kg
Fraction of flame heat released as radiation	0.48
Density	1710 kg/m3
Specific Heat	1040 J/kgK
Thermal Conductivity	0.092 W/mK
Emissivity	0.8
Damage temperature	643 K

Variation of Parameters

1. Heat Release Rate for cable tray stack = 1 MW, 2 MW, and 3 MW (reaching peak heat-release rate through a linear growth taking 3, 6, and 10 minutes, respectively) at a horizontal distance, D = 3.1, 4.6, 6.1 m (~10, ~15, and 20 ft). Assume door and ventilation system is closed for these simulations. For simulations with the door closed, assume a crack (2.4 m x 0.005 m) at the bottom of the doorway.

2. At a heat release rate = 2 MW and D = 6.1 m (20 ft), simulations should be conducted with:
   i. Door closed and ventilation system operational initially; and door opened, and ventilation system shut after 15 minutes.
   ii. Door and ventilation system open throughout the simulation.

3. At a heat release rate = 2 MW and D = 6.1 m (20 ft.), and the door and ventilation system closed, three elevations for tray B should be analyzed to examine the possible effects of the ceiling jet sub-layer and the elevation of the target:
   i. 2.0 m (6.5 ft) above tray A, (i.e., 0.3 m (1 ft) below the ceiling).
   ii. 1.1 m (3.5 ft) above tray A.
   iii. Same elevation as tray A.

The resulting temperatures of the HGL and target tray B, and time to damage of tray B, should be presented for these analyses. All results should be presented in SI units.

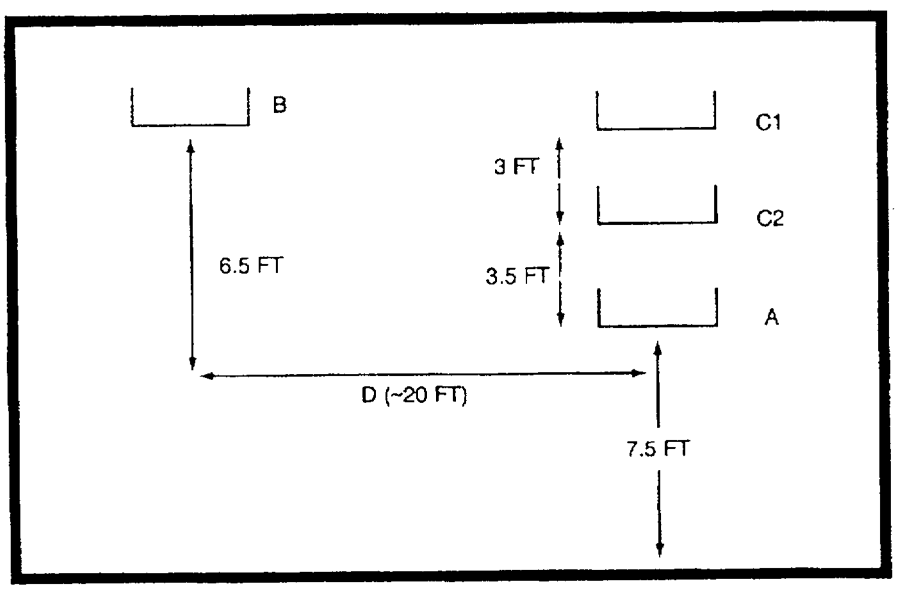


Figure 1 Representative Emergency Switchgear Room

Attachment B: Agenda

International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

2nd Meeting

June 19-20, 2000
Fontenay-aux-Roses, France

Hosted by the
Institute of Protection and Nuclear Safety, France

June 19, 2000
Room 004, Building 8

Registration: 8:30 - 9:00 a.m.

Welcome: 9:00 a.m.

Remy Bertrand, IPSN

Session 1: 9:15 a.m. - 1:00 p.m., June 19, 2000
Discussion Leader, Moni Dey, NRC

Topic - Presentation of proposals and comments for standard problem exercises, including a description of the models participants intend to use in the exercise. Allotted time for each paper is twenty minutes.

1. NRC Proposal for the Standard Problem Exercises, Moni Dey, NRC

2. Overview of CFAST, Walter Jones, NIST, and Moni Dey, NRC (presented by Moni Dey)

3. IPSN Fire Computer Codes - FLAMME_S Zone and ISIS CFD Models, Chantal Casselman, IPSN

4. Proposals and Comments for Standard Problem Exercises, Jocelyne Lacoue, IPSN

5. Effects of Physical Sub-models and Design Fire in Zone Model Calculations, Dietmar Hosser, G. Blume, and J. Will, iBMB of TU Braunschweig (presented by J. Will)

6. Status of Fire Simulation with the GRS code COCOSYS, Walter Klein-Hessling, and Bernd Schwinges, GRS (presented by Bernd Schwinges)

7. Proposals and Comments for Standard Problem Exercises, Marina Roewekamp, GRS

8. Proposals and Comments for Standard Problem Exercises, Olavi Keski-Rahkonen, VTT

9. Proposals and Comments for Standard Problem Exercises, Other attendees

Session 1: Continued, 2:30 - 5:30 p.m., June 19, 2000

10. Group discussion to formulate the standard problems

Session 2: 9 - 10:30 a.m., June 20, 2000
Discussion Leader, Moni Dey, NRC

Topic - Planning Session

1. Review and finalize formulation of standard problems, All attendees

2. Plan milestones and schedule for completion of analyses for standard problems

3. Formulate future tasks, including tasks for collaborative experimental research for fire model validation and development

4. Plan future meetings

Session 3: 11:00 a.m. - 1:00 p.m., June 20, 2000
Discussion Leader, Remy Bertrand, IPSN

Topic - Presentations of tasks conducted in national programs for fire modeling (e.g., test results pertinent to the issues under examination). Allotted time for each paper is twenty minutes.

1. Fire Tests Related to Electrical Cables and other Fire Tests in Progress, Jean-Marc Such, IPSN

2. Burning Behavior of Electrical Cables Using Different Experimental Methods, Dietmar Hosser, and Juergen Will, iBMB of TU Braunschweig (presented by Juergen Will)

3. Cable Tunnel Fire Experiments at VTT, Olavi Keski-Rahkonen, VTT

4. Estimation of Probability Distribution of Secondary Target Ignition in a Cable Tunnel, Olavi Keski-Rahkonen, VTT

5. French Fire Modeling of Scenarios Under Nuclear Plant Conditions, Bernard Gautier, Olivier Pages, Maurice Kaercher, EdF

Session 3: Continued 2:30 - 3:15 p.m., June 20, 2000

6. Some Blind Fire Simulations Using CFD, Stewart Miles, BRE/FRS

7. Risk-Informed, Performance-Based Analysis of Turbine-Generator Fires in a Nuclear Power Plant Turbine Building, Moni Dey, NRC

Session 4: Closing Session 3:30 - 5:30 p.m., June 20, 2000
Discussion Leader: Moni Dey, NRC

1. Continue discussion of approaches for collaborating on experimental research for fire model validation and development

2. Comments and suggestions on the use of and improvements for the project web site

3. Discussion of other logistical issues for project coordination

4. Finalize an action plan

Concluding remarks:

Remy Bertrand, IPSN

Lunches and Coffee Breaks in the morning will be provided courtesy of IPSN

Attachment C: View Graphs Used for Comments on Benchmark Exercise, and Description of Fire Codes

NRC Proposal for Standard Problem Exercises

Moni Dey
U.S. Nuclear Regulatory Commission

Project Review

- Goal and objectives
- Project plan
- NRC proposal for more aggressive plan

Goals and Objectives

- Collaborate to evaluate and improve fire models for NPPs
- Phase 1 - Evaluate current state-of-the-art models. Define:
  - capabilities & limitations
  - need for improvements
- Phase 2 - Validate and improve fire models

Needs and Issues

- Develop guidance for users for specific applications
- Bridge gap between research community and users
- Simple, usable, and acceptable models needed
- Define capabilities, benefits and limitations for specific problems

Project Products

- User guides to serve as reference documents
- Define areas for improvements, including experiments for further validation of models

Outline of User Guides/Reference Documents

- Objective and use of document
- Capabilities and limitations of models for specific applications
- Appropriate input parameters and assumptions
- Insights from tests for interpretation of model results
- Uncertainties in predictions

NRC Proposal for Additional Tasks

- Compile existing data for code validations for NPP scenarios
- Conduct comparisons of code results with existing data
- Define need for and value of additional code validation with new experiments

Proposed Standard Problems

- Safe separation distance
- Compare codes with existing experimental data (choose one data set at this meeting)

Proposed Products

- User Guides
- Document code validation (using existing data)
- Define experiments for extending code validation

Proposed Plan for Phase 2

- Conduct blind standard problem exercises with new experiments
- Each country serve as host for a specific standard problem
- Document extended validation of codes

Proposed Schedule

Phase 1	Schedule
User Guides	1st report – 3/01 2nd report –12/01
Document code validation	Same as above
Define new experiments	3/01
Phase 2	Schedule
Conduct code validation with new tests	10/01 – 9/04

Safe Separation Standard Problem

- Identified at last meeting and included in project plan
- Objective is to evaluate adequacy of fire models for examining issue
- Probabilistic risk analysis (PRA) framework proposed for examining issue

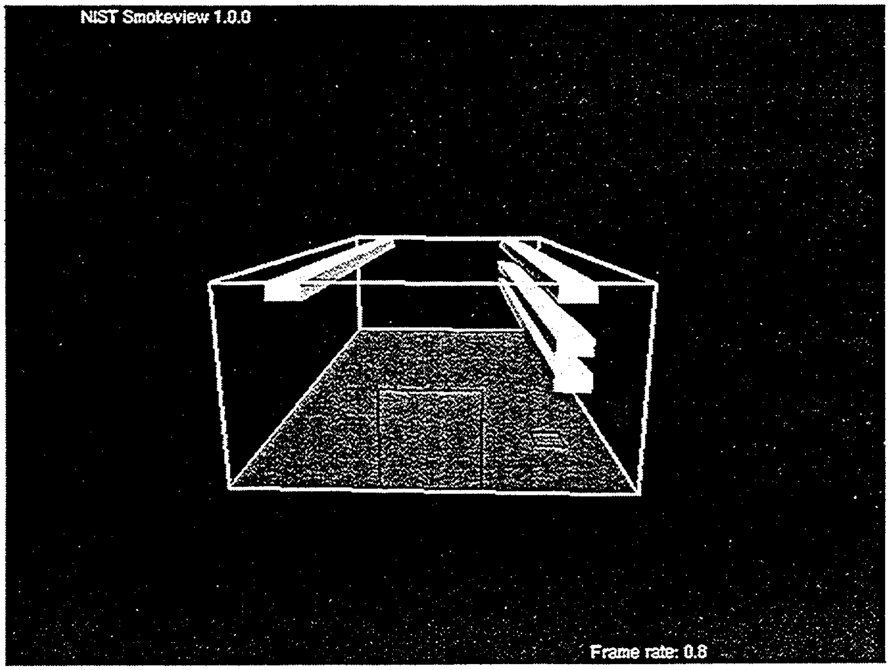
Parameters for PRA Framework

- Estimate conditional probability of equipment damage
- Simulate realistic conditions, including mechanical ventilation
- Fire detection and suppression not generally included
- Compare target damage time with sequence duration

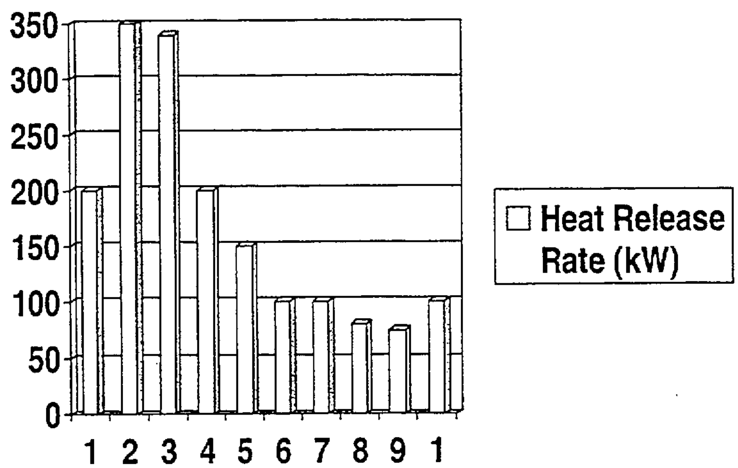
Protocol for Standard Problem

- Agree on input data, and form of results to be compared, prior to conducting exercise
- Developers, and users of codes can participate in exercise
- Conduct blind simulations
- Same code may be used, but version used should be same

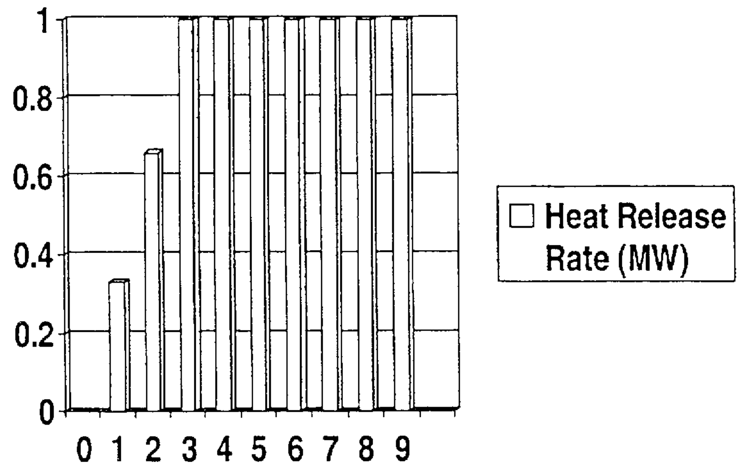
Typical PWR Switchgear Room



32-Gallon Trash Bag Fire



Burning of Cable Tray Stack



Issues for Safe Separation Analyses

- Fire source magnitude and frequency
- Fire spread rate in cable trays
- Characterization of cable tray as fire source and target in a zone model
- Target heating by ceiling jet and plume

Issues for Safe Separation Analyses

- Acceptable degree of conservatism
- Need for and value of CFD models and experimental data

Overview of CFAST

Walter Jones, and Moni Dey

The Three Legs of Modeling for Public Safety

- Zone Modeling
  - **CFAST (and the GUIs)**
- Validation and Verification
- Data for comparisons
  - **FASTData database development**

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Modeling

- CFAST - zone model
  - Large (complex) building simulation
  - Input/model/output
- FAST/FASTLite/FireWalk/FireCAD
  - GUI interfaces for fire models
  - Includes simple back of the CRT calculation

Concept of a Zone Model

Each compartment is subdivided into "control volumes," or zones. Conservation of mass and energy is applied to each zone.

A few zones (2 to 10)

Predictive equations are derived from conservation of energy and mass (momentum at boundaries)

Use ordinary differential equations rather than partial differential equations

Adding phenomena is *relatively* easy

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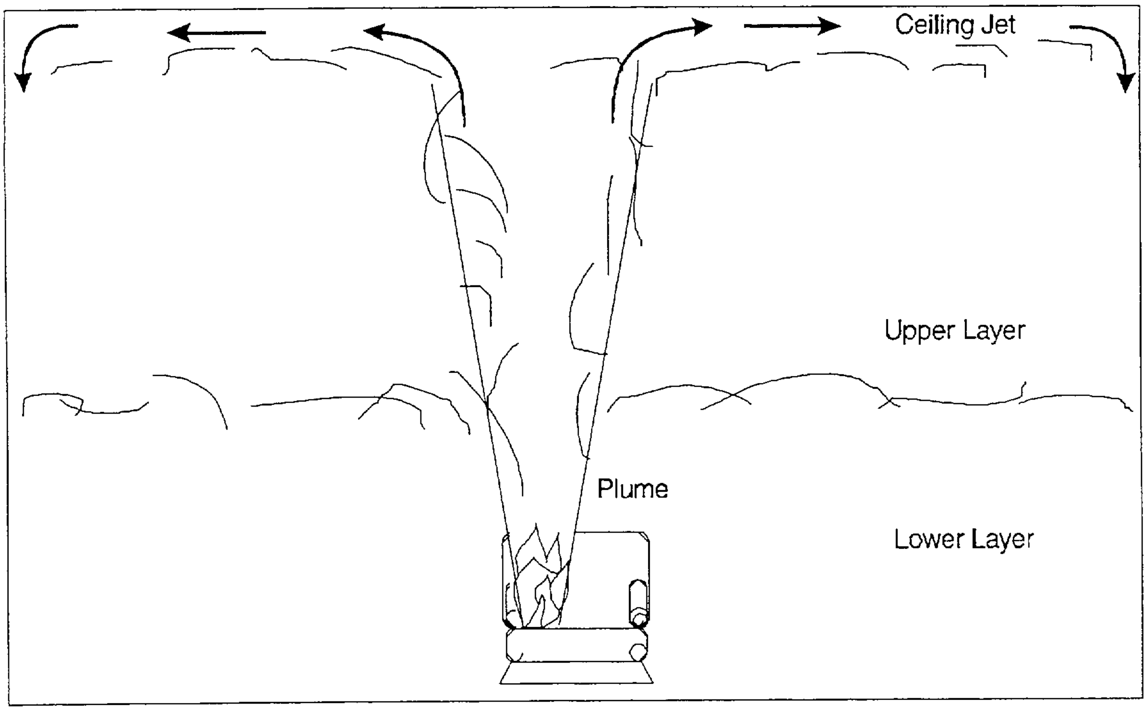
Concept of a Zone Model



The Mathematical Basis

$$\frac{dV_U}{dt} = \frac{1}{\gamma P}\left((\gamma - 1)\dot{h}_U - V_U\frac{dP}{dt}\right)$$

$$\frac{dP}{dt} = \frac{\gamma - 1}{V}\left(\dot{h}_L + \dot{h}_U\right)$$

$$\frac{dT_U}{dt} = \frac{1}{c_p \rho_U V_U}\left(\left(\dot{h}_U - c_p \dot{m}_U T_U\right) + V_U\frac{dP}{dt}\right)$$

$$\frac{dT_L}{dt} = \frac{1}{c_p \rho_L V_L}\left(\left(\dot{h}_L - c_p \dot{m}_L T_L\right) + V_L\frac{dP}{dt}\right)$$

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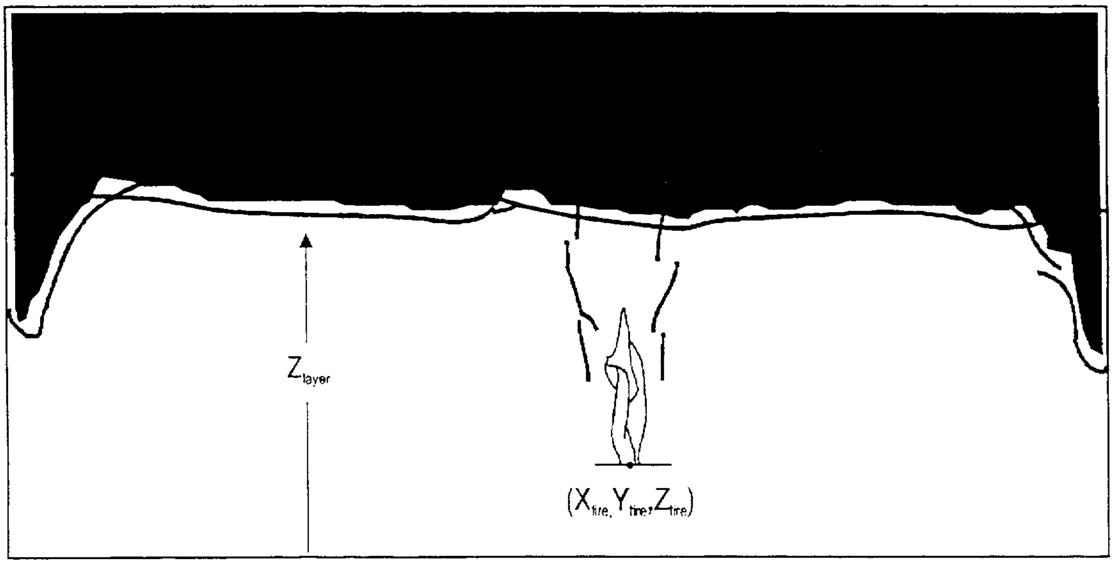
Ceiling Jet / Asymetric Heat Loss



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Why Is this Modeling Important?

- Speed – algorithm implementation is very important
- Do parameter studies of complex buildings
  - Complex and numerous connections
- Predict (small variations do not matter)
  - Environment (CO, ...)
  - Insult to the structure

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Zone Models in the U.S.

CFAST - 2.0.1 - HAZARD I version 1.2

CFAST - 3.1.6 being used in fire reconstruction

Compbrn III - UCLA - consulting with EPRI

BRI2 (Japan) - Factory Mutual Risk Analysis

Many specialize tools such as FPETool (ASET, ASCOS, ...)

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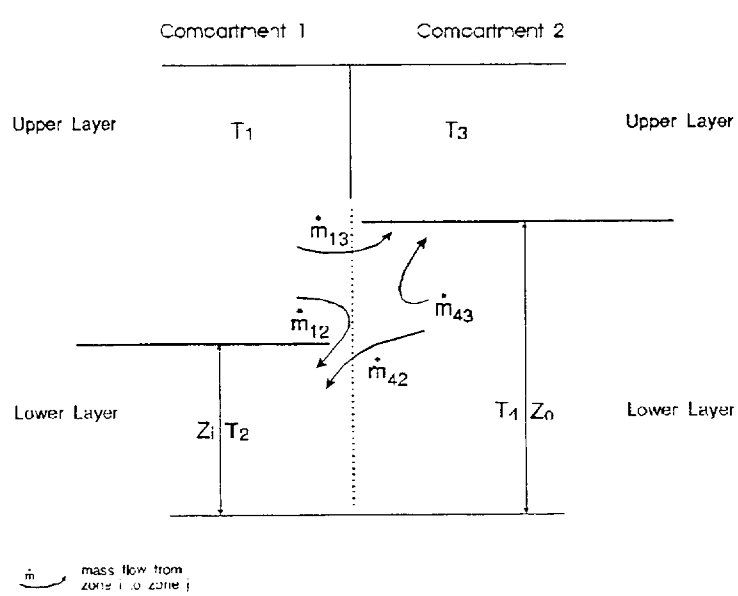
Phenomena

- Multiple compartments (60->~100)
  - Variable geometry
- Multiple fires
  - Ignition from time, flux or object temperature
- Fire plume and entrainment in vent flow
- Vitiated or free burn chemistry
- Four wall and two layer radiation
- Target heating
- Wind effects
- 3D specification of the location of the fire and non-uniform heat loss thru boundaries

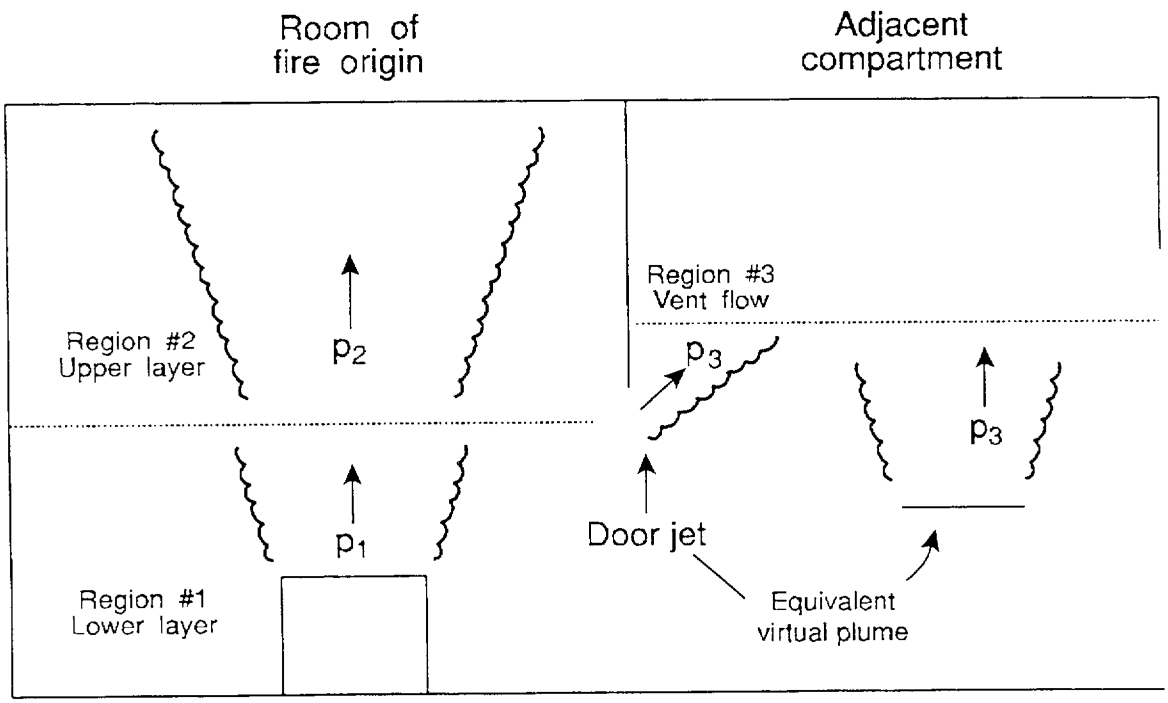
Phenomena

- Generalized vent flow
  - Horizontal flow (doors, windows , ...)
  - Vertical flow (holes in ceilings/floors)
  - Forced flow (mechanical ventilation)
- Intercompartment heat transfer
  - Ceiling/floor
  - Horizontal - compartment to compartment
- Horizontal smoke flow
- Detection - smoke, heat
- Suppression - heat release knockdown
- Separate internal and external ambient(s)

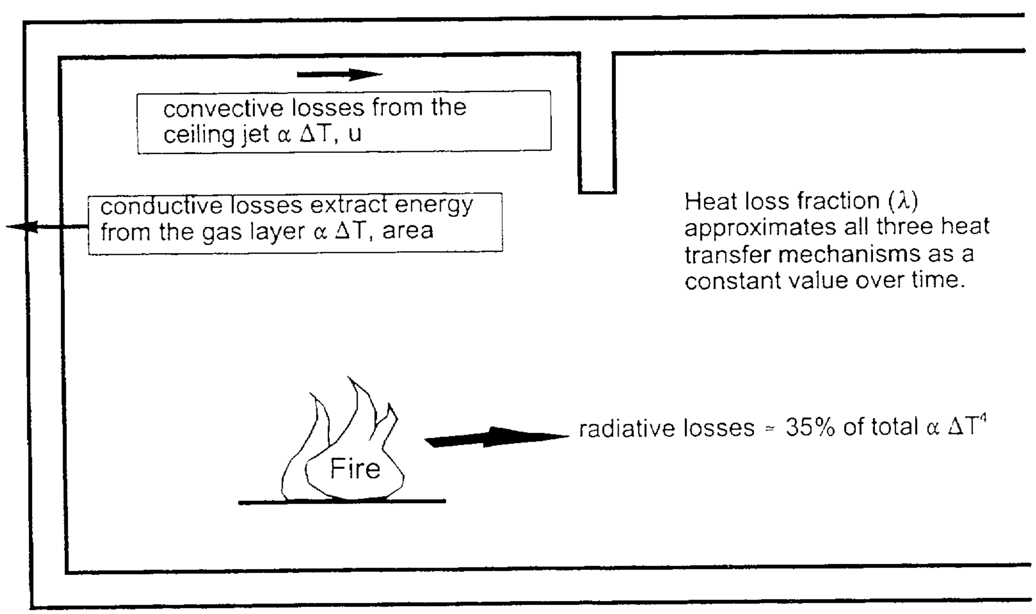
Entrainment in Vents



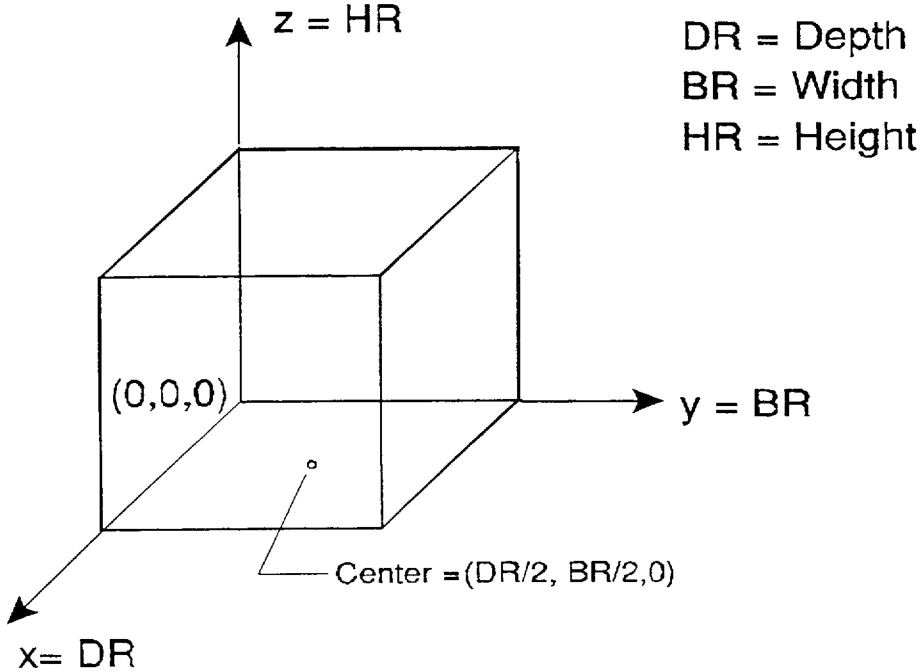
Fires in Plumes and Vents



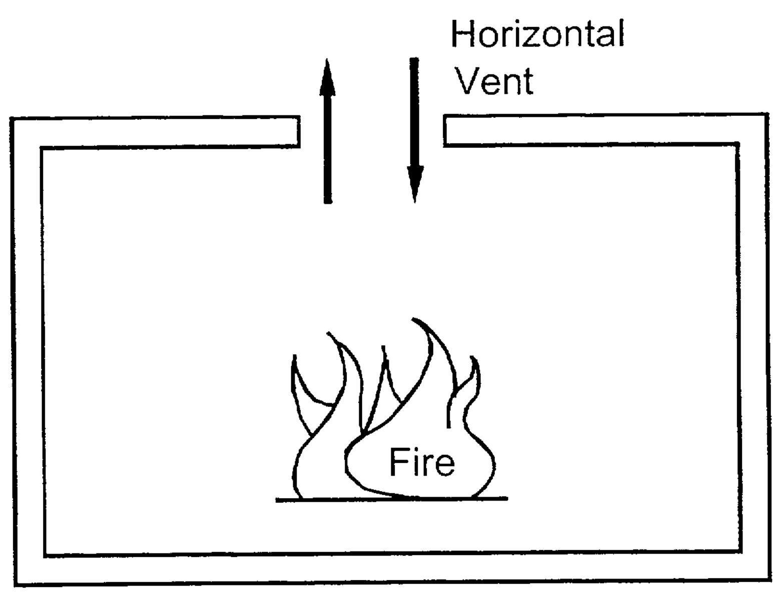
Heat Transfer Through Multilayered Partitions



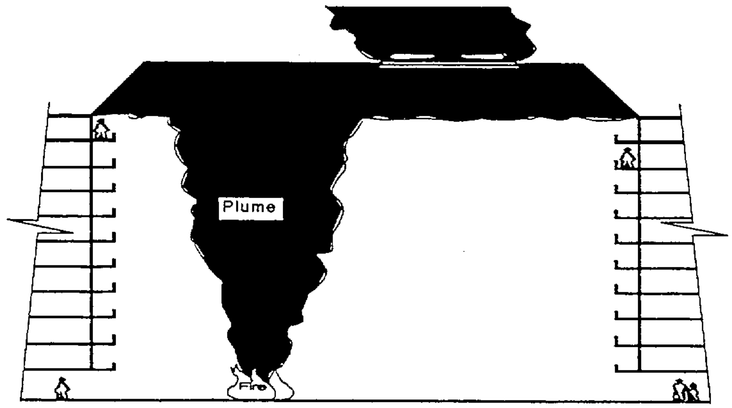
XYZ Positioning of Objects, Fires and Surfaces



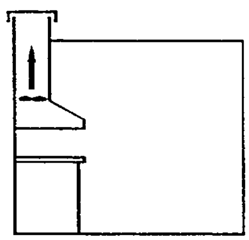
Vertical Flow
(Horizontal Vents)



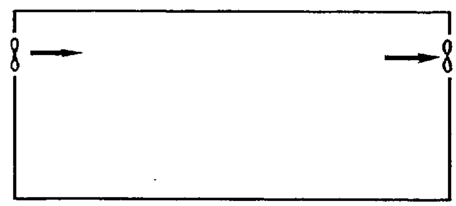
Examples of Forced Flow



(a) Atrium Smoke Management

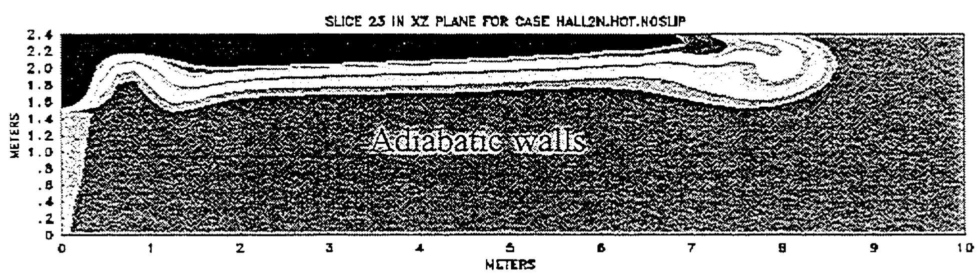


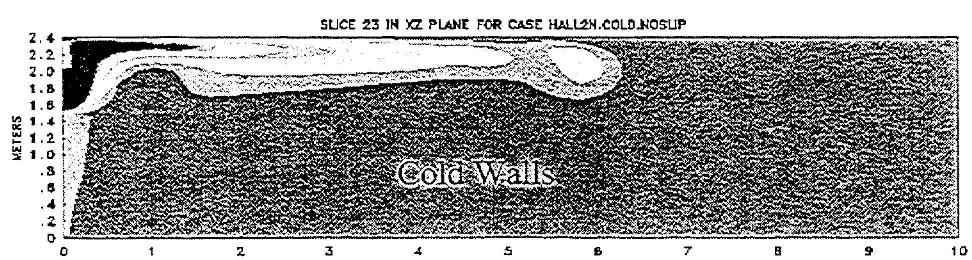
(b) Kitchen Exhaust



(c) Space With Cross Ventilation

Corridor Flow





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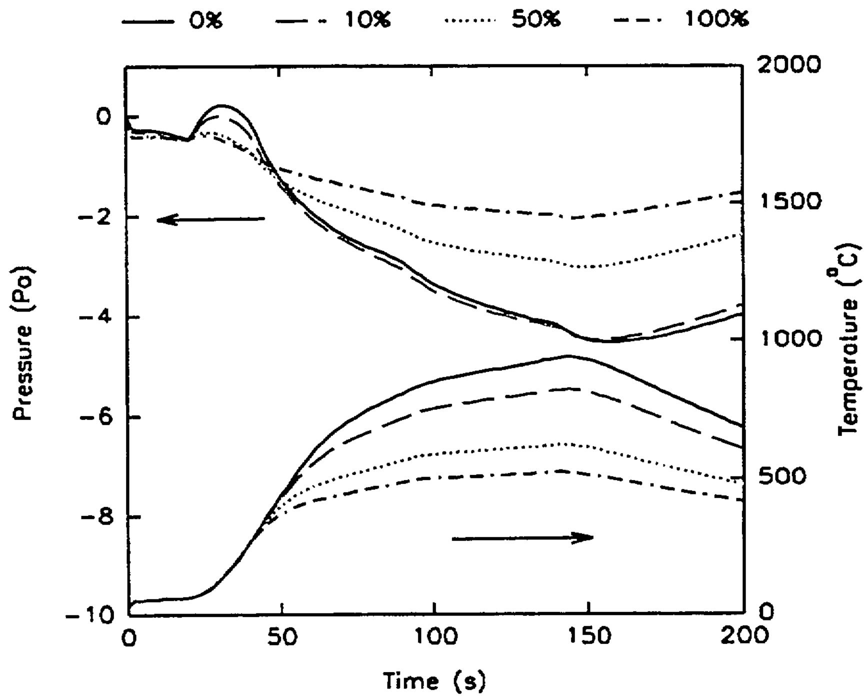
Leakage – Specification Errors



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Verification *vs* Validation

- Verification: insuring that the phenomenology is implemented correctly in the model
- Validation: insuring that a model makes the correct (expected) prediction for a given set of input data
- For public safety and finding economies of scale, both are important

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Issues Related to Verification

- Comparison with experimental data, including error analysis
- Open system - published code (verification, not validation)
- Documentation - crucial
- Sensitivity analysis (suite)

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Quotes on Verification

- "The simulations generally compare favorably with the experiments"
- "Upper layer temperatures were not predicted well by either model"
- "Layer heights are well predicted by both models only in the burn room"
- "All of the models simulated the experimental conditions quite satisfactorily"
- "For the 4 MW fire size, all of the model do reasonably well"

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Possible "Norms"

$$\|\vec{x}\| = \sqrt{\sum_{i=1}^{n} x_i^2}$$

$$\langle \vec{x}, \vec{y} \rangle = \frac{\sum_{i=1}^{n} (x_i - x_{i-1})(y_i - y_{i-1})}{t_i - t_{i-1}}$$

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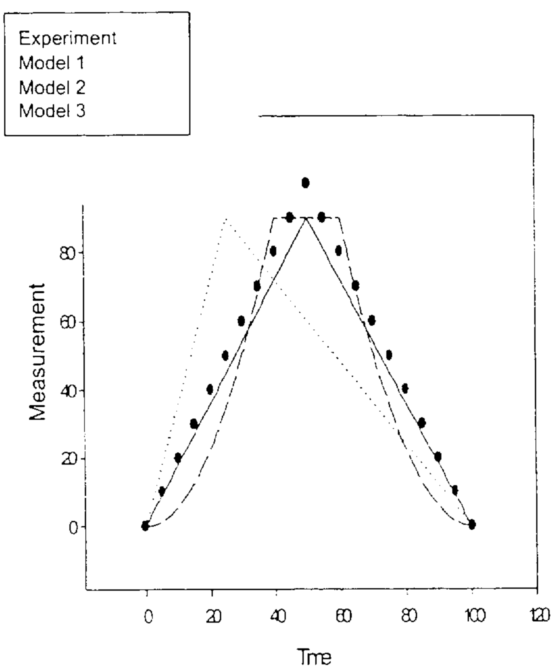
Example of Metrics



product definitions

Geometry	Model	Relative Difference	Cosine
Euclidean	1	0.10	1.00
	2	0.40	0.92
	3	0.20	0.98
Hellinger	1	0.10	1.00
	2	0.94	0.58
	3	0.74	0.77
Secant	1	0.10	1.00
	2	0.92	0.58
	3	0.66	0.83
Hybrid	1	0.10	1.00
	2	0.64	0.78
	3	0.43	0.91

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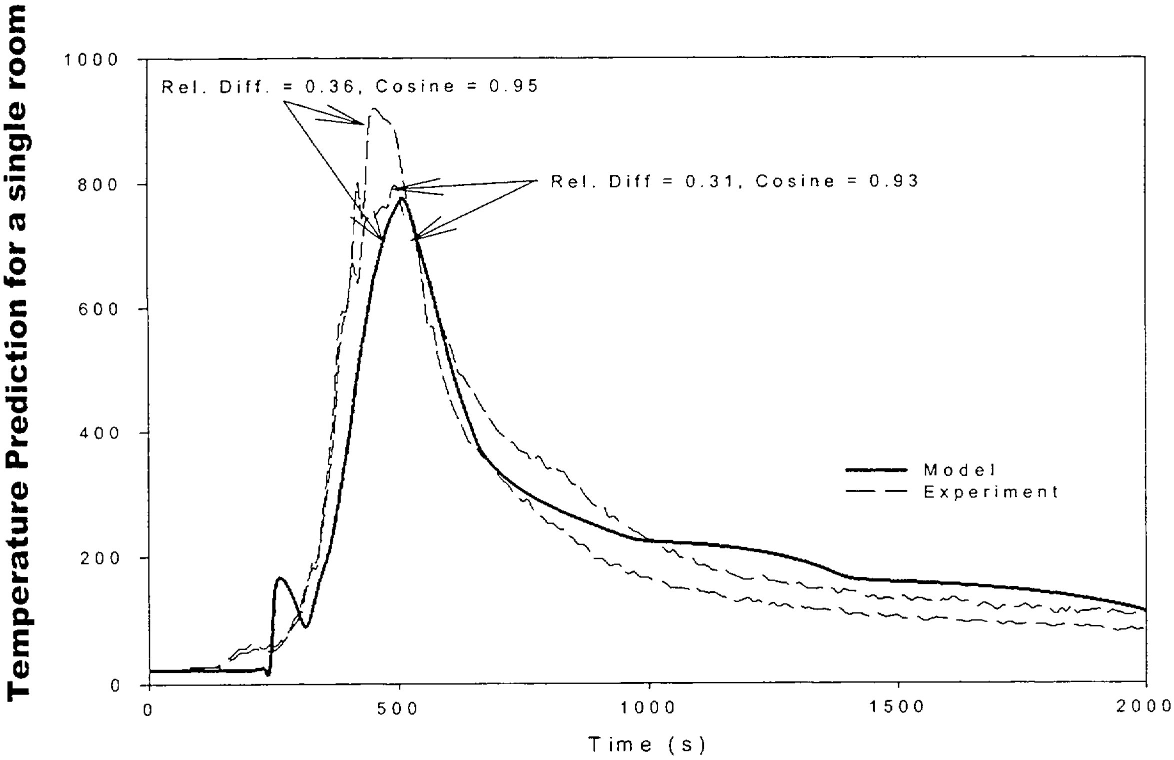
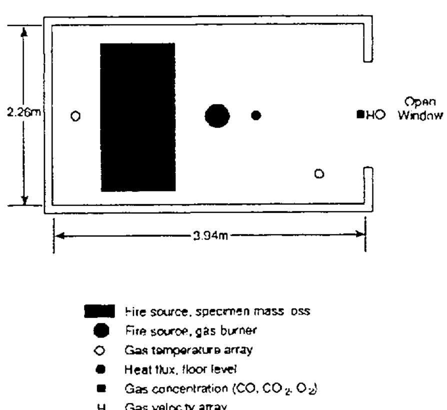
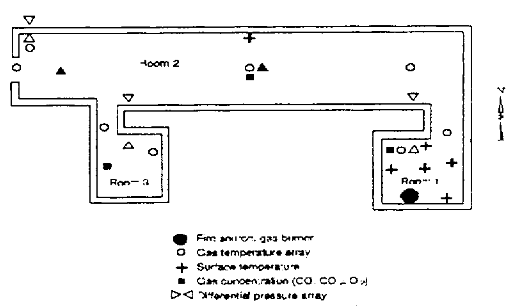
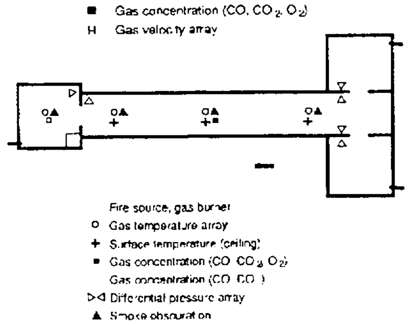
One of our real room comparisons

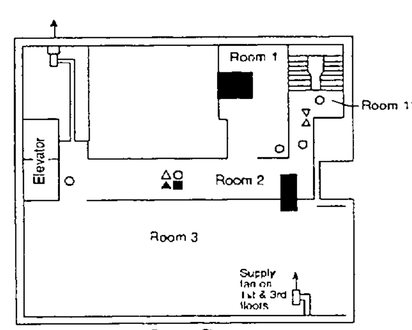


1, 3, 4 and Multistory Configurations









Fire source, specimen mass loss
Gas temperature array
Gas concentration
Differential pressure (room 2 to room 4
do

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An example with four real scale experiments

	Position / Compartment	Relative Difference	Cosine	Relative Difference	Cosine	Relative Difference	Cosine
Upper Layer Temperature and Interface Position							
		Upper Layer Temperature		**Lower Layer Temperature**		**Interface Position**	
Single-room furniture tests	1	0.31	0.95	0.47	0.92	1.38	-0.60
	2	0.36	0.93	0.63	0.78	0.63	0.78
Three-room tests with corridor	1	0.25	0.97	–	–	–	–
	2	0.26	0.99	–	–	–	–
	3	0.26	0.98	–	–	–	–
Four-room tests with corridor	1	0.51	0.93	0.33	0.95	2.26	0.06
	2	0.54	0.91	0.52	0.87	–	–
	3	0.36	0.97	0.78	0.86	–	–
	4	0.20	0.98	–	–	–	–
Multiple-story building	1	0.28	0.97	–	–	–	–
	2	0.27	0.96	–	–	–	–
	7	2.99	0.20	–	–	–	–
Gas Concentration							
		Oxygen		**Carbon Monoxide**		**Carbon Dioxide**	
Single-room furniture tests	1	0.48	0.90	0.93	0.66	0.69	0.93
Four-room tests with corridor	1	0.85	0.53	1.05	0.61	1.16	0.63
	2	0.93	0.39	1.02	0.57	0.90	0.63
Multiple-story building	2	0.74	0.68	0.72	0.90	0.87	0.93
Heat Release, Pressure, and Vent Flow							
		HRR		**Pressure**		**Vent Flow**	
Single-room furniture tests		0.19	0.98	–	–	0.61	0.79
Single-room tests with wall burning		0.21	0.98	1.31	0.80	–	–
Three-room tests with corridor	1	0.43	0.96	0.15	0.99	0.14	0.99
	2	–	–	0.68	0.98	0.20	0.98
Four-room tests with corridor		–	–	6.57	0.74	–	–
Multiple-story building	1	–	–	1.12	-0.41	–	–

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Limitations

Pyrolysis still depends on test methods

Need model of smoke agglomeration and settling

Better detector and other sensor activation

Suppression - include fire size, drop size and distance effects

Corrosion and structural effects

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Data Resources

Fire On the Web http://fire.nist.gov/

FASTData 

Modeling websites: http://cfast.nist.gov/

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FIRE MODELLING IN IPSN COMPUTER CODE

The objectives

to provide safety analysis with *computer codes* qualified in the field of interest for nuclear plant safety

several different fuels into one or several rooms connected by doors or ventilation network

room temperatures, pressure increase

components behaviour

(concrete structures, electric equipments, filters)

FIRE MODELLING IN IPSN COMPUTER CODE

The two-tier approach

zones code **FLAMME_S** rather simple approach *to allow engineering calculations*

3 D code **ISIS** field modelling *to overcome the limitations of zones code*

good confidence level: rigourous validation ⟹ *strong connection experiments-modelling* models limitations

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code

to predict the resulting conditions of the development of a fire within a compartment

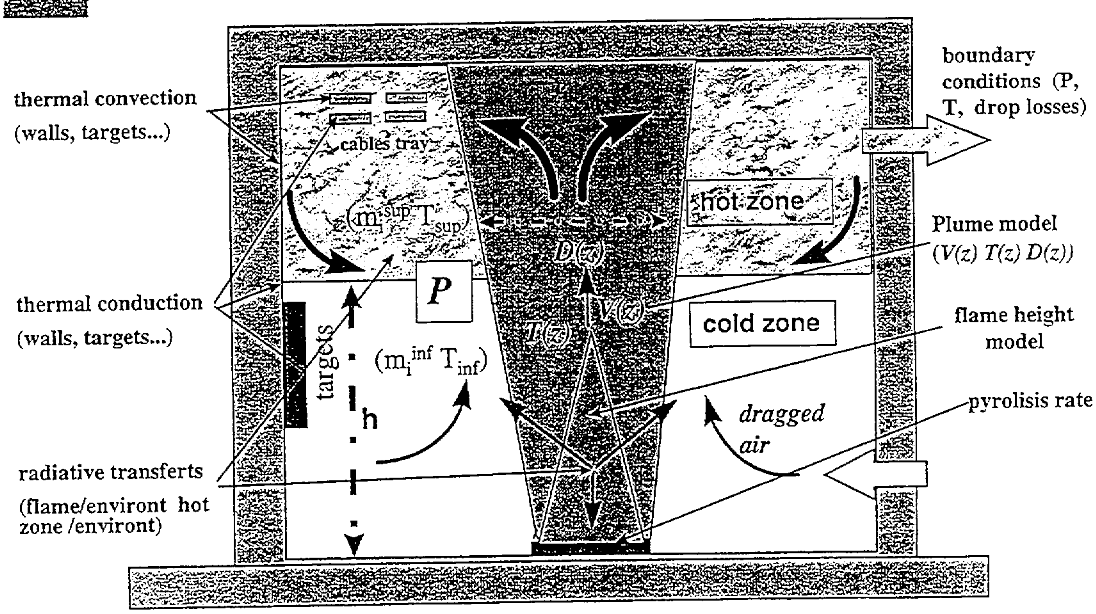
in term of

gas pressure, temperatures (gases, walls,targets..), species concentrations ,

flow rates and species concentrations of released gases (ventilated room)

development started in 1993 - new functionnalities : multi room model , coupled with a ventilation code

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code



FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code

- each component (fuel, gaseous zone , walls, openings....)
  → a physical and mathematical model
- *determination of gas temperature and pressure from mass and energy balance equations + perfect gas state equation*
- mass transfers from the lower layer to the upper one + temperature along the plume axis
  → plume models (Gupta, Heskestad)

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code

- *flows through openings : Bernouilli's law*
- *SIMEVENT* code : network components behaviour
- radiative heat transfers : point source, fraction of total combustion heat, shape factors, semi transparent gases and soot concentration
- convective heat transfer coefficient deduced from experimental results
- heat conduction equation for transient heating of walls and objects

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code

Mass flow combustion rate : $\dot{m}''$ kg/s.m^2

- input data , based on experimental results
- *combustion reaction constant*
- limited by oxygen amount in air dragged by the plume
- *extinction on oxygen concentration threshold*

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S code

<u>Limitation of Zones codes</u>

★ only **mean** value of gas temperature

★ *validation domain of used correlations*

★ rather simple geometry

★ *no simulations of flame- struture and flame-flame interactions*

but a zones code allows to study a large number of scenarios and $to perform sensitivity study

FIRE MODELLING IN IPSN COMPUTER CODE
ISIS code

Detailed approach of fire simulation

based

on the **Navier-Stokes** equations applied to

turbulent flows with **buoyancy** effect

+ balance equations

for

momentum mass and energy

FIRE MODELLING IN IPSN COMPUTER CODE
ISIS code

Computational Fluid Dynamics theory

Conservation equations solved using discretization process

3D numerical grid of several ten of thousand elementary control volume

Resulting set of algebraic equations

solved by usual methods of linear systems (ADI/TDMA, GMRES...)

FIRE MODELLING IN IPSN COMPUTER CODE
ISIS code

governing equations : conservation equations for mass momentum energy ansd species + transport equations for the turbulence variables k and ε

$$\frac{\partial}{\partial t}(\rho\,\Phi)+\frac{\partial}{\partial x_j}(\rho\,u_j\,\Phi)=\frac{\partial}{\partial x_j}\left(\Gamma_\Phi\frac{\partial\,\Phi}{\partial x_j}\right)+S_\Phi$$

Φ : 1(mass of the mixture) u_i (velocity) h (enthalpy)

K and ε (transport of turbulence kinetic and its dissipation rate)

FIRE MODELLING IN IPSN COMPUTER CODE
FLAMME_S - qualification
multiroom configurations

- 19 tests performed by Cooper and al.

  2 or 3 rooms (with a corridor), connected by doors

  HRR : 25 to 300 kW

  combustion rating : stationary or transient

  fire durations = or < 10 min

- good tendancies and levels : pressure, gas temperature, heat fraction absorbed by the walls, zones interface

FLAMME_S code
a two zones model

the room is divided into

two distinct but homogeneous zones:

upper layer contains the ***hot gases*** produced by the fire and the air entrained by the plume ; these gases are floating over the ***cold gases*** *of the lower layer* as a result of the thermal stratification due to buoyancy

FLAMME_S code- qualification single room configuration

The main characteristics of the 17 tests used for the FLAMME_S code qualification are summarised below :

oil fires surface

⇒ 0.03 and 0.06 m^2 in a 5 m^3 room either closed or under forced ventilation

⇒ 1 to 2 m^2 in a 400 m^3 room under forced ventilation

⇒ 5 m^2 in a 2000 m^3 room under natural ventilation

FLAMME_S code- qualification
single room configuration

solvent fires surface

⇒ ***1 m^2 in a 100 m^3 room under natural ventilation,***

⇒ ***1 m^2 in a 400 m^3 room and a 3600 m^3 room under forced ventilation,***

⇒ ***1 to 5 m^2 in a 2000 m^3 room under natural ventilation,***

⇒ ***20 m^2 in a 3600 m^3 room under forced ventilation ;***

forty experimental variables were used to estimate the code ability to calculate the thermal consequences of a given fire

FLAMME_S - qualification

Qualification work

- *In progress ...*
  - liquid pool fire closed to a wall or a corner
- *Planed ...*
  - electrical cabinets (2001)
  - multiroom configuration (forced and natural ventilation) - tests in DIVA : 2001....

ISIS code - *Status of development*

- 03/1999 - basic version : *inert turbulent flow with variable density*
- end of 2000 - first version : *classical combustion models*

- *2001 : radiative transfers*
- *2001 : qualification work based on analytical tests and large scale tests*
- *2001-2002 : using of multi grid approach with local refinement for the numerical methods*
-

GENERAL UNDERSTANDING

What is the *final* purpose of the benchmark ?

- to judge the adequacy of physical models regarding a define configuration
- to define the limits of using zones codes versus CFD codes regarding a define configuration
- ....to define acceptance criterias for safety evaluation

CHOICE OF THE CONFIGURATION

According to the position of cables from walls and to the position of the transient source from cables, this source can be considered as a centered source

➡ advantage : simpler

➡ inconvenient : In practice, cabletrays are installed nearest than 0.9m from walls

What about considering transient combustible in a corner or along the walls?

CHOICE OF THE TRANSIENT COMBUSTIBLE

The choice of the transient combustible is it resulting of walkdown feedback ?

1 MW peak value → pool of acetone =1m2 (i. e. Babrauskas)

20 mn fire duration → volume = 47 litres

According to viscosity of acetone the transient source seems to be non realistic in case of a spill of liquid

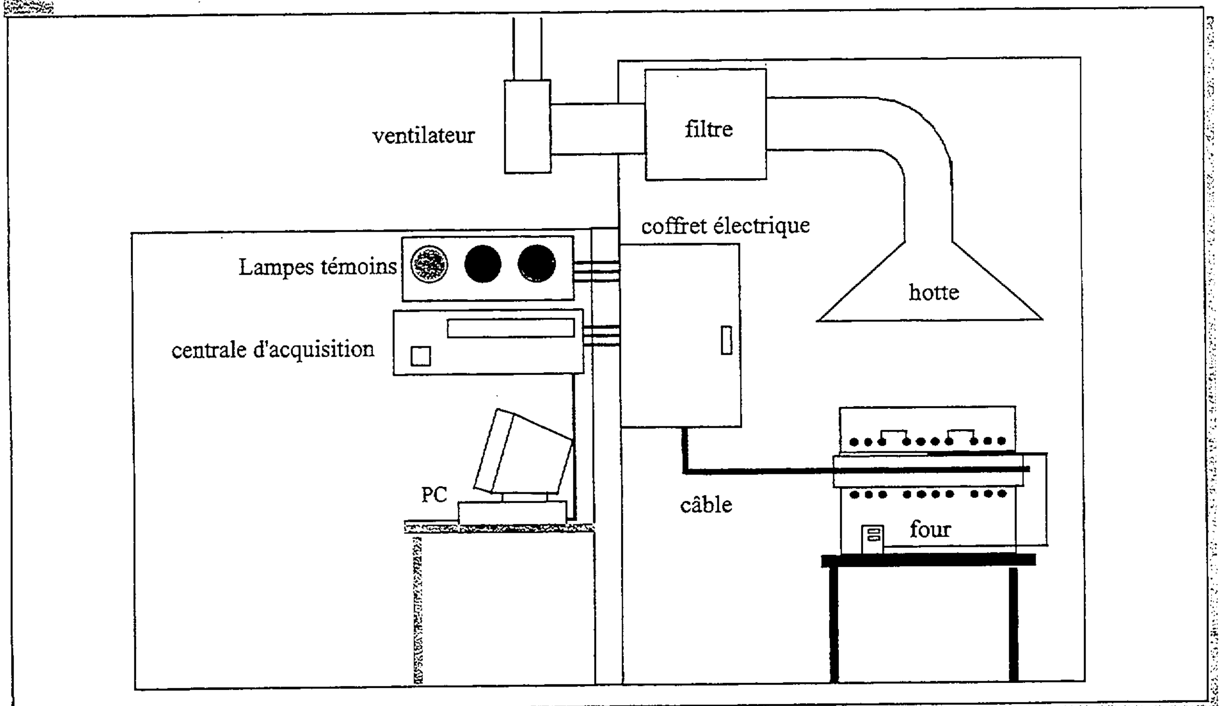
criterias of cables

Are 500°C and 370°C ambiant temperatures or inside temperatures of cables ?

IPSN experiments : inside temperature of cables is about 220°C when malfunction occurs

Ambiant temperature (°C)	Duration (min)	Malfunction
200	90	no
250	17-20	yes
300	10	yes
400	7	yes

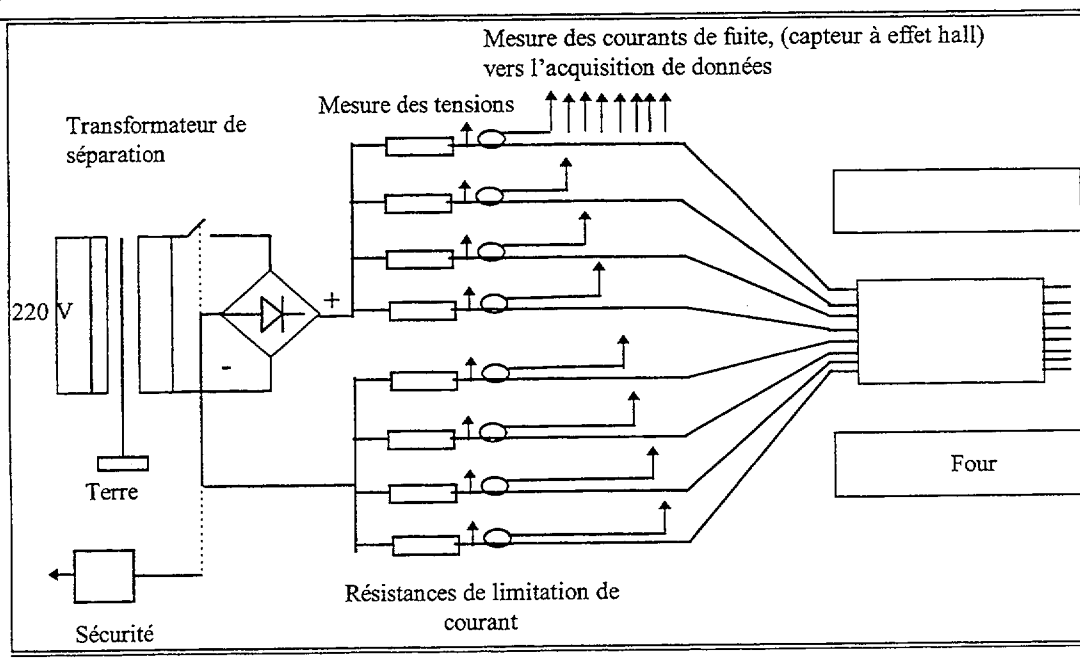
IPSN EXPERIMENTS



DES / SERS / SPI / BETSIE

June 19-20, 2000

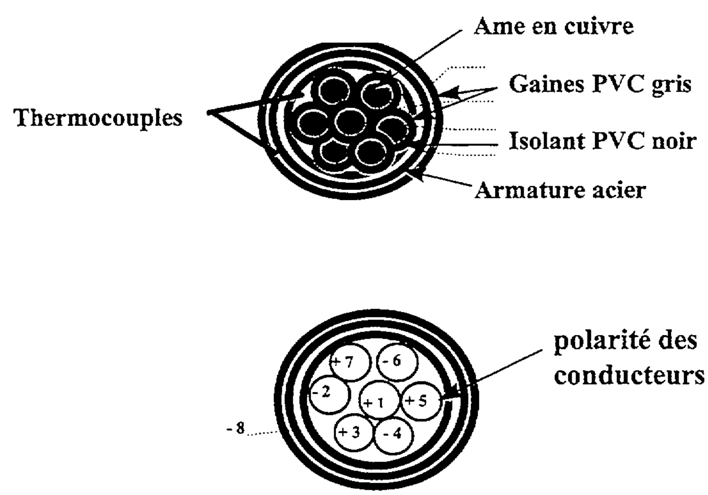
IPSN EXPERIMENTS



DES / SERS / SPI / BETSIE

June 19-20, 2000

IPSN EXPERIMENTS



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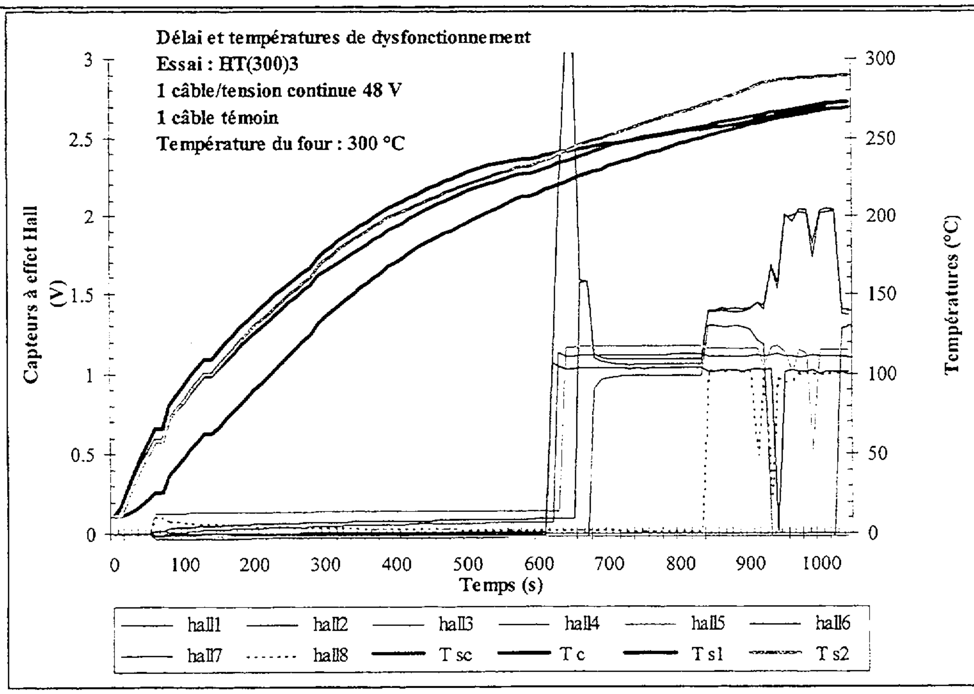
June 19-20, 2000

IPSN EXPERIMENTS

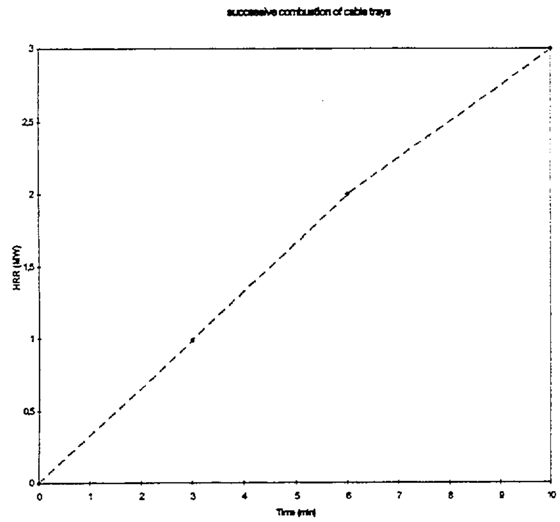


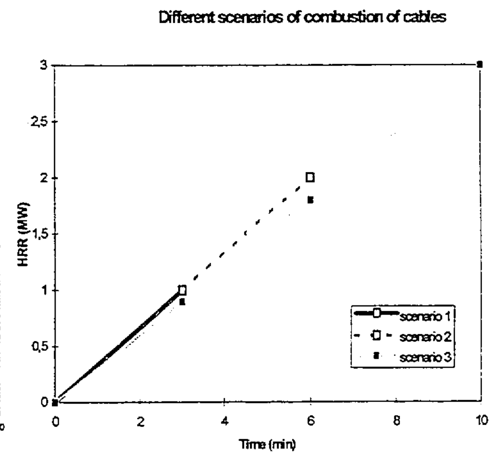
DES / SERS / SPI / BETSIE

June 19-20, 2000

Part II combustion scenarios

The description of fire scenarios has to be precised :





Assumption of a small opening

Interest of such a tiny crack ?

If it remains, it should be better to give a leakage rate

Needs for data

- Thermal exchange coefficient of gaz with boundaries (walls and ceiling)
- Thermal properties of boundaries (
- contraction coefficient (natural ventilation through the door)
- chemical reaction of cables and extinction threshold of O2
- location of the door (CFD codes)
- plume model (eventually)
- leakage rate or higher dimensions for the opening (!)

TU Braunschweig iBMB

Effects of Physical Sub-models and Design Fire in Zone Model Calculations

D. Hosser
J. Will

"International Collaborative Project to Evaluate Fire Models for Nuclear Power Plants Applications"
2nd Meeting

June 19 - 20, 2000
IPSN, Fontenay-aux-Roses

Contents

iBMB

- Introduction
- Plume models
- Design fire
  - Burning area
  - Standard problem part I
    - Acetone pool fire (1055 kW)
    - Door open (area 2.4 m × 2.4 m)
  - Effects of ventilation
- Conclusions

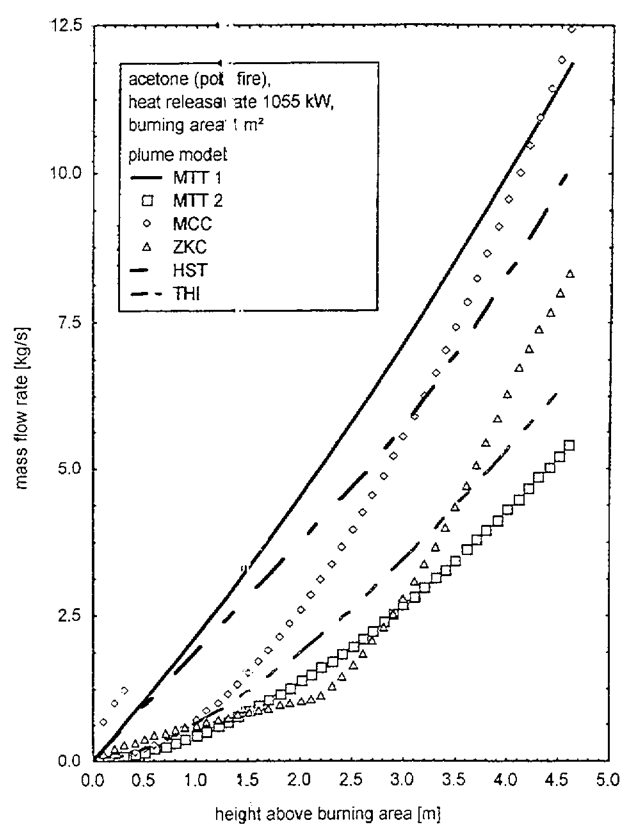
Plume models

iBMB

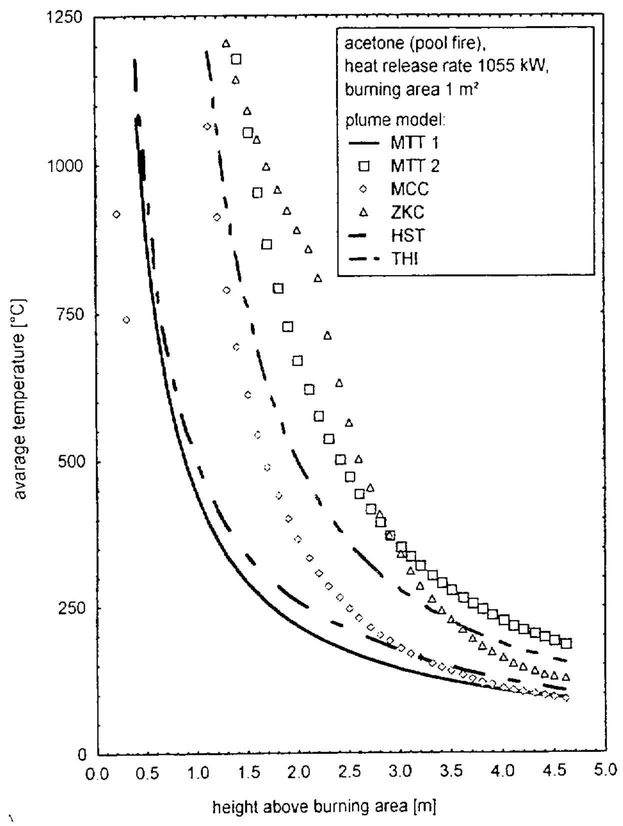
MTT1	Morton, Taylor, Turner: Turbulent Gravitational Convection from Maintained and Instantaneous Sources. Proceedings of the Royal Society of London, Vol 234, pp1-23, 1956
MTT2	same as MTT1, but virtuell point source
MCC	McCaffrey: Momentum Implications for Buoyant Diffusion Flames. Combustion and Flame, Vol 52, 149-167, 1983
ZKC	Cetegen, Kubota, Zukoski: Entrainment and Flame Geometry of Fire Plumes. PhD Thesis of Cetegan, 1982
HST	Heskestad: Engineering Equations for Fire Plumes. Fire Safety Journal, Vol 7, No 1, pp 25-32, 1984
THI	Hinkley: Building and Research Establishment BRE, Report No. 83/75, Borehamwood, 1975

Plume mass flow rate

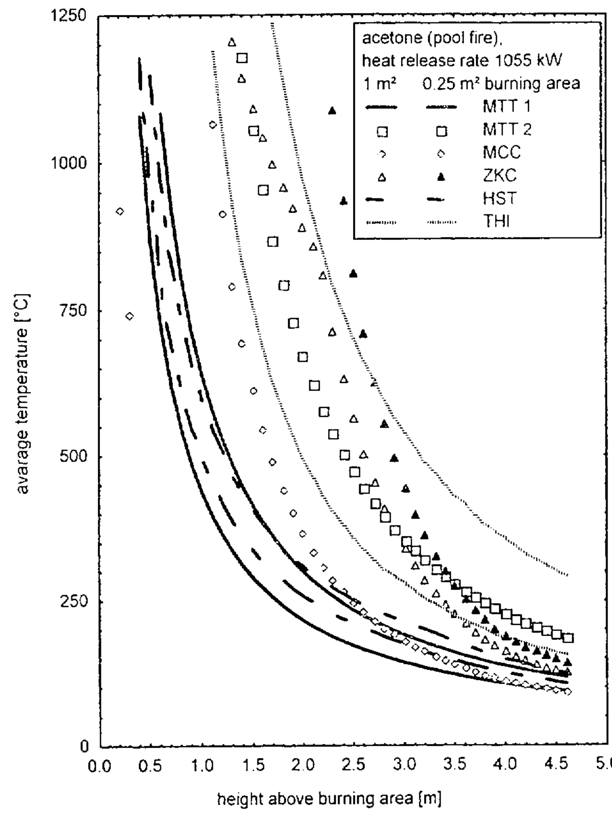
iBMB



Plume temperature



Effect of burning area



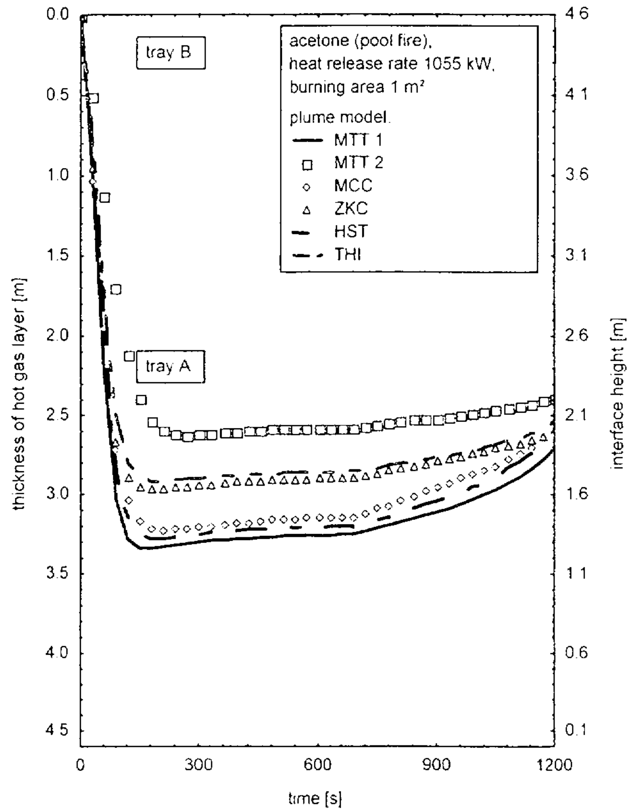
Effects

- MTT1-plume
  - High values of mass flow rate
- MTT2-plume
  - Low values of mass flow rate
- MCC-plume
  - Great height: Overestimation of mass flow rate
- ZKC-plume
- HST-plume
- THI-plume
  - Simple formular
  - No dependency on burning area

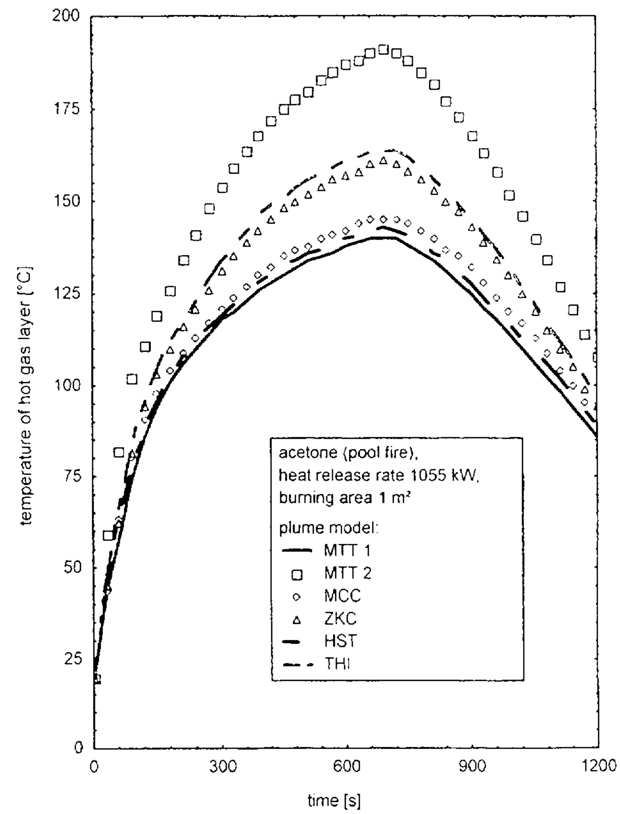
Standard problem

- Room
  - 15.2 m × 9.1 m area, 4.6 m height
  - Walls, floor and ceiling of concrete
  -
- Ventilation
  - 2.4 m × 2.4 m door
  -
- Fire
  - Acetone pool fire (1055 kW)

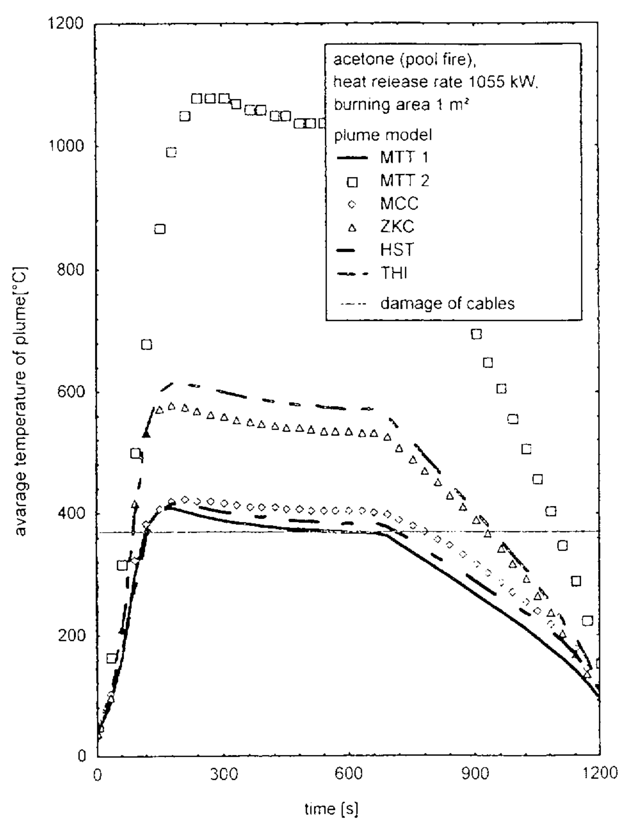
Layer thickness iBM



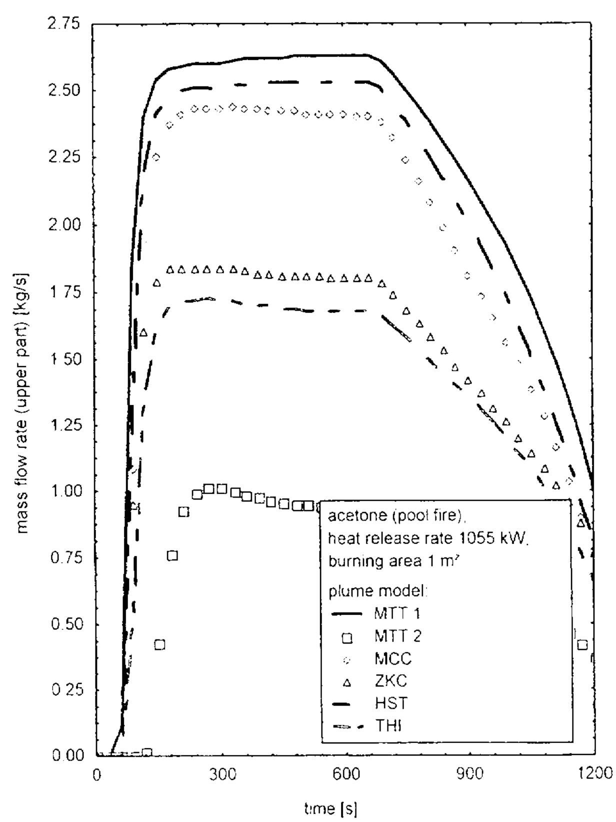
Layer temperature iBM



Temperature of plume iBM



Mass flow rate (upper) iBM



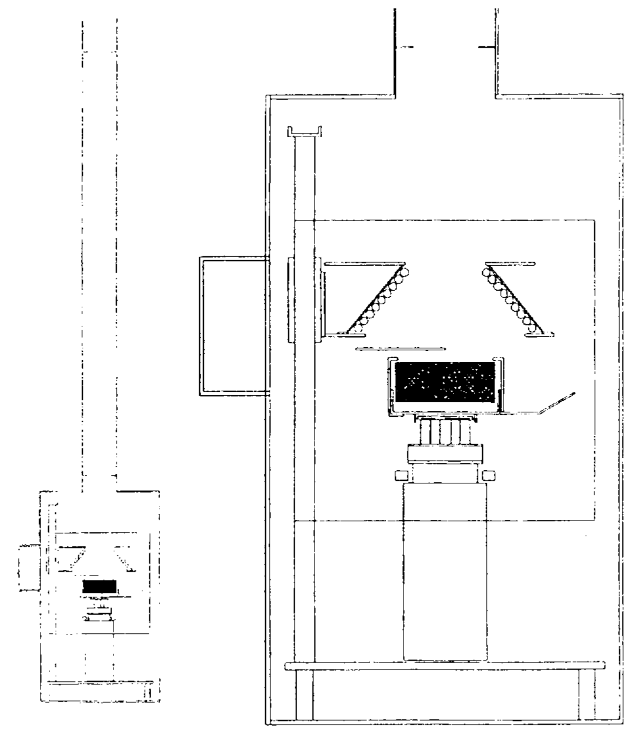
Results

iBM
B

- Layer thickness
  - 2.95 ± 0.35 m (24 % deviation)
  -
- Layer temperature
  - 148 ± 36 K (24 % deviation)
  -
- Plume temperature
  - 720 ± 295 K (40 % deviation)
  -
- Mass flow through door
  - 1.79 ± 0.83 kg/s (46 % deviation)
  -
-

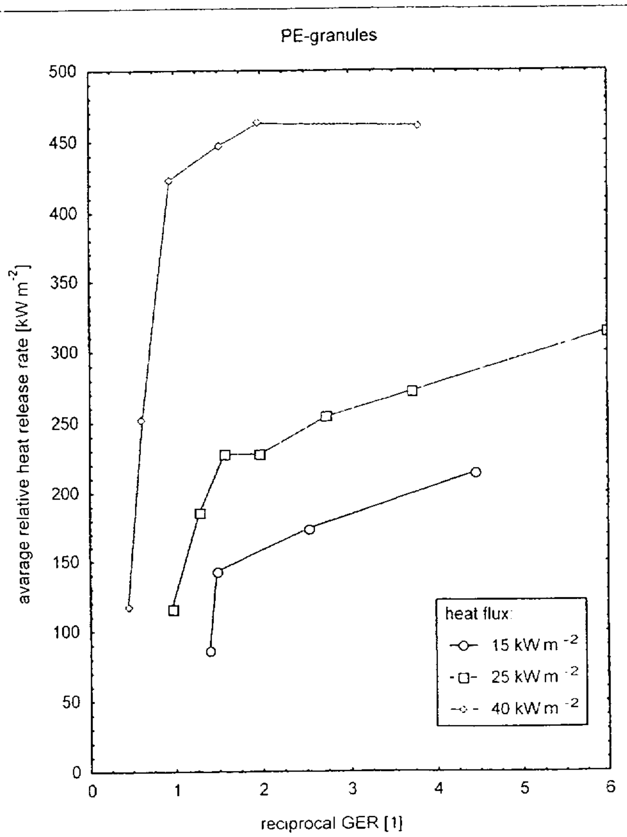
„Cone-Kammer“

iBM
B



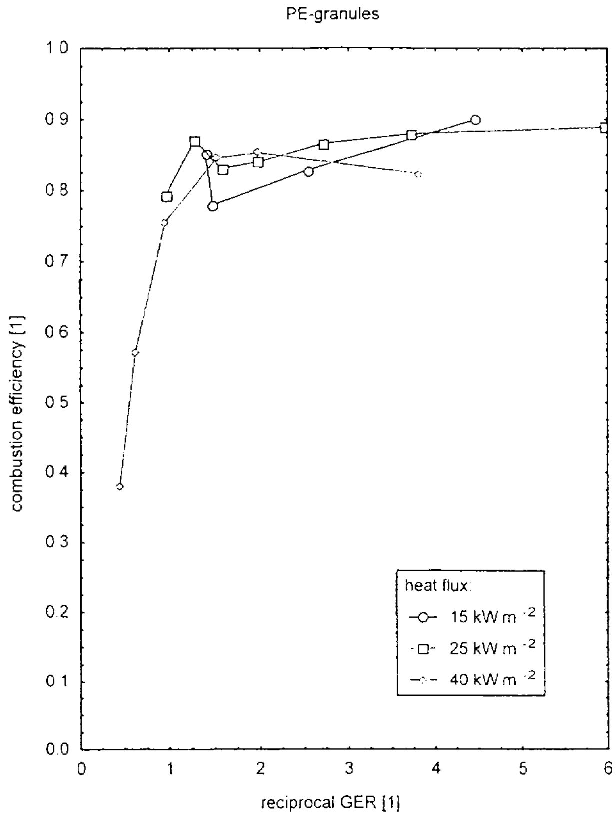
Heat release rate

iBM



Heat of combustion

iBM



Conclusions

iBM

B

- Strong effects of plume model
- Design fire defined by
  - Material properties
  - Geometry of fire load (area)
  - Location of fire load
  -
- Standard problem part 1
  - Bandwidth of significant results
  -
- Effects of ventilation
  - Heat release rate decreases
    - Combustion efficiency

      and
    - Mass loss rate
  - New attempt

Status of Fire Simulation with the GRS-Code COCOSYS

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)mbH

International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

IPSN, Fontenay-aux-Roses, June 19-20, 2000

W. Klein-Heßling (presented by B. Schwinges)

Contents

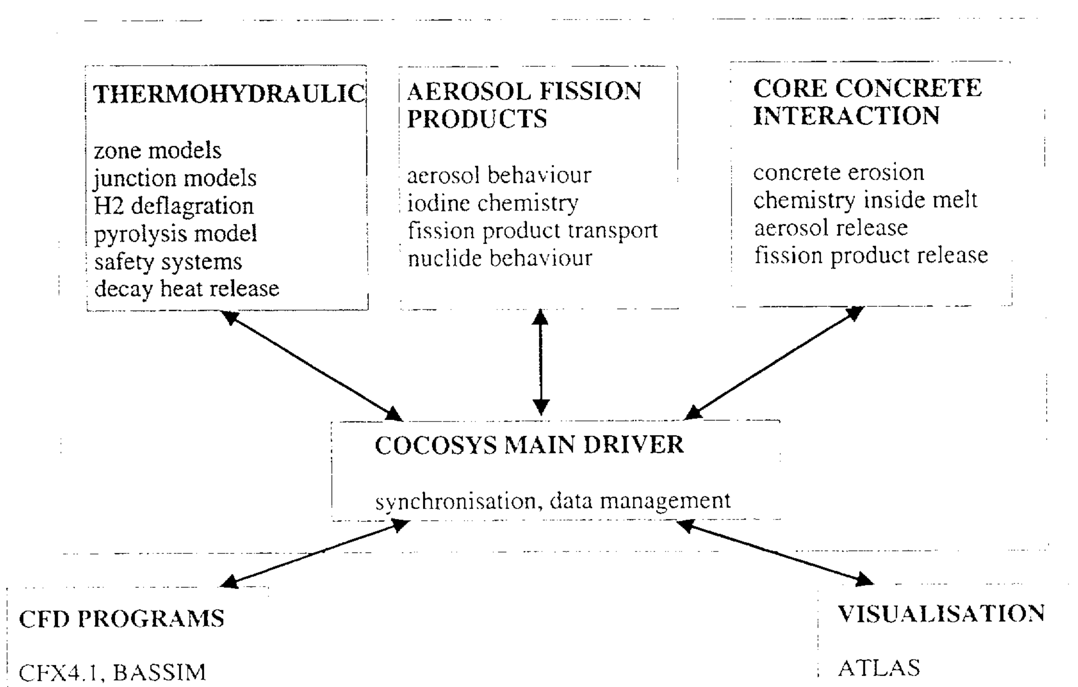
- Objective and Structure of COCOSYS
- Pyrolysis models in COCOSYS
  - oil and cable fire model
  - simple cable line model
- Validation on HDR 41.7 (oil fire)
- Application to a cable room of a VVER1000
- Outlook

Objective of COCOSYS

- Provision of a code system on the basis of mechanistic models for the comprehensive simulation of all relevant processes and plant states during severe accidents in the containment of light water reactors, also covering the design basis accidents

- Used for:
  - Identification of possible deficits in plant safety
  - Qualification of the safety reserves of the entire system
  - Assessment of damage - limiting or mitigating
  - Accident management (AM) measures
  - Safety evaluation of new plant concepts

Structure of COCOSYS

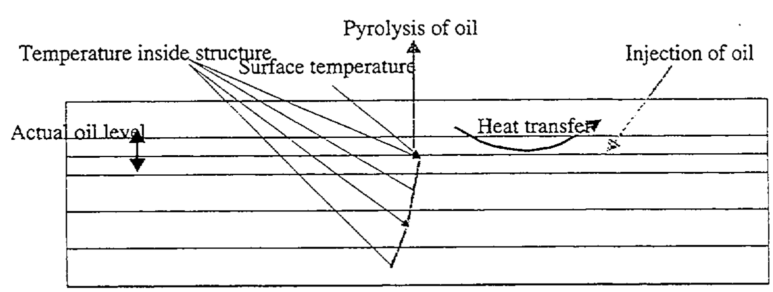


Structure of COCOSYS (cont.)

- Main modules (THY, AFP, CCI) are separate processes
- Independent main driver
- Use PVM (parallel virtual machine) for communication
- Coupling to other CFD codes possible
- Good basis for parallelisation
- On- and offline connection to visualisation tool ATLAS possible

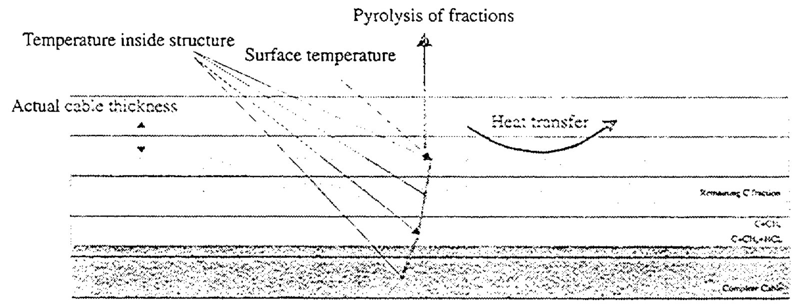
Pyrolysis models in COCOSYS

- Based on models of CRDLOC
- Pyrolysis model for oil fires
  - Oil pool subdivided into several layers (temperature nodes)
  - Calculate surface temperature by spline interpolation
  - Variable oil level in fixed temperature grid can be calculated
  - Use of diffusion like equation for calculation of release rates CH_x, H, HCL



Pyrolysis models in COCOSYS (cont.)

- Pyrolysis model for cable fires
  - Similar to oil fire model
  - Using fractions H, HCL, CH_X, C
- Combustion of CH_x fractions
  - According to pyrolysis rate or using mixing factor
  - Consideration of oxygen content
- Combustion of CO $\rightarrow$ CO_2
  - regarding oxygen content
  - using Boudoir equilibrium
- Combustion of H together with CH_X



Simple cable tray burning model

- Pyrolysis rate:

$$\dot{r}_+ = \begin{cases} r_{f+} \cdot bd_0 + r_{f+} \cdot bv_+ t & 0 \le t < t_{a+} \\ r_{f+} \cdot b(l - l_0) & t_{a+} \le t < t_{e+} \\ 0 & t > t_{e+} \end{cases}$$

mit

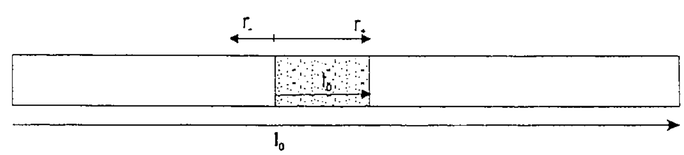
r_{f+} specific burning rate $\left[\frac{kg}{m^2 s}\right]$

b width of try$[m]$

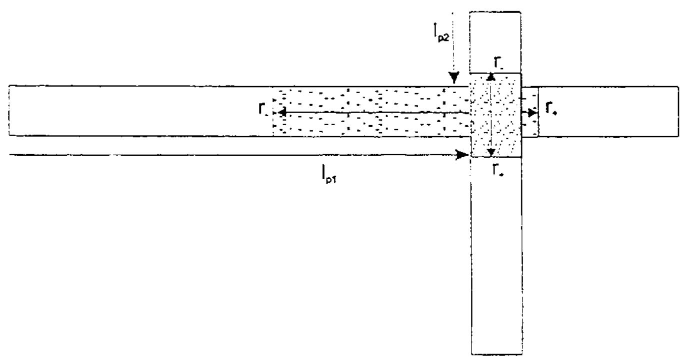
d_o "initial length"

v_+ propagation velocity $\left[\frac{m}{s}\right]$

- Ignition by
  - Signals (ignition sources)
  - Propagation
  - Hot zone temperatures



Propagation along cable trays

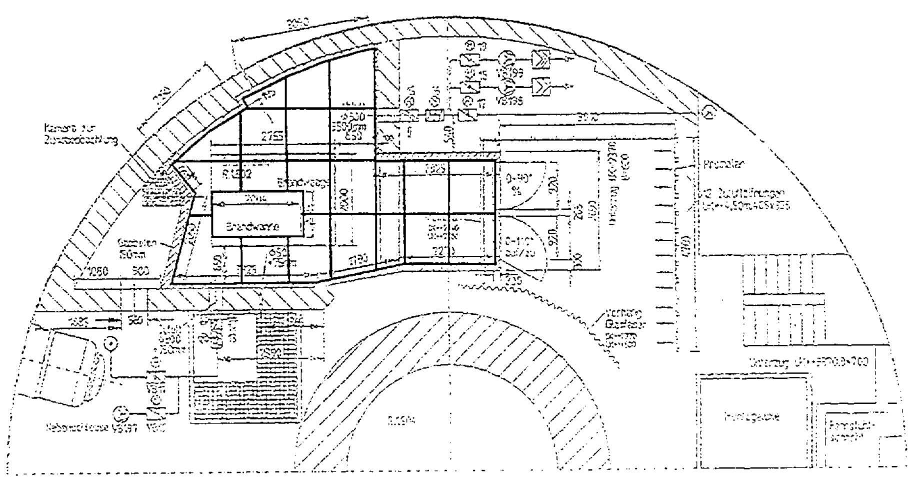


Validation of model on HDR E41.7 Experiment

- HDR E41.7 : oil fire experiment in room 1502
  - Initially 40l of oil
  - Using fan systems (vented conditions)
  - Using variable openings (doors)
- Use of a detailed nodalisation
  - 211 zones (82 zones for burning room)
  - 456 junctions
  - 371 structures

Validation of model on HDR E41.7 Experiment (cont.)

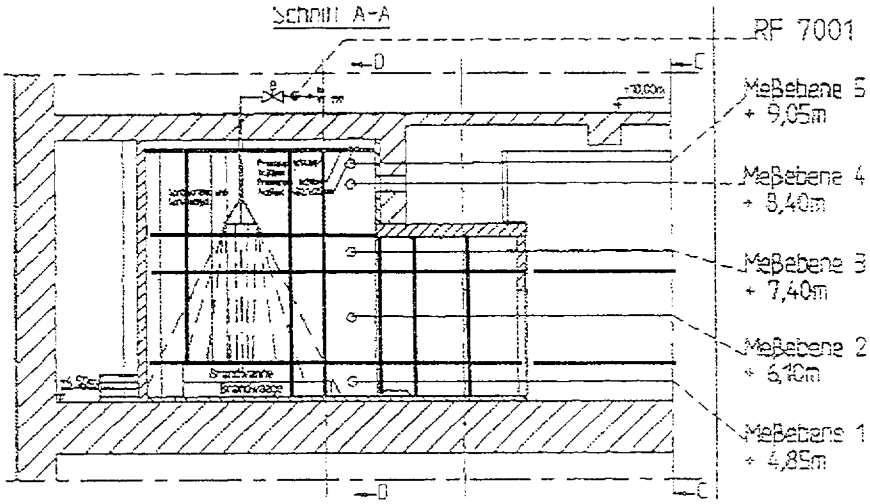
- Nodalisation of the fire compartment (top view)



GRS

Validation of model on HDR E41.7 Experiment (cont.)

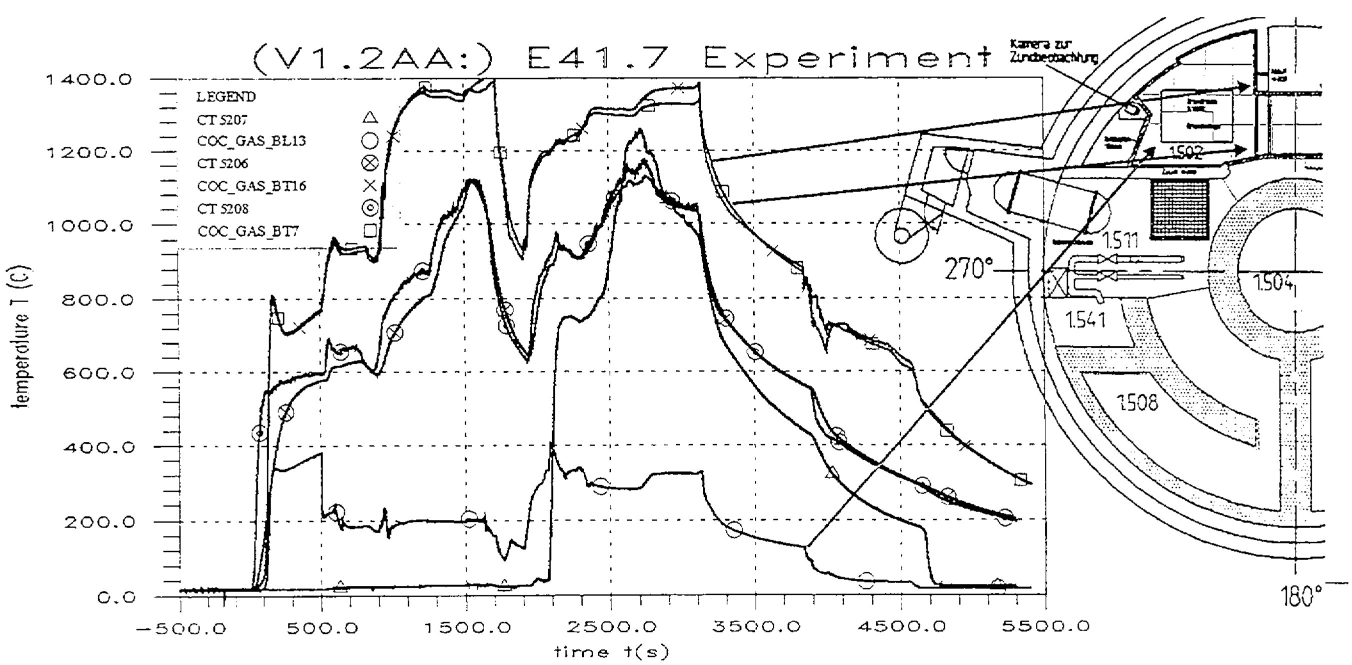
- Nodalisation of the fire compartment (side view)



GRS

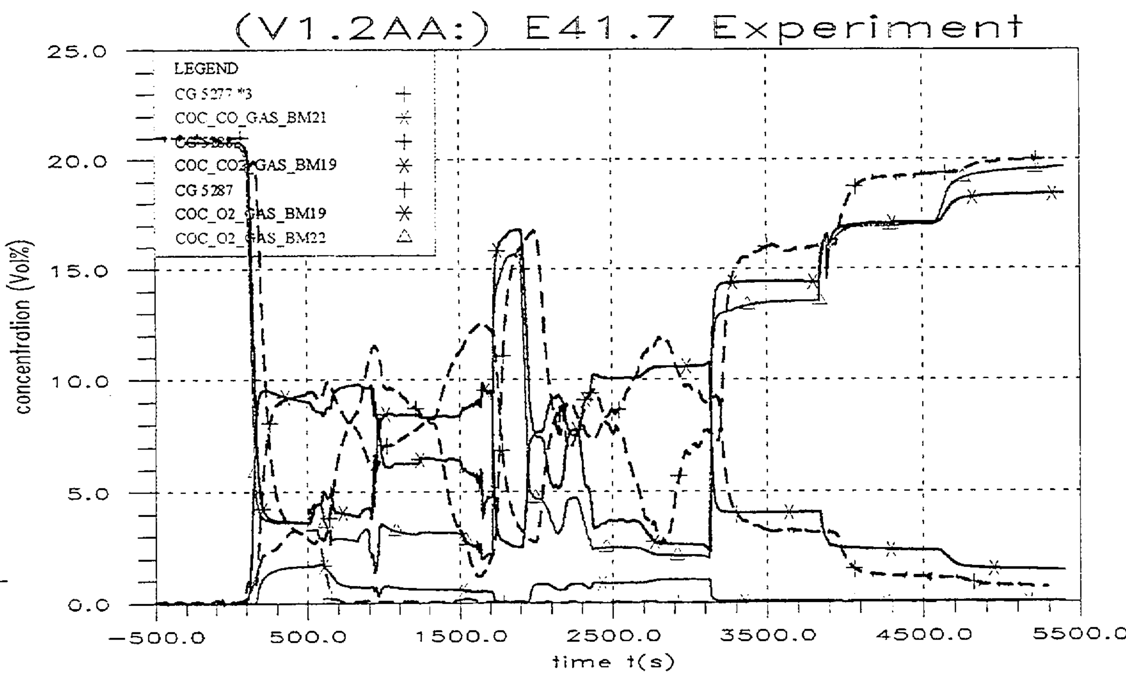
Validation of model on HDR E41.7 Experiment (cont.)

- Temperatures in the fire compartment

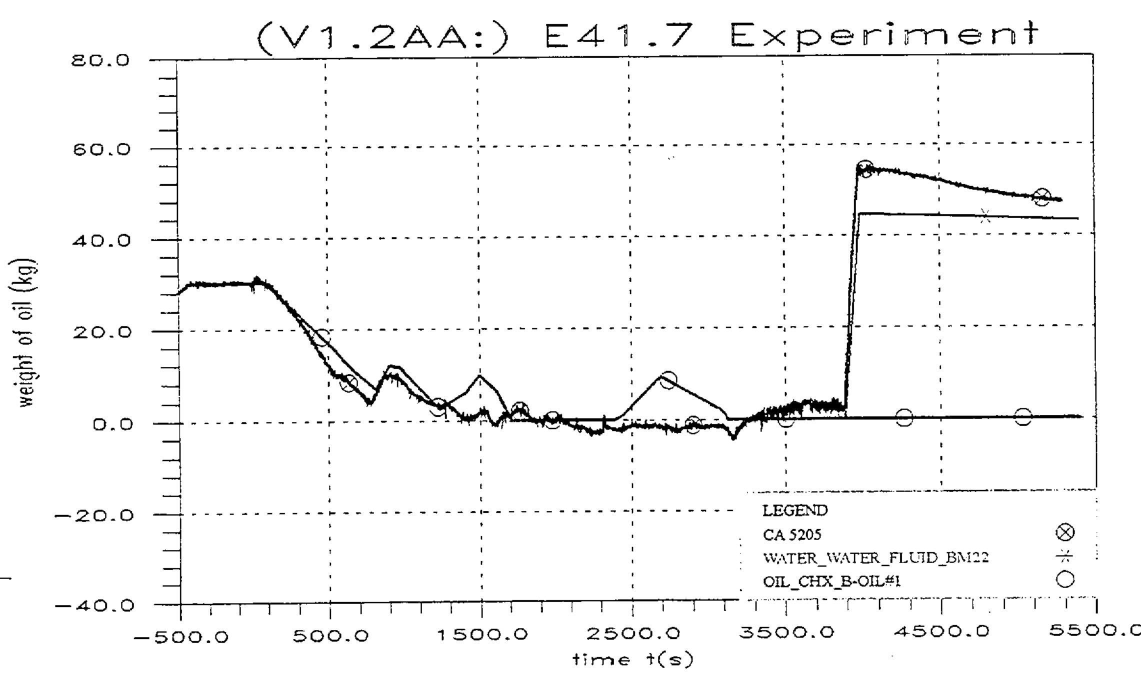


Validation of model on HDR E41.7 Experiment (cont.)

- Concentrations (O_2, CO, CO_2 in front of the doors)

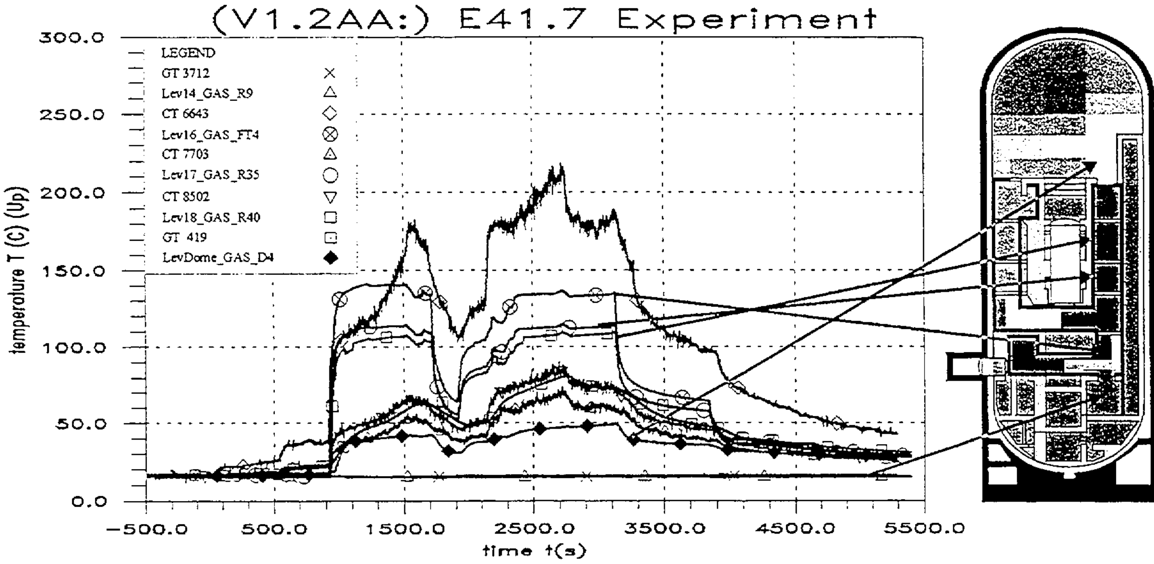


- Mass of oil (and spray water)



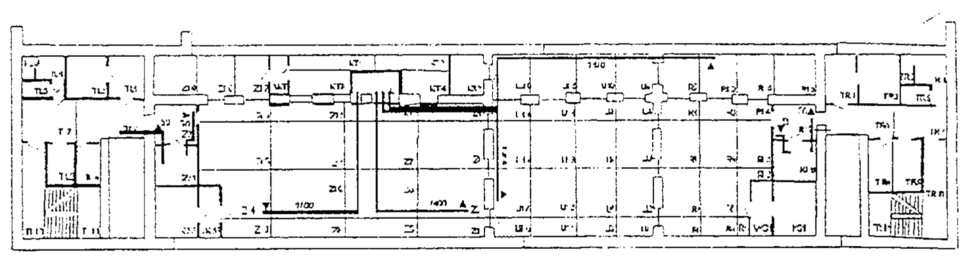
Validation of model on HDR E41.7 Experiment (cont.)

- Temperatures in the staircase (90°)

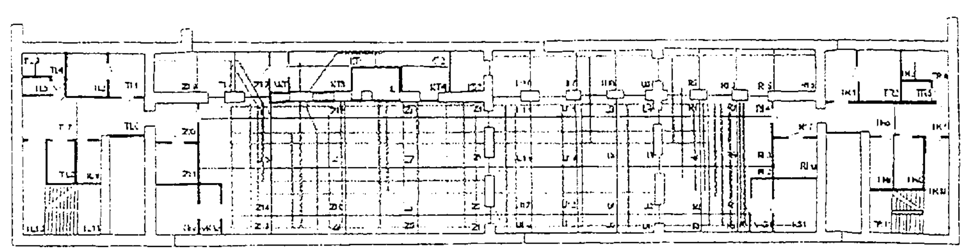


Application to a cable room of a VVER 1000

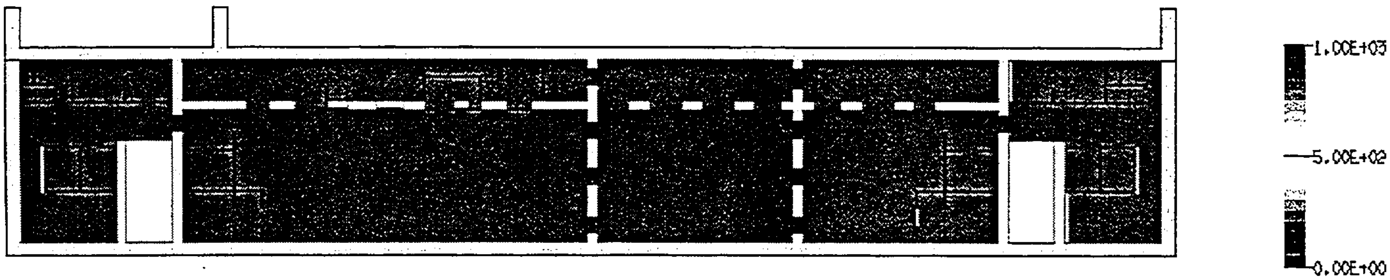
- Nodalisation
  - 409 zones
  - 910 junctions
  - 732 structures
  - 407 cable tray segments



- Conservative scenario
  - all fire doors open open
  - no fan system
  - no spray system
  - no cable protection
  - old cables



Application to a VVER1000 cable room : Temperatures



Outlook

- Further developments on the cable fire model
  - Propagation models
  - Chemical behaviour
  - Radiation from flame
- Perform more validation
- Extension of zone model
  - Separation of hot gas layer (two zone parts)
  - Coupling to hydrogen deflagration model

GERMAN PROPOSALS AND COMMENTS FOR STANDARD PROBLEM EXERCISE

M. Roewekamp, W. Klein-Hessling

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

J. Will

iBMB, Braunschweig University of Technology

2nd Meeting of "International Collaborative Project to Evaluate Fire Models for NPP Applications"

IPSN, Fontenay-aux-roses, June 19-20, 2000

CONTENTS

GENERAL REMARKS (1)

- **The standard problem is not a standard problem but a benchmark (no comparison with experimental data)**
- **The benchmark goals are clearly explained:**
  - Simple problem
  - Problem defined in sufficient detail
  - Evaluation of model adequacy and capabilities with respect to the given problem
- **The given scenario is representative with respect to:**
  - Fire compartment geometry
  - Fire compartment inventory

GENERAL REMARKS (2)

- **The fire protection features mentioned are representative for influencing the fire event sequence**
- **The selected ventilation conditions are not the best for a first evaluation approach**
  - Ventilation controlled fire in case of door closed
  - Assessment difficulties because of significant model differences for ventilation controlled fire

COMMENTS AND PROPOSALS (1)

Background

- **Fire simulation codes alone are not able to predict the target damage time of structures and components ⇨**
- **The failure modes of the structures / components have to be defined, e.g.:**
  - Loss of stability by thermal loading
  - Fire containment failure (release of hot gases, exceeding critical temperatures outside fire compartment)
  - Passage of radiation (via doors etc.)
  - Loss of smoke tightness
- **Need for additional calculations and assumptions**

COMMENTS AND PROPOSALS (2)

Discussion

- **A comparative list also assessing the adequacy of the physical sub-models implemented in the codes for modeling the physical phenomena is needed as a basic document for future collaboration**
- **Simulation results have to be compared taking into consideration:**
  - Different codes
  - Different types of analysts (code developer, code applicants)
  - Adequacy of modeling physical phenomena
- **A comparison with data from realistic NPP specific experiments does not seem to be possible within the first step of this project but has already been done in the frame of HDR-experiments**

COMMENTS AND PROPOSALS (3)

Procedure

- **It is essential for the blind simulations to determine in advance those output values/ parameters to be compared and discussed**
- **To meet the goals of the collaborative effort and to guarantee success in evaluating fire models for NPP applications, there is a need for two types of analysts to use the same codes to find out deficiencies:**
  - Code developers as well as
  - Codes applicants (pure users)
- **To improve efficiency, the first standard problem should be discussed and the results assessed in detail before starting the series of further standard problems**

COMMENTS AND PROPOSALS (4)

Definition (1)

Room Size and Geometry

- **The door position has to be defined**
- **The thickness of walls, floor and ceiling is needed**
- **There is a need for more information on position, length, cross-section, type and number of cables**
- **Type (material values, etc.), amount and detailed dimensions of the cable tray support structures have to be given**
- **Size and exact location of the acetone pool on the floor under the cable train are needed**
- **It has to be considered that not all zone models are able to give results if there are no openings to the outside (fire dampers, doors closed, mechanical ventilation off)**

COMMENTS AND PROPOSALS (5)

Definition (2)

Analyses

- The objective of Part I is not completely coincident with the goals of multi-compartment zone models
- Part I requires plume models for estimation of the convective and/or radiative heat flux density at cable tray A for a given ignition source ⇒ such plume calculations can be done manually without codes
- For Part II there are the following questions:
  - Heat release rates of 1MW / 2 MW / 3 MW *per* cable tray?
  - Is there a constant heat release rate after 3 / 6 / 10 min?
  - Is there no fire propagation along the cable tray, which means the heat source is a point source?

  ⇒ more detailed description of the fire model

COMMENTS AND PROPOSALS (6)

Definition (3)

Thermophysical Data

- The material properties (heat conductivity λ, density ρ) and thickness of the fire compartment boundaries are needed
- The emissivity is necessary for some models, others need information on the heat transport coefficient [$Wm^{-2}K^{-1}$]

COMMENTS AND PROPOSALS (7)

Definition (4)

Input Data for Part I

- The floor area / diameter of the acetone pool has to be given to apply different plume models
- The physical properties (heat conductivity λ, density ρ and c_p) and thickness of the fire door are needed
- The chemical properties of the cables (C, Cl, O, H amounts) the necessary amount of oxygen and the yields of CO, CO_2, H_2O vapor and soot should be given

COMMENTS AND PROPOSALS (8)

Definition (5)

Input Data for Part II – Heat Release Rates

- Up to now, there is no validated zone model known for the prediction of a burning cable heat release rate
- Field models may partly have the difficulty to simulate plume which can be calculated by empirical equations and has been verified experimentally
- Cable fires can be defined by design fires via the energy release rate and/or burning rate considering material characteristics (e.g. effective heat of combustion, production of CO, CO_2, smoke, etc.) given in more detail by the recent German cable fire tests

COMMENTS AND PROPOSALS (9)

Definition (6)

Input Data for Part II – Geometry

- **It is really difficult to assess horizontal dependencies by means of zone models**

Input Data for Part II – Thermophysical Data for Cables

- **Several parameters have to be added in the table, such as**
  - Type and chemical properties of the cable insulation material
  - Ignition and pyrolysis temperature
  - Effective heat of combustion

COMMENTS AND PROPOSALS (10)

Definition (7)

Input Data for Part II – Variation of Parameters

- **It has to be mentioned again that it is not easy to analyse the horizontal assignment of objects**
- **Analysing vertical effects by zone models, subtly diversified statements can only be given within the plume; outside the plume it is only possible to differentiate between hot gas layer and cold gas layer**

Assumption of Small Opening

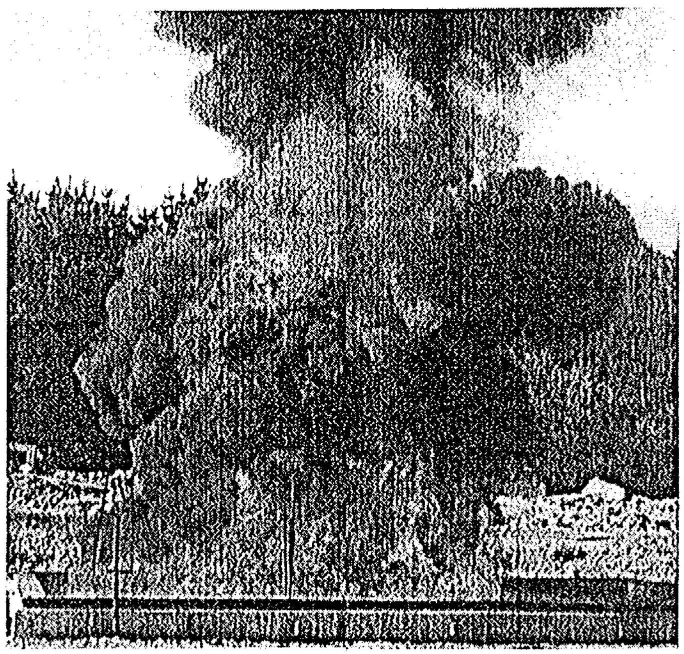
- **Even in case of a tiny crack for the case of the fire door closed the fire will be ventilation controlled resulting in stronger differences between the different code types**

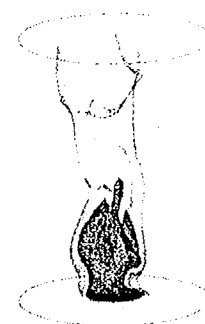
PROPOSALS FOR CONTINUATION

- **Completion of the information needed for the first benchmark problem**
- **Common definition of the output parameters for comparison**
- **Need for additional definitions and calculations with respect to failure modes and damage conditions of targets including a clear definition of the target damage time for the selected first benchmark problem**

USE OF CFX FOR BENCHMARK PROBLEM

- Considering
  - Radiation
  - Combustion
- Example of pool fire





from Yehuda Sinai, AEA Technology, CFX Update No18, Autumn 1999

Proposals and Comments for Standard Problem Excercise

O. Keski-Rahkonen

VTT Building Technology

RHR

- **How was the RHR estimated?**
- **Did you use real experimental data to estimate it?**

LOI

- Oxygen consumed
  - 1 MW 18 min
  - 2 MW 9 min
  - 3 MW 6 min
  -
- Value of LOI should be defined as input

VTT Building Technology

Door crack

- Leakage in a crack might create high velocities
- Is it necessary to have such a tiny leak
- I am afraid, the door floe approximations of most of the codes do not account for that
- Recommend using a 5 mm gap

Flame spread

- In the realistic scenario speed of flame spread would be the most significat input variable
- I do not know any program with good enough algorithm on flame spread on cables
- Do such exist?
- I know several serious attempts, but the succes is not yet convincing

Flame spread 2

- At the moment complicated codes are not better for flame spread than simple codes
- We have tried somewhat all from hand calculations to LES simulations
- Different parts of flame spread are emerging
- Very little relevant data is available for evaluating calculation codes
- We could start producing such data and speed up the developing

Input data

- Specify relevant variables on concrete
  - Thickness: 150 mm?
  - Density kg/m^3 ?
  - Thermal conductivity W/Km ?
- Cable tray dimensions
- Door location dimensions
- Ventilation opening dimensions

VTT Building Technology

SI units

- P. 3: Specific heat capacity 1000 J/kgK
- Heat of combustion 28.6 MJ/kg
- P. 4: Specific heat capacity 1040 J/kgK
- Heat conductivity 0.092 W/Km
- SI units compulsory when delivering calculation results

TU Braunschweig
iBMB

Effects of Physical Sub-models and Design Fire in Zone Model Calculations

D. Hosser

J. Will

"International Collaborative Project to Evaluate Fire Models for Nuclear Power Plants Applications"

2nd Meeting

June 19 - 20, 2000

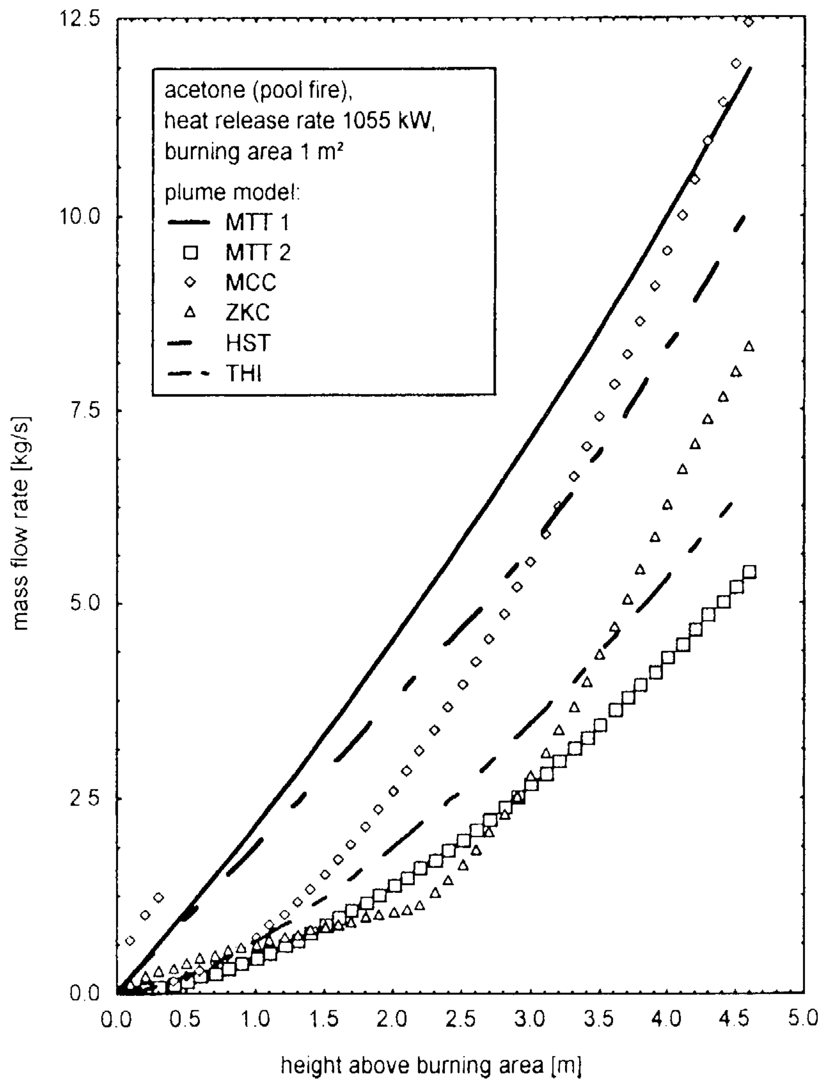
IPSN, Fontenay-aux-Roses

C-57

Contents

iBMB

Plume mass flow rate **iBM**



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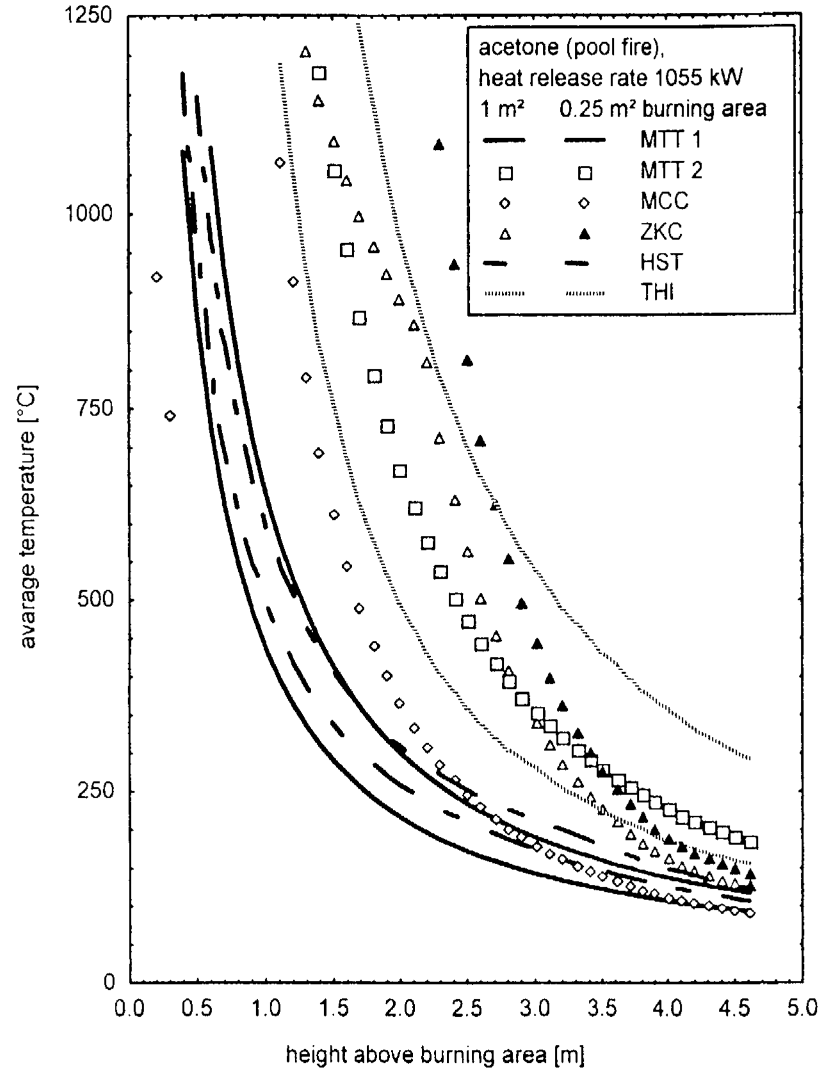
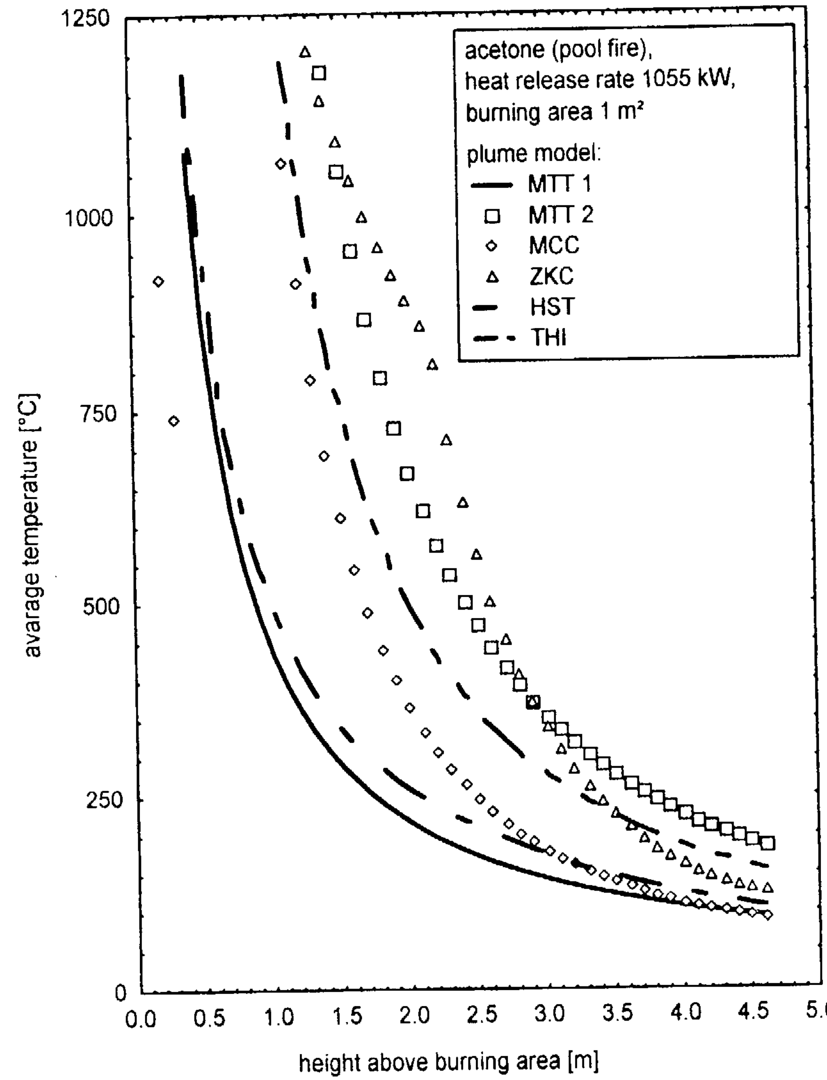
Plume models **iBM B**

MTT1	Morton, Taylor, Turner: Turbulent Gravitational Convection from Maintained and Instantaneous Sources. Proceedings of the Royal Society of London, Vol 234, pp1-23, 1956
MTT2	same as MTT1, but virtuell point source
MCC	McCaffrey: Momentum Implications for Buoyant Diffusion Flames. Combustion and Flame, Vol 52, 149-167, 1983
ZKC	Cetegen, Kubota, Zukoski: Entrainment and Flame Geometry of Fire Plumes. PhD Thesis of Cetegan, 1982
HST	Heskestad: Engineering Equations for Fire Plumes. Fire Safety Journal, Vol 7, No 1, pp 25-32, 1984
THI	Hinkley: Building and Research Establishment BRE, Report No. 83/75, Borehamwood, 1975

Effect of burning area iBM



Plume temperature iBM



Standard problem

iBMB

- Room
  - 15.2 m × 9.1 m area, 4.6 m height
  - Walls, floor and ceiling of concrete
  -
- Ventilation
  - 2.4 m × 2.4 m door
  -
- Fire
  - Acetone pool fire (1055 kW)

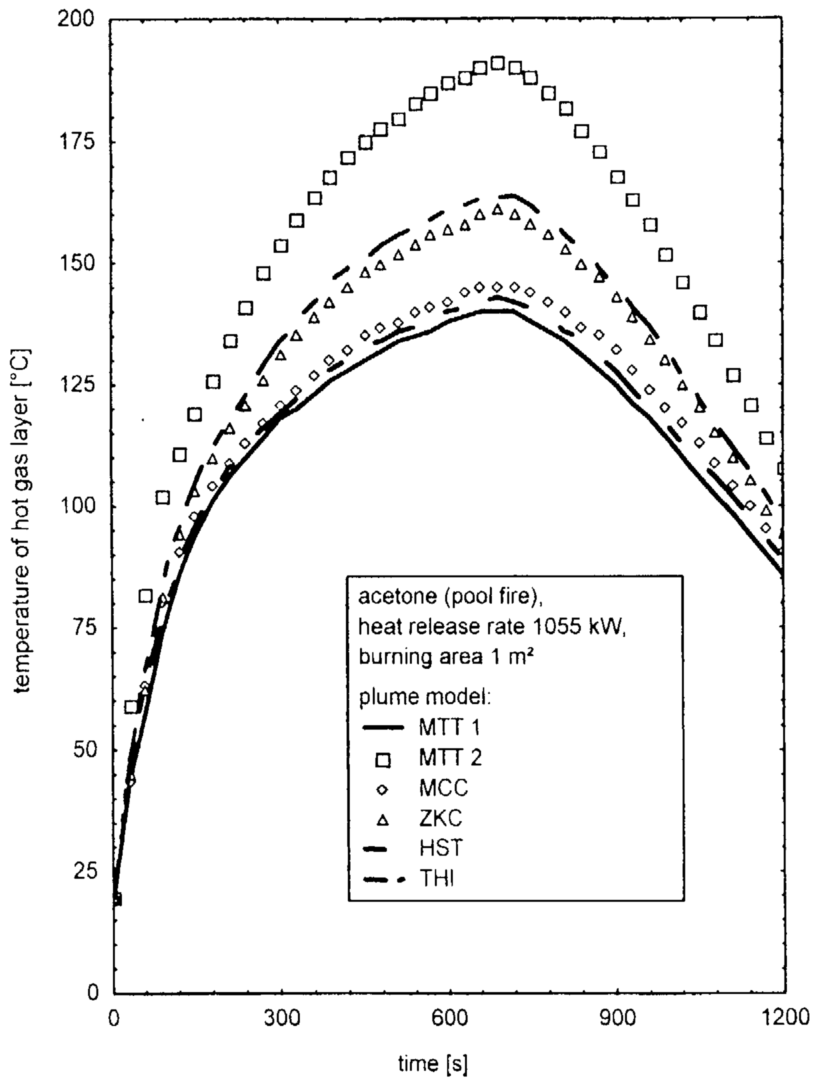
Effects

iBMB

- MTT1-plume
  - High values of mass flow rate
- MTT2-plume
  - Low values of mass flow rate
- MCC-plume
  - Great height: Overestimation of mass flow rate
- ZKC-plume
- HST-plume
- THI-plume
  - Simple formular
  - No dependency on burning area

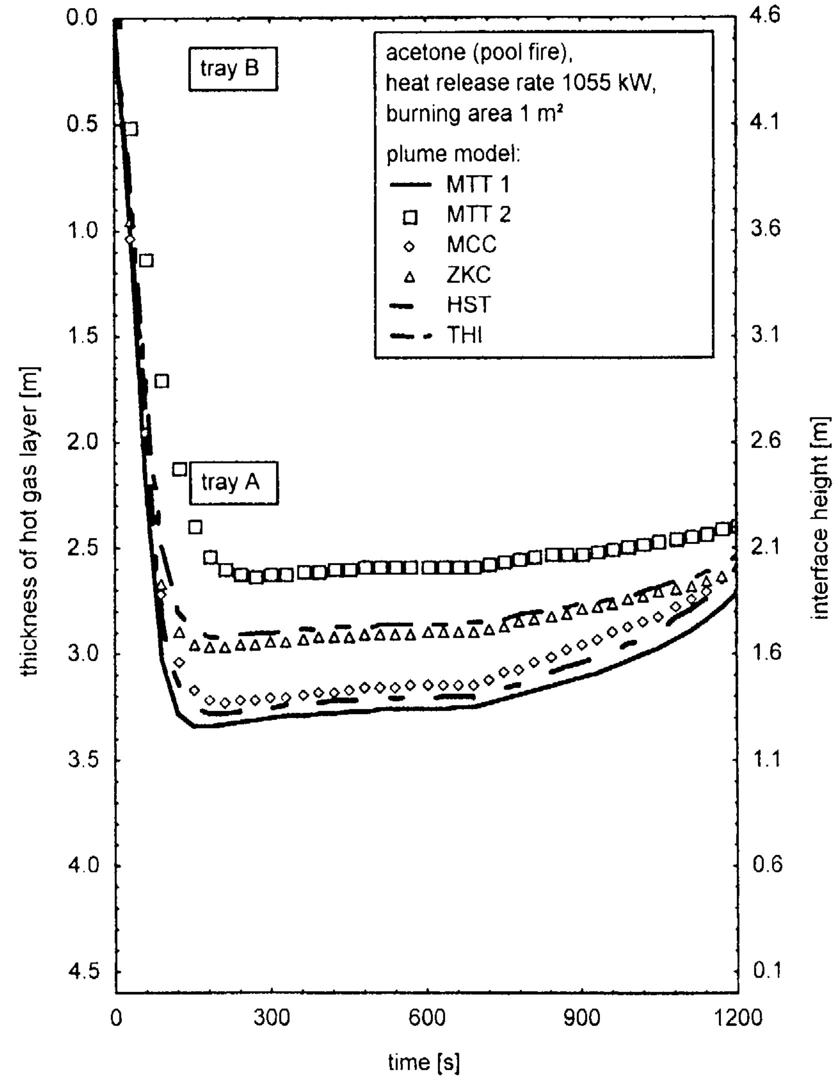
Layer temperature

iBM

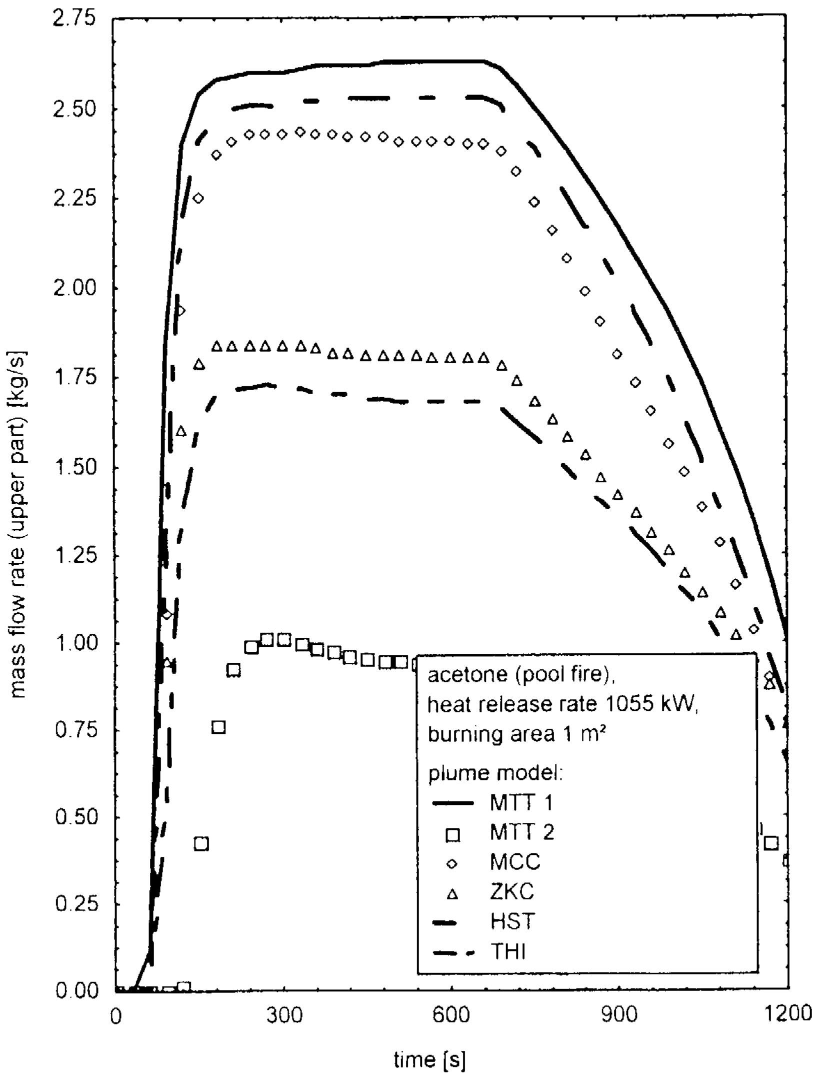


Layer thickness

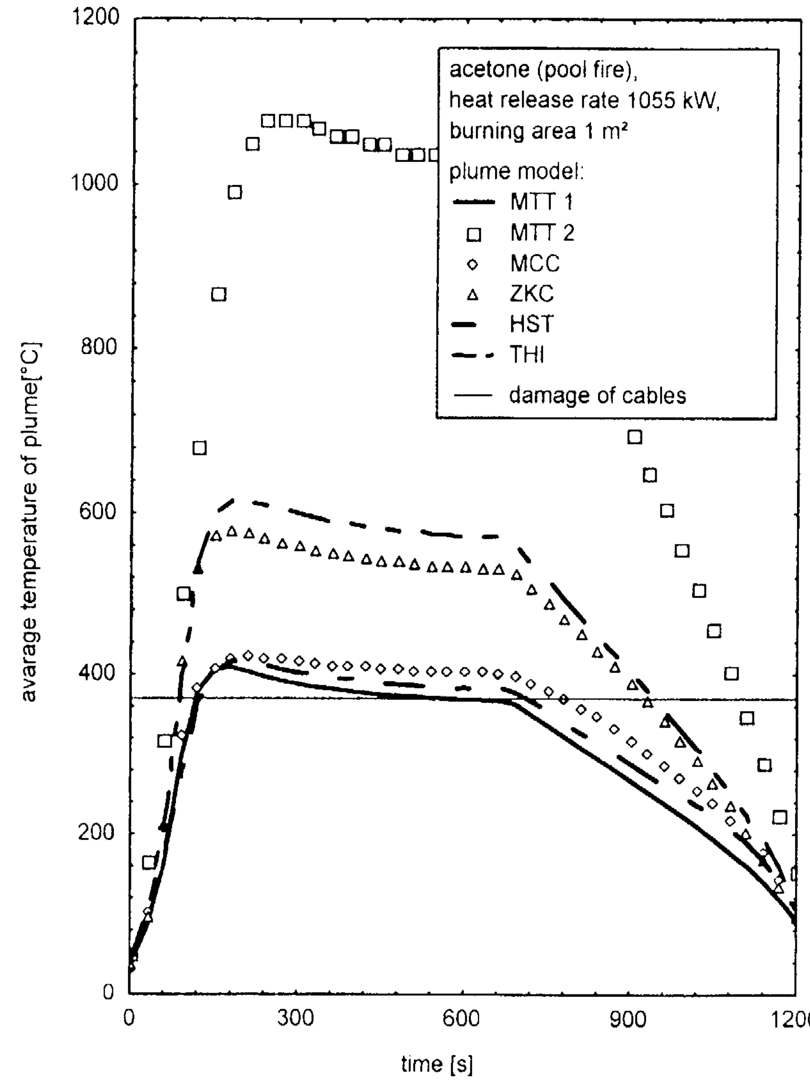
iBM



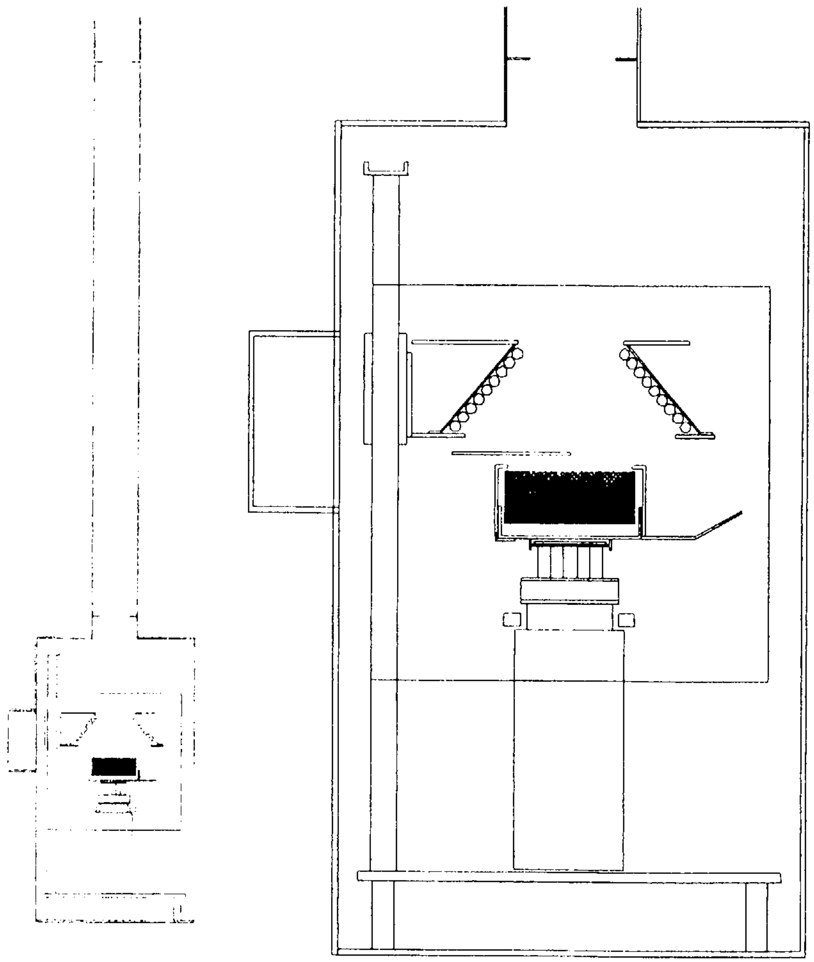
Mass flow rate (upper) iBM



Temperature of plume iBM



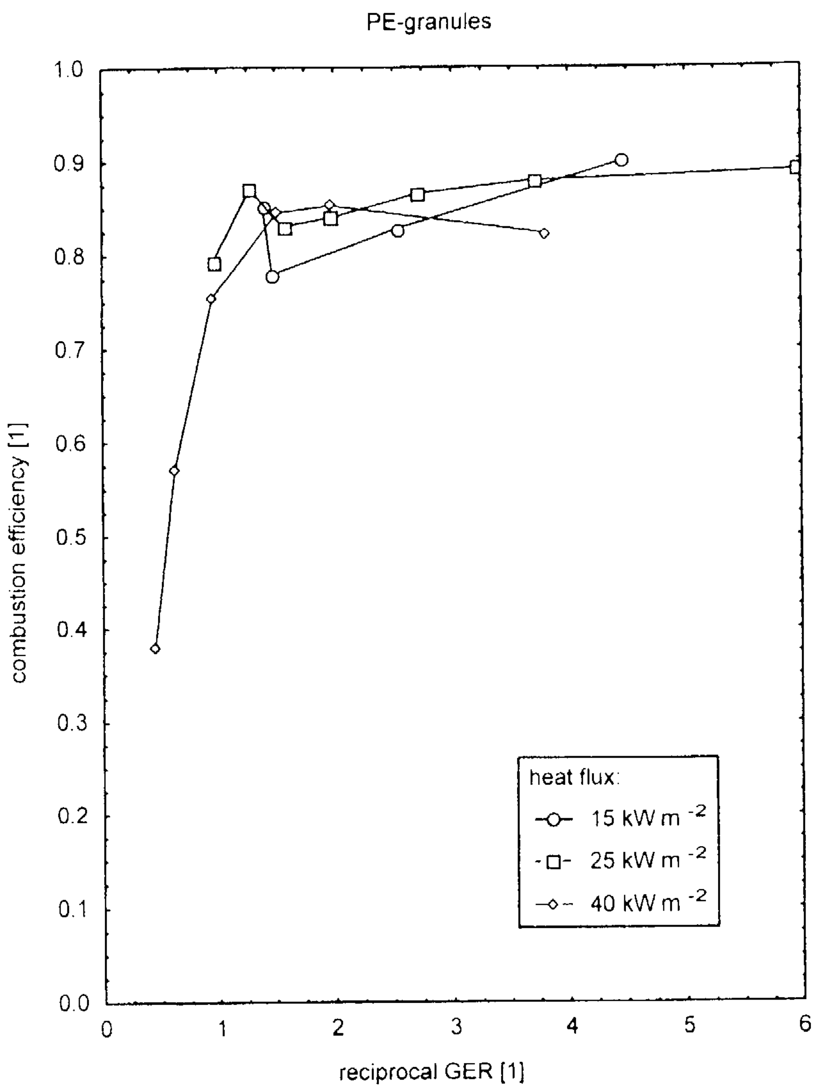
„Cone-Kammer“ iBM B



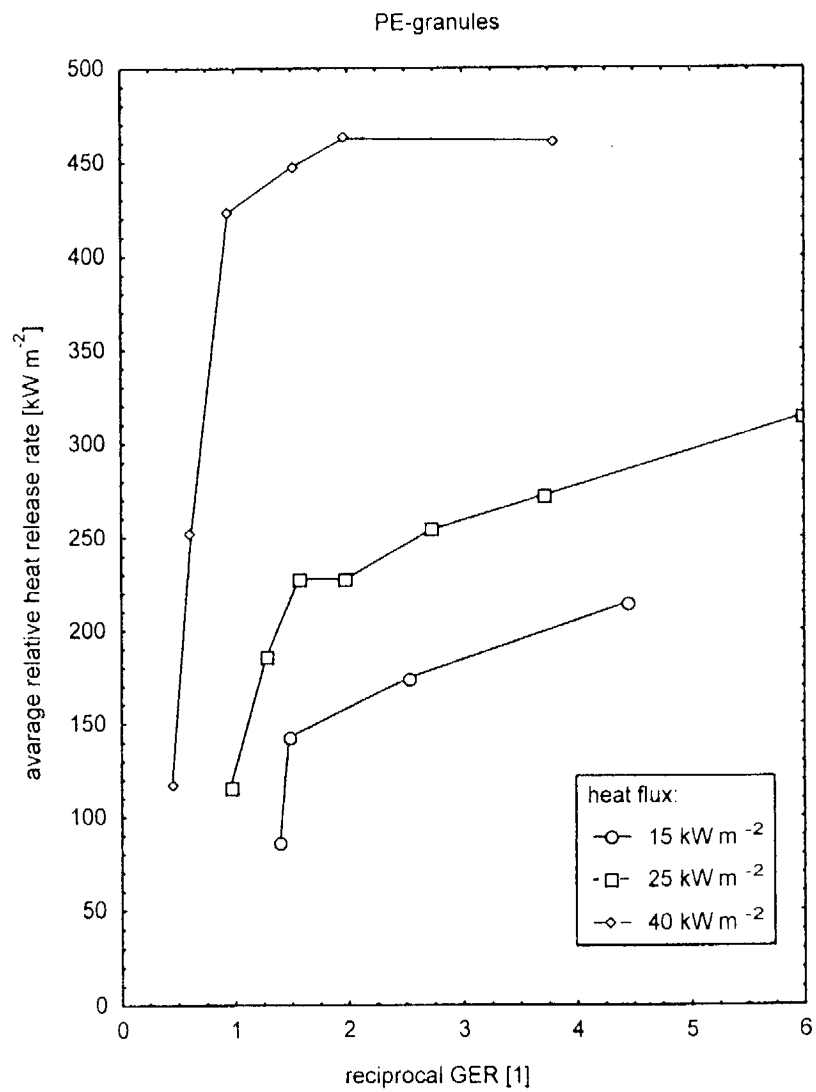
Results iBM B

- Layer thickness
  - 2.95 ± 0.35 m (24 % deviation)
- Layer temperature
  - 148 ± 36 K (24 % deviation)
- Plume temperature
  - 720 ± 295 K (40 % deviation)
- Mass flow through door
  - 1.79 ± 0.83 kg/s (46 % deviation)

Heat of combustion iBM



Heat release rate iBM



Conclusions

iBMB

- Strong effects of plume model
- Design fire defined by
  - Material properties
  - Geometry of fire load (area)
  - Location of fire load
  -
- Standard problem part 1
  - Bandwidth of significant results
  -
- Effects of ventilation
  - Heat release rate decreases
    - Combustion efficiency

      and
    - Mass loss rate
  - New attempt

Attachment D: View Graphs Used to Present Fire Modeling Research in National Programs

PEPSI 1 experiment

Jean-Marc SUCH
IPSN / DRS /SESHP
INSTITUT DE PROTECTION ET DE SURETE NUCLEAIRE
Department of Safety Research
Out of Pile Safety Experiments Sub-department

CONTENTS

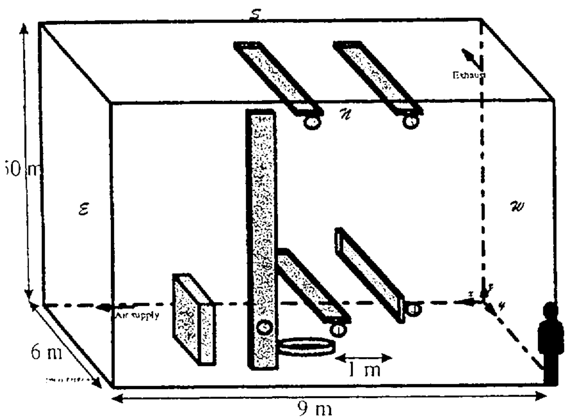
FAR, June 2000
IPSN meeting

PEPSI 1 : Main objectives

- Asked by IPSN/DES, this experiment was performed to study the behaviour of targets (cable trays, cabinet-like box) face to an oil fire.
- For the cable trays, we were asked to determine the failure (time, temperature, flux) according to :
  - ✗ The location of the cable tray against the fire location :
    - ✓ Fire plume influence, Ceiling jet influence, Direct flame radiation influence
  - ✗ The type of cable :
    - ✓ 3 x 16 mm², 3 x 6 mm², 2 x 35 mm², 7 x 1.5 mm², 2 x 0.5 mm²
    - ✓ verifying the NFC 32 070 and CST 74 C 057.00 specifications

PEPSI 1 : Experimental conditions

Experimental facility (PLUTON vessel, 400 m³)



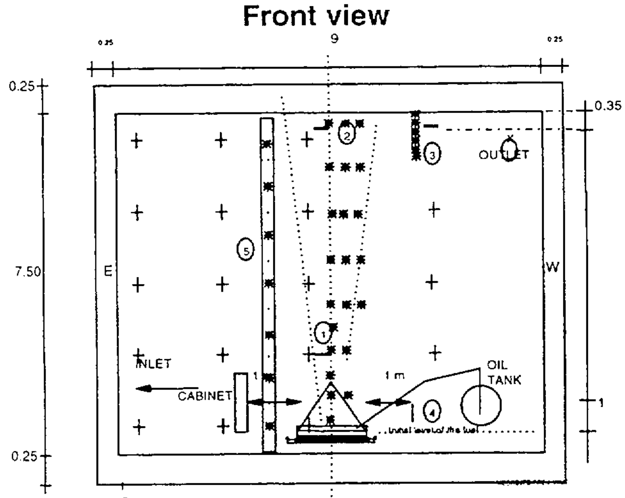
Cables trays 1 to 4 electrically supplied

- Study the behaviour of targets (cable trays, cabinet-like box) during an <u>oil fire</u> (100 l, 1 m^2).
- Determine the failure parameters (time, temperature, flux) according to :
  - ✗ The location of the cable tray :
    - ✓ inside, outside the plume, in the ceiling jet,
  - ✗ The type of cable :
    - ✓ 3 x 16 mm^2 : 380 V_{AC},
    - 3 x 6 mm^2 : 380 V_{AC},
    - 2 x 35 mm^2 : 125 V_{DC},
    - 7 x 1.5 mm^2 : 48 V_{DC},
    - 2 x 0.5 mm^2 : 24 V_{DC} (4 - 20 mA).

PEPSI 1 : Experimental conditions

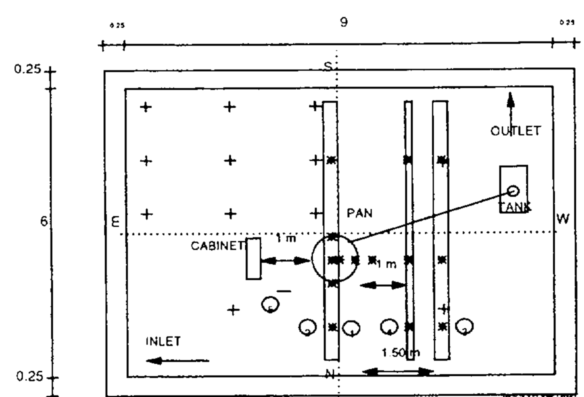
Measurements within the experimental vessel

Front view



○ : CABLE TRAY N° (i=1 à 5)

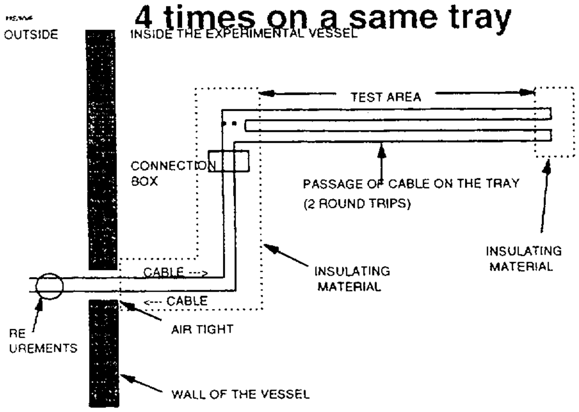
Top view



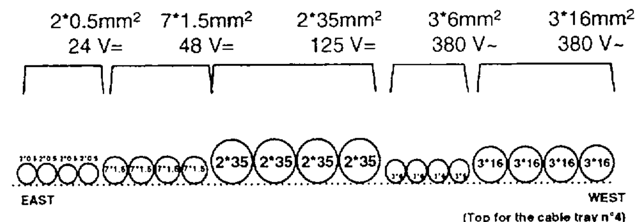
○ : CABLE TRAY N° (i=1 à 5)

PEPSI 1 : Experimental conditions

Advance of each type of cable : 4 times on a same tray



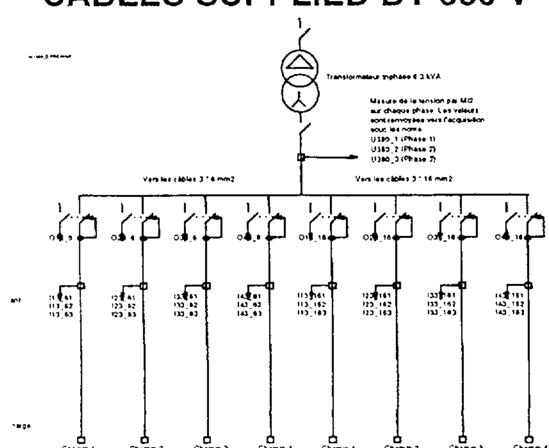
Cables arrangement on a tray : by type of cable



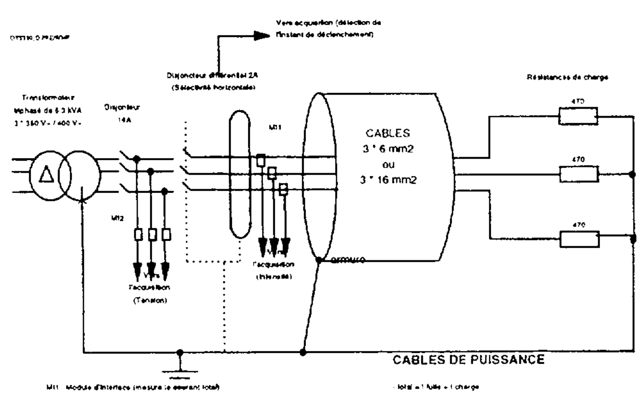
The cables are not joined

PEPSI 1 : Experimental conditions

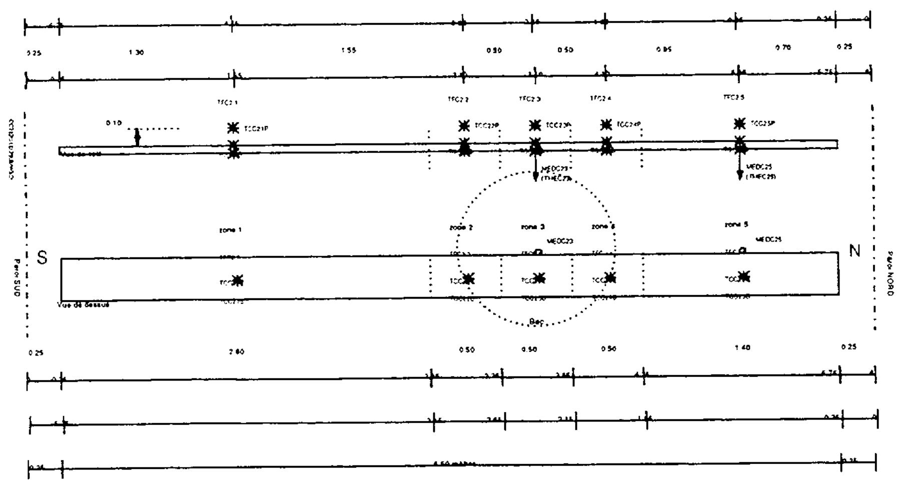
EXAMPLE : MOUNTING DIAGRAM, ALL CABLES SUPPLIED BY 380 V~



REPRESENTATIVE DIAGRAM FOR THE MEASUREMENT OF STRAY CURRENT (380 V~)

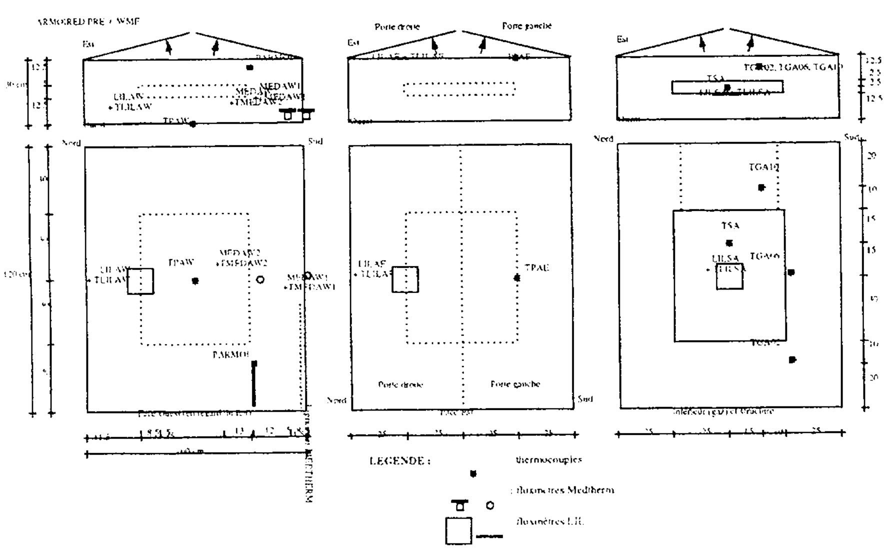


PEPSI 1 : Experimental conditions



- Cable specific measurements :
  - ✗ Temperature
  - ✗ Total heat fluxes
  - ✗ Leakage courant
  - ✗ Failure time

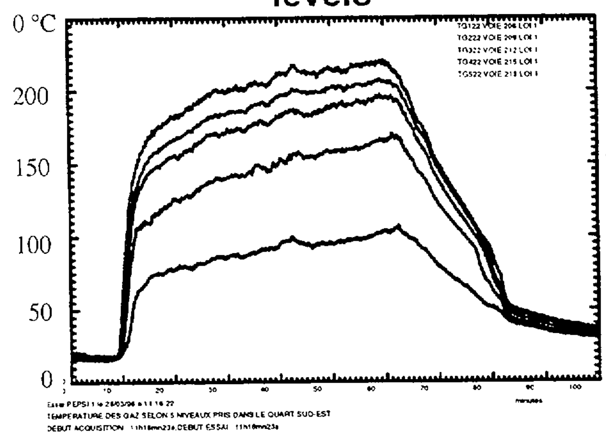
PEPSI 1 : Experimental conditions



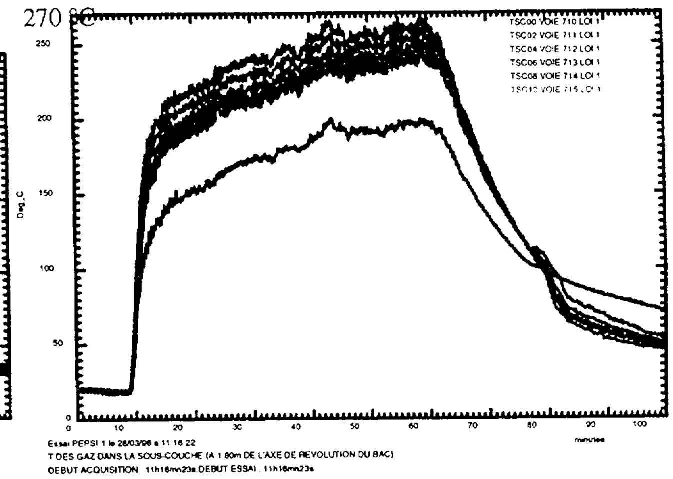
- Cabinet-like box specific measurements :
  - ✗ Temperatures
  - ✗ Fluxes
  - ✗ Pressure

PEPSI 1 : Some results

Gas temperature in the vessel versus time, for 5 levels



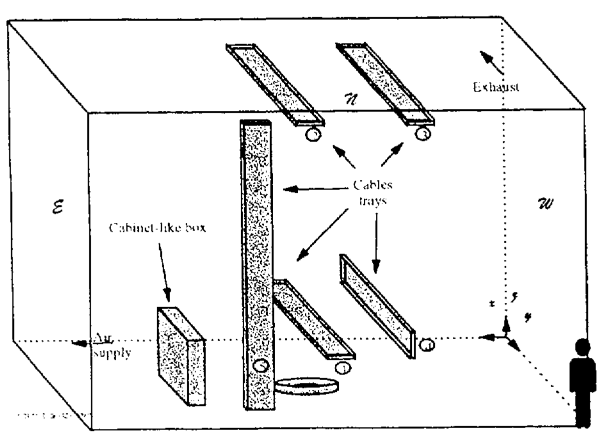
Ceiling jet temperature versus time (0 to 1 m under the ceiling)



FAR, June 2000

PEPSI 1 : Some results

Experimental facility (PLUTON vessel)



- Flame spread duration : 15 s
- Fire duration (steady state) : 54.30 min
- Flame duration : 73 min
- Maximum temperature in the flame zone : 950°C
- After ignition, the flame remained vertically during 2.8 minutes (2'48''), then slanted until the end of the fire.
-

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PEPSI 1 : Some results

Failure time and failure temperature (+ heat flux)

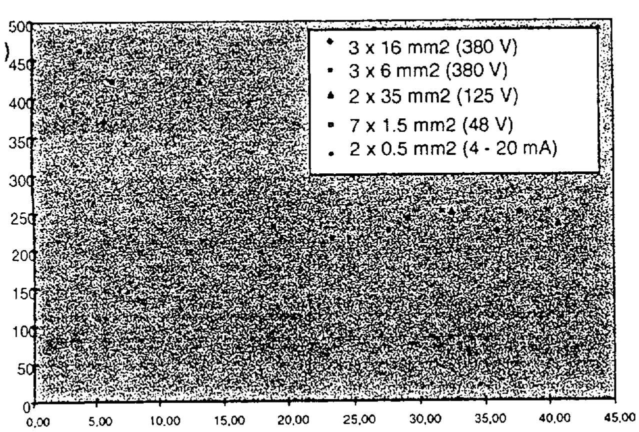
(time from the beginning of the oil fire)

Time / Failure temperature	Cable tray 1	Cable tray 2	Cable tray 3	Cable tray 4
Mean temperature during the period	~350°C	~220°C	~210°C	~130°C
Mean Flux	-	~5400 W.m^{-2}	~5300 W.m^{-2}	~5700 W.m^{-2}
3 x 16 mm^2	5.75 min / 370°C*	37.75 min / 250°C	36 min / 225°C	-
3 x 6 mm^2	4 min / 460°C*	19 min / 230°C	24.75 min / 215°C	-
2 x 35 mm^2	13.25 min / 420°C*	32.5 min / 250°C	40.75 min / 235°C	-
7 x 1.5 mm^2	Failure : 6.5 min / 420°C* Cut out : 7.25 min / 420°C*	Failure : 29.25 min / 240°C* Cut out : 39.5 min / 250°C	Failure : 23.5 min / 215°C* Cut out : 38 min / 235°C	-
2 x 0.5 mm^2	2.5 min / 390°C*	31.75 min / 250°C	27.75 min / 225°C	-

* : Peaks up to 550°C during the period before the failure time.

PEPSI1 : Some results

Failure temperature versus failure time, for each type of cable

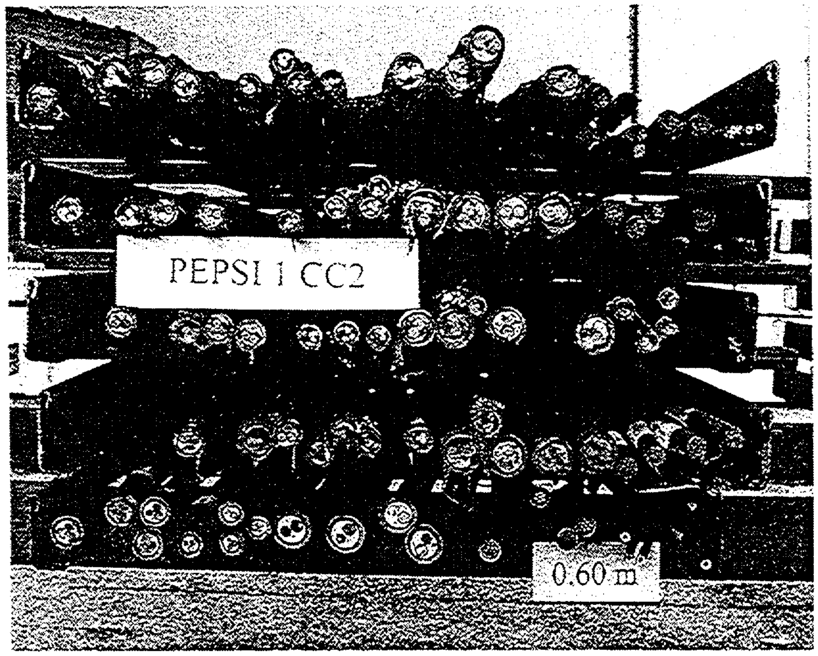


Failure time, after the beginning of the fire (minutes)

- **Whatever the type of cable, the origin of the failure is always the same :**
  - ✗ **short circuit between two or several wires**
  - ✗ **i.e. never short circuit between a wire and the cable sheathing**
- **Due to the slant of the flame, the cable tray n°3, located at the beginning outside the plume, is damaged before the cable tray n°2**

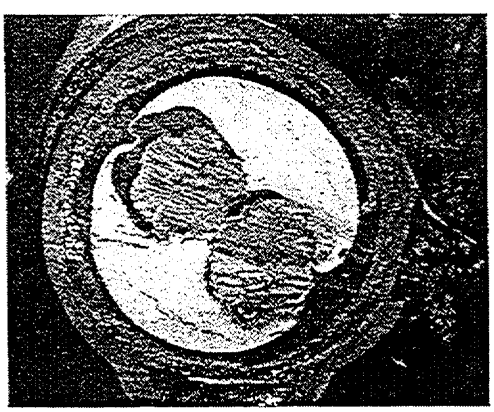
PEPSI 1 : Some results

Cables tray n°2 when cut
(after the test)



PEPSI 1 : Some results

Cables when cut
(after the test)



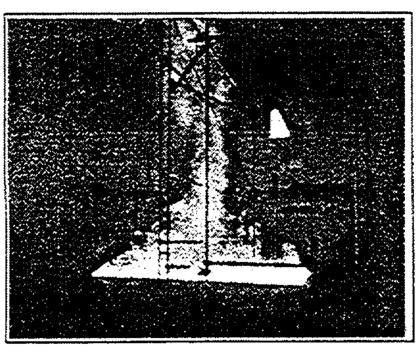
PEPSI 1 : Main conclusions

- Whatever the type of cable, the origin of the failure is always the same :
  - ✗ short circuit between two or several wires
  - ✗ i.e. never short circuit between a wire and the cable sheathing
- In a second phase, a short circuit between two or several wires and the sheathing can occur
- The order of failure of the cable trays was not 1, 2, 3 as expected, but 1, 3, 2 as a consequence of the slant of the flame and the deviation of the plume
- Only the cable tray n°4 did not fail, in spite of its location in front of the flame (~1 m far from the edge of the burning pan)
-

EXPERIMENTAL PROGRAMS CARRIED OUT

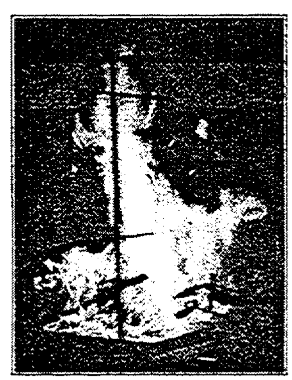
10 YEARS OF FIRE EXPERIMENTAL STUDIES : ABOUT 100 TESTS PERFORMED

→ QUALIFICATION OF COMPUTER CODES



LIC 2.5 TEST : 20 m² TPH/TBP POOL FIRE IN JUPITER FACILITY (3600 m³)

- COMBUSTIBLES USED :
  - ETHANOL,
  - OIL,
  - THP/TBP (sort of kerosene),
  - LEXAN (PC),
  - PMMA ...
- VENTILATION MODES :
  - NONE,
  - NATURAL,
  - MECHANICAL.
- POOLS AREAS : from 10 cm² to 20 m²



LIC 1.13 TEST : 5 m² E1 POOL FIRE IN SATURNE FAC

IPSN

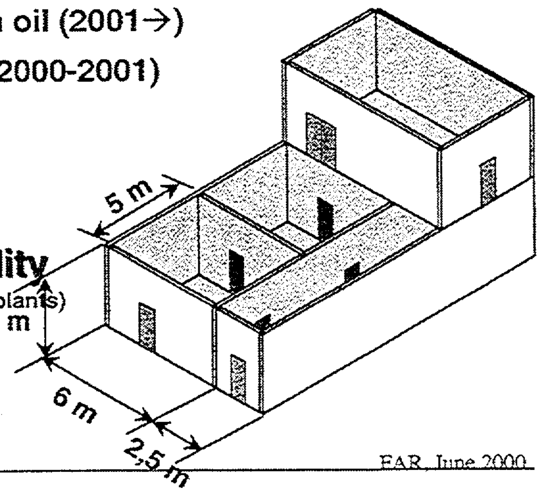
IPSN RESEARH PROGRAMS

PROGRAMS DIRECTLY RELATED TO FIRE SAFETY CONCERNS (1)

* FIRE PSA :

- Insulating materials impregnated with oil (2001→)
- Electronic cabinets (CARMELA tests 2000-2001)
- Electrical cables (beyond 2002)
- Multiroom fire propagation (2001-?)

The multiroom facility
(Nuclear power and reprocessing plants)

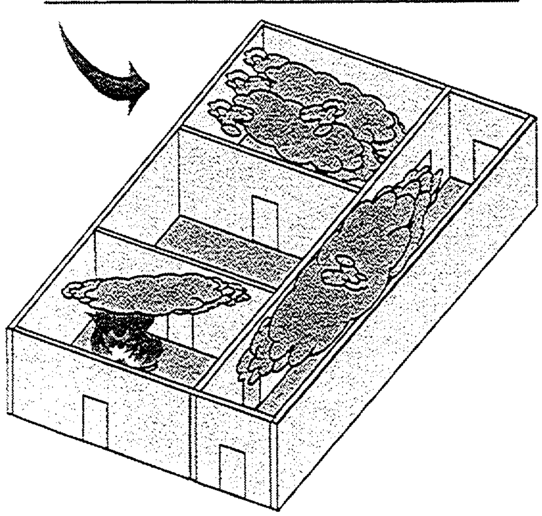


FAR, June 2000

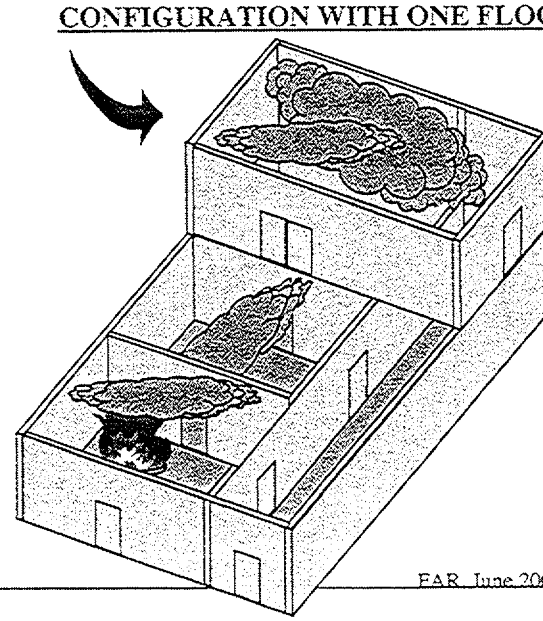
IPSN RESEARH PROGRAMS

EXAMPLES OF SCENARIO IN DIVA FACILITY (under construction)

THREE ROOMS CONFIGURATION



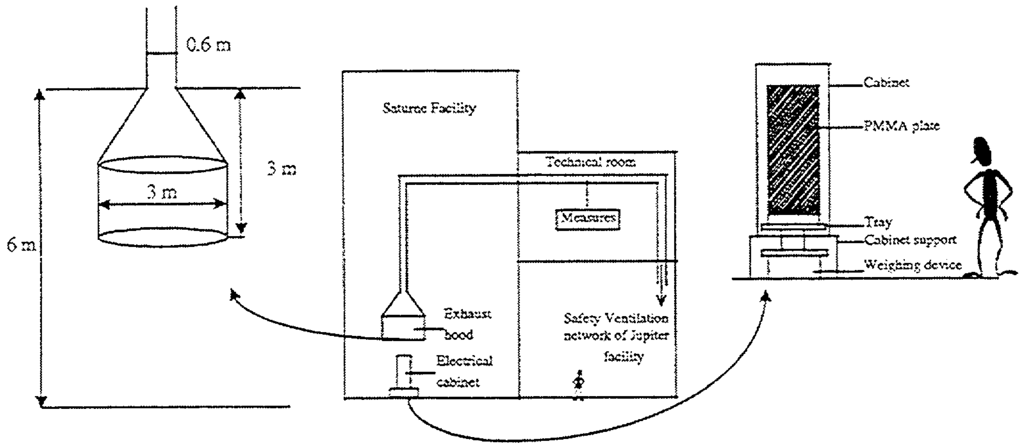
CONFIGURATION WITH ONE FLOOR



FAR, June 2000

IPSN RESEARH PROGRAMS

ELECTRICAL CABINET FIRE : An analytical program, CARMELA (in progress)



To be completed by the CARMELO PROGRAM : fire in real electrical cabinet

IPSN RESEARH PROGRAMS

PROGRAMS DIRECTLY RELATED TO FIRE SAFETY CONCERNS (2)

* COLLABORATION BETWEEN IPSN AND COGEMA :
  - Follow-up of fire-wall interaction tests (fire near a wall or in a corner) (1996→2001)
  - Fire of solid materials (gloves box) , with the LEX experiments (→1998)

TU Braunschweig iBMB

Burning Behaviour of Electric Cables Using Different Experimental Methods

D. Hosser
J. Will

"International Collaborative Project to Evaluate Fire Models for Nuclear Power Plants Applications"
2nd Meeting

June 19 - 20, 2000
IPSN, Fontenay-aux-Roses

Contents

iBMB

- Introduction
- Set-up of test procedures
- Experimental program
- Goals

Introduction

iBMB

- Risk of Fire
  - Different insulation materials
  - (cable coatings)
- Experimental research
  - Burning behaviour
  - Qualification method
  - Licensing procedure
  - Acceptance by building authorities
- Current program
  - Comparing different test facilities
    - Describing boundary conditions
  - Testing cables with different insulation materials
    - (PVC), PE, Silicone, FRNC

Parameter

iBMB

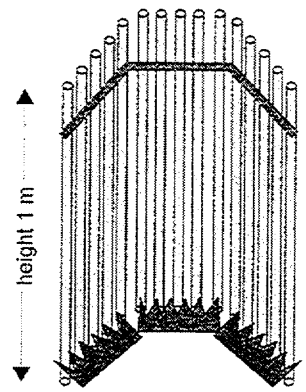
- Cable
  - Construction
  - Insulation material
    - Physical properties
    - Chemical properties
  - ➡ (PVC), PE, Silicone, FRNC
- Testing facility
  - Cable arrangement
    - Package density
    - Location
    - Orientation
  - Boundary conditions
    - Ignition source
    - Other fire loads
    - Compartment dimensions
    - Ventilation

Testing facilities

- "Brandschacht" test
  - DIN 4102-1
- Cable fire test
  - IEC 332-3 / DIN VDE 0472-804
    - Adding rhr - measurement
- Cone calorimeter test
  - ISO 5660-1
- Room fire test
  - Pre-heating of the compartment

„Brandschacht"

- DIN 4102-1
  - Hardly inflammable
    - ➩ Self-extinguishing
    - ➩ Area not affected > 15 cm

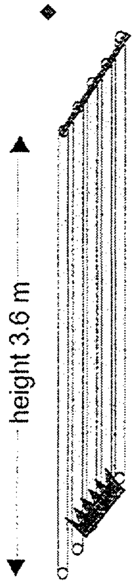


local flame application
20.85 kW overall
(about 5 kW per frame)

➩ Phase of starting fire (pilot fire)

Cable fire test

- IEC 332-3
  - Tests on bunched wires or cables
  -



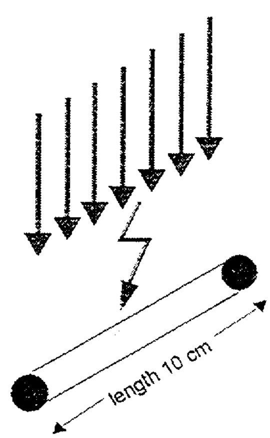
➩ Self-extinguishing
➩ Area not affected > 0 cm
➩
- Heat release rate
- CO_2, CO-production
- Smoke production

local flame application
21 kW overall

➩ Phase of starting fire (pilot fire)

Cone-Calorimeter

- ISO 5660-1
  - Ignition
  - Heat release rate
  - Effective heat of combustion
  - CO_2, CO-yield
  - Smoke production



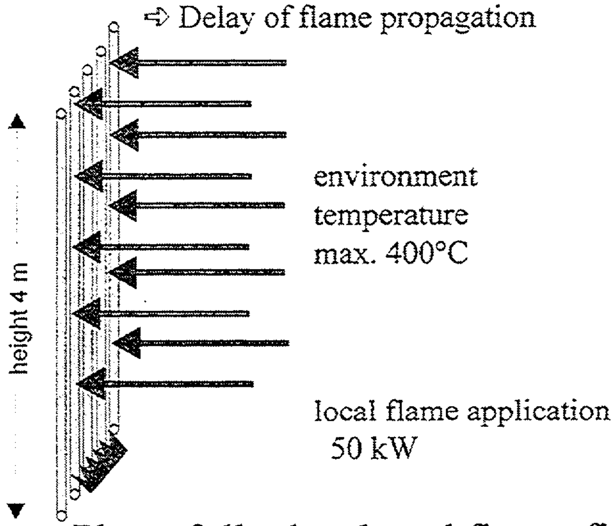
Heat flux 50 kW/m²

Electric spark

➩ Phase of fully developed fire

Room fire test

- Qualification method
  - Ignition
  - Flame spread
    - ➪ Delay of ignition
    - ➪ Delay of flame propagation



➪ Phase fully developed fire or fire spreading

Goals

➪ Distinguished qualification and application of cables

➪

➪ More detailed description of cable fire
  - ➪ Determination of design fire
  - ➪ Input data for fire models

➪

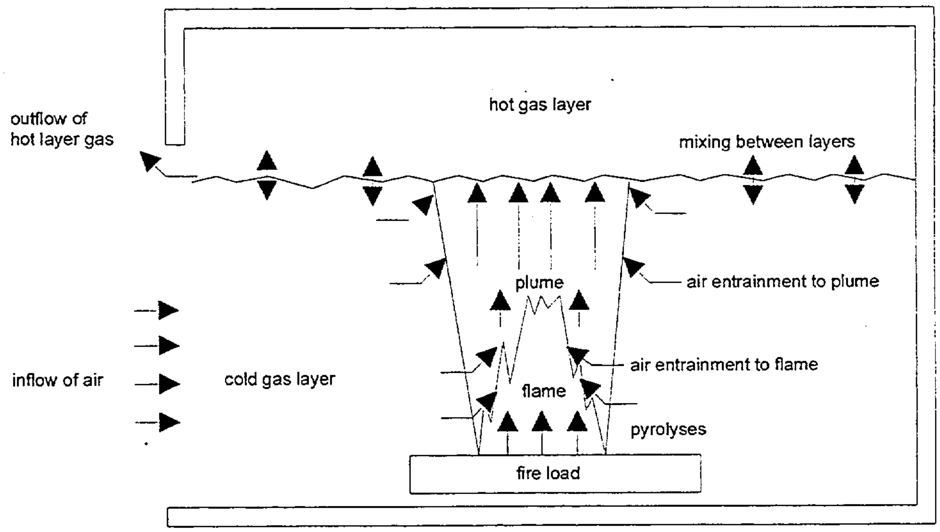
➪ Basis for calculation methods
  - KTA 2101.2 (NPP)
  - DIN 18230-1 (industrial buildings)

Results

- "Brandschacht" test
  - Classification
- Cable fire test
  - Classification
  - Parameter
- Cone calorimeter test
  - Parameter
- Room fire test
  - Ignition time
  - Flame spread velocity
  - Comparison to PVC cables

Principle

iBMB



Program

iBMB

	Cone-Calorimeter	"Brandschacht" DIN 4102 Part 1	Cable fire test IEC 332 - 3	Room fire test
Preparation of apparatus			Exhaust duct with oxygen consumption measurement	Set-up for qualification-method
Characterization		Measuring convective and radiative heat flux		
PVC		control cable power cable	control cable power cable	
PE	control cable power cable heat flux of 20, 40, 60 kW/m²	control cable power cable	control cable power cable	vertical 400 °C horizontal 400 °C horizontal 200 °C vertical 20 °C
Silicone	control cable power cable heat flux of 20, 40, 60 kW/m²	control cable power cable	control cable power cable	vertical 400 °C horizontal 400 °C
FRNC	control cable power cable heat flux of 20, 40, 60 kW/m²	control cable power cable	control cable power cable	vertical 400 °C horizontal 400 °C

2nd Meeting of International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

Institute de Protection et de Surete Nucleaire (IPSN)

Fontenay-aux-Roses, France, June 19 - 20, 2000

Cable Tunnel Fire Experiments at VTT

O. Keski-Rahkonen

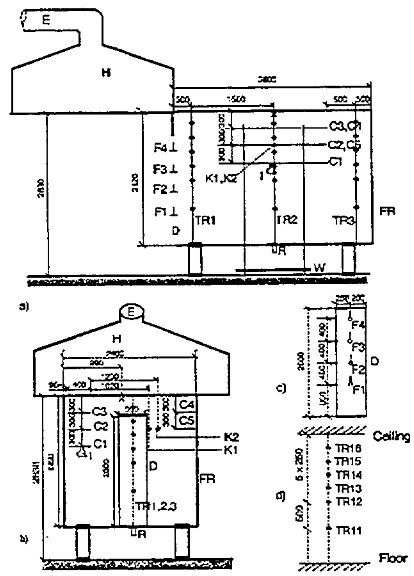
Full-scale fire experiments on vertical and horizontal cable trays

J. Mangs & O. Keski-Rahkonen
Espoo

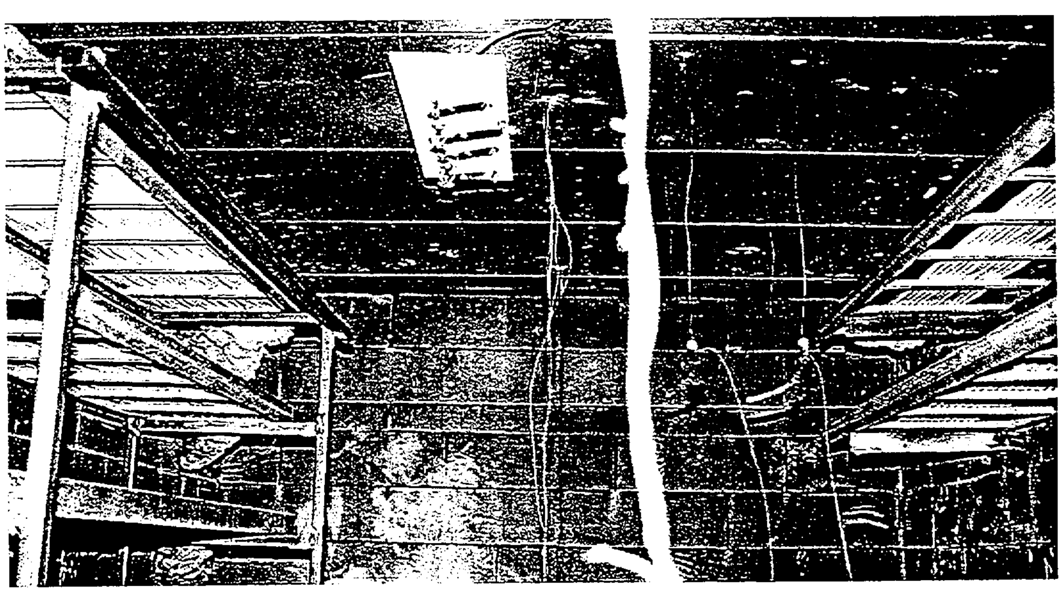
VTT Publications 324

Espoo 1997, 58 p + 44 p. app.

Experimental setup



Cable trays before the experiment



Measurements

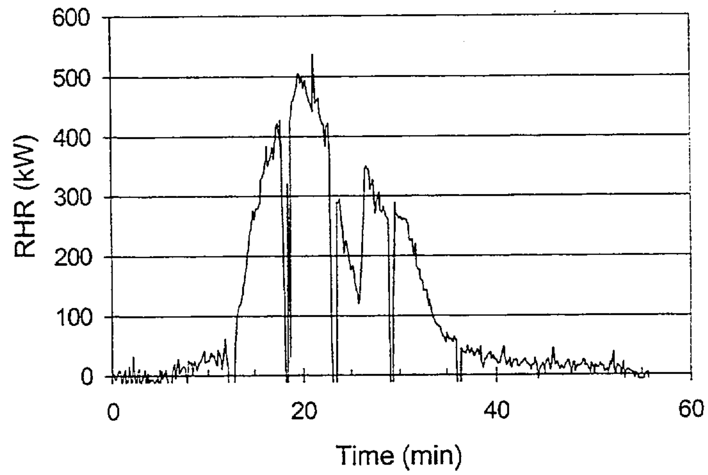
- RHR
- Mass weight loss
- Gas flow (4)
- Heat flux (1)
- Gas temperatures (19)
- Surface temperatures (58)
- Gas concentrations (O_2, CO_2, CO)
- Smoke density

Cable material inventory

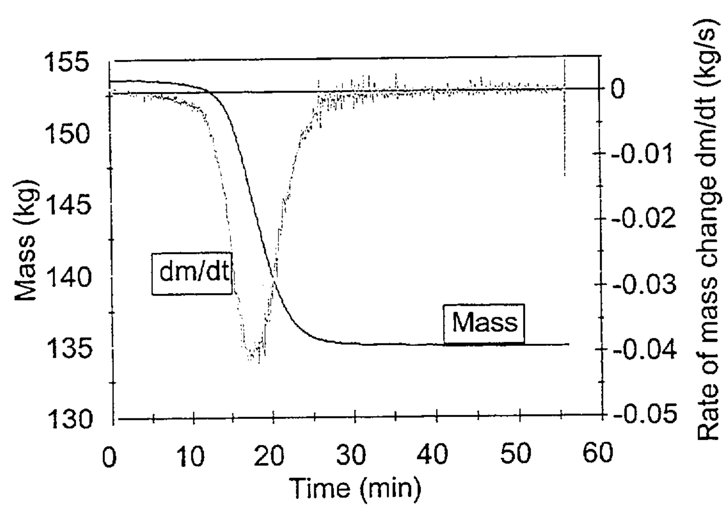
•Total energy released	MJ	452
•Initial total cable mass	kg	56.05
•Total cable mass loss	kg	25.98
•Total cable mass loss	%	46
•Effective heat of combustion	MJ/kg	17.4

Ignition by a small gas burner

RHR in the cable tunnel



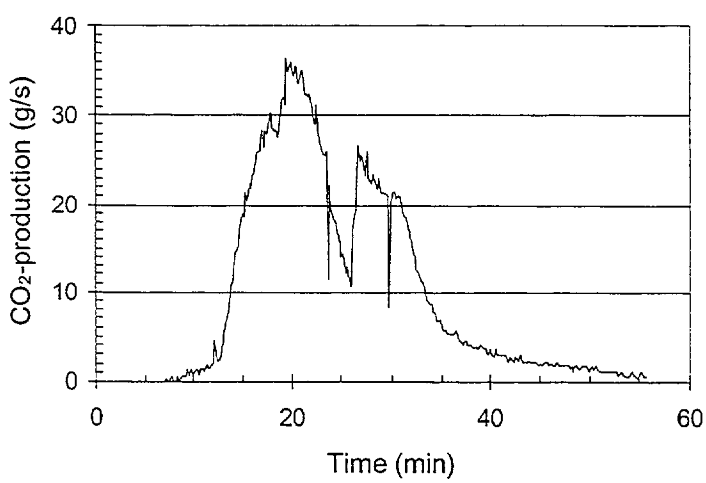
Mass weight and mass loss



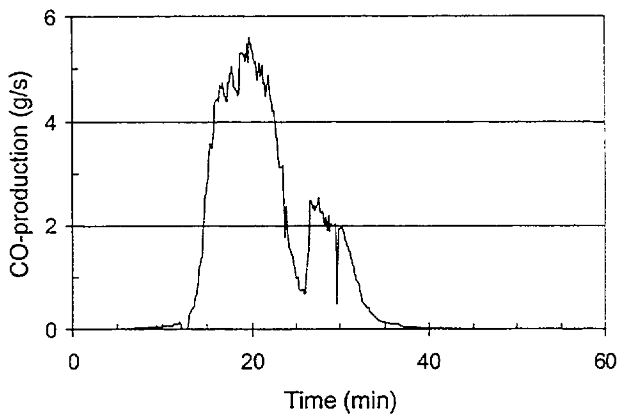
Cable tray during the experiment

Only the lowest tray visible 17 min after ignition

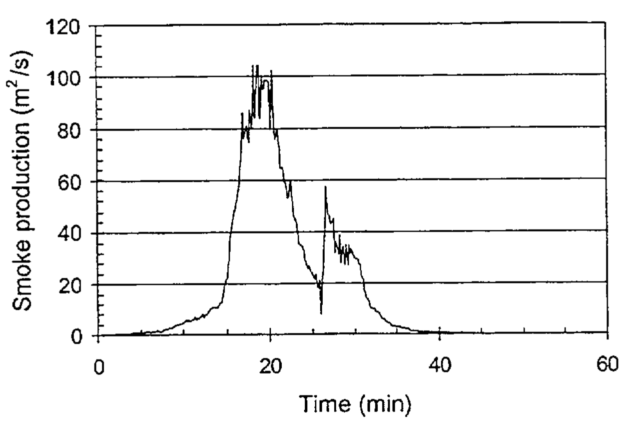
CO_2 production



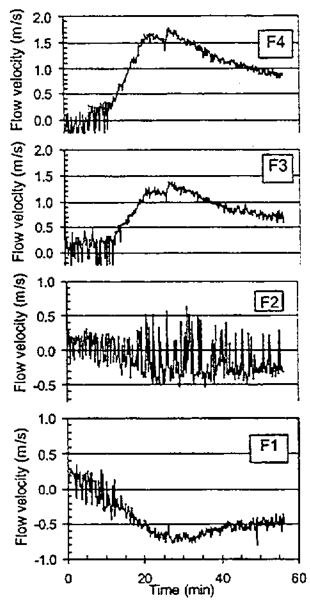
CO -production



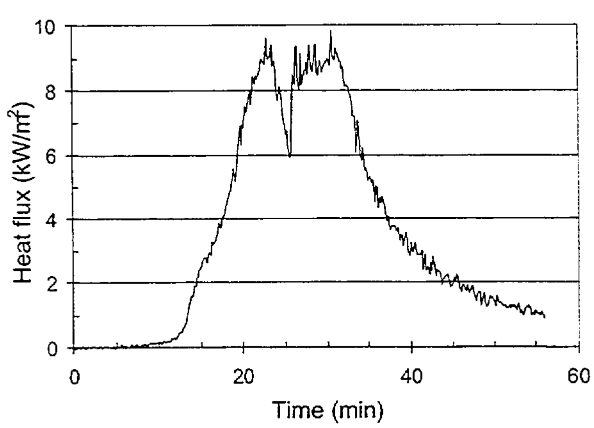
Smoke production



Flow velocity in doorway

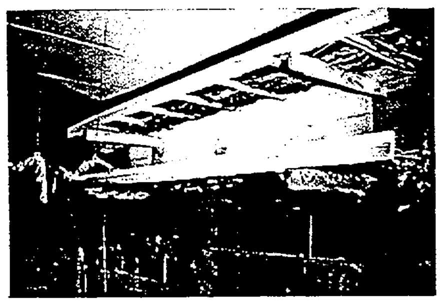


Heat flux



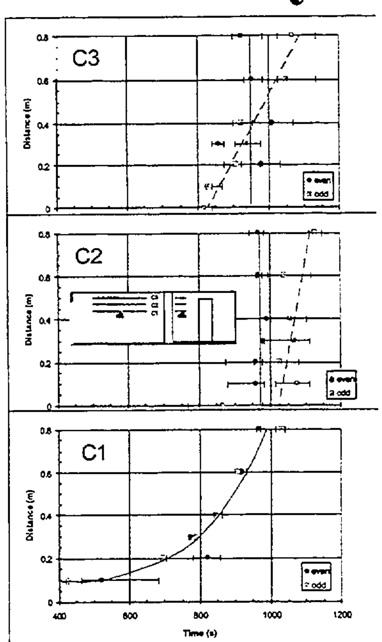
Cable trays after the experiment

Ignited tray

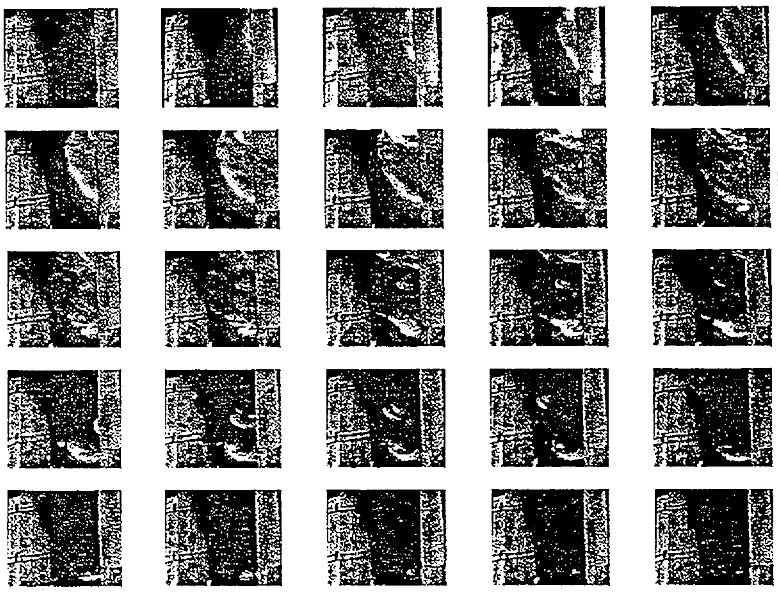


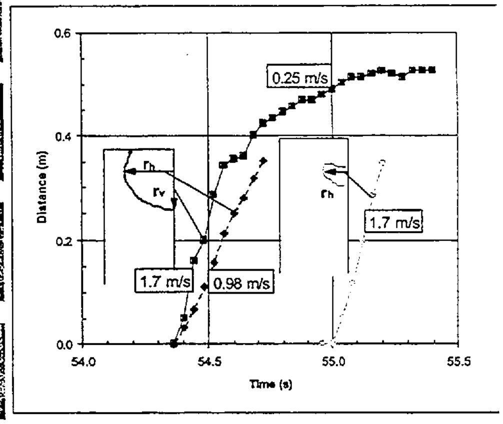
Opposite tray

Flame spread velocity on cable trays



Deflagration





Conclusions

- Careful design of experiments
- Scaling tests before full scale test
- Experiment a ‘success’
- Still many surprises
- Good for cable burning demonstration
- Too few measurement instruments/channels
- Too complicated for model evaluation

VTT Building Technology

2nd Meeting of International Collaborative Project to Evaluate
Fire Models for Nuclear Power Plant Applications
Institute de Protection et de Surete Nucleaire (IPSN)
Fontenay-aux-Roses, France, June 19 - 20, 2000

Estimation of Probability of Secondary Target Ignition in a Cable Tunnel

O. Keski-Rahkonen

Report

Modelling of fire scenarios for PSA

Probabilistic fire development for a cable tunnel

S. Hostikka & O. Keski-Rahkonen

VTT Building Technology

Fire Technology

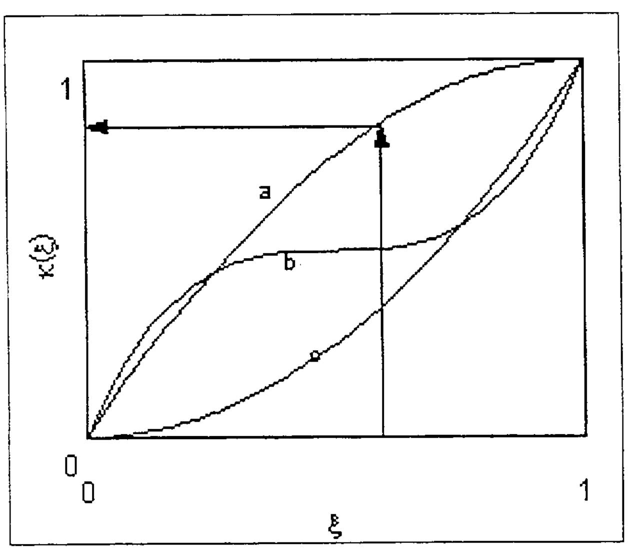
29 p. (unpublished)

Model

$$g(t,x) \leq 0, \text{ if component/system is lost at time } t$$
$$g(t,x) > 0, \text{ if component/system is not lost at time } t$$

$$P_{loss}(t) = \iint_{\{x|g(t,x)\leq 0\}} \cdots \int \phi_x(x)dx_i$$

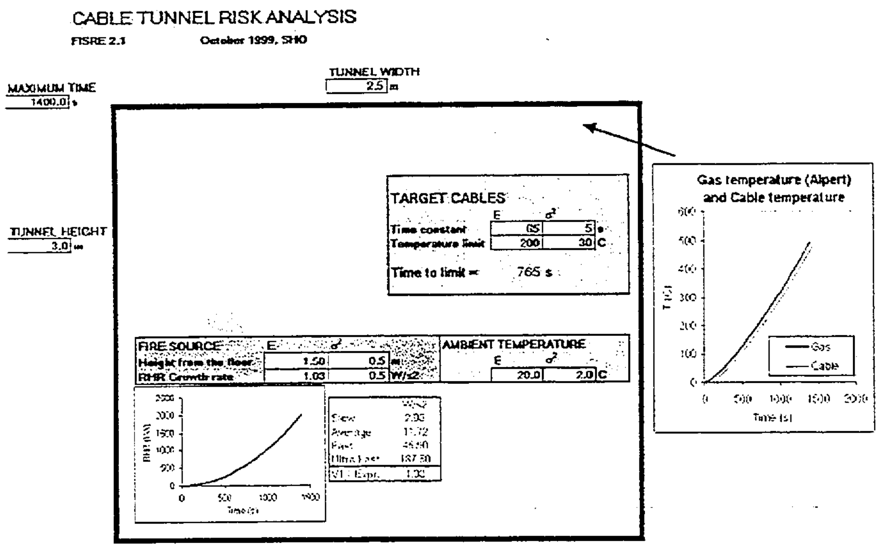
Sampling



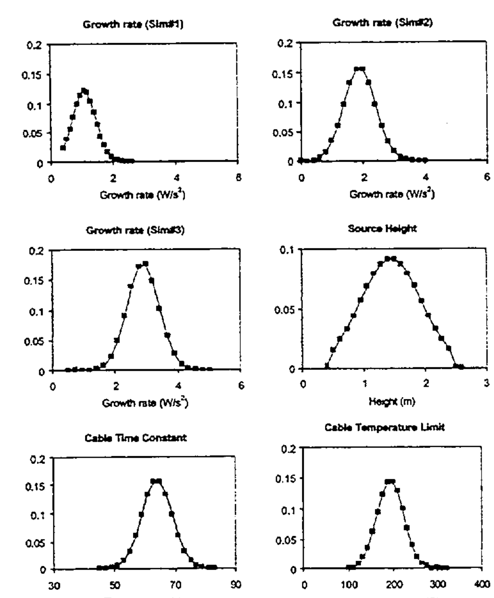
Make a change in your integration space

$$x_i \rightarrow F_i$$

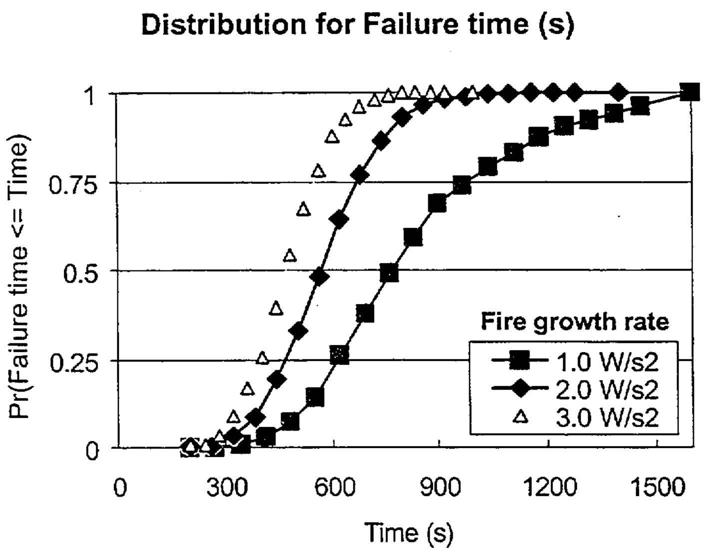
Cable tunnel demonstration model



Growth rate distributions



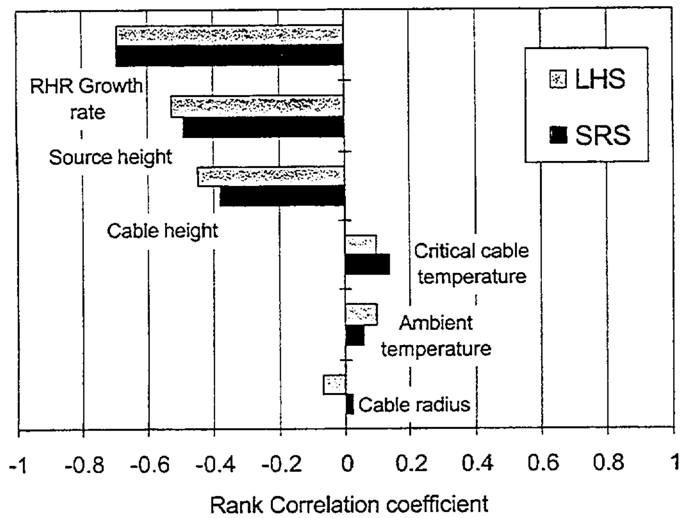
Target failure time distribution



Input distributions

Variable	Distribution	μ	σ	min	max
RHR Growth rate (W/s^2)	TNormal	1	0.5	0.0	3.0
Source height (m)	TNormal	1.5	0.5	0.5	2.1
Cable diameter (mm)	Normal	1.1	0.1		
Critical Cable Temperature (°C)	Normal	200	20		
Cable height (m)	TNormal	2.0	0.2	0.0	2.6
Ambient temperature (°C)	Normal	20	2		

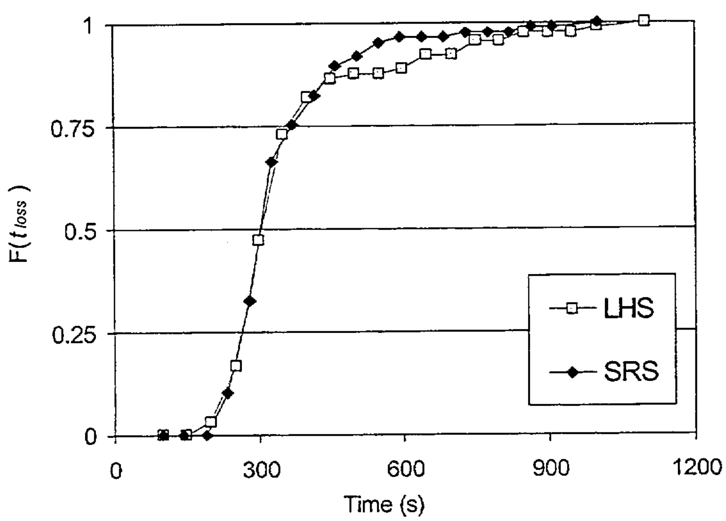
Rank correlations



LHS Latin hypercube sampling

SRS Simple random sampling

Cumulative loss time distribution



LHS Latin hypercube sampling

SRS Simple random sampling

1

EDF Division Ingenierie et Services

Determinist fire safety studies in French NPP : a concrete case

M. KAERCHER EDF/SEPTEN
B. GAUTIER O. PAGES EDF/DR&D

2

EDF fire safety assessment context

- PAI : Modification and up-grading of NPP
  - » Application of Regulation up-date :
    - *RFS V.2.f*
    - *Directives Incendies* (900 MWe, 1300 MWe , 54 units)
    - *RCC-I* (1450 Mwe, 4 units) : conception
- Use of numerical determinist tool MAGIC:
  - Definition and revision of generic safety rules (SEPTEN/IN)
  - Simulations of fire in concrete NPP configurations (CIG)

3

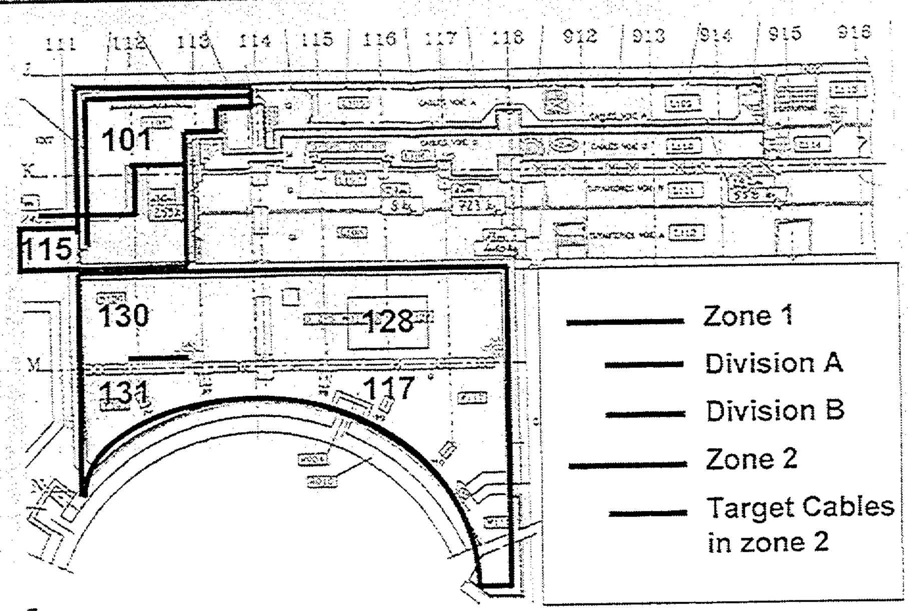
Objectives of this study case

- **Simulation of critical realistic fires in a NPP set of compartments**
  - Check the efficiency of the design in cases of deviation from the basic prescriptive rules
  - Avoid too conservative prescriptions in the design of "complex" situations
    - ⇒ Safety Demonstration

- **MAGIC :** Evaluation of aerothermal conditions induced by a fire into compartments
  - Temperatures, oxygen depletion, smoke-filling of rooms
  - Spread through the building (ignition of secondary sources)
  - Thermal behavior of cables, etc...

4

Room configuration



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Fire Safety issues

- Divisions A and B both present in room 101 (deviation from basic prescriptive rules).
  - Different solution are available:
    - Local Sprinklers?
    - 1h 30 wrap protection on train B ? —> high power cable !
    - ventilated wrap (radiative protection) on train B ?
    - ventilated wrap with automatic closing device on train B ?
    - new train B path
  - > Train B is protected from radiation by screens. Train A is fitted with sprinklers.
- Zone 1 and zone 2 are separated by an opened wall (geographical separation of fire loads)

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Aim of the work

Hypothesis: ignition of a fire on division A in room 101

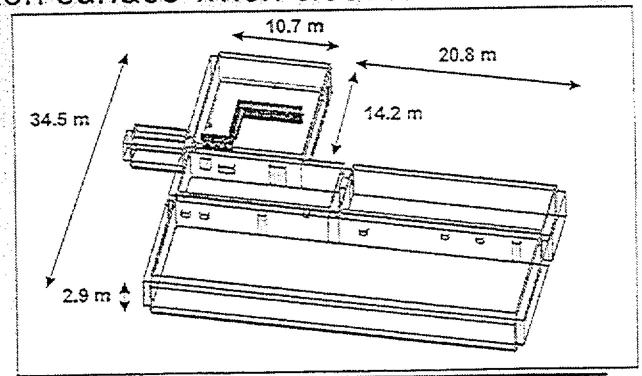
- **Efficiency of the corrective dispositions (deviation from basic rules) : To evaluate the risk of loss of function of cables from train B in room 101.**
- **Verify the geometrical separation (basic rules) efficiency : cables in room 130 (zone2, train B) don't loose their function.**

7

Configuration hypothesis

- **Geometry :** room shape approximation (parallelepipeds), respecting air volumes
- **Walls :** mainly concrete
- **Sprinklers* :** detection at 70°C, time delay of 120s
- **Doors/openings :** infiltration surface when closed
- **Vents :** natural ventilation
- **Fire load density :** 30 MJ/m² (room 101)

(*) : extinction is not considered



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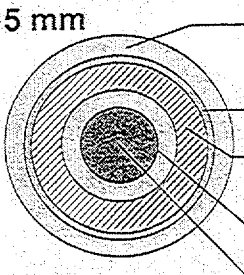
Electrical Cable characteristics

- **Measurement cable (≤ 220 V), PVC, d: 15 mm**
- **Power cable (12 kV) , PVC, d: 49 mm**



630 mm² Alu power cable

– **Cable temperature thresholds (thermal modelling):**

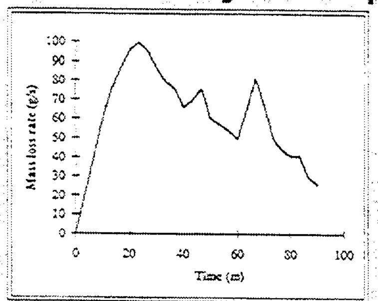
» loss of function : 160°C (SEPTEN/EL tests, may 96)

» fire spread : 200°C (pyrolysis threshold (Calorimeter-DR&D))

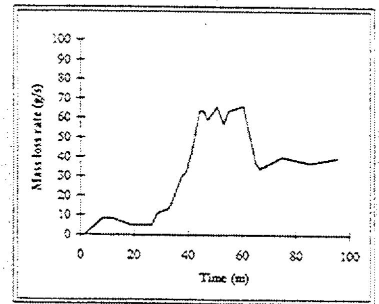
- **Room 101: Pilot power cable protected by screen**
- **Room 130 : Both pilot meas. and power cable without protection**

Initial Fire Source: ignition hypothesis

- The initial lighter has a deciding effect of further fire dynamic profile:



Fast Ignition: 12 l heptane (500 kW)
(Vernon 97)



Slow Ignition : gaz burner (75KW)
(Chelles 84)

- Presence of solvant is possible —> FAST IGNITION.
  (12 l ignition is a conservative hypothesis)

Reference mass loss rate profile (I)

—> Several EDF full-scale cable fire tests available
[cf. Helsinki OECD 99]

- **How to build a reference mass loss rate profile for fast cable fires ?**
  - The referenced tests are conservative:
    - » Number of trays (7) : (here $\leq$ 5)
    - » fire load by tray: maximum allowed by specification
  - Combustible mass balance factor :
    - » the burning rate is evaluated for 1000 kg of combustible mass

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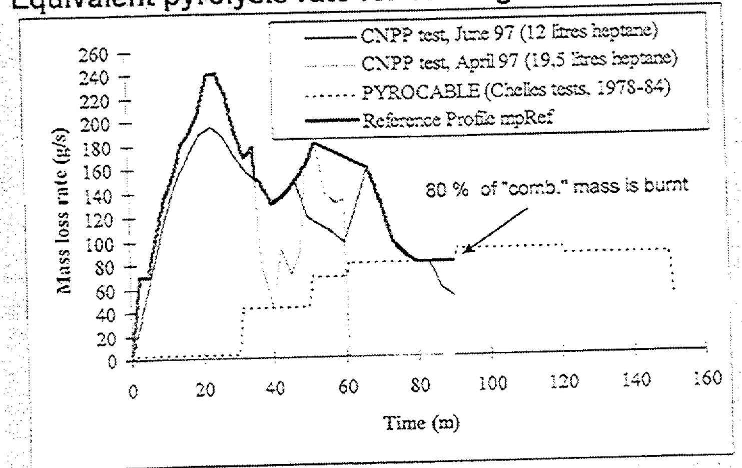
Reference mass loss rate profile (II)

Equivalent pyrolysis rate for 1000 kg combustible mass



➪ The envelope curve $\dot{m}_{pRef}$ will be considered as a critical profile for a 1000 kg combustible mass cable fire

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Division A cable fire

- Combustible characteristics (PVC cable)
  - mean ΔH_C: 13 MJ/kg
  - radiative part : 30%
  - stoechiometric ratio : 1,28
  - extinction coefficient : 0,5 m^{-1}
- Pyrolysis rate: use of the Reference Profile
  - R= comb.mass/1000kg ; $\dot{m}_p = R.\dot{m}_{pRef}$

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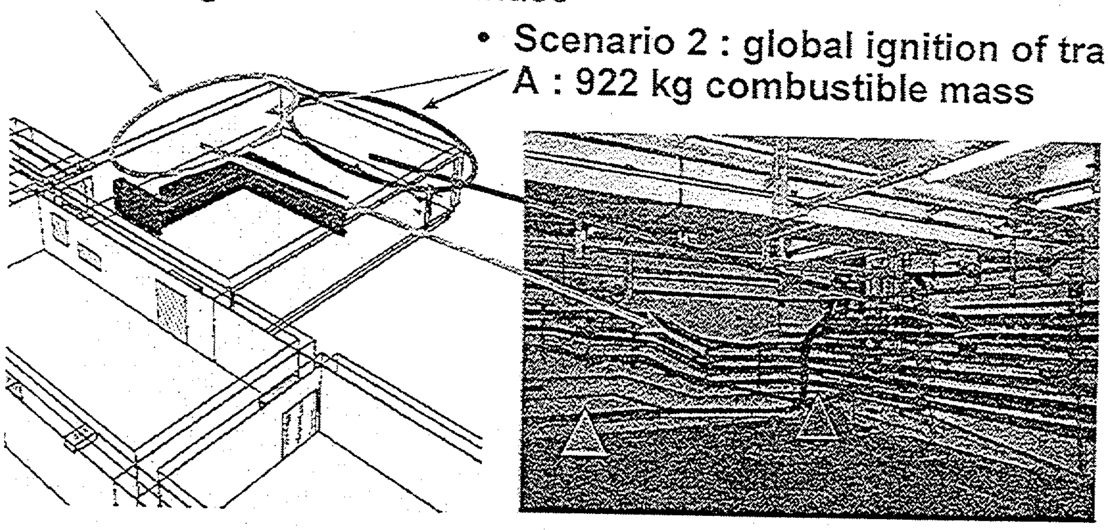
The presented scenarios :

- Scenario 1 : Fire on train A (west wall) : 155 kg combustible mass
- Scenario 2 : global ignition of train A : 922 kg combustible mass



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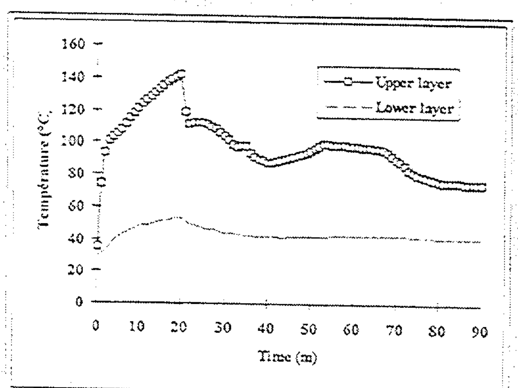
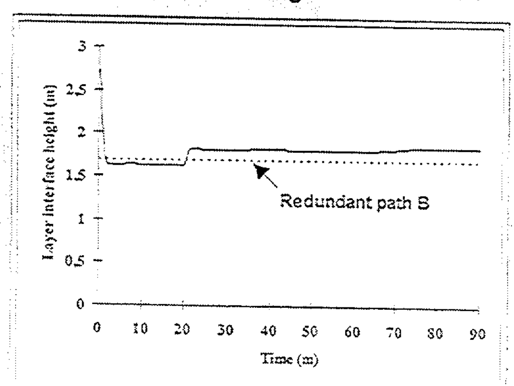
Scenario 1 : Results (I)

Fire on division A (room 101 - west)

Gas temperature in room 101



Layer interface height in room 101



Hot upper layer reaches division B
Upper layer Temperaure < 150°C

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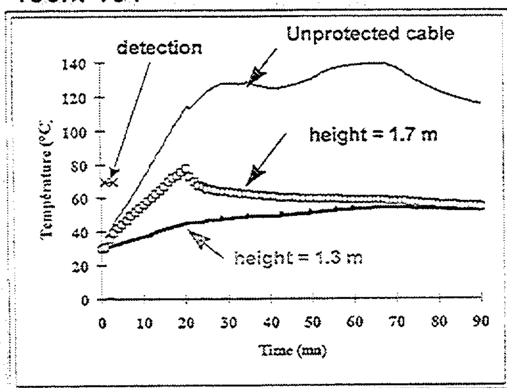
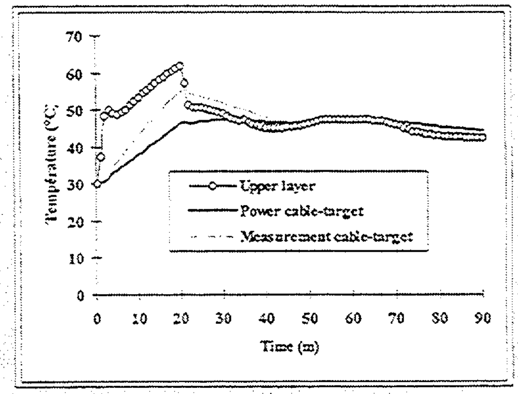
Scenario 1 : Results (II)

Pilot cable surface temperature train B, room 101



Cable and Upper Layer temperatures, room 130



→ low temperature increase for lower cables

→ temperature of all cables under disfunction treshold

"Passive" protection avoid simultaneous damage of redundant path

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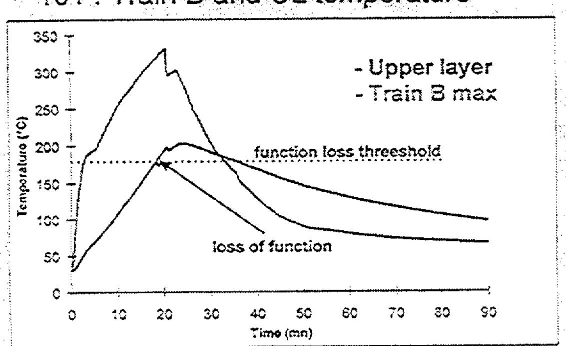
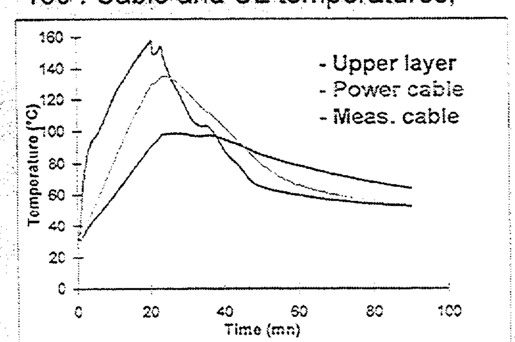
Scenario 2 : Results

Global Fire propagation in room 101

101 : Train B and UL temperature



130 : Cable and UL temperatures,



Room 101 —> Division B : risk of function loss.

Room 130 —> no damage

Sprinkler sytem is warranted on division A,
Geographical separation is efficient.

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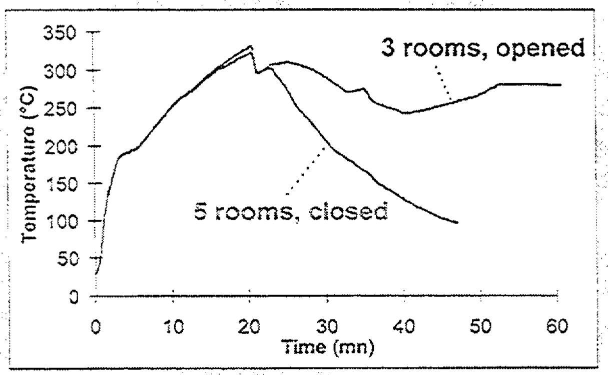
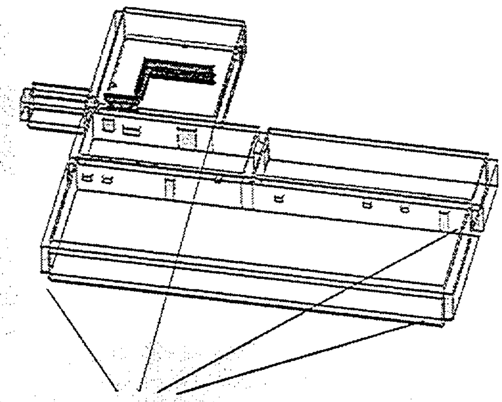
Scenario 2 : discussion

Taking into account the ventilation boundaries (oxygen depletion effect)





Vent boundaries (infiltrations)

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Conclusion

The lower the wanted margin ...
...the deeper the modelling needed !

Simulating realistic fires for "in the field" situations

– Several relevant issues :
  » Ventilation boundaries (multi-compartment model is necesary)
  » Thermal behavior or targets —> loss of function, fire propagation
  » Heat release rate profile : depends on the type of ignition event considered.

SOME CFD VALIDATION STUDIES AND BLIND SIMULATIONS

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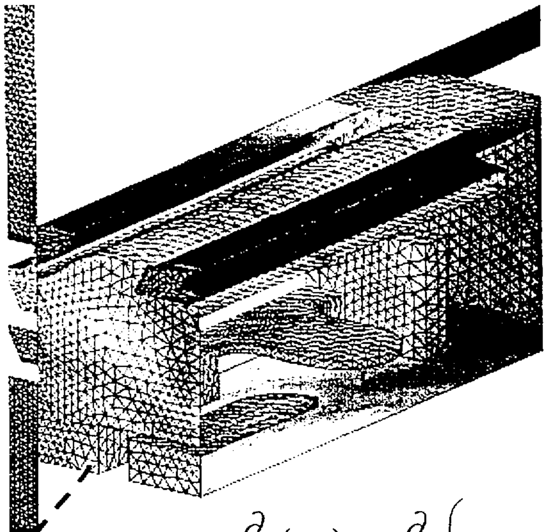
Fax: +44 (0)1923 664910
E-mail: miless@bre.co.uk

Current status of CFD fire models

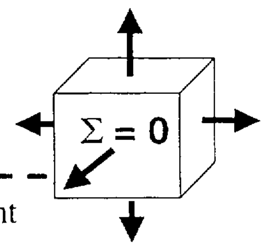
- Emergence of powerful computing resources in 1980s & 1990s and the development of practical modelling tools motivated the subject of CFD (field) modelling
  - 'purpose-built' models & general purpose 'commercial' codes
- Overcomes many of the limitations of zone & network models
  - 'minimal' reliance on empirical formulae
  - extendible to arbitrary shape and size of building
- BUT models require validation and users require guidance & training
  - comparisons against experiment & 'blind' simulation exercises

General CFD methodology



- discretise geometry
- select physical sub-models
- apply boundary conditions
- solve coupled equations
- process solution data

$$\frac{\partial}{\partial t}(\rho\phi) + \frac{\partial}{\partial x_j}\left(\rho u_j - \Gamma_\phi \frac{\partial \phi}{\partial x_j}\right) = S_\phi$$



conservation equations imposed at each mesh element

Generic transport equation

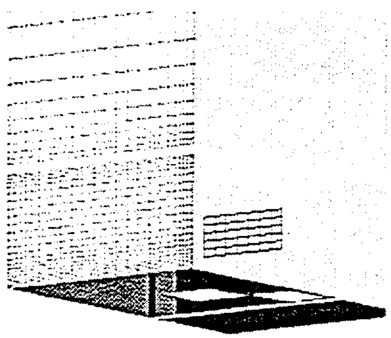
- A generic equation holds for all the main conserved properties associated with fluid flow

$$\underbrace{\frac{\partial}{\partial t}(\rho\phi)}_{\text{time rate of change}} + \frac{\partial}{\partial x_j}\left(\underbrace{\rho u_j}_{\text{convection}} - \underbrace{\Gamma_\phi \frac{\partial \phi}{\partial x_j}}_{\text{diffusion}}\right) = \underbrace{S_\phi}_{\text{source terms (e.g. heat from fire)}}$$

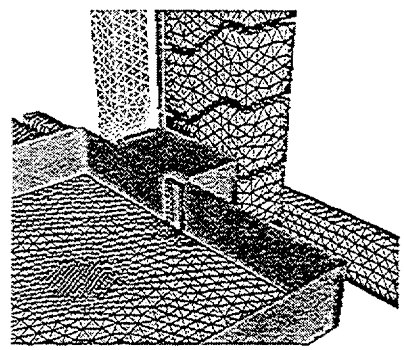
  - satisfied for each conserved property at each control volume
  - generates a very detailed (and potentially accurate) solution

Alternative types of CFD mesh

- <u>Structured</u>
  - one or more blocks of rectangular (or warped rectangular) control volumes
  - mesh generation not too complicated



- <u>Unstructured</u>
  - full flexibility to fit around complex geometries
  - tetrahedral (3-d triangular) control volumes often used
  - mesh generation requires a sophisticated pre-processor



Basic CFD fire model components

- Heat sources
  - fires, HVAC, radiators
- Solid boundaries
  - arbitrary geometric shapes for building elements and internal obstacles
  - heat losses to walls etc
- Ventilation openings
  - doors, windows etc
    - any number or configuration
- Smoke exhaust
  - naturally or mechanically ventilated
- External wind
- Radiation heat transfer
  - surface to surface
  - from 'smoke' layer

Advanced CFD fire model components

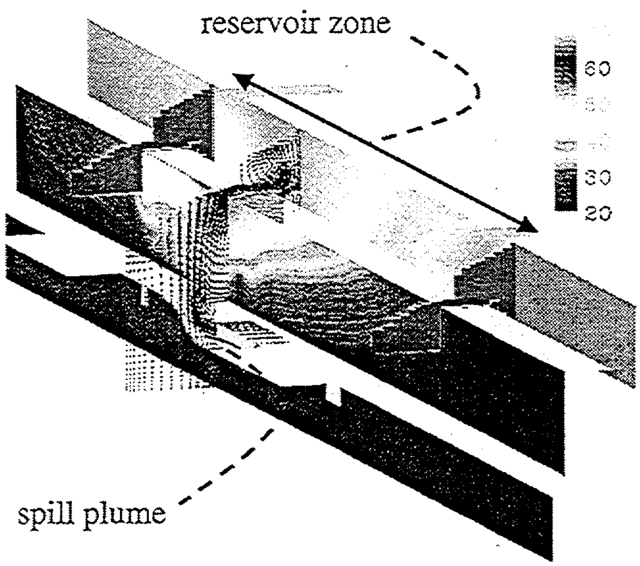
- Combustion process
  - provides a more accurate distribution of heat release
  - allows combustion product species to be modelled
- Soot formation and oxidation
  - allows accurate modelling of radiation from flaming region
- Sprinkler sprays
  - principally the cooling of the hot gases by the water droplets
- Implicit fire growth and flame spread
  - the CFD model predicts the growth of the fire source according to heat transfer to the fuel surface and local oxygen levels
  - still a research topic
  - some success with pool fires
- Under-ventilated conditions
- Explosions

Typical applications of CFD fire models

- For complex buildings
  - irregular geometries
  - large spaces, atria etc
- For complex fluid dynamics
  - where zone model assumptions break down
    - uniform one/two-layer approximation not valid
    - leaning fire plumes
    - wall flows
  - interaction with HVAC, solar gain etc
- When fine details of fluid flow and smoke/heat distribution required
  - siting of detectors
- Interaction with external air flows important
  - wind effects at vents
  - dispersion of combustion products

CFD for Fire Safety Engineering

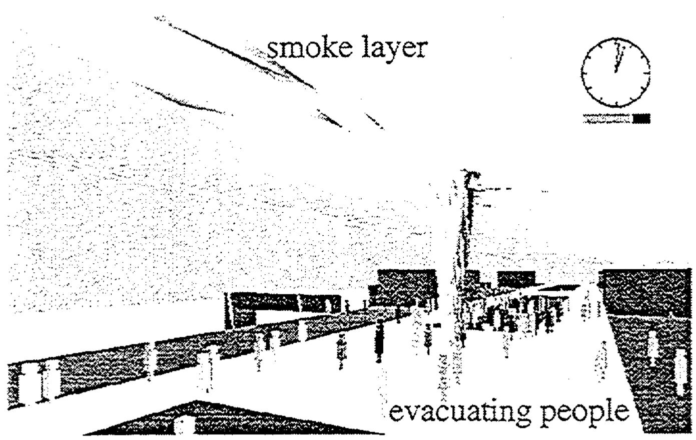
- Two-storey shopping mall



- temperature contours for a given exhaust rate

CFD for Fire Safety Engineering

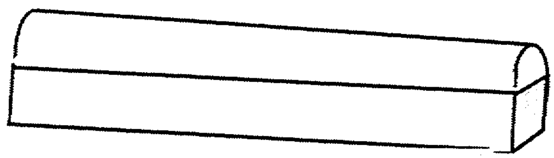
- An airport development

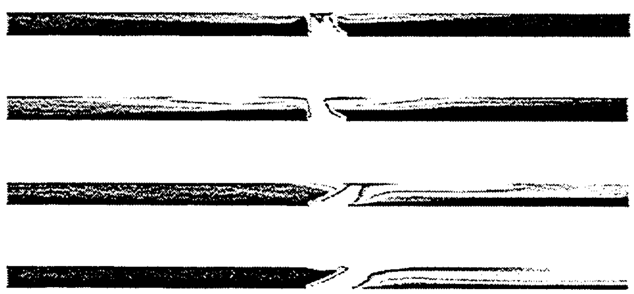


- new airport building
- proposal to have exposed steel
- required performance based design
- in event of fire HVAC left running in 100% replacement mode
- CFD to model smoke and heat transport
  - output used in egress analysis

CFD for Fire Safety Engineering

- Tunnel Air & Smoke Ventilation





CFD predictions of the effect of smoke control methods, e.g. longitudinal ventilation with jet fans

Review of *JASMINE* cases

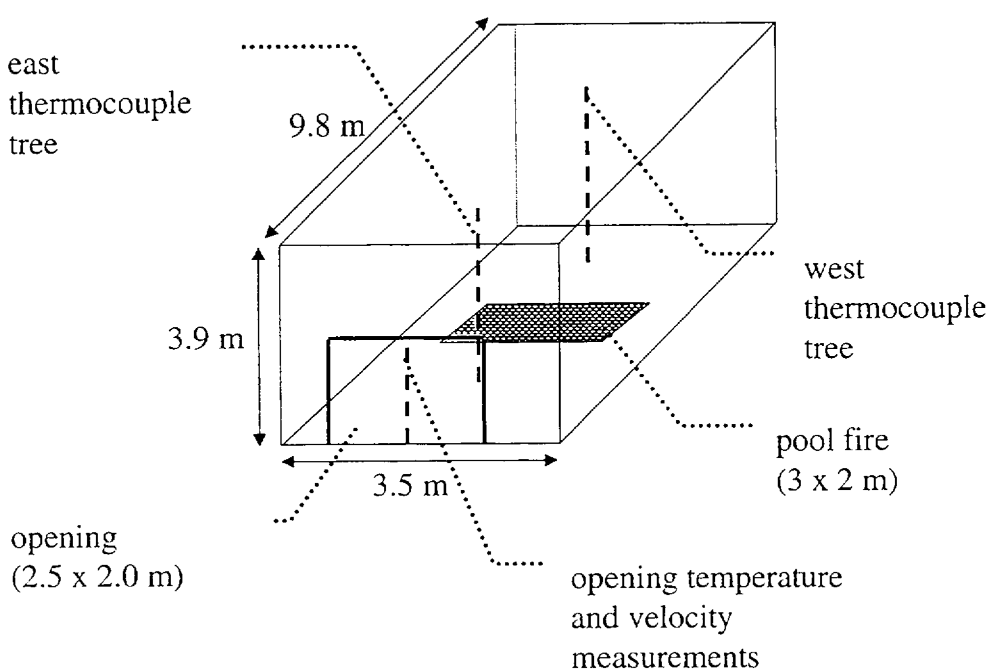
- Various validation cases undertaken in 1980s, e.g.
  - Steckler room fire
  - Lawrence Livermore test cell
- More recent compartment fire examples:
  - post-flashover, ventilation controlled scenarios for the offshore industry
  - CIB W14 'blind' simulations of a two crib enclosure fire
- Tunnel ventilation
  - Memorial Tunnel test programme

BRE

Fire Safety Engineering for the offshore industry

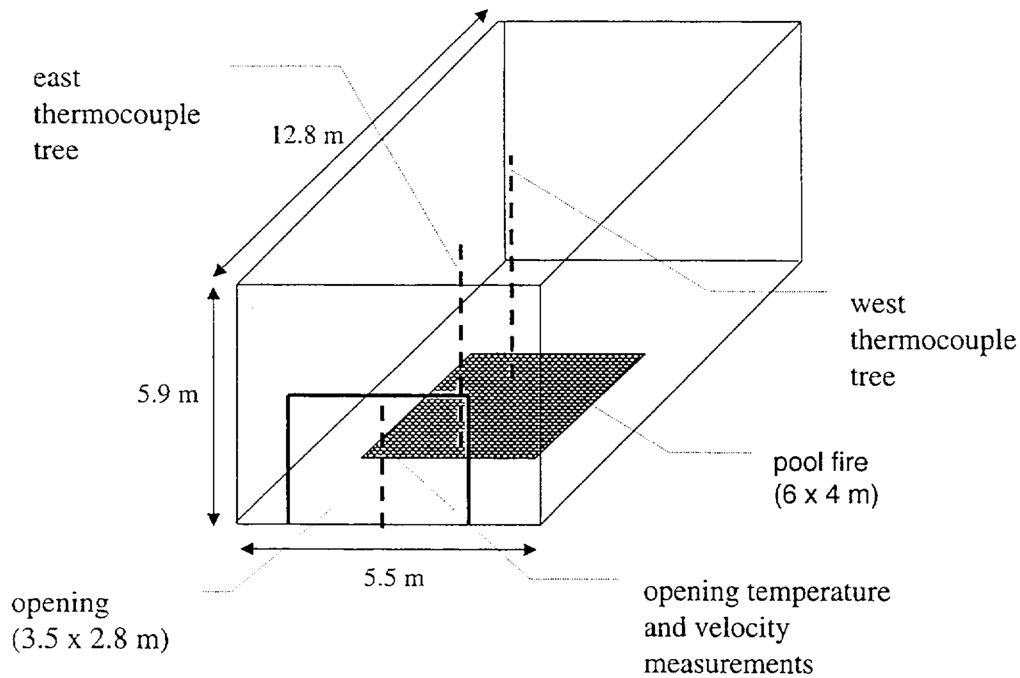
- Series of confined pool & jet fires
- Pool fires in enclosures with different opening sizes
  - creating various fully developed fire scenarios
  - post-flashover conditions
  - ventilation controlled burning
- Measurements:
  - gas temperatures
  - incident thermal fluxes
  - opening flow (vent) rates
  - species concentrations (O_2, CO_2, CO)

Test PF2A ~ 10 MW steady burn

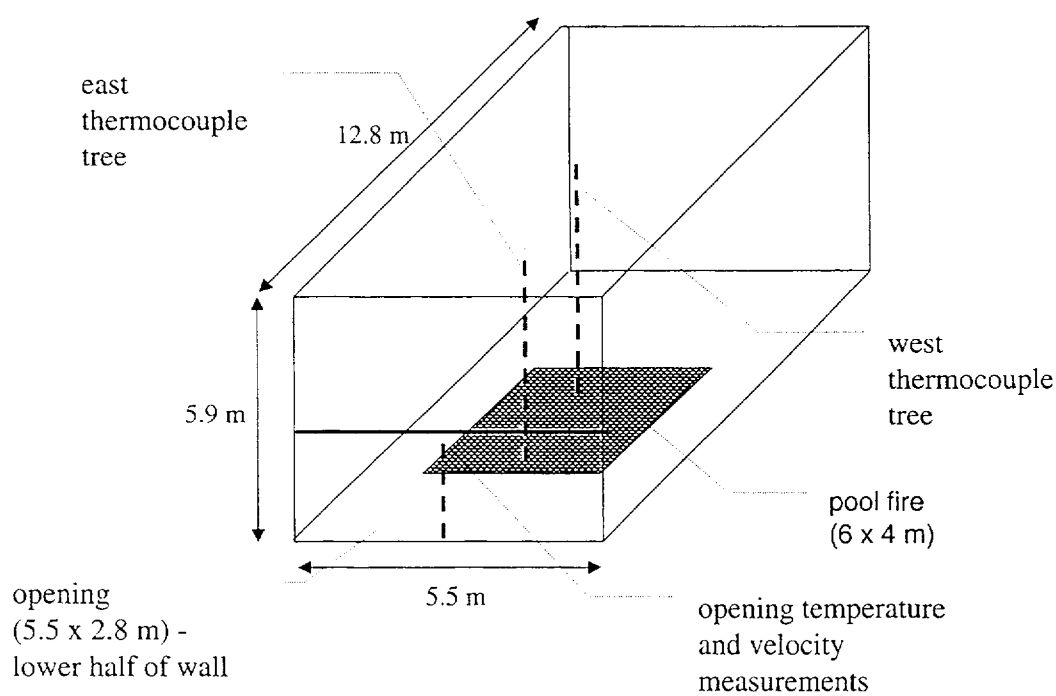


BRE

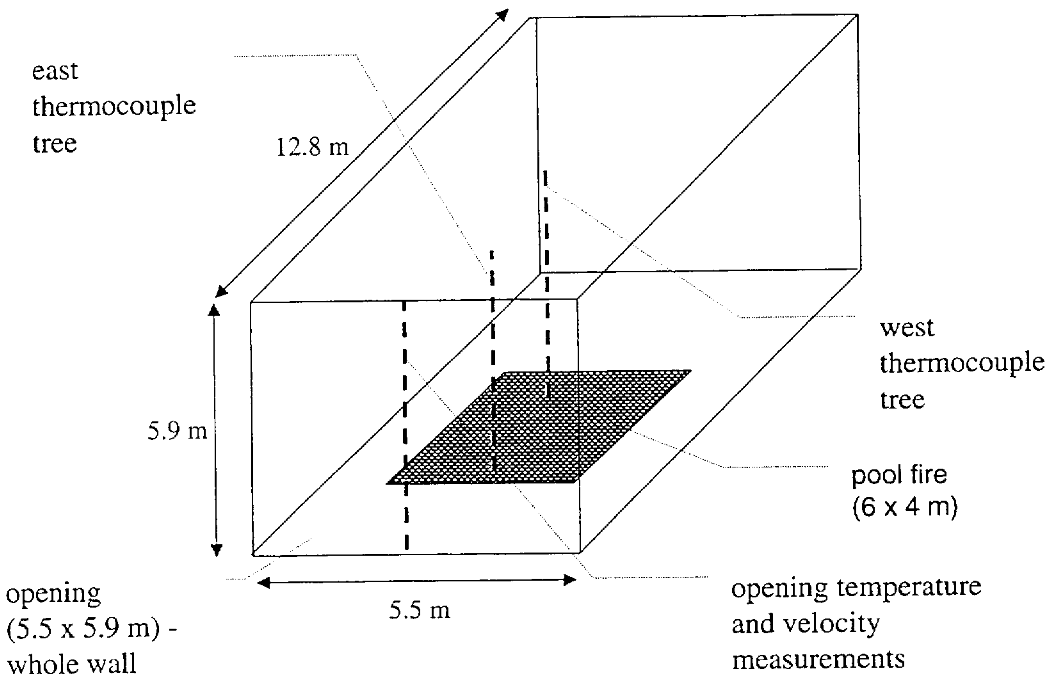
Test PF10 ~ 30 MW steady burn



Test PF11 ~ 45 MW steady burn

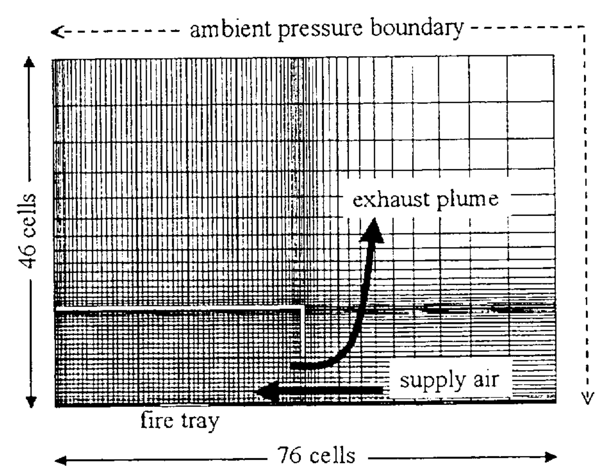


Test PF13 ~ 80 MW steady burn



JASMINE details

- Cartesian mesh
  - small compartment - 100,000 elements
  - large compartment - 200,000 elements
  - symmetry plane imposed
- k, ε turbulent closure
  - using buoyancy source terms
- steady-state (mainly) and transient simulations
- eddy break-up combustion
- six-flux and dtm radiation models



Combustion modelling

- Assumed a one-step, infinitely fast process:

  1 kg fuel + s kg oxygen $\rightarrow$ $(1+s)$ kg product

  - approximated Statoil Sleipner fuel as heptane

    $$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$$

  - local gas phase reaction modelled using eddy break-up

    $$R_{fu} = C_R \rho \frac{\varepsilon}{k} \min\left(m_{fu}, \frac{m_{O_2}}{s} \right)$$

Radiation modelling

- Six-flux radiation model
  - radiation along the 3 Cartesian directions
    - energy balance within each CFD mesh element
- Discrete transfer model
  - radiation in 'all' directions from boundary cells
    - does not necessarily use the CFD mesh
- Truelove's mixed grey-gas absorption-emission model
  - local absorption coefficient a function of:
    - temperature
    - CO_2 & H_2O concentration (three bands) plus soot (broad band)

Boundary heat transfer

Convection flux (CFD solver)	+	Radiation flux (six-flux model)	$\Leftrightarrow$	Conduction flux into solid

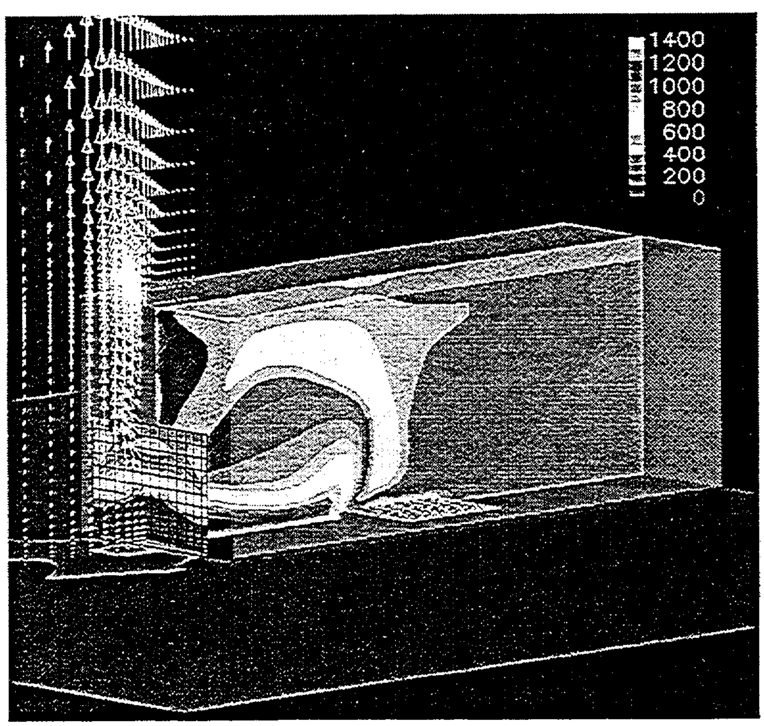
quasi-steady, semi-infinite, 1-D approximation

$$\dot{q}''_{cond} = \frac{\kappa_w}{\delta}(T_w - T_0)$$

thermal conduction depth given approximately by:

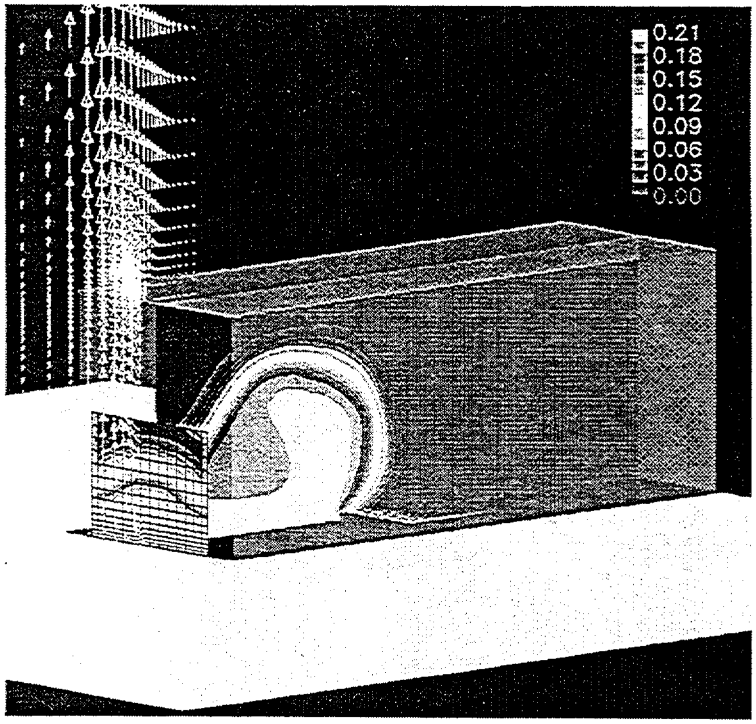
$$\delta = \frac{2}{\sqrt{\pi}}\left(\frac{\kappa_w t}{c_w \rho_w}\right)^{1/2}$$

PF2A quasi-steady temperature prediction

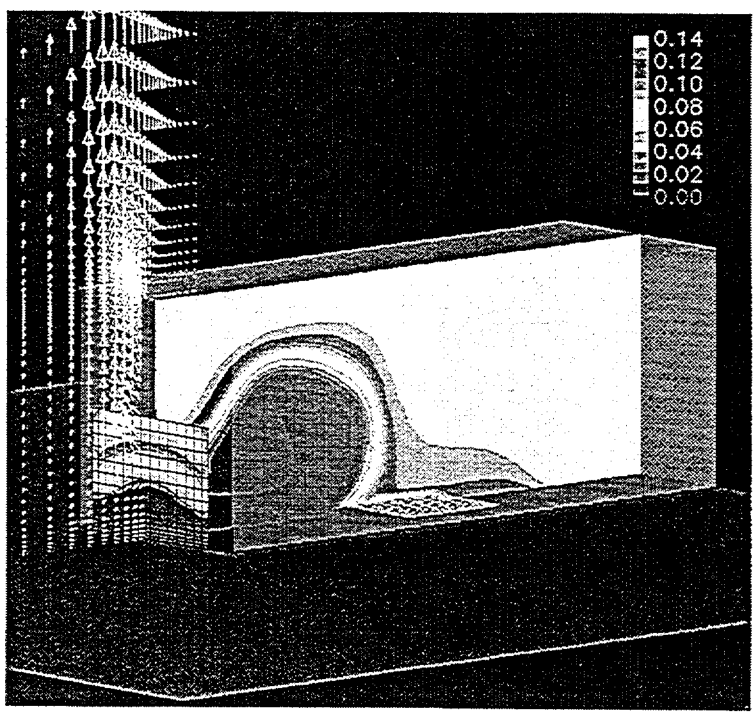


BRE

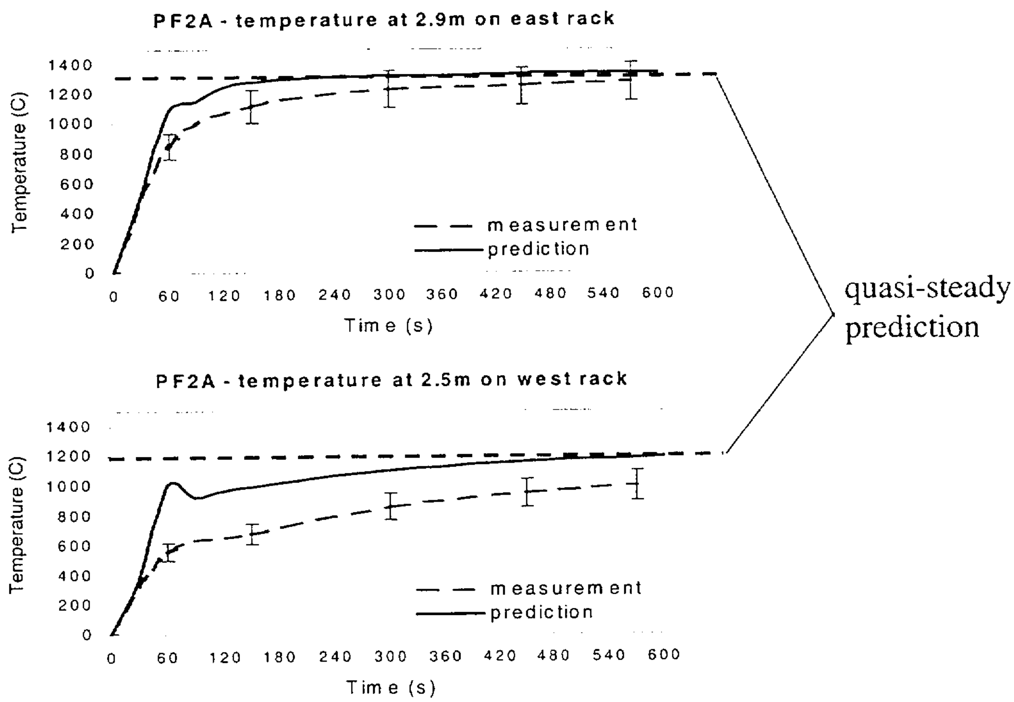
PF2A quasi-steady O_2 prediction



PF2A quasi-steady CO_2 prediction



PF2A transient simulation



Quasi-steady Vent Flow Rates

Test	Opening mass flow rate (kg s^{-1})			
	Measured		Predicted	
	in	out	in	out
PF2A	2.8	-3.1	2.8	-3.0
PF10	8.2	-7.5	6.5	-7.2
PF11	14.9	-11.3	9.9	-10.8
PF13	41.1	-36.6	31.7	-33.3

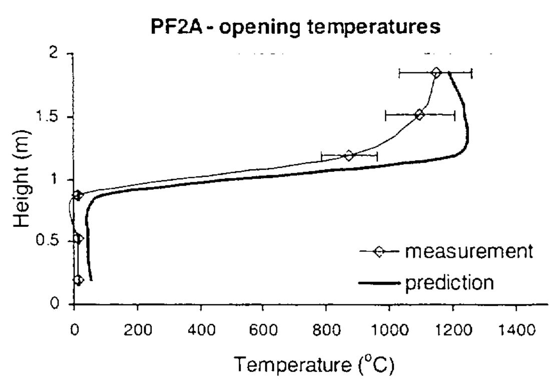
Quasi-steady Concentrations

Test	O_2 conc. (%)		CO_2 conc. (%)		CO conc. (%)	
	Measured	Predicted	Measured	Predicted	Measured	Predicted
PF2A	0.6	0.6	9.1	13.8	5.4	-
PF10	1.7	0.6	5.4	13.6	6.1	-
PF11	0.1	0.7	4.9	13.6	> 6	-
PF13	no data	0.6	no data	13.8	no data	-

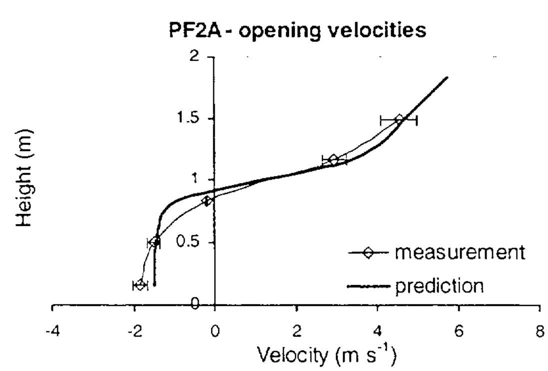
(measurement location near top of opening)

Σ ~ predicted CO_2

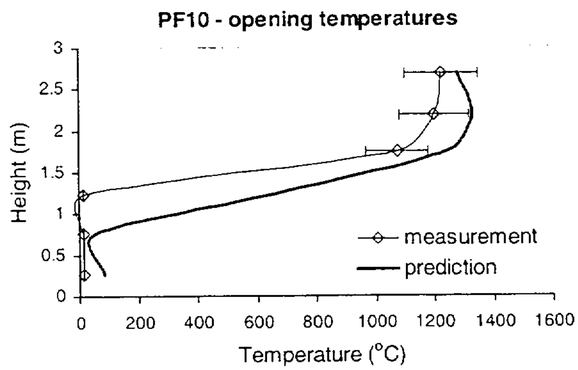
PF2A opening (vent) profiles

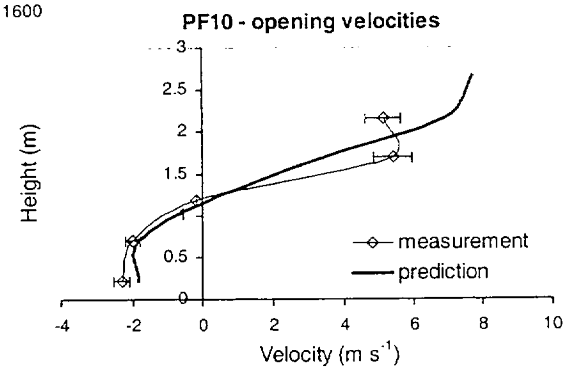


10 % error bars imposed on measurement data

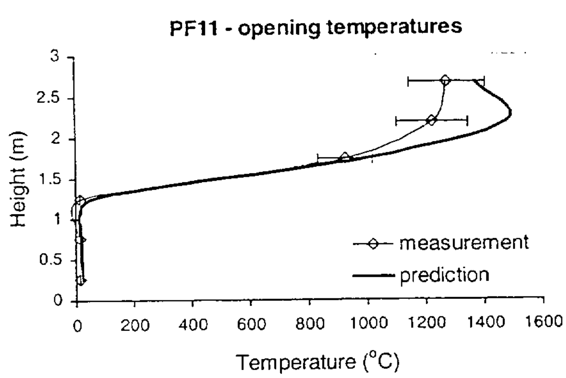


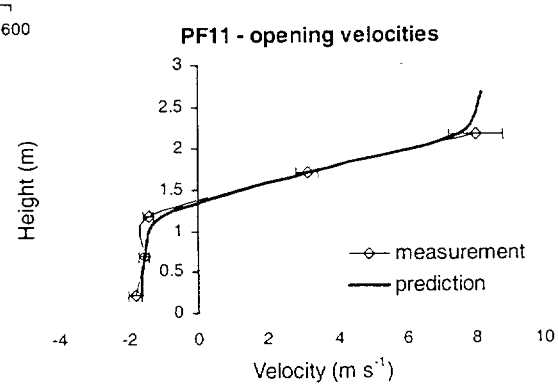
PF10 opening (vent) profiles



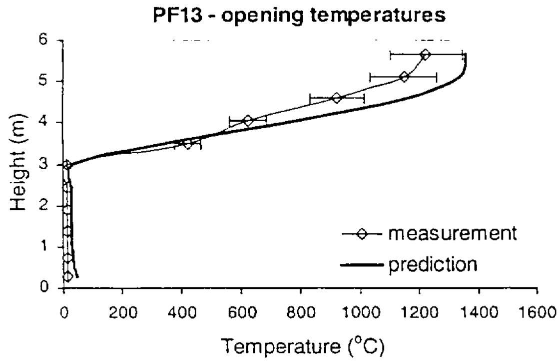


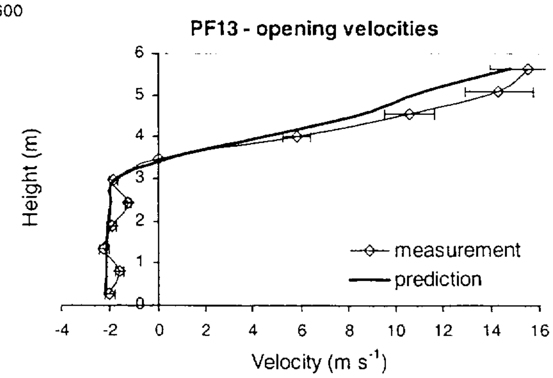
PF11 opening (vent) profiles



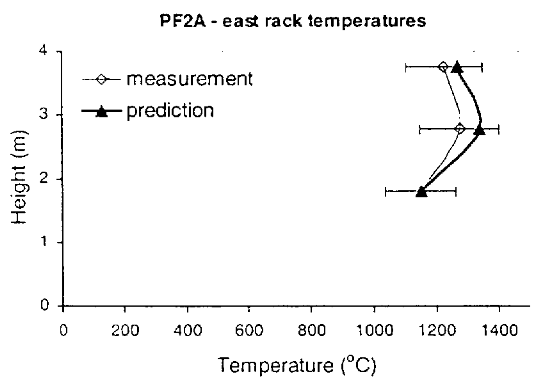


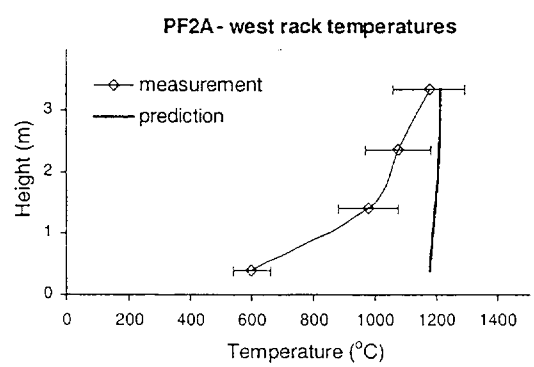
PF13 opening (vent) profiles



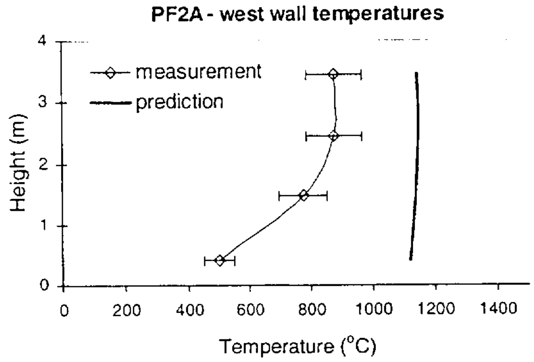


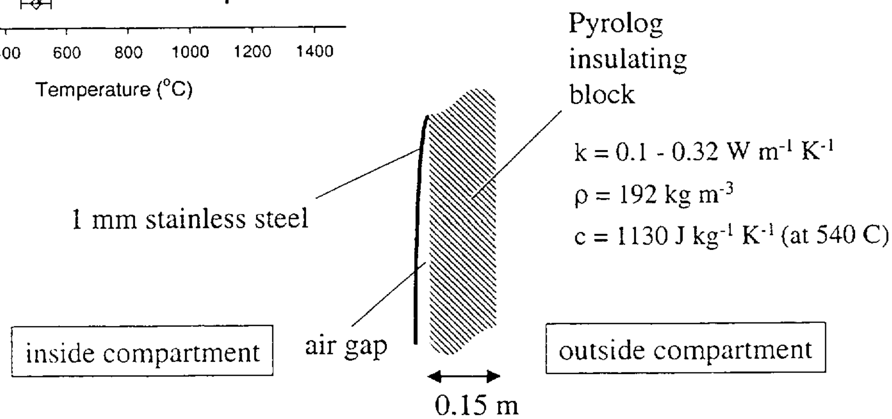
PF2A internal temperatures





PF2A west (back) wall temperature





Post-flashover scenario - conclusions

- Successful application of a CFD fire model to post-flashover, fully developed compartment fires demonstrated
  - ventilation controlled (but not oxygen 'starved') regime
- Combination of one-step chemistry and an eddy break-up combustion model proved sufficient to reproduce the main species predictions
- The six-flux and discrete transfer radiation models performed successfully

CIB W14 Round Robin of 'blind' simulations

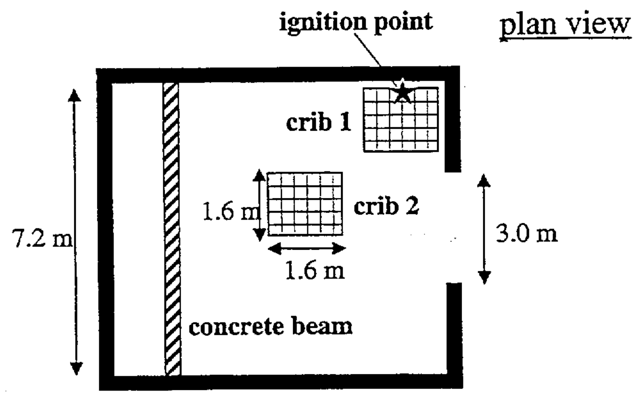
- An rigorous evaluation of existing fire models for a wide range of scenarios
  - single plume under a hood (1996)
  - ***single room with a door/vent opening*** (1998)
  - other scenarios planned
- All issues being addressed
  - numerical methods, physical sub-models, documentation, the user
- *JASMINE* simulations performed as part of the CFD evaluation

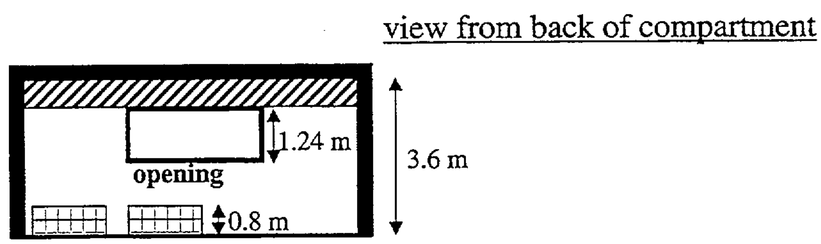
Round Robin Scenario B

- Conducted at VTT in 1980s
  - compartment with single opening
  - concrete block construction
  - wood crib fire sources
  - measurements
    - temperature
    - gas species
    - wall fluxes

BRE

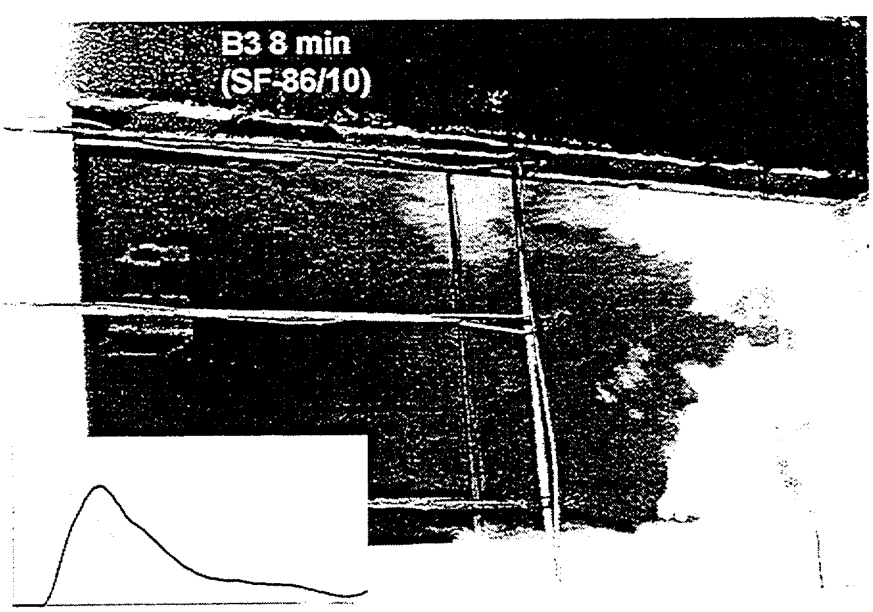
Scenario B3 geometry



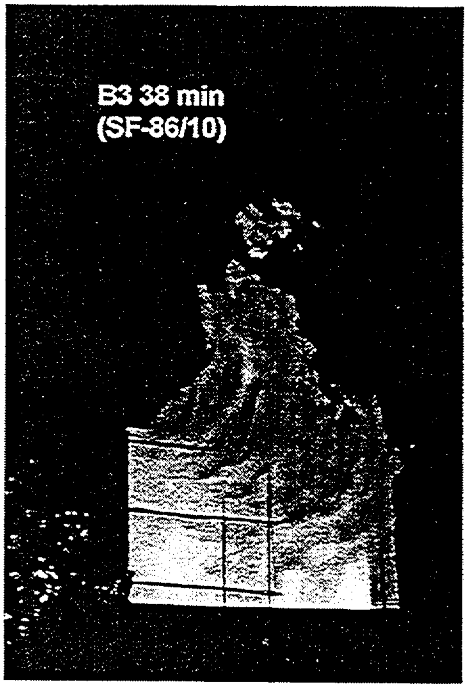


B3 - Test at 8 mins

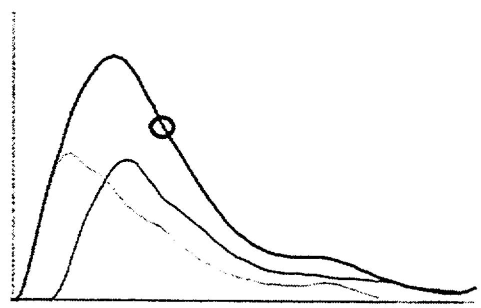
- Corner crib fully involved



B3 - Test at 38 mins

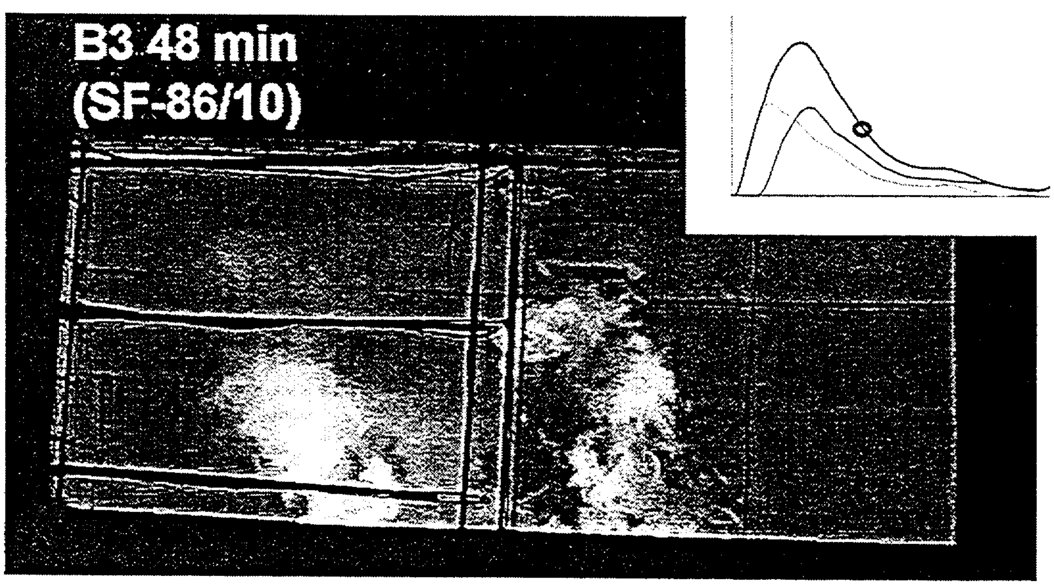


- Room flashed over
- Flames emerging from window



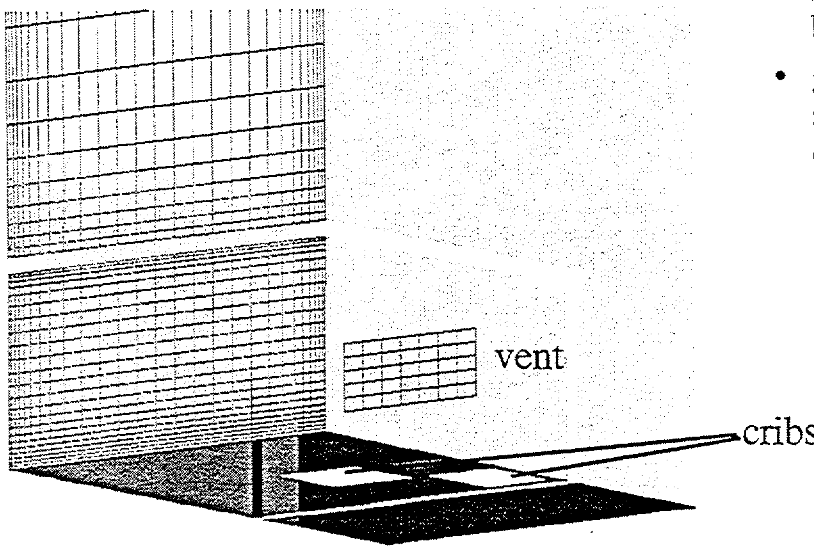
B3 - Test at 48 mins

- Fire decaying



Geometry and mesh

- Domain extended into Test Hall

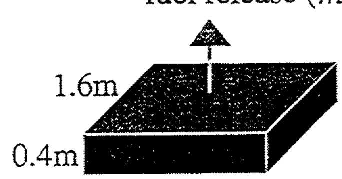


- 46,000 cells
  - finer grid at solid boundaries
  - grid sensitivity study with 370,000 cells

Combustion model

- Simplified crib
  - fuel released from top surface

  $\dot{Q} = \dot{m}\Delta H_{eff}$



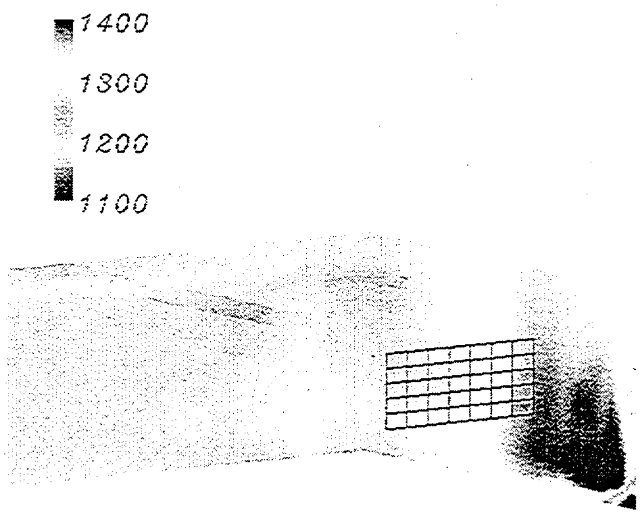
- Approximate one-step chemistry

  $CH_2O + O_2 \rightarrow CO_2 + H_2O$

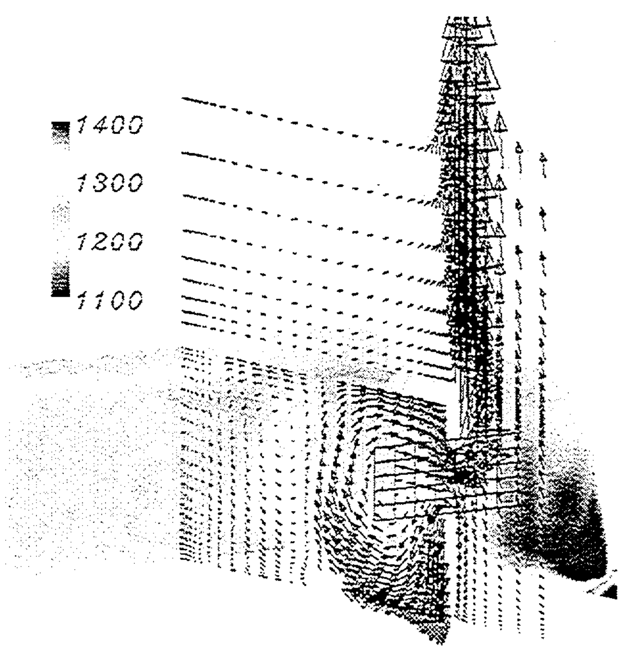
- Eddy dissipation reaction mechanism

$$S_{fu} = -\rho \frac{\varepsilon}{k} C_R \min\left(m_{fu}, \frac{m_{o2}}{s} \right)$$

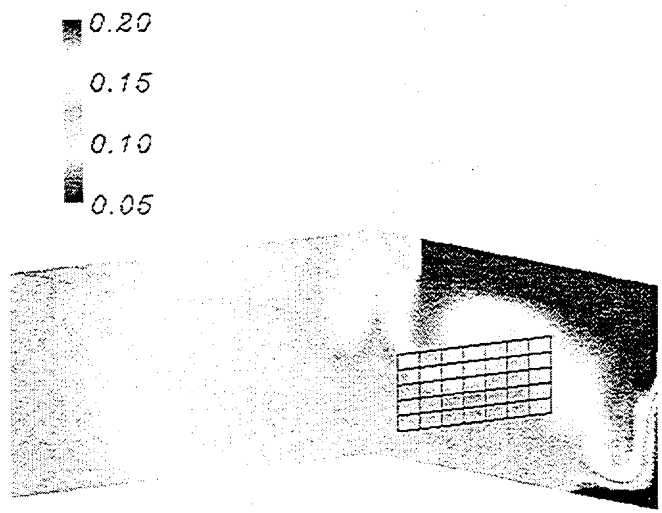
Predicted temperature at flashover



Predicted temperature at flashover

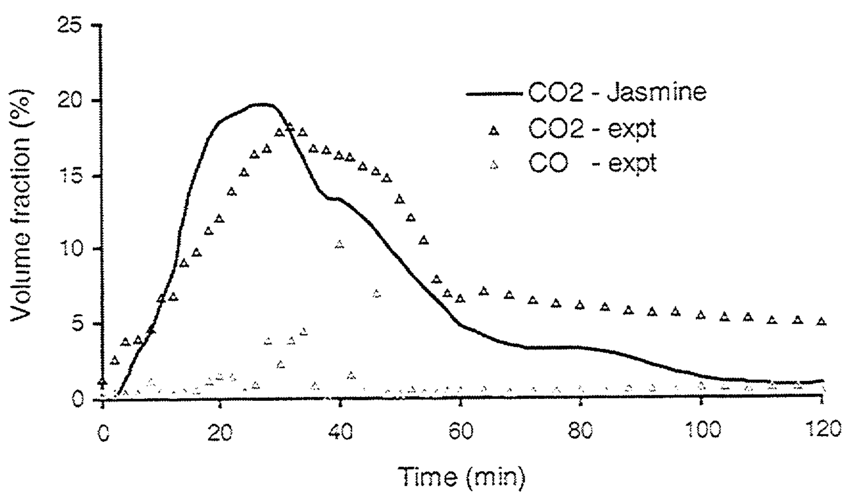


Predicted CO_2 at flashover

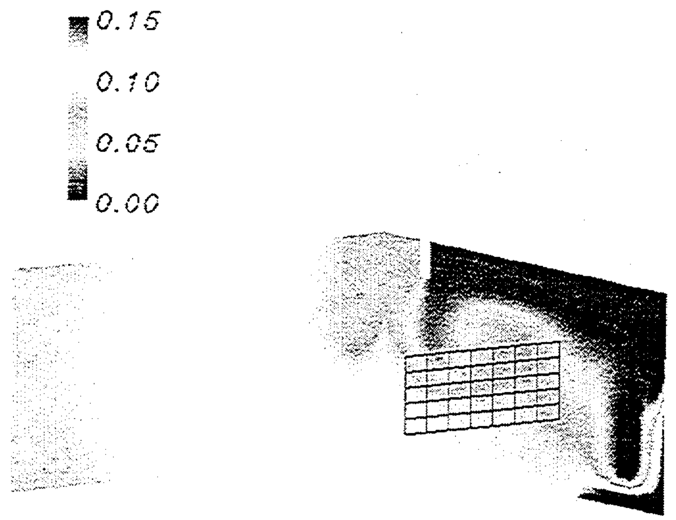


Predicted & measured CO_2

- Under centre of ceiling

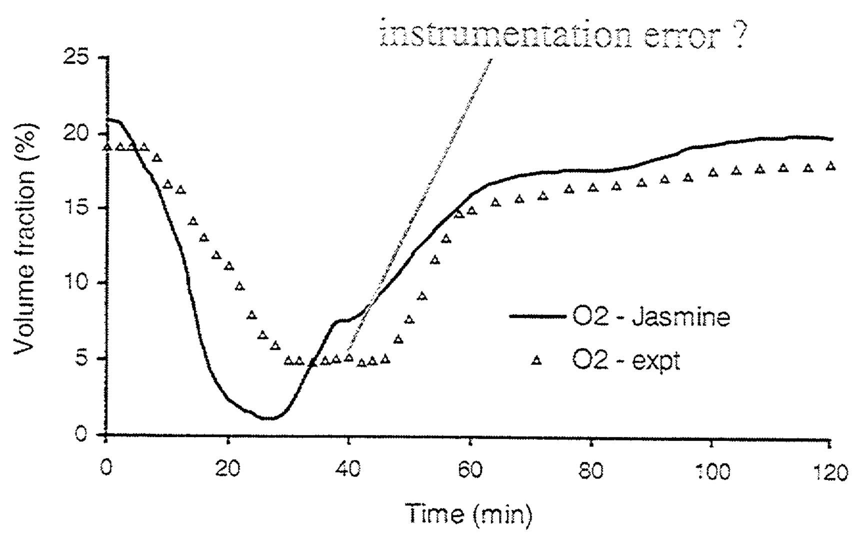


Predicted O_2 at flashover



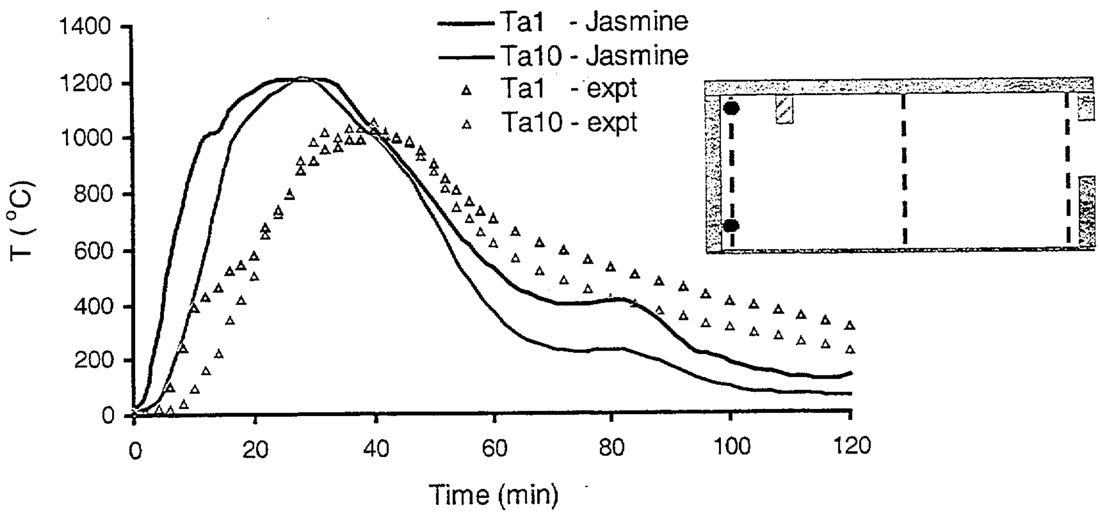
Predicted & measured O_2

- Under centre of ceiling



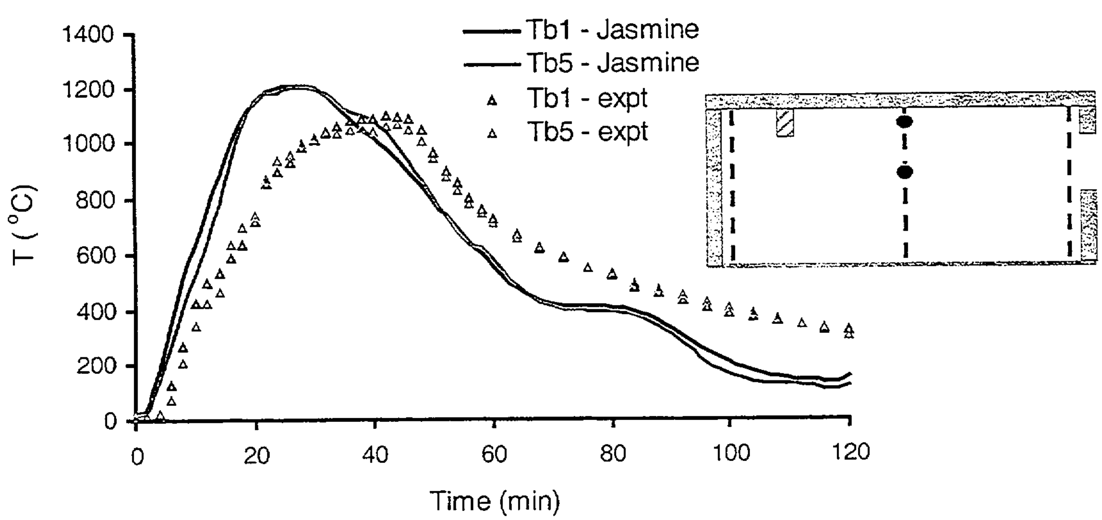
Predicted & measured temperature

- Rear thermocouple tree



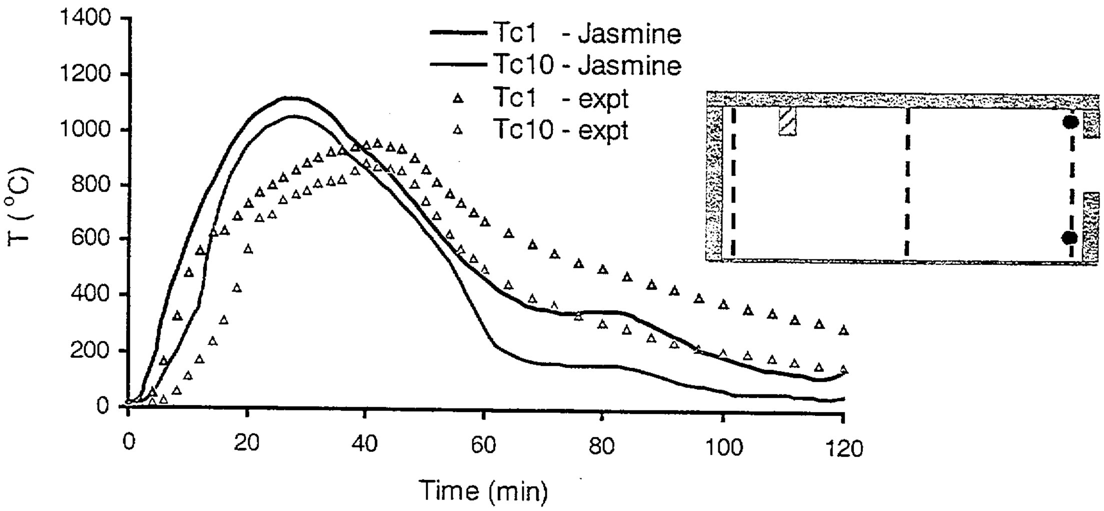
Predicted & measured temperature

- Centre thermocouple tree



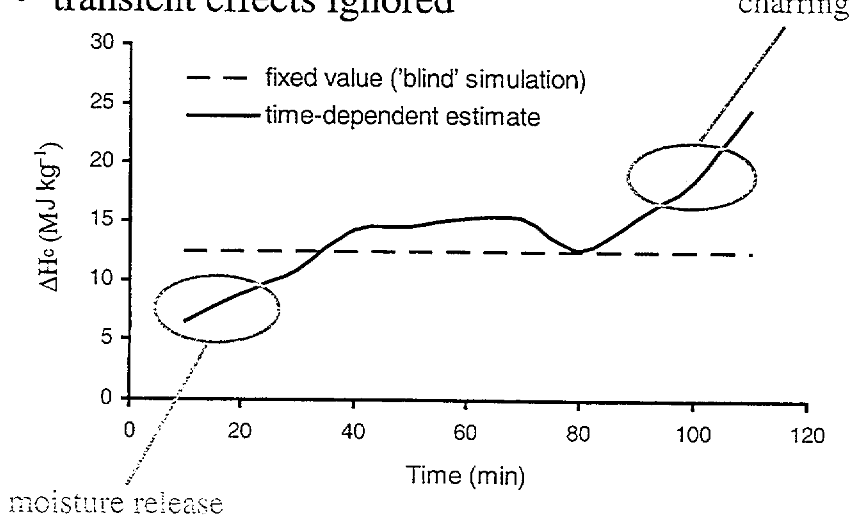
Predicted & measured temperature

- Corner thermocouple tree

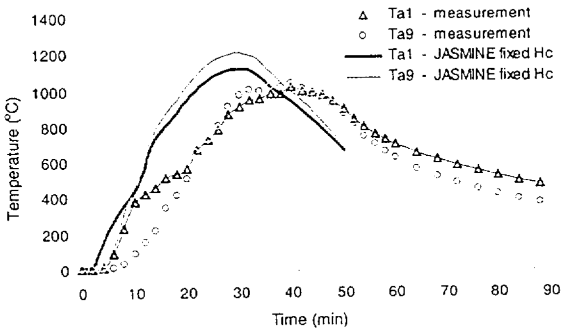


Effective heat of combustion

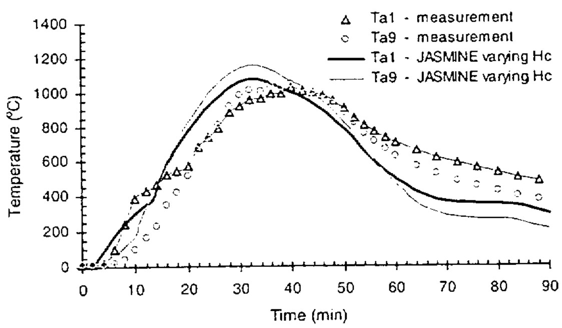
- Constant value used for 'blind' simulation
  - transient effects ignored



'Open' simulations - temperature

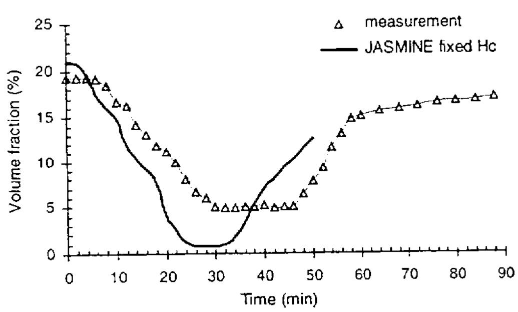


- Corrected geometry
- Fixed ΔH_C

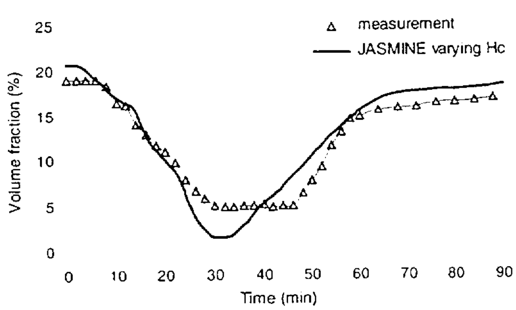


- Corrected geometry
- Varying ΔHC

'Open' simulations - O_2 concentration



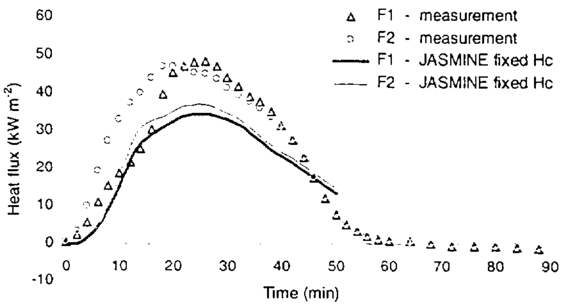
- Corrected geometry
- Fixed ΔH_C



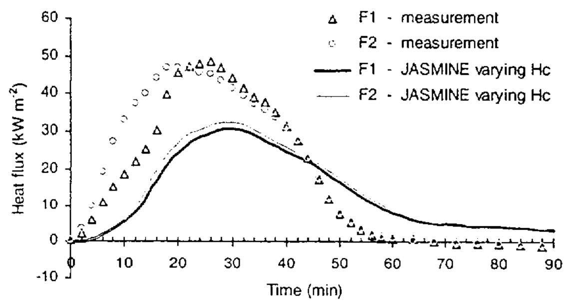
- Corrected geometry
- Varying ΔHC

![BRE]

'Open' simulations - wall fluxes



- Corrected geometry
- Fixed ΔH_C



- Corrected geometry
- Varying ΔHC

CIB W14 scenario - conclusions

- Overall agreement between prediction and measurement good
  - peak temperatures within 15%
  - species concentrations similar
- Temporal shift and discrepancy in decay stage
  - variation in ΔH_{eff} an important factor here
- Solid boundary heat fluxes under-predicted during 'flashover'
  - 'simple' quasi-steady conduction model
  - soot formation

Risk-Informed, Performance-Based Fire Safety Analysis of Turbine Buildings in Nuclear Power Plants

Moni Dey

U.S. Nuclear Regulatory Commission (USNRC)

Objective

- Identify challenges for risk-informed, performance-based analyses
- Discuss benefits of approach

Outline

- Background
- Statement of problem
- Scenario development and analytical methods
- Key issues for study

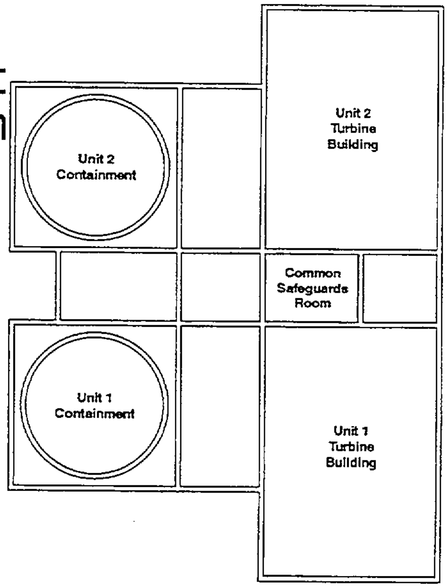
Background

- USNRC regulates the radiological safety of nuclear power plants
- USNRC is improving its capability to conduct probabilistic risk analysis (PRA) of fires
- Effort presented here examines ability to analyze smoke effects in PRAs

Statement of Problem

- Several turbine-generator fire events have occurred worldwide
- Safety equipment in US plants are generally protected from thermal effects
- Smoke may impede the safe shutdown of the nuclear reactor

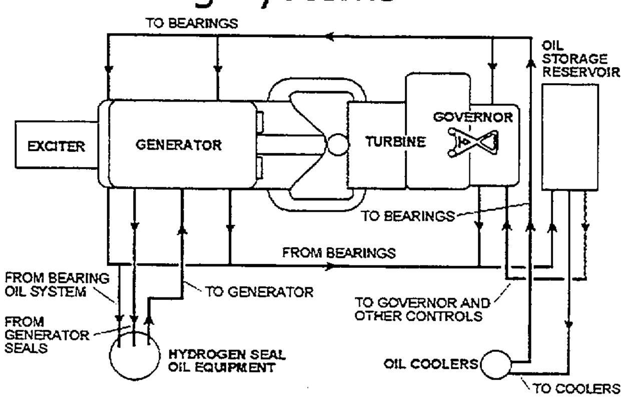
Typical Plant Building Plan



Distribution of Fires in Nuclear Power Plants

Turbine building	18 %
Auxiliary building	15 %
Diesel generator bld.	15 %
Reactor building	13 %
Containment and switchyard	16 %

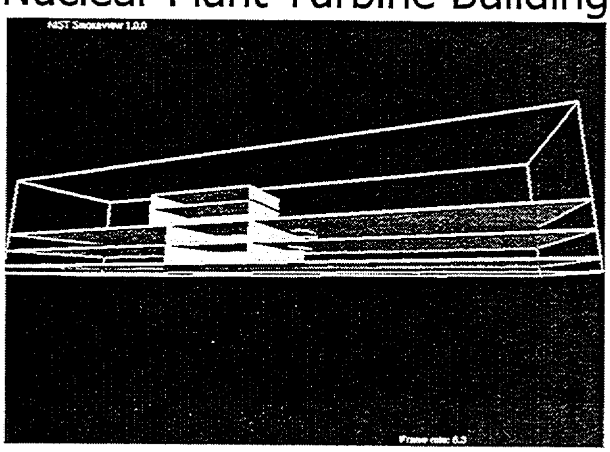
Schematic of Turbine-Generator Lubricating Systems



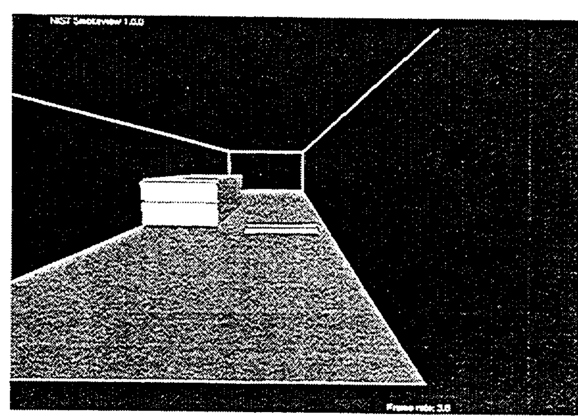
Impact of Smoke on Reactor Shutdown

- Smoke transport from turbine building to rooms containing emergency equipment for reactor shutdown
- Descent of smoke layer to control room

Nuclear Plant Turbine Building



Nuclear Plant Turbine Building



Scenario Definition for Risk Assessment

- Magnitude and frequency of fires
- Fire protection system failure rates
- Probability of manual suppression
- Isolation of ventilation systems
- Impact of smoke on equipment and manual actions for reactor shutdown

Distribution and Fire Frequency of Combustible Material

Combustible Material	Percentage (%)	Frequency (fires/yr.)
Oil	72.7	2.1E-2
Electrical Components	9.1	2.6E-3
Hydrogen	7.3	2.1E-3

Distribution of Fires by Location

Location	Percentage (%)	Frequency (fires/yr.)
T-G bearings	27.3	7.9E-3
Below opera-ting floor	14.5	4.2E-3
Oil tanks	7.3	2.2E-3

Fire Protection System Failure Rates

Type of System	Probability of failure per demand
Manual Spray	5.6E-3
Auto Sprinkler – Wet Pipe	1.5E-4
Auto Spray – Open Head	2.3E-3

Key Issues for Assessing Smoke Levels

- Fire source magnitude
- Capability of zone models to predict smoke transport to vital rooms
- Adequacy of zone models to estimate smoke layer descent for fires not directly under the hatch

Potential Impact of Smoke

- Corrosion
- Circuit bridging
- Fouling of open electrical contacts
- Fouling of fine mechanical movement
- Human actions

Challenges for Quantifying Event Sequences

- Fire source and frequency
- Effect of smoke on equipment and human actions for reactor shutdown
- Estimating degree of conservatism

Concluding Remarks

- Including smoke effects in a probabilistic risk assessment may be feasible
- Completion of analyses will yield further insights, but large uncertainties are expected
- Approach will provide benefits, even with large uncertainties in analytical results

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10. SUPPLEMENTARY NOTES
See NUREG/CP-0170 for summary of 1st meeting.

11. ABSTRACT *(200 words or less)*

The 2nd meeting of the International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications was hosted by the Institute for Protection and Nuclear Safety (IPSN) and held in the IPSN offices at Fontenay-aux-Roses, France on June 19 and 20, 2000. The Organizing Committee for the meeting included Remy Bertrand from the IPSN (France), and Moni Dey from the U.S. NRC. Eighteen experts from five countries attended this international meeting.

The purpose of the 2nd meeting was mainly to finalize the definition of a bench mark exercise to evaluate zone and Computational Fluid Dynamics (CFD) fire models for application in nuclear power plants. This exercise was identified as the first task of the project and was aimed at evaluating the capability of fire models for simulating cable tray fires of redundant safety trains in nuclear power plants. The discussions at the meeting resulted in three main issues regarding input parameters for the scenarios in the benchmark exercise: (1) specification of the fire source; (2) modeling of the target; and (3) value for the lower oxygen limit. The specification of the fire source is fundamental to the input for fire models, and can significantly affect the predicted thermal environment. A consensus was reached on the characterization of the heat release rates for the scenarios in the benchmark exercise. Although agreement was reached on the specification and values for the target model and lower oxygen limit to be used for the benchmark exercise, participants did not reach a consensus on the most appropriate specification that could be recommended for model users. The specification of the above three parameters could lead to "user effects," and are the largest sources of uncertainty in the predicted results from the input parameter specification process for the types of scenarios examined in the benchmark exercise.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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