Appendix E: Benchmark Analysis with MAGIC, Daniel JOYEUX, and Olivier LECOQ-JAMMES, CTICM, France

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

Benchmark Exercise # 1 - SUMMARY

Cable Tray Fires of Redundant Safety Trains

Simulations with MAGIC (V 3.4.7)
(Revised September 11, 2000)

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1. INTRODUCTION

We used for the benchmark (references are given in the following text) the 2-zone model MAGIC version 3.4.7. MAGIC is a classic thermal model of fire in multi-compartment building simulation.

The simulations were made according to the document revised in September 2000.

All results have been given in an additional document and only results of three variables are given in this report :

- gas temperature
- surface temperature of target cable
- centerline temperature of target cable

Reference :

International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications
Benchmark Exercise # 1
Cable Tray Fires of Redundant Safety Trains
(Revised September 11, 2000)
Simulations with MAGIC (V 3.4.7)

2. THE MODEL MAGIC

The software MAGIC (Global Analysis Model for fire into Compartments) is a numerical tool which simulates the behaviour and growth of a fire occurring into adjacent rooms.

It is made of modules accessible from the same front panel : a pre-processor, a computation code called MAGIC_M, a post-processor and an animation module.

The version 3.4.7 proposes physical modelling as : modelling improvement of linear fires, modelling improvement of cable thermal behaviour, mass consumption control, improvement of initial condition and density calculation, improvement of the net radiation flux received by a target placed in a room contiguous to fire room, temperature calculation in the ceiling-jet and in the plume.

3. APPLICATION TO THE BENCHMARK EXERCICE : PART I

3.1 RESULTS PART I

The following table gives the results for these four variables in part I.

Part I	$T_{upper\ layer}$(°C)	$T_{lower\ layer}$(°C)	$T_{surface\ target}$(°C)	$T_{centerline\ target}$(°C)
Base case	63.2	29.4	45.7	27.1
Case 1	62.7	29.4	72.8	27.1
Case 2	63.0	29.4	59.9	27.1
Case 3	63.1	29.4	50.3	27.1
Case 4	63.5	28.9	46.6	27.1
Case 5	60.8	29.3	44.7	27.1

Table 1 : Overview of results Part I

3.2 ANALYSIS OF RESULTS PART I

According to the results part I, we can notice the three following points:

- low temperature of gases
- low temperature of target cable
- non ignition of target cable whatever is the distance from fire centerline

4. APPLICATION TO THE BENCHMARK EXERCICE: PART II

4.1 RESULTS PART II

The following table gives the results for these four variables in part II.

Part II	$T_{upper\ layer}$(°C)	$T_{lower\ layer}$(°C)	$T_{surface\ target}$(°C)	$T_{centerline\ target}$(°C)
Base case LOL=0%	180.2	35.7	134.5	49.4
Base case and case 1 at case 8	169.2	31.5	100.7	37.5
Case 9	168.4	30.7	100	37.5
Case 10	169.1	30	100.6	37.5
Case 11	169.2	31.5	101	37.7
Case 12	169.2	31.5	41.4	29.6
Case 13	169.2	31.5	111.7	78.2

Table 2 : Overview of results Part II

4.2 ANALYSIS OF RESULTS PART II

According to the results part II, we can notice the two following points :

- limitation of heat release between 10 and 15 minutes due to the lack of oxygen
- no damage on target because the centerline target cable temperature is below 100°C.

4.3 ADDITIONAL CASE

We added a case on part II (see the table 3 below) with fire source at 2.1 m ; so ventilation is in the upper layer. According to the results of this additional case, we observe no limitation of rate of heat release.

Part II	Rate of heat release (MW)	D (m)	Door	Vent. Sys.	Target	Elev. (m)
Base Case	1 MW	6.1	Closed	Off	Power	3.4
Additional case	3 MW	3.1	Open	On	Power	2.1

Table 3 : Overview of additional case

- The temperature curves are shown in figures 1, 5 and 8.
- The rate of heat release is shown in figure 3.

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- The concentration of O_2 is shown in figure 4.
- The flow rate through vents and door is shown in figure 6.
- The radiative flux on target is shown in figure 7.

The following maximum temperatures are reached :

- upper layer temperature = 350°C
- target surface temperature = 330°C

MAGIC V 3.4.7 / BENCHMARK CTICM / PART II additional case

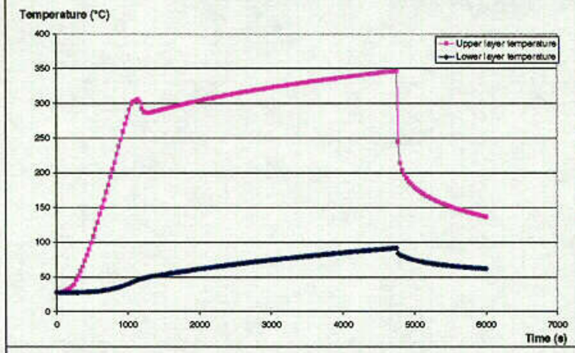

Figure 1 : Upper and lower layer temperature

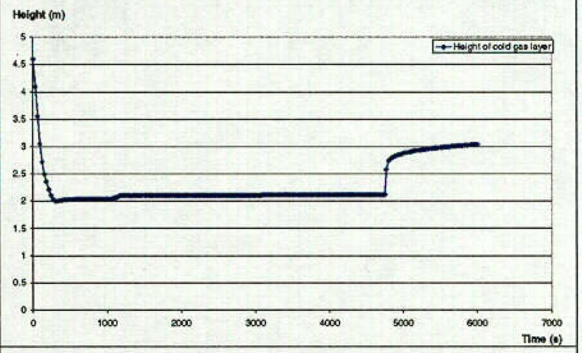

Figure 2 : Height of cold gas layer

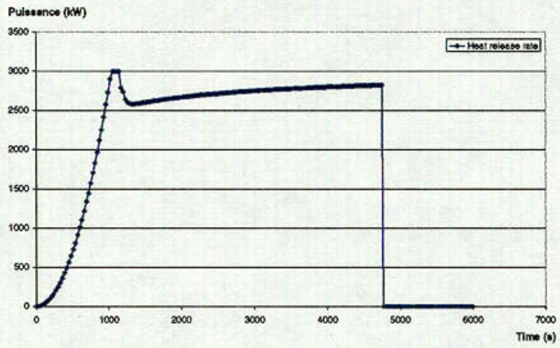

Figure 3 : Heat release rate

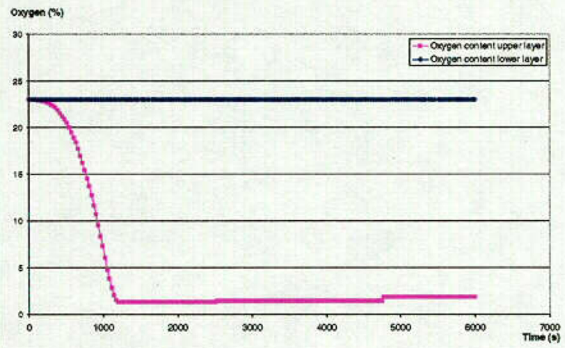

Figure 4 : Oxygen concentration

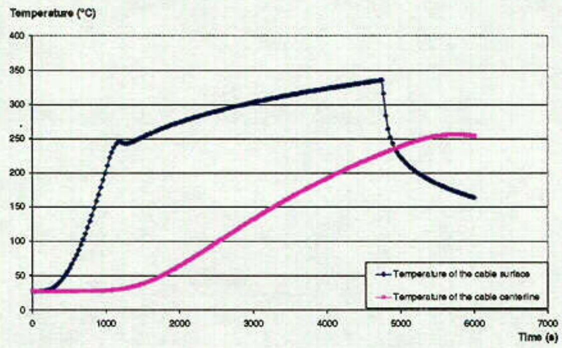

Figure 5 : Cable temperature

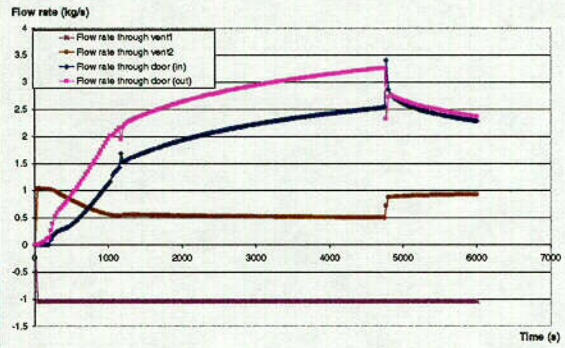

Figure 6 : Flow rate through vents and door

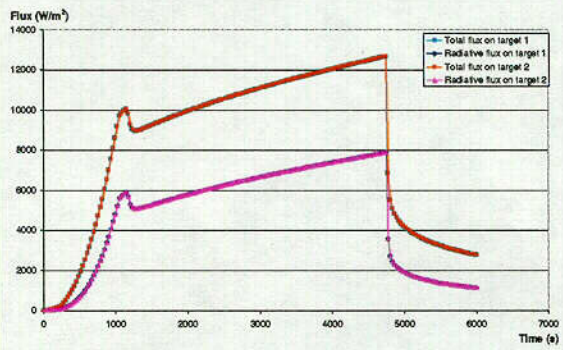

Figure 7 : Radiative flux on target

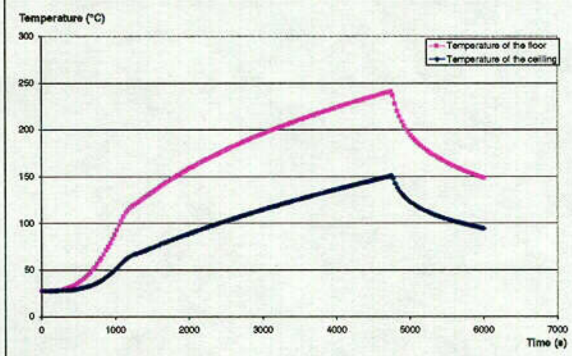

Figure 8 : Floor and ceiling temperature

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5. CONCLUSION

According to the simulations, the following comments about the code MAGIC can be given :

- If the target is into the plume, we have a simplified prediction of the target temperature.
- The use of cable target gives better information than the use of a simple target.
- The mechanical ventilation model is an important parameter in this benchmark because it controls the rate of heat release.
- Target centerline temperature = 260°C

According to the criteria for cable damage given by the benchmark (centerline temperature of 200°C), cable damage is observed in this additional case.

According to the different cases of the benchmark, it should be interesting to define more sensitive case for models.

In part I, a higher rate of heat release should be used with a parameter study leading to the ignition or non-ignition of the cable.

In part II, lower source height and ventilation in the hot layer should be used for occurrence of damage criteria.

Appendix F: Benchmark Analysis with COCOSYS, Walter KLEIN-HESSLING, GRS, Germany

Technische Notiz

TN – KLH 2/2000

COCOSYS Calculations for Benchmark Exercise #1
Cable Tray Fires of Redundant Safety Trains

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

W. Klein-Heßling

11. Dezember 2000, Revision 0

1 Introduction

The objective of the fire modelling analyses in a probabilistic risk analysis (PRA) is to estimate the conditional probability of safe-shutdown equipment damage given a fire. Fire modelling results are necessary in order to make this estimate. In the "International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications" different fire codes will be compared and the applicability of the codes for typical questions rising up in PRA's will be evaluated. From the results gained a consensus report will be developed by the participants. The report will be in the format of a user's guide for applying fire models for NPP fire safety design and assessment.

For the comparison of the codes a first benchmark exercise (see Appendix A) has been set up. This benchmark consists of two parts: a trash bag fire to analyse the possibility for an ignition of a cable tray for various distances to the tray, and a cable tray fire to evaluate the possibility of a damage of another tray in a certain distance or on certain evaluations. The comparison between codes can be used to understand the modelling of the physics in them. In project following codes are used (by different institutions): FLAMME-S (IPSN), CFAST (NRC, NIST, VTT, BRE/NII, ???), COCOSYS (GRS), CFX (GRS), MAGIC (EDF), JASMINE (BRE/NII) and WPIFIRE (WPI).

In this technical note the COCOSYS results will be presented.

2 Containment Code System COCOSYS

The Containment Code System (COCOSYS) is being developed and validated for the comprehensive simulation of severe accident propagation in containments of light water reactors [1, 2, 3]. This system is to allow the simulation of all relevant phenomena, containment systems and conditions during the course of design basis accidents and severe accidents. In COCOSYS, mechanistic models are used as far as possible for analysing the physical and chemical processes in containments. Essential interactions between the individual processes, like e.g. between thermal hydraulics, hydrogen combustion as well as fission product and aerosol behaviour, are treated in an extensive way. With such a detailed approach, COCOSYS is not restricted to relevant severe accident phenomena, but will also be able to demonstrate interactions between these phenomena as well as the overall behaviour of the containment.

The complete system is divided into several so-called main modules (Fig. 2-1). Each main module is a separate executable program used for specified topics of the whole process. Between these main modules the communication is realised via a driver program using PVM [4]. The separation into different main modules considers that the strongest coupling between the main modules is on the time step level to avoid a high-frequency data transfer. The amount of data transferred is relatively small, due to a suitable distribution of the complete topology and topics of the systems to the different main modules. The complete separation into several executable programs inhibits side effects from one to other modules. Furthermore, the maintenance effort of the complete system decreases significantly. To reduce the complexity of the whole system, a direct communication between the different main modules is not used. For future versions this concept will be extended to realise parallelism on the main module level.

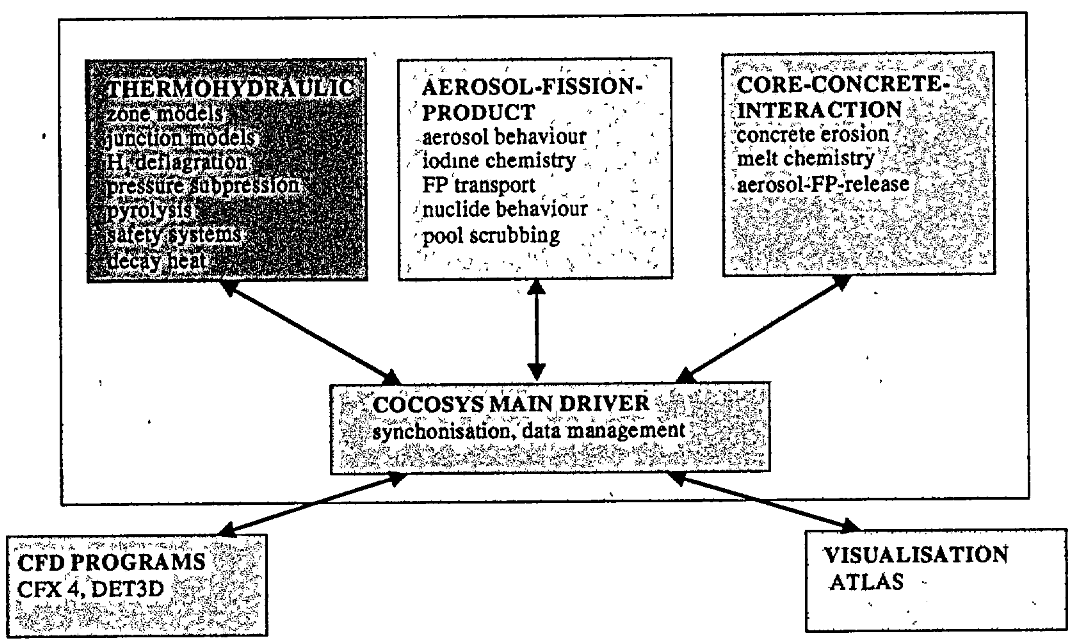


Figure 2-1 Structure of COCOSYS

2.1 Thermal hydraulic main module

The compartments of the considered power plant (or other building types) have to be subdivided into control volumes (zones). The thermodynamic state of a zone is defined by its temperature(s) and masses of the specified components. This is the so-called lumped parameter concept. The momentum balance is not considered. To realise more complex boundary conditions or processes, a flexible program and data structure is installed. For example, each zone can be split into several so-called zone parts.

The thermal hydraulic main module contains different kinds of **zone models.** These are an equilibrium zone model assuming a homogeneous mixing in the control volume, a non-equilibrium zone model simulating an additional sump volume. For the one dimensional simulation of hydrogen deflagration a separate zone model is used, separating the atmosphere in a burnt and unburned zone part. For the simulation of pressure suppression systems the DRASYS zone model can be used, calculating the hydrodynamic behaviour of the water level inside and outside the pipe and the steam condensation processes.

The **junction models** describe the flow interaction between different zones. In COCOSYS, the simulation of gas flow and water drainage is strongly separated, although water can be transported via atmospheric junctions by gas flow and dissolved gases can be transported via drain junctions. For an adequate simulation of the different systems or boundary conditions, specific junction models are implemented, like rupture discs, atmospheric valves, flaps/doors and specific pressure relief valves used in the VVER-440/213 NPPs. For the simulation of water drainage, several models are realised, describing the sump balance, water flow through pipes and along walls. The implemented pump system model is flexible enough to simulate complete cooling systems (like emergency core cooling systems).

The walls, floors and ceilings of the considered building are represented by **structure objects.** The structure objects include all types of metallic and non metallic heat sinks within zones and between them. The heat flux calculation is one-dimensional, solving the Fourier equation. Plate-type as well as cylinder-type structures can be simulated. The whole wall (heat slab) can be subdivided into layers. Their thermodynamic state is defined by a layer temperature. The arrangement of layers can be chosen freely. Gaps inside a structure are possible, too. The heat exchange between structures and their assigned zones are calculated via convection, condensation or radiation (including wall-to-wall) heat transfer correlations. In these correlations, averaged properties (valid until 3000°C) of the specified components are used. The initial temperature profile and the boundary conditions to the zones can be directly defined by the user.

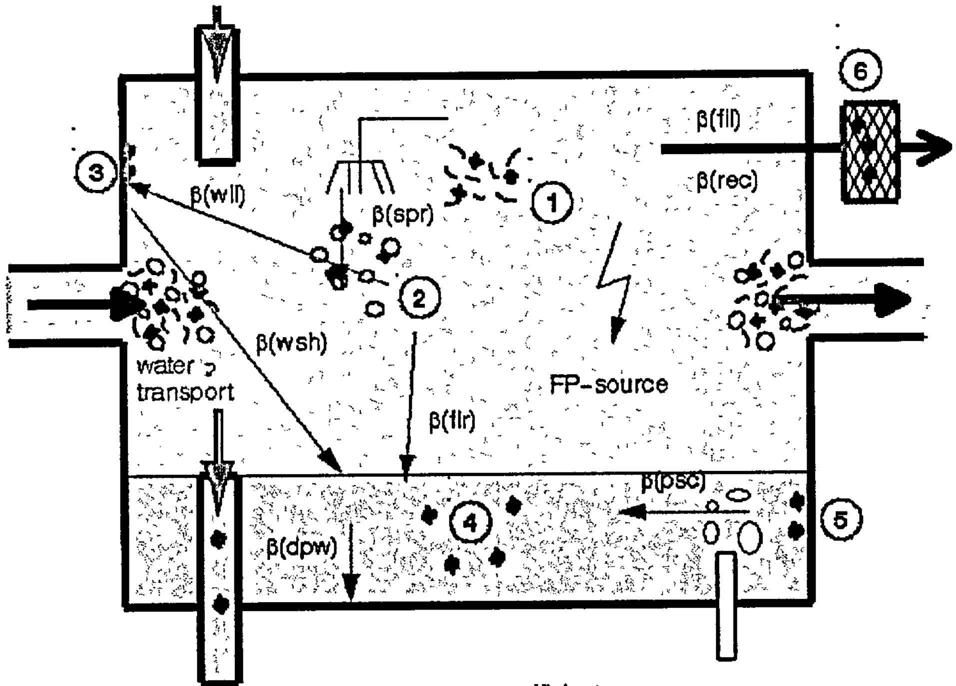
For a realistic simulation of a severe accident propagation, a detailed modelling of the **safety systems** is important. The THY main module can simulate cooler (including intermediate cooling circuits), spray systems, fan and air conditioning systems, ice condensers and catalytic recombiner systems. Especially for the last topic, a detailed one-dimensional model has been developed.

2.2 Aerosol-fission-product main module

The COCOSYS aerosol-fission-product (AFP) main module is used for best-estimate simulations of the fission product behaviour in the containment of LWRs. Both the thermal hydraulic (THY) and the aerosol-fission-product (AFP) main module consider the interactions between the thermal hydraulics and aerosol fission product behaviour.

The **aerosol behaviour** inside a control volume is solved with the FEBE integration package zone by zone. The condensation on aerosols is solved using a multi-grid method [5]. Especially for hygroscopic aerosols, a very tightly coupled feedback on the thermal hydraulic (especially for the saturation degree) can be considered. The transport of aerosols between the control volumes is solved in a tight way (on time-step level), according to the calculated flow pattern of the THY part. For relative large particles, a different transport velocity is calculated. Heat transfer and condensation influence the deposition rates on wall structures. AFP can calculate up to eight different aerosol components, with their own chemical characteristics and size distribution.

The **FIPHOST** module calculates the transport of fission products carried by so-called hosts in the containment (Fig. 2-2). The mobile hosts are gas, aerosol and water, the immobile hosts are the surfaces in atmospheric and sump spaces. The transport of the hosts will be calculated in other parts of COCOSYS. FIPHOST can handle an arbitrary number of fission product elements, isotopes and/or chemical species in multi-compartment geometry with arbitrary atmospheric and liquid flows between the compartments. All relevant transfer processes of the fission products between hosts are modelled: aerosol depletion by natural processes and by engineered systems like filters, recombiners or spray systems, wash-down from walls into sumps, etc. Host changes as a consequence of chemical reactions or the decay of radioactive isotopes are also taken into consideration.



host:
1 - gas
2 - aerosol
3 - gas phase surfaces
4 - water
5 - water phase surfaces
6 - systems (filter, recombiner)

coefficients:
β(flr) - deposition on floor
β(wll) - deposition on wall/ceiling
β(spr) - spraying
β(psc) - pool scrubbing
β(wsh) - washing
β(dpw) - deposition in water
β(fil+rec) - decontamination in systems

Figure 2-2 FIPHOST control volume, fission product hosts

Using the **FIPISO** module, the behaviour of all nuclides relevant for the mass transport and heat release in the containment can be simulated. FIPISO considers the core inventory of the reactor at the initial accident time and calculates the decay of the activity and the decay heat release according to established nuclide libraries and packages for up to 1296 isotopes inside each zone separately. The transport of isotopes is calculated by the FIPHOST module. The FIPISO module uses the implicit solution method ORIGEN with the exponential matrix method [6]. To reduce calculation time, FIPISO will compress the libraries to the relevant nuclides for the specific cases. Depending on the first release time, usually about 400 to 600 isotopes are considered. The core inventory has to be pre-calculated by other GRS programs. The user can mix the specific core inventory using different inventory files. The results are used for the calculation of decay heat release. The code distinguishes between alpha/beta and gamma radiation.

According to the position (host) of the nuclides, the heat is released in the corresponding zone part (atmosphere, sump) and wall structure, respectively. The heat distribution inside the wall structure is calculated according to the energy spectrum of the nuclides.

The **Iodine** calculations include 70 different reactions. The iodine transport process between water and gas is taken into account. The aerosol behaviour of the particulate iodine species can be calculated by the aerosol calculation part of COCOSYS. The retention of aerosols from a carrier gas conducted through a water pool is determined by SPARC model. Thus, for example, **pool scrubbing** in the suppression pool of a boiling water reactor can be simulated.

2.3 Core-concrete-interaction main module

In case of a reactor vessel failure during a severe accident, the molten core would drop onto the concrete base structure of the reactor building. The interaction of the core melt with concrete would continue for a long period of time. The COCOSYS core-concrete-interaction (CCI) main module is based on a modified version of WECHSL, calculating the **concrete erosion** and the thermodynamics of the core melt. For a very detailed consideration of the **chemical processes** in the melt (mixed or separated option) and the gas, aerosol and fission product release, the XACCI module has been developed. This module uses the equilibrium thermochemical model ChemApp [7]. The XACCI module calculates for each phase and for the atmosphere above the melt the equilibrium conditions for the chemical components. For the future it is planned to improve the modelling of the core melt (e.g. using real geometric boundary conditions) and to introduce models for simulation of DCH and melt relocation.

2.4 Simple cable burning model

For the simulation of fires of cable tray a simplified pyrolysis model has been implemented in the THY main module. This model assumes a constant specific pyrolysis rate R $\left[\frac{kg}{sm^2}\right]$ and a propagation velocity $v_\pm$ [m/s] in the positive and negative direction. The resulting pyrolysis rate is assumed as:

$$r = Rb\,(d_0 + vt) \tag{7}$$

with the reaction rate r $\left[\frac{kg}{s}\right]$, the initial burning length d_0, the width b [m] of the cable tray (Fig. 2-3). The flame propagation depends on the direction of the tray. Therefore the model distinguish between horizontal and vertical cable trays. The propagation velocity may depend on the surrounding zone temperature. For the connection of different cable trays or tray segments the relative position of the connection are given by the user (Fig. 2-4). It is possible to connect the tray segments at each end point (segmentation of cable trays according the control volumes), or to define a crossing of tray segments, or to define parallel tray segments. The user defined distance Δ defines the time needed to propagate from one to the other tray segment

$$t_{prop} = \frac{\Delta}{v_{\pm}} . \qquad (8)$$

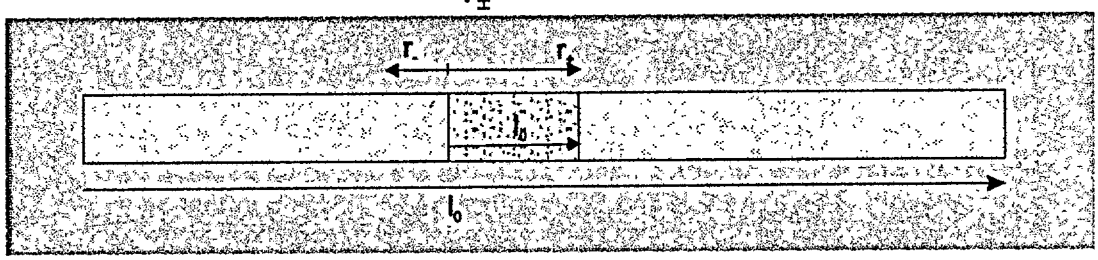


Figure 2-3 Concept of the simple cable pyrolysis model

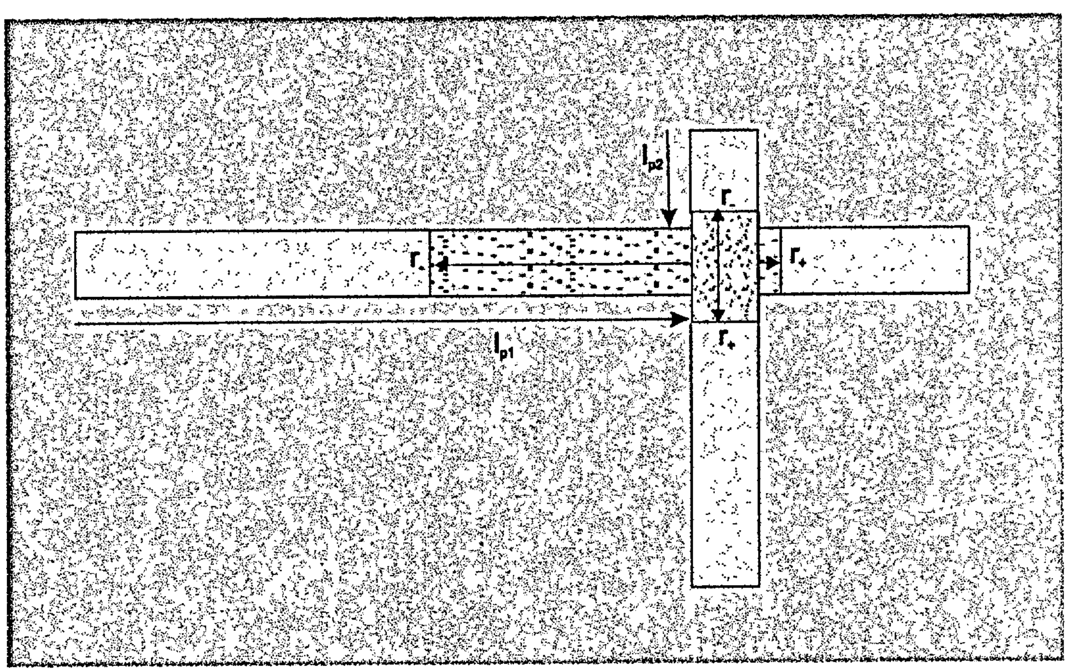


Figure 2-4 Fire propagation along connected cable trays

For a cable tray exist several conditions for ignition or stopping of pyrolysis (Tab. 2-1).

Table 2-1 Criteria for ignition of a cable tray or stop of burning

Reason	**Criteria**	**Time delay**
Ignition via signal (user input)	l_0, d_0	-
High zone temperature	T_{ign}	t_{delay}
Ignition via another cable tray	l_0, d_0 (calculated by connection data)	$\frac{\Delta}{v_\pm}$
Finish due to low zone temperature	T_{out}	t_{out}
Complete burn out	$t \geq t_{e_\pm}$	

The simplified cable burning model considers somewhat the thermal hydraulic boundary conditions, but the real temperatures on the cable surface needed for a deterministic calculation of the pyrolysis are not calculated. Especially under low oxygen conditions this model may lead to some deficiencies. Therefore an additional criteria has been introduced for low oxygen conditions to reduce the pyrolysis rate. The considered species in the cable burning model are H_2, HCl, CO and CH_X fractions. As already used in the oil burning model [8] these fractions may combust in the atmosphere or be transported to other regions under low oxygen conditions.

3 Description of Benchmark

The benchmark exercise is split into two parts. For both parts a representative PWR emergency switchgear room is selected. The size of the room is assumed to be 15.2 m long, 9.1 m wide and 4.6 m high. In the first part a trash bag fire is assumed as an initial event. Varying the distance to a target cable, the behaviour of the cable is evaluated. In two cases vented conditions are regarded. In the second part of the benchmark, it is assumed that one tray on the left side is already burning. Varying the evaluation and distance of the target tray, the different temperature evaluations inside the tray are evaluated. In the appendix A the complete description of the benchmark is given.

4 Nodalisation of the compartment

For the simulation of the fire in the compartment defined in the benchmark description, the compartment have to be subdivided into several zones. To be able to simulate stratified conditions several levels of zones (at least 4 levels) have to be used. It has been decided to use one nodalisation for all different cases. Therefore the special requirements, for example the plume simulation above the trash bag and the different locations of the target cables requires further subdivisions of the compartment. At least 8 levels of zones indicated by RA.., RB.. and so on have been defined (Fig. 4-1). Looking on the top view of the compartment a fine grid around the trash bag position have been used. This has been done for all possible positions of the trash bag. For a larger distance to the trash bag and the considered cable trays the grid becomes more rough. The digit number in the zone name indicate the position in x-direction. The last letter from L to Q indicates the position in y-direction. Fig. 4-2 shows the top view of the nodalisation for the different levels. For the levels A to C 27 zones are defined for each level, in the level D and E 37 zones are defined for each level and in the upper levels F to H in total 56 zones are used for each level. The number of zones per level is increased for the higher levels to consider the local effect on the cable trays in these levels. This results into 323 zones in total.

The heat release for the trash bag fire is relatively small. To calculate in detail the plume behaviour additional (cylinder) zones (RTBB to RTBE) above the trash bag have been defined. It has to be pointed out, that a specific plume model using empirical correlations is not implemented in COCOSYS. Therefore the plume behaviour have to be simulated via a more detail nodalisation around the fire position.

The zones inside the fire compartments are connected using atmospheric junctions. The cross section of these junctions results from the geometry. The resistant coefficient used are taken from validation calculations against different experiments (e.g. integral HDR experiments).

To simulate the door behaviour and leakage atmospheric junctions are defined to the environment. For the environment the same subdivision of different levels is defined. It is important to use the correct static total pressure for these zones. In the given configuration, this results in four atmospheric junctions for the open door (see side view in Fig. 4-1) and one addiional junction for the leakage. With these four junctions it is possible to calculate counter current flows through the door.

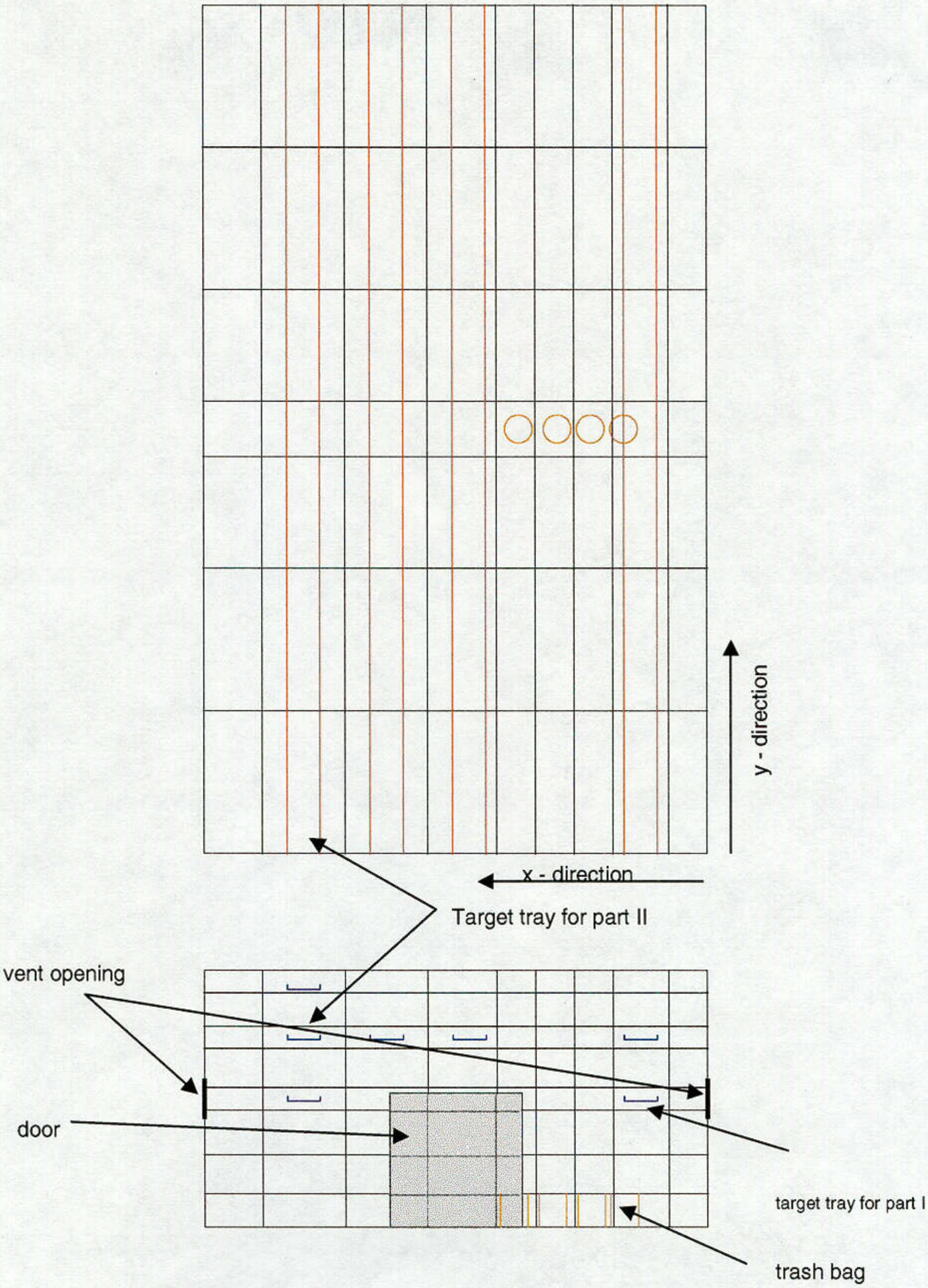


Figure 4-1 Overview of the nodalisation of the fire compartment

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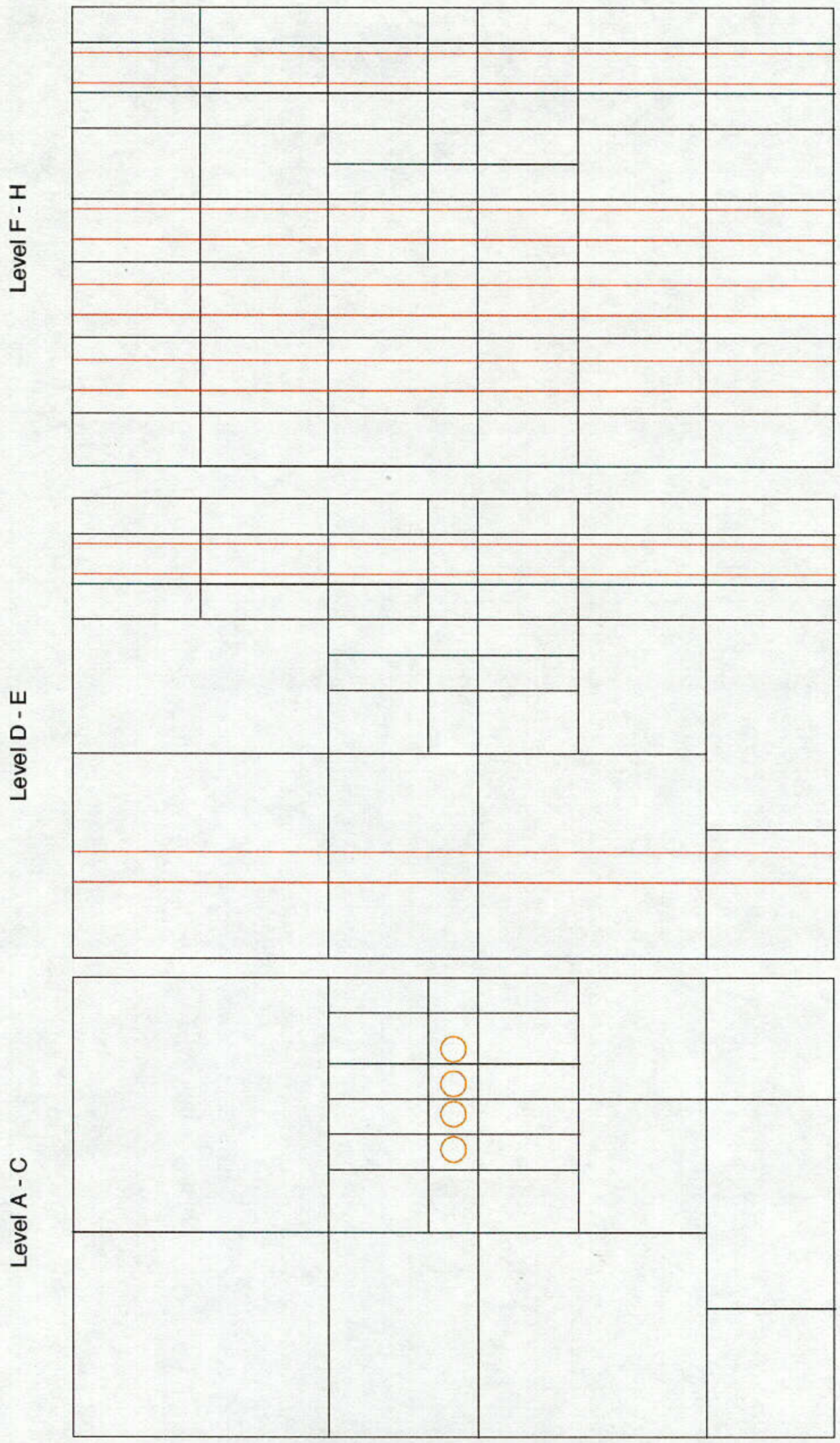

Figure 4-2 Nodalisation in different levels

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The ventilation system is simulated by a fan system with a constant volume flow rate. It is assumed that the fan injects fresh air through the right vent opening. On the left side three atmospheric junctions are defined. The use of atmospheric junctions avoids an over or under pressure of the fire compartment.

As a boundary the concrete wall structures and the door are simulated by the structure objects as defined in the benchmark description. As defined in the benchmark description a constant heat transfer coefficient of 15 W/mK is used, although this value seems to be very high. Usually in COCOSYS calculations a combination of correlation describing free and forced convection, condensation and radiation is used.

The trash bag fire is simulated as a heat injection in the zone above the trash bag. This is possible, because the oxygen consumption is relatively small. The oxygen consumption due to the fire, is simulated by an extraction of oxygen and a corresponding CO_2 injection in the zone above the trash bag. To simulate the radiation fraction, especially the heat up of the target by radiation, a given fraction of 0.3 is released as radiative heat. For the distribution of this heat view factors are used. These view factors (especially between the flame and the target cable) are pre-calculated by a tool using a Monte-Carlo method. Therefore for different distances between trash bag and target cable different view factors are used.

For the calculations of part II, the heat release is assumed at the cable tray C2. The heat release is much larger and the oxygen consumption may influence the fire. Therefore for these cases the simple cable pyrolysis model is used. The pyrolysis rate is given by input according to the given heat release rate and distributed homogeneously over the whole cable length. This model calculates the release of pyrolysis fractions (here H, HCl, CH_X) according to the composition of the burning material. The burning process is calculated by the detail models, considering the available oxygen concentration. Because the cable tray C2 is not simulated by structure objects, view factors can not be defined and therefore the radiation fraction of heat release is not considered. Additionally the release of pure carbon fraction (as soot) is not possible.

The target cable is simulated as a cylinder type structure with a diameter of 5 cm. The heat conduction is calculated one-dimensional. Therefore the surface temperature is the same on the top and the bottom of the cable. In CFD calculations different temperatures are calculated, because only the bottom of the cable is directed to the fire. The target cable is subdivided in nine layers. So the centerline temperature can be calculated. The length of the cable is subdivided according to the subdivision of the fire compartment, leading to 7 cable segments (TCABLEL to TCABLER). The target cable in the room centre is named TCABLEO. In the case 1 of part 1 the trash bag is more or less direct below the target cable. To consider in detail the plume effect the target cable is further subdivided into two parts (TCABLEO and TCABLEO2)

5 Results for Part I

First the results of the base case (trash bag fire with a distance of 2.2 m to the target) are discussed. Then the case 1 to 3 with different distances to the target are compared with the base case. After this the cases with vented conditions (case 4 open doors and case 5 active ventilation system) are compared with the base case. To reduce somewhat the effort, only the results specified in the benchmark description are discussed. The fire compartment temperatures and concentrations shown are taken from the room centre. Because 8 level of zones are defined 8 curves are presented. The depth of the hot gas layer is not presented, because it is not a direct result of the COCOSYS calculation. The heat release rate is here the specified rate. The heat loss to the boundaries are presented only for the closed conditions.

5.1 Base case

First the results of the base case will be presented. The effect of the burning trash back is simulated as a heat injection in the zone RTBB surrounded by the zone RB5O. To simulate the oxygen consumption the corresponding mass of oxygen is removed and CO_2 is injected. The hot gas moves upward leading to a temperature stratification in the atmosphere. In Fig. 5-1 the zone temperatures of the room centre is presented. The maximum calculated temperature is about 450 K. The behaviour of the temperature corresponds to the heat injection rate, presented in Fig. 5-2. The oxygen consumption due to trash bag fire is relatively small. Therefore the oxygen concentration is only slightly reduced (Fig. 5-3). The concentration shows a stratification corresponding to the temperature stratification. In Fig 5-4 the leakage rate through the door is plotted. In the first phase with high heat release the leak flow is directed to the environment. Later the heat release is not high enough to compensate the heat loss into the concrete walls. Therefore the temperatures are decreasing leading to a leak flow into the fire compartment.

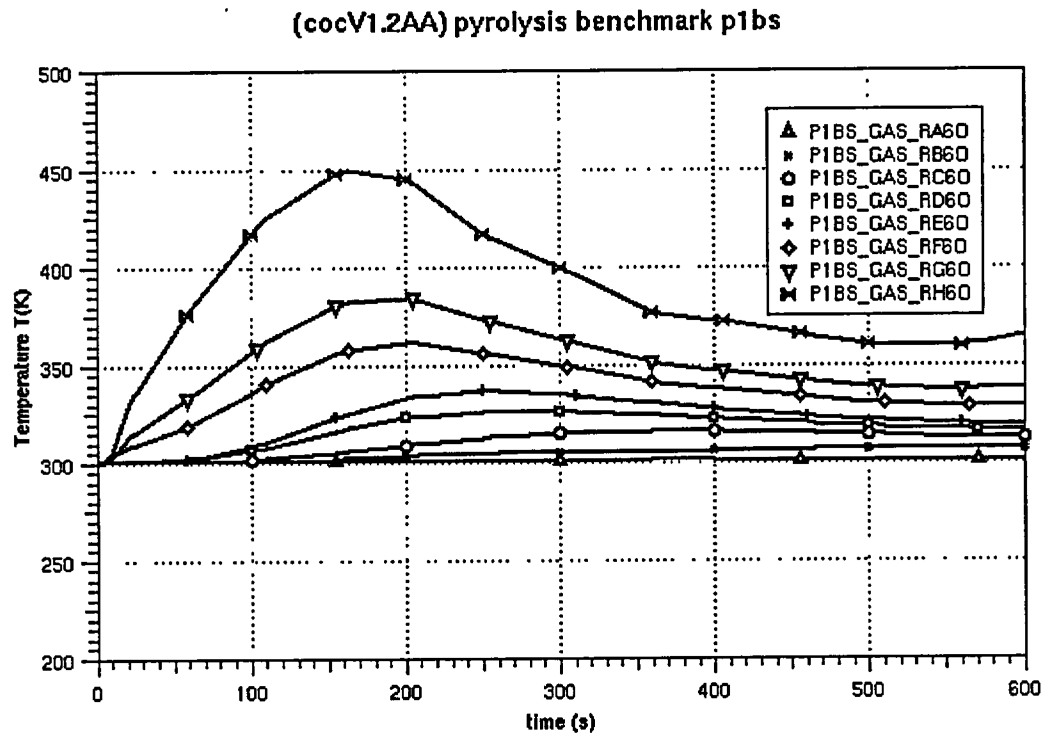

Figure 5-1 Temperature stratification in the centre of room

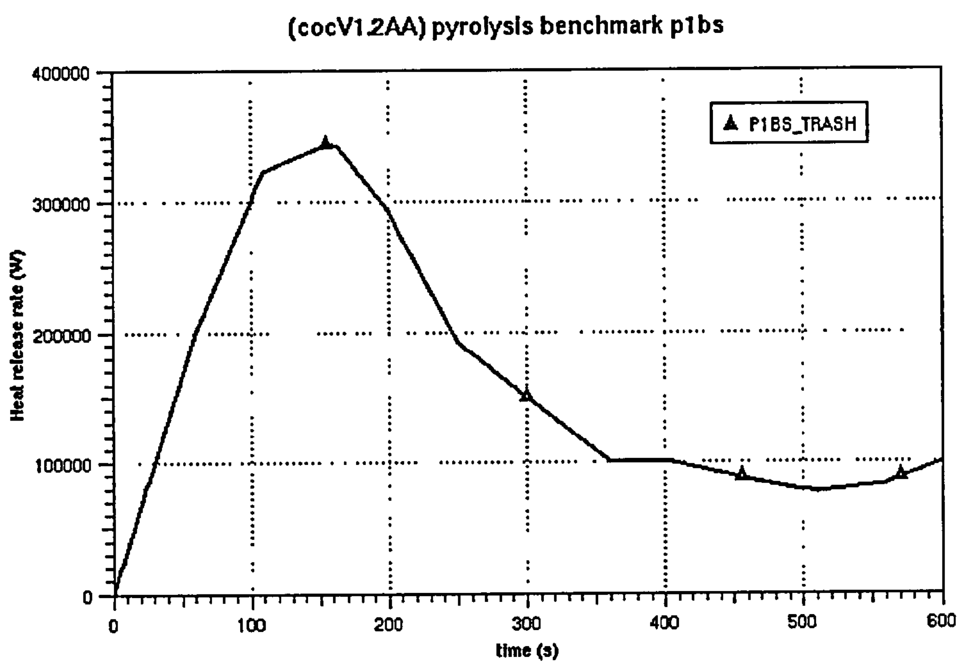

Figure 5-2 Heat release rate

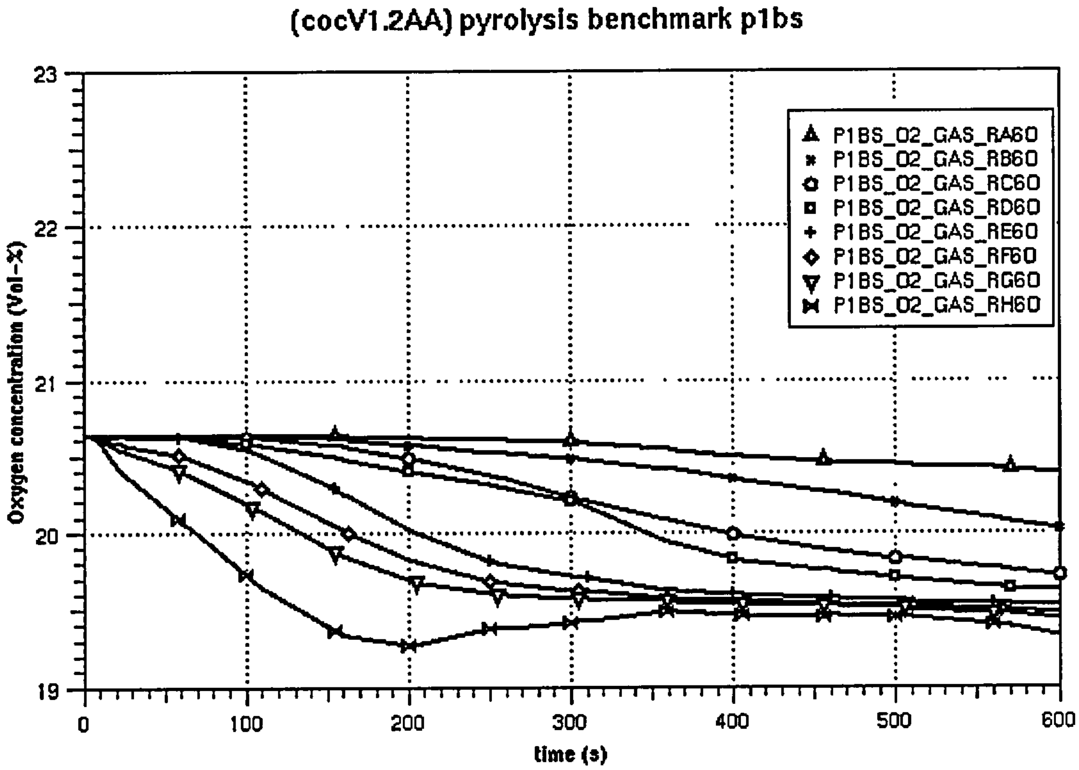

Figure 5-3 Oxygen concentration in the room centre

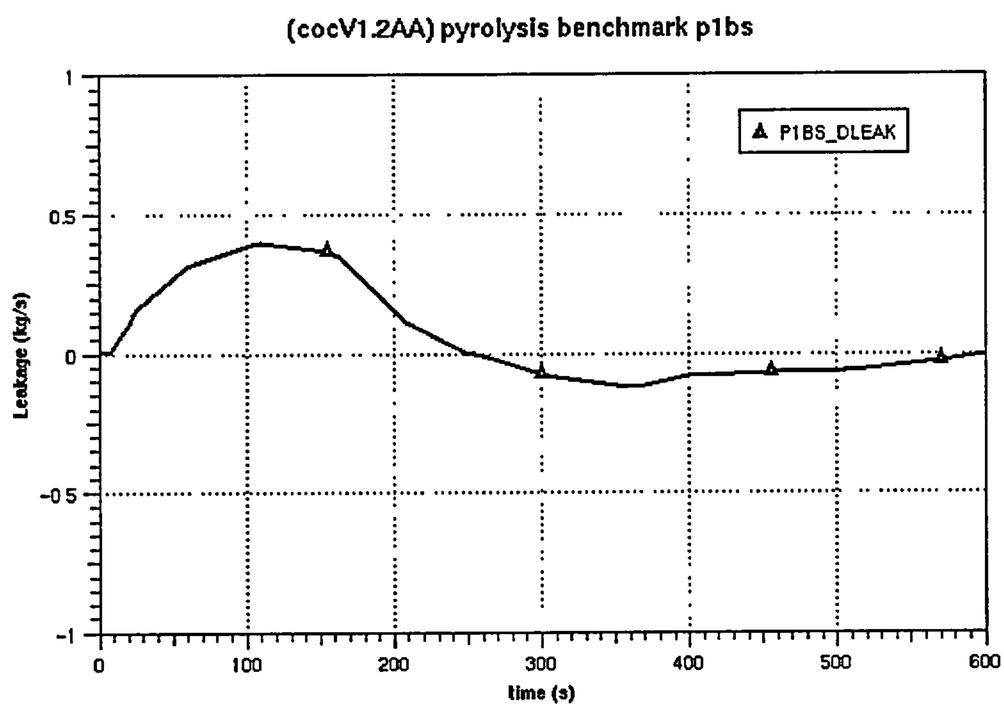

Figure 5-4 Leak mass flow rate through the door

Fig 5-5 presents the heat flux in [W/m] into the target cable. The red curve corresponds to the total heat flux into the target and the black curve shows the fraction due to radiation. In the initial phase the main fraction is determined by the radiation, because the atmosphere around the target cable is not heated up yet. Later the heat flux is mainly caused by the convective heat transfer. In this situation the atmosphere is still hotter than the target surface but the heat release is reduced. The heat release is relatively small leading to a moderate temperature behaviour. Therefore the surface temperature rise up only about 12 K (Fig. 5-6). Due to the low heat conductivity of the (full) PVC cable and the short time period, nearly no reaction on the centerline temperature is observed. Fig. 5-7 shows the heat loss into the concrete structures. Comparing this with the total heat release, about 70% of the total heat injection is transferred into the concrete structure. To be more realistic the given constant heat transfer coefficient of $15 \left[\frac{W}{m^2K}\right]$ should be replaced by a free convection correlation resulting usually to lower values (especially for the floor structures). The curve presented in Fig. 5-7 looks somewhat curious. This is due to the numerical derivation of the plot data with relatively large time step sizes.

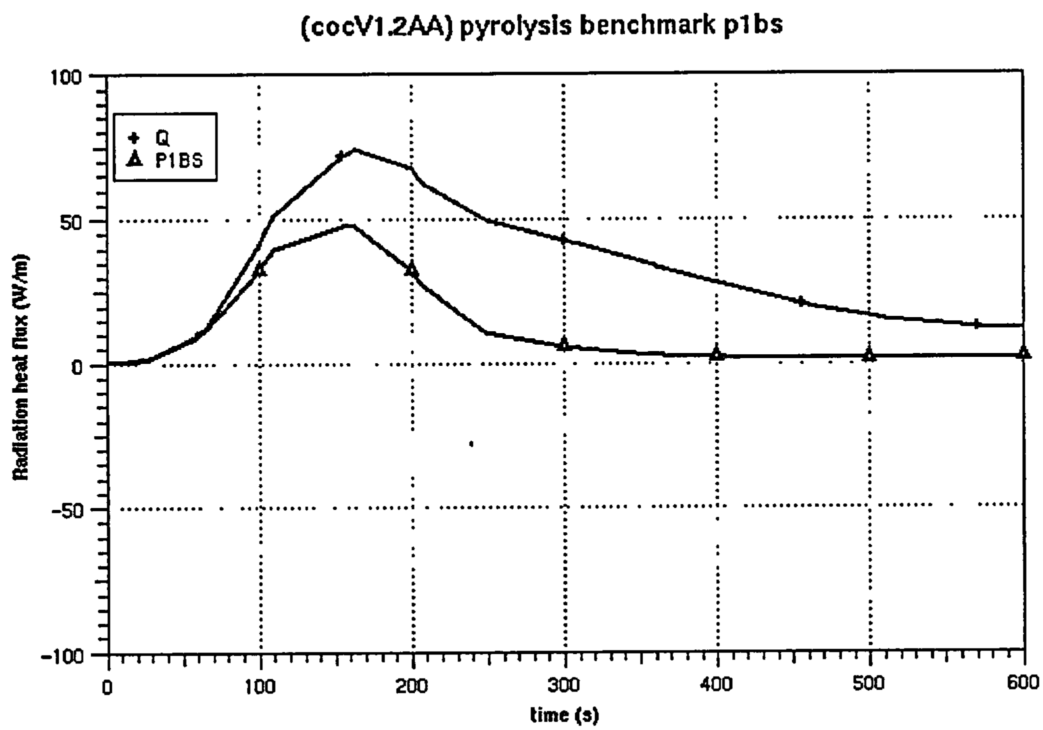

Figure 5-5 Radiation heat flux on the target

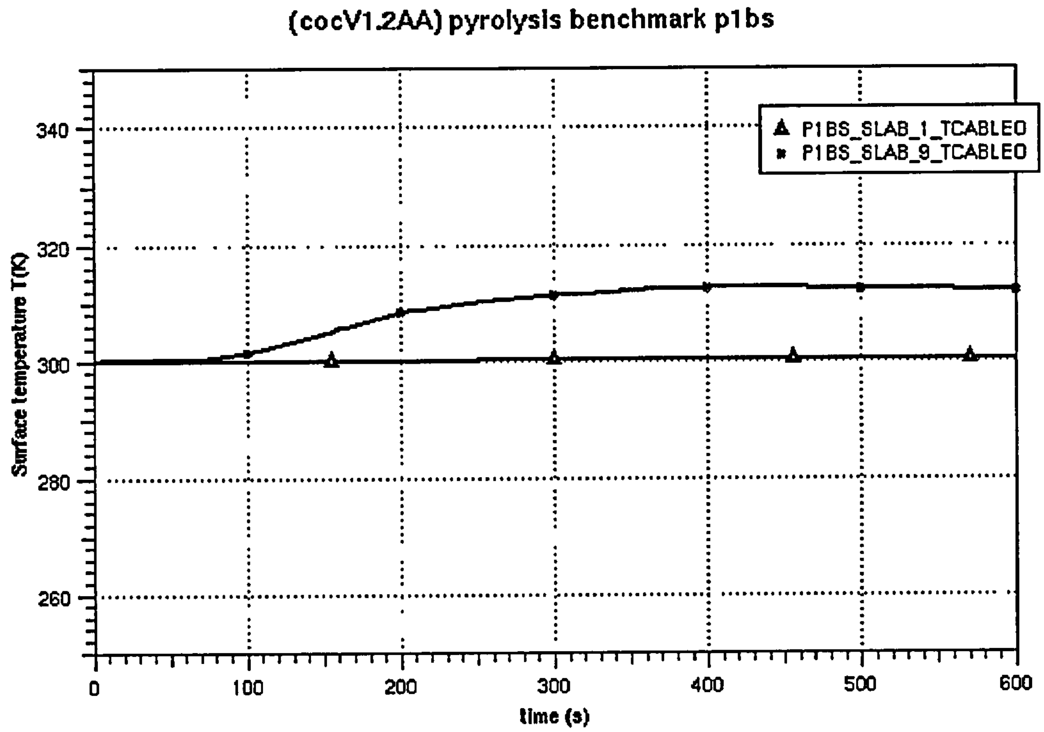

Figure 5-6 Target surface and inner temperature

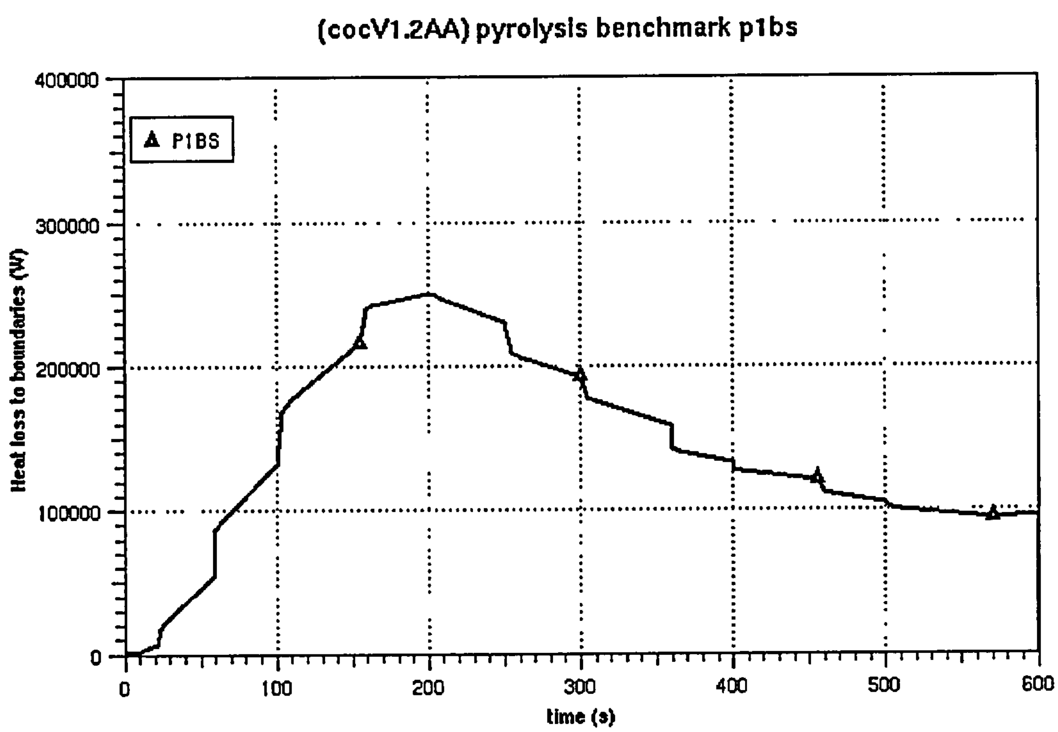

Figure 5-7 Total heat loss to boundaries

5.2 Case 1 to case 3

In the following the results of the cases 1 to 3 will be discussed in comparison to the base case. In these cases the position of the trash bag is shifted to the direction of the target. The nodalisation is detailed enough to consider this shift of the trash back. For each case the view factors have been recalculated.

Fig. 5-8 shows the temperatures in the highest zone RH6O in the room centre. Here the case 1 (red curve), where the trash bag is more or less below the target, but more far away from the centre leads to the lowest temperature. Also the results for the oxygen concentration (Fig. 5-9) are consistent according to the distance between the trash bag and the room centre. The leakage rate (Fig. 5-10) is practically the same for all four cases. This underlines that the overall behaviour and especially the pressure built up due to the trash bag fire is the same for all considered cases. Additionally the leak position is on the floor level, where the effect of the fire is relatively small. Therefore no differences are expected.

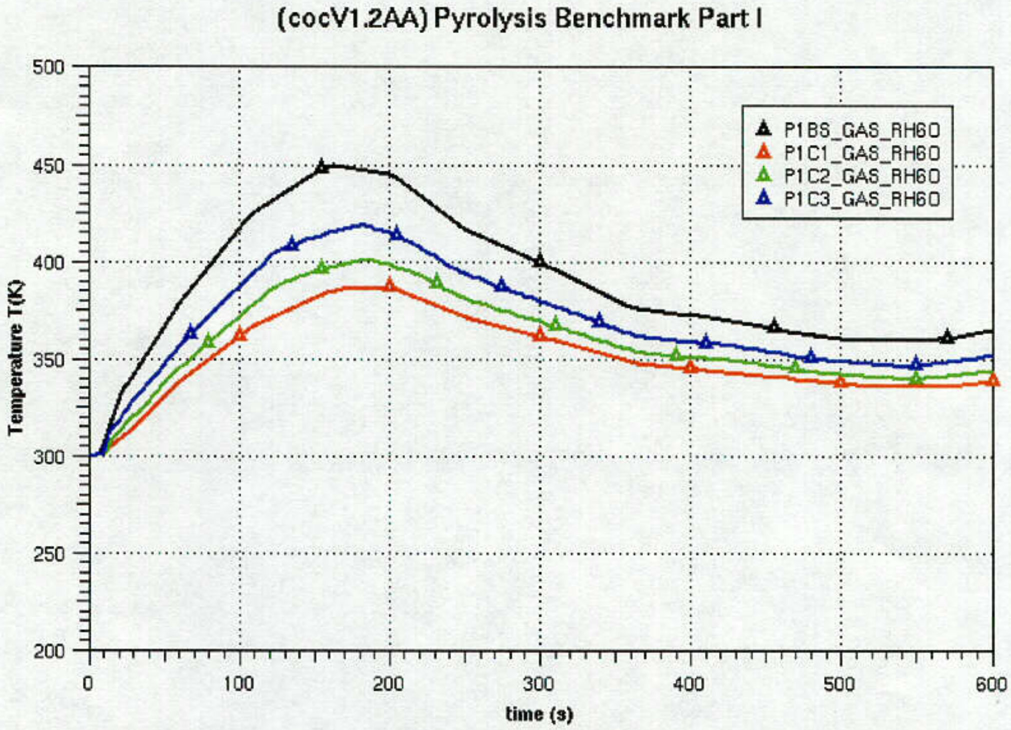

Figure 5-8 Atmospheric temperatures in the centre below the ceiling (RH6O)

C04

228

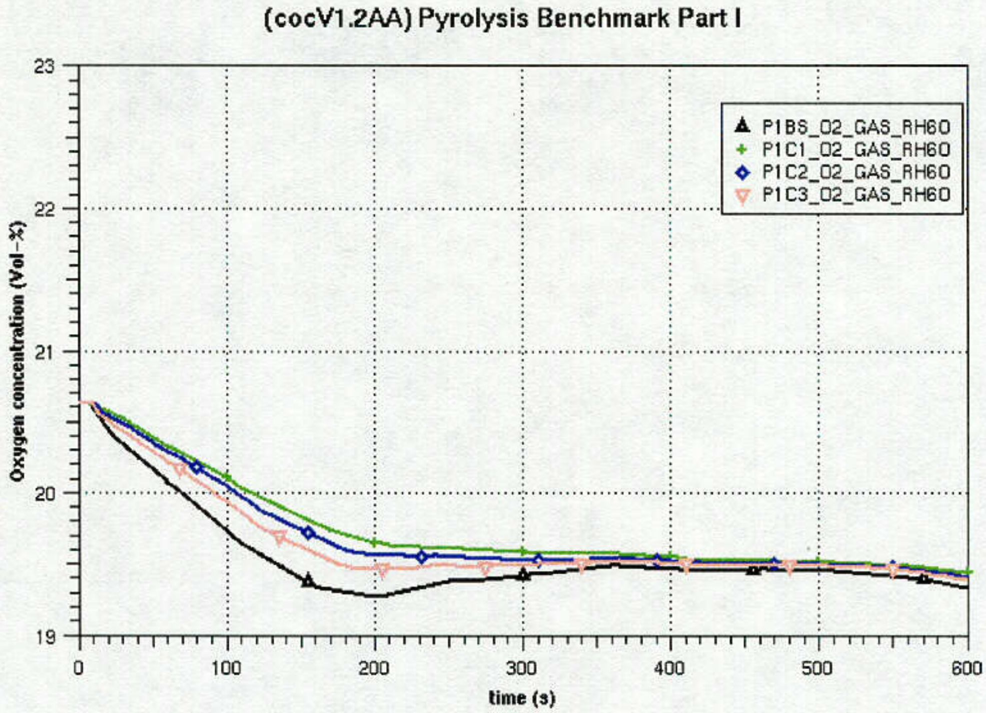

Figure 5-9 Oxygen concentration in the centre of the ceiling (RH6O)

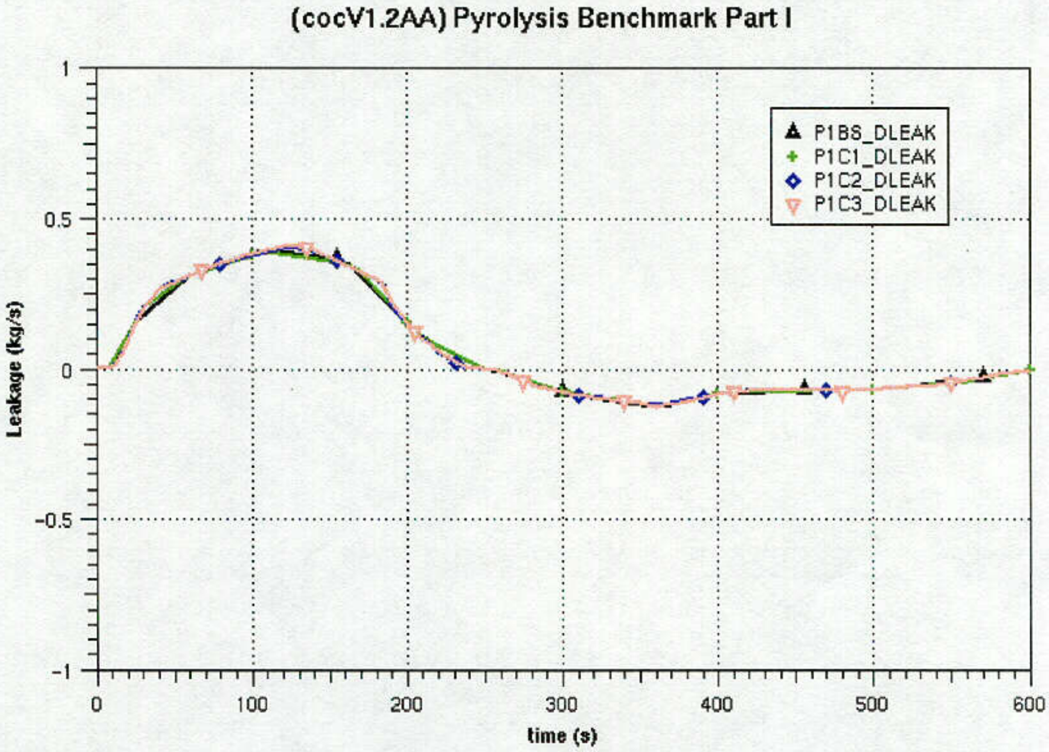

Figure 5-10 Leak flow through door

C05

225

For the heat flux into the target cable strong differences between the regarded cases can be observed. To simulate the fire plume the zones above the trash bag are further subdivided. An additional zone with the same diameter as the trash bag has been defined above. Therefore an increasing of the fire plume size is not calculated. This leads to similar results (Fig. 5-11 and 5-12) in case the trash bag fire is not below the target cable (blue, black and green curves). Therefore it can be concluded that the effect of the position between the trash bag and the target cable is calculated to strongly. It can be assumed, that the temperatures in case 1 (0.3 m distance) are calculated too high and on the other side the temperatures in case 2, case 3 and the base case may be somewhat to low. The consequences can be seen in Fig. 5-13. Here the calculated surface temperatures are very different between case 1 (about 900 K) and the other cases (about 330 K). Even in the case 1 the ignition temperature of 643 K in the centerline is never reached. Therefore the extrapolation mentioned in the benchmark description cannot be performed. As already mentioned the heat loss to the boundaries should be quite similar for all cases (Fig. 5-14).

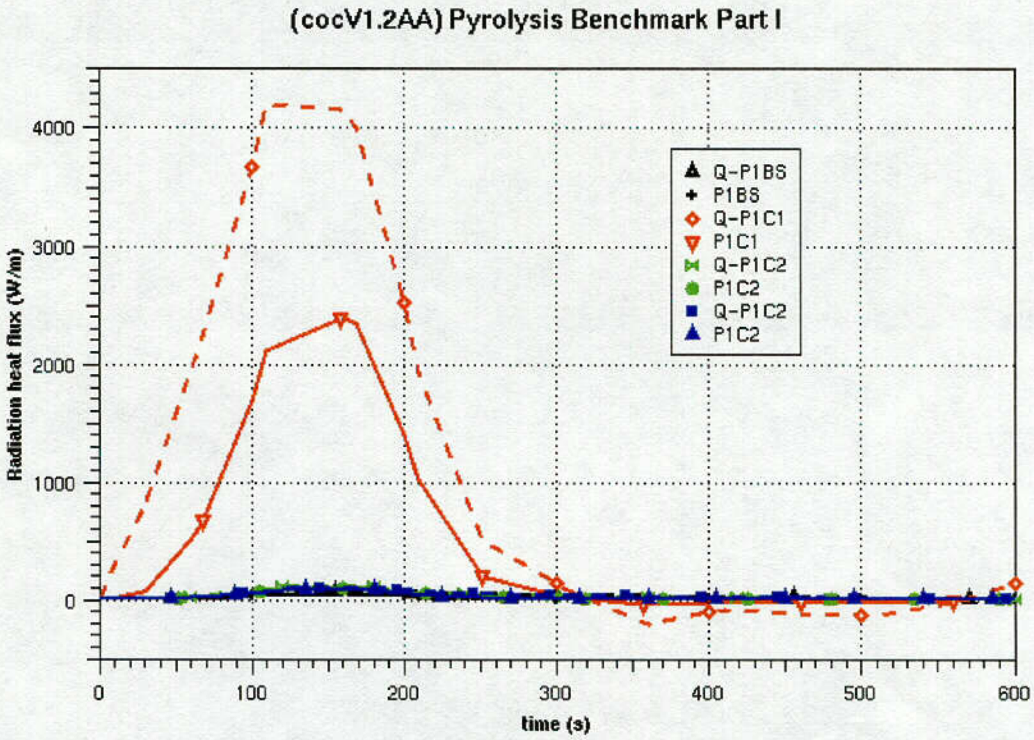

Figure 5-11 Radiation heat flux on the target

C06

230

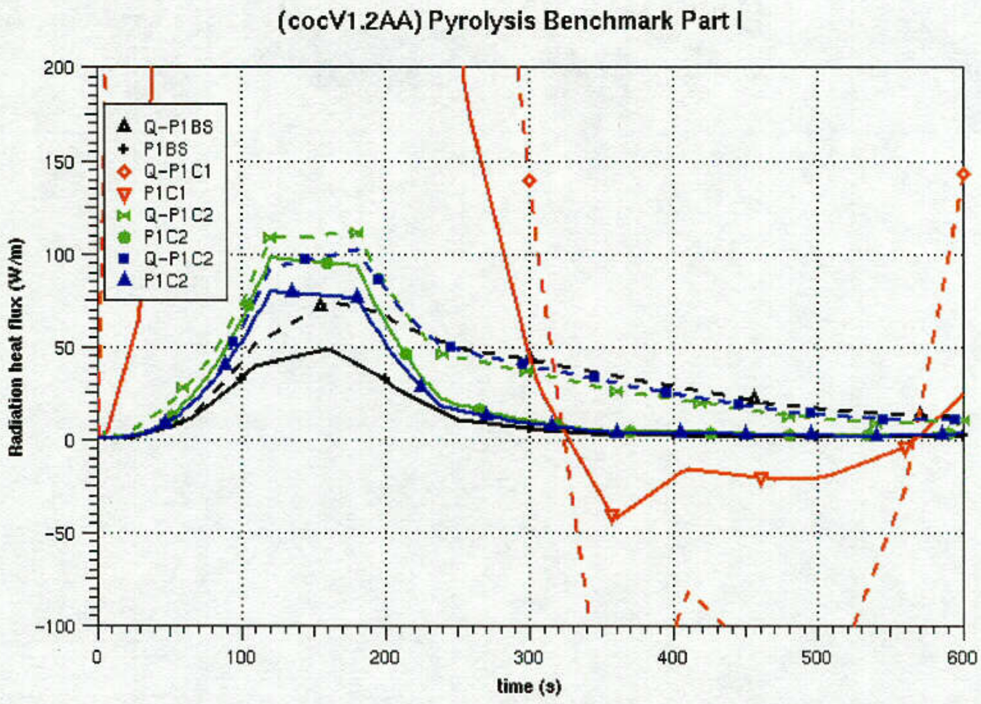

Figure 5-12 : Radiation flux on target (detailed view)

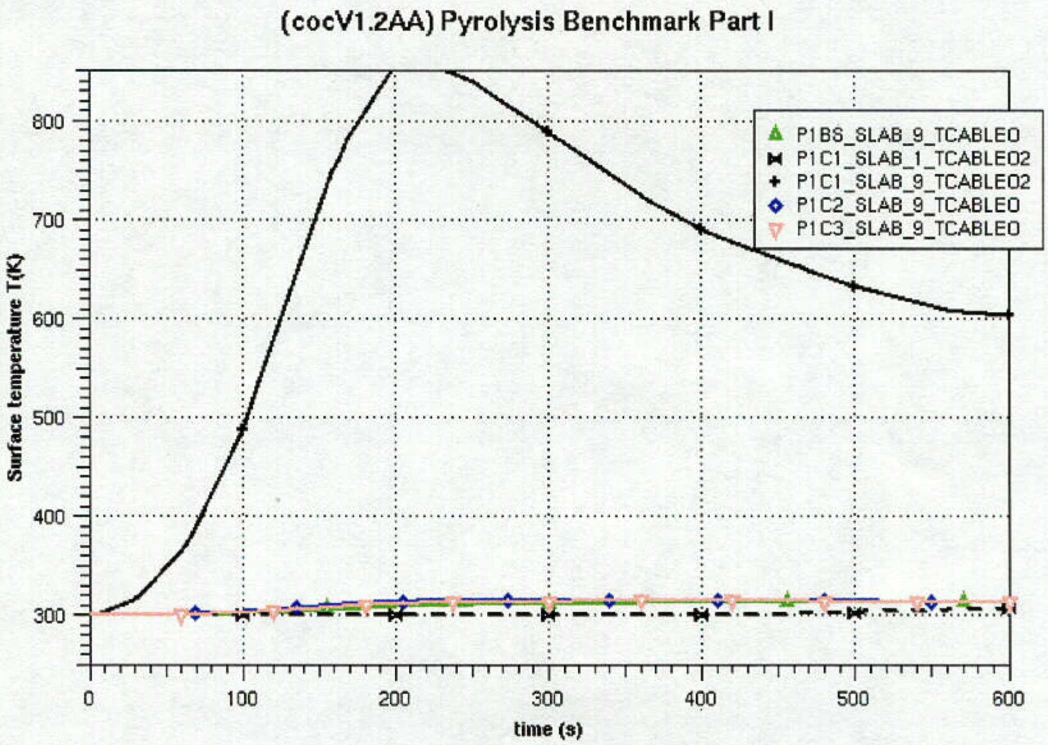

Figure 5-13 Target surface temperature

C07

231

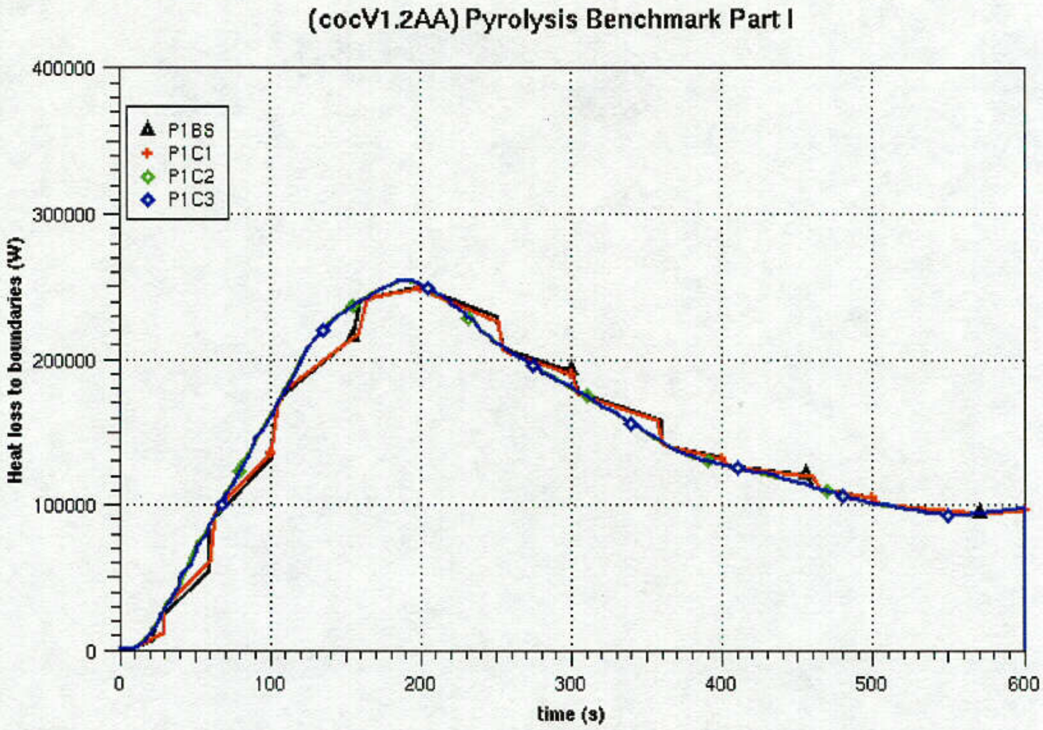

Figure 5-14 Heat loss to boundaries

5.3 Case 4 and case 5: open doors or active ventilation system

In case 4 the door stays open during the whole problem time of 600s. Because the fire is relatively small leading to oxygen rich conditions, the effect on the fire is relatively small. It has to be mentioned, that the fire is simulated via a simple heat injection. There is no feed back from the oxygen concentration on the fire process. The calculated temperatures in the room centre of case 4 are very similar to the base case (Fig. 5-15). Only the temperatures in the lower levels are slightly lower. This is caused by the hot gas removal through the upper part of the door (Fig. 5-18). The behaviour in case 5 with a running ventilation system is very similar. The calculated temperatures (Fig. 5-16) are very similar to the base case. In the vented cases the oxygen concentration is somewhat higher (Fig. 5-17). Fig. 5-18 presents the mass flow rate through the open door for the case 4. The height of the door is subdivided into 4 level of zones. Therefore a counter current flow can be calculated. In the beginning the in all levels the flow rate is directed to the environment. This is due to the heat up and expansion of the atmosphere of the burning room. At about 100s the counter current flow is established.

C08

232

In the upper part of the door hot gas is moved to the environment and in the lower part of the door cold gas is going into the burning room.

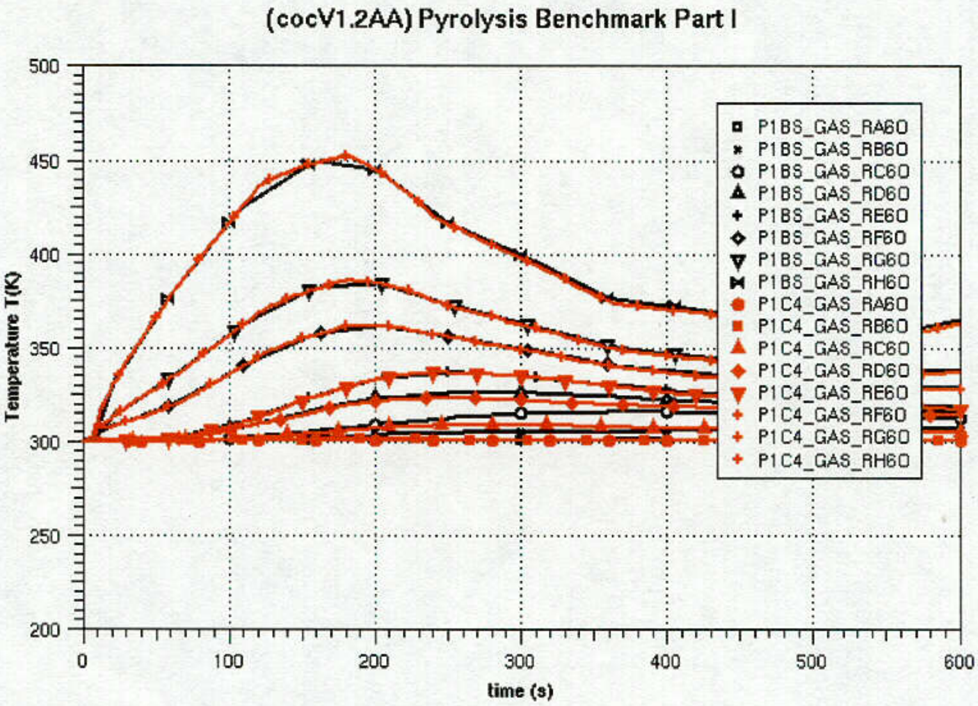

Figure 5-15 Comparison of temperatures (open doors)

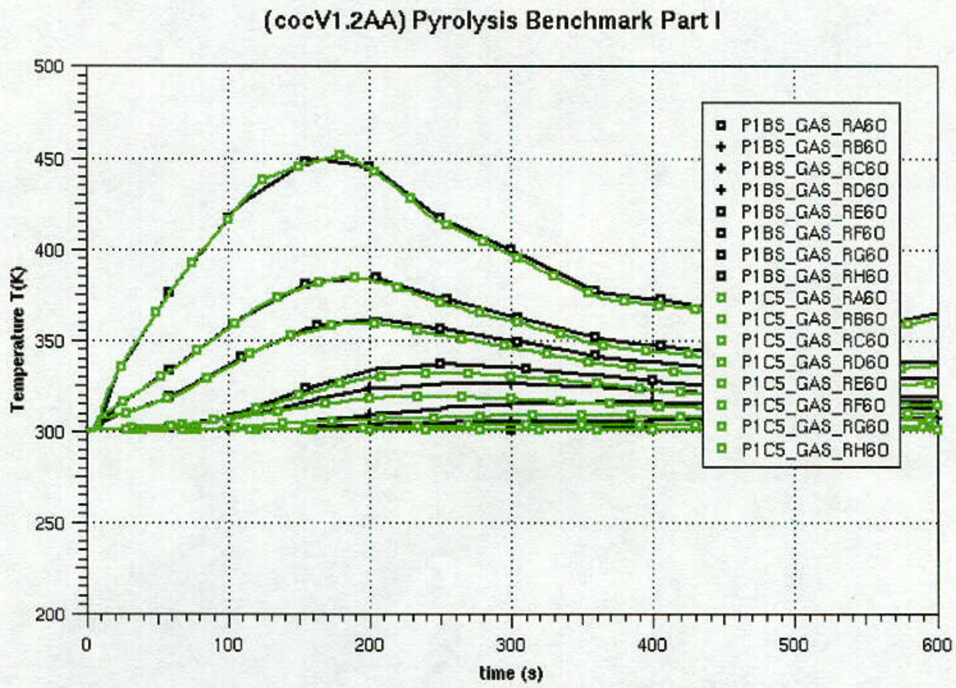

Figure 5-16 Comparison of temperatures (ventilation system)

C09

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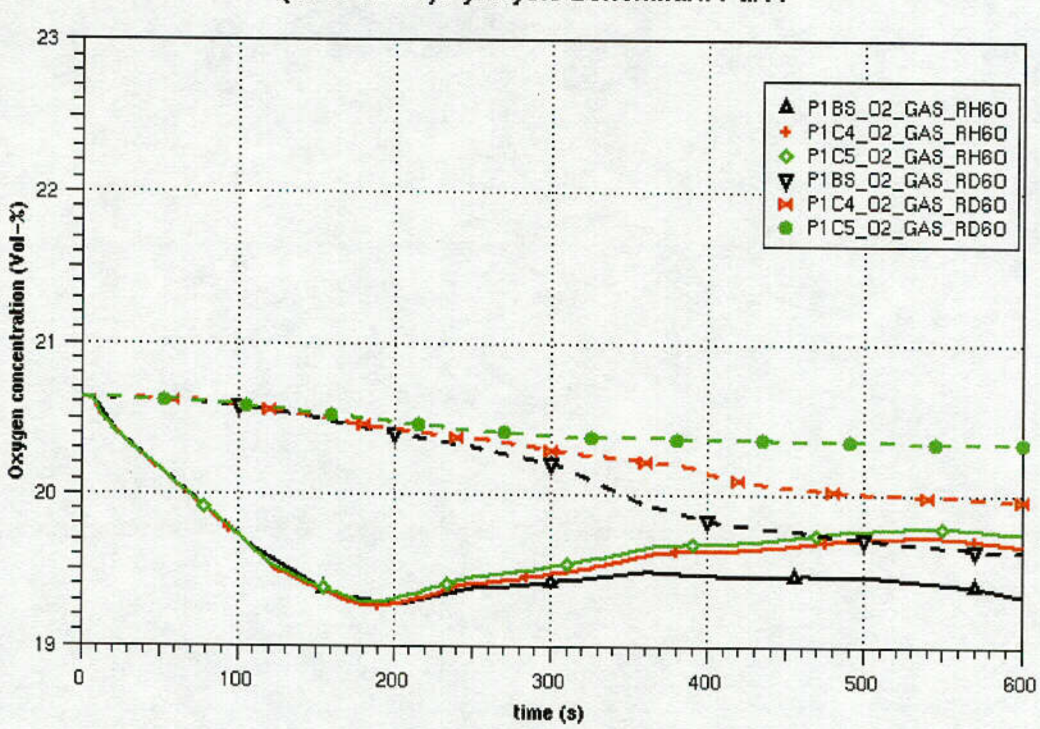

Figure 5-17 Comparison of oxygen concentration below the ceiling and on level D

In case 5 fresh air is injected into the burning room through the right vent opening by a fan system with a constant volume flow rate. The vent opening on the left side is opened. On this side usual atmospheric junctions are used, to avoid an over or under pressure inside the fire compartment. In Fig. 5-19 the mass flow rate through is opening is plotted. According to the defined zone levels the vent opening is subdivided into the three part. Therefore three junctions are defined.

In the considered cases 4, 5 and the base case the position of the trash bag is the same. The heat release and the radiation fraction is given by input. Therefore the radiation flux on the target cable should be the same for all cases. This is shown in Fig. 5-20. In the vented cases the atmospheric temperature near the cable are somewhat lower. Therefore the convective heat transfer is different. Especially the case 5 has a lower heat flux into the target cable, because the cold air is injected relatively close to the target cable. These effects lead to the corresponding differences for the surface temperature on the target (Fig. 5-21).

C10

234

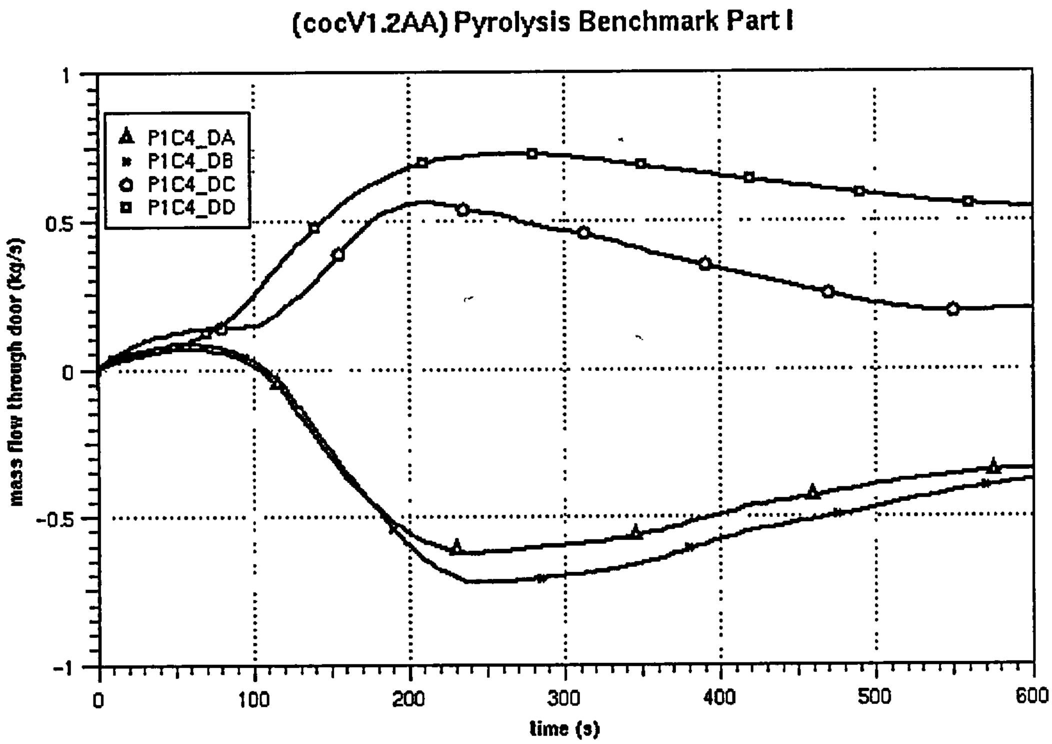

Figure 5-18 : Mass flow rate through door (case 4)

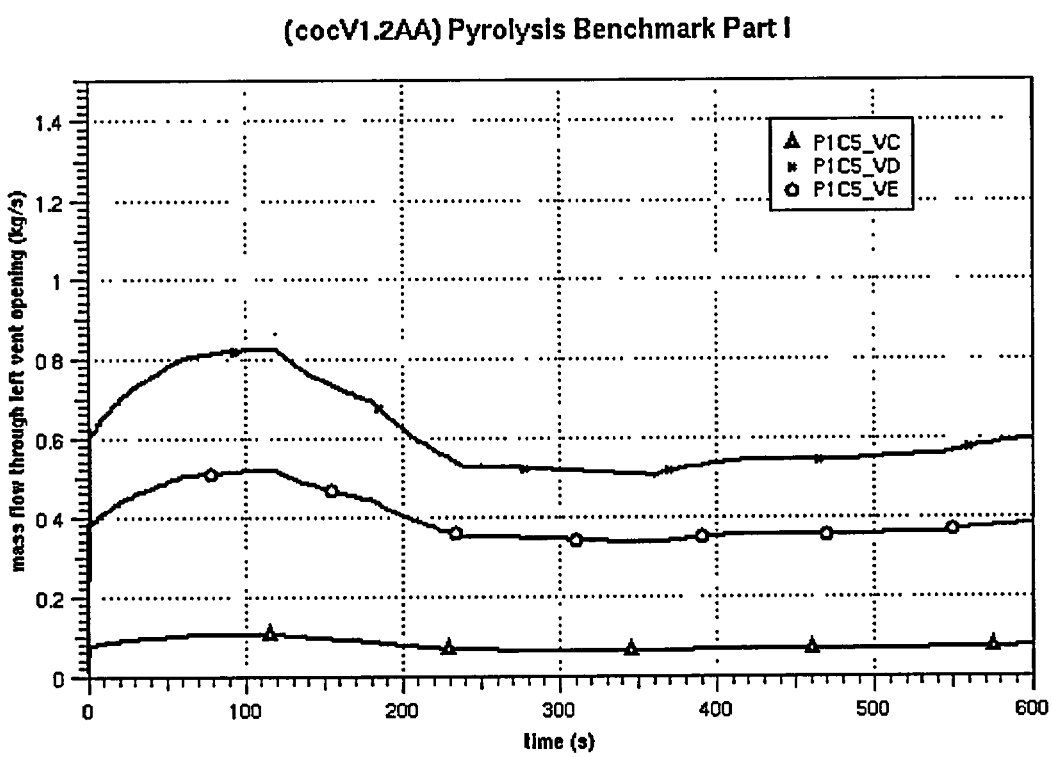

Figure 5-19 Mass flow rate through the left vent opening

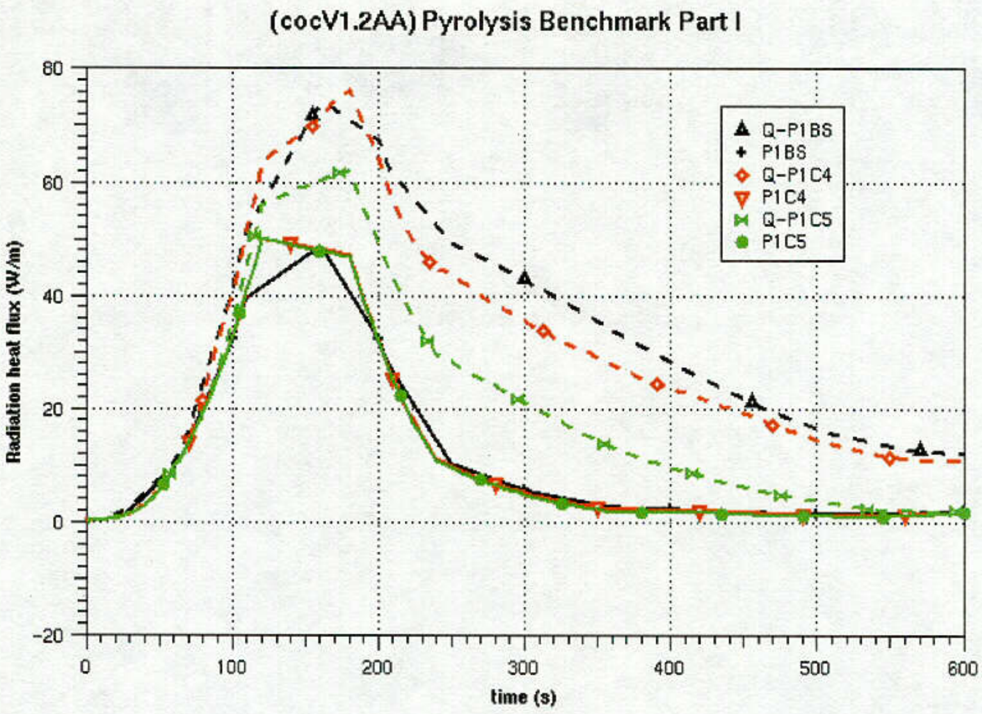

Figure 5-20 Total heat flow and radiation flux on the target

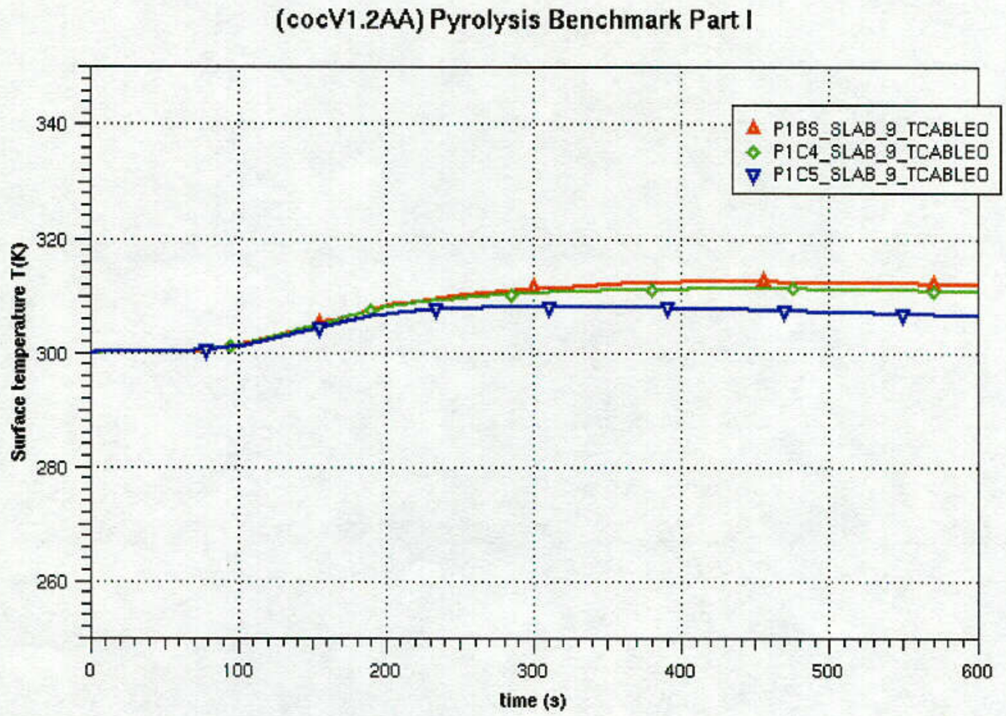

Figure 5-21 Surface target temperature

C11

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6 Results for Part II

First the base case of the part II of the benchmark is discussed. Here the maximum heat release is 1MW. The distance between the burning and the target tray is 6.1m. There are practically closed conditions. The results presented are corresponding to the previous part. Because the pyrolysis rate is given by input and the burning process is calculated by the models inside COCOSYS the heat release may be lower than the specified heat release. The radiation flux on the target is not considered in these calculations. Instead the total heat flux on the target are plotted. The concentrations of the chemical species CO, CO_2, HCl and unburned CH_X fractions are plotted. The optical density (smoke) is not calculated. To simplify the presentation, sometimes only the upper and lower values at the ceiling or at the floor are plotted.

6.1 Base case

In comparison to the part I the heat release and oxygen consumption are much larger for the situation considered in part II. Because the oxygen concentration should be considered for the burning process, the simple cable pyrolysis model (see 2.4) is used for this calculation. As a boundary condition the pyrolysis rate (derived from the proposed heat release rate) is given by input. This rate is not influenced by other effects. This may result to higher concentrations of unburned pyrolysis fractions. The calculated temperatures (Fig. 6-1) at the ceiling near the room centre rise up to about 700 K. At about 1000 s the temperatures are decreasing again. Here the burning rate is reduced due to the low oxygen concentration. Fig. 6-2 shows the comparison of the calculated heat release due to the cable burning and the proposed heat release underlining the situation. At this time the oxygen concentration below the ceiling falls below at about 4 Vol%. At this concentration the burning of the pyrolysis fractions is strongly restricted. In the COCOSYS calculations the value of 4 % is used instead of the proposed 12 %, due to the gained experience in the code validation. Fig 6-4 presents the leak flow through the door. In the beginning the over pressure due to the heat up is compensated. Under low oxygen conditions the leak flow is moderate indication nearly constant pressure conditions. Using the simple cable burning model up to now a radiation fraction of the heat release due to the burning process could not be considered. Therefore the heat flux into the target cable results from the convective heat transfer only. This may lead to somewhat too low values. Fig 6-5 shows the total heat flux into the target. After a strong heat up of the target, it starts to cool down after about 2250 s.

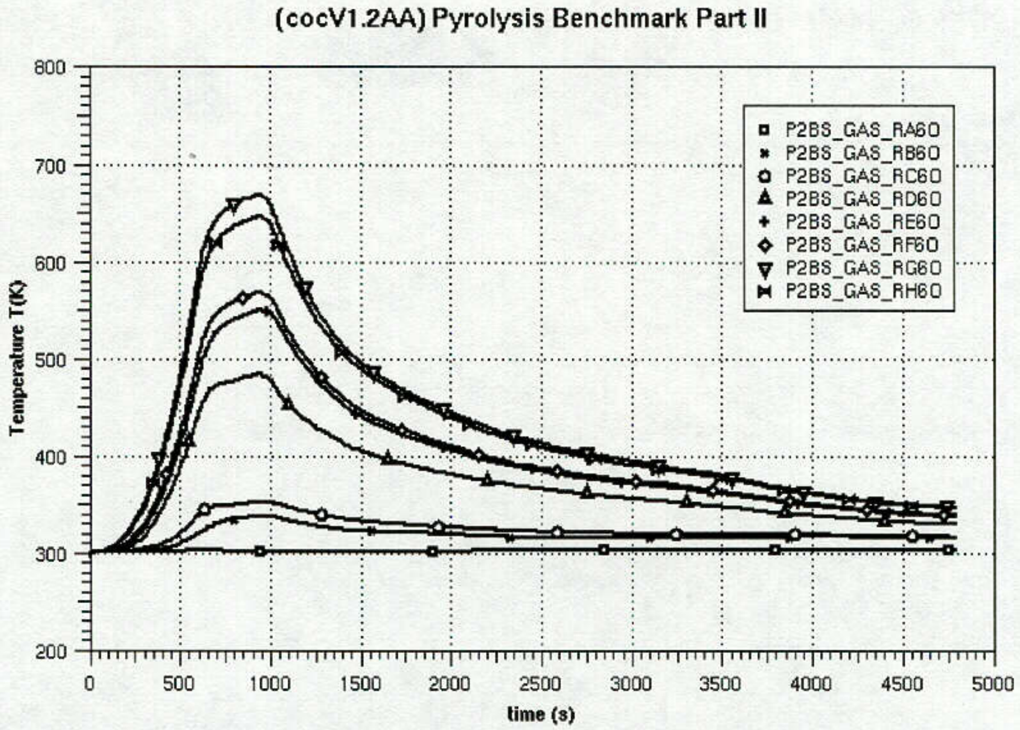

Figure 6-1 : Temperature profile in the room centre

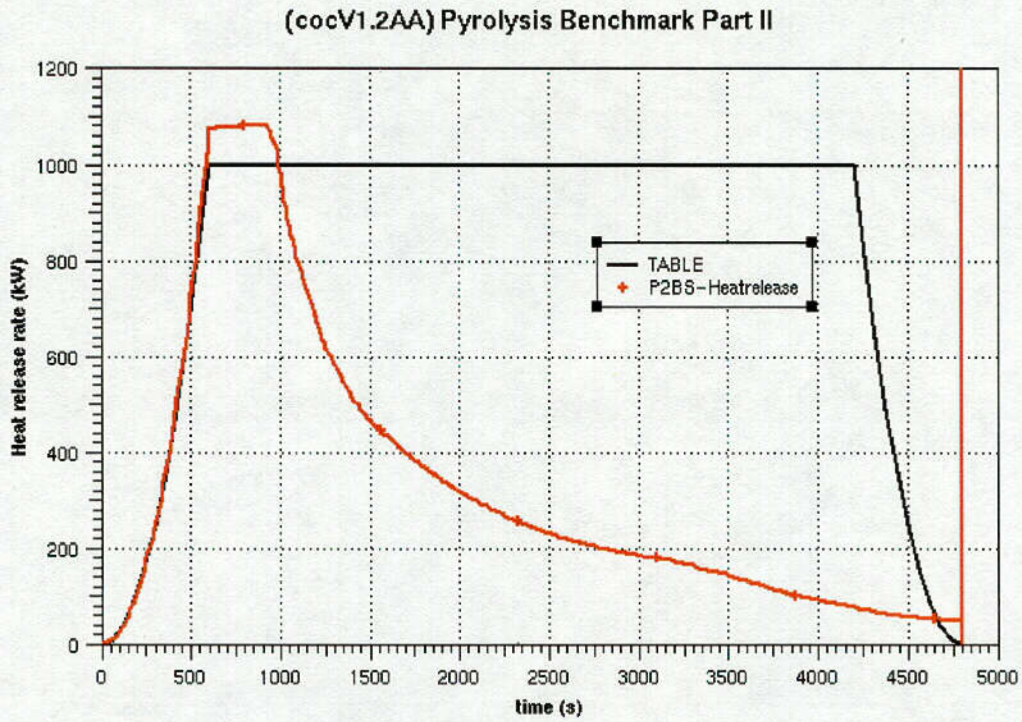

Figure 6-2 Heat release

C12

238

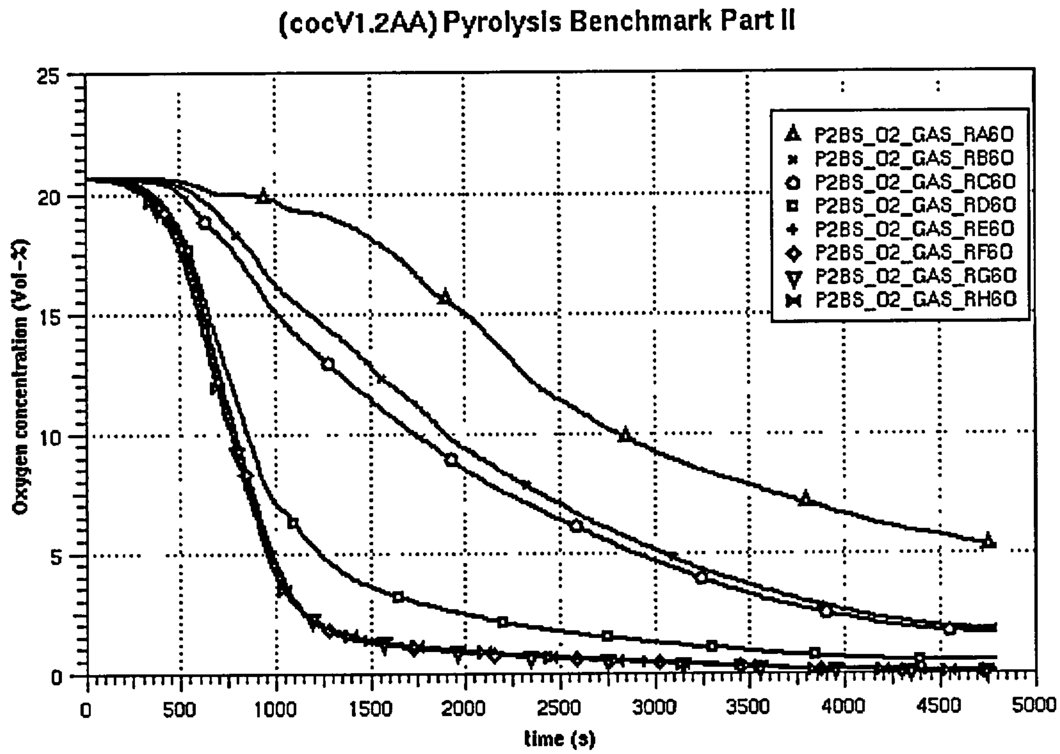

Figure 6-3 Oxygen concentration in the room centre

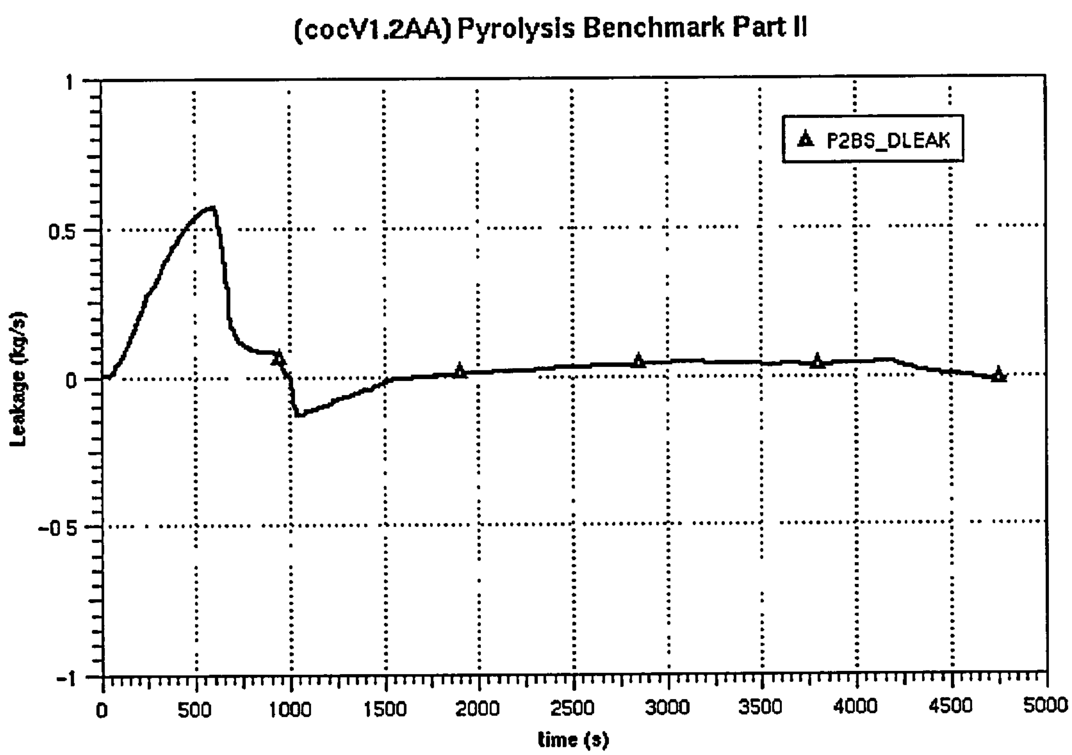

Figure 6-4 Leak rate through door

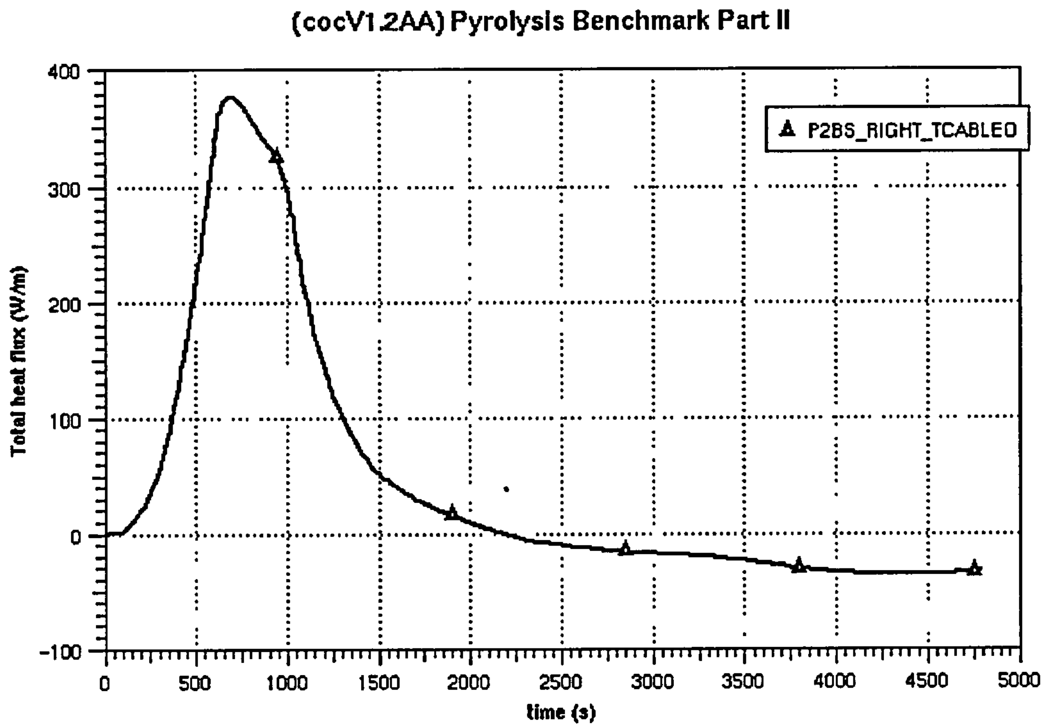

Figure 6-5 : Total heat flux into target

In comparison to part I the surface temperature of the target is now about 430 K and much higher (Fig. 6-6). The maximum temperature is reached at about 1000s. Although the surface temperature is decreasing the centerline temperature is still rising. At the end of 4800 s a temperature of about 375 K is reached, so the cable is not damaged, according to the definition of the benchmark exercise. In comparison to the part I the fraction of heat transferred to the boundary structures is larger (Fig. 6-7). At maximum heat release about 95% of the released heat is absorbed inside the structures. This value is higher because the atmospheric temperatures are higher in comparison to part I. Fig 6-8 to 6-11 present the concentrations of the pyrolysis fractions and products in the room centre for the different elevations. The simple pyrolysis model releases H, HCl and CH_X fractions. Against to the detailed model, a burning of the remaining carbon fraction is not possible. Considering the available oxygen the H and CH_X fractions are combust to steam and CO. The CO can be further burned to CO_2. The HCl will be released as a gas component. Chemical reactions with water and wall structures are not yet considered. This will lead to higher HCl concentrations in the atmosphere.

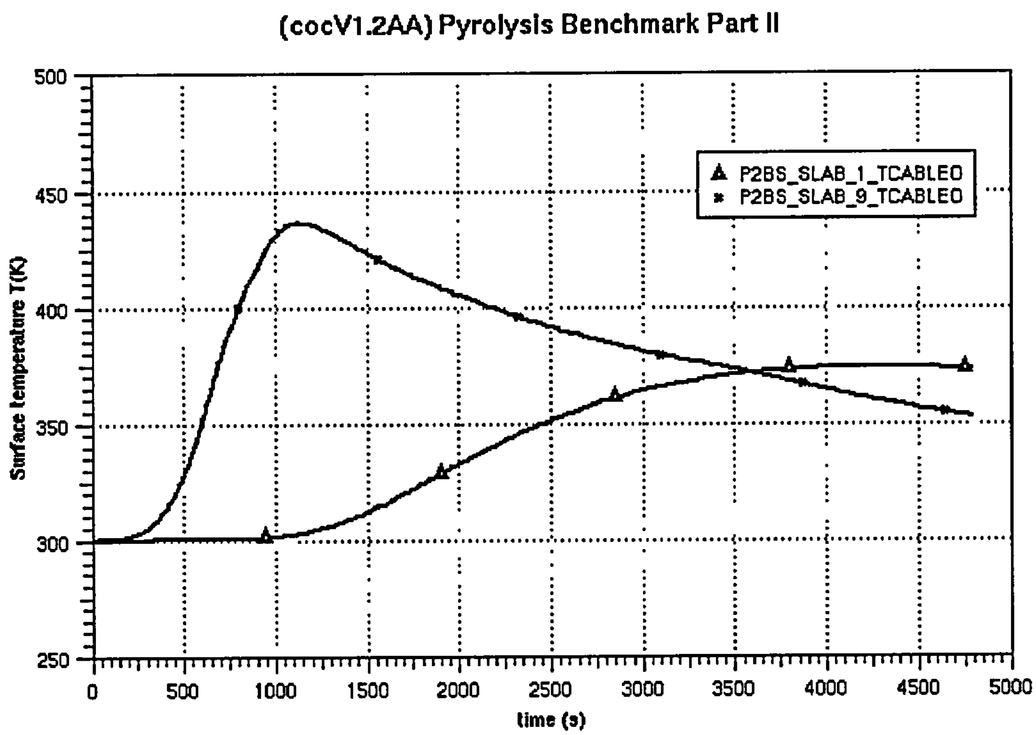

Figure 6-6 Surface and inner temperature of the target

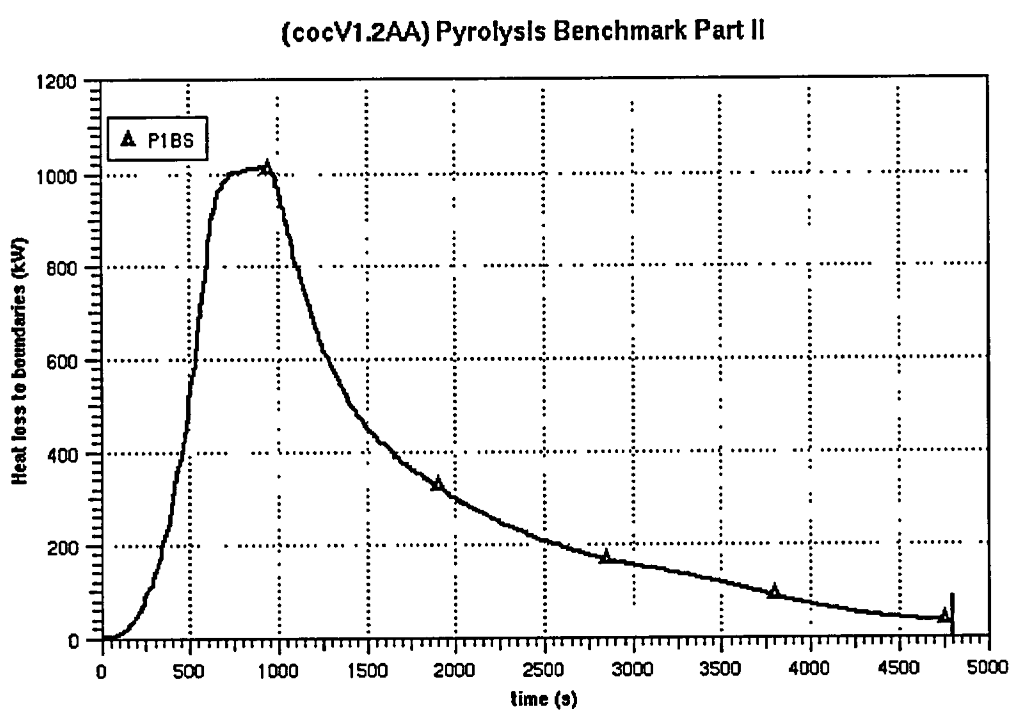

Figure 6-7 Heat loss to the boundaries

Fig 6-8 shows the CO concentration. If the oxygen concentration in the fire compartment is high enough the burning process is complete. Therefore the first peak of CO up to 0.8 Vol% occurs at about 1000s. Later the CO concentration decreases again. This indicates that the reductions due to the burning of CO is higher than the CO production due to the burning of the CH_X fraction. The behaviour of the CO_2 concentration is similar (Fig. 6-9). CO_2 is produced from the beginning on. Later the production rate is decreasing. As a result the stratified conditions of the CO_2 concentration is vanishing. At the end of the calculation the concentration at the ceiling is lower than the concentration at the floor level. This is caused by the increasing concentrations of CH_X and HCl. Fig. 6-10 and 6-11 presents the HCl and CHX concentration, respectively. The behaviour of both is very similar. It should be pointed out that the release of the pyrolysis fraction is given by input. In the reality there is a strong feed back of the burning process, depending on the available oxygen on the cable tray temperatures and release of pyrolysis gases.

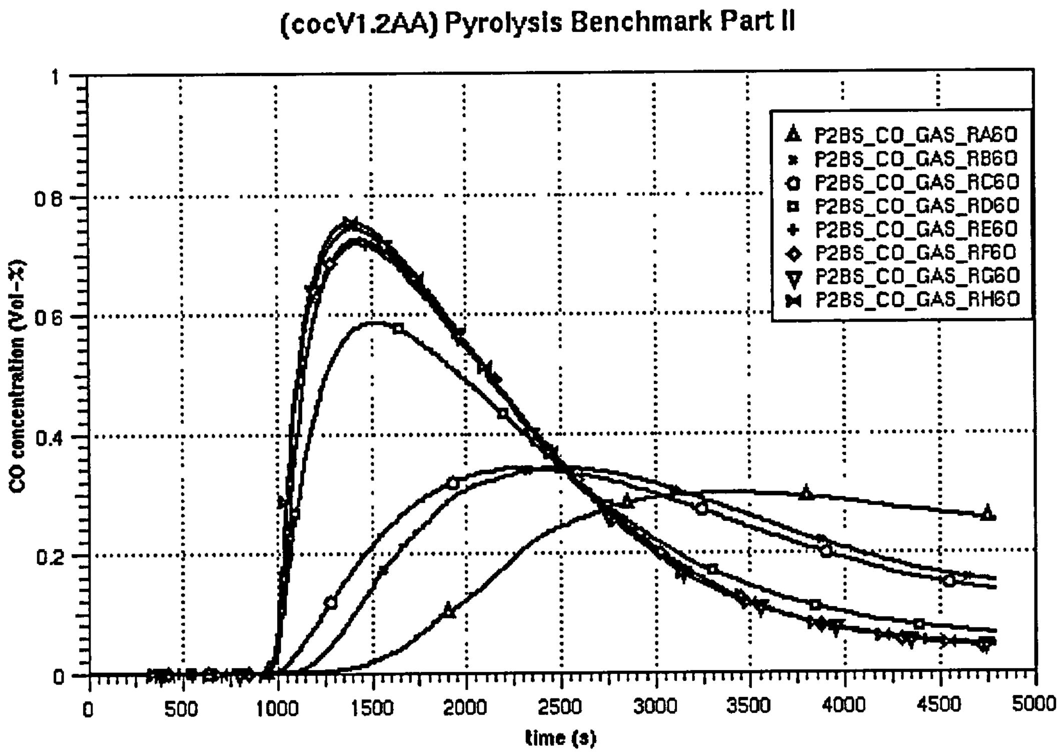

Figure 6-8 CO concentration in the room centre

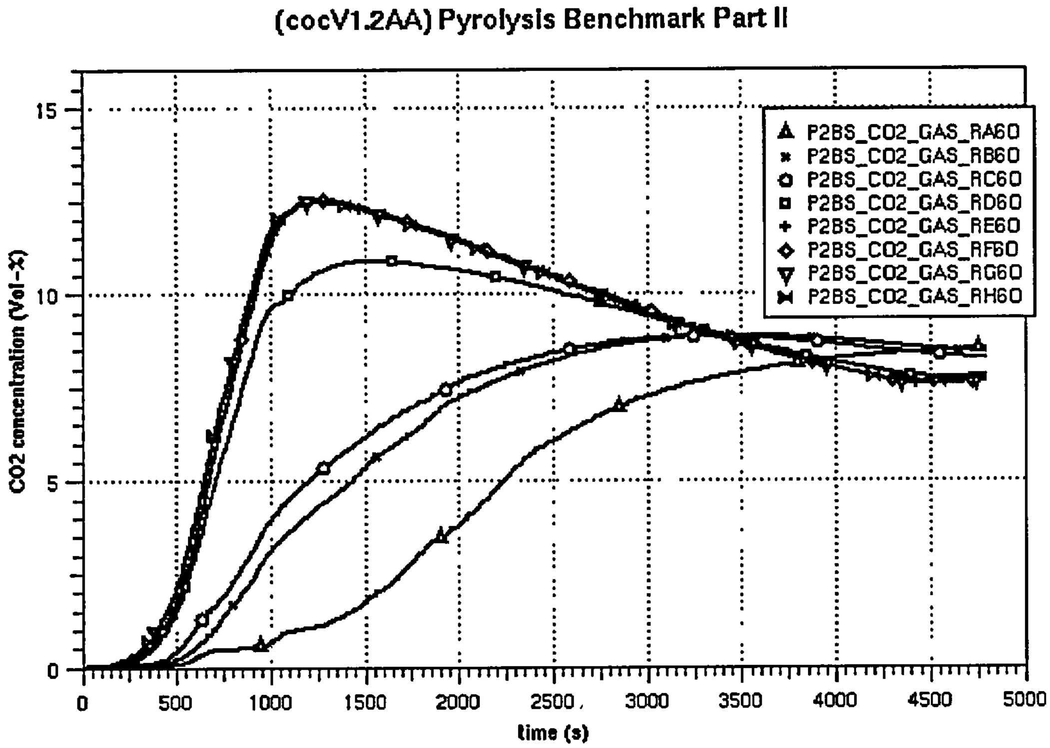

Figure 6-9 CO_2 concentration in the room centre

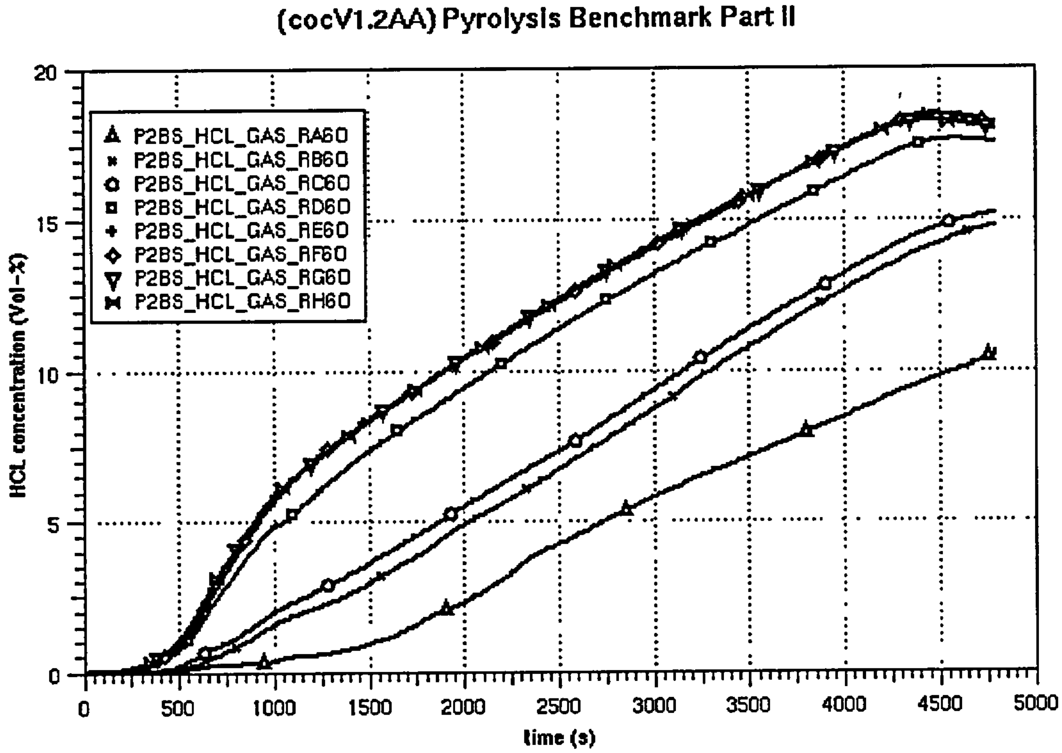

Figure 6-10 HCl concentration in the room centre

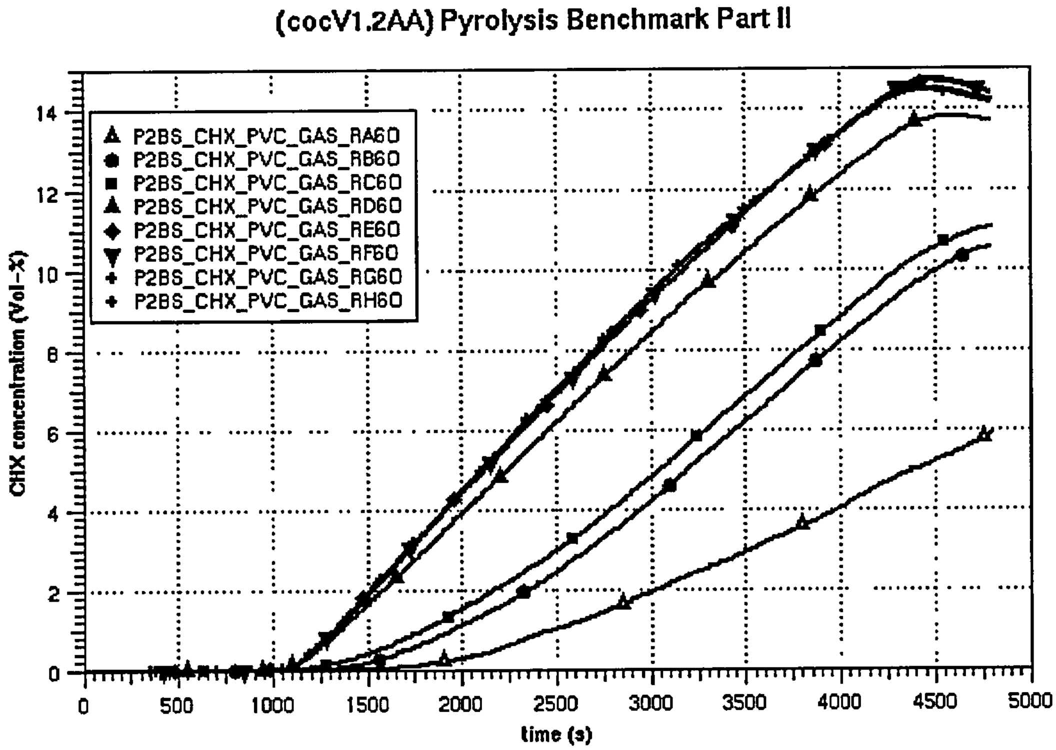

Figure 6-11 CH_X concentration in the room centre

6.2 Case 1 to case 8

In these variations the position of the target cable tray is shifted sidewards and the heat release (in practice the release of pyrolysis fractions) is increased from 1MW to 3MW. In 6-12 the temperatures at the ceiling in the room centre are plotted for all cases. Shifting the target, does not influence the temperature at the ceiling. Therefore the temperatures for the base case, case 5 and case 8 are equal for example. The maximum atmospheric temperatures increases for higher heat release rates. But the effect is much higher for the increase from 1 MW to 2 MW as for the step from 2 MW to 3 MW. The time of the maximum temperature is lower also. It is interesting, that the atmospheric temperatures in the case of 1 MW release is higher than for the 2 or 3 MW release later. This corresponds to the experience gained with the code, that higher release rates can 'move' the burning process away from the release point leading to lower temperatures and may be to not conservative results. Fig. 6-13 presents the real heat release rates in comparison to the given one. The small difference in the maximum temperatures in the 2 and 3 MW case is underlined here again. Later the heat release is lower in comparison to the base case.

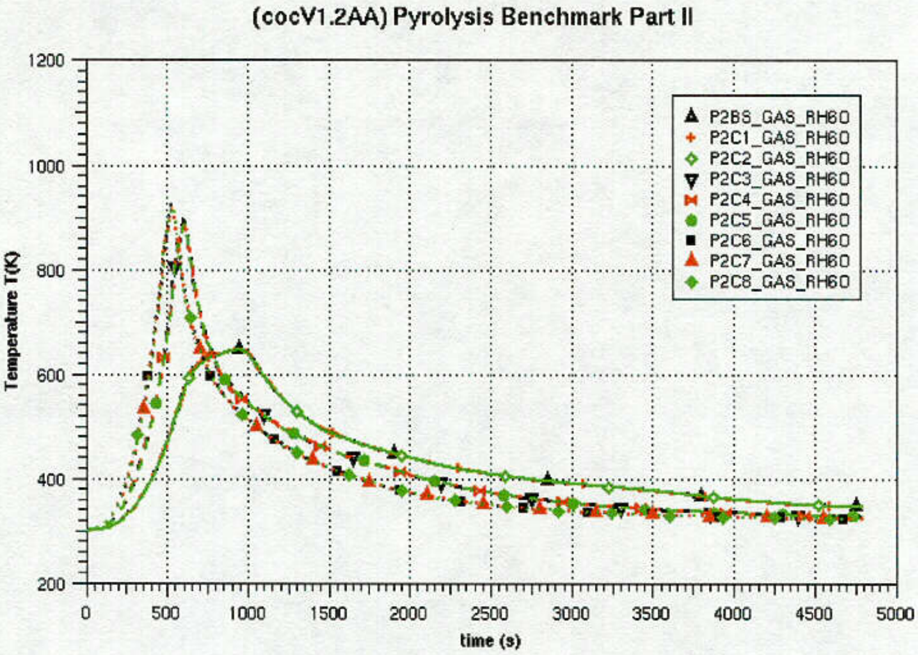

Figure 6-12 Temperatures below the ceiling in the room centre

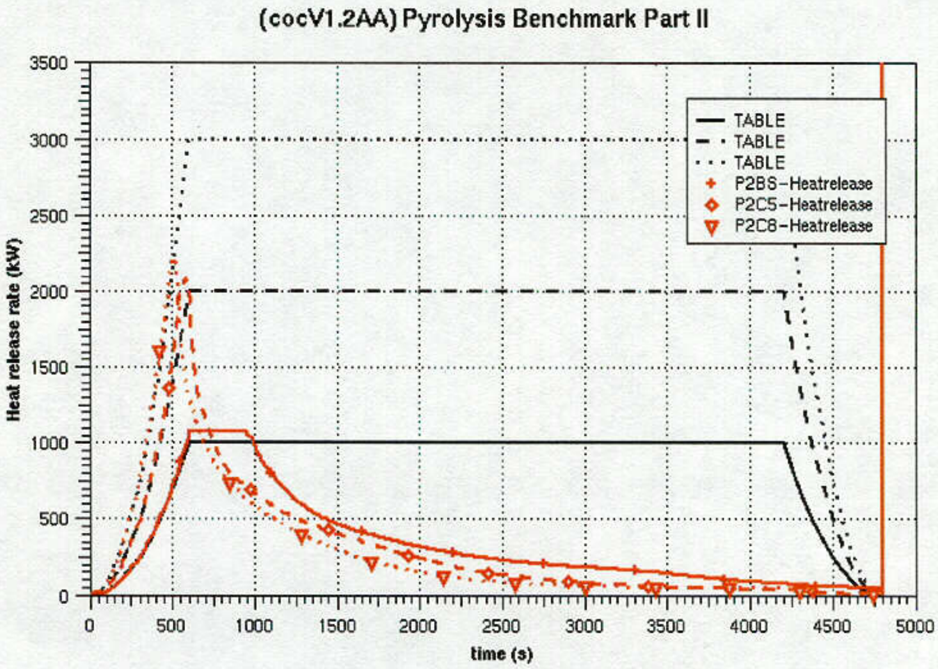

Figure 6-13 Heat release (base case, case5, case8)

C13

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Fig 6-14 shows the oxygen concentrations at the ceiling for the different cases. It is evident, that the oxygen is consumed earlier in the 2 and 3 MW cases, resulting in the above described behaviour. The leak rate through the door is presented in Fig. 6-15. In the first heat up phase gas is moved in the atmosphere. After this the direction of the leak flow turns around, due to the cool down inside the fire compartment. Then between 1000s and 1500s the leak flow turns around again. Here the pressure built up due to the release of pyrolysis gases is able to compensate the cool down of the fire compartment. At this time no fresh air can enter the fire compartment. This underlines again, that the release of pyrolysis gases may inhibit the burning process. Fig 6-16 shows, that the heat flux into the target depends only on the 'heat release rate'. This is caused by the neglecting of the direct radiation. The maximum surface temperature (Fig. 6-17) is increased by about 20 K. The low difference results from the less amount of oxygen inside the fire compartment. Fig 6-18 presents the heat loss to the boundaries. Increasing the 'heat release' the consumption of oxygen is higher. Therefore the maximum CO concentration is slightly higher and earlier. The overall qualitative behaviour of the concentration for higher heat release is quite similar to the base case (Fig 6-19 to 6-22).

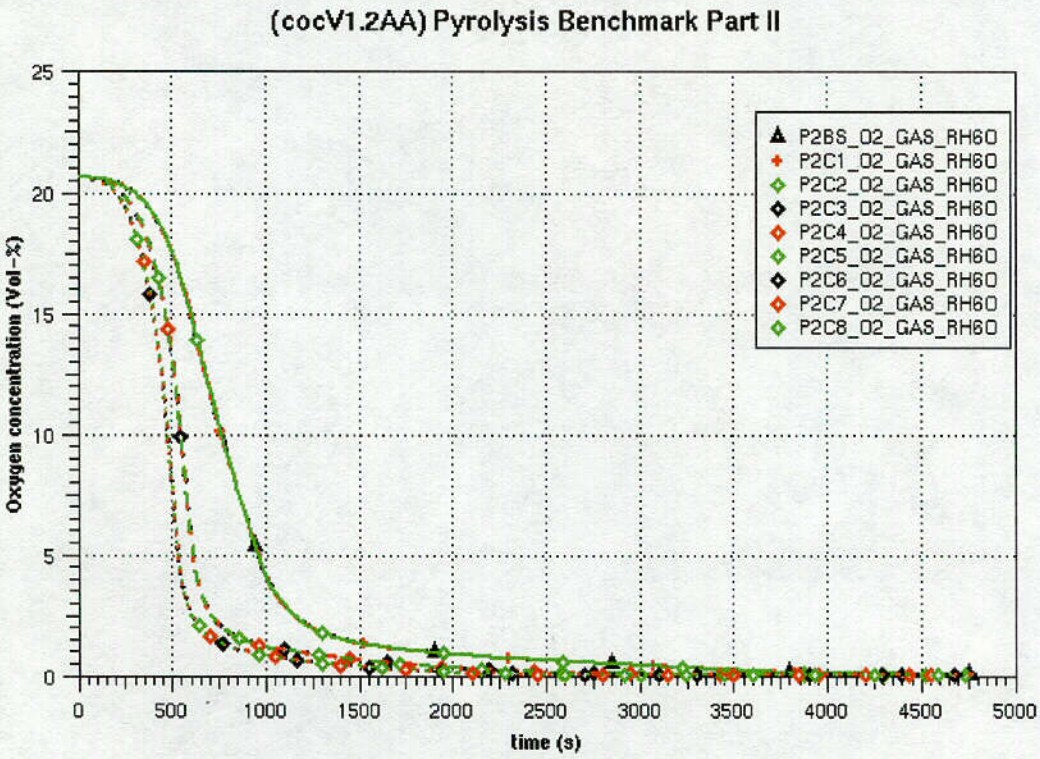

Figure 6-14 Oxygen concentration below the ceiling in the room centre

C14

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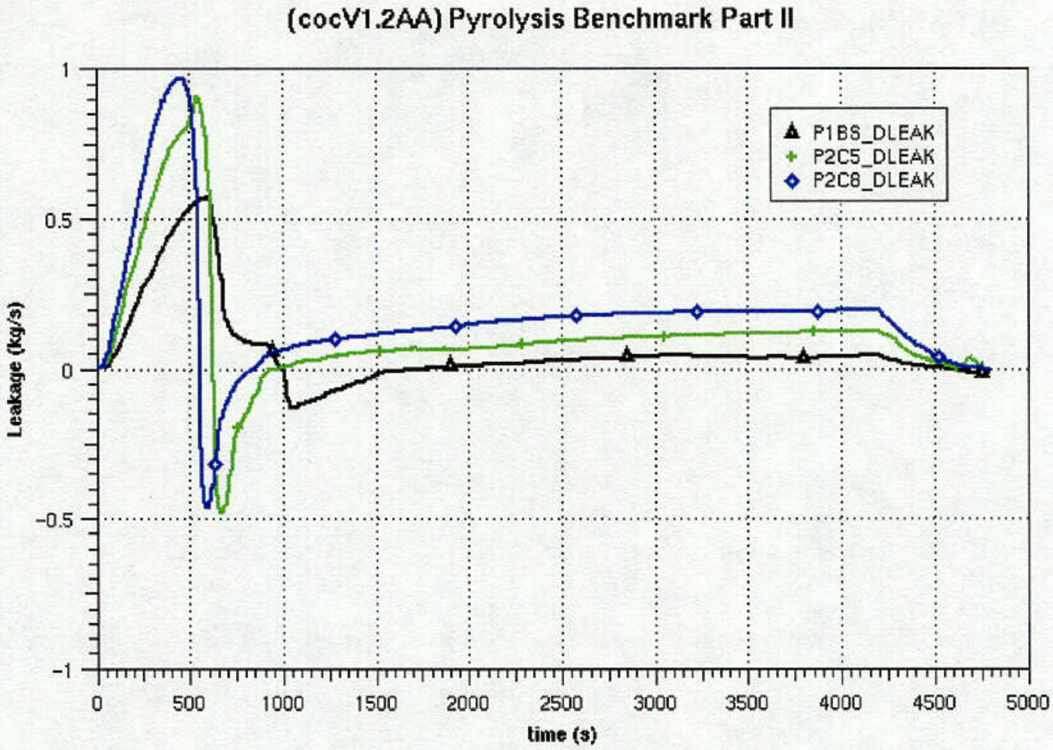

Figure 6-15 Leak rates (base case, case 5, case8)

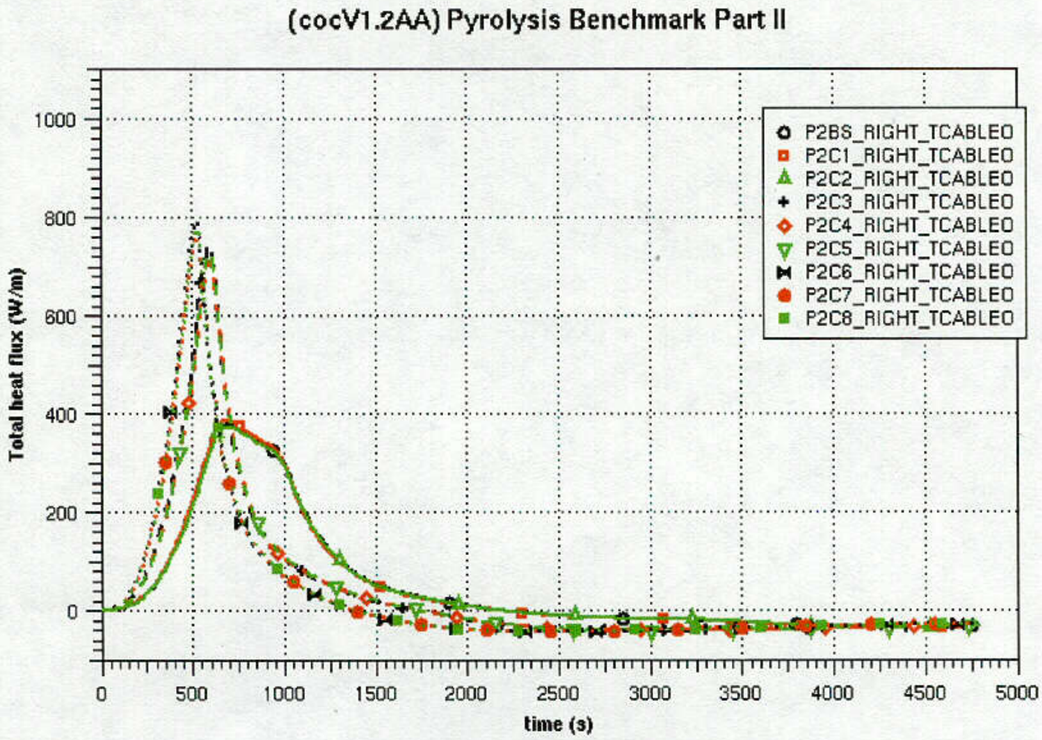

Figure 6-16 Heat flow into the target

C15

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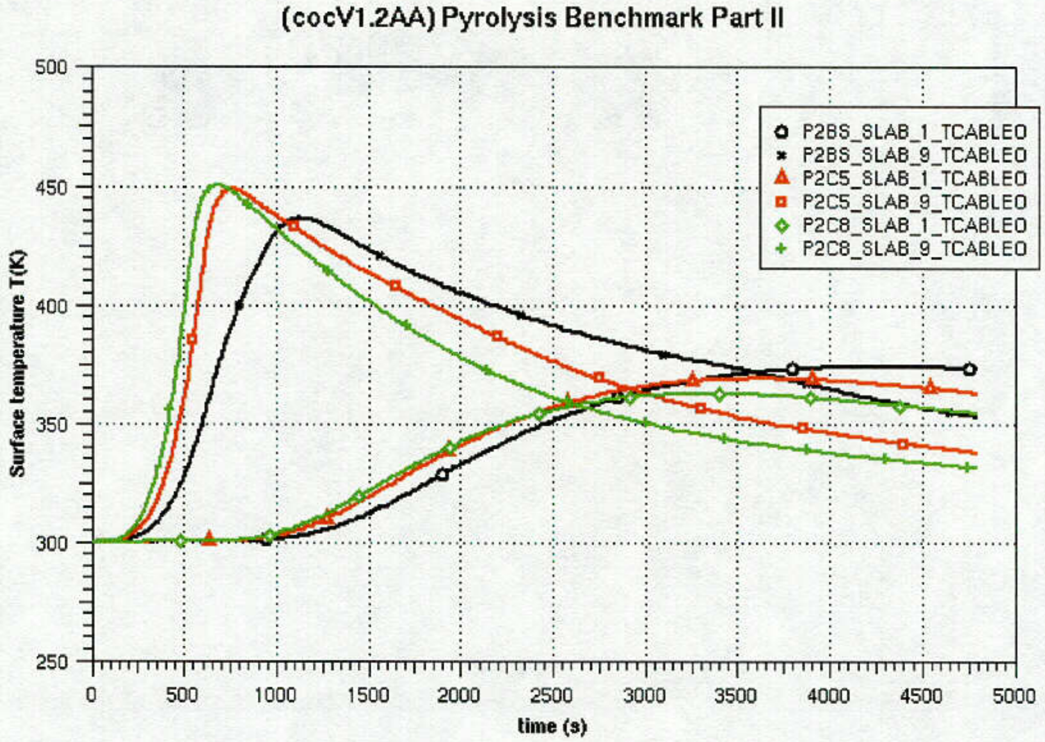

Figure 6-17 Surface and inner temperatures of the target (base case, case5, case8)

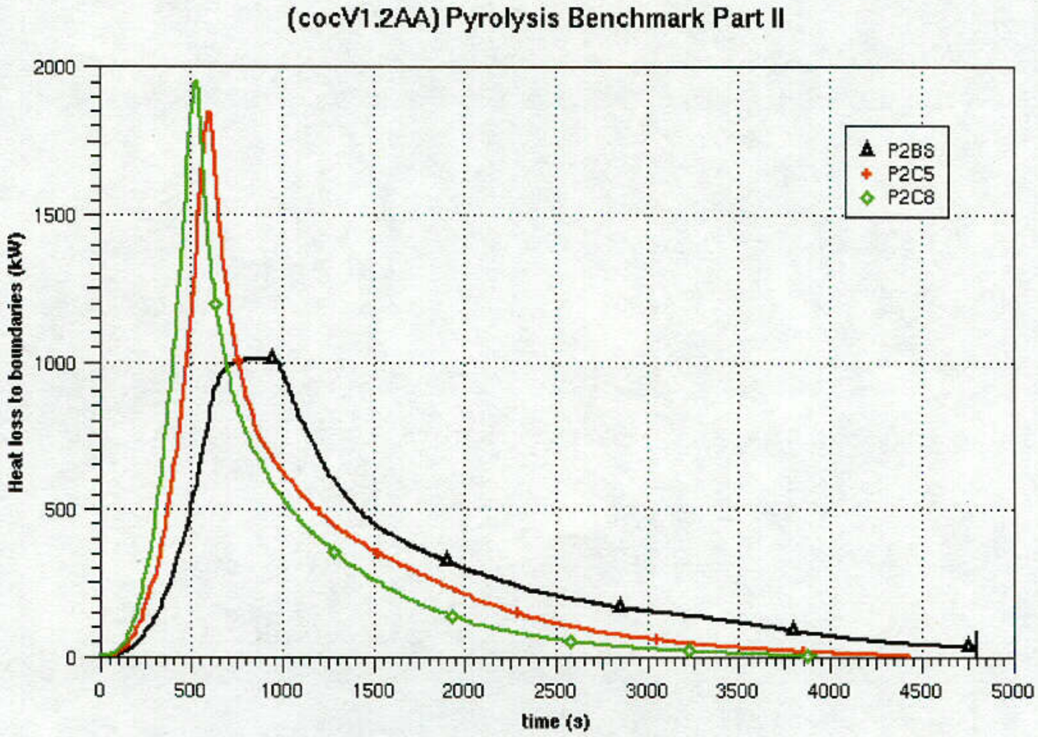

Figure 6-18 Heat loss to boundaries (base case, case5, case8)

C16

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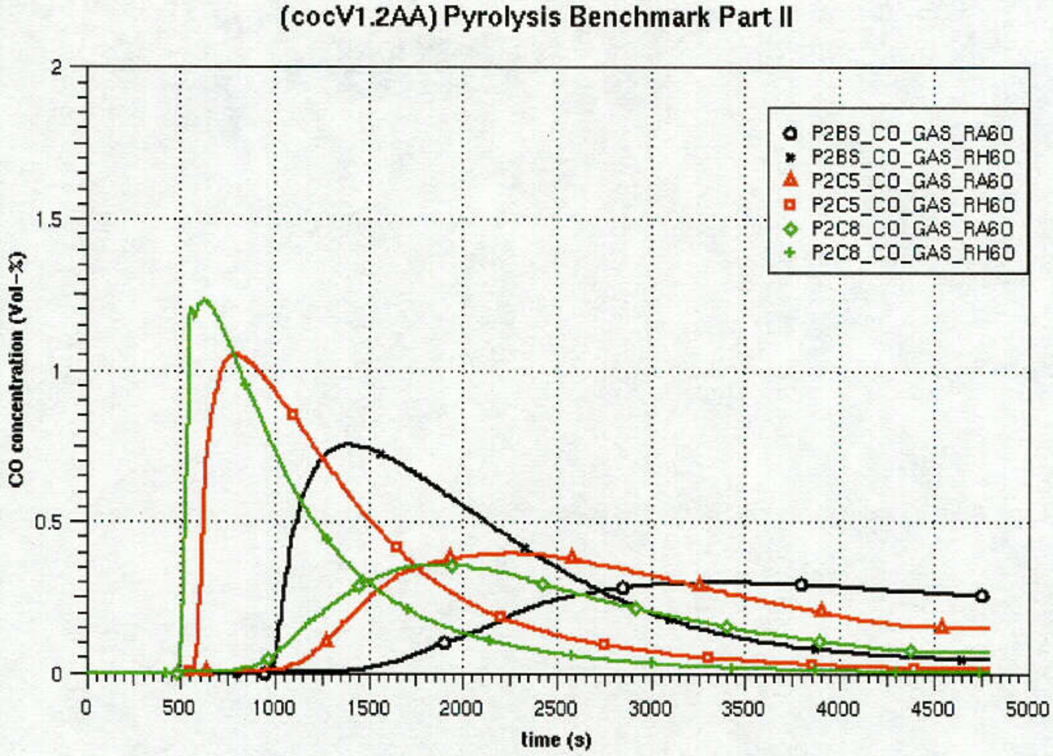

Figure 6-19 CO concentration at ceiling and bottom in room centre

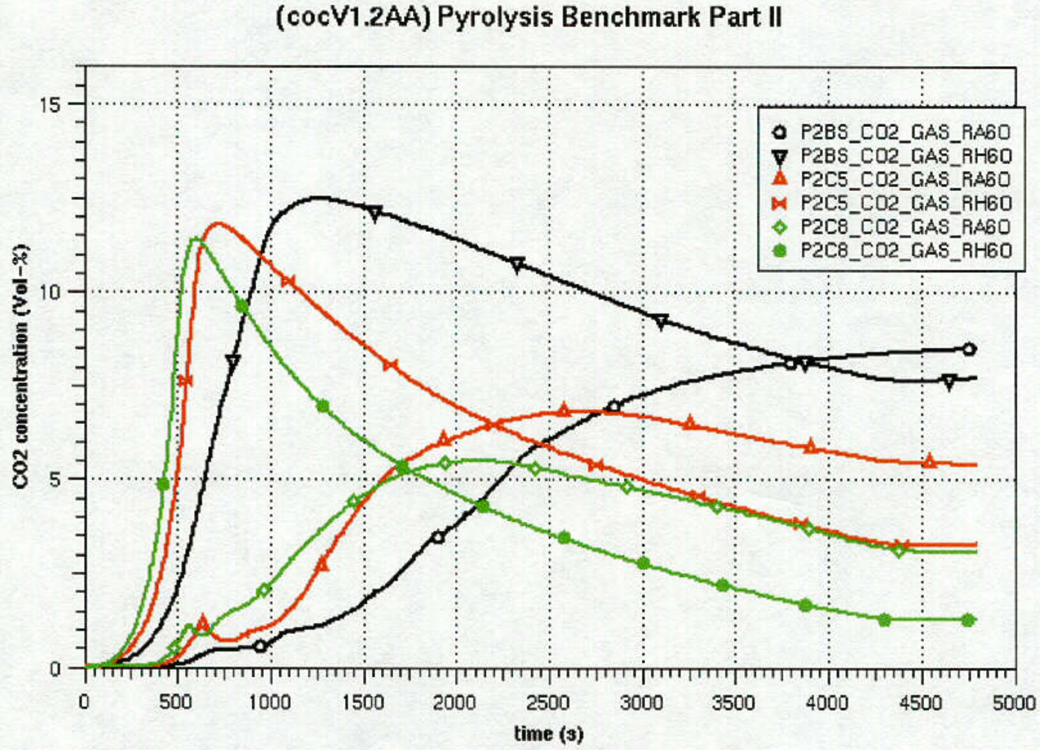

Figure 6-20 CO_2 concentration at ceiling and bottom in room centre

C17

251

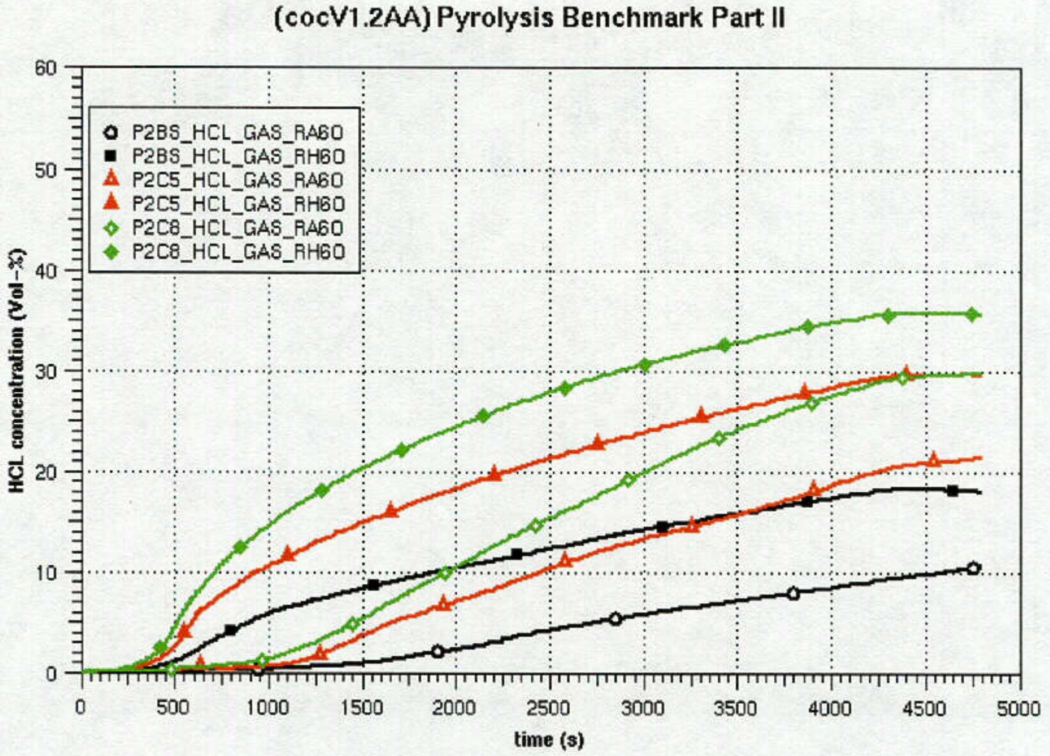

Figure 6-21 HCl concentration at ceiling and bottom of room centre

C18

252

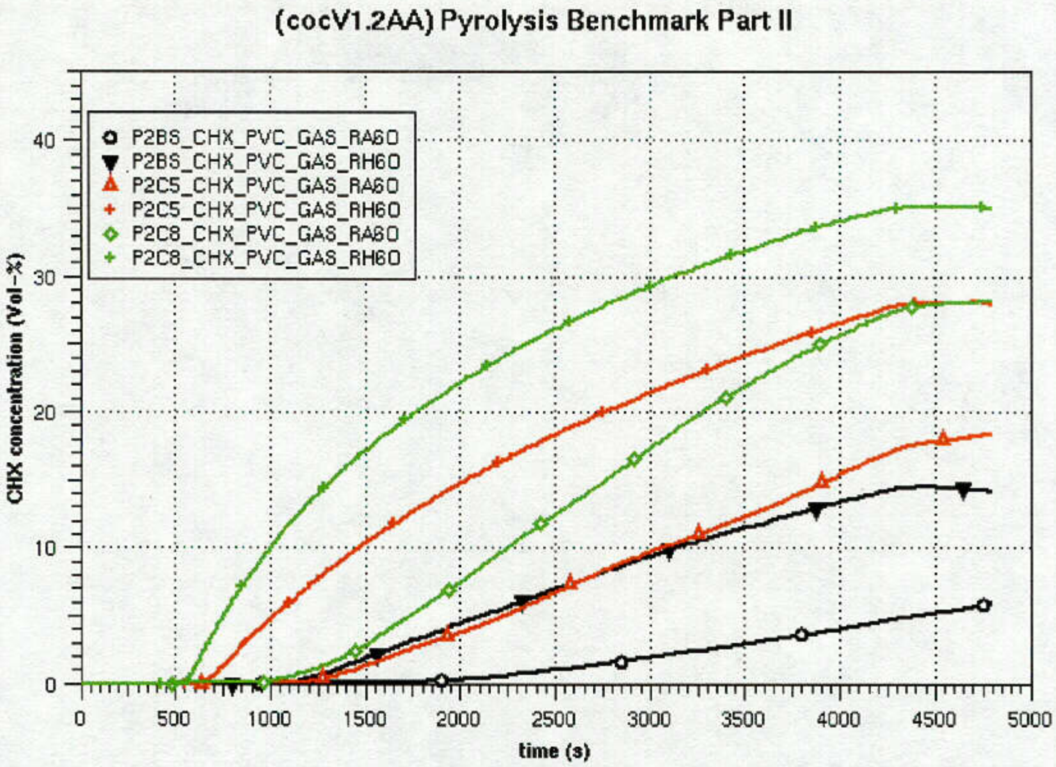

Figure 6-22 CH_X concentration at ceiling and bottom of room centre

6.3 Case 9 and Case 10 : Ventilation and door effects

In case 9 the ventilation system is running until 15 min. Then the door is opened. In case 10 the door is open and the ventilation system is running all the time. The main difference is the available oxygen concentration. Therefore the temperatures below the ceiling are much higher. The temperature at floor level is quite similar in all cases (Fig. 6-23). As it can be seen in Fig. 6-24 in case 9 and 10 the burning is nearly complete. Only in case 9 the oxygen concentration (Fig. 6-25) goes under the limit of 4 % leading to an incomplete burning of about 10%. Fig 6-26 shows the flow rate through the open door. In case 9 the counter current flow is established shortly after the opening of the door. In the cool down phase at the end of the problem time the flow through the door starts to turn around. Fig. 6-27 shows the mass flow rate through the left vent opening. In case 9 the ventilation system is stopped and additionally the vent opening is closed. The flow rate is always directed to the environment. The heat flow to the target in the vented cases is very similar according to the similar heat release (Fig. 6-28). In comparison to the base case the values are much higher, leading therefore to much higher

C19

253

surface temperatures (Fig. 6-29). At about 4500s the threshold value of about 200 C for cable damage is reached.

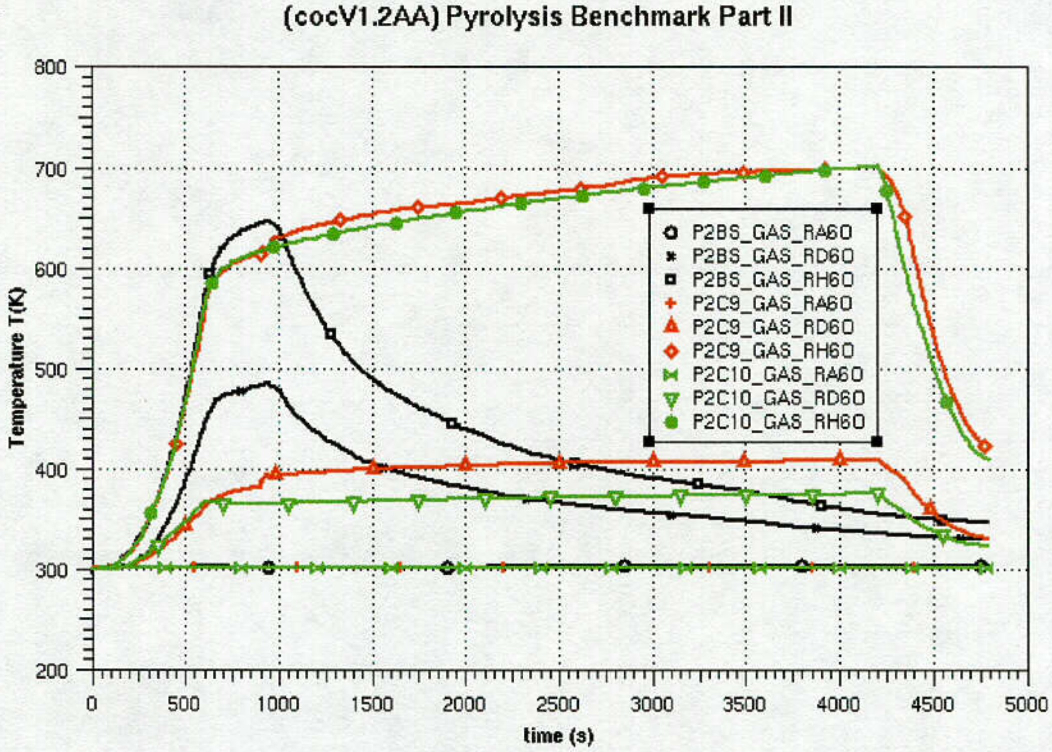

Figure 6-23 Temperatures at 0.3, 2.3 and 4.4 m in the room centre

C20

254

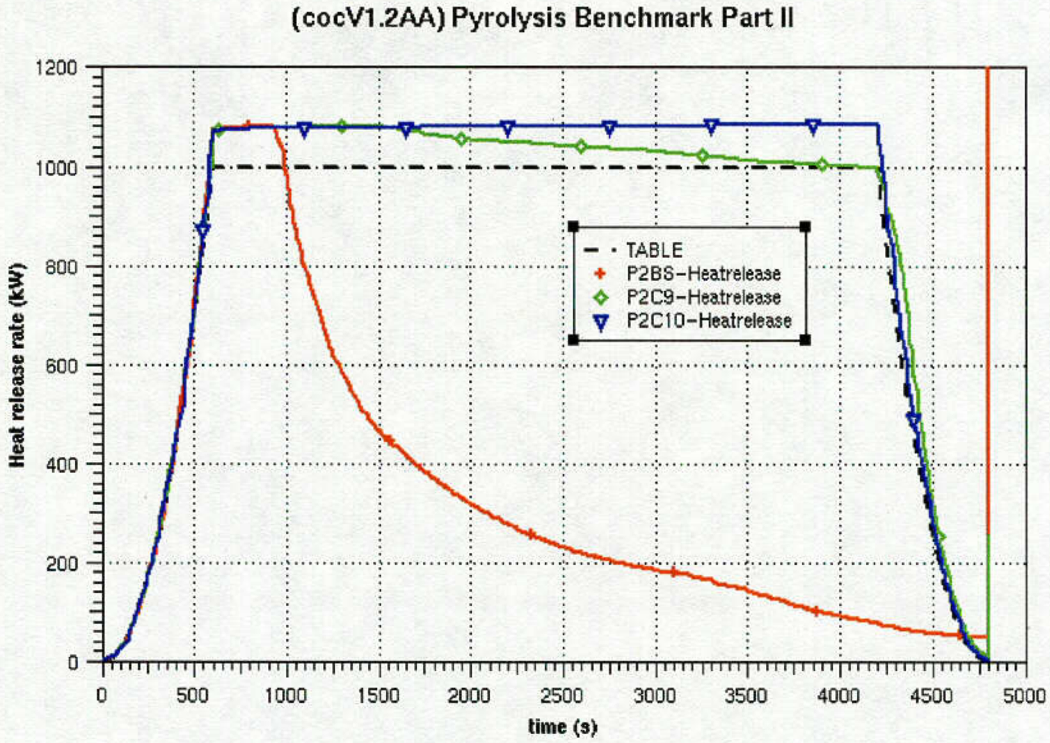

Figure 6-24 Heat release (base case, case9 and case10)

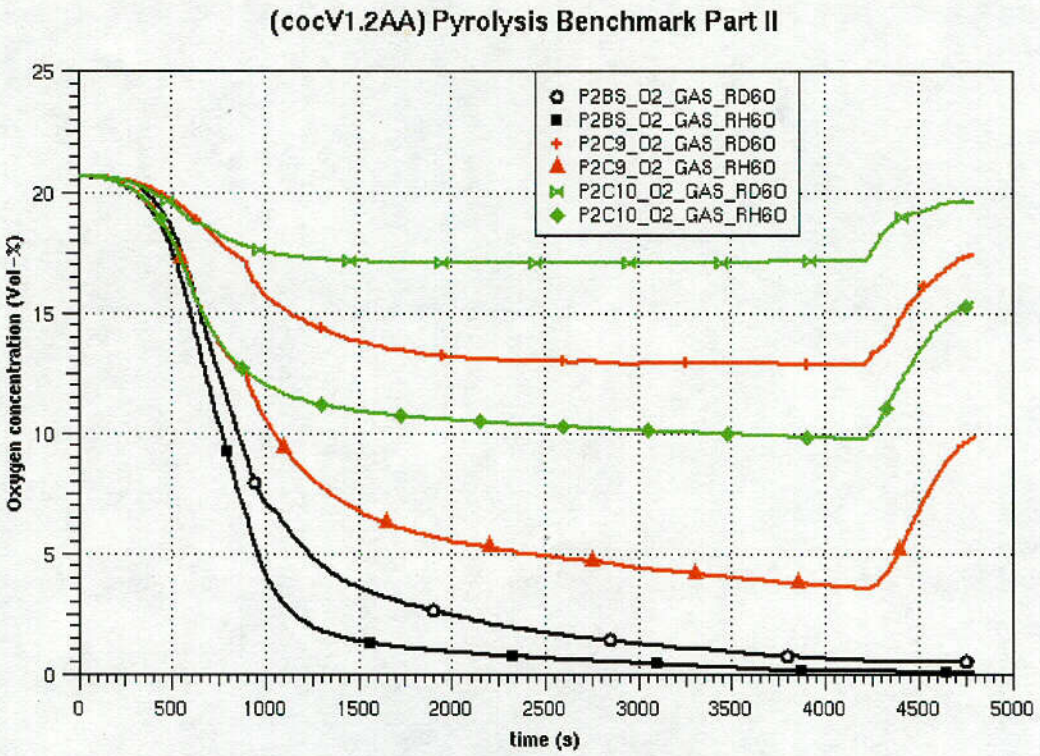

Figure 6-25 Oxygen concentration at 2.3 and 4.4m in the room centre

C21

255

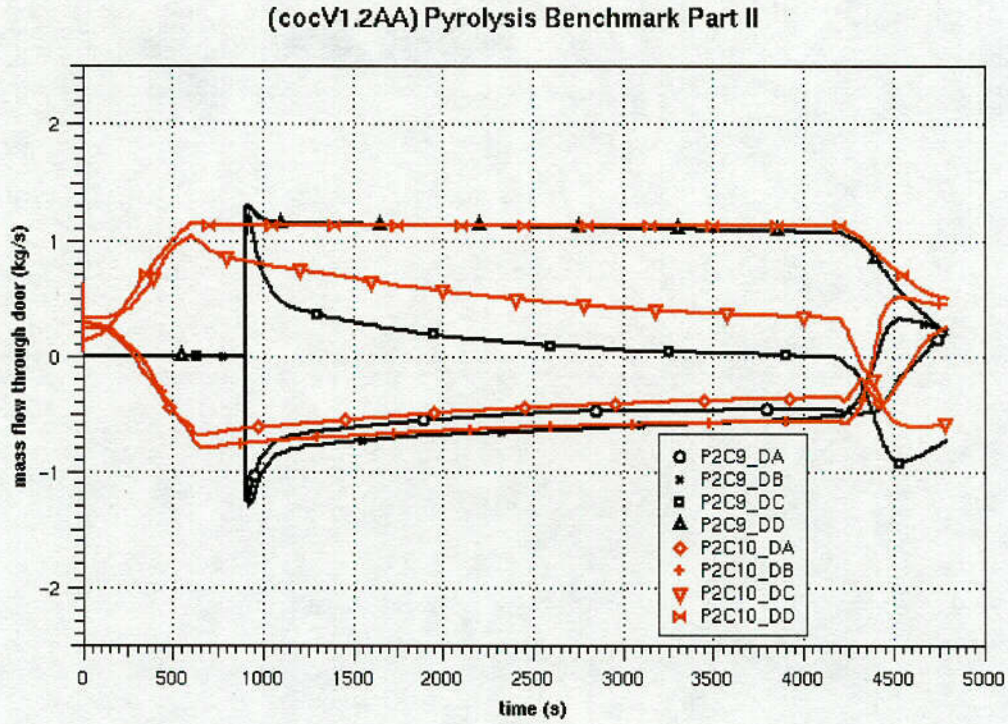

Figure 6-26 Mass flow rate through door (case 9 and 10)

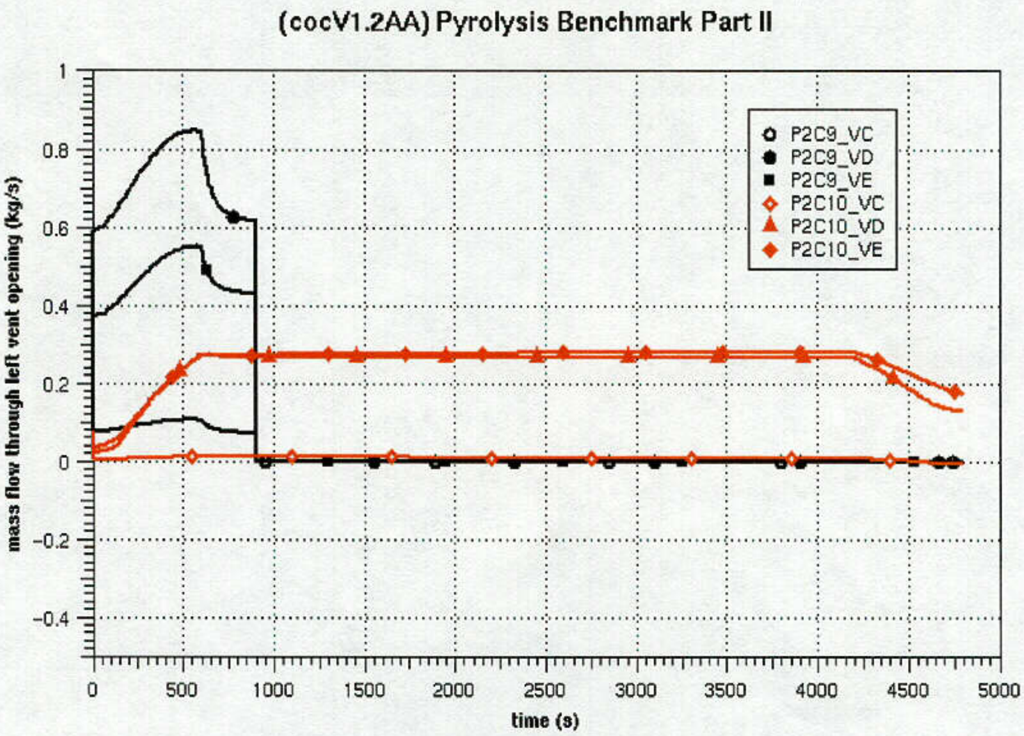

Figure 6-27 Mass flow rate through left vent opening (case 9 and 10)

C22

256

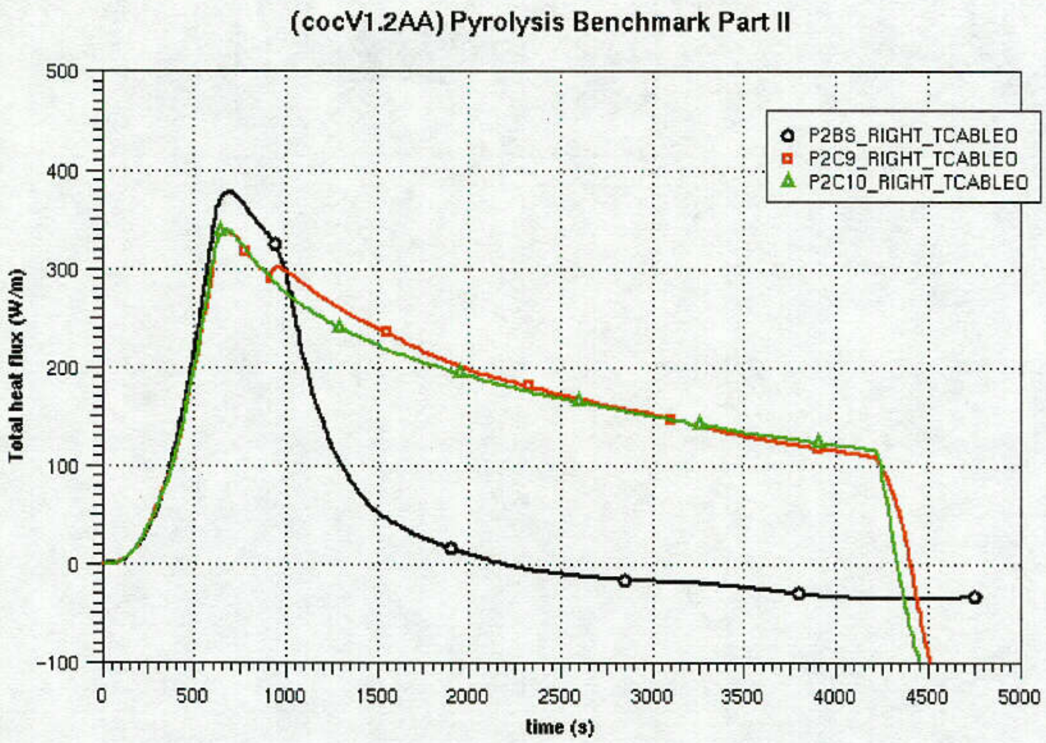

Figure 6-28 Total heat flow into target

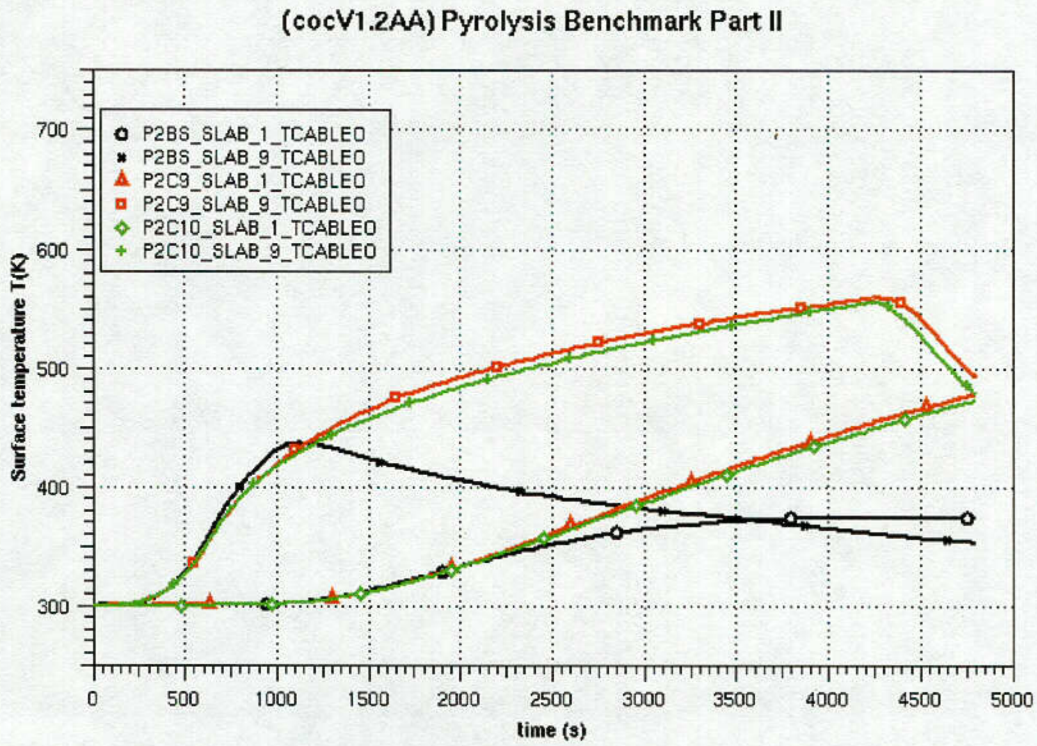

Figure 6-29 Surface and inner temperature of target

C23

(251)

In case 10 there are always oxygen rich conditions. Therefore the CO concentration is always zero. In case 9 the oxygen concentration in the highest level is somewhat lower. At about 1500s the burning rate is incomplete, leading to some amount of CO there. The behaviour of the CO_2 concentration (Fig. 6-31) is very different in comparison to the base case. This is the result of two opposite effects: the open conditions reducing the concentrations of the gases and the higher pyrolysis and burning rate increasing the concentrations. The CO_2 concentration for case 9 is somewhat higher. The reason is the convection flow through the door needs some time to build up, leading to lower exchange rates during this time. The behaviour of HCl (Fig. 6-32) is qualitative similar to the behaviour of CO_2. The oxygen concentration in the vented cases is high enough for the complete burning of the CH_X fraction (Fig. 6-33).

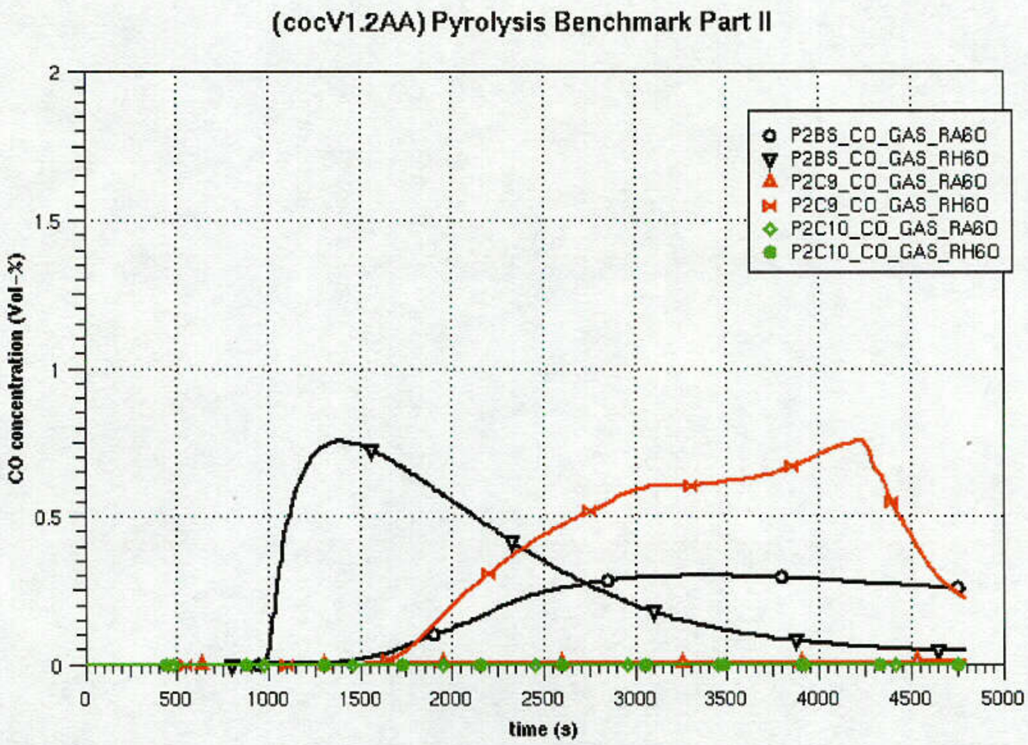

Figure 6-30 CO concentration at bottom and ceiling in the room centre

C24

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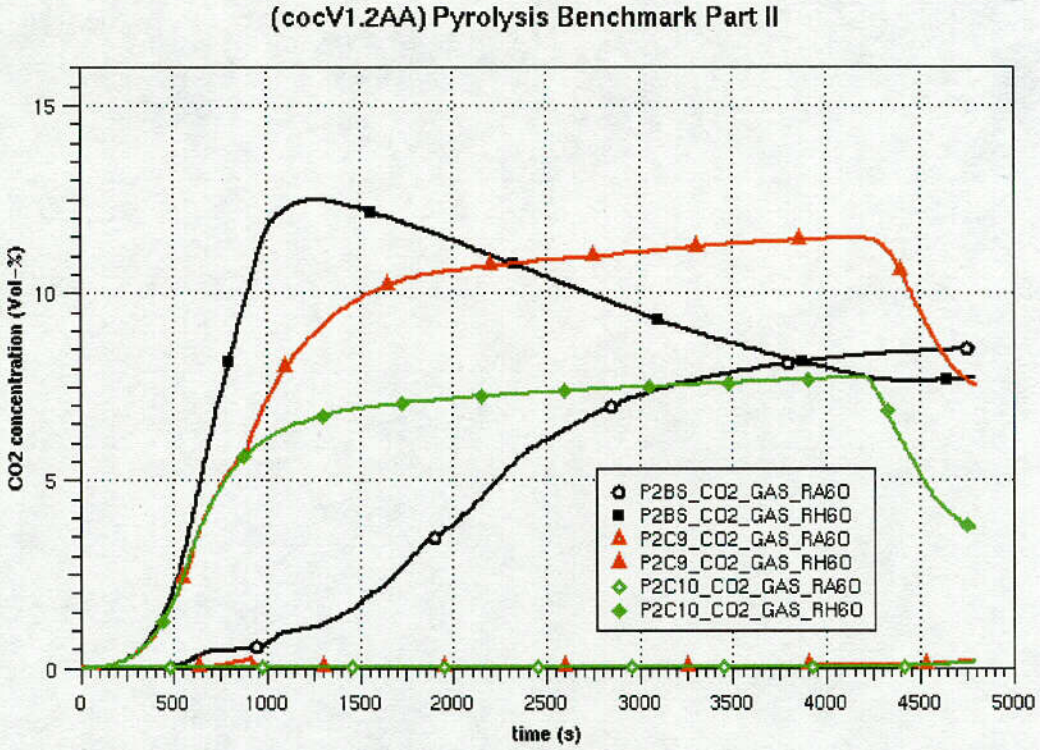

Figure 6-31 CO_2 concentration at bottom and ceiling in the room centre

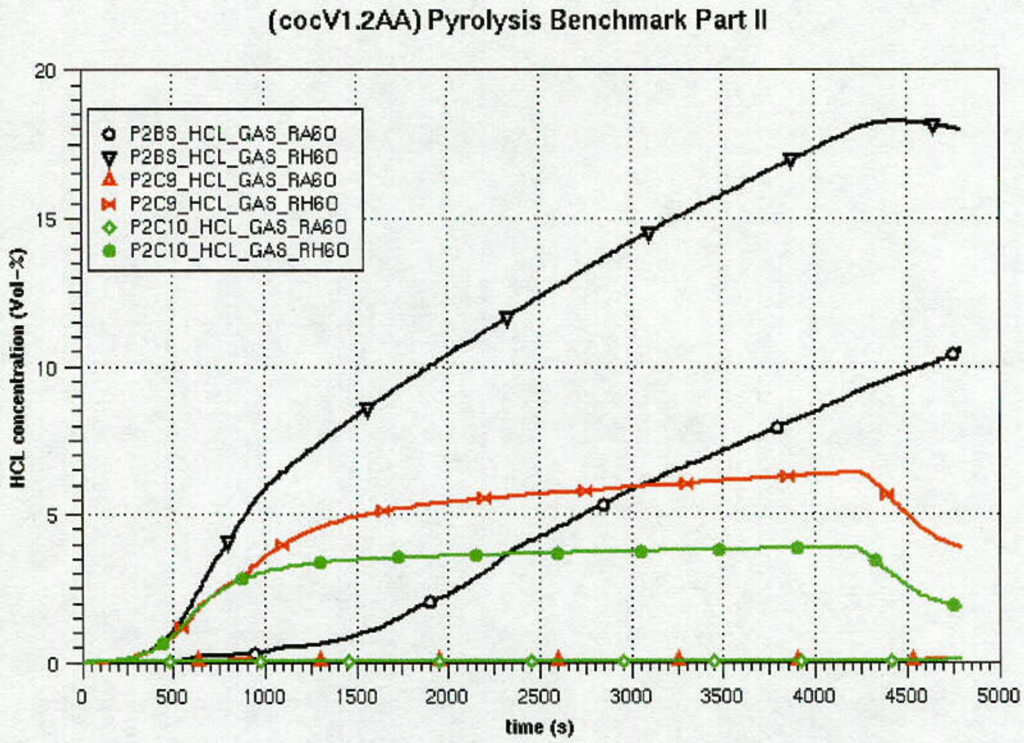

Figure 6-32 HCl concentration at bottom and ceiling in the room centre

C25

255

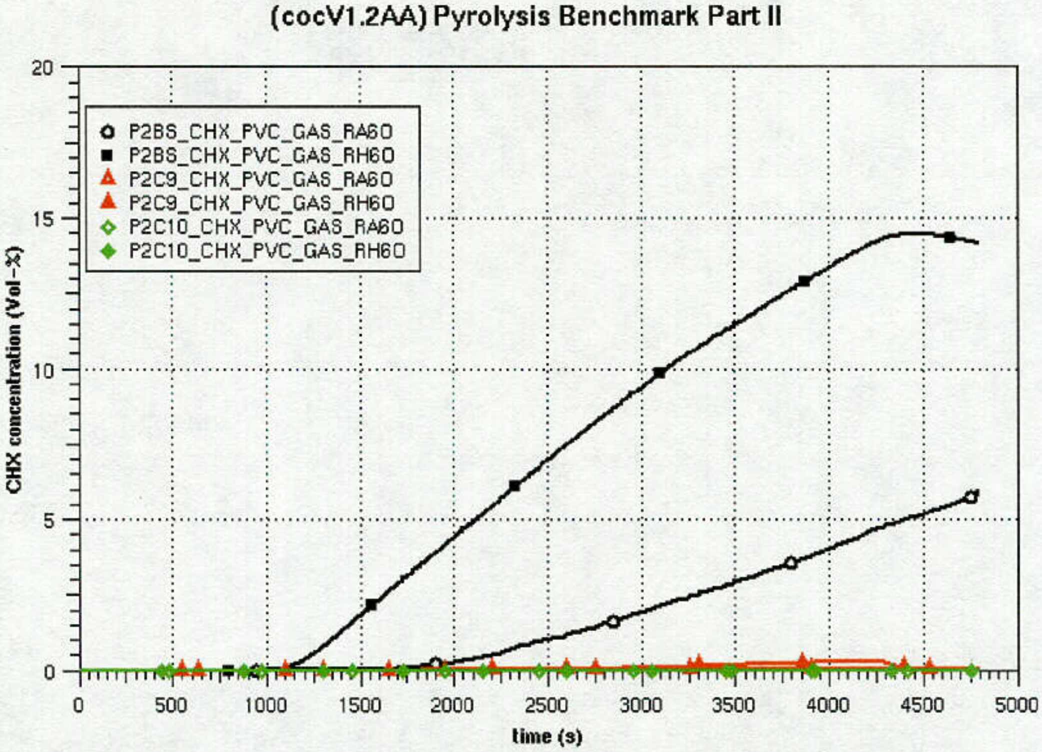

Figure 6-33 CH_X concentration at bottom and ceiling in room centre

6.4 Case 11 and 12 : Elevation of the target

In this set of variations the elevation of the target is changed. In the base case the elevation of the target cable is 1.1 m above tray A and on the same level as of C2 the heat release level. In case 11 the elevation of target tray is 2.0 m above tray A and in case 12 the elevation is equal to tray A. It is clear, that the heat release and the burning process are the equal to the base case, because there is no feed back from the target cable. Due to the different elevation and the stratified conditions inside the fire compartment the heat flux into the target is different. As one would expect the heat flux and the surface temperature is higher for the higher elevations (Fig. 6-34 and Fig. 6-35).

C26

260

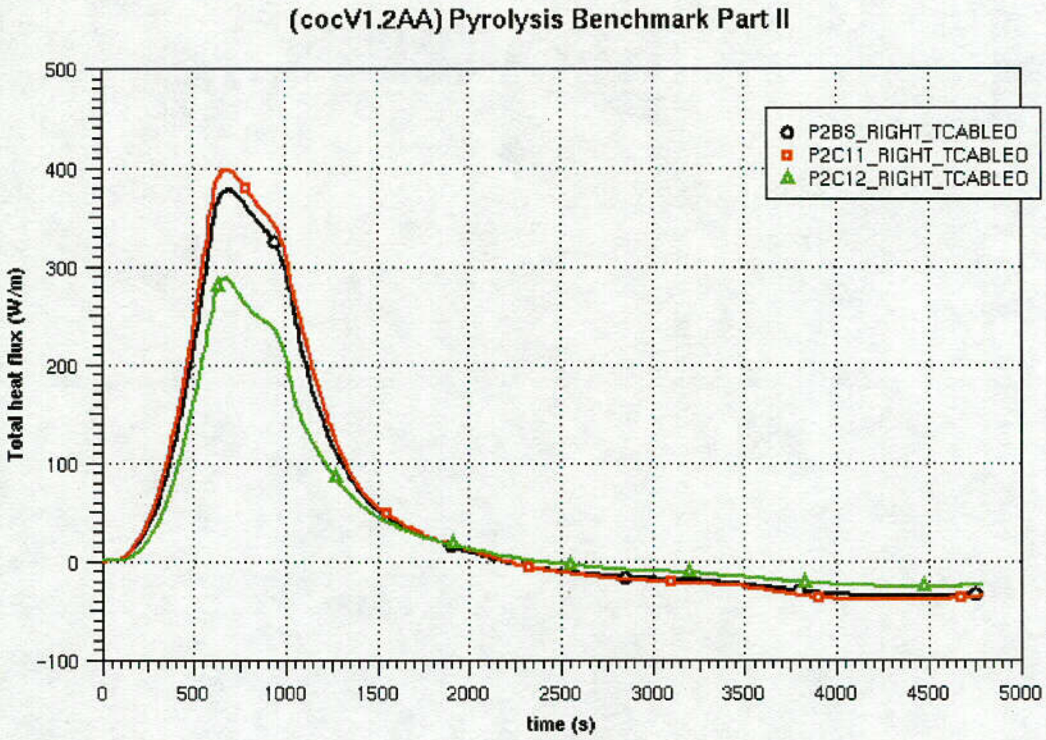

Figure 6-34 Total heat flux into target (base case, case 11, case 12)

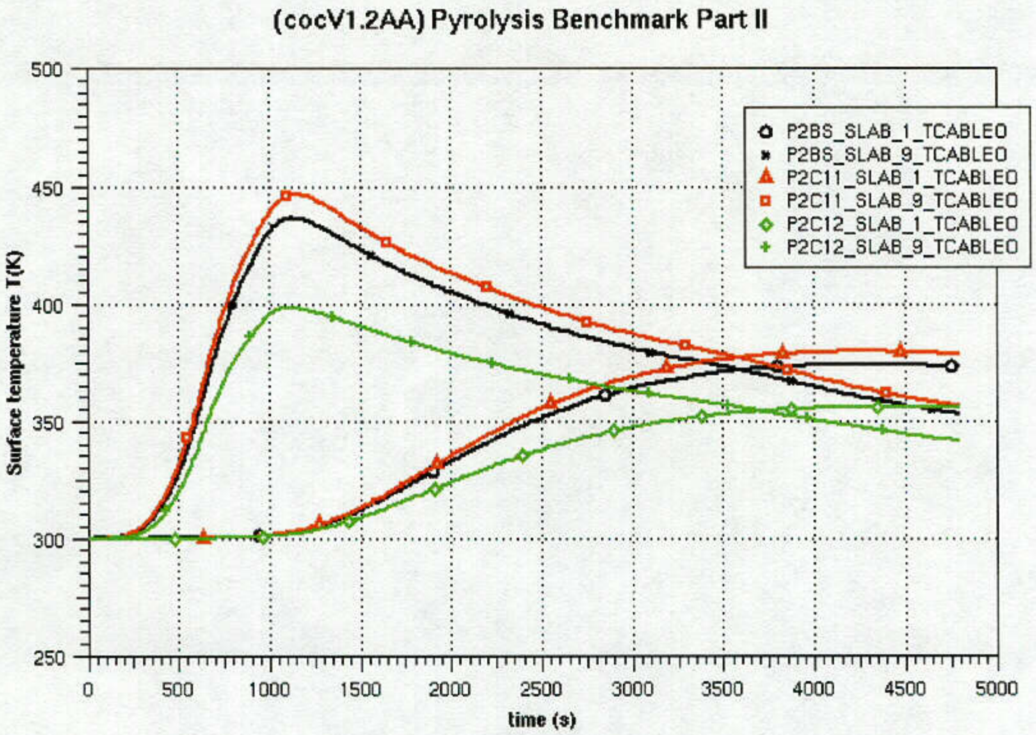

Figure 6-35 Surface temperatures (base case, case 11and 12)

C27

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6.5 Case 13 : different cable types

In this case 13 the cable type has been changed. The diameter of the target is now changed from 50 mm to 15 mm, complete filled with PVC also. The heat flux into the cable is lower, due to the reduced surface (Fig. 6-36). On the other side the surface temperature and especially the inner temperature of the target are much larger. In this case the damage criteria of 473 K is reached.

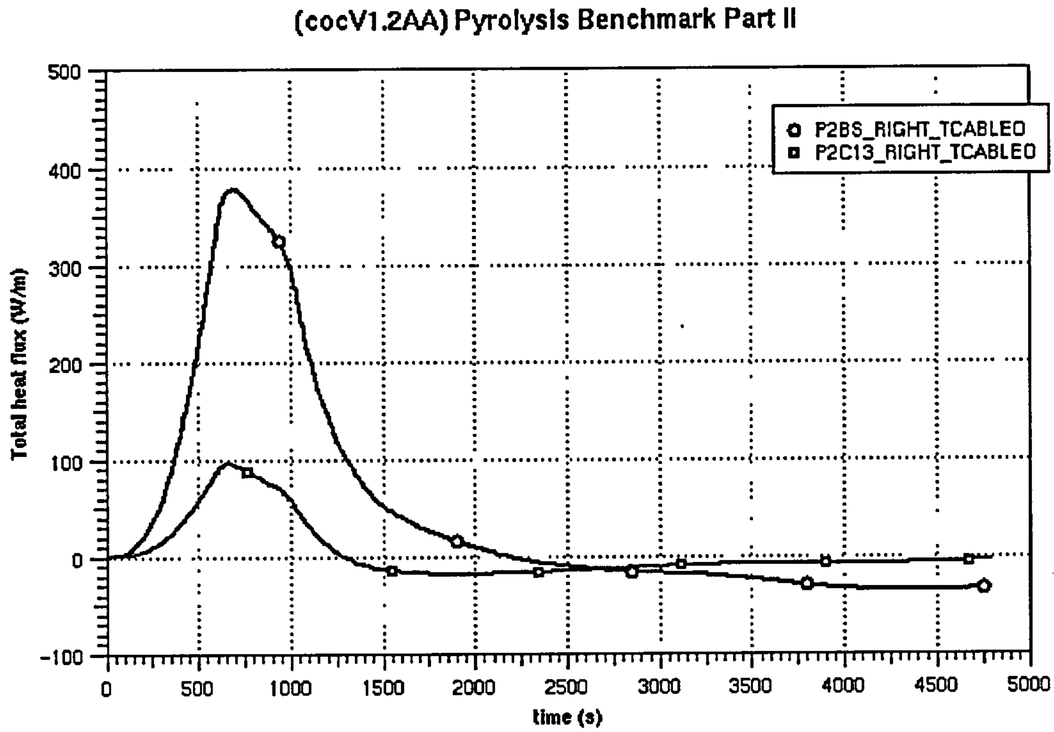

Figure 6-36 Comparison of different cable types (total heat flux)

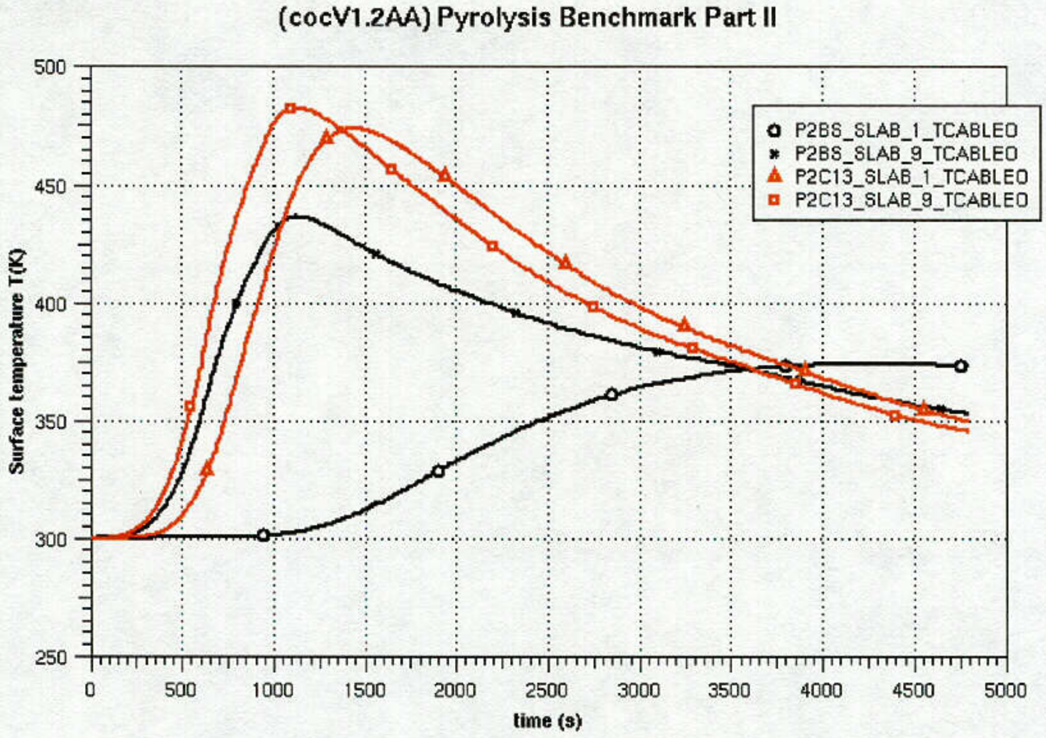

Figure 6-37 Comparison of cable types (surface and inner temperature)

7 Conclusions

To evaluate the capabilities and the applicability of different fire code a benchmark problem has been set up in the frame of the "International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications". In the technical note the results of the COCOSYS system code are presented.

COCOSYS is a so called lumped parameter code. Therefore a detailed nodalisation with more than 320 nodes has been set up for the simulation of all parameter variations, with different trash bag positions (part I) and different locations of the target tray (part II). Additional the detailed nodalisation is able to calculate local convection loops and stratified conditions.

Regarding the results of all variations for part I and part II could be qualitatively explained. The following tables give an overview of the analytical results:

C28

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Table 7-1 Results of part I

Part I	O_2 conc. @ 600s in RH6O [Vol-%]	Max. plume flow [kg/s]	Max. over-pressure [Pa]	Max. Out-flow [kg/s]	Layer height @ 240s [m]	Max. temp. at ceiling (zone RH6O) [K]	Max. flux on target [W/m^2]	Max. Target Cable Temp. [K]
Base c.	19.33	0.2910	975.	0.3978	-	449.2	total: 472.2 radiation: 302.9	surface: 312.54 centre: 300.09
Case 1					-	386.6	total: 26763 radiation: 15234	surface: 326.49 centre: 300.31
Case 2					-	400.7	total: 711.4 radiation: 624.1	surface: 314.73 centre: 300.15
Case 3					-	418.4	total: 648.0 radiation: 507.4	surface: 313.95 centre: 300.12
Case 4			open (-12.)	1.26	-	452.4	total: 485.5 radiation: 318.2	surface: 311.26 centre: 300.09
Case 5	19.74		open		-	451.1	total: 395.7 radiation: 317.5	surface: 308.09 centre: 300.07

Table 7-2 Results of part II

Part II	O_2 conc. in RH6O [Vol-%]	Max. over-pressure [Pa]	Layer height [m]	Max. temp. at ceiling (zone RH6O) [K]	Max. flux on target [W/m^2], total	Max. Target Cable Temp. [K]
Base c.	@500s: 17.6	2104.	-	646.2	2400.	surface: 436. centre: 374.
case 1			-		814.	surface: 438. centre: 374.
case 2			-		2368.	surface: 435. centre: 373.
case 5			-		4628.	surface: 448. centre: 369.
case 10	@ 3800s: 9.85		-	702.	2158.	surface: 555. centre: 472.
case 11			-		2527.	surface: 446. centre: 379.
case 12			-		1827.	surface: 398. centre: 355.
case 13			-			surface: 482. centre: 473.

According to the benchmark description, an ignition of the target tray is assumed, if the centerline temperature exceeds 643 K. Because this temperature is never reached (even in case 1) an extrapolation was not possible. It has been found that the difference between case 1 (0.3 m distance, nearly below the target) and case 2 (0.9 m distance) is very strong. The main reason is, that the form of the plume is not really calculated. COCOSYS has no specific plume models. Therefore the form of plumes is mainly caused by the used nodalisation. Consequently the width and additionally the inner temperature inside the plume is not really calculated. In reality the form of plume will be larger and the inner temperature somewhat lower, resulting in a more smooth behaviour changing the distance.

For the nodalisation small zones are defined. Using the lumped parameter concept, one has to keep in mind, that the momentum balance is not calculated. Defining a fan system injecting fresh air into these small nodes, may lead to wrong results in the nodes around the inlet, because the momentum of the gas flow is not considered.

In part II the pyrolysis rate is much larger, so that the burning process is mainly caused by the available oxygen. In the benchmark an oxygen limit is assumed by about 12 %. In the benchmark calculations a limit of about 4 % is used. This value has been validated against the HDR 41.7 oil fire experiment. Because the fire is oxygen controlled there is a strong difference between the closed conditions and vented conditions. In case of oxygen controlled conditions, the release of pyrolyzed gases is still according to the specified formula in the benchmark description. Then these gases are transported to other nodes, where these may be burned. In reality there will be a strong feed back from the burning process (heat release, radiation) to the surface temperature and following the pyrolysis rate. To consider this effect is important. One of the reason is, that for example a reduced release of pyrolyzed gases may lead to increased temperatures in the fire compartment. This effect can be seen, comparing the cases 5 and 8 with the base case. Therefore higher pyrolysis rates will not lead automatically to conservative results for the temperatures.

Using the simple cable burning model, the radiation of the burning trays can not be calculated. Therefore the results of the cases 1 to case 8 and the base case are depending only on the 'heat release' rate. The target temperatures are calculated lower, because only the convective heat transfer is used.

In all calculations a constant convective heat transfer coefficient of 15 $\left[\frac{W}{m^2K}\right]$ is used for the boundary structures and the cables. This value seems to be very high, especially for the low level zones near the floor. Usually composed correlations are used for free and forced convection, condensation and radiation are used. To simplify the benchmark problem, the real structure of cables is not considered. In COCOSYS it is possible, to compose a structure (plate or cylinder type) with different materials (like PVC, isolation material, copper).

8 Literature

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9 Acknowledgement

The benchmark calculations and analysis have been sponsored by the Ministry for the Environment (BMU) within the framework of INT9236.

10 Appendix A

In the following the benchmark description is given:

Room Size and Geometry

A representative PWR emergency switchgear room is selected for this benchmark exercise. 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 safe-shutdown equipment. 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 varied and examined in this problem. The cable trays are 0.6 m (~24 in.) wide and 0.08 m (~3 in.) deep.

A simplified schematic 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 labelled 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, labelled "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), located at the midpoint of the front wall, assumed to lead to the outside. The room has a mechanical ventilation system with a flow rate of 5 volume changes per hour in and out of the room. Assume a constant flow rate in the mechanical ventilation system. 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 0.5 m^2 each. Assume vents are square and located at the centre of the side walls (parallel to the cable trays). Assume air is supplied from the outside through the right wall, and exhausted to the outside from the left wall.

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

It is 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 fires of redundant cable trays.

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)

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

Assume the walls, floor and ceiling are 152 mm thick.

Thermophysical Data for Cables

Heat of combustion of insulation	16 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

Chemical Properties of Cables

Assume cable insulation is PVC – polyvinyl chloride. Chemical formula is C_2H_3Cl. The oxygen-fuel mass ratio = 1.408. The yields (mass of species/mass of fuel) are listed in the following Table.

Yields for PVC

Species	Yield
CO_2	0.46
CO	0.063
HCl	0.5
Soot	0.172

Assume the Smoke Potential of PVC = 1.7 ob.m3/g, where the smoke potential is defined as the optical density (dB/m or ob) x Volume of the compartment (m3)/mass of the fuel pyrolyzed (g).

Ambient Conditions (Internal and External)

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

Other Constants and Indices

Constriction coefficient for flow through door	0.68
Convective heat transfer coefficient (assume same for all surfaces)	15 $Wm^{-2}K^{-1}$
Lower Oxygen Limit	12 %

Construction and Properties of Fire Door

The following are properties of the fire door for use in models that allow the incorporation of such features. Assume fire door is a metal-clad door with a wood core, and insulating panels between the wood core and the metal clad (on both sides of the wood core). Assume metal clad = 0.6 mm, wood core = 40 mm, and insulating panel = 3 mm.

Properties of Fire Door

	Conductivity (W/mC)	**Density (Kg/m^3)**	**Specific Heat (kJ/KgC)**
Metal Clad - Carbon Steel	43	7801	0.473
Wood Core - Yellow Pine	0.147	640	2.8

Fiber, insulating panel	0.048	240	

Input Data for Part I

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

The trash bag consists of: (1) straw and grass cuttings = 1.55 kg; (2) eucalyptus duff = 2.47 kg; and (3) polyethylene bag = 0.04 kg. Contents were thoroughly mixed, and then placed in the bag in a loose manner. Approximate the trash bag as a cylinder with a diameter = 0.49 m and height = 0.62 m. Assume the fraction of heat released as radiation is 0.3, and the heat of combustion of the trash bag material = 24.1 MJ/Kg.

Assume the trash bag and the target (representing tray A) are at the center of the cable tray lengths. In order to conduct a simplified and conservative analysis, assume the target is a single power cable with a diameter = 50 mm at the bottom left comer of the cable tray A. For models in which targets are represented as a rectangular slab, assume the slab is oriented horizontally with a thickness of 50 mm. Assume the cable ignites when the centerline of the cable reaches 643 K.

Base case

Distance between the midpoints of the trash bag and tray A = 2.2 m (~7 ft), the door is closed, and mechanical ventilation system is off.

Variation of Parameters

A. To facilitate comparisons of code results, simulations for horizontal distances between the trash bag and tray A of 0.3, 0.9, and 1.5 (~1, ~ 3, and ~ 5 ft) should be conducted (Cases 1–3)

B. Simulations should also be conducted with (a) the door open and mechanical system off; and (b) mechanical ventilation system on and door closed (Cases 4-5).

Summary of Cases for Part I

	Distance from Fire	**Door**	**Ventilation System**
Base Case	2.2 m	Closed*	Off
Case 1	0.3⁺		
Case 2	0.9		
Case 3	1.5		
Case 4		Open	
Case 5			On

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

⁺A value in a cell indicates the parameter is varied from the base case.

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 (Base case to Case 3).

The resulting centerline temperature of the cable should be presented for these simulations. In addition, the following parameters should be reported:

- Upper layer temperature
- Lower layer temperature
- Depth of the hot gas layer
- Heat release rate
- Oxygen content (upper and lower layer)
- Flow rates through door and vents
- Radiation flux on the target
- Target surface temperature
- Total heat loss to boundaries

For CFD and lumped-parameter models, the profile at the midpoint of the room should be presented. All results should be presented in SI units.

Input Data for Part II

Heat Release Rates

The modeling of and predicting the heat release rate of a burning cable tray stack is extremely complex, and current models are not capable of realistically predicting such phenomena. Therefore, the heat release rates of the burning cable tray stack is defined as input in the problem. The consecutive ignition and burning of all 3 cable trays (trays A, C2, and C1) will be modeled as one fire. Conduct analyses assuming peak heat release rate for the whole cable tray stack between 1 – 3 MW. Assume t-squared growth with t_0 = 10 min., and Q_0 = 1 MW.

$$Q=Q_0\,(t/t_0)^2$$

Assume a fire duration of 60 minutes at peak heat release rate, and then a t-squared decay with similar constants as for growth.

Geometry

For point source calculations, assume the heat source (trays A, C2, and C1) is at the center of the cable tray length and width and at the elevation of the bottom of tray C2. For 3-D calculations, assume the fire source is the entire length of tray C2 (15.2 m), width (0.6 m), and height of 0.24 m (0.08 x 3). Assume the target (representing tray B) is at the center of the cable tray length. In order to conduct a simplified and conservative analysis, assume the target is a single power or instrumentation cable with no electrical conductor inside the cable, and with a diameter of 50 mm or 15 mm respectively at the bottom right corner of cable tray B. For models in which targets are represented as a rectangular slab, assume the slab is oriented horizontally with a thickness of 50 mm or 15 mm. Assume the cable is damaged when the centerline of the cable reaches 200 C.

Base Case

Heat Release Rate for cable tray stack = 1 MW (reaching peak heat-release rate and decaying as specified above) at a horizontal distance, D = 6.1 m (20 ft). Door is closed and ventilation system is off. Target is a power cable 1.1 m (3.5 ft) above tray A.

Variation of Parameters

A. Vary D = 3.1, 4.6 m (~10, ~15 ft.) – Cases 1-2

B. Vary peak heat release rate for cable tray stack = 2 MW, and 3 MW (reaching peak heat-release rate and decaying as specified above) at a horizontal distance, D = 3.1, 4.6, 6.1 m (Cases 3-8).

C. Door closed and ventilation system operational initially; and door opened, and ventilation system shut after 15 minutes (Case 9).

D. Door and ventilation system open throughout the simulation (Case 10).

E. Two elevations for tray B should be analyzed to examine the possible effects of the ceiling jet sub-layer and the elevation of the target:

   •2.0 m (6.5 ft) above tray A, (i.e., 0.3 m (1 ft) below the ceiling) – Case 11

   •Same elevation as tray A – Case 12

F. Instrumentation cable with diameter = 15 mm (Case 13)

The resulting centerline temperature of the target, and time to damage of target, should be presented for these analyses. In addition, the following parameters should be reported:

- Upper layer temperature
- Lower layer temperature
- Depth of the hot gas layer
- Heat release rate
- Oxygen content (upper and lower layer)
- Flow rates through door and vents
- Radiation flux on the target
- Target surface temperature
- Total heat loss to boundaries
- Chemical species (CO, HCl, soot) in upper layer
- Optical density of smoke (optional)

For CFD and lumped-parameter models, the profile at the midpoint of the room should be presented. All results should be presented in SI units.

Summary of Cases for Part II

	HRR (MW)	D (m)	Door	Vent. Sys.	Target	Elev. (m)
Base Case	1 MW	6.1	Closed*	Off	Power	1.1
Case 1		3.1+				
Case 2		4.6				
Case 3	2	3.1				
Case 4	2	4.6				
Case 5	2	6.1				
Case 6	3	3.1				
Case 7	3	4.6				
Case 8	3	6.1				
Case 9			Open>15 min	Off>15 min		
Case 10			Open	On		
Case 11						2.0
Case 12						Same
Case 13					Instrument	

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

+A value in a cell indicates the parameter is varied from the base case.

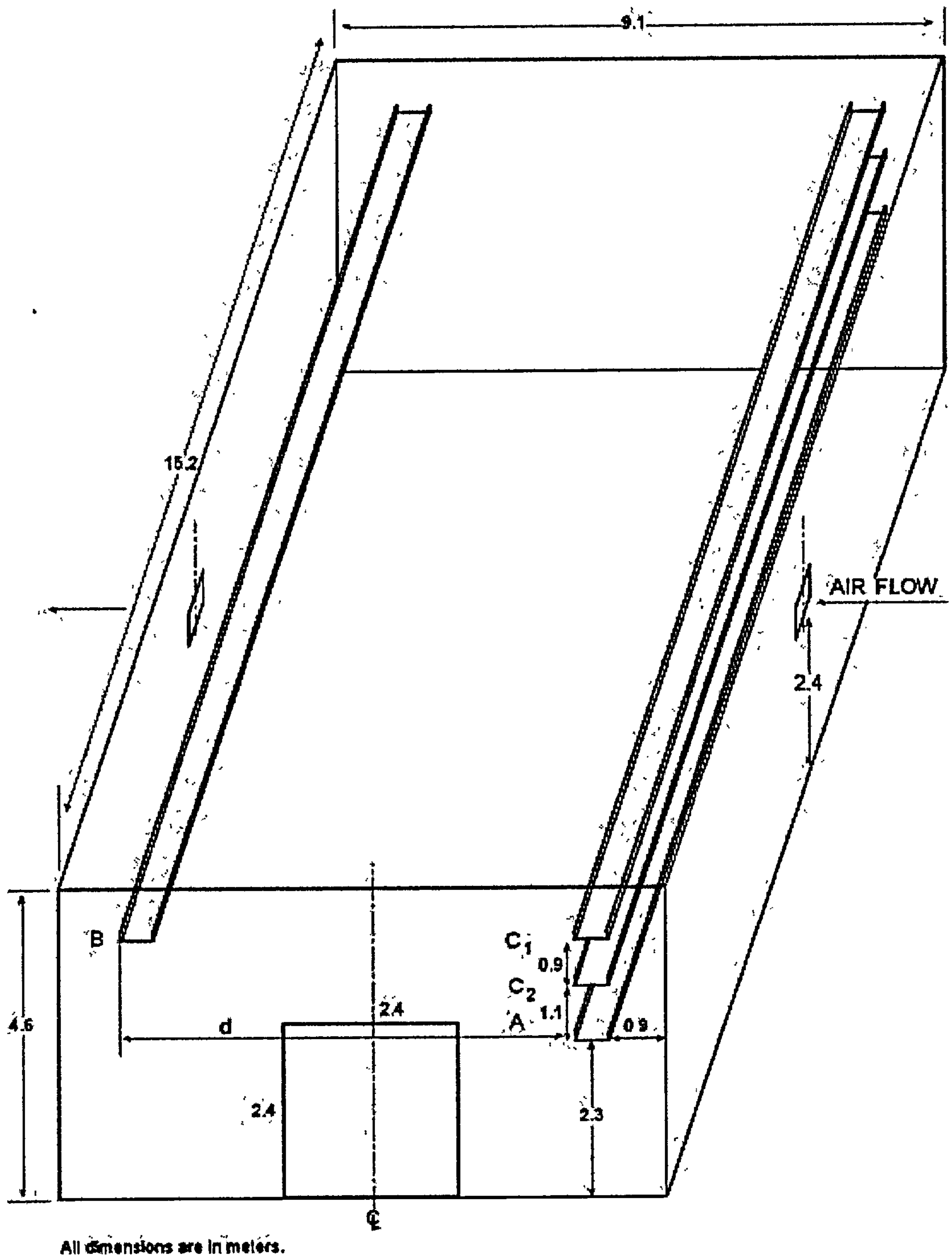

Fig. 9-1 Representative PWR Emergency Switchgear Room