Experimental analysis of storage fires for a better understanding of warehouse fires

Stéphanie Patej, Luc Fournier, André Carrau

EXPERIMENTAL ANALYSIS OF STORAGE FIRES FOR A BETTER UNDERSTANDING OF WAREHOUSE FIRES

Stéphanie Patej, Luc Fournier & André Carrau
INERIS, France

INTRODUCTION

Land-use Planning rules applicable in France around listed hazardous industrial premises rely on a deterministic evaluation of the consequences of major accidents such fires, explosions, toxic cloud releases. Major fire scenarios relevant to storage areas shall in this context be carefully analyzed by safety engineers in concerned industrial facilities like large warehouses storing combustible materials.

In this background, the French Ministry for Ecology and Sustainable Development currently supports INERIS for the performance of a research program concerning the warehouse fire problem. The program mainly focuses on the development of a methodology addressing the evaluation of the toxic and thermal threats pertaining to warehouse fires.

This paper presents a series of large experiments aiming at analyzing the influence of storage configuration on the development and overall behavior of warehouse fires. The document is divided in two sections:

- the first one presenting the experimental apparatus,
- the second introducing results derived from the global measurement analysis.

EXPERIMENTAL APPARATUS

Aims of the campaign

The global aim of the INERIS program is to characterize, through correlation laws, the flame of a warehouse fire (in terms of form, size and surface emissive power) to study its thermal effects in the environment. To achieve it, the first actions are to:

- identify the potential parameters,
- study their influence in the development and the propagation of the fire inside the racks,
- study their influence in the whole flame.

Some authors, as Ingason[1] at SP or Heskestad[2] at FM, have carried some experiences in rack storage. These works were essentially focused on the fire propagation inside the racks in order to study the efficiency of automatic fire system extinction.

INERIS has identified, four important parameters and has studied experimentally their influence in its fire gallery apparatus[3]:

- the vertical free space size between cardboard boxes,
- the horizontal free space size between cardboard boxes,
- the quantity of fuel and its arrangement,
- the number of levels used for storage.

The first two parameters have an influence on the fire ventilation. They control the free space inside the rack and can increase or decrease the fire development. Concerning the third parameter, only cellulose products (wood sticks associated with cardboard boxes) are considered because of :

- these products are well known,
- the combustion of these products reduces the toxic emission risk.

Indeed, the campaign has been realised in a natural configuration and so without the activation of the smokecleaning device.

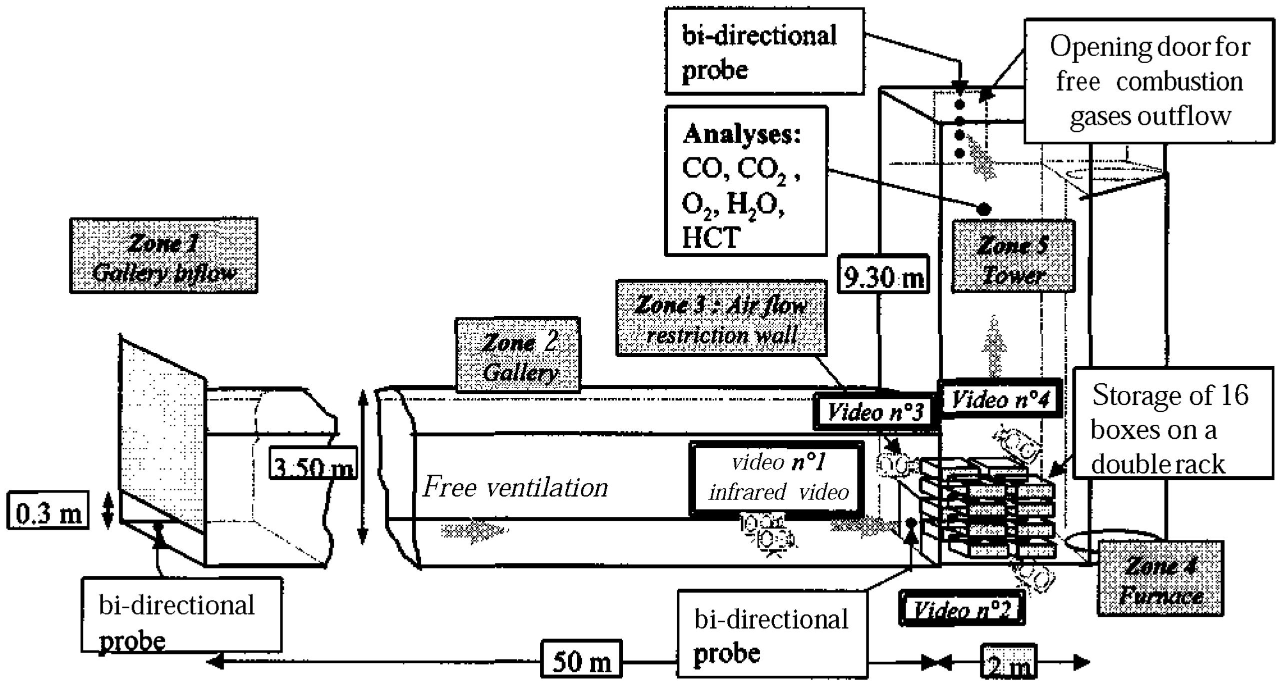
In this campaign, the cardboard boxes have been filled with sticks of wood (pine) but the influence of the quantity and the stick arrangement inside boxes has been studied. The last parameter concerns the storage height through the number of level in use for storage. The idea is to analyse how storage height and flame height can be relied together.

Global description

The tests are realised within the INERIS fire gallery that provide a semi-confined medium. The furnace is set at the bottom of the 12 m height tower which has a 6 m^2 section (3 m X 2 m). Figure 1 presents a diagram of the gallery and the experimental installation.

As mentioned in the previous section, experiments are realised with a free ventilation system. The 30 cm opening of the gallery's guillotine door is the unique inflow into the gallery. A calibrated air speed measure is used to get the inflow fresh air rate. The outflow is possible through an open access door (1.5 m height and 0.5 m large) at the top of the tower. To increase the local confinement, a fire resistant wall has been built between the main part of the gallery and the tower. This wall has a centred opening of 2.2 m^2 section as presented at figure 3. Consequently, this opening provides the air supply of the furnace.

Figure 1 : Use of the fire gallery for the campaign



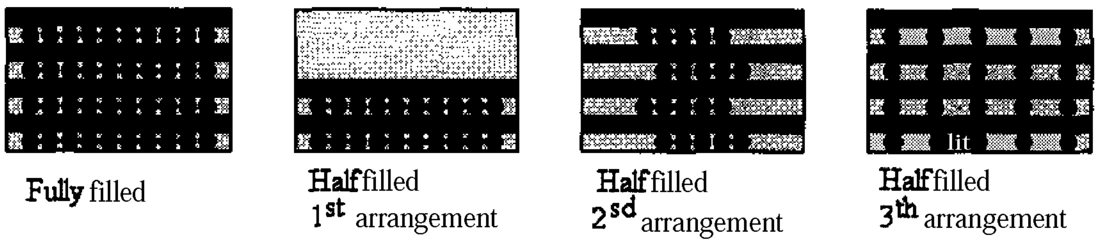
The furnace is set on a retention container put on a weighing gauge of 500 g accuracy until 1000 kg. The retention container is used to collect combustion residues and has a rectangular shape of 2 m x 1.5 m size and 0.1 m height. In its centre, a double rack of 4 levels is set. This double rack is 2,4 m height, 2*0.5 m large and 1.8 m long . This last dimension is parallel to the wall build for confinement.

The combustible material has a 35 cm x 35 cm x 20 cm size and consists of:

- empty cardboard boxes,
- cardboard boxes fully filled with 80 pine wood sticks,
- cardboard boxes half filled with 40 pine wood sticks.

For this last configuration, three ways of arranging the sticks have been tested (see figure 2). The sticks are maintained in position using a wire or nails. Finally, the conditioned boxes are kept at least 24 hours in a drying oven at temperature between 30°C and 40 °C before a test.

Figure 2: Wood sticks arrangement in boxes

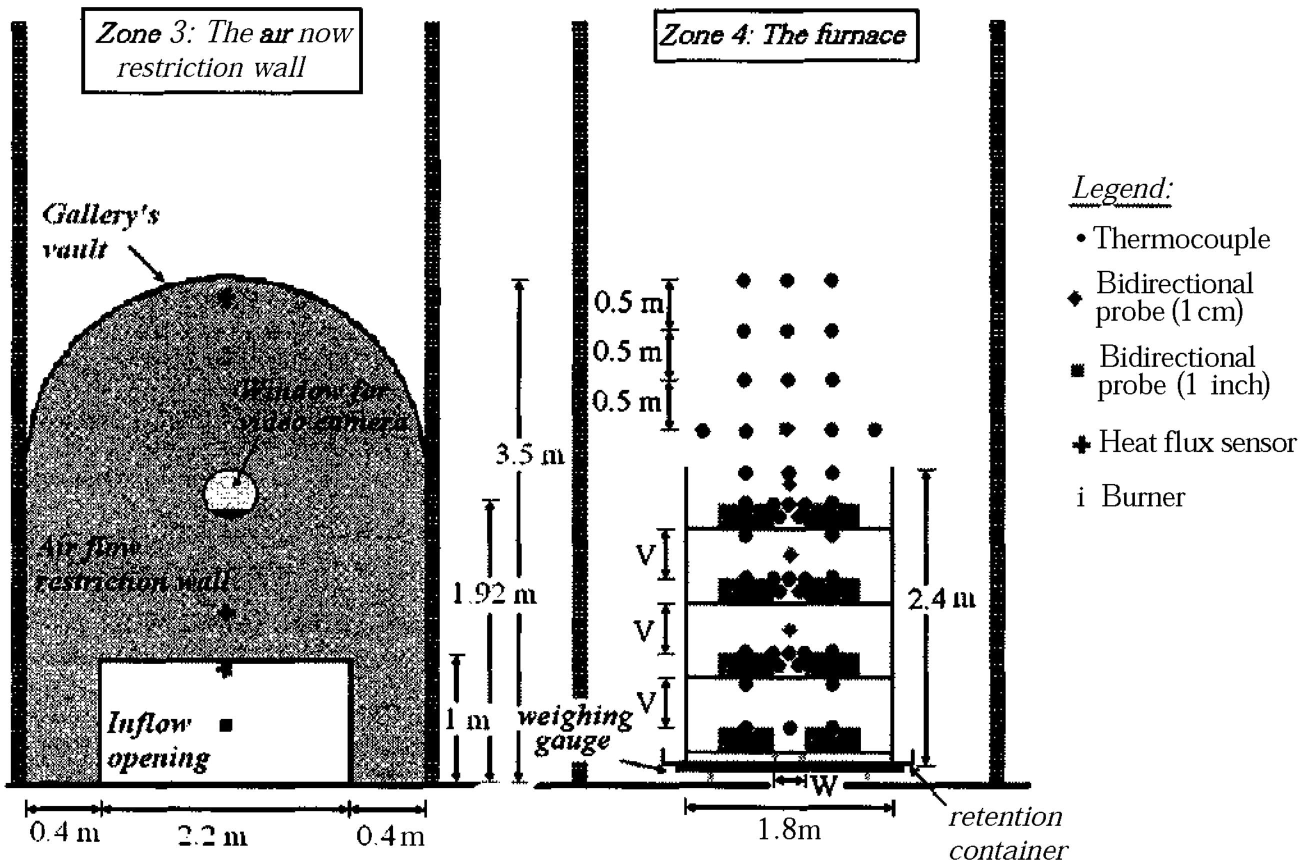


Each level in used is filled with four boxes arranged with a square design in order to produce an ignited axi-symmetrical plume. The vertical space v and the horizontal space w between boxes are fully controlled. These spaces are studied parameters of the campaign.

The ignition is performed using four burners set at the inner corner of the first level boxes. Each of these burners, fitted by N45 propane flow rate of 1.5 Nl/min, develops a theoretical power of 2,3 kW. The four burners are lighted simultaneously using a mass flow rate controller.

Measurements

Figure 3: Instruments dispatching in zone 3 and 4



Globally, over 130 instruments have been dispatched in the five zones of the fire gallery. These instruments are thermocouples, bi-directional probes, heat flux sensors, gas analysis, video camera (visible and infrared) and a weighing gauge. They have been used for several aims as depicted below.

The fire Heat Release Rate (HRR):

The HRR is measured using different technologies. A theoretical HRR is obtained using the combustible mass loss and a theoretical heat of combustion. The effective HRR is obtained by gas plume analysis. The air inflow rate is measured at the guillotine door of the gallery and the gas concentration measured at the top of the tower gives what is effectively burned. Two concurrent gases are analysed, CO/CO_2 production and O_2 depletion. And finally, the convective heat flux is estimated using the inflow rate and the smoke temperature at the outflow door. The temperature at this point has been measured homogenous through the door.

The flame height:

The flame height is estimated using video recording at different levels and view angles but also using thermocouples in the furnace zone. Consequently, a large number of thermocouples are positioned in this zone in order to get a measure.

The fire propagation:

The fire propagation is observed using video recording and specially the infrared one for the first part of tests when the flames are inside the rack.

PRELIMINARY RESULTS

Finally, over 60 experiments have been performed including some repeatability experiments. From all of these tests, some global observations can be made.

Main general observations

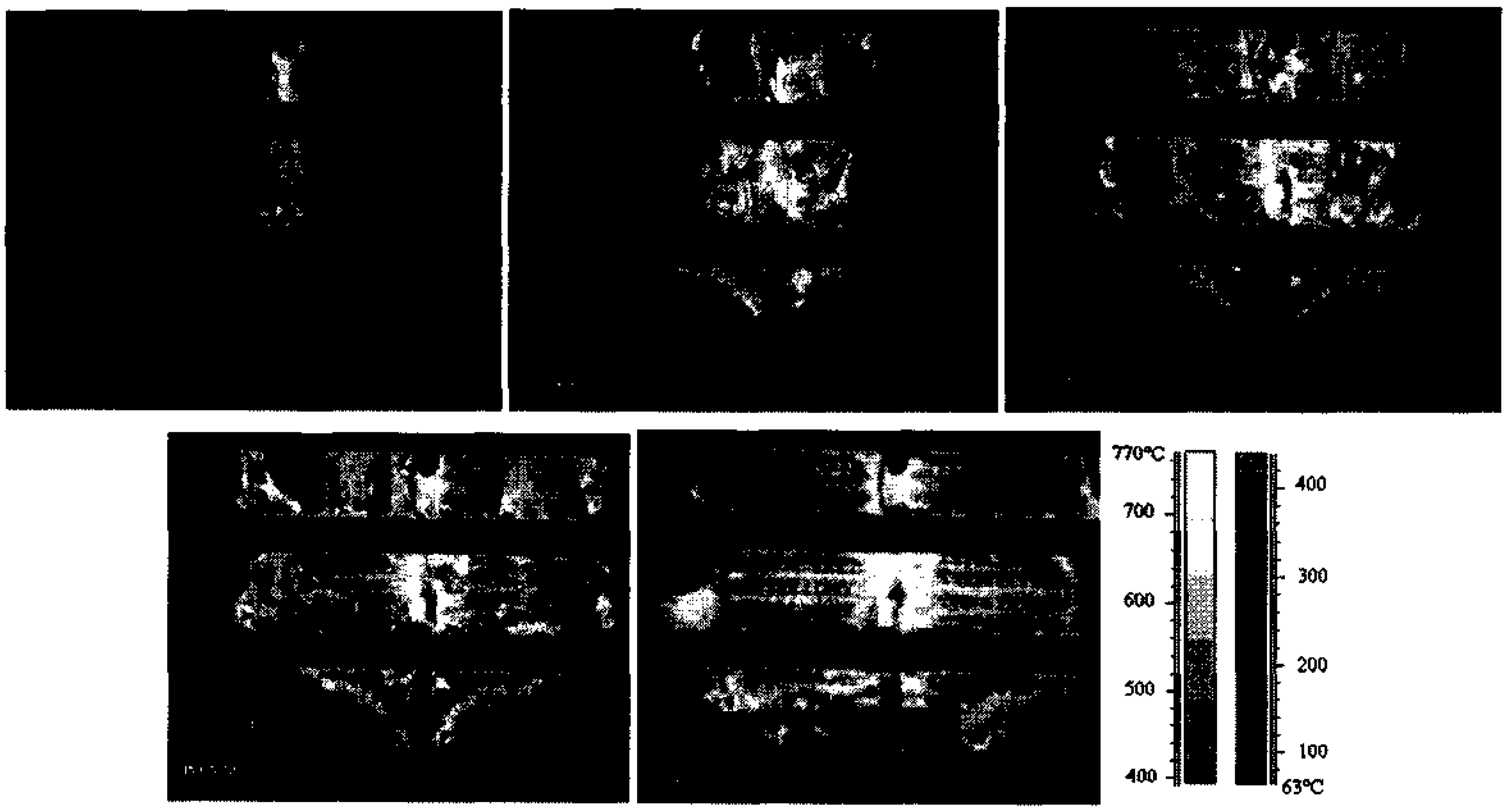
Firstly, a set of global observations is presented. These observations are divided in two groups. The first one is a general description of the fire behaviour. The second one is an exploitation of the infrared video camera as measurement instrument.

Fire behaviour:

During the campaign, the fire has followed a single propagation scene. This can be observed with video cameras as well as with the infrared one. Nevertheless, the infrared video camera has produced pictures much easier to treat than a simple video camera as presented at Figure 4. The fire propagation behaviour can be split in five steps:

1. The ignition is set using burner. The paperboard boxes starts burning locally.
2. The flame ignited at the bottom in the interspaces between boxes starts to grow inside the central space. This space plays the role of a chimney and in this way makes easier the vertical fire propagation (first picture of Figure 4).
3. The fire reaches the top of the rack and starts a horizontal propagation firstly at the top. The fire has a V-shape design. It will keep this shape until all of the racks are not fully lighted.
4. The V-shape has a slow progression from the top to the bottom (second to fourth picture of the Figure 4).
5. All the rack is lighted, the fire is going to reach a stabilised rate (fifth picture of the Figure 4)

Figure 4: A representative sequence of the fire propagation (from the IR video)

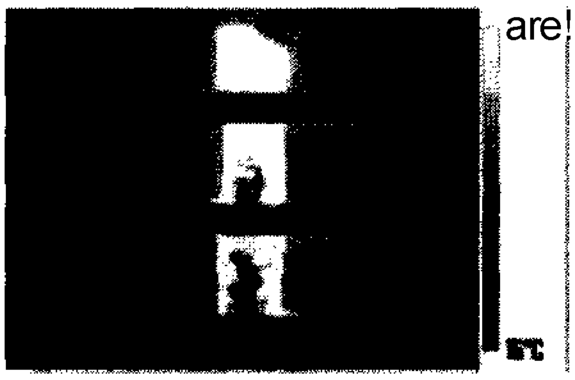


Thermal wave

The V-shape, which is observed during the fire propagation, is also observed without flame on the face ofthe boxes. The thermal video gives the temperature ofthe boxes surface. This temperature distribution shows the same kind of V-shape on each level. This observation shows that the heat source is at that time principally at the centre ofthe rack. As shown at Figure 5, for each box, the central top corner is the warmer part ofthe box. So during the chimney propagation process, the heating ofboxes is already announcing the V-shape propagation step. This heat distribution controls the **pyrolysis** phenomena and consequently the flame apparition.

This temperature distribution scheme can be explained by the air supply. The vertical interspaces are probably the main air inflow corridor. Consequently, the fresh air can play the role of **'cooling'**.

Figure 5: Temperature distribution at the boxes surface obtained by IR video



The use of Heat Release Rate measurement

As previously presented, the HRR has been measured by four ways. The figure 6 presents these four measures for a sixteen box test. We can observe a good fitting between the two gas analysis technologies. These two curve gives the effective heat released by the combustion. The convective part is always less that the effective total HRR. In that case, between the 8^{th} and the 10^{th} minutes the radiative fraction is around 30% to 35% of the total HRR. By comparing, on the same period, the theoretical and the effective HRR, the efficiency of combustion can be estimated between 0.75 and 0.8. At the end of the test, the theoretical HRR turns to be lower than all the others. It can be explained by the combustible property modification during the experiment. The heat of combustion used is considered unique and constant during the test to **16.4 MJ/kg** which is representative of **unburned** wood. The combustible turns to charcoal at the end of the tests. Then, its heat of combustion is around 33 **MJ/kg.**

Figure 6: 4 ways of HRR measurement

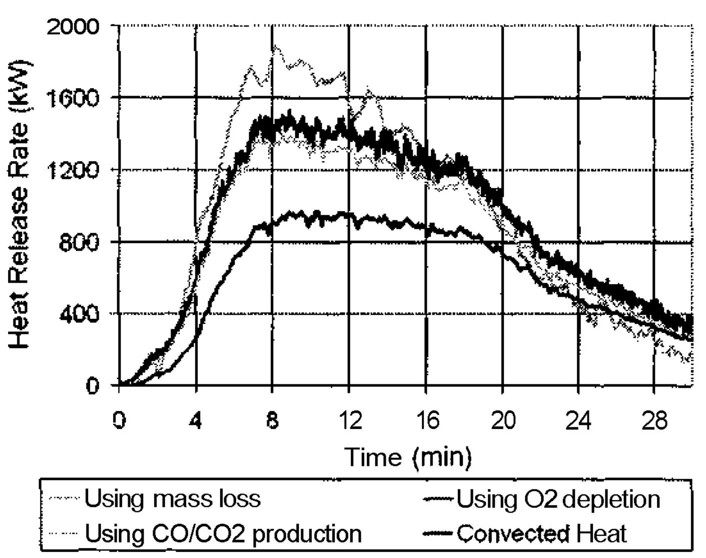
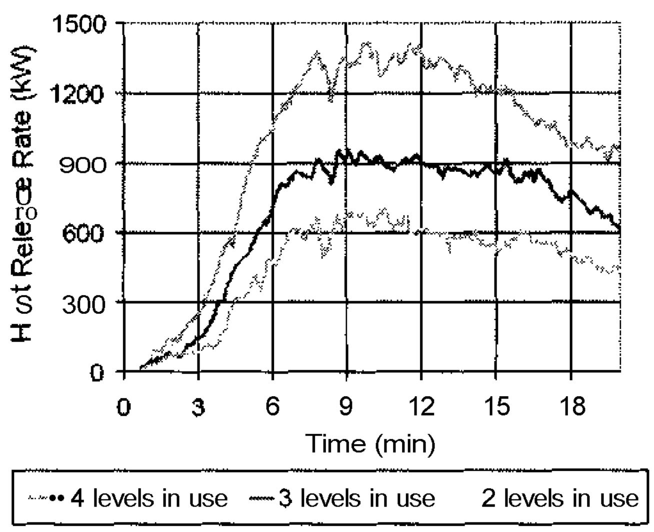


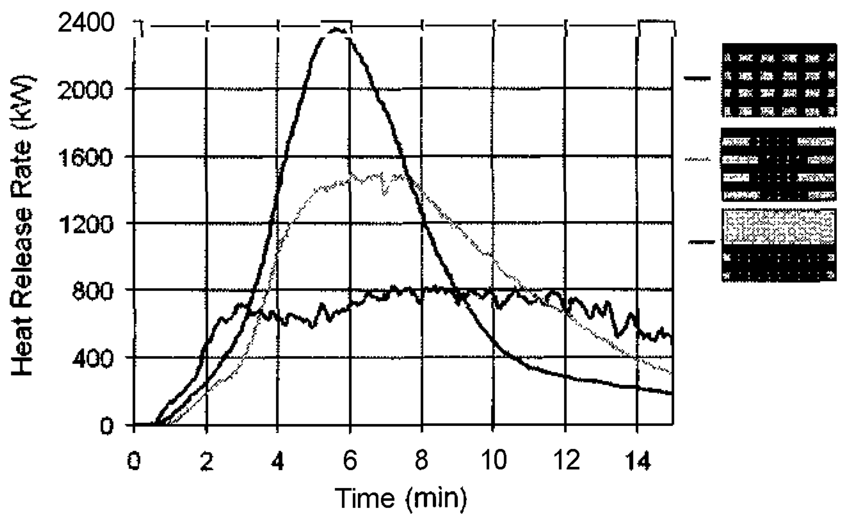
Figure 7: HRR variation with the number of level in use



The figure 7 represents the influence of the number of levels in use on the HRR. This curves shows the great importance of the volume notion for such kind of fire. Nevertheless, by decreasing the number of levels used, the total mass of combustible has been also decreased. The dependence of each parameter is not so clear but this kind of fire may be compared to wood crib fires. Babrauskas[4] has established correlation to estimate the burning rate of cribs. To use this correlation the global properties of the boxes have first to be characterised. This way of development is actually studied.

This crib fire approach can be used to model the influence of wood sticks arrangement on the HRR. Babrauskas[4] has classifieds such fire in three kind controlling phenomena. The first one is said *fuel surface controlled,* the second one is said *crib porosity controlled* and the last one is said *room ventilation controlled.* The large variations observed at the figure 8 may be explained by the change controlling phenomena. This parameter appears as first order of importance as the HRR has been modified by a factor 3.
The influence of stick arrangement in these tests is interesting to illustrate the difficulty to evaluate the consequences of warehouses large fires. The impact of stick arrangement appears really simple compare to real industrial storage.

Figure 8: Influence of sticks arrangement on HRR



CONCLUSION

INERIS has realised an experimental campaign of over 60 tests. A large number and variety of instruments have been installed. This campaign has concerned rack storage fire in a semi-confined medium. The main studied parameters were, the number of levels used, the way of filling (the quantity and the arrangement) the boxes used as combustible, and the compacity of the overall storage.
The campaign provides a large amount of data form qualitative nature to quantitative one. The complete analyse of these data are not yet fully finished, but some synthetic results have briefly been presented in the present paper.

Nevertheless, this campaign was only focused on the vertical fire propagation in storage racks. To improve the knowledge of fire propagation in rack storage, this campaign has to be completed by a new campaigns to study the horizontal fire propagation inside and between racks.

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