Down-scaled fire tests using a trailer mock-up

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Fire Technology

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Abstract

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A series of down-scaled (scale 1:4) fire tests aimed at simulating fires on the trailer of a freight truck has been conducted. The fire tests were conducted with two types of commodities, different loading and without and with a roof over the test set-up.

The tests were conducted with either 2, 4, 6, 8 or 10 rows of commodity. The point of ignition was usually positioned at the centre point of the central stack of commodity. However, for some of the tests using 10 rows of commodity, the point of ignition was moved to the centre point of the far right flue space between the rows. During all tests the heat release rate and heat flux were measured.

The results show that the commodity consisting of idle pallets produced a maximum heat release rate that was higher or comparable to the commodity consisting of cardboard cartons with plastic cups. The roof had no or limited influence on the maximum heat release rate of the cardboard cartons with plastic cups, but reduced the maximum heat release rate of the idle pallets.

The commodities were consumed at about the rate of fire spread. The maximum heat release rate only exhibited a marginal increase when using 8 or 10 rows of commodity.

If converted to full scale, the maximum fire size (based on the one minute average total heat release rate) of the idle pallets would range from 12,4 to 34,1 MW and from 9,0 to 29,4 MW for the commodity using the cardboard cartons with plastic cups, dependent on the number of rows of commodity.

Key words: Small-scale fire tests, ships, ro-ro decks, trailer, freight truck, fire spread

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Preface

This report summarises the outcome of the first phase of the IMPRO-project, “Improved water-based fire suppression and drainage systems for ro-ro vehicle decks”.

The project is sponsored by VINNOVA, the Swedish Governmental Agency for Innovation Systems (project number P31711-1), the Swedish Mercantile Marine Foundation, Brandforsk, the Fire Research Board (project number 401-081) and the Swedish Maritime Administration.

The help from Ms Ulrika Beckman during the fire tests is gratefully acknowledged.

The internal SP project number was BRd 6001.

Sammanfattning

Rapporten redovisar en serie försök med en nedskalad (skala 1:4) försöksuppställning som simulerade brand på ett släp till en långtradare.

På ’släpet’ placerades två typer av gods; dels tompallar av trä och dels wellpappkartonger med ett fackinrede med plastmuggar. Försöken genomfördes utan och med tak över försöksuppställningen och med 2, 4, 6, 8 respektive 10 rader med gods. Vid försöken mättes brandeffekten från branden och värmestrålningen från försöksuppställningens ena långsida.

I flertalet av försöken startades branden i mitten av försöksuppställningen och branden fick sprida sig mot respektive kortsida. I några av försöken startades branden vid en av kortsidorna och spred sig därför endast i en riktning.

Resultaten visar att den uppmätta brandeffekten och värmestrålningen från respektive gods är jämförbar eller något högre för tompallarna jämfört med wellpappkartongerna med plastmuggar. Taket påverkade inte den maximala brandeffekten för wellpappkartongerna med plastmuggar, däremot reducerades den maximala brandeffekten något för tompallarna. Sannolikt beror det på att taket begränsar lufttillgången till branden och/eller att värmeåterstrålningen från flamman reduceras.

Godset förbrukades i princip i takt med brandspridningen ut mot kortsidorna. Den maximalt uppmätta brandeffekten ökade därför endast marginellt med 8 eller 10 rader gods.

För båda typerna av gods ökade den maximalt uppmätta värmestrålningen när taket var placerat över försöksuppställningen. Sannolikt för att taket pressar ned flamman närmare strålningsmätaren.

Brandeffekten kan skalas till fullskala och var då mellan 12,4 till 34,1 MW för tompallarna och mellan 9,0 till 29,4 MW för wellpappkartongerna med plastmuggar, beroende på hur mycket gods som användes vid försöket.

Projektet finansierades av VINNOVA (projekt P31711-1), Stiftelsen Sveriges Sjömanshus, Brandforsk (projekt 401-081) och Sjöfartsverket.

1 Introduction

1.1 Background

The aim of this IMPRO project is to evaluate modern water based fire suppression technologies in order to replace the design criteria in Resolution A.123(V) , published in 1967, see reference [1]. Experimental research and fire incident reports indicate that the combustible loading of vehicles on ro-ro vehicle decks, in the event of fire, has the potential to exceed the fire suppression and control capabilities of the sprinkler systems installed in accordance with design criteria given in IMO Resolution A.123(V), dated 1967. Modernisation of the requirements outlined in this Resolution is long overdue. The goal of the project is to increase the level of safety to a point where a fire can be at least suppressed, in order to allow for manual intervention under safe conditions. Thus, fire suppression will be the required functionality of the system when defining suitable system solutions.

The ultimate aim of the project is to replace the design criteria in Resolution A.123(V).

1.2 The objective of the tests

The objective of the tests was to replicate fires on the trailer of a freight truck in order to investigate the influence of the following parameters on the heat release rate and the heat flux:

- Different commodities (two different commodities were used).
- The amount of cargo on the trailer.
- The point of ignition.
- The size of the igniter (one commodity only).
- The use of a roof on the trailer.

The information from the fire tests will improve our understanding of fire growth and fire spread on freight truck fires. Furthermore, it will facilitate the design of a fire test set-up in intermediate scale, which is planned within an upcoming part of the project.

2 Instrumentation and measurements

The heat release rate and heat flux was measured in all tests. Additionally, all tests were documented using visual observations, still photos and video recordings.

2.1 Heat Release Rate measurement

All tests were conducted under an *ISO 9705 Room-Corner Test* calorimeter in order to determine the Heat Release Rate (HRR) of the fires.

The hood of the calorimeter measures 3000 mm by 3000 mm. In the duct connecting the hood to the evacuation system, measurements of the gas temperature, the velocity and the generation of gaseous species such as CO_2 and CO and depletion of O_2, are made.

Based on these measurements, both the convective and the total heat release rate can be calculated. The convective heat release rate is denoted HRRconv and can be defined as follows:

HRRconv: The convective part of the heat release rate measured during a test, calculated on the basis of the gas temperature and mass flow rate in the calorimeter system.

The total heat release rate is denoted HRRtot and can be defined as follows:

HRRtot: The total heat release rate measured during a test, calculated on the basis of oxygen depletion. HRRtot is comprised of both the convective and radiative heat release rate.

2.2 Heat flux measurements

The heat flux from the fire was recorded using Schmidt Boelter total heat flux meters manufactured by Medtherm Co (water cooled system). The instruments had a measurement range of 0 - 100 kW/m^2.

The heat flux meter was positioned at the long side of the trailer mock-up, directed towards the transversal centreline of the stacks of commodity at a horizontal distance of 500 mm.

3 The fire test set-up

3.1 The trailer model mock-up

The model mock-up was constructed to geometrically replicate the typical trailer of a freight truck. Table 1 shows the dimensions in both 1:4 scale and the corresponding full scale.

Table 1 The dimensions of the trailer model.

Dimensions	1:4 scale [mm]	Corresponding full scale [mm]
Length	3175	12700
Width	650	2600
Overall height	970	3880
Height of cargo space*	640	2560

*) When the roof of the trailer was in use.

The mock-up was constructed from 30 mm square iron and the bottom and the roof of the platform of the mock-up was constructed from nominally 10 mm thick Promatect® non-combustible boards. The vertical distance measured from floor level to the platform was 340 mm (equalling 1360 mm in full scale).

Tests were conducted both without and with a roof over the cargo space of the trailer model, see figure 1.

Figure 1 The trailer mock-up with the roof installed. In this case 10 rows of idle wooden pallets are placed on the platform.

The mock-up was placed on a stand, 3500 mm by 1250 mm, that was raised 600 mm above floor level, with the intent to simplify practical work and move the mock-up closer to the hood of the calorimeter.

3.2 The commodity used in the tests

Two different commodities were used in the tests, idle wooden pallets and cardboard cartons with plastic cups.

3.2.1 Idle wooden pallets

Standard European 1200 mm by 800 mm wood pallets were geometrically scaled 1:4. The scaled-down pallets had an overall dimension of 300 mm by 200 mm by 36 mm (L × W × H), see figure 2.

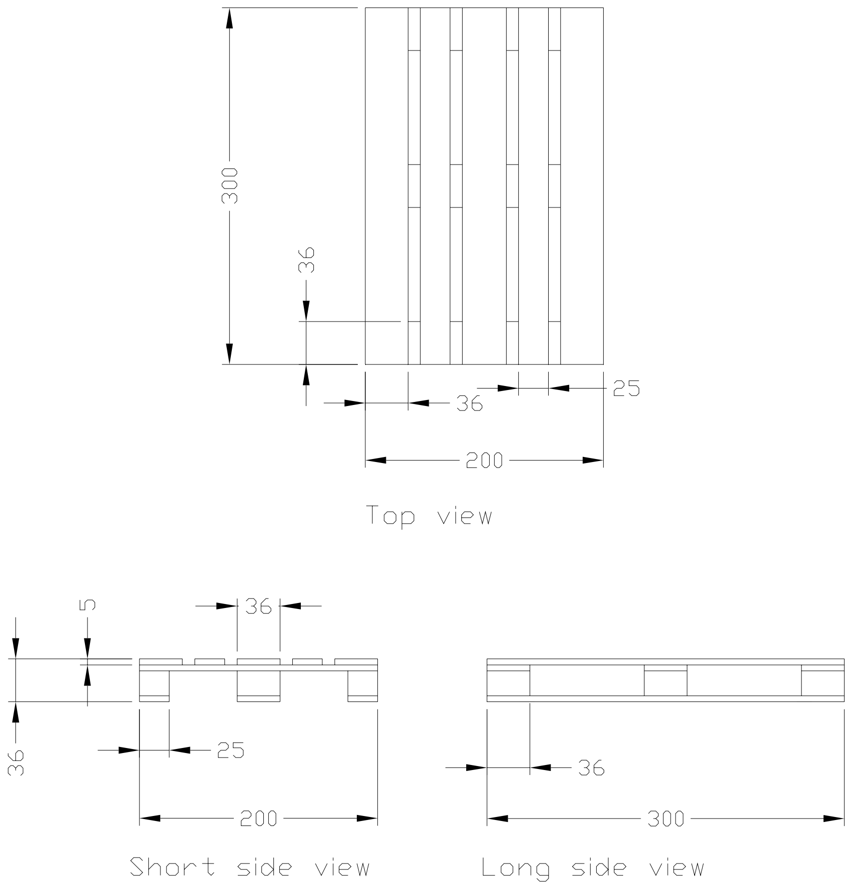

Figure 2 The scaled-down wood pallets used in the tests.

The average weight of one pallet was approximately 354 g (22,6 kg in full scale).

For the tests, 14 pallets were stacked on top of each other. This equalled an overall height of 504 mm (2016 mm in full scale) and the total weight of each stack was approximately 4,95 kg (317 kg in full scale). A photo of one stack of pallets is given in figure 3.

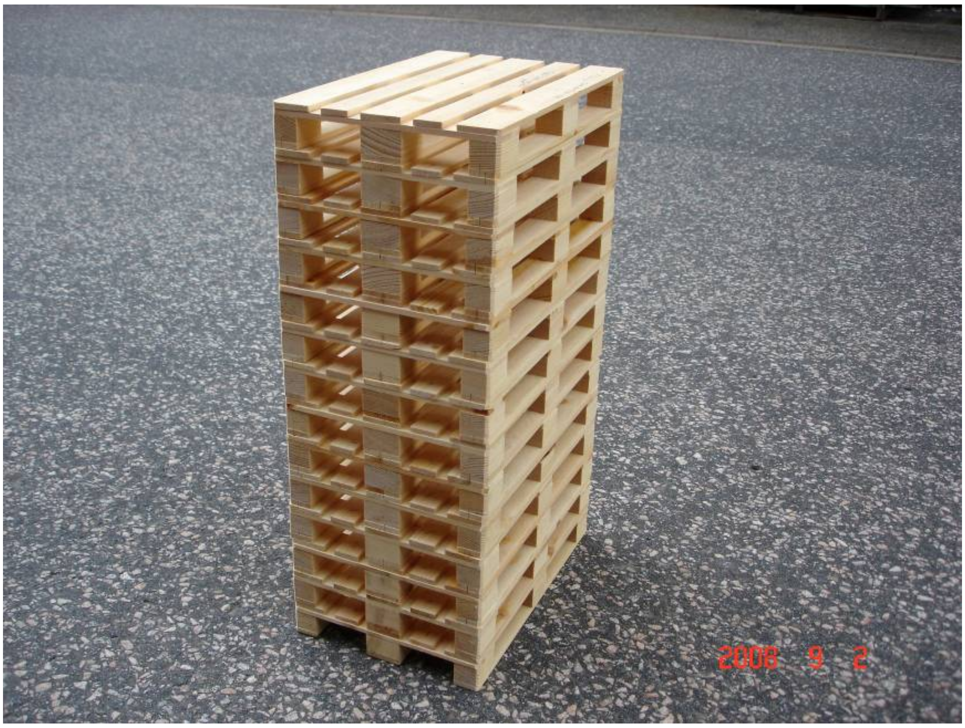

Figure 3 One stack of 14 pallets on top of each other.

The pallets were made from soft wood (Pine) and conditioned indoors to a measured moisture content of approximately 10% by weight.

3.2.2 Cardboard cartons with plastic cups

This commodity consists of empty polystyrene cups without lids, placed upside down, in compartmented cartons, 12 cups per carton. The cartons measured 300 mm by 200 mm by 214 mm (L x W x H) and were made from single-wall, corrugated cardboard. When compartmented, the cartons are divided into two layers by corrugated sheets, with each layer divided into six compartments by overlocking corrugated cardboard partitions, forming a total of 12 compartments where the plastic cups are placed, as shown in figure 4.

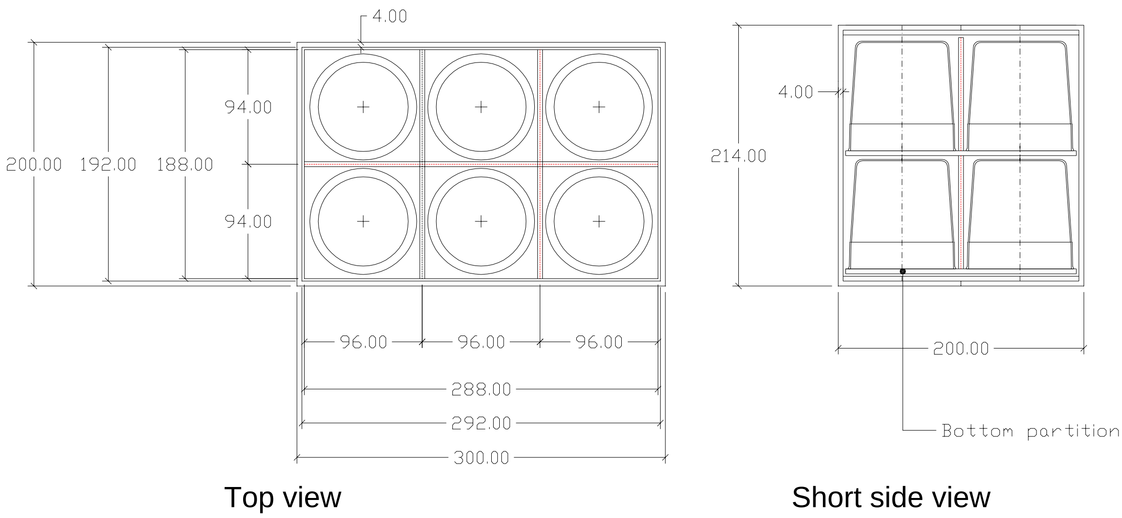

Figure 4 The cardboard cartons with plastic cups used in the tests.

The individual average weigh of one carton, complete with the interior, was 290 g.

The cups were made from Polystyrene and the individual cups had an average weight of 28,2 g, i.e. the total weight of the plastic was 338 g per carton.

The total weight of the commodity, including the plastic cups, equalled 628 g. This corresponded to approximately 54% by weight of plastic. This is slightly lower as compared to the EUR Std plastic commodity, where approximately 63% by weight is plastic, excluding the pallet [2].

The wood pallet added an additional 324 g to the commodity, such that the overall weight of one ‘pallet load’ equalled 952 g (61 kg in full scale), see figure 5.

Figure 5 One pallet load of the cardboard cartons with plastic cups.

For the tests, the individual cartons were stapled against the wood pallet to increase stability. Two pallets loads were positioned on top of each which equalled an overall height of 500 mm (2000 mm in full scale).

3.3 The arrangement of the commodity

The commodity was positioned on the platform such that longitudinal and transversal gaps of 25 mm (100 mm in full scale) were created between the stacks of commodity, see figure 6.

Figure 6 An illustration of the arrangement of the commodity. In this case 6 rows of cardboard cartons with plastic cups are placed on the platform. The heat flux meter was positioned at the long side and directed towards the transversal centreline at a horizontal distance of 500 mm.

The tests were conducted with either 2, 4, 6, 8 or 10 rows of commodity. The point of ignition was usually positioned at the centre point of the central stack of commodity. However, for some of the tests using 10 rows of commodity, the point of ignition was moved to the centre point of the far right flue space of the rows.

3.4 Ignition source

The small ignition source consisted of a cube, 30 mm by 30 mm by 25 mm (L × W × H), that was soaked in 10 mL of heptane. This ignition source was used for all tests with the cardboard cartons with plastic cups and for one of the tests using idle wood pallets.

A larger ignition source was used for all (except for one) tests where the commodity consisted of idle wood pallets. This ignition source consisted of 20 mm by 25 mm (W × H) strips of Rockwool® mineral insulation that were soaked in heptane. The length of the strips were adjusted such that the inner flue space of the central stack of wood pallets was exposed to the flames. This ignition source provided a faster, more symmetrical and repeatable fire ignition of the idle wood pallets than the small ignition source.

The fire size of the larger igniter was not measured. However, based on the experimental data from the fire tests it seems that the heat release rate of this ignition source was of the order of 30 kW.

For the majority of the tests, the ignition source was positioned at the central flue space of the central stack of commodity. This allowed the fire to spread in two directions. However, for some of the tests using 10 rows of commodity, the ignition source was positioned at the flue space at the far right of the rows of commodity. This allowed the fire to primarily spread in one direction only.

4 Fire test programme

4.1 Fire test series with idle wood pallets

Tables 2 and 3 summarise the fire tests that were conducted using the idle wood pallets, without and with the roof on the trailer mock-up.

Table 2 Fire tests conducted using the idle wood pallets, <u>without</u> the roof on the trailer mock-up.

Test no.	Number of rows	Total number of pallets	Total mass [kg]
1P(2)*	2	2 × 2 × 14 = 56	19,8
2P(2)	2	2 × 2 × 14 = 56	19,8
3P(4)	4	4 × 2 × 14 = 112	39,7
4P(6)	6	6 × 2 × 14 = 168	59,5
5P(8)	8	8 × 2 × 14 = 224	79,3
6P(10)	10	10 × 2 × 14 = 280	99,1
7P(10)O**	10	10 × 2 × 14 = 280	99,1

*) The small fire ignition source was used.
**) The point of ignition was moved to the centre point of the far right flue space.

Table 3 Fire tests conducted using the idle wood pallets, <u>with</u> the roof on the trailer mock-up

Test no.	Number of rows	Total number of pallets	Total mass [kg]
1P(2)R	2	2 × 2 × 14 = 56	19,8
2P(4)R	4	4 × 2 × 14 = 112	39,7
3P(6)R	6	6 × 2 × 14 = 168	59,5
4P(8)R	8	8 × 2 × 14 = 224	79,3
5P(10)R	10	10 × 2 × 14 = 280	99,1
6P(10)RO*	10	10 × 2 × 14 = 280	99,1

*) The point of ignition was moved to the centre point of the far right flue space.

4.2 Fire test series with cardboard cartons with plastic cups

Tables 4 and 5 summarise the fire tests that were conducted using the cardboard cartons with plastic cups, without and with the roof on the trailer mock-up.

Table 4 Fire tests using the cardboard cartons with plastic cups, without the roof on the trailer mock-up.

Test no.	Number of rows	Total number of cartons	Total mass [kg]
1C(2)	2	2 × 2 × 2 = 8	7,6
2C(4)	4	4 × 2 × 2 = 16	15,2
3C(6)	6	6 × 2 × 2 = 24	22,8
4C(8)	8	8 × 2 × 2 = 32	30,5
5C(10)	10	10 × 2 × 2 = 40	38,1
6C(10)O*	10	10 × 2 × 2 = 40	38,1
7C(6)**	6	6 × 2 × 2 = 24	22,8

*) The point of ignition was moved to the centre point of the far right flue space.
**) Repeat of Test 3C(6) due to technical problems with the calorimeter.

Note that baffles were installed around the left and right hand side perimeter of the hood from test 6C(10)O in order to improve the collecting of the combustion gases.

Table 5 Fire tests using the cardboard cartons with plastic cups, with the roof on the trailer mock-up.

Test no.	Number of rows	Total number of cartons	Total mass [kg]
1C(2)R	2	2 × 2 × 2 = 8	7,6
2C(4)R	4	4 × 2 × 2 = 16	15,2
3C(6)R	6	6 × 2 × 2 = 24	22,8
4C(8)R	8	8 × 2 × 2 = 32	30,5
5C(10)R	10	10 × 2 × 2 = 40	38,1
6C(10)RO*	12	12 × 2 × 2 = 48	38,1

*) The point of ignition was moved to the centre point of the far right flue space.

5 Fire test results

5.1 Key parameters

Given below are tables summarizing the test results using the following key parameters:

- The peak total heat release rate (HRRtot).
- The maximum one minute average total heat release rate.
- The peak convective heat release rate (HRRconv).
- The maximum one minute average convective heat release rate.
- The total energy.
- The total convective energy.
- The ratio convective energy to total energy.
- The maximum one minute average heat flux.

Heat release rate and heat flux graphs are shown in figures 7 through 14.

Table 6 Test results for the fire tests conducted using the idle wood pallets, <u>without</u> the roof on the trailer mock-up.

Test	Peak HRRtot [kW]	Max. one minute average HRRtot [kW]	Peak HRRconv [kW]	Max. one minute average HRRconv [kW]	Total energy [MJ]	Convective energy [MJ]	Ratio convective to total energy	Max. one minute average heat flux [kW/m^2]
1P(2)*	408	388	298	283	269	196	0,73	45
2P(2)	554	533	391	379	294	207	0,70	N/A
3P(4)	983	951	624	599	535	357	0,67	81
4P(6)	1122	1080	653	637	748	488	0,65	109
5P(8)	1080	1065	657	642	942	614	0,65	116
6P(10)	1023	979	612	597	1171	753	0,64	104
7P(10)O**	658	645	433	416	1409	931	0,66	59

*) The small fire ignition source was used, see description above.
**) The point of ignition was moved to the centre point of the far right flue space.

Table 7 Test results for the fire tests conducted using the idle wood pallets, <u>with</u> the roof on the trailer mock-up.

Test	Peak HRRtot [kW]	Max. one minute average HRRtot [kW]	Peak HRRconv [kW]	Max. one minute average HRRconv [kW]	Total energy [MJ]	Convective energy [MJ]	Ratio convective to total energy	Max. one minute average heat flux [kW/m^2]
1P(2)R	521	512	363	357	271	184	0,68	56
2P(4)R	758	735	513	500	487	335	0,69	114
3P(6)R	914	900	597	583	665	445	0,67	121
4P(8)R	884	856	567	555	819	565	0,69	130
5P(10)R	946	932	610	587	1043	683	0,65	137
6P(10)RO*	767	744	504	496	1205	794	0,66	102

*) The point of ignition was moved to the centre point of the far right flue space.

Table 8 Test results for the fire tests using the cardboard cartons with plastic cups, without the roof on the trailer mock-up.

Test	Peak HRRtot [kW]	Max. one minute average HRRtot [kW]	Peak HRRconv [kW]	Max. one minute average HRRconv [kW]	Total energy [MJ]	Convective energy [MJ]	Ratio convective to total energy	Max. one minute average heat flux [kW/m^2]
1C(2)	325	306	182	168	158	91	0,58	40
2C(4)	696	675	385	371	300	180	0,60	72
3C(6)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	84
4C(8)	887	862	472	461	543	319	0,59	89
5C(10)	852	824	468	458	626	370	0,59	93
6C(10)O*	702	693	416	411	703	431	0,61	72
7C(6)**	773	758	443	436	425	266	0,63	82

*) The point of ignition was moved to the centre point of the far right flue space.
**) Repeat of Test 3C(6) due to technical problems with the calorimeter.

Table 9 Test results for the fire tests using the cardboard cartons with plastic cups, with the roof on the trailer mock-up.

Test	Peak HRRtot [kW]	Max. one minute average HRRtot [kW]	Peak HRRconv [kW]	Max. one minute average HRRconv [kW]	Total energy [MJ]	Convective energy [MJ]	Ratio convective to total energy	Max. one minute average heat flux [kW/m^2]
1C(2)R	291	282	149	141	146	82	0,56	61
2C(4)R	692	653	383	362	277	168	0,61	109
3C(6)R	767	737	416	400	398	238	0,60	119
4C(8)R	863	836	468	452	499	303	0,61	122
5C(10)R	935	919	489	479	595	358	0,60	113
6C(10)RO*	779	769	431	425	653	389	0,60	113

*) The point of ignition was moved to the centre point of the far right flue space.

5.2 Heat release rate graphs

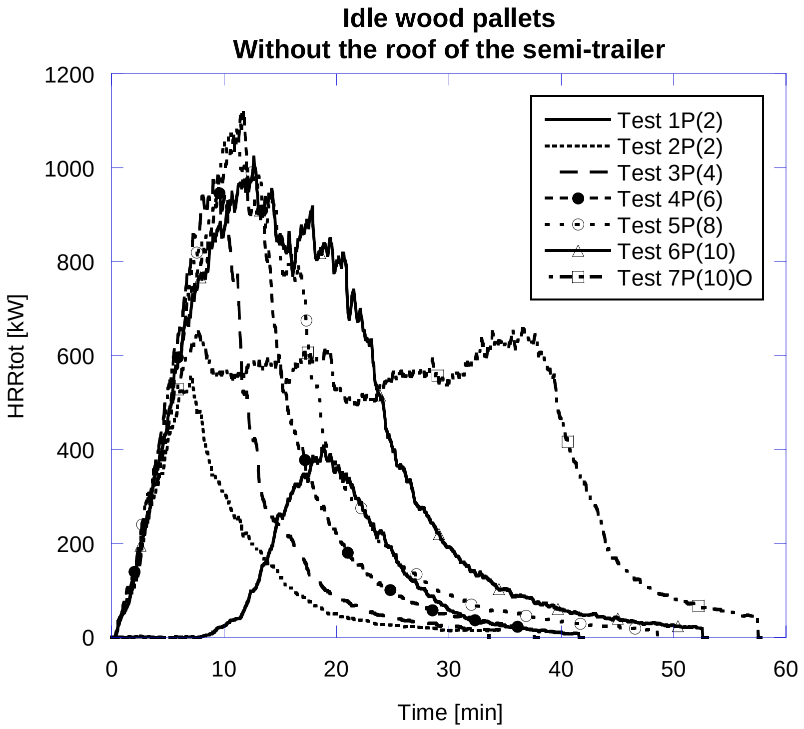

Figure 7 The total heat release rate for the tests using idle wood pallets, <u>without</u> the roof on the trailer.

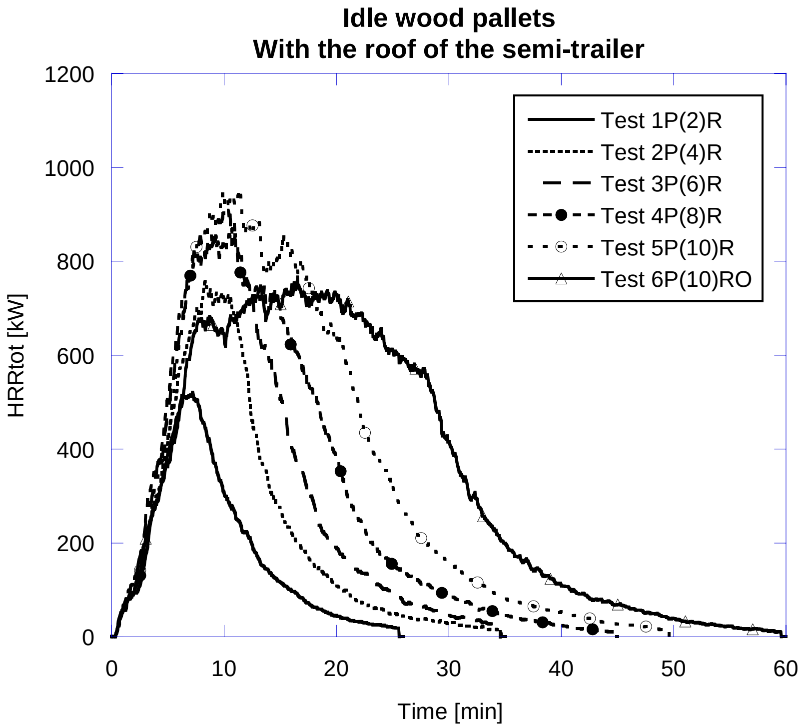

Figure 8 The total heat release rate for the tests using idle wood pallets, <u>with</u> the roof on the trailer.

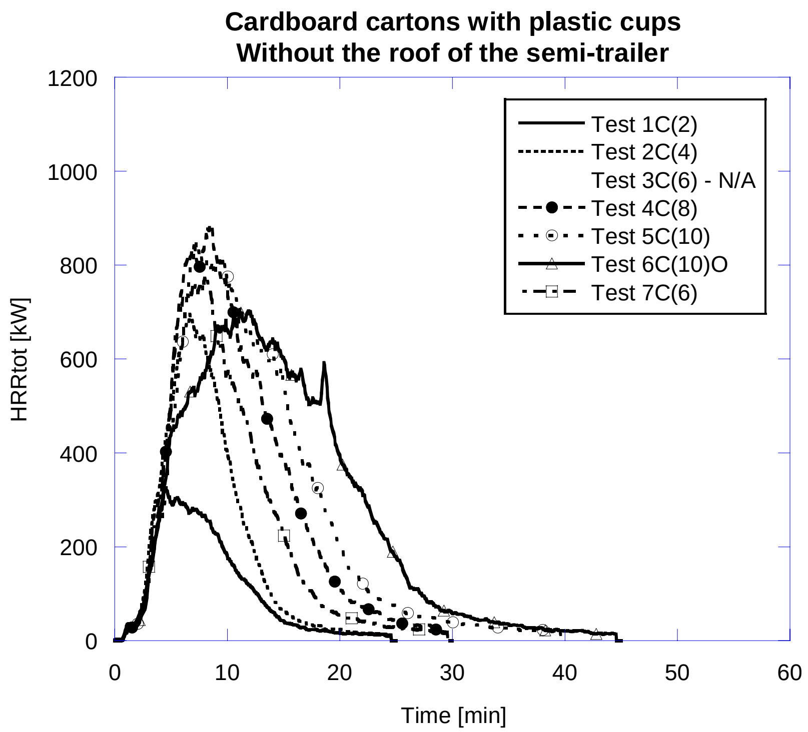

Figure 9 **The total heat release rate for the tests using cardboard cartons with plastic cups, <u>without</u> the roof on the trailer.**

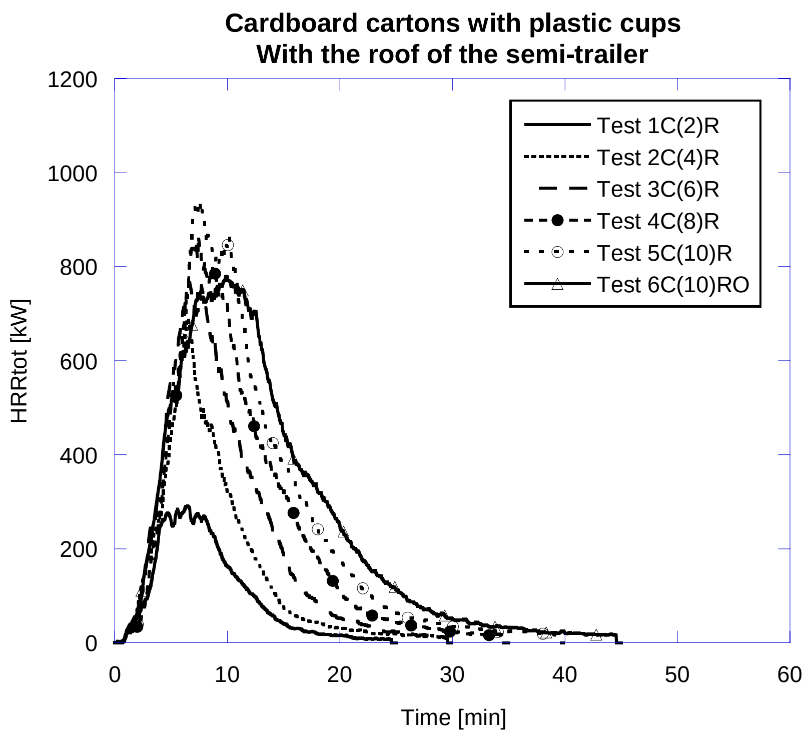

Figure 10 **The total heat release rate for the tests using cardboard cartons with plastic cups, <u>with</u> the roof on the trailer.**

5.3 Heat flux graphs

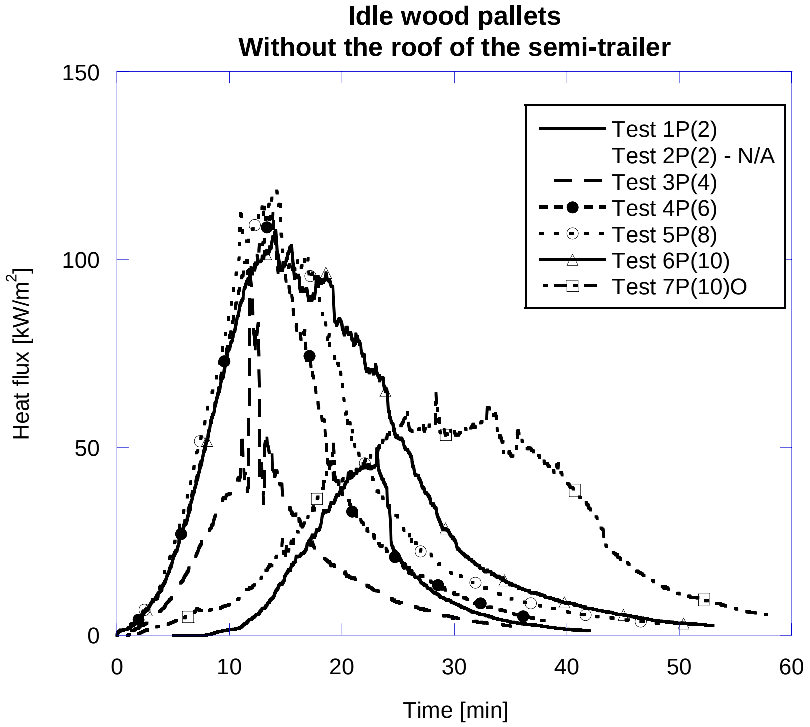

Figure 11 The heat flux for the tests using idle wood pallets, <u>without</u> the roof on the trailer.

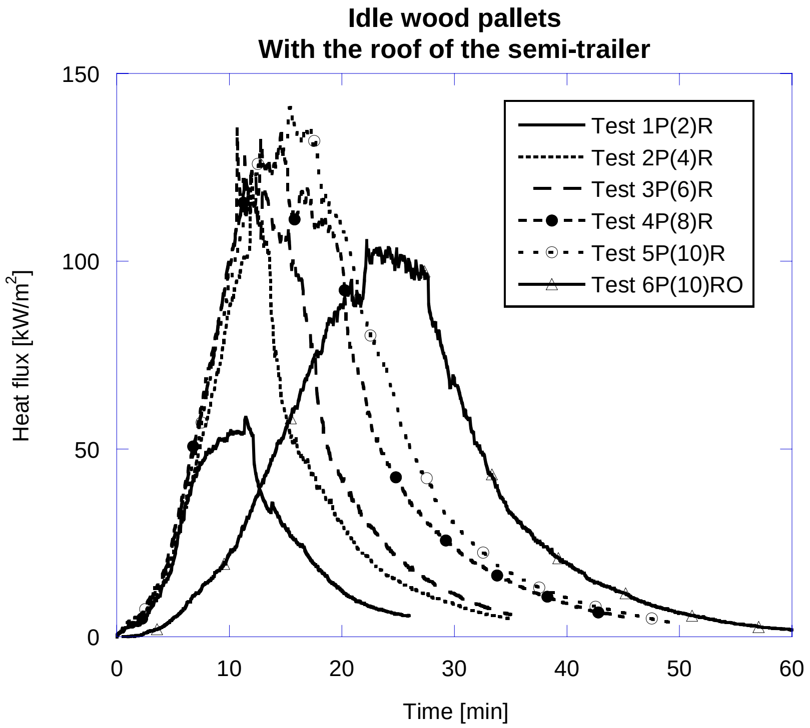

Figure 12 The heat flux for the tests using idle wood pallets, <u>with</u> the roof on the trailer.

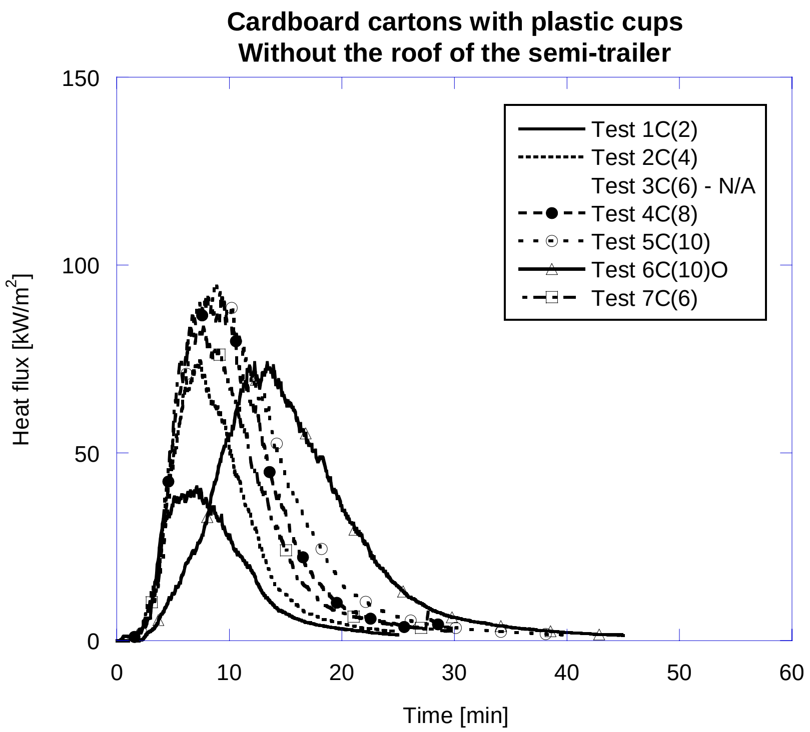

Figure 13 **The heat flux for the tests using cardboard cartons with plastic cups, <u>without</u> the roof on the trailer.**

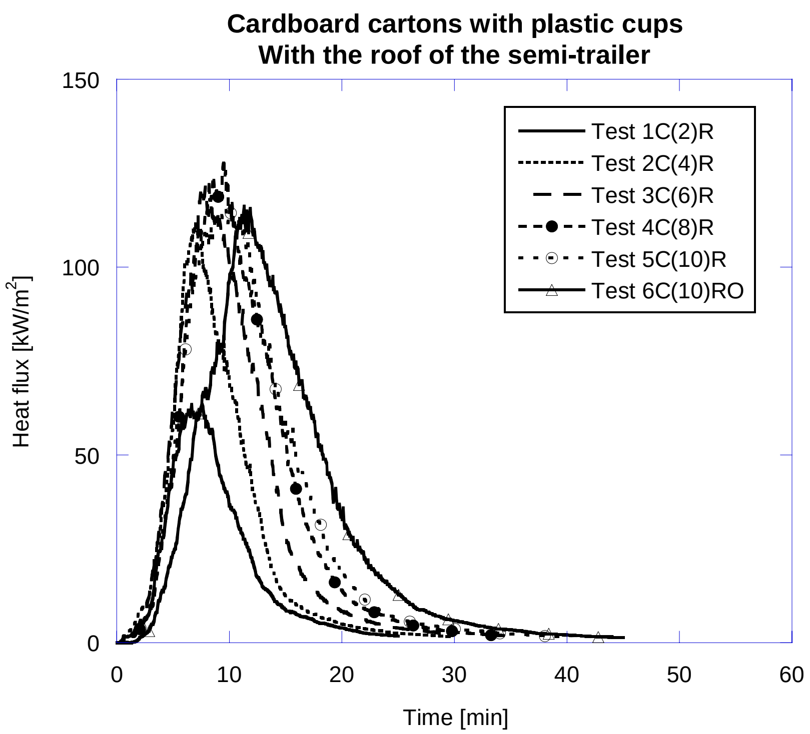

Figure 14 **The heat flux for the tests using cardboard cartons with plastic cups, <u>with</u> the roof on the trailer.**

6 Discussion

6.1 Visual observations of the fire spread

Based on visual observations and the photos in Appendix A, the fire development and fire spread can be described as follows:

Idle pallets, without the roof on the trailer: After ignition, flames were established in the flue space formed by the pallets facing each other. Thereafter, fire started to spread horizontally between the individual pallets. During this increase of fire size, flames ignited the top surface of the first four stacks of pallets. Gradually, fire progressed in a horizontal direction, involving one stack of pallets after the other. However, fire spread was fairly slow and the fire in the central four stacks decreased at about the same rate as fire spread towards the short ends of the set-up. When the combustibles of the four central stacks were consumed, they burnt out and collapsed.

For the tests involving a larger number of stacks, the heat radiation from the flame influenced the horizontal spread such that the pallets at the top were involved before the pallets at the bottom of the stacks.

Idle pallets, with the roof on the trailer: After ignition, the initial fire development was similar to the behaviour described above. However, as the fire size increased, the roof directed the flames over the tops of the adjacent stacks of pallets. This changed the fire spread such that the top layer of pallets became involved in the fire faster than without the roof. However, it seemed that the roof reduced the peak heat release rate.

Cardboard cartons with plastic cups, without the roof on the trailer: After ignition, the fire rapidly spread vertically up the transversal / longitudinal flue space of the central stack of commodity. When all the inner surfaces of the central stack of commodity were involved in the fire, the fire started to spread horizontally between the top and bottom cartons, which involved the outer surfaces of the top cartons. When the fire size increased, the increased heat radiation from the flame ignited the horizontal top surface of the adjacent commodity, i.e. the top surface areas of the adjacent commodity were involved in the fire and fire spread from the top and down. When the combustibles of the four central stacks of commodity were consumed, the fire size of the central part decreased as the fire involved more and more of the outermost stacks.

Cardboard cartons with plastic cups, with the roof on the trailer: After ignition, the initial fire development was similar to the behaviour described above. However, as the fire size increased, the roof directed the flames over the tops of the adjacent stacks of commodity. This made the fire spreading from the top and down. When the combustibles of the four central stacks of commodity were consumed, the fire size of the central part decreased, which gradually reduced the heat release rate.

6.2 General observations

The use of a roof on the trailer mock-up had a limited influence on the peak heat release rates for the commodity consisting of cardboard cartons with plastic cups. However, the roof reduced the peak heat release rates for the commodity consisting of idle wood pallets. This effect can probably be explained by the reduction of the access of fresh air, but it could also be an effect that was caused by a reduction of the heat radiation from the flames and back towards the commodity, see figure 15.

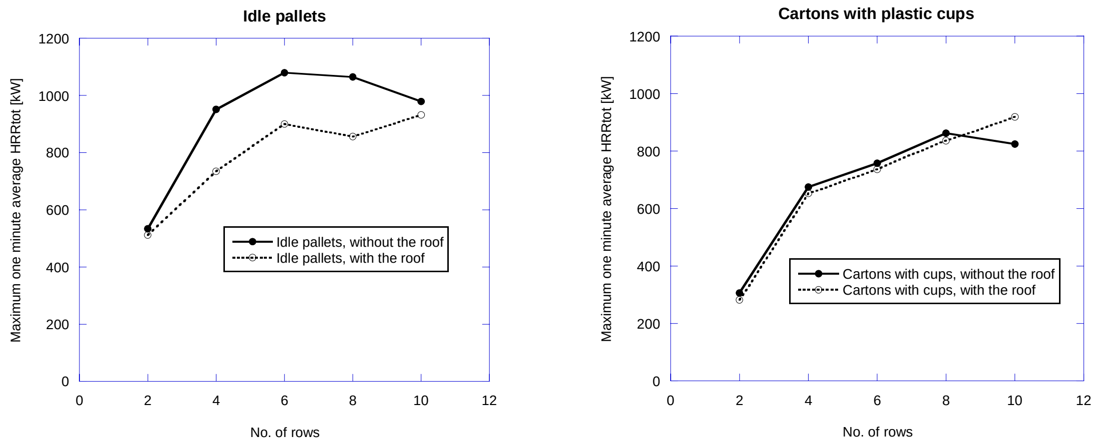

Figure 15 The maximum one minute average heat release rate without and with the roof for the idle pallets (left hand graph) and the cardboard cartons with plastic cups, as a function of the number of rows of commodity.

Without the roof, the maximum one minute average heat release rate of the idle pallets was consistently higher (a factor of 1,2 to 1,7) than the cardboard cartons with plastic cups. However, the difference was reduced with an increasing number of rows. With the roof, the maximum one minute average heat release rate of the idle pallets were a factor of 1,1 to 1,8 higher using 6 rows or less, but similar to the cardboard cartons with plastic cups when using 8 or 10 rows of commodity, see figure 16.

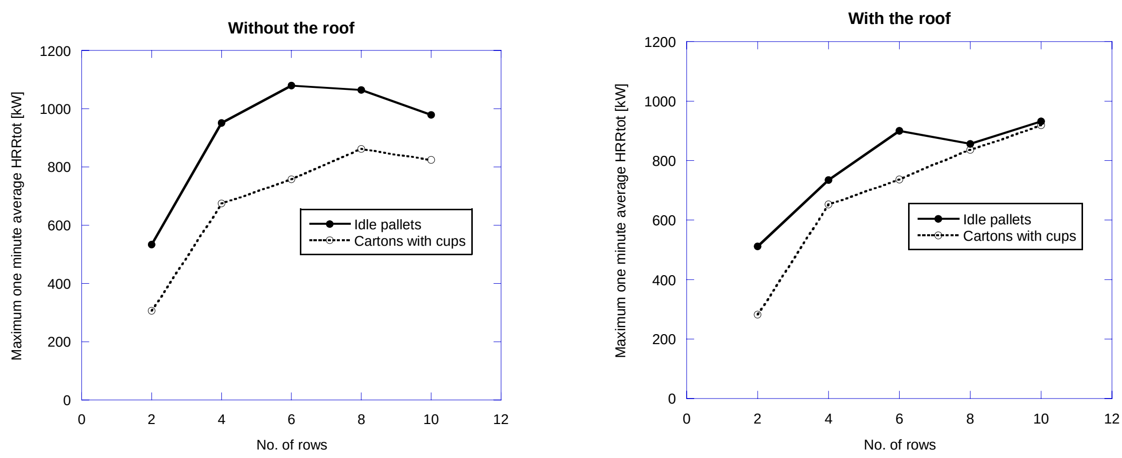

Figure 16 The maximum one minute average heat release rate without (left hand graph) and with the roof, as a function of the number of rows of commodity.

The total and convective energy was approximately a factor of 2 higher for the tests using the idle pallets as compared to the cardboard cartons with plastic cups, which corresponds to a longer fire duration time.

The use of a roof on the trailer mock-up increased the peak heat flux for both types of commodity. This effect can probably be explained by the fact that the flames of the fire were pushed down by the roof, see figure 17.

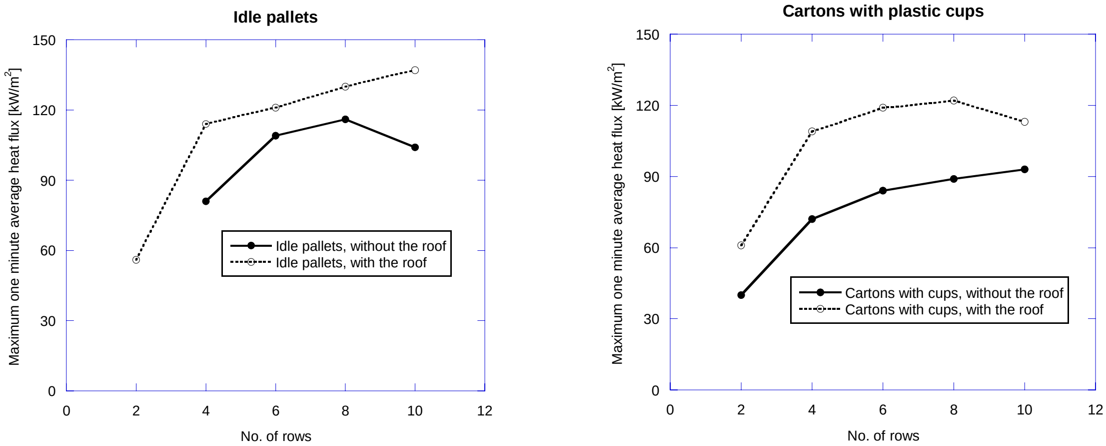

Figure 17 The maximum one minute average heat flux without and with the roof for the idle pallets (left hand graph) and the cardboard cartons with plastic cups, as a function of the number of rows of commodity.

Without the roof, the maximum one minute average heat flux from the idle pallets was consistently higher (a factor of 1,1 to 1,3) than the cardboard cartons with plastic cups. With the roof, the maximum one minute average heat flux of the idle pallets was similar using 6 rows or less, but higher than the cardboard cartons with plastic cups when using 8 or 10 rows of commodity, see figure 18.

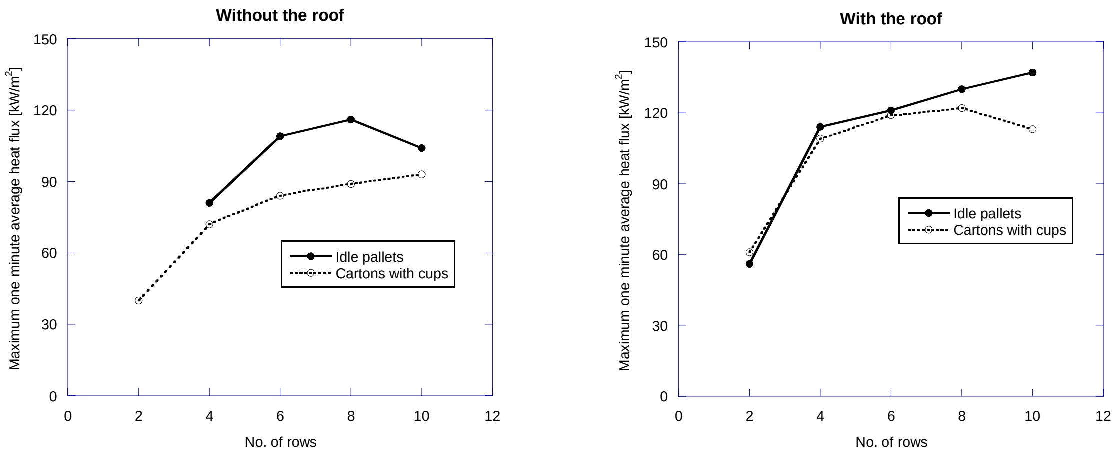

Figure 18 The maximum one minute average heat flux without (left hand graph) and with the roof, as a function of the number of rows of commodity.

Both the peak heat release rate and the fire growth rate were reduced when the point of ignition was moved to the centre point of the far right flue space of the rows of commodity, as this allowed fire spread in one direction only. It is noticeable, however, that the use of a roof increased the peak heat release rate for the commodity consisting of idle wood pallets. This is contradictory to the observation made with the point of ignition at the central flue of the central stack of commodity, where the fire size was reduced.

The small ignition source used for one of the tests with idle wood pallets provided a significant reduction of the fire growth rate and a reduction of the peak heat release rate, as compared to the larger ignition source used in the majority of the idle wood pallet tests.

The fire growth rate of the cardboard cartons with plastic cups was significantly faster than the fire in the idle wood pallets when using the small ignition source. However, the fire growth rate was similar for both types of commodity when using the larger ignition source.

6.3 Conversion of the test results to full scale

The test set-up was built in scale 1:4, which means that the size was scaled geometrically according to this ratio. If the influence of the thermal inertia of the involved material, the turbulence intensity and radiation are neglected, the heat release rate, velocity (not applicable in this particular case), time, energy content and mass can be scaled using correlations defined in Table 10. Additional information about scaling theories can be obtained for example in reference [3].

Table 10 A list of scaling correlations.

Type of unit	Scaling model
Heat Release Rate (kW)	$\dot{Q}_F = \dot{Q}_M \left(\frac{L_F}{L_M}\right)^{5/2}$
Velocity (m/s)	$u_F = u_M \left(\frac{L_F}{L_M}\right)^{1/2}$
Time (s)	$t_F = t_M \left(\frac{L_F}{L_M}\right)^{1/2}$
Energy (kJ)	$E_F = E_M \left(\frac{L_F}{L_M}\right)^{3} \frac{\Delta H_{c,M}}{\Delta H_{c,F}}$
Mass (kg)	$m_F = m_M \left(\frac{L_F}{L_M}\right)^{3}$
Temperature (K)	$T_F = T_M$

L is the length scale, the index M is related to the model scale and the index F to full scale ($L_M = 1$ and $L_F = 4$ in this particular case).

Given below are tables where the total mass of the combustibles, the one minute average total and convective heat release rates, and the total energy are converted to full scale.

Table 11 Test results for the fire tests conducted using the idle wood pallets, without a roof on the trailer mock-up, when converted to full scale.

Test	Total mass [tons]	Max. one minute average HRRtot [MW]	Max. one minute average HRRconv [MW]	Total energy [GJ]
1P(2)*	1,27	12,4	9,1	8,6
2P(2)	1,27	17,0	12,1	9,4
3P(4)	2,54	30,4	19,2	17,1
4P(6)	3,81	34,6	20,4	23,9
5P(8)	5,08	34,1	20,5	30,1
6P(10)	6,34	31,3	19,1	37,4
7P(10)O**	6,34	20,6	13,3	45,1

*) The small fire ignition source was used.
**) The point of ignition was moved to the centre point of the far right flue space.

Table 12 Test results for the fire tests conducted using the idle wood pallets, with the roof on the trailer mock-up, when converted to full scale.

Test	Total mass [tons]	Max. one minute average HRRtot [MW]	Max. one minute average HRRconv [MW]	Total energy [GJ]
1P(2)R	1,27	16,4	11,4	8,7
2P(4)R	2,54	23,5	16,0	15,6
3P(6)R	3,81	28,8	18,7	21,3
4P(8)R	5,08	27,4	17,8	26,2
5P(10)R	6,34	29,8	18,8	33,4
6P(10)RO*	6,34	23,8	15,9	38,6

*) The point of ignition was moved to the centre point of the far right flue space.

Table 13 Test results for the fire tests using the cardboard cartons with plastic cups, without the roof on the trailer mock-up, when converted to full scale.

Test	Total mass [tons]	Max. one minute average HRRtot [MW]	Max. one minute average HRRconv [MW]	Total energy [GJ]
1C(2)	0,49	9,8	5,4	5,0
2C(4)	0,97	21,6	11,9	9,6
3C(6)	1,46	N/A	N/A	N/A
4C(8)	1,95	27,6	14,8	17,4
5C(10)	2,44	26,4	14,7	20,0
6C(10)O*	2,44	22,2	13,1	22,5
7C(6)**	1,46	24,3	14,0	13,6

*) The point of ignition was moved to the centre point of the far right flue space.
**) Repeat of Test 3C(6) due to technical problems with the calorimeter.

Table 14 Test results for the fire tests using the cardboard cartons with plastic cups, with the roof on the trailer mock-up, when converted to full scale.

Test	Total mass [tons]	Max. one minute average HRRtot [MW]	Max. one minute average HRRconv [MW]	Total energy [GJ]
1C(2)R	0,49	9,0	4,5	4,7
2C(4)R	0,97	20,9	11,6	8,9
3C(6)R	1,46	23,6	12,8	12,7
4C(8)R	1,95	26,8	14,5	16,0
5C(10)R	2,44	29,4	15,3	19,0
6C(10)RO*	2,44	24,6	13,6	20,9

*) The point of ignition was moved to the centre point of the far right flue space.

Based on the conversion, it can be concluded that the maximum fire size (based on the maximum one minute average total heat release rate) of the idle pallets would range from 12,4 to 34,1 MW in full scale and from 9,0 to 29,4 MW for the commodity using the cardboard cartons with plastic cups.

The measurement graphs have not been converted to full scale, but it can be noted that the time scale would convert with a factor of 2, i.e. the total duration time of equivalent tests would be twice as long in full scale.

7 Conclusions

A series of down-scaled (scale 1:4) fire tests aimed at simulating fires on the trailer of a freight truck has been conducted. The fire tests were conducted with two types of commodities, different loading and without and with a roof over the test set-up.

The tests were conducted with either 2, 4, 6, 8 or 10 rows of commodity. The point of ignition was usually positioned at the centre point of the central stack of commodity. However, for some of the tests using 10 rows of commodity, the point of ignition was moved to the centre point of the far right flue space between the rows. During all tests the heat release rate and heat flux were measured.

If converted to full scale, the maximum fire size (based on the one minute average total heat release rate) of the idle pallets would range from 12,4 to 34,1 MW and from 9,0 to 29,4 MW for the commodity using the cardboard cartons with plastic cups, dependent on the number of rows of commodity.

Further, it can be concluded that a fire test set-up consisting of at least 6 rows of commodity would mimic a fire in a larger set-up, for the parameters studied with the exception of the fire duration.

References

1 Resolution A.123(V), “Recommendation on fixed fire extinguishing systems for special category spaces”, International Maritime Organization, London, United Kingdom, October 26, 1967

2 Arvidson, Magnus, “An Intermediate Scale Comparison between the FMRC and the EUR Standard Plastic Commodities, Brandforsk Project 735-941”, SP Report 1999:30, SP Report 2005:49, SP Technical Research Institute of Sweden (may be downloaded from www.sp.se)

3 Ingason, Haukur, Model Scale Tunnel Fire Tests, Longitudinal Ventilation, Brandforsk project 404-011, SP Report 2005:49, SP Technical Research Institute of Sweden (may be downloaded from www.sp.se)

Appendix A: Selected photos from the tests

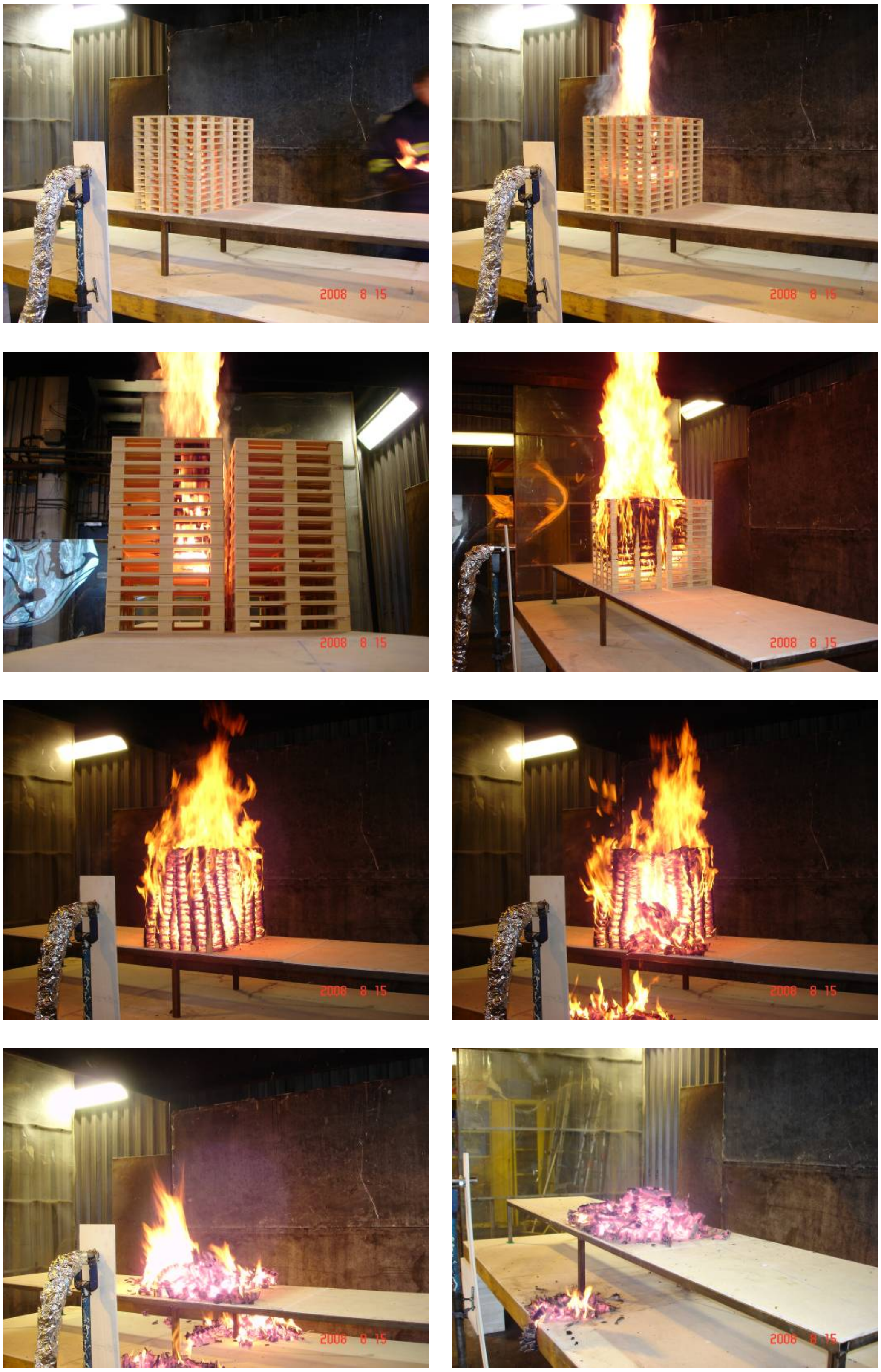

Figure A-1 **A photo sequence showing the fire development in Test 1P(2), with two rows of idle wooden pallet stacks. For this particular test, the small ignition source was used.**

Figure A-2 **A photo sequence showing the fire development in Test 2P(2), with two rows of idle wooden pallet stacks. For this, and all remaining tests with idle wooden pallets, the large ignition source was used.**

Figure A-3 **A photo sequence showing the fire development in Test 3P(4), with four rows of idle wooden pallet stacks.**

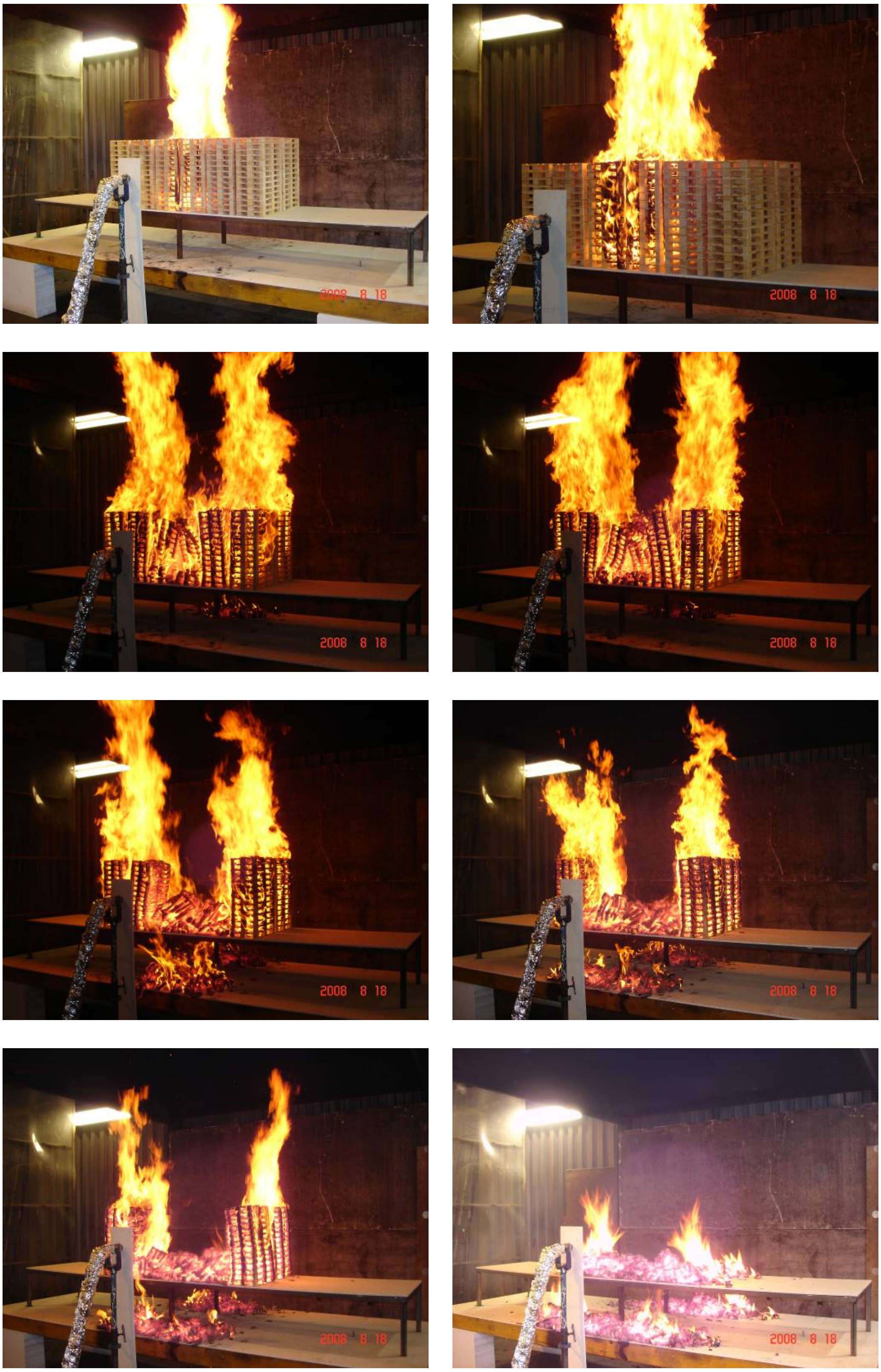

Figure A-4 A photo sequence showing the fire development in Test 4P(6), with six rows of idle wooden pallet stacks.

Figure A-5 **A photo sequence showing the fire development in Test 5P(8), with eight rows of idle wooden pallet stacks.**

Figure A-6 **A photo sequence showing the fire development in Test 6P(10), with ten rows of idle wooden pallet stacks.**

Figure A-7 **A photo sequence showing the fire development in Test 7P(10)O, with ten rows of idle wooden pallet stacks. The ignition source was positioned at the flue space at the far right of the rows of commodity.**

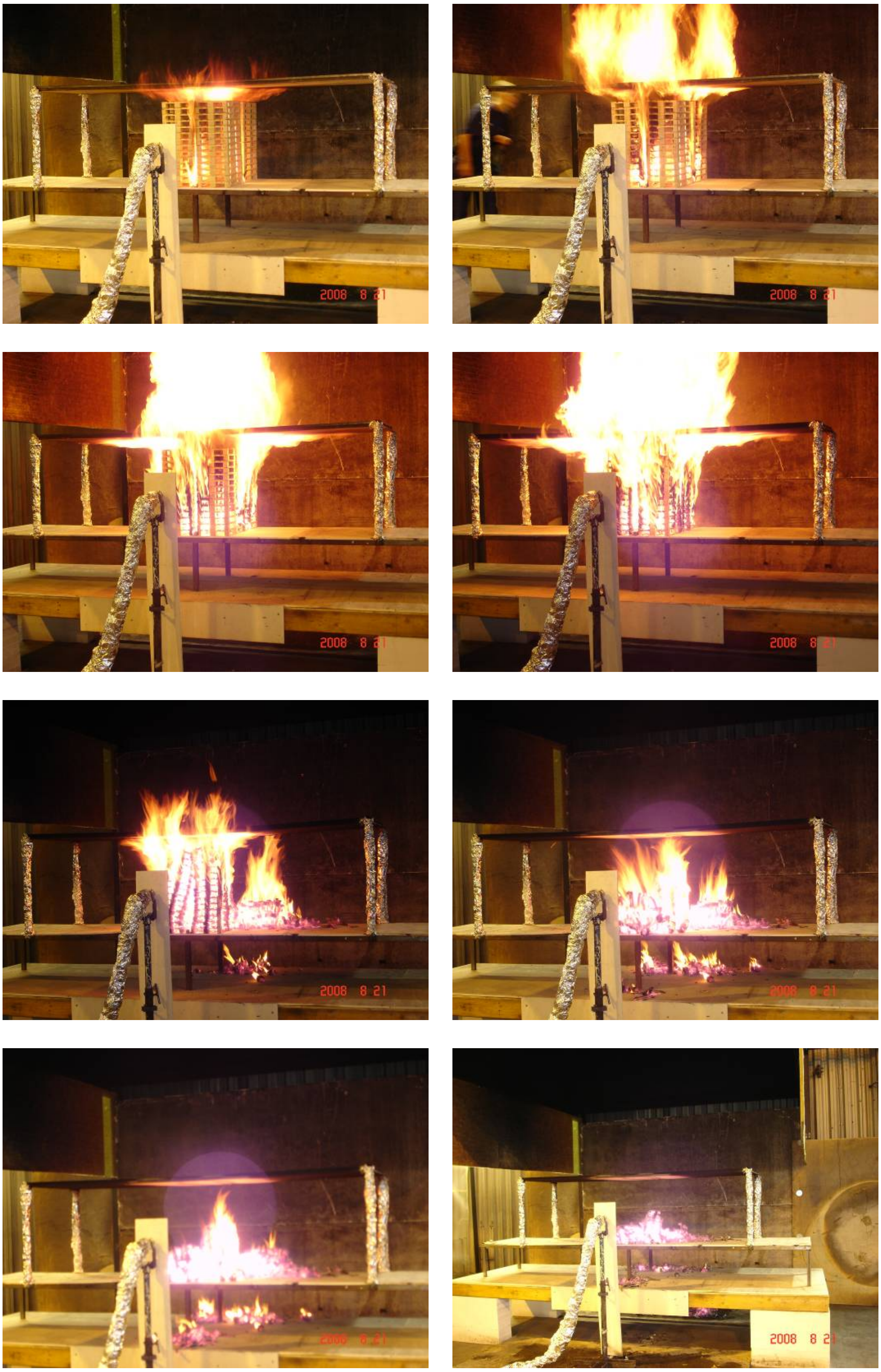

Figure A-8 **A photo sequence showing the fire development in Test 1P(2)R, with two rows of idle wooden pallet stacks and the roof on the trailer mock-up installed.**

Figure A-9 **A photo sequence showing the fire development in Test 2P(4)R, with four rows of idle wooden pallet stacks and the roof on the trailer mock-up installed.**

Figure A-10 **A photo sequence showing the fire development in Test 3P(6)R, with six rows of idle wooden pallet stacks and the roof on the trailer mock-up installed.**

Figure A-11 **A photo sequence showing the fire development in Test 4P(8)R, with eight rows of idle wooden pallet stacks and the roof on the trailer mock-up installed.**

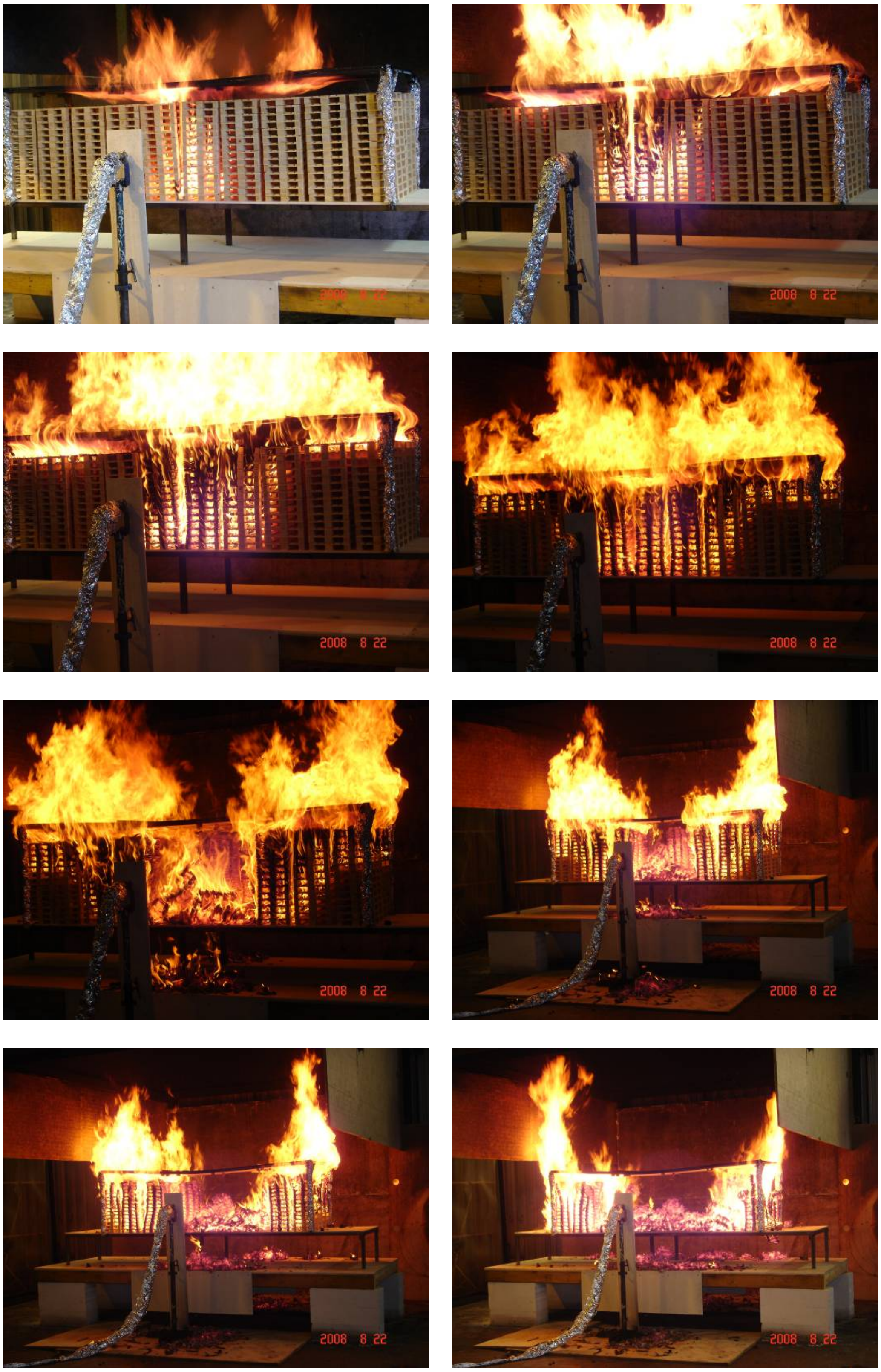

Figure A-12 **A photo sequence showing the fire development in Test 5P(10)R, with ten rows of idle wooden pallet stacks and the roof on the trailer mock-up installed.**

Figure A-13 **A photo sequence showing the fire development in Test 6P(10)RO, with ten rows of idle wooden pallet stacks and the roof on the trailer mock-up installed. The ignition source was positioned at the flue space at the far right of the rows of commodity.**

Figure A-14 **A photo sequence showing the fire development in Test 1C(2), with two rows of cardboard cartons.**

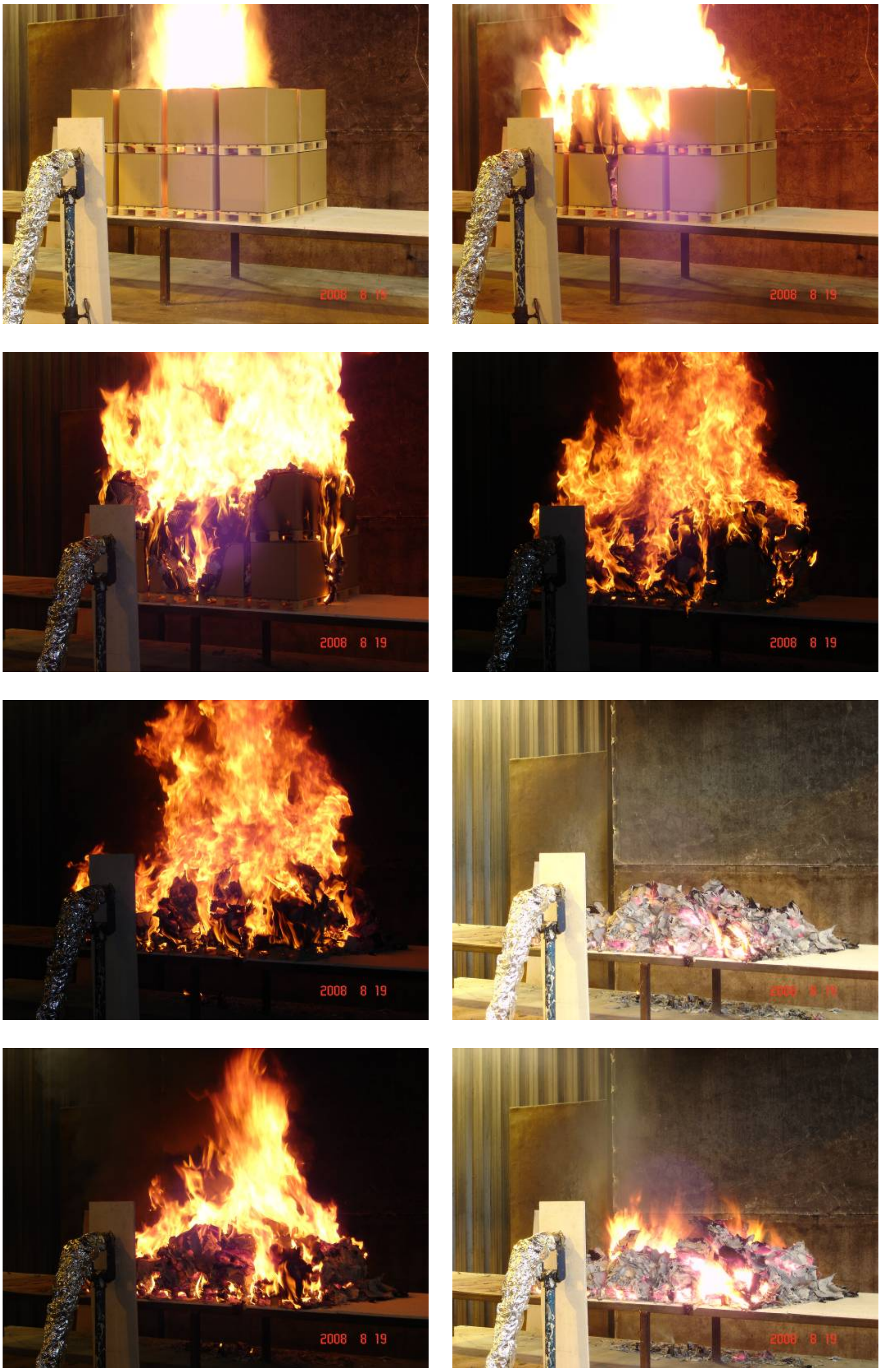

Figure A-15 A photo sequence showing the fire development in Test 2C(4), with four rows of cardboard cartons.

Figure A-16 A photo sequence showing the fire development in Test 3C(6), with six rows of cardboard cartons.

Figure A-17 **A photo sequence showing the fire development in Test 4C(8), with eight rows of cardboard cartons.**

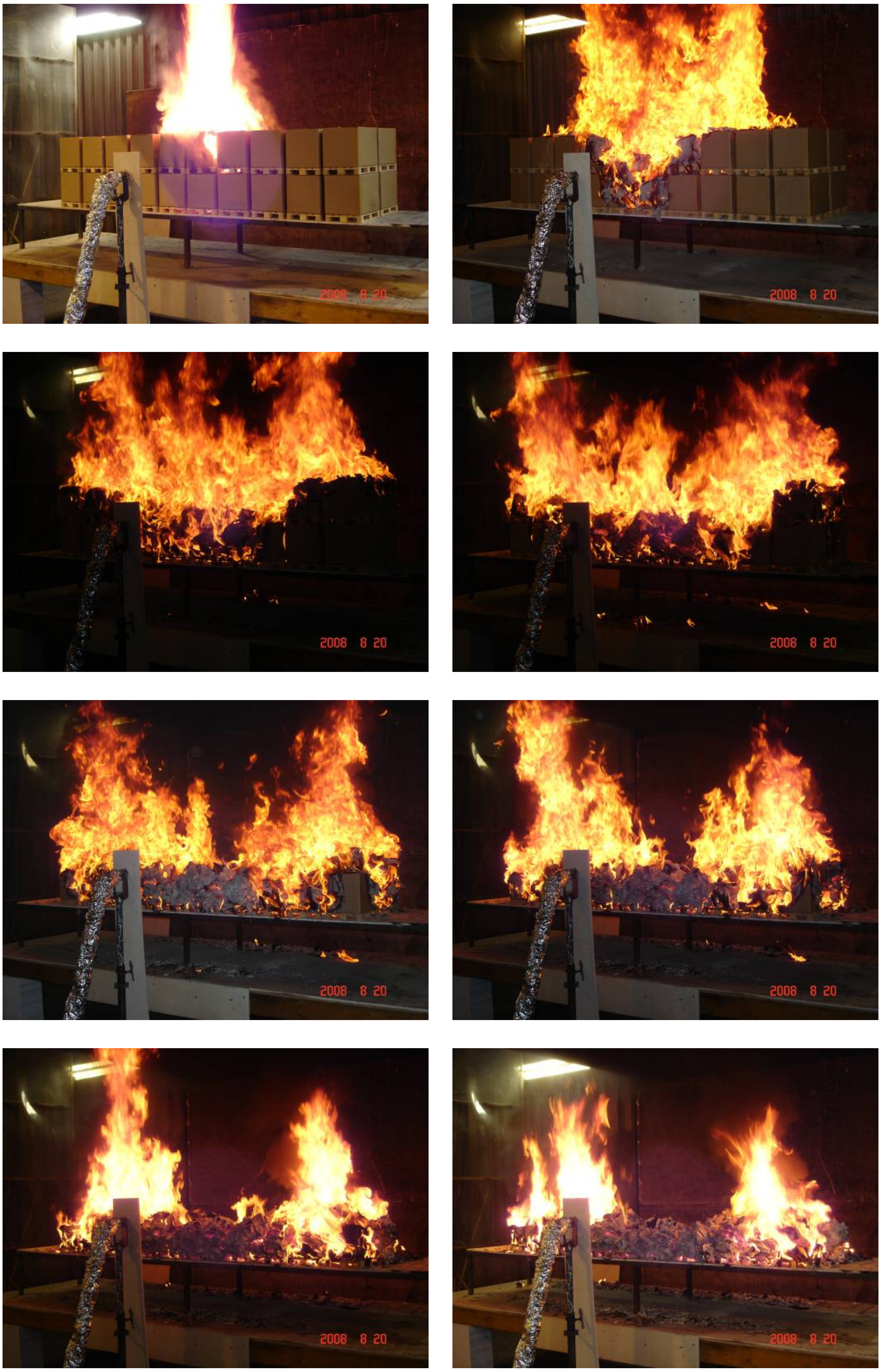

Figure A-18 **A photo sequence showing the fire development in Test 5C(10), with ten rows of cardboard cartons.**

Figure A-19 **A photo sequence showing the fire development in Test 6C(10)O, with ten rows of cardboard cartons. The ignition source was positioned at the flue space at the far right of the rows of commodity.**

Figure A-20 **A photo sequence showing the fire development in Test 7C(6), with six rows of cardboard cartons. This test was a repeat of Test 3C(6) due to technical problems.**

Figure A-21 A photo sequence showing the fire development in Test 1C(2)R, with two rows of cardboard cartons and the roof on the trailer mock-up installed.

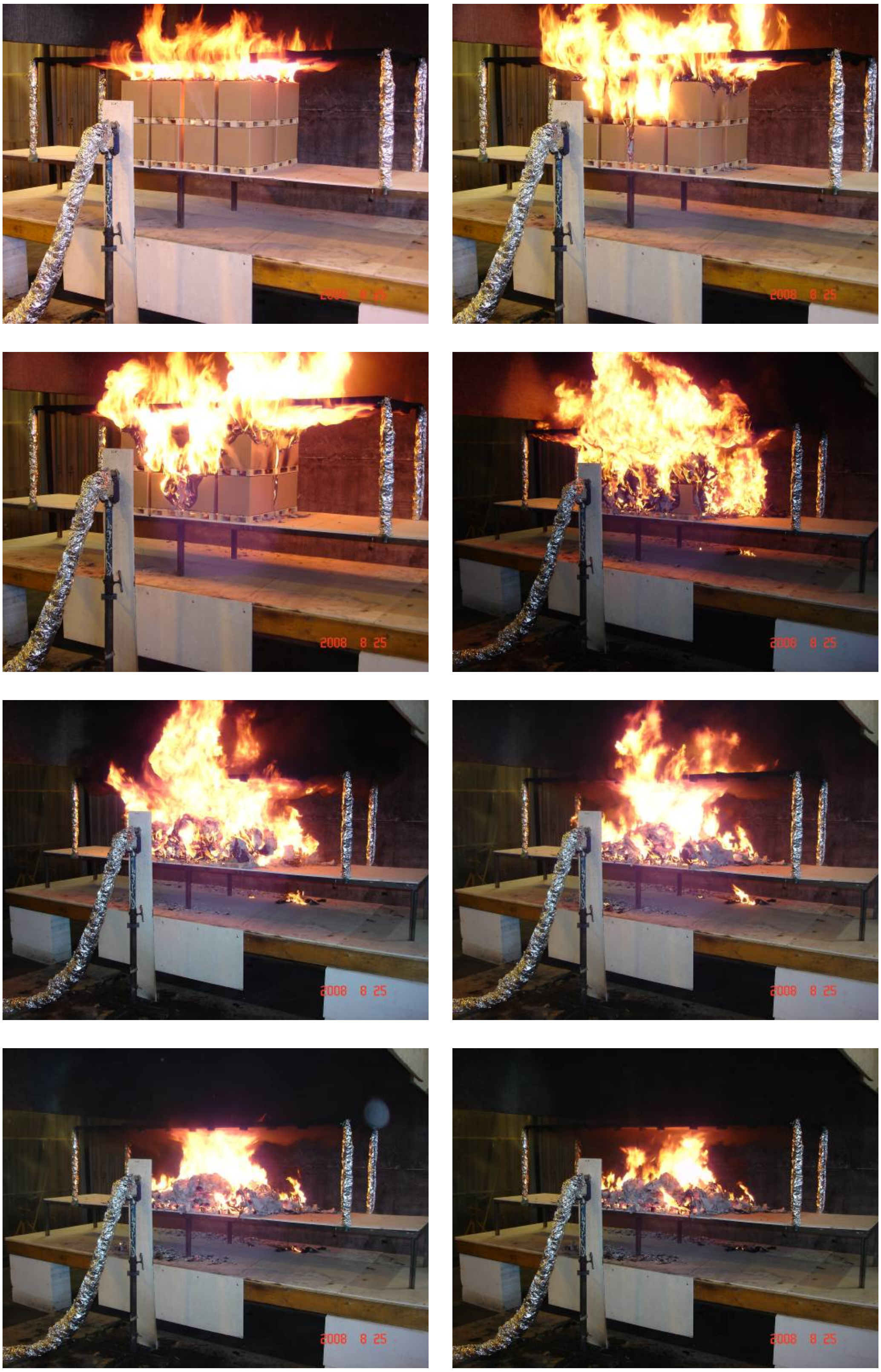

Figure A-22 A photo sequence showing the fire development in Test 2C(4)R, with four rows of cardboard cartons and the roof on the trailer mock-up installed.

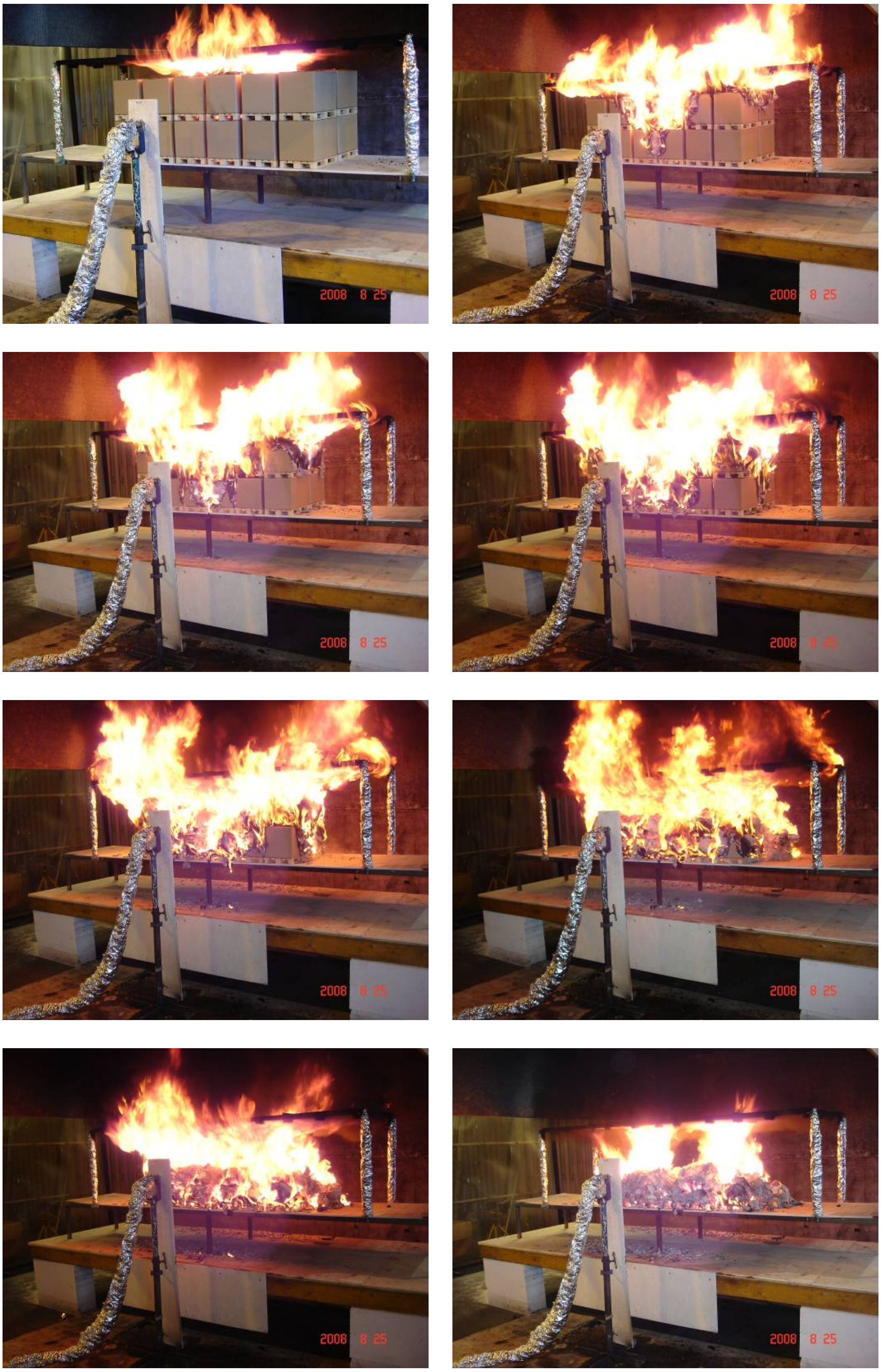

Figure A-23 **A photo sequence showing the fire development in Test 3C(6)R, with six rows of cardboard cartons and the roof on the trailer mock-up installed.**

Figure A-24 **A photo sequence showing the fire development in Test 4C(8)R, with eight rows of cardboard cartons and the roof on the trailer mock-up installed.**

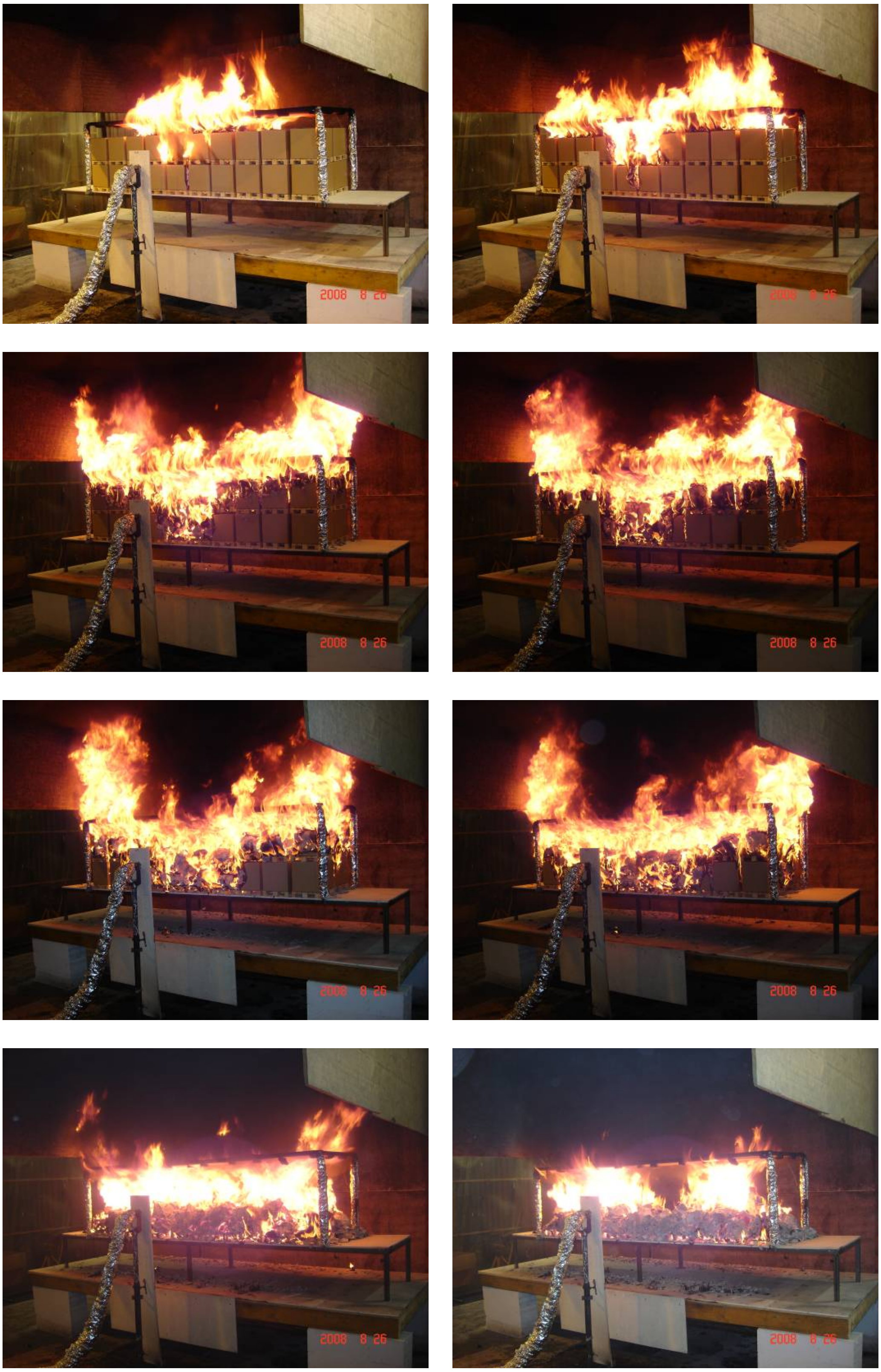

Figure A-25 **A photo sequence showing the fire development in Test 5C(10)R, with ten rows of cardboard cartons and the roof on the trailer mock-up installed.**

Figure A-26 **A photo sequence showing the fire development in Test 6C(10)RO, with ten rows of cardboard cartons and the roof on the trailer mock-up installed. The ignition source was positioned at the flue space at the far right of the rows of commodity.**

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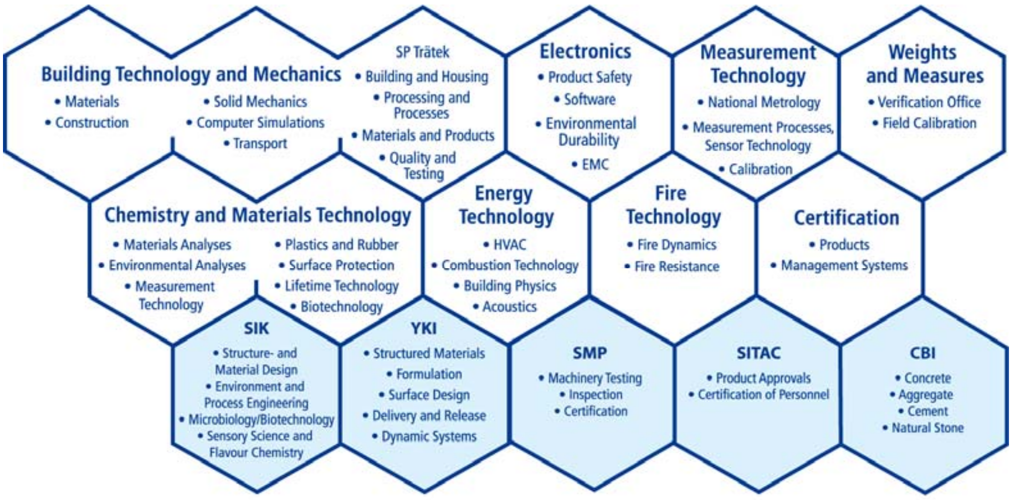

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