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Anders Lönnermark

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Brandforsk Project 620-001

SP Swedish National Testing and Research Institute
SP Fire Technology
SP REPORT 2002:03

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Abstract

Commodity classification tests of selected ordinary combustible products

This report presents the results from a series of commodity classification tests. The primary objective of the project was to establish test data for a selection of different commodities. These commodities were chosen such that they were related to the commodity classification scheme used in the forthcoming European Standard prEN 12845, “Fixed fire fighting systems, Automatic sprinkler systems, Design, installation and maintenance”.

The test array consisted of four pallet loads of commodity arranged in a 2 by 1 by 2 rack segment. Each commodity was tested using three different water application delivered densities and water was applied at a predetermined heat release rate.

Test results showed significant differences in the fire hazard among the tested commodities, however, it can be concluded that most of the commodities, with a few exceptions, had a hazard level that corresponded to the commodity categories given in prEN 12845. With the data obtained from the tests, any commercial commodity could be tested and classified in accordance with the requirements of prEN 12845.

Key words: Commodities, intermediate scale fire tests, commodity classification, sprinkler systems.

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SP Swedish National Testing and Research Institute
SP Report 2002:03
Postal address:
Box 857, SE-501 15 BORÅS, Sweden
Telephone: +46 33 16 50 00
Telefax: +46 33 13 55 02
E-mail: info@sp.se
Internet: www.sp.se

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Preface

These tests were financed by Brandforsk (project 620-001) and by SP and are a continuation of previous projects using the commodity classification technique.

The reference group for the project consisted of the following persons:

Bo Andersson	Statens Räddningsverk
Gunnar Annelind	Willis AB (representing Sveriges Försäkringsförbund)
Leif Beisland	Trygg-Hansa AB (representing Sveriges Försäkringsförbund)
Kaare Brandsjö	FRC Fire and Rescue Consultant
Jens Hjort	Svenska Brandförsvarsföreningen (SBF)
Göran Holmstedt	LTH-Brandteknik
Sven Jönsson	IKEA AB
Lars Hellsten	Scania CV AB
Lennart Håkansson	NVS Västra Sprinklerfilial (representing VVS-installatörerna)
Per Sjölander	AssiDomän Försäkrings AB
Ari Santavuori	Sampo Industriförsäkring AB
Torsten Södergren	if…skadeförsäkring (representing Sveriges Försäkringsförbund)
Anders Wallin	Brandforsk
Haukur Ingason	SP Brandteknik
Henry Persson	SP Brandteknik

The input from the group is greatly acknowledged.

Sammanfattning

Denna rapport redovisar så kallade godsklassificeringsförsök för nio olika gods. Avsikten med denna typ av försök är att utvärdera godsens brand- och släckegenskaper. Med resultaten från försöken klassificeras godset och denna klassificering tjänar som underlag vid dimensionering av sprinklersystem. Många gånger är klassificering av godset avgörande för hur sprinklerskyddet skall utformas.

Försöken genomfördes under Industrikalorimetern, med vars hjälp brandeffektutveckling som funktion av tid kan mätas. Under kalorimetern placerades en uppställning med totalt fyra stycken pallar gods i ett pallställage. Vatten påfördes, vid en given brandeffekt, med hjälp av en matris av vattenspraymunstycken placerade ovanför godset. Samtliga gods provades vid tre olika vattentätheter, i vissa fall genomfördes dock först ett fribrinnande försök och därefter två försök vid olika vattentätheter. Nedanstående nio gods provades:

- Tjockväggiga (sex lager) wellpappkartonger (EUR standard Class II commodity)
- Wellpappkartonger med inredning.
- Wellpappkartonger med 15 vikt-% hårdplast (polystyren).
- EUR standard plast godset (42 vikt-% hårdplast (polystyren)).
- Plastlådor (HDPE, hög densitets polyeten).
- Wellpappkartonger med 25 volym-% cellplast (polystyren).
- Wellpappkartonger med 40 volym-% cellplast (polystyren).
- Cellplastblock i wellpappkartonger (polystyren).
- Staplade träpallar.

Godsen valdes så att de entydigt faller in inom de fyra (kategori I – IV) godskategorier som är specificerade i Annex B av prEN 12845, “Fixed fire fighting systems, Automatic sprinkler systems, Design, installation and maintenance” alltså de kommande Europareglerna för sprinklersystem. Kategori I räknas som ett gods med ”låg” riskklass och kategori IV som ett gods med ”hög” riskklass.

Resultaten visar att godsens uppmätta brand- och släckegenskaper i de flesta fall väl överensstämmer med klassificeringen enligt prEN 12845. Ett undantag finns, nämligen EUR standardplastgodset (42 vikt-% hårdplast) som enligt klassificeringen i prEN 12845 är ett kategori III gods, men enligt försöken gått och väl är ett kategori IV gods. Grundat på denna erfarenhet föreslås att gods med mer än 25 vikt-% hårdplast behandlas som ett kategori IV gods.

Baserat på försöken föreslås klassificeringsgränser för kategori I – IV gods och för gods som överskrider kategori IV och som därmed kräver speciella brandskyddsåtgärder. Denna kategori benämns RSP, ”Requires Special Protection”. Försöksmetodiken och dessa klassificeringsgränser innebär att ett godtyckligt gods kan klassificeras med betydligt högre noggrannhet än en ren bedömning enligt Annex B av prEN 12845.

Projektet visar även att det är möjligt att reducera försöksuppställningen från den ursprungliga metodiken, där varje försök kräver åtta pallar gods, till en försöksuppställning som kräver fyra pallar. Eftersom tre försök krävs för varje typ av gods kan den totala godsmängden reduceras från 24 pallar till 12 pallar. Detta gör försöksmetodiken betydligt mera ekonomiskt gångbar.

Sökord: Sprinkler, plast, godsklassificering, mellanskaleförsök, varulager.

1 Introduction

1.1 Background

The Factory Mutual Research Corporation (FMRC) established the commodity classification methodology, using heat release rate calorimetry, in the beginning of the 1990's [1]. The aim of the methodology is to determine the hazard level of a commodity by comparing the test results with data from identical tests with commodities with a known hazard level.

The methodology has previously been evaluated [2] by the Swedish National Testing and Research Institute (SP) and has also been adopted as a Nordtest test method [3].

SP has also developed a standardised plastic commodity for use on European pallets sizes, designated the EUR Standard Plastic commodity and has suggested that the original commodity classification 2 by 2 by 2 (eight pallets) test arrangement is reduced to a 2 by 1 by 2 arrangement (four pallets) [4].

1.2 Objective of the test series

The objective of this project was twofold. The primary objective was to establish benchmark commodities that correlates to the commodity categories that is used in the forthcoming European Standard prEN 12845, "Fixed fire fighting systems, Automatic sprinkler systems, Design, installation and maintenance" [5].

The secondary objective was to test these benchmark commodities using the reduced commodity classification arrangement (four pallets) and establish correlating classification (ranking) data. With this data, any commercial commodity could be tested and classified in accordance with the requirements of prEN 12845.

1.3 The European commodity classification scheme

The European commodity classification scheme described in Annex B of prEN 12845 is based on an analysis of the materials (the 'material factor') and the storage configuration of the commodity.

There are four main commodity categories, category I, II, III and IV, where category I represent the least hazardous and category IV the most hazardous commodity. To categorise the commodity, the method is to first analyse the materials involved, in order to determine a material factor and thereafter to determine its storage configuration.

The material factor shall take into account the product, packaging material and the pallet material. The material factors and typical commodities are listed below:

Material factor 1 is defined as non-combustible products in combustible packaging and low or medium combustibility products in combustible or non-combustible packaging. The commodity is only allowed to contain modest amounts of plastics. The amount of unexpanded plastic or rubber content should be less than 5% (by weight) and the amount of expanded plastic or rubber content less than 5% (by volume). Examples include metal parts with or without cardboard packaging on wood pallets, leather products, wood products and canned food.

Material factor 2 corresponds to products with a higher energy content than material factor 1 products, for example those containing greater quantities of plastics. Examples include wood or metal furniture with plastic seats, electrical equipment with plastic parts or packaging and synthetic fabrics.

Material factor 3 corresponds to products containing predominantly unexpanded plastic or materials with higher energy content. Examples include empty car batteries, plastic brief cases, personal computers and unexpanded plastic cups and cutlery.

Material factor 4 corresponds to products containing predominantly expanded plastic (more than 40% by volume) or materials with a similar energy content. Examples include foam mattresses, expanded polystyrene packaging and foam upholstery.

Figure 1 is used to determine the material factor when a commodity consists of mixtures of materials. The commodity shall be considered to include all packing and the material of the load pallet. Rubber should be treated in the same way as plastic.

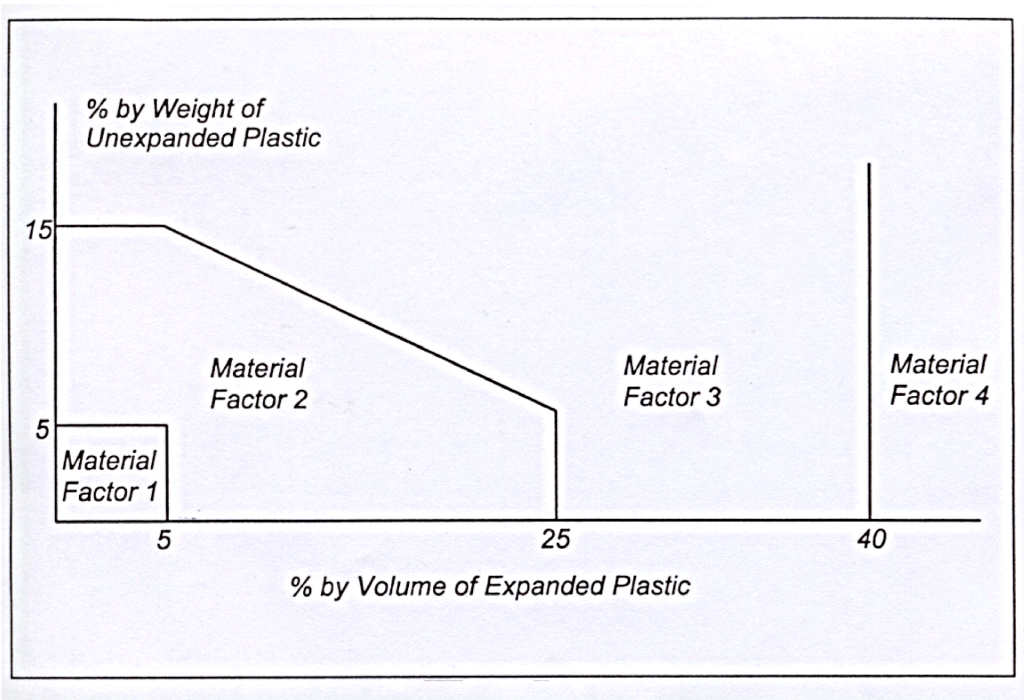


Figure 1 According to Annex B of prEN 12845, the material factor for a commodity that consists of mixtures of materials, should be determined based on the content of plastics using this figure.

After the material factor has been determined, the storage configuration shall be evaluated using Table 1. Detailed descriptions of the storage configurations are given below the table.

Table 1 The influence of the storage configuration on the classification of a commodity.

Storage configuration	Material factor			
	1	2	3	4
Exposed plastic container with non-combustible content	Cat. I, II, III	Cat. I, II, III	Cat. I, II, III	Cat. IV
Exposed plastic surface – expanded	Cat. IV	Cat. IV	Cat. IV	Cat. IV
Exposed plastic surface – unexpanded	Cat. III	Cat. III	Cat. III	Cat. IV
Open structure	Cat. II	Cat. II	Cat. III	Cat. IV
Solid block materials	Cat. I	Cat. I	Cat. II	Cat. IV
Granular or powdered material	Cat. I	Cat. II	Cat. II	Cat. IV
No special configuration	Cat. I	Cat. II	Cat. III	Cat. IV

The following descriptions of storage configurations given above are given in Annex B of prEN 12845:

Exposed plastic containers with non-combustible content. Applies only to plastic containers containing liquids or solids in direct contact with the container and does not apply to metal parts in plastic storage boxes. Examples include plastic bottles of soft drinks or liquids with less than 20% alcohol.

Exposed plastic surface – expanded. Exposed, expanded plastics are generally more severe than unexposed plastics and should be treated as Category IV.

Exposed plastic surface – unexpanded. The category should be increased to either III or IV when the commodity has exposed plastic surfaces comprising one or more side or more than 25% of the surface area. Examples include metal parts in PVC storage bins or shrink-wrapped tinned foods.

Open structure. Commodities stored with, or having a very open structure, generally present a higher hazard than materials with a closed structure. The high surface area together with high access of air encourages rapid combustion.

Solid block materials. Materials in solid block form have usually have a low surface area to the volume or the mass ratio, which reduces the burning rate and permits a reduction in classification (however not applicable to blocks of expanded plastics, which should be treated as Category IV.)

Granular or powdered materials. Granular or powdered material that will spill out during a fire and tend to smother the fire will be less hazardous than their basic material counterparts.

No special configuration. Commodities that have none of the characteristics described above, e.g. cartoned commodities.

2 A description of the tested commodities

The following commodities were used in the tests:

- Triple, bi-wall corrugated cardboard cartons (EUR standard Class II commodity)
- Corrugated cartons with interiors.
- Corrugated cartons with 15% (by weight) unexpanded plastic.
- The EUR standard plastic commodity (42% (by weight) unexpanded plastic).
- Plastic (HDPE) containers.
- Corrugated cartons with 25% (by volume) expanded plastic.
- Corrugated cartons with 40% (by volume) expanded plastic.
- Solid polystyrene blocks in corrugated cartons.
- Wooden pallets.

The commodities were chosen such that they either fell right within a category or such that the material factor was at the boundary between two different classes as indicated in the table below.

Table 2 Classification of the commodities used in the test programme according to Annex B of prEN 12845.

Commodity	Judgment according to prEN 12845		Classification according to prEN 12845
	Material factor	Storage configuration	
Triple, bi-wall corrugated cardboard cartons (EUR standard Class II commodity)	1	Solid block materials	I
Corrugated cartons with interiors	1	Open structure	II
Corrugated cartons with 15% (by weight) unexpanded plastic	Boundary between 2 and 3	Open structure	Boundary between II and III
Corrugated cartons with 25% (by volume) expanded plastic.	Boundary between 2 and 3	Open structure	Boundary between II and III
The EUR standard plastic commodity (42% (by weight) unexpanded plastic)	3	Open structure	III
Plastic (HDPE) containers	3	Exposed plastic surface - unexpanded	III*
Corrugated cartons with 40% (by volume) expanded plastic.	Boundary between 3 and 4	Open structure	Boundary between III and IV
Solid polystyrene blocks in corrugated cartons	4	Solid block materials	IV
Piled wooden pallets	1	Open structure	II**

*) Polypropylene or polyethylene storage bins shall be protected in accordance with Annex G, “Protection of Special Hazards” of prEN 12845.

**) Idle pallets shall be protected in accordance with Annex G, “Protection of Special Hazards” of prEN 12845.

All commodities were supported on slatted 1200 mm by 1000 mm wooden pallets, see Figure 3, and the individual cartons or containers were stapled together to delay or prevent them from falling apart during the tests.

Appendix D provides photos of the tested commodities.

2.1 Triple, bi-wall cartons (EUR standard class II commodity)

This commodity consisted of large, triple, bi-wall corrugated cardboard cartons with a steel liner. The overall dimension of one pallet load was 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 103 kg. The combined thickness of the carton was a nominal 21 mm.

The design of the commodity is similar to the FMRC standard class II commodity [1] and is therefore also denoted European standard class II commodity. The primary difference is due to the fact that the FMRC standard class II commodity consists of double, tri-wall corrugated cardboard cartons with a steel liner.

The cardboard cartons were made in quality SIS 210B+C by Maxbox Emballage AB, Sweden.

2.2 Corrugated cartons with interiors

This commodity was almost identical with the EUR Standard Plastic commodity, see section 2.4, except that no plastic cups were used inside the cartons. Ten cartons were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 49 kg.

2.3 Corrugated cartons with 15% (by weight) unexpanded plastic

This commodity was almost identical with the EUR Standard Plastic commodity; however, a limited number (30 pcs per carton instead of 120 pcs) of plastic cups were used to achieve a total content of approximately 15% (by weight) of unexpanded plastic. Ten cartons were placed on each pallet. The commodity therefore contained 300 pcs of polystyrene cups per pallet load.

The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 57 kg.

2.4 The EUR standard plastic commodity

The EUR Standard Plastic commodity consists of empty polystyrene cups without lids, placed upside down, in compartmented cartons, 120 cups per carton. The cartons measures 600 mm by 400 mm by 500 mm (L × W × H) and are made from single-wall, corrugated cardboard. Ten cartons were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet.

When compartmented, the cartons are divided into five layers by corrugated sheets, with each layer divided into 24 compartments by overlocking corrugated cardboard partitions, forming a total of 120 compartments where the plastic cups are placed. The commodity therefore contained 1200 pcs of polystyrene cups per pallet load.

The individual cups have a measured average weight of 28,2 g. The total weight of the plastic is therefore 3,4 kg per carton. The overall weight of one carton including the cups is approximately 5,4 kg. For the tests described within this report, the cardboard cartons were made in quality E 300 C, by Maxbox Emballage AB, Sweden.

The total weight of one pallet load of the commodity was approximately 54 kg of which approximately 63% by weight was plastic, excluding the pallet. If the weight of the wooden pallet is included in this estimation, approximately 42% by weight was plastic. The resin for the polystyrene was made by Hüls, in quality Vestyron 114. The total weight of one pallet load of the commodity was approximately 81 kg.

2.5 Plastic (HDPE) containers

This commodity consisted of empty plastic containers made from high density polyethylene (HDPE). The individual container had a size of 600 mm by 400 mm by 320 mm (L × W × H). Fifteen containers were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 960 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 76 kg.

Each container on the top layer had a lid made from the same material as the actual container.

The plastic containers were manufactured and delivered by Arca Systems AB in Sweden.

2.6 Corrugated cartons with 25% (by volume) expanded plastic

This commodity was based on the corrugated cartons used for EUR Standard Plastic commodity. However, inside 50 of the 120 compartments an 85 mm cube of expanded polystyrene were positioned to achieve approximately 20% (by volume) of expanded plastic. Ten cartons were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 54 kg.

The expanded polystyrene consisted of an 85 mm cube block that was positioned in the outer 10 (along the long sidewalls) of the 24 compartments on each layer of the interior of the carton, i.e. a total of 50 polystyrene cubes were used inside each carton which totalled 500 per pallet load.

The expanded polystyrene cubes had a nominal density of 20 kg/m^3 and were made by PACFEX AB in Sweden.

2.7 Corrugated cartons with 40% (by volume) expanded plastic

This commodity was based on the corrugated cartons used for EUR Standard Plastic commodity. However, inside 80 of the 120 compartments an 85 mm cube of expanded polystyrene were positioned to achieve approximately 40% (by volume) of expanded plastic. Ten cartons were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 59 kg.

The expanded polystyrene consisted of an 85 mm cube block that was positioned in the outer 16 of the 24 compartments on each layer of the interior of the carton, i.e. a total of 80 polystyrene cubes were used inside each carton which totalled 800 per pallet load.

The expanded polystyrene cubes had a nominal density of 20 kg/m^3 and were made by PACFEX AB in Sweden.

2.8 Solid polystyrene blocks in corrugated cartons

This commodity was based on the corrugated cartons used for EUR Standard Plastic commodity, however, the cartons were completely filled with a solid block of expanded polystyrene. Ten cartons were placed on each pallet. The overall dimension of one pallet load was therefore 1200 mm by 1000 mm by 1000 mm (L × W × H) plus the height of the pallet. The total weight of one pallet load of the commodity was approximately 56 kg.

The expanded polystyrene blocks had a nominal density of 20 kg/m^3 and were made by PACFEX AB in Sweden.

2.9 Wooden pallets

Piles of slatted wooden pallets of the same type used for the storage of the tested commodities were also tested. The pallets had an overall dimension 1200 mm by 1000 mm by 150 mm (L × W × H) and seven pallets plus a bottom pallet was piled on top of each other at the support beams of the rack. The overall height of one pile of pallets was 1040 mm plus the height of the bottom pallet. The individual weight of one pallet was approximately 27,0 kg and the total weight of each pile was 216 kg.

The pallets were made from softwood (Pine) and conditioned prior to the tests, to a measured moisture content of between 10 and 12%.

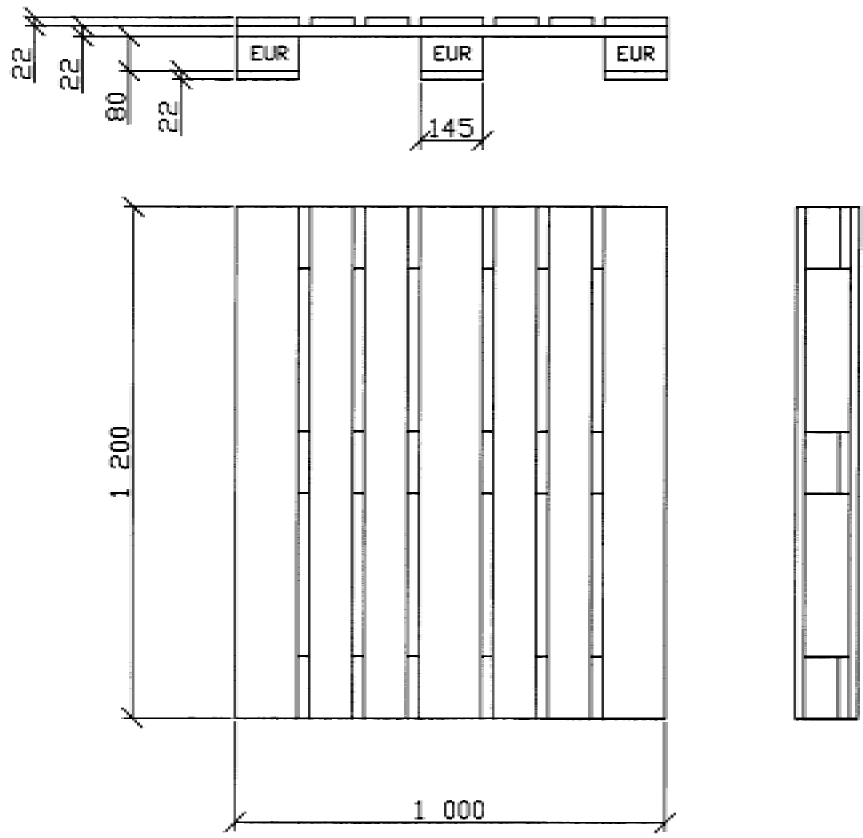


Figure 2 The slatted wooden pallets used in the tests.

3 The test equipment and the test procedure

3.1 The Industry Calorimeter

The tests were conducted under the Industry Calorimeter, a large hood connected to an evacuation system capable of collecting all the combustion gases produced by the fire. The hood is 6 m in diameter with its lower rim 8 m above the floor. To increase the gas collecting capacity of the hood, a cylindrical fibreglass ”skirt”, hanging from the lower rim of the hood, was used. The height of the fibreglass “skirt” was 2,5 m. In the duct to the evacuation system, measurements of gas temperature, velocity and the generation of gaseous species such as CO_2 and CO and depletion of O_2 were made. Based on these measurements both the convective and the total heat release rate were calculated.

3.2 The water applicator

The water applicator consists of six parallel, double-jacketed, steel pipes fitted with six spray nozzles along each pipe, forming a matrix of nozzles 450 mm apart. The nozzles produce a full-cone, wide angle spray, resulting in an even water distribution over a maximum area of 7,29 m^2. For these tests, only four of the pipes were used (the two outer pipes were disconnected). This arrangement provided a matrix of six by four water spray nozzles, which corresponded to a total coverage area of 4,86 m^2. This resulted in some degree of overlap, outside of the pallets.

The distance from the top of the commodity to the tips of the nozzles of the water applicator was approximately 300 mm.

The suppression water is fed from both ends into the pipe. In order to reduce the fill-up time as much as possible, an air relief device is installed at the midpoint of the pipes. This allows the air in the pipes to bleed, but shuts off as soon as the pipes are filled with water. In order to reduce the fill-up time even more, a special charge line is also connected. This is controlled with a time relay and is shut off at the same moment that the pipes are filled with water. This ”charge time” has to be adjusted for each flow rate. The feeding line is equipped with a flow meter and a pressure transducer in order to adjust the flow rate corresponding to the desired water density.

In order to protect the water applicator from the heat of the fire, the applicator is cooled by water in the annular area of the double jacketed pipes. The cooling water is fed from one end and discharged through the other.

3.3 Test procedure

The commodity was placed on pallets and placed in a row rack storage segment. In each tests, four pallets were placed in a 2 by 1 by 2 configuration. As previously mentioned, this set-up differs from the original Commodity Classification set-up where eight pallets in a 2 by 2 by 2 configuration are used. The commodities were ignited at the flue, near the bottom of the commodity at the lower tier, using two standardised ignition sources. These igniters consists of a cube, 60 mm by 60 mm by 75 mm, made from pieces of insulating fibre board. The cube was soaked with 120 mL of heptane and wrapped in a polyethylene plastic foil bag prior to the test. Figure 3 provides a schematic drawing of the set-up.

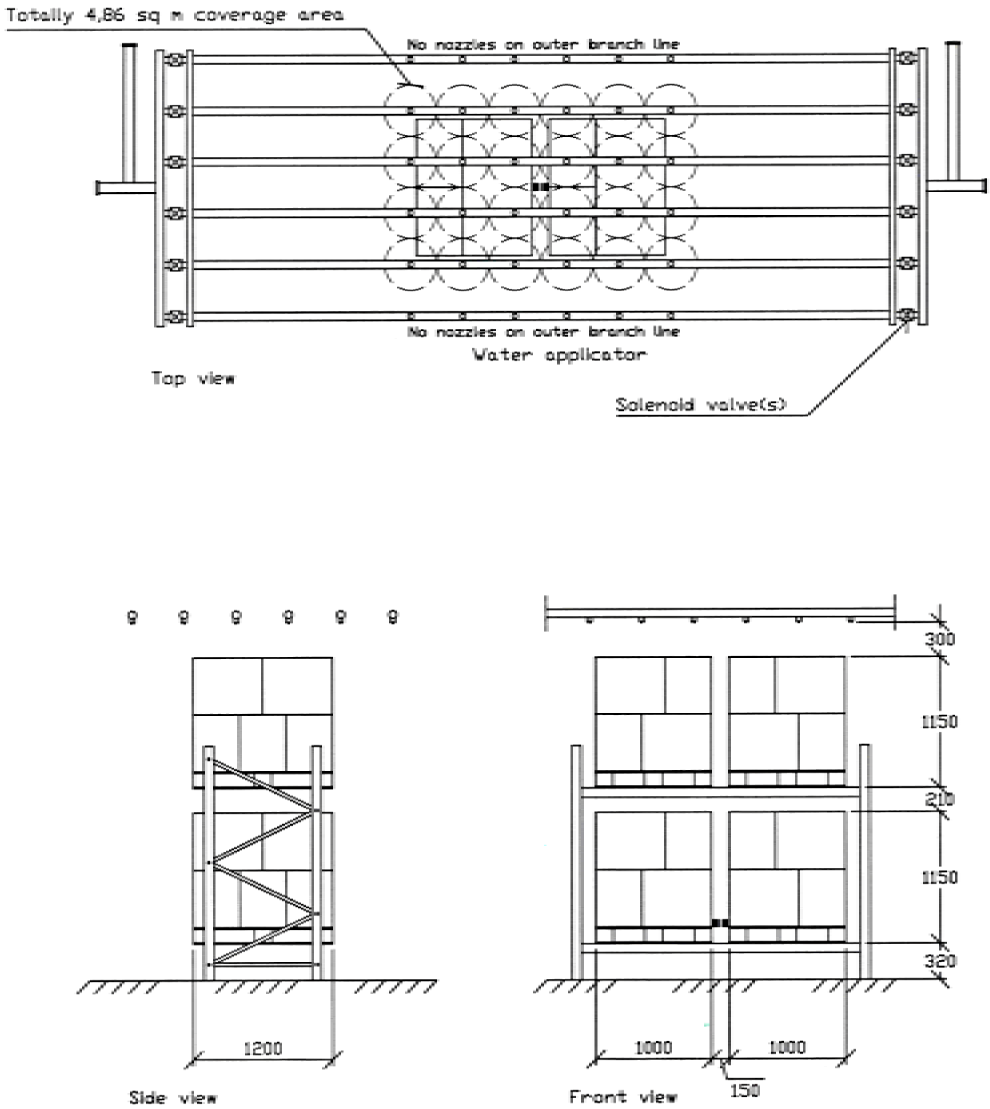


Figure 3 A schematic drawing of the test set-up. The Industry Calorimeter is not shown.

The water was manually activated when the fire had reached a convective heat release rate of 2 MW (this is approximately half the heat release rate when water is applied if eight pallets are used). At that point the fire involved the whole upper tier of the commodity.

The principal approach was that each of the commodities was tested using three different water discharge densities, chosen from the table below. However, for some of the commodities the first test involved a free burn test, without any application of water followed by two additional tests with water application.

Table 3 Water discharge densities, water flow rates, pressures and the associated spray nozzles.

Nominal water discharge density [mm/min]	Total water flow rate [L/min]	Approximate water pressure [bar]	Nozzles used, manufactured by Lechler GmbH
2,5	12	1,5	460.368
5,0	24	2,0	460.408
7,5	36	3,0	460.448
10,0	49	2,0	460.528
15,0	73	2,0	460.608

4 Observations and results

This section summarises the results for each of the commodities. The results are presented as heat release rate histories and a tabulated selection of test data. Appendix C provides a table with all test data.

The judgement of the amount of commodity that was consumed during a test was done visually and was made exclusive of the wooden pallet.

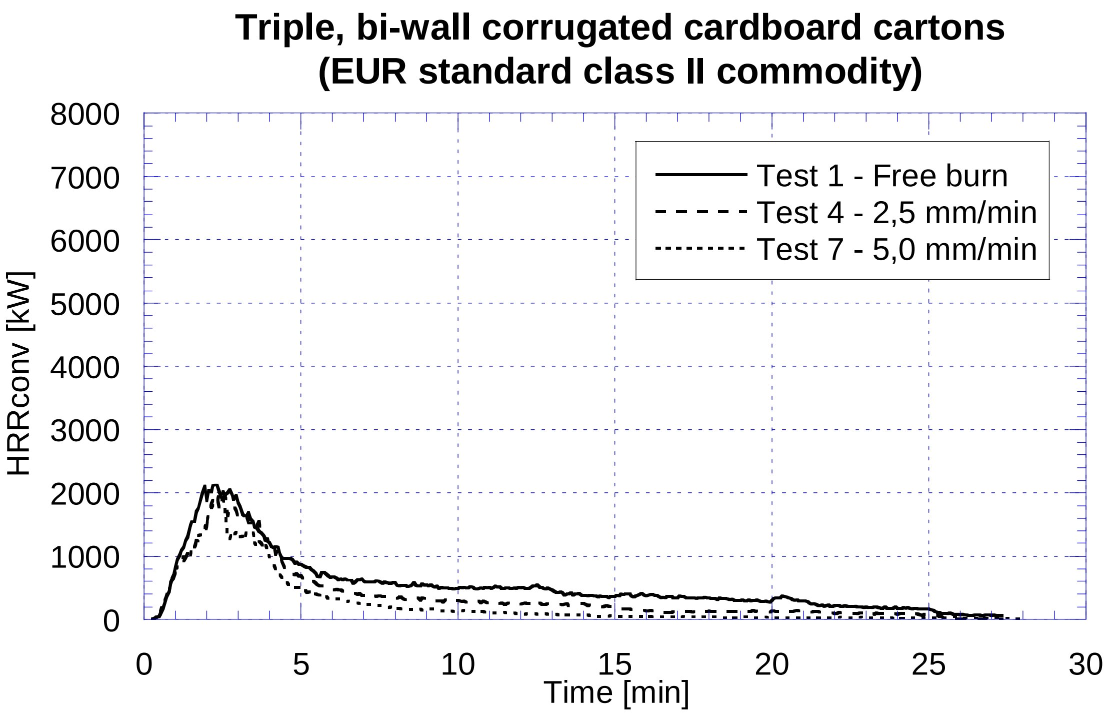
4.1 Triple, bi-wall corrugated cardboard cartons (EUR standard class II commodity)

Three tests were conducted, a free burn test and two tests at 2,5 and 5,0 mm/min, respectively. The free burn test indicated that the convective peak heat release rate barely exceeded 2 MW, the predetermined heat release rate for the application of water. At that time, all outer surfaces of the upper two pallet loads were involved in the fire. The application of water in the following two tests reduced the heat release rate of the fire such that it burned out under controlled conditions.

It can be concluded that the effect of the application of water was not very significant. This is due to the limited amount of combustibles. The upper pallet loads were almost consumed at the start of the water application and the amount of water that was able to reach down to the lower level pallets were probably quite low, irrespective of the water application rate.

Table 4 Test results for the triple, bi-wall cartons (EUR standard class II commodity).

Test no.	1	4	7
Date of test	2001-09-28	2001-10-03	2001-10-04
Nominal delivered density [mm/min]	Free burn	2,5	5,0
Start of water application [min:s]	(01:57)	02:34	02:33
Max. one minute average total HRR [kW]	2885	2673	2508
Max. one minute average convective HRR [kW]	2016	1819	1643
Average effective convective HRR over the five minutes interval of most severe fire [kW]	1350	1169	1028
Convective energy during 10 minutes [MJ]	572	458	369
Amount of consumed goods [%]	100	100	95



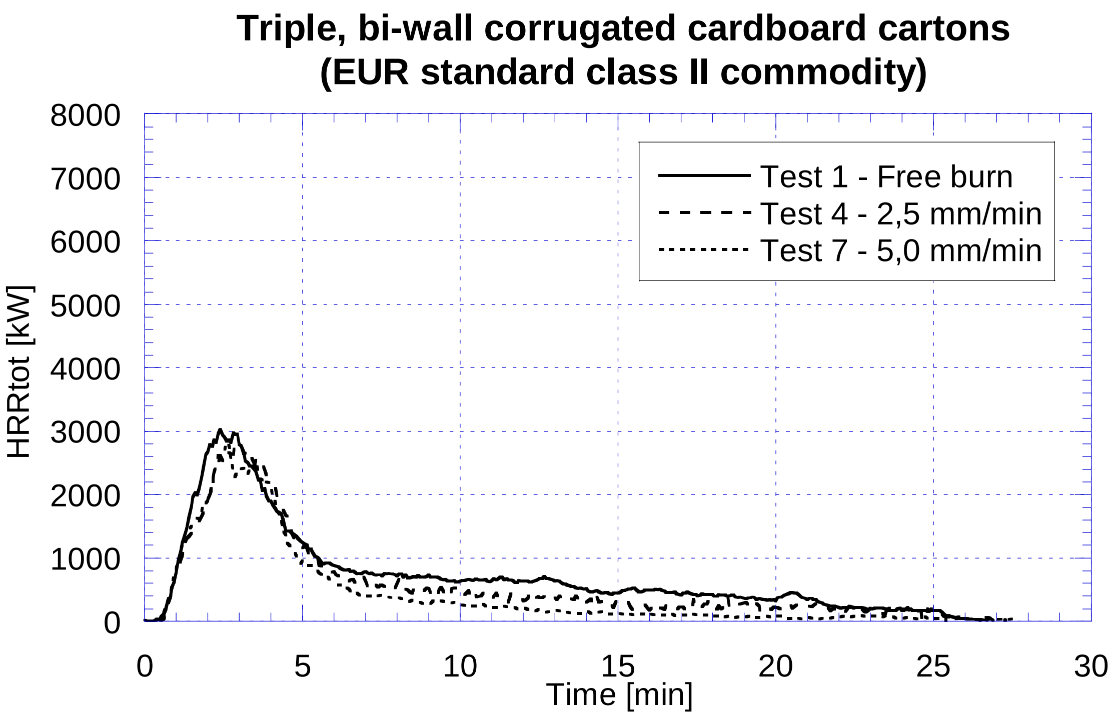


Figure 4 *Total and convective heat release rate histories for the triple, bi-wall cartons (EUR standard class II commodity).*

4.2 Corrugated cartons with interiors

Three tests were conducted, one free burn test and two tests at 2,5 and 5,0 mm/min, respectively.

The application of 2,5 mm/min of water resulted in some degree of reduction of the heat release rate, however, all of the material was consumed.

Unfortunately, test 8 failed as water spray nozzles over the left hand side of the rack did not operate as intended. The reason for this was determined afterwards to be an electrical failure of the solenoid valves. The results for this test are therefore higher than they should have been for a correct test.

Table 5 Test results for the corrugated cartons with interiors.

Test no.	2	5	8
Date of test	2001-09-28	2001-10-03	2001-10-05
Nominal delivered density [mm/min]	Free burn	2,5	5,0
Start of water application [min:s]	(01:25)	01:47	01:42*
Max. one minute average total HRR [kW]	3515	3116	3280
Max. one minute average convective HRR [kW]	2374	2021	2177
Average effective convective HRR over the five minutes interval of most severe fire [kW]	2006	1668	1639
Convective energy during 10 minutes [MJ]	850	740	669
Amount of consumed goods [%]	100	100	99

*) The water spray nozzles over the left hand side of the rack never operated because of an electrical failure of the solenoid valves.

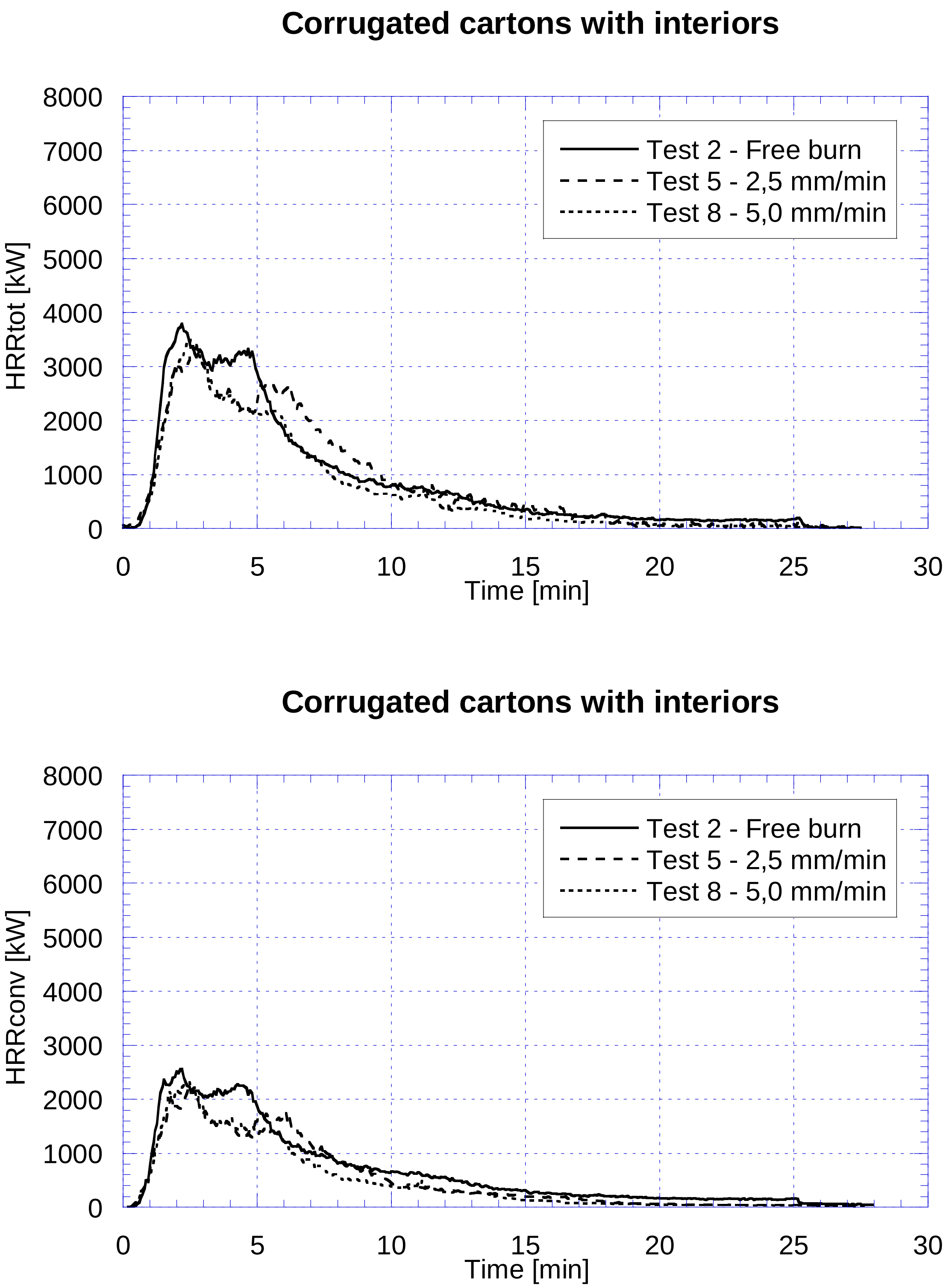


Figure 5 Total and convective heat release rate histories for the corrugated cartons with interiors.

4.3 Corrugated cartons with 15% (by weight) unexpanded plastic

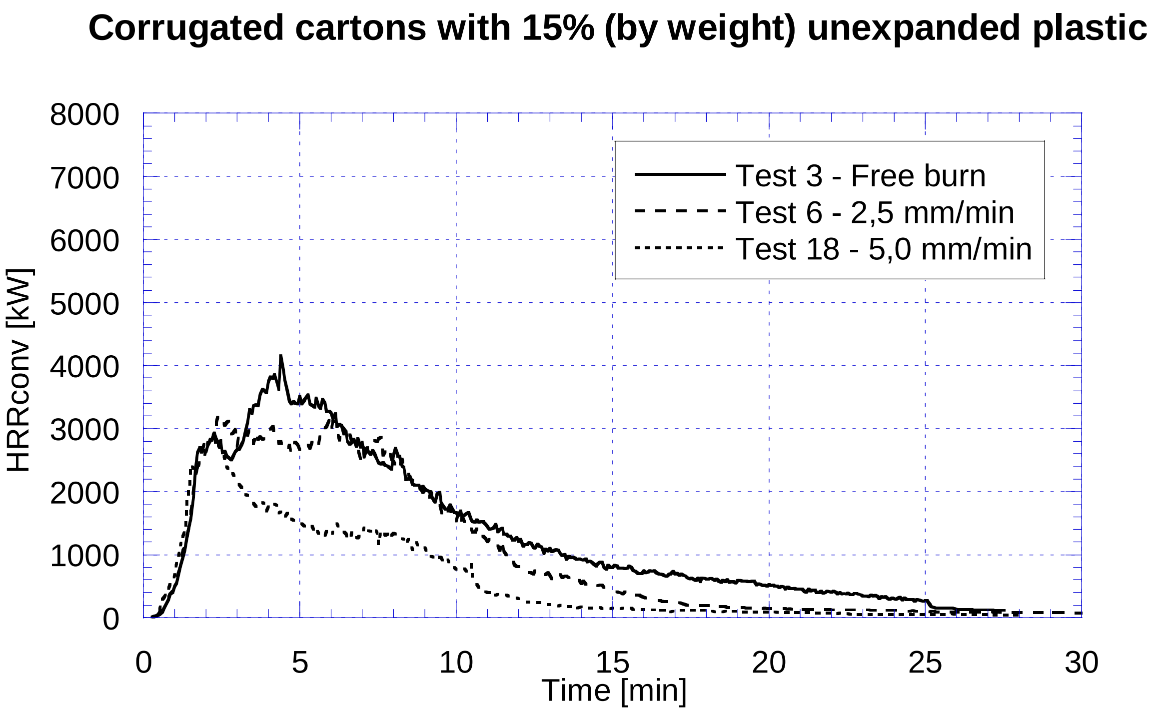
Three tests were conducted, one free burn test and two tests at 2,5 and 5,0 mm/min, respectively.

The water application of 5,0 mm/min (test 18) had an initial effect on the heat release rate and the fire burned out under controlled conditions. The water application of 2,5 mm/min reduced the peak heat release rate of the fire as compared to free burn conditions.

For all tests, all or almost all of the combustible material was consumed.

Table 6 Test results for the corrugated cartons with 15% (by weight) unexpanded plastic.

Test no.	3	6	18
Date of test	2001-10-01	2001-10-04	2001-10-19
Nominal delivered density [mm/min]	Free burn	2,5	5,0
Start of water application [min:s]	(01:45)	01:38	01:31
Max. one minute average total HRR [kW]	5858	4815	4593
Max. one minute average convective HRR [kW]	3719	3011	2646
Average effective convective HRR over the five minutes interval of most severe fire [kW]	3183	2873	1904
Convective energy during 10 minutes [MJ]	1561	1458	893
Amount of consumed goods [%]	100	100	99



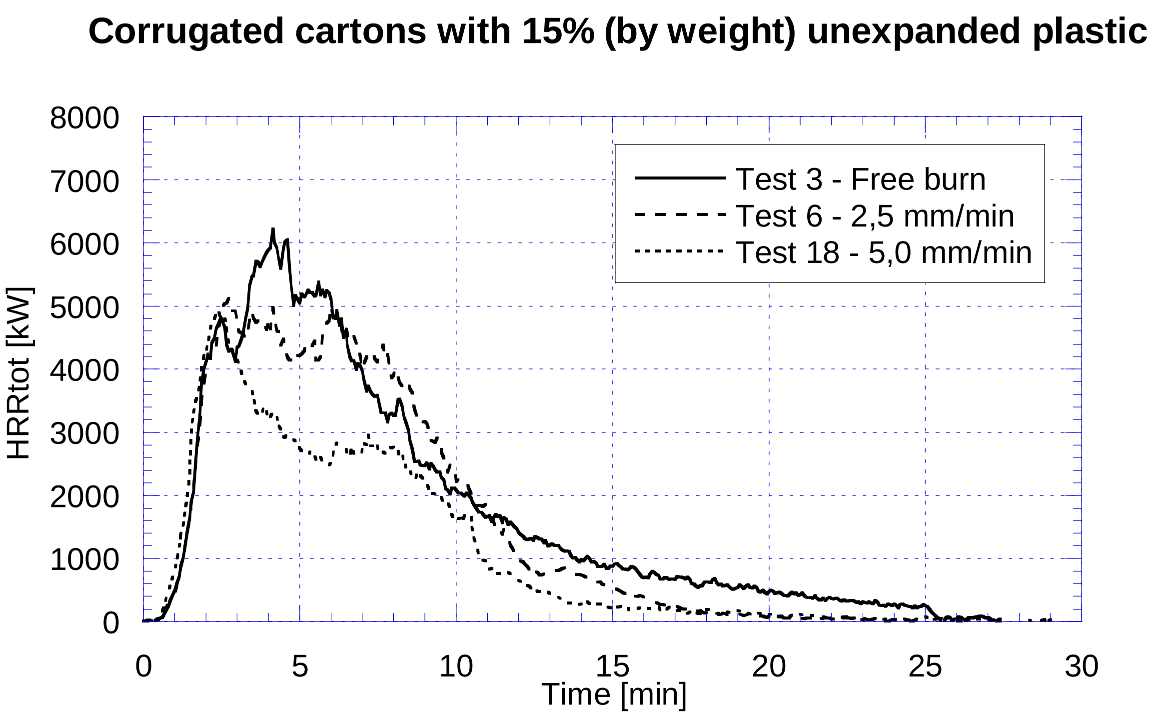


Figure 6 Total and convective heat release rate histories for the corrugated cartons with 15% (by weight) unexpanded plastic.

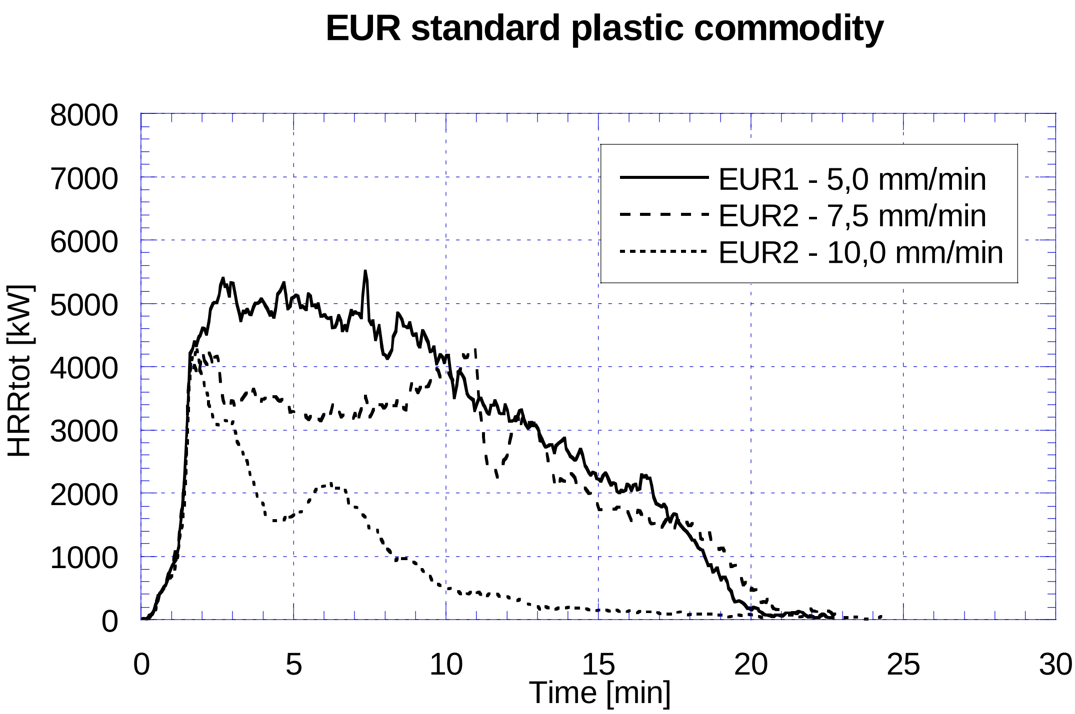
4.4 The EUR standard plastic commodity

The tests with the EUR standard plastic commodity were conducted in a previous test programme, see SP Report 1999:30 [4]. Three tests were conducted at 5,0, 7,5 and 10,0 mm/min, respectively.

The two tests at the lower water application rates resulted in fire control and continued to burn until all, or most of the commodity, was consumed. The 10,0 mm/min water application rate resulted in an initial suppression and gradual reduction of the heat release rate. More material was left after the test at this application rate.

Table 7 Test results for the EUR standard plastic commodity.

Test no.	EUR1	EUR2	EUR3
Date of test	1999-02-05	1999-02-05	1999-02-08
Nominal delivered density [mm/min]	5,0	7,5	10,0
Start of water application [min:s]	01:42	01:40	01:41
Max. one minute average total HRR [kW]	5136	4065	3681
Max. one minute average convective HRR [kW]	2986	2280	2084
Average effective convective HRR over the five minutes interval of most severe fire [kW]	2812	1737	1219
Convective energy during 10 minutes [MJ]	1598	1020	510
Amount of consumed goods [%]	100	90	72



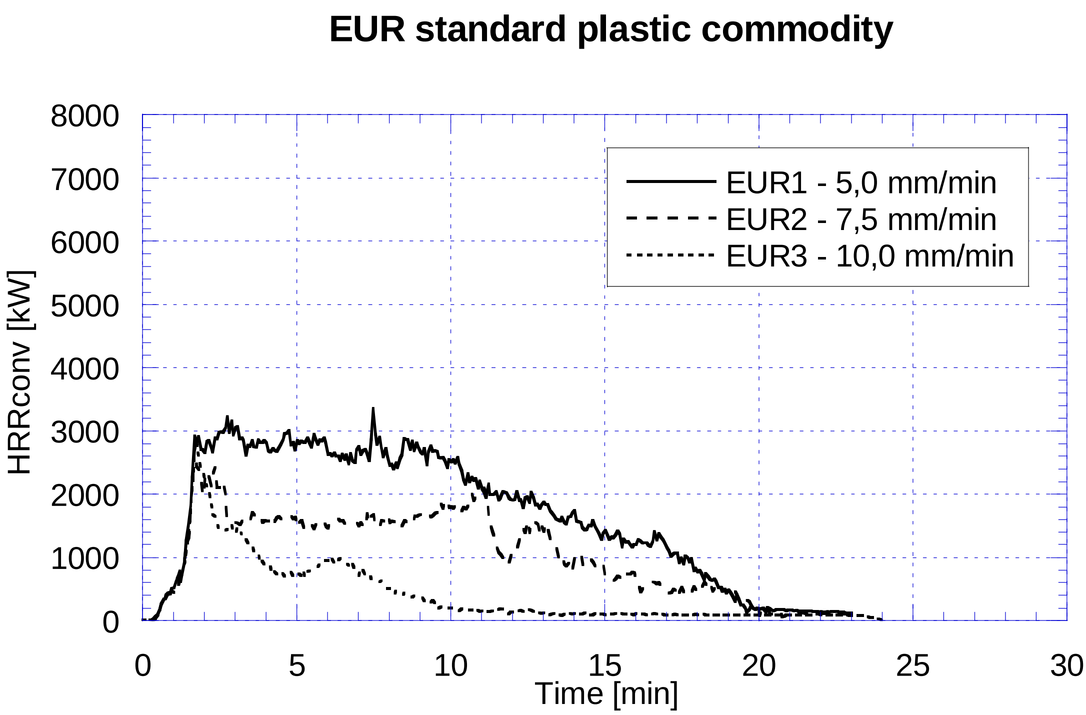


Figure 7 *Total and convective heat release rate histories for the EUR standard plastic commodity.*

4.5 Plastic (HDPE) containers

Three tests were conducted, with water application rates of 5,0, 7,5 and 10,0 mm/min, respectively.

These fires developed very slowly after ignition. However, melted plastic dripped to the floor and the fire developed very rapidly when a pool fire had formed under the lower level pallets. This occurred after approximately seven minutes from ignition.

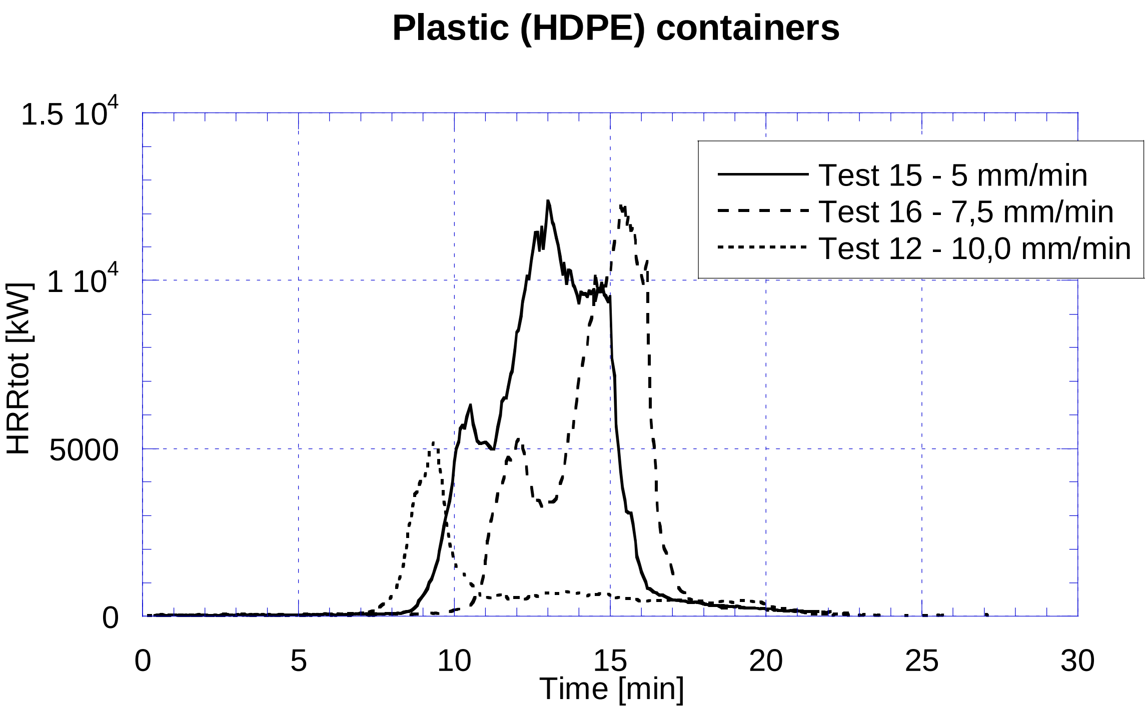
At the first test (10,0 mm/min), the initiation of the water suppressed the fire in the upper pallets within a minute, which significantly reduced the fire size. The fire continued, mainly on the right hand side lower level pallets.

The water application rate was reduced to 5,0 mm/min in test 15. This water application rate was too low to have any noticeable effect and the plastic containers melted down and formed pool fire, both at the floor and at each of the pallets. The capacity of the calorimeter was exceed and the test was manually terminated 15 minutes after ignition. The area of the melted plastic on the floor was afterwards determined to be approximately 6 m by 4 m.

For the third test, the water application rate was increased to 7,5 mm/min. Compared to test 15, this water application rate had a better, initial effect on the fire as the fire of the upper two pallets were suppressed. Eventually, the fire in the pallets below involved the upper level, the containers melted down, and the heat release rate became significant. This test was also manually terminated, 16 minutes from ignition, but at that time almost all the plastic material was consumed. The area of the melted plastic on the floor was determined afterwards to be approximately 6 m by 4 m for this test.

Table 8 Test results for the plastic (HDPE) containers.

Test no.	12	15	16
Date of test	2001-10-10	2001-10-11	2001-10-12
Nominal delivered density [mm/min]	10,0	5,0	7,5
Start of water application [min:s]	08:38	09:50	11:22
Max. one minute average total HRR [kW]	4338	11376	11354
Max. one minute average convective HRR [kW]	1813	6877	6496
Average effective convective HRR over the five minutes interval of most severe fire [kW]	731	5188	3535
Convective energy during 10 minutes [MJ]	303	1943	1075
Amount of consumed goods [%]	68	100	100



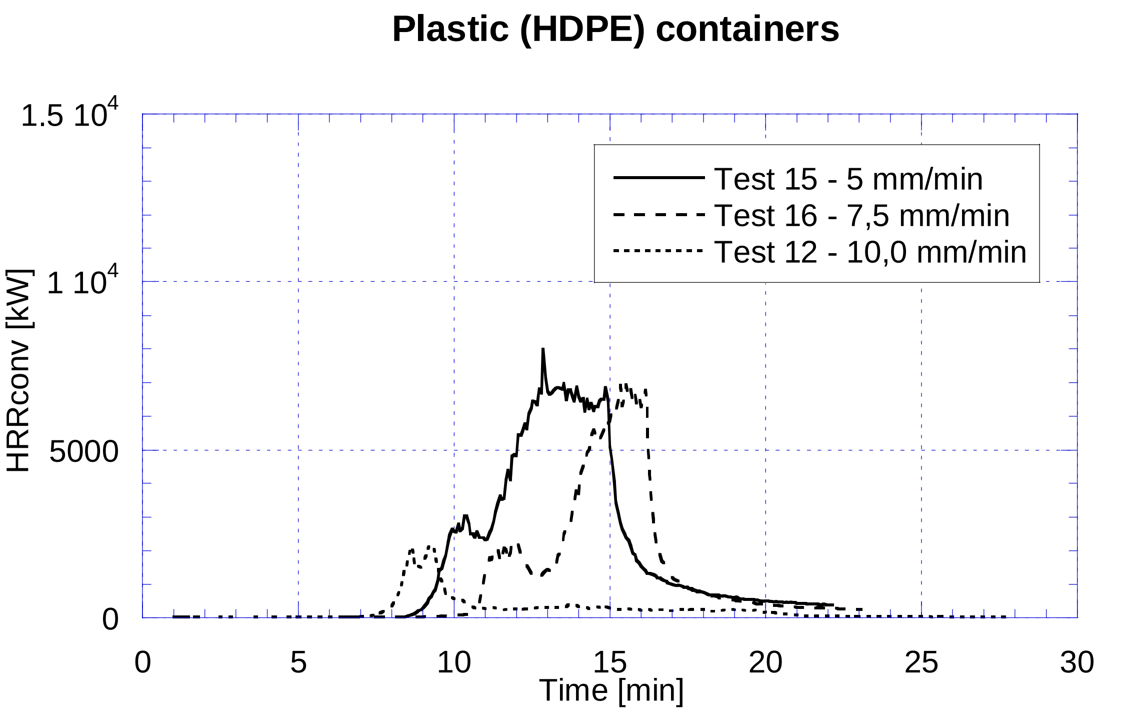


Figure 8 *Total and convective heat release rate histories for the plastic (HDPE) containers. Note the different scale of the y-axis for this test.*

4.6 Corrugated cartons with 25% (by volume) expanded plastic

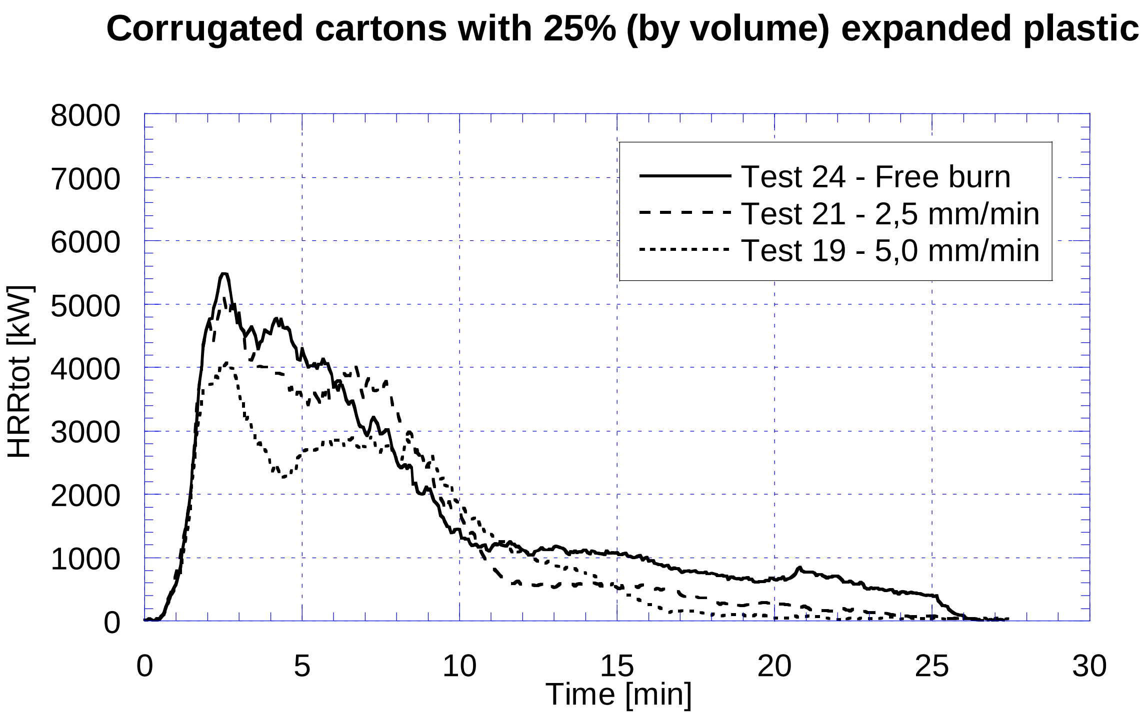
Three tests were conducted, one free burn test and two tests at 2,5 and 5,0 mm/min, respectively.

The water application rate was set to 5,0 mm/min in test 19. This water application rate had an initial, but a slightly delayed effect on the fire, after which it was controlled as the combustibles were consumed.

The reduction of the water application rate to 2,5 mm/min had less influence on the fire, but still some degree of control was observed.

Table 9 Test results for the corrugated cartons with 25% (by volume) expanded plastic.

Test no.	19	21	24
Date of test	2001-10-19	2001-10-25	2001-10-26
Nominal delivered density [mm/min]	5,0	2,5	Free burn
Start of water application [min:s]	01:35	01:34	(01:35)
Max. one minute average total HRR [kW]	3901	4809	5108
Max. one minute average convective HRR [kW]	2304	2933	3429
Average effective convective HRR over the five minutes interval of most severe fire [kW]	1638	2427	3079
Convective energy during 10 minutes [MJ]	824	1187	1446
Amount of consumed goods [%]	100	100	100



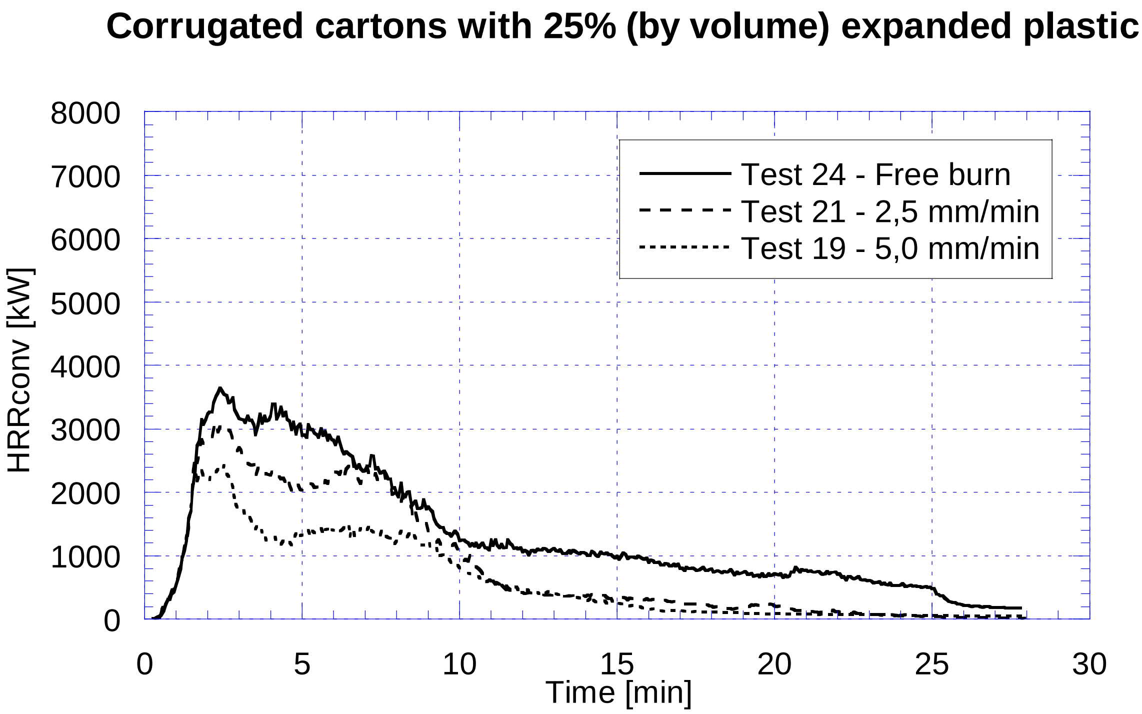


Figure 9 *Total and convective heat release rate histories for the corrugated cartons with 25% (by volume) expanded plastic.*

4.7 Corrugated cartons with 40% (by volume) expanded plastic

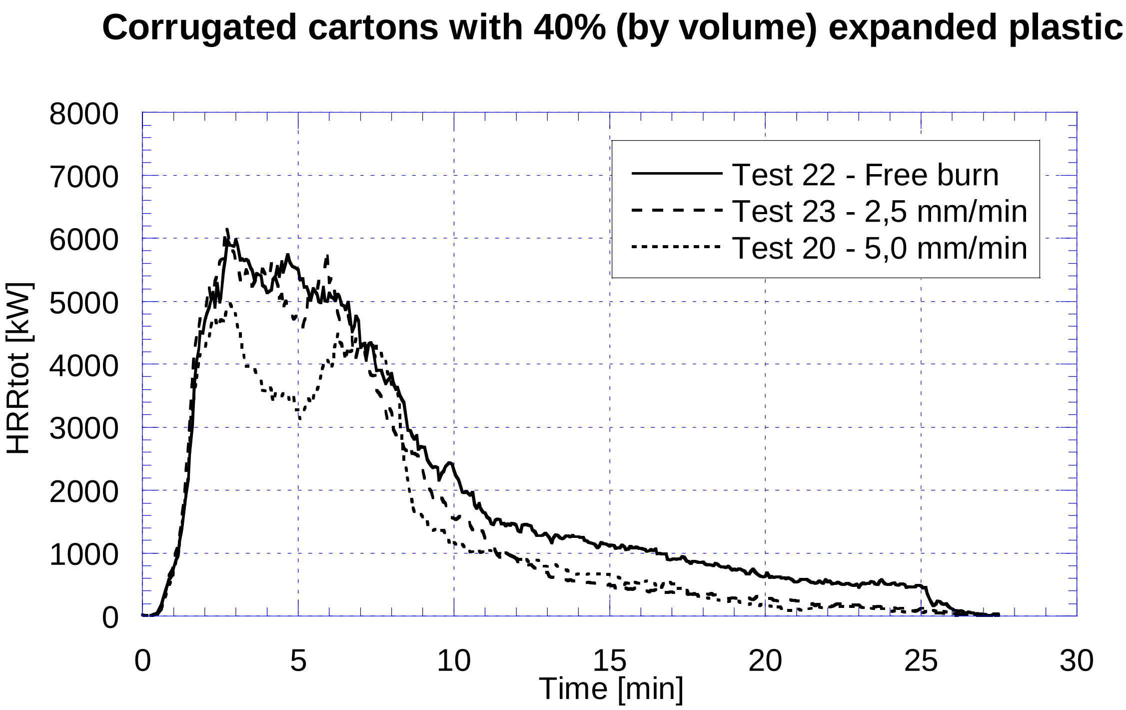
Three tests were conducted, one free burn test and two tests at 2,5 and 5,0 mm/min, respectively.

The water application rate was set to 5,0 mm/min in test 20. This water application had a certain, but not significant, effect on the heat release rate. The fire size was reduced dramatically after approximately eight minutes from ignition as the pallets loads on the upper level was consumed. The fire remained in the pallet loads at the lower level and then gradually decreased.

In test 23, the water application rate was set to 2,5 mm/min. This application rate had a limited effect on the heat release rate when comparing with the free burn test in test 22.

Table 10 Test results for the corrugated cartons with 40% (by volume) expanded plastic.

Test no.	20	22	23
Date of test	2001-10-24	2001-10-25	2001-10-25
Nominal delivered density [mm/min]	5,0	Free burn	2,5
Start of water application [min:s]	01:30	(01:33)	01:26
Max. one minute average total HRR [kW]	4736	5729	5673
Max. one minute average convective HRR [kW]	2682	3552	3398
Average effective convective HRR over the five minutes interval of most severe fire [kW]	2160	3370	3131
Convective energy during 10 minutes [MJ]	1070	1632	1438
Amount of consumed goods [%]	99	100	99



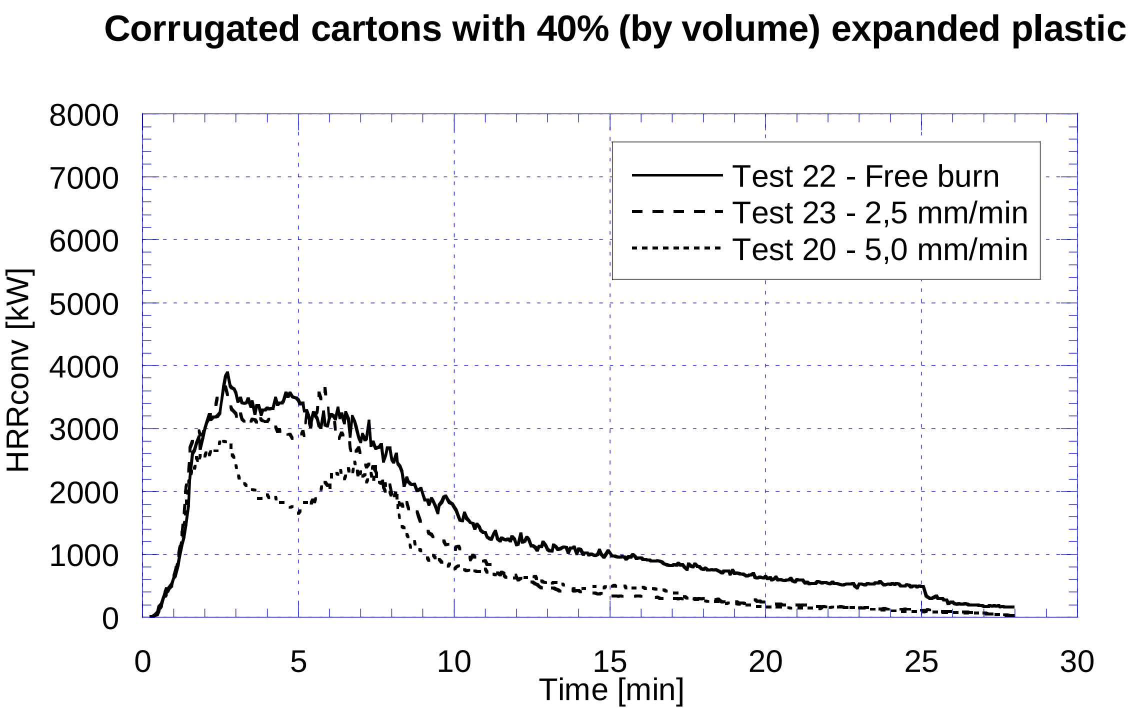


Figure 10 Total and convective heat release rate histories for the corrugated cartons with 40% (by volume) expanded plastic.

4.8 Solid polystyrene blocks in corrugated cartons

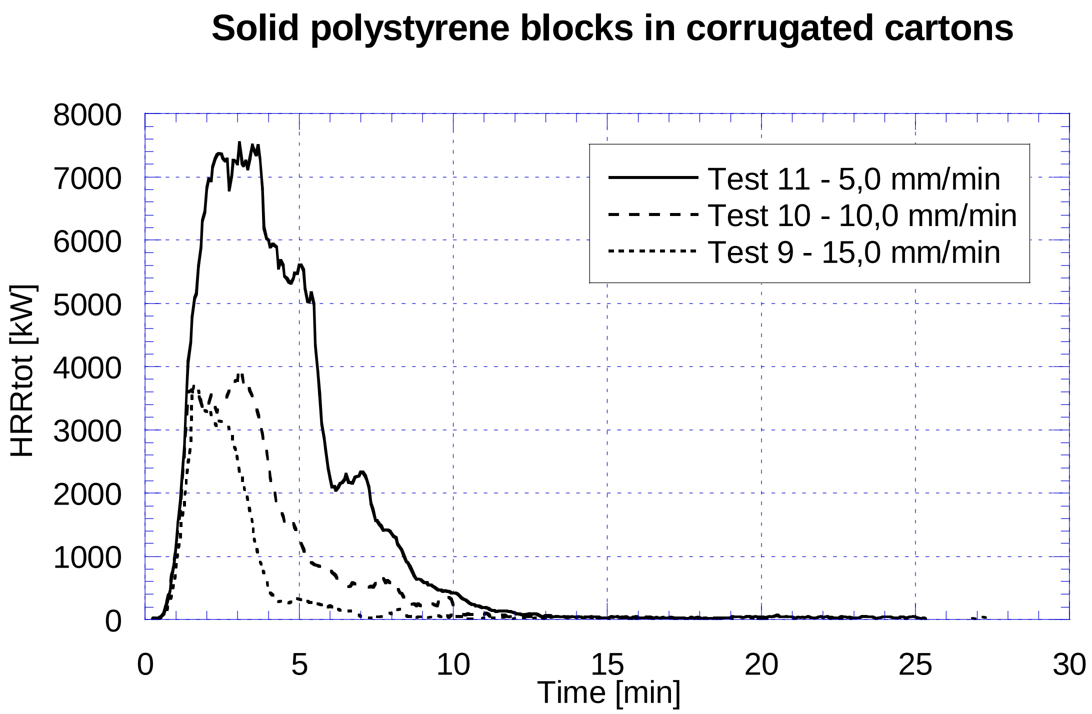
Three tests were conducted, at 15,0, 10,0 and 5,0 mm/min, respectively.

It can be concluded that the peak heat release rate was not particularly influenced when the water application rate was reduced from 15,0 mm/min to 10,0 mm/min.

At 5,0 mm/min the fire was intense and the entire commodity, except for the wooden pallets, was consumed. The HRR graphs indicate a rapid drop at about five minutes, which correlates to the time when the commodity at the top level of the rack was consumed.

Table 11 Test results for the solid polystyrene blocks in corrugated cartons.

Test no.	9	10	11
Date of test	2001-10-08	2001-10-08	2001-10-09
Nominal delivered density [mm/min]	15,0	10,0	5,0
Start of water application [min:s]	01:26	01:16	01:15
Max. one minute average total HRR [kW]	3340	3680	7294
Max. one minute average convective HRR [kW]	1603	1640	4277
Average effective convective HRR over the five minutes interval of most severe fire [kW]	722	1077	3354
Convective energy during 10 minutes [MJ]	232	379	1279
Amount of consumed goods [%]	75	90	100



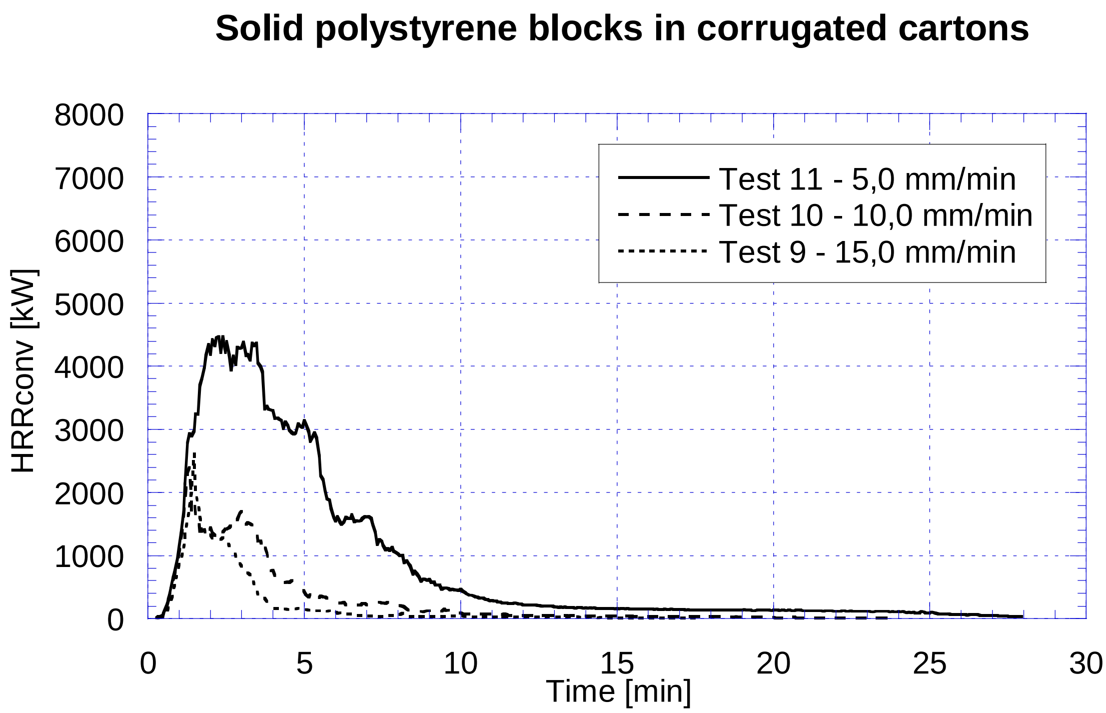


Figure 11 *Total and convective heat release rate histories for the solid polystyrene blocks in corrugated cartons.*

4.9 Wooden pallets

Three tests were conducted, using water application rates of 5,0, 7,5 and 10,0 mm/min, respectively.

For these test another, larger ignition source was used, consisting of a 300 mm by 300 mm steel tray with 100 mm rim height. The tray was filled with 0,5 L of heptane on a 1 L water base. This fire burnt for almost four minutes and had self-extinguished prior to the application of the water. For test 14 and 17, the amount of heptane was increased to 1 L, which increased the burn time to approximately five minutes.

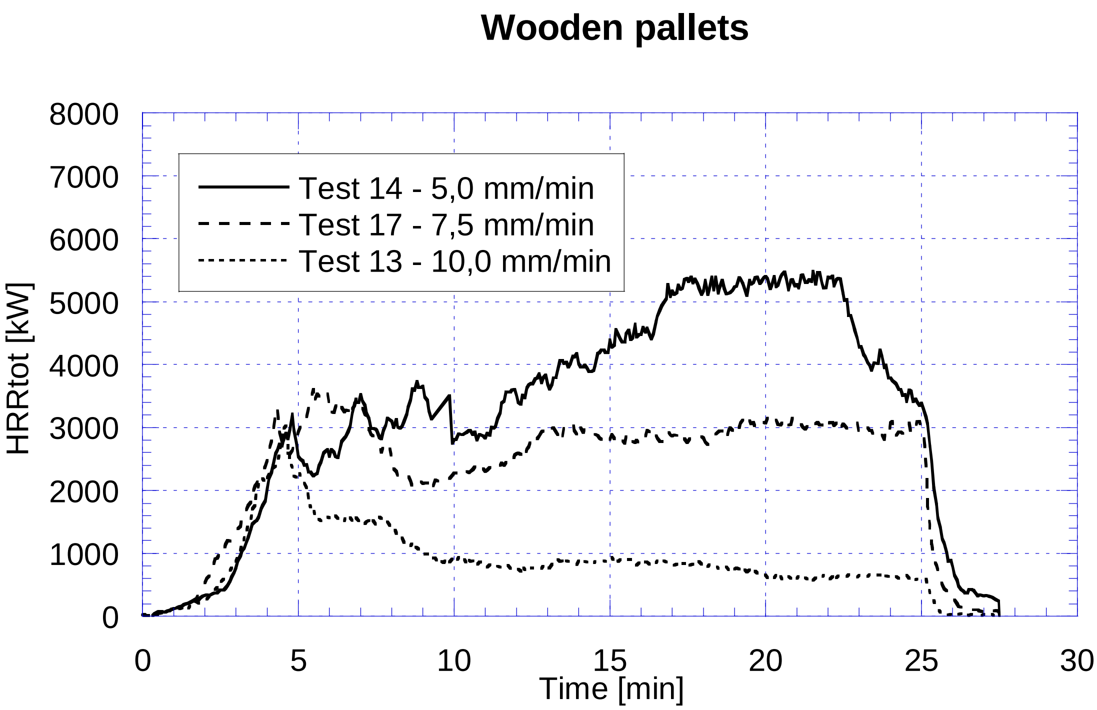
As expected the fire developed relatively slowly in these tests, despite the larger ignition source. For the first test at 10,0 mm/min the fire initially spread towards the left hand side of the piles of pallets. When water was applied, this resulted in a fast suppression of the right hand side and a continued burn at the left hand side. After approximately eight minutes from ignition the fire of the upper, left hand side was suppressed after which the fire gradually decreased. A small fire was manually extinguished after 25 minutes.

The water application rate was reduced to 5,0 mm/min for test 14. This water application rate had an initial effect on the fire, however, the fire redeveloped and the heat release rate increased gradually for a period of about 12 – 13 minutes, after which it stabilised at a constant, high level. At the peak, all pallets, except for the upper two or three were completely involved in the fire. The fire size reduced as the material was consumed and, eventually (after 22 minutes from ignition), all four piles collapsed and all pallets fell down to the floor.

For test 17 the water application rate was increased to 7,5 mm/min. This water application rate made the fire burn at a more or less constant, controlled level throughout the test. Visually, it was concluded that the upper 3 – 5 pallets not were particularly involved at any stage of the fire. After the test, approximately 60% of the upper two piles were left, however, the fire consumed the majority of the lower level piles.

Table 12 Test results for the wooden pallets.

Test no.	13	14	17
Date of test	2001-10-10	2001-10-11	2001-10-15
Nominal delivered density [mm/min]	10,0	5,0	7,5
Start of water application [min:s]	04:30	04:44	04:14
Max. one minute average total HRR [kW]	2494	5353	3442
Max. one minute average convective HRR [kW]	1562	3255	1595
Average effective convective HRR over the five minutes interval of most severe fire [kW]	910	3226	1406
Convective energy during 10 minutes [MJ]	399	1778	809
Amount of consumed goods [%]	15	85	65



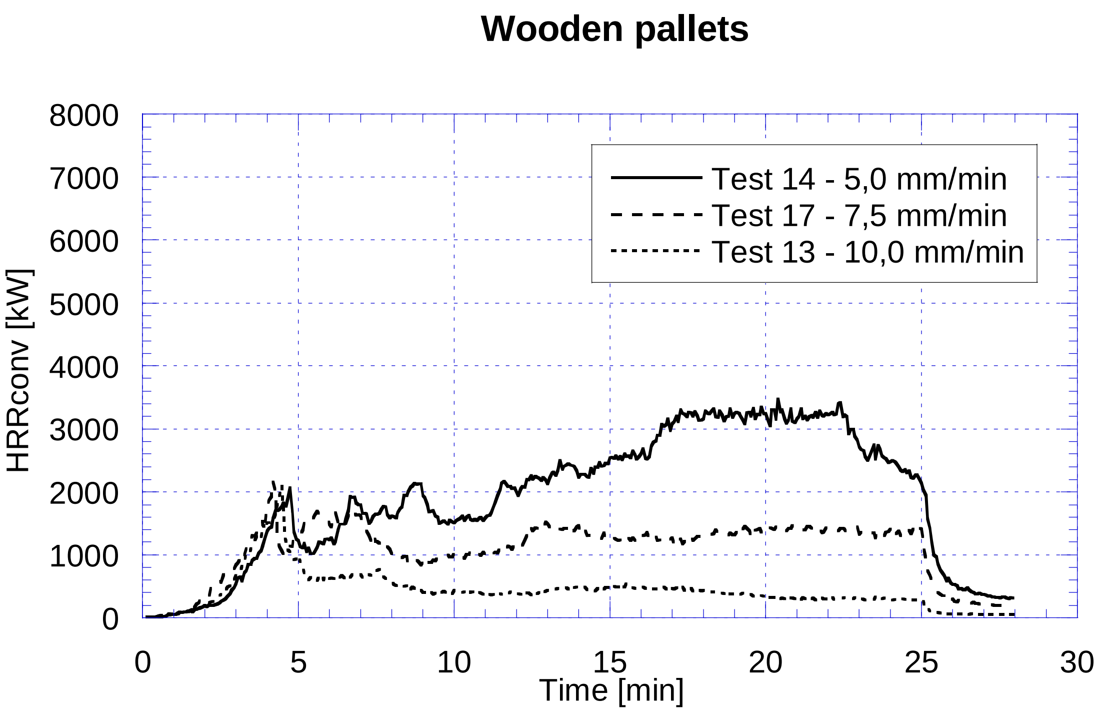


Figure 12 Total and convective heat release rate histories for the wooden pallets.

5 Discussion and conclusions

5.1 Characterisation of the fire behaviour

Based on the heat release rate measurements, the following quantities were determined for each of the tests. For a more detailed description of each of the quantities, see Chicarello and Troup [1].

V1 - Maximum one minute average convective heat release rate. About two-thirds of the energy generated by a fire is released through convection. The convection produces the velocities and the temperatures in the fire plume and since the proportion of penetration of water droplets from a sprinkler, which penetrates the fire plume, depends on the velocities and the temperatures, the penetration depends on the convective heat release rate.

V2 - Maximum one minute average total heat release rate. The total heat release rate includes the energy released both by convection and radiation, as well as the heat being conducted away and absorbed within the storage array. The radiation component of the total heat release rate is accounts for approximately one-third of the energy generated by a fire. Radiation is the primary mechanism by which the fire spreads across aisles and other open spaces to adjacent combustibles. The total heat release rate is therefore a measure of the potential for fire spread as well as an overall fundamental measure of fire severity.

V3 - The convective heat release rate averaged over the most severe five minute interval of the fire. The energy convected upwards is largely responsible for the heating of exposed steel at the ceiling and the operation of automatic sprinklers. The maximum value of the convective heat release rate does help to characterize the severity of the fire. However, regarding the heat transfer, the duration time is as important as magnitude.

V4 - The convective energy generated during the most severe ten minute interval of the fire. This value is an important measure of a fires maximum potential for causing thermal damage, the higher the convective energy the greater the damage potential.

These values are tabulated with the results in section 4 and plotted as a function of the delivered water application rate in Appendix B.

The parameters V1, V2, V3, and V4 are good measures of different types of the fire characteristics as described above. However, since the early development of the fire differs significantly for the tested commodities, it can be of interest to also study the initial phase before the water application was initiated. Water was applied when the convective heat release rate had reached 2 MW. The elapsed time to reach this value is tabulated in Appendix C. The shape of the HRR-curve for the initial phase is also interesting to study for the determination of the amount of energy released prior to the application of water for a certain configuration. The early fire growth is also necessary to know when using computerized simulation tools to model fire development.

A commonly used representation for the early fire growth is the αt^2-curve (*t* is time). However, previous work by Ingason [6] shows that there are other curve fits that better represent rack storage fires. This suggestion is supported by the work presented here. The similar αt^3-curve is already a better representation. For several of the commodities it is proven to be significantly better then the αt^2-curve and almost as good as more complex curve fits. However, it gives a poor representation of the HRR-curve for commodities with a slow initial fire development, e.g. the plastic (HDPE) containers. In this case a more general curve fit needs to be used. The curve fit suggested by Ingason, $\dot{Q}(t) = \alpha e^{\beta t}(a + bt)$, provides a good agreement in most cases and can also be derived from flame spread formulas and material properties [7].

It can be argued that αt^3 is preferred due to the low number of unknown parameters, one parameter in comparison to four parameters. The general applicability and the physical ground, however, defend the use of $\alpha e^{\beta t}(a + bt)$. In addition, the parameter *a* is related to the width of the ignition zone and can be treated as a constant. In this work the value 0,1 m has been used. The parameter α corresponds to the level of the curve, including the height of the ignition source, while β is the main parameter for the flame spread and fire growth, including the heat flux from the flame and the thermal response parameter [8]. The parameter *b*, finally, corresponds to the delay before the rapid increase in the HRR starts.

The trend of the parameter β for the best curve fit corresponds well with the different categories of commodities, with two exceptions. The plastic (HDPE) containers have, after the initial slow fire development, a very rapid increase in HRR (high value of β). The increase is as rapid as for the solid polystyrene blocks in cardboard cartons. The other exception is the piled wooden pallets. The initial fire growth for this particular commodity is slow, only somewhat faster than the class I commodity. The piled wood pallets are, however, a special case from many aspects.

Appendix C provides tabulated data on the curve fit parameters.

5.2 Observations and conclusions from the tests

The following observations and conclusions can be drawn from the tests:

- The triple, bi-wall corrugated cardboard cartons (EUR standard Class II commodity) had the lowest hazard level of all tested commodities, which was expected. This commodity is representative of a Category I commodity.

- The corrugated cartons with interiors have a material factor that is identical to the triple, bi-wall corrugated cardboard cartons, but should according to Annex B of prEN 12845, however, be treated as a Category II commodity due to its configuration. The hazard level was proven to be in excess of the triple, bi-wall corrugated cardboard cartons. Because the commodity involved no plastic, it can be assumed that the tested commodity represents the low end of the hazard group.

- The two commodities chosen to be on the boundary between Category II and III, the corrugated cartons with 15% (by weight) unexpanded plastic and 25% (by volume) expanded plastic, had similar, although not identical, fire characteristics.

  It is also worthwhile noticing the significant difference between these two commodities and the corrugated cartons with interiors. The reasonable small amount of either expanded or unexpanded plastic has a significant influence on the fire characteristics.

- The commodity chosen to be on the boundary between Category III and IV, the corrugated cartons with 40% (by volume) expanded plastic had fire characteristics in excess of the two commodities described above, which is expected. However, the relative difference between these three commodities is not very significant.

- The EUR standard plastic commodity should be classified as a Category III commodity according to prEN 12845. However, the tests indicate that the fire characteristics are in excess of the corrugated cartons with 40% (by volume) expanded plastic and in fact similar to the solid polystyrene blocks in corrugated cartons. It can therefore be argued that the EUR standard plastic commodity should be classified as a Category IV commodity and not Category III commodity.

- The solid polystyrene blocks in corrugated cardboard cartons are by definition in prEN 12845 a Category IV commodity. The values for V1, V2, and V3 are all in excess or similar to the values for the EUR standard plastic commodity and the piles of wooden pallets. The value for V4 were, however, lower probably due to the lesser weight of the particular commodity.

- Piles of wooden pallets are a type of commodity with well-known severe fire characteristics and should be protected with special protection requirements according to prEN 12845. The severe fire characteristics were demonstrated in the tests.

- The plastic (HDPE) containers had the worst fire characteristics of all the tested commodities. This is related to the fact that the plastic melted and formed a large pool fire on the floor and on the actual load pallets. The commodity should be protected with special protection requirements according to prEN 12845.

5.3 Comments regarding the commodity classification scheme in prEN 12845

The commodities used in the project were chosen either such that they fell right within a category or such that the material factor was at the boundary between two different classes. The results from the tests therefore provide good feedback on the commodity classification scheme in prEN 12845. The following observations and conclusions can be made:

- The influence of the storage configuration, going from a “solid block” configuration to an “open structure” was proven by the tests.

- A commodity containing 15% (by weight) unexpanded plastic have got fire characteristics that is similar to a commodity having 25% (by volume) expanded plastic, as anticipated by prEN 12845.

- It may be argued that the influence of unexpanded plastic is underestimated for commodities containing larger amounts of plastic. As previously mentioned, the EUR standard plastic commodity should be classified as a Category III commodity according to prEN 12845. However, the tests indicate that the fire characteristics are in excess of the corrugated cartons with 40% (by volume) expanded plastic and in fact similar to the solid polystyrene blocks in corrugated cartons.

It is therefore suggested that a new material factor limit is introduced in Annex B of prEN 12845 requiring that product having more than 25% (by weight) unexpanded plastic should be given a material factor of 4, see figure 1.

- The tests support the approach that piles of wooden pallets should be protected with special protection requirements.

- Polypropylene or polyethylene storage bins shall be protected in accordance with Annex G, “Protection of Special Hazards” of prEN 12845. The tests of the plastic (HDPE) containers in this project support this approach.

5.4 A methodology for commodity classification using heat release rate calorimetry

This chapter describes a proposed methodology and proposed classification criteria for a commodity classification methodology that relates to the commodity classification scheme of prEN 12845.

The test array should consist of four pallet loads of commodity arranged in a 2 by 1 by 2 rack segment. The size of the load pallet should be 1200 mm by 1000 mm. Each commodity shall be tested using three different water application delivered densities, or alternatively, using two different water application delivered densities and one free burn test. Water shall be applied at a predetermined heat release rate of 2 MW (convective heat release rate).

The water application rates should either be 0, 2,5, 5,0, 7,5 or 10,0 mm/min. The first test should always be conducted at 5,0 mm/min and based on the results, the decision should be made whether the water application rate should be increased or decreased.

Tables 13 through 15 provide proposed classification criteria for Category I, II, III and IV commodities as well as the limit for commodities that have so severe fire characteristics that they require special protection. The data is also plotted in Figures 13 through 16.

Table 13 Classification criteria for free burn tests.

	Category I	Category II	Category III	Category IV
V1 [kW]	0 – 3200	3200 – 5100	5100 – 5700	>5700
V2 [kW]	0 – 2200	2200 – 3400	3400 – 3800	>3800
V3 [kW]	0 – 1700	1700 – 3000	3000 – 3500	>3500
V4 [MJ]	0 – 700	700 – 1400	1400 – 1600	>1600

Table 14 Classification criteria for a water application rate of 5,0 mm/min.

	Category I	Category II	Category III	Category IV	RSP
V1 [kW]	0 – 3000	3000 – 4000	4000 – 4700	4700 – 7200	>7200
V2 [kW]	0 – 2000	2000 – 2600	2600 – 3100	3100 – 4200	>4200
V3 [kW]	0 – 1300	1300 – 1700	1700 – 2100	2100 – 3300	>3300
V4 [MJ]	0 – 500	500 – 800	800 – 1000	1000 – 1800	>1800

RSP = Requires Special Protection

Table 15 Classification criteria for a water application rate of 10,0 mm/min.

	Category IV	RSP
V1 [kW]	<3700	>3700
V2 [kW]	<1800	>1800
V3 [kW]	<1000	>1000
V4 [MJ]	<500	>500

RSP = Requires Special Protection

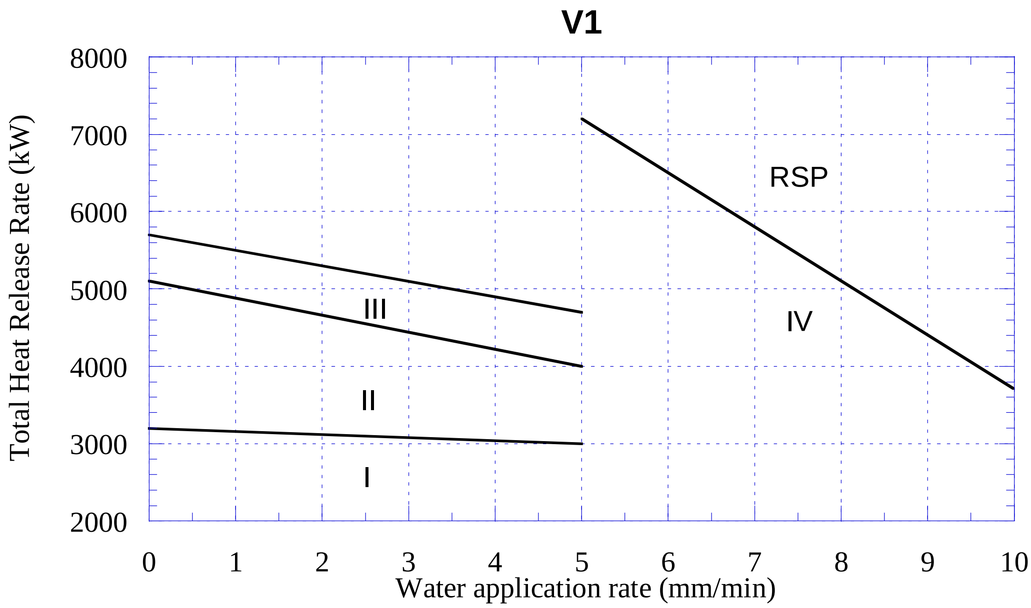


Figure 13 Classification limits for V1, the maximum one minute average convective heat release rate.

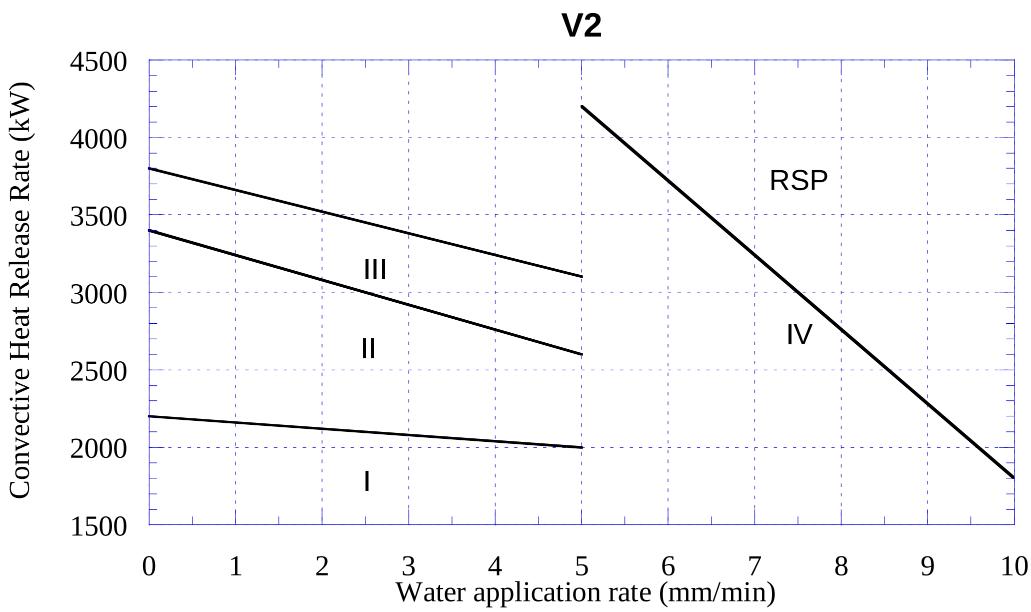


Figure 14 Classification limits for V2, the maximum one minute average total heat release rate.

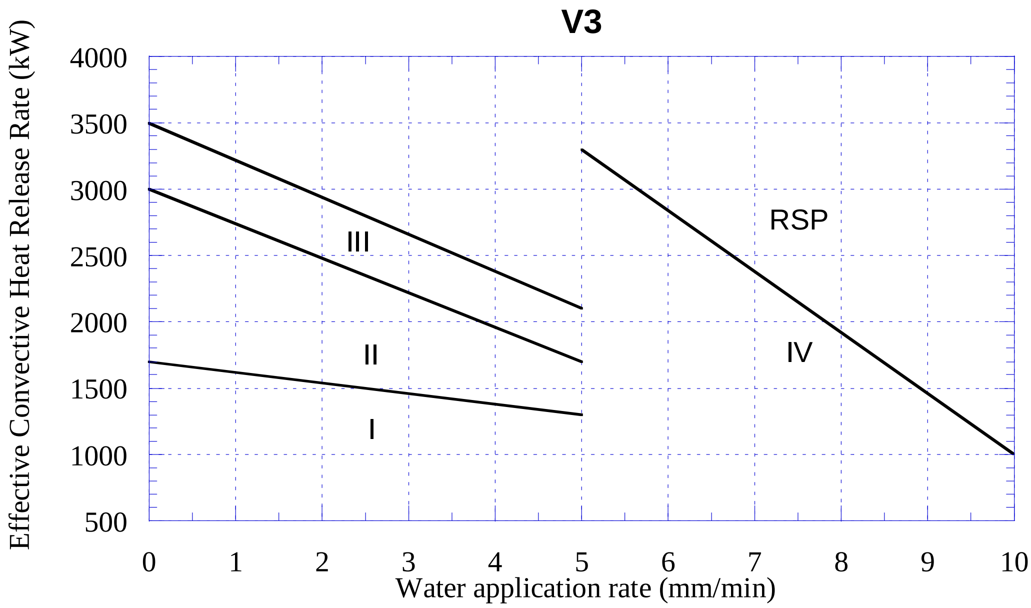


Figure 15 Classification limits for V3, the convective heat release rate averaged over the most severe five minute interval of the fire.

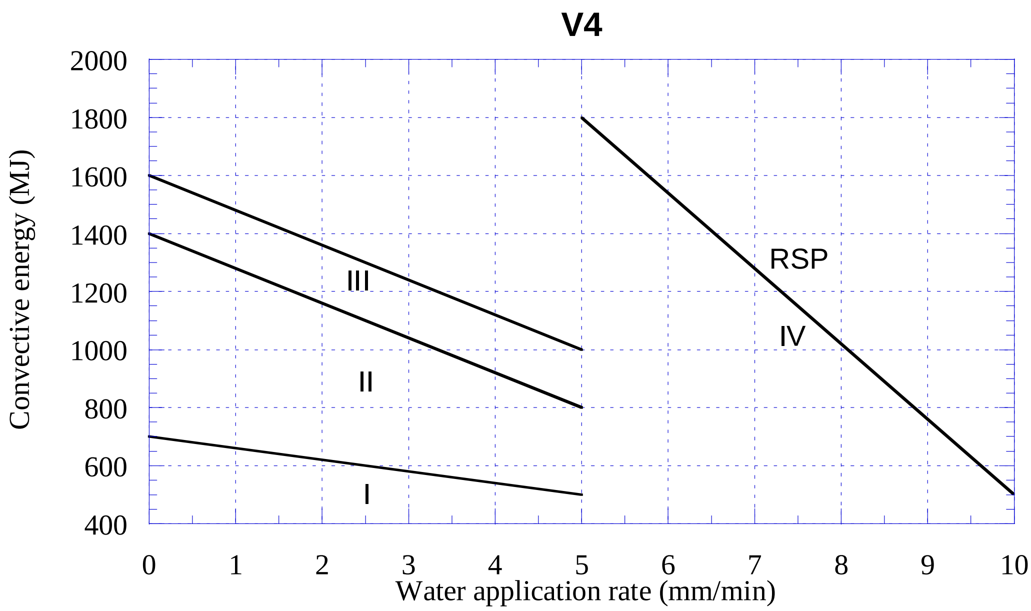


Figure 16 Classification limits for V4, convective energy generated during the most severe ten minute interval of the fire.

5.5 Final conclusions and proposed new projects

The primary objective of the project was to establish test data for a selection of different commodities. These commodities were chosen such that they were related to the commodity classification scheme used in the forthcoming European Standard prEN 12845, “Fixed fire fighting systems, Automatic sprinkler systems, Design, installation and maintenance”.

The test array consisted of four pallet loads of commodity arranged in a 2 by 1 by 2 rack segment. Each commodity was tested using three different water application delivered densities and water was applied at a predetermined heat release rate. It is the intention that this new methodology will replace the current Nordtest method [3] in the near future.

Test results showed significant differences in the fire hazard among the tested commodities, however, it can be concluded that most of the commodities, with a few exceptions, had a hazard level that corresponded to the commodity categories given in prEN 12845. With the data obtained from the tests, any commercial commodity could be tested and classified in accordance with the requirements of prEN 12845.

There are primarily two areas where further research and development seem to be necessary. It may be possible to expand the test methodology to also include measurements of the combustion products, in order to evaluate the environmental impact from a fire in a certain commodity. The experimental set-up represents a storage configuration. Furthermore, the procedure followed during a test includes different phases with different nature of combustion. First an initial phase where the fire develops freely, and thereafter a water application with an associated reduction of the fire size. After this phase the course of events depend on the configuration, material and the water density. The fire may be extinguished or controlled, but the intensity can also increase until it is limited by the amount of fuel. The water application decreases the temperature of the gases and the flames and also wet the fuel. This leads to a combustion very different from the case without water application. Therefore, the production of various emissions probably differs between the different phases. Since the conditions during the phases vary between different commodities, the methodology is suitable for studies of the emissions and environmental impact from different types of commodities.

The other area to be studied is the influence of different types of plastic material on the classification. Only polystyrene and HDPE were tested in the project. The unexpanded and expanded plastics were also only studied separately. No commodities with mixtures of unexpanded and expanded plastics were tested. Therefore, it would be of interest to study how well the properties of mixture commodities at the boundary between Category II and III correlates with the results from this project. One of the conclusions from this work is that the boundary between Category III and IV needs to be changed to be a function of the amount of unexpanded and expanded plastics in the same manner as the boundary between Category II and III. Further work is therefore needed to assess the definition of this boundary.

6 References

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Appendix A – Weights of the tested commodities

Triple, bi-wall corrugated cardboard cartons (EUR standard Class II commodity)

Overall weight (including wooden pallet): **103 kg**
Corrugated cardboard cartons (only): 18,3 kg
Steel liner (only): 58,1 kg
Wooden pallet (only): 27,0 kg

Corrugated cartons with interiors

Overall weight (including wooden pallet): **49,1 kg**
Corrugated cardboard cartons (only): 22,1 kg
Wooden pallet (only): 27,0 kg

Corrugated cartons with 15% (by weight) unexpanded plastic

Overall weight (including wooden pallet): **57,0 kg**
Commodity (excluding wooden pallet): 30,0 kg
Wooden pallet (only): 27,0 kg

Each pallet load contains 300 pcs of plastic cups (28,2 g each) i.e. 8,5 kg, or 15% (by weight) unexpanded plastic.

The EUR standard plastic commodity (42% (by weight) unexpanded plastic

Overall weight (including wooden pallet): **81,1 kg**
Commodity (excluding wooden pallet): 54,1 kg
Wooden pallet (only): 27,0 kg

Each pallet load contains 1200 pcs of plastic cups (28,2 g each) i.e. 33,8 kg, or 42% (by weight) unexpanded plastic.

Plastic (HDPE) containers

Overall weight (including wooden pallet): **75,6 kg**
Commodity (excluding wooden pallet): 48,6 kg
Wooden pallet (only): 27,0 kg

Each pallet load contains 15 pcs of plastic (HDPE) containers (3,0 kg each) with 5 lids (0,73 kg each).

Corrugated cartons with 25% (by volume) expanded plastic

Overall weight (including wooden pallet): **54,3 kg**
Commodity (excluding wooden pallet): 27,3 kg
Wooden pallet (only): 27,0 kg

Each pallet load contains 500 pcs of expanded polystyrene cubes (12,5 g each), i.e. 6,25 kg.

Corrugated cartons with 40% (by volume) expanded plastic

Overall weight (including wooden pallet): **58,8 kg**
Commodity (excluding wooden pallet): 31,8 kg
Wooden pallet (only): 27,0 kg

Each pallet load contains 800 pcs of expanded polystyrene cubes (12,5 g each), i.e. 10,0 kg.

Solid polystyrene blocks in corrugated cartons

Overall weight (including wooden pallet): **56,5 kg**
Commodity (excluding wooden pallet): 29,5 kg
Wooden pallet (only): 27,0 kg

Wooden pallets

Overall weight (including bottom pallet): **216 kg** per pile of pallets
Commodity (excluding bottom pallet): 189 kg
Wooden pallet (only): 27,0 kg

Appendix B – V1, V2, V3 and V4 for the tested commodities

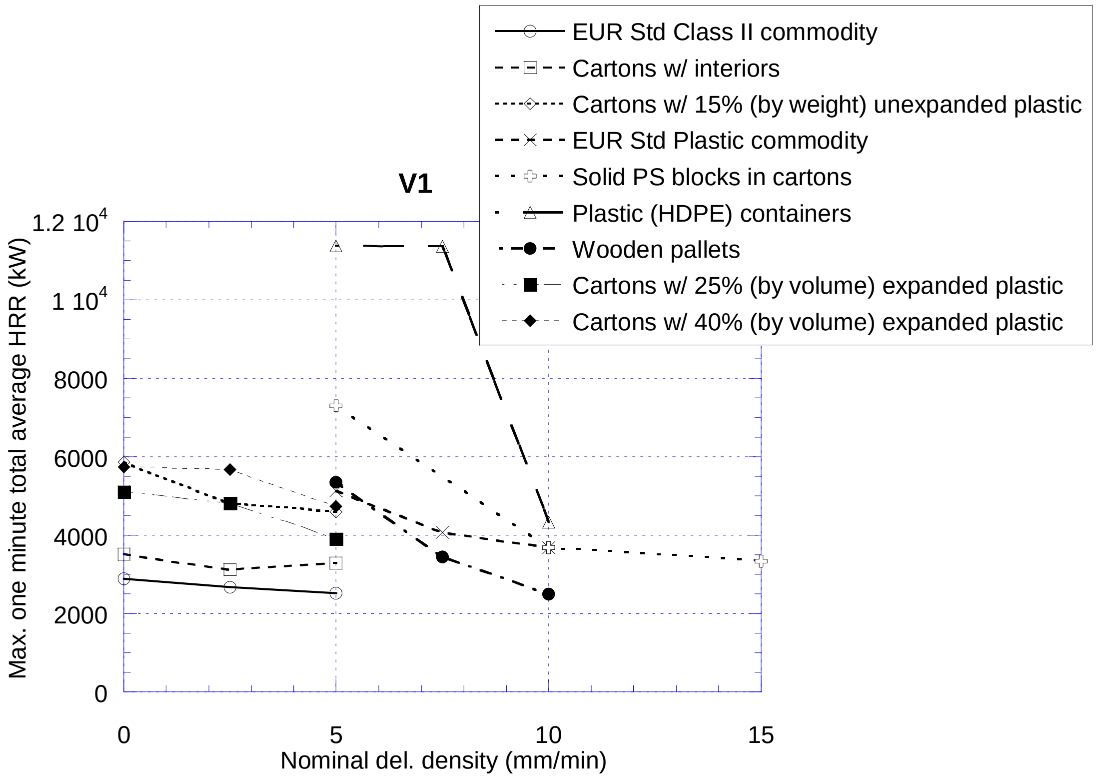

Figure B-1 The maximum one minute average convective heat release rate versus water application rate.

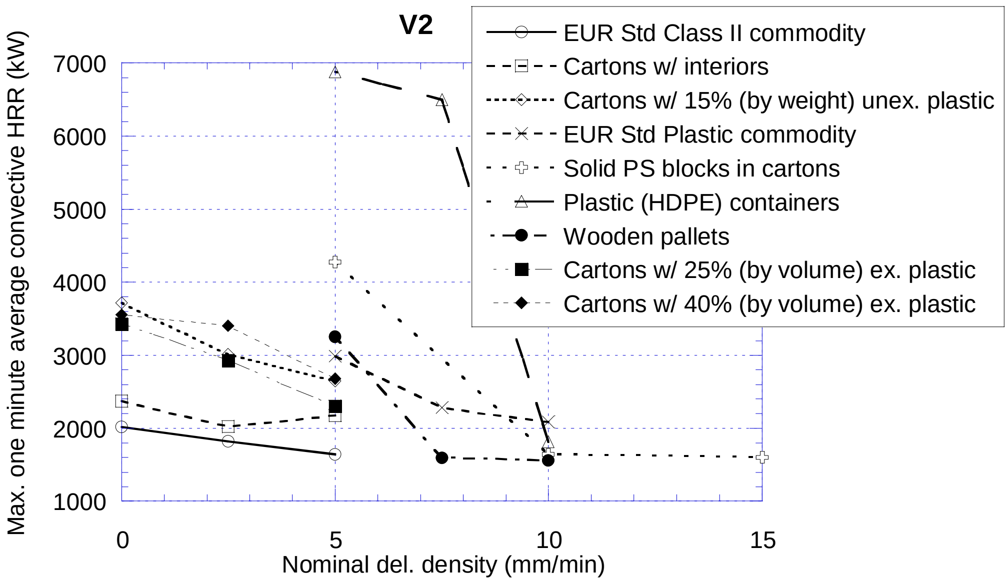

Figure B-2 The maximum one minute average total heat release rate versus water application rate.

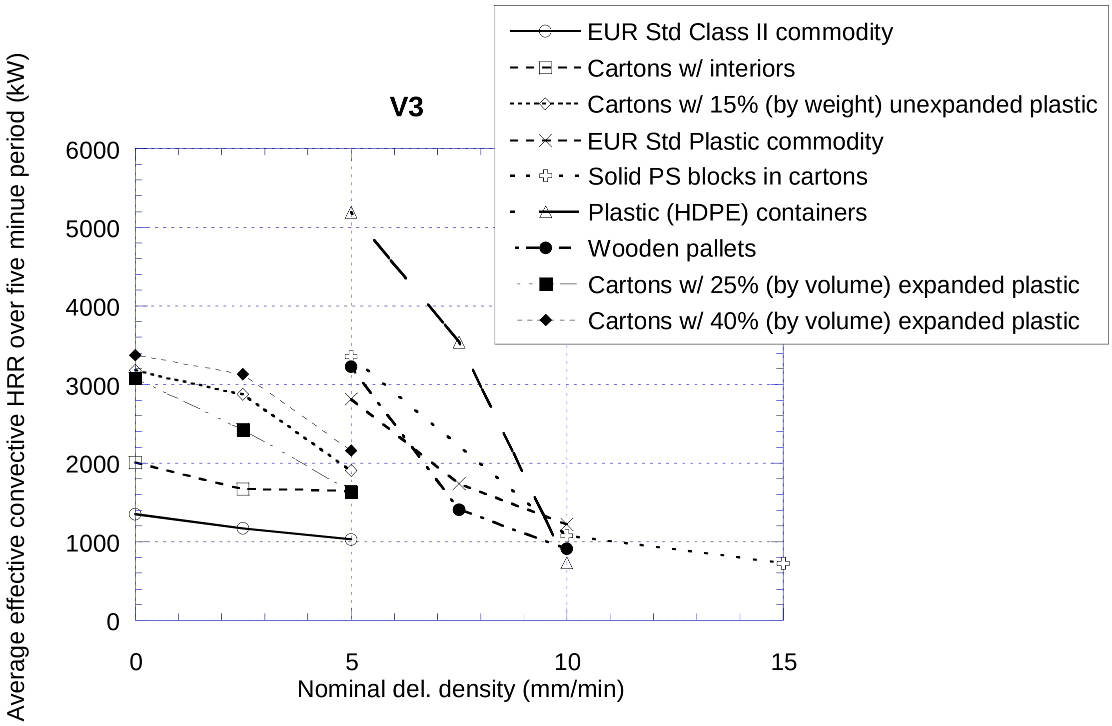

Figure B-3 The average effective convective heat release rate versus water application rate.

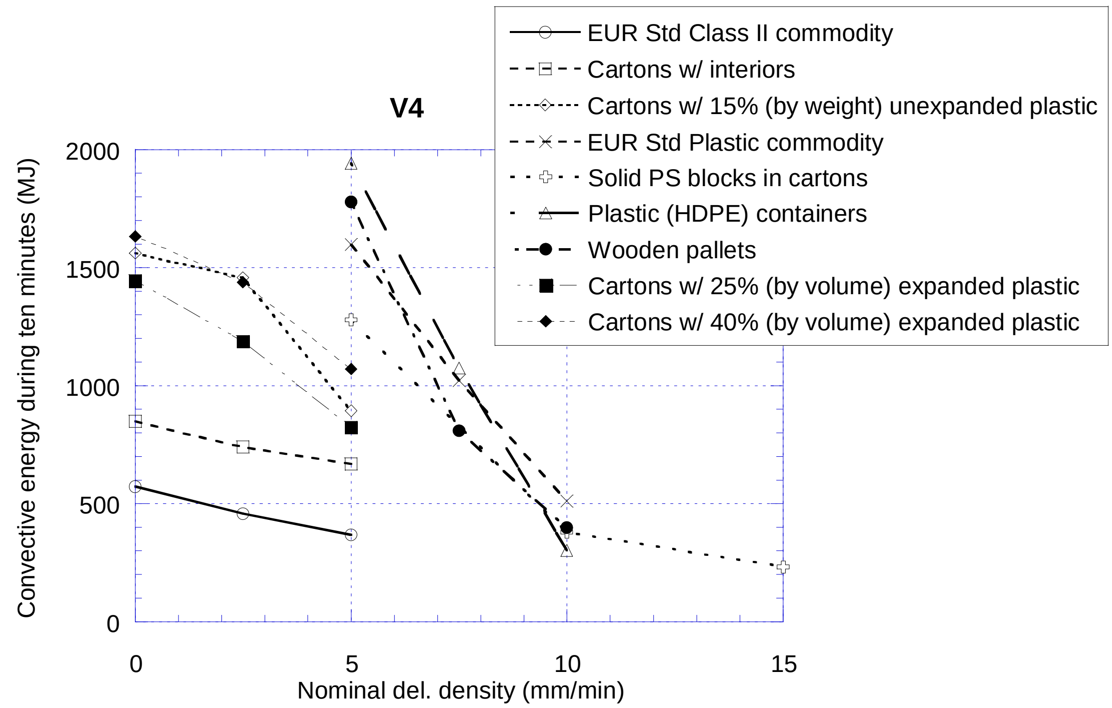

Figure B-4 The convective energy generated during the most severe ten minute interval of the fire versus water application rate.

Appendix C – Tabulated test data

Test id	Date	Commodity	Water application rate [mm/min]	Start water applic. [min:s]	V1 [kW]	V2 [kW]	V3 [kW]	V4 [MJ]	Conv Energy up to 2 MW [MJ]	Conv. Energy after 2 MW [MJ]	Total conv. energy [MJ]	Final time [s]
Test1 (FB)	01-09-28	EUR std Class II	0	(01:57)	2884,8	2016,3	1349,6	571,93	92,9	769,0	861,9	1620,2
Test2 (FB)	01-09-28	Cartons w/ interiors	0	(01:25)	3515,4	2374	2006,4	849,77	43,4	1035,2	1078,5	1620,2
Test3 (FB)	01-10-01	Cartons w/ 15 % plastic	0	(01:45)	5858,4	3718,7	3182,9	1561,1	55,0	2070,7	2125,7	1620,2
Test4 (2,5)	01-10-03	EUR std Class II	2,5	02:34	2672,9	1819,1	1169,2	457,92	137,2	459,3	596,5	1620,2
Test5 (2,5)	01-10-03	Cartons w/ interiors	2,5	01:47	3115,5	2020,9	1667,8	739,93	77,7	793,7	871,4	1620,2
Test6 (2,5)	01-10-04	Cartons w/ 15 % plastic	2,5	01:38	4815,2	3011,4	2872,8	1457,8	49,5	1695,0	1744,5	1620,2
Test7 (5)	01-10-04	EUR std Class II	5	02:33	2508,1	1642,8	1027,6	369,39	123,7	292,5	416,1	1620,2
Test8 (5)	01-10-05	Cartons w/ interiors	5	01:42	3279,5	2176,9	1639,4	669,3	60,3	718,5	778,8	1620,2
Test9 (15)	01-10-08	PS blocks in cartons	15	01:26	3340,4	1602,8	722,36	232,07	44,0	195,8	239,8	1620,2
Test10 (10)	01-10-08	PS block in cartons	10	01:16	3680,4	1640	1076,8	378,65	41,8	365,0	406,7	1620,2
Test11 (5)	01-10-09	PS blocks in cartons	5	01:15	7293,9	4277,1	3354,3	1279,5	45,0	1380,0	1425,0	1620,2
Test12 (10)	01-10-10	HDPE containers	10	08:38	4337,8	1813,1	730,47	303,1	53,6	309,7	363,2	1620,2
Test13 (10)	01-10-10	Wood pallets	10	04:30	2494	1562,5	909,94	399,49	146,0	560,9	706,9	1620,2
Test14 (5)	01-10-11	Wood pallets	5	04:44	5353,2	3254,8	3225,5	1778,1	152,8	2893,6	3046,4	1620,2
Test15 (5)	01-10-11	HDPE containers	5	09:50	11376	6876,7	5188,4	1943,7	57,1	1956,2	2013,4	1388,2
Test16 (7,5)	01-10-12	HDPE containers	7,5	11:22	11354	6495,9	3534,9	1075,3	93,7	985,7	1079,4	1080,2
Test17 (7,5)	01-10-15	Wood pallets	7,5	04:14	3441,6	1594,6	1406,2	809,49	143,9	1611,9	1755,8	1620,2
Test18 (5)	01-10-19	Cartons w/ 15 % plastic	5	01:31	4592,8	2646,1	1903,8	892,62	48,9	967,2	1016,1	1620,2
Test19 (5)	01-10-19	PS cubes (25 %)	5	01:35	3901,4	2304,3	1637,9	823,66	48,3	945,6	993,9	1620,2
Test20 (5)	01-10-24	PS cubes (40 %)	5	01:30	4735,6	2681,7	2159,8	1069,5	44,2	1344,9	1389,0	1620,2
Test21 (2,5)	01-10-25	PS cubes (25 %)	2,5	01:34	4808,6	2932,9	2427,5	1186,7	48,2	1351,1	1399,3	1620,2
Test22 (FB)	01-10-25	PS cubes (40 %)	0	(01:33)	5729,3	3552,4	3370,5	1631,7	50,0	2265,8	2315,8	1620,2
Test23 (2,5)	01-10-25	PS cubes (40 %)	2,5	01:26	5672,9	3398,2	3131,3	1438,1	40,6	1673,1	1713,7	1620,2
Test24 (FB)	01-10-26	PS cubes (25 %)	0	(01:35)	5108,3	3429,1	3078,8	1445,7	46,4	2099,3	2145,7	1620,2
EUR1	99-02-05	EUR Standard Plast	5	01:42	5136	2986,5	2812,3	1598,6	50,0	2241,6	2291,6	1501,2
EUR2	99-02-05	EUR Standard Plast	7,5	01:40	4065,5	2280	1737,4	1020,7	50,9	1423,3	1474,2	1501,6
EUR3	99-02-08	EUR Standard Plast	10	01:41	3680,8	2083,7	1218,7	510,07	45,6	548,9	594,6	1501,1

Note: During test 8 the water spray nozzles over the left hand side of the rack did not operate as intended. The reason for this was determined afterwards to be an electrical failure of the solenoid valves. The V1, V2, V3 and V4 values for this test are therefore higher than they should have been for a correct test.

Test id	αt^2		αt^3		$\alpha e^{\beta t}(a+bt)$; a = 0,1			
	α	R	α	R	α	β	b	R

Test1 (FB)	EUR std Class II	0,17845	0,98626	0,001865	0,92333	10,62	0,009323	0,63874	0,98386
Test2 (FB)	Cartons w/ interiors	0,26494	0,97634	0,003365	0,99399	9,1148	0,025413	0,30016	0,98875
Test3 (FB)	Cartons w/ 15 % plastic	0,20119	0,97346	0,002192	0,99818	10,608	0,024242	0,18073	0,99732
Test4 (2,5)	EUR std Class II	0,11594	0,96143	0,000956	0,85612	14,948	0,00437	0,52486	0,98674
Test5 (2,5)	Cartons w/ interiors	0,18322	0,99449	0,00193	0,95134	11,327	0,011533	0,50297	0,99037
Test6 (2,5)	Cartons w/ 15 % plastic	0,19175	0,98077	0,002243	0,99786	8,4655	0,024121	0,239	0,99837
Test7 (5)	EUR std Class II	0,11063	0,94749	0,000857	0,8163	14,26	0,002939	0,64016	0,98809
Test8 (5)	Cartons w/ interiors	0,19271	0,99394	0,00214	0,98636	8,9399	0,017378	0,39953	0,99358
Test9 (15)	PS blocks in cartons	0,2692	0,97102	0,003589	0,99721	8,9874	0,030296	0,22168	0,99552
Test10 (10)	PS block in cartons	0,32657	0,97073	0,005027	0,99824	7,7157	0,03557	0,26068	0,99733
Test11 (5)	PS blocks in cartons	0,36491	0,95467	0,005663	0,99383	3,1385	0,041551	0,4799	0,99763
Test12 (10)	HDPE containers	0,001745	0,54685	4,48E-06	0,63951	-5,43E-05	0,039786	-0,00029	0,99699
Test13 (10)	Wood pallets	0,024616	0,98057	0,000109	0,99431	3,0903	0,008508	0,25636	0,99334
Test14 (5)	Wood pallets	0,022021	0,97311	9,22E-05	0,99625	3,0228	0,008899	0,20108	0,99417
Test15 (5)	HDPE containers	0,001355	0,53	3,09E-06	0,62557	-8,29E-08	0,038439	-0,00731	0,99695
Test16 (7,5)	HDPE containers	0,000917	0,49119	1,80E-06	0,57874	5,84E-09	0,039703	0,00096	0,98157
Test17 (7,5)	Wood pallets	0,028516	0,98992	1,33E-04	0,98939	3,29E-03	0,007916	335,65	0,99574
Test18 (5)	Cartons w/ 15 % plastic	0,24339	0,98148	3,08E-03	0,99475	1,24E-02	0,02536	204,92	0,99706
Test19 (5)	PS cubes (25 %)	0,21454	0,97655	2,62E-03	0,99803	3,1287	0,02635	0,6282	0,99848
Test20 (5)	PS cubes (40 %)	0,2271	0,97314	2,89E-03	0,99684	3,2898	0,028138	0,57448	0,99672
Test21 (2,5)	PS cubes (25 %)	0,22126	0,97007	2,71E-03	0,99485	3,8709	0,028094	0,45179	0,99684
Test22 (FB)	PS cubes (40 %)								
Test23 (2,5)	PS cubes (40 %)	0,25615	0,96743	3,27E-03	0,99491	4,0811	0,029951	0,45127	0,997
Test24 (FB)	PS cubes (25 %)	0,22094	0,97057	2,60E-03	0,99844	3,0189	0,027271	0,5882	0,99894
EUR1	EUR Standard Plast	0,19765	0,93386	2,32E-03	0,97191	3,0566	0,033905	0,28262	0,98702
EUR2	EUR Standard Plast	0,18055	0,95274	2,17E-03	0,97254	4,4645	0,027585	0,32727	0,98138
EUR3	EUR Standard Plast	0,18118	0,93641	2,13E-03	0,97317	3,01E+00	0,033326	0,27798	0,9872
		0,36491	0,99449	0,005663	0,99844	14,948	0,041551	335,65	0,99894
		0,000917	0,49119	1,8E-06	0,57874	-5,4E-05	0,002939	-0,00731	0,98138
		0,172017	0,920589	0,002099	0,934264	5,431001	0,02434	20,34876	0,993103

Appendix D – Selected photos from the tests

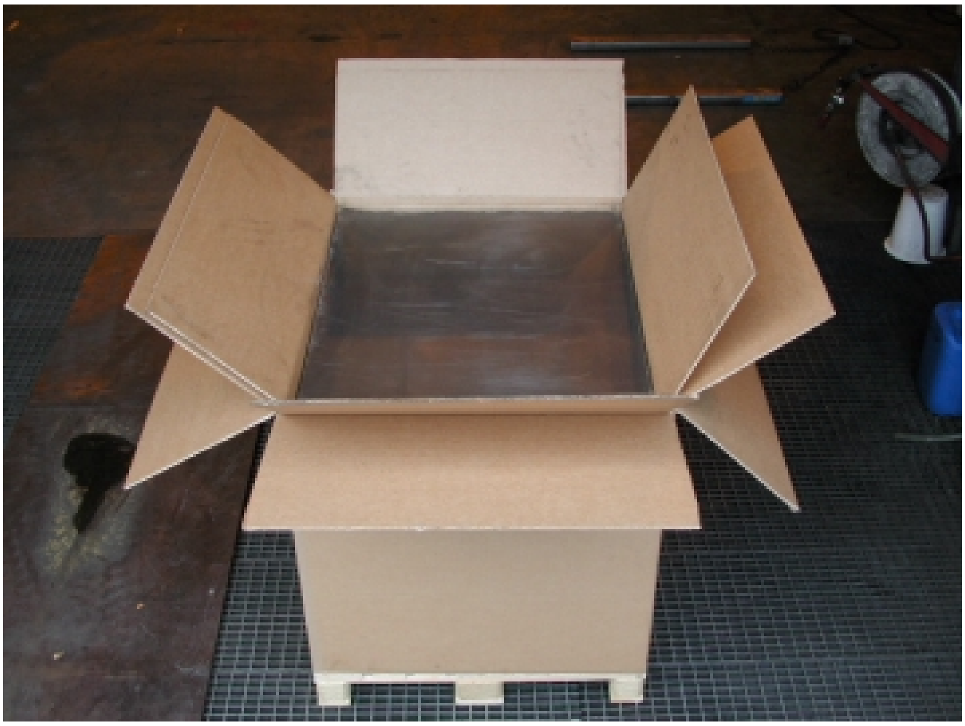

Figure D-1 The triple, bi-wall corrugated cardboard cartons (EUR standard Class II commodity).

Figure D-2 The corrugated cartons with 15% (by weight) unexpanded plastic. Each pallet contained 300 pcs of polystyrene plastic cups. Note: The EUR standard plastic commodity is identical, except that plastic cups are placed in every compartment, i.e. 1200 cups per pallet load.

Figure D-3 Plastic (HDPE) containers. Each pallet load contained 15 pcs of containers. The top layer had a lid.

Figure D-4 Plastic (HDPE) containers seen from above.

Figure D-5 *Corrugated cartons with 25% (by volume) expanded plastic. Each pallet load contained 500 pcs of expanded polystyrene cubes.*

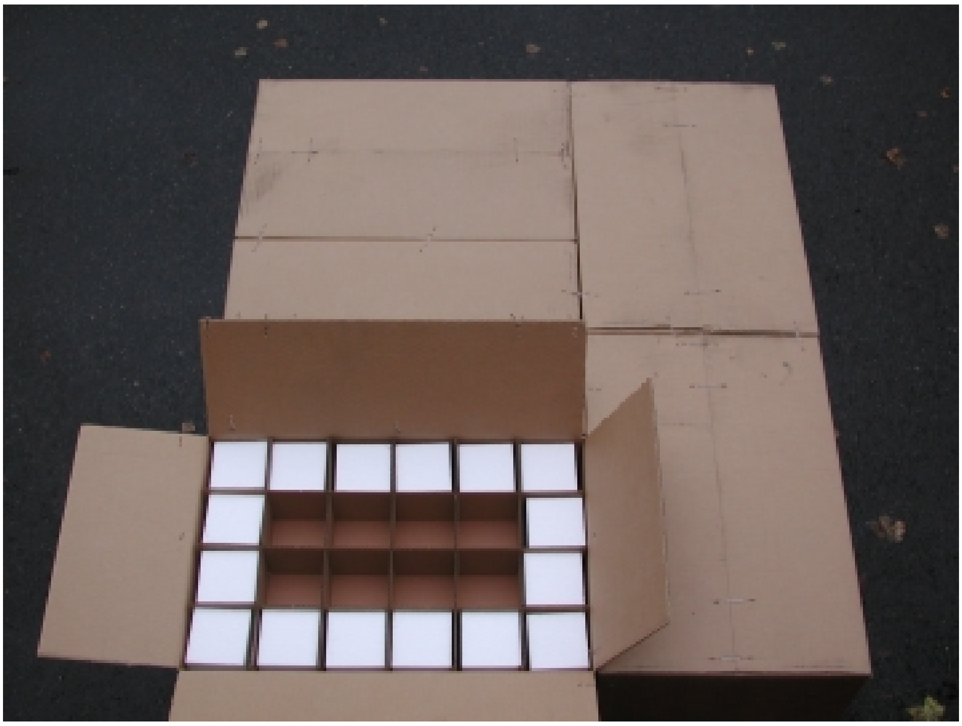

Figure D-6 *Corrugated cartons with 40% (by volume) expanded plastic. Each pallet load contained 800 pcs of expanded polystyrene cubes.*

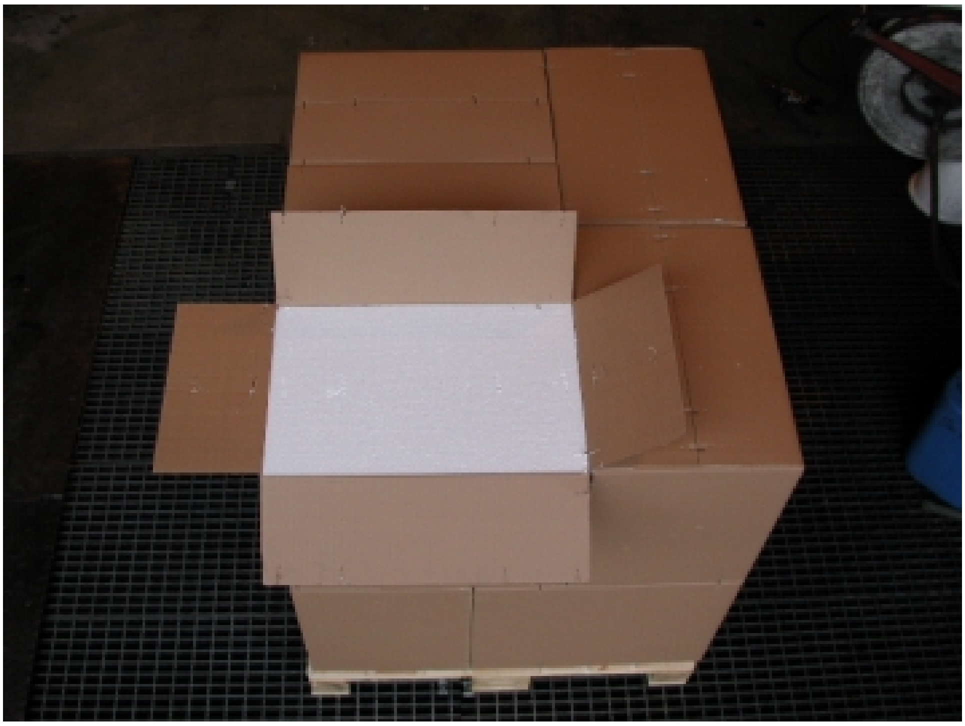

Figure D-7 Solid polystyrene blocks in corrugated cartons.

Figure D-8 The piled wooden pallets.

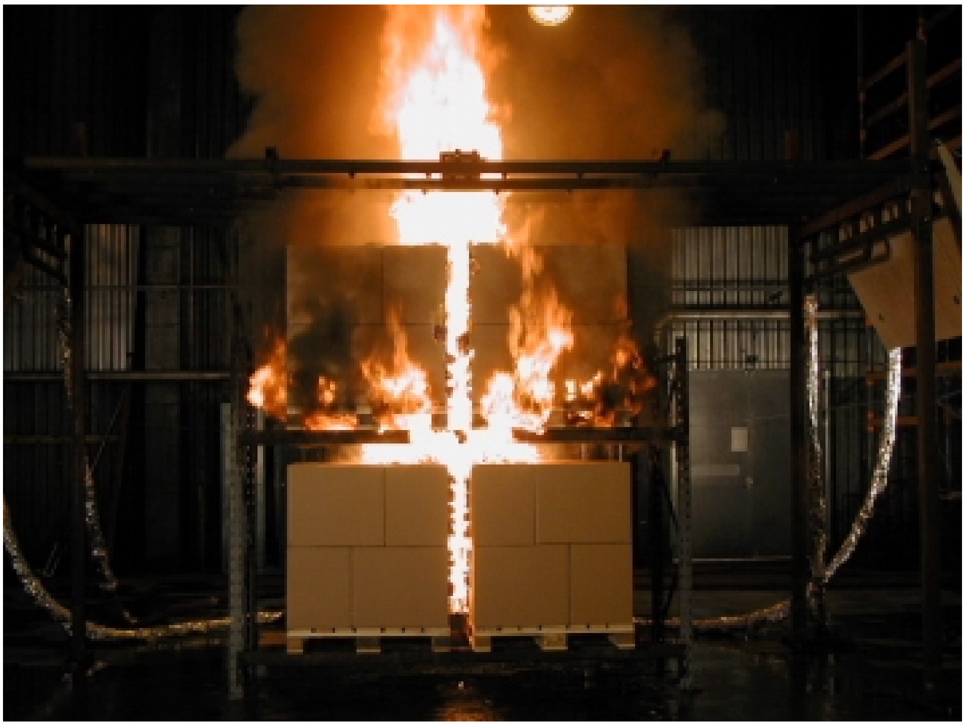

Figure D-9 The corrugated cartons with interiors during a test.

Figure D-10 The triple, bi-wall corrugatd carboard cartons (EUR standard class II commodity) during a test.

Figure D-11 The meltdown of the plastic (HDPE) containers during a test.

Figure D-12 The wooden pallets during a test.

SP Swedish National Testing and Research Institute
Box 857, SE-501 15 BORÅS, Sweden
Telephone: +46 33 16 50 00, Telefax: +46 33 13 55 02
E-mail: info@sp.se, Internet: www.sp.se

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