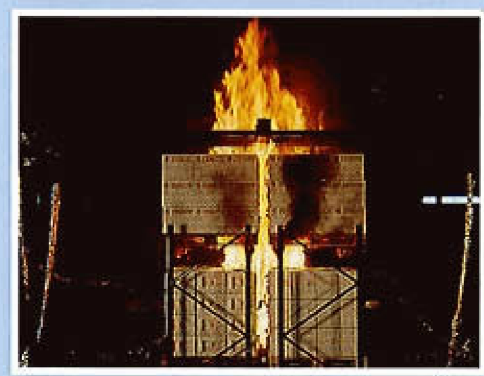
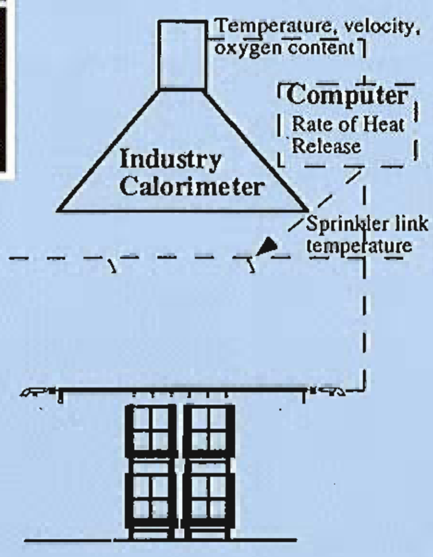
Henry Persson

Commodity Classification

– A more objective and applicable methodology





SP
Swedish National Testing and Research Institute
Fire Technology
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Front page

The drawing shows the principal test arrangement used for commodity classification tests. Based on continuous rate of heat release measurements using the Industry Calorimeter, the computer system calculates the activation time for a virtual sprinkler. A water application system placed directly above the commodities is activated. Based on measurements during water application, the fire characteristics of the commodities can be determined and form the base for a proper classification. The pictures show different stages during the test procedure shortly after ignition, before the water applicator is activated and shortly after water application has started.

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Abstract

A correct commodity classification is one of the most important factors in order to design an efficient and reliable sprinkler system. In this project, commodity classification tests have been conducted using a test method developed by Factory Mutual Research Corporation (FMRC).

18 tests with 8 different types of commodities have been tested and the indicated classification achieved has been compared to existing classification. The classification and required level of protection stated in the Swedish sprinkler standards has also been compared to corresponding FMRC and NFPA standards.

The classification tests are conducted below the Industry Calorimeter, where 8 pallet loads of the commodity to be tested are placed in a double-row rack storage segment, i.e. in a configuration of 2x2x2 pallets. The array is ignited and the fire is allowed to develop until the heat release rate measurements indicate that a sprinkler system would have operated in a real installation. Water is then applied on top of the array using a specially designed water applicator. Normally, three tests are conducted using three different delivered water densities. The classification is then based on the total and convective heat release rates measured during the three tests.

The general conclusion from the tests, is that the FMRC classification test method will have a very great potential to form the basis for an international accepted procedure for commodity classification. The method is able to provide a better and more reliable classification which of course also will lead to a more reliable sprinkler protection.

The tests have also shown the importance of using identical test equipment and test procedure and to use test commodities as close to the specifications as possible. This has been the reason to some problems during the project which made a final classification of the tested commodities impossible. However, this information and experience will be very valuable in the work to specify the test procedure in more detail which will be required for such a test method.

The comparison of the classification systems used in Sweden and US, respectively, shows in general that the Swedish storage category L1 corresponds to US classification I-III, L2 to Class IV, L3 to Unexpanded Plastic A and L4 to Expanded Plastic A.

The comparison of required level of protection shows that the Swedish sprinkler standard requires higher protection on low hazards while the required protection is lower for the plastics.

Key words: Commodity classification, sprinkler protection, required delivered density (RDD), rate of heat release (RHR)

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Based on the design of FMRC, a similar calorimeter [9-10] and water application system has been built at SP. The system has been used for the evaluation of the RDD technique and some comparison tests have also been conducted in collaboration with FMRC [11-13].

This report concerns a project in which a series of tests has been conducted using the same commodity classification procedure as used by FMRC. The aim of the project is to gain experience of the test procedure and to study how the commodity classification used by FMRC correlates with the European classification system.

3 Principle of the new classification

The classification test procedure developed by FMRC is highly standardized. The aim is to determine the hazard level of a commodity by comparing the test results with data from identical tests on commodities of known hazard level as described in 3.1. In order to get these "basic test data", FMRC has run some calibration tests using the standard commodities fulfilling the definition of their various commodity classes, denoted Class I, II, III, IV and Plastic commodity. These commodities have been used in full scale sprinkler tests and the required protection for each of these standard commodities is well known.

If a tested product shows similar fire behaviour and suppressability as one of the standard commodities, it is assumed that the protection requirements are also the same.

It is important to note that the classification tests do not directly give the protection requirements e.g. design density for the commodity tested although reference is made to various water densities in the tests. The purpose is to determine the hazard level of a commodity. When the tested product has been classified, the protection requirements, based on the storage configuration and its height are covered by the FMRC sprinkler standards. For convenience the rack storage configuration is used in the classification tests. The results may then be applied to palletized, solid piled or rack storages.

In order to get an objective, numerical system of classification, each category of hazard has been assigned a rating number. In the development of the test method, FMRC chose to attach this "Product Rank" to their existing classification system [14] and the correlation between Product Rank and commodity classes is shown in table 1.

Table 1 Correlation between Product Rank and commodity classes. The table also shows the standard commodities used as a reference for the classification system

FMRC Commodity Class	Product Rank	Standard commodity used as reference
I	1.0	Glass jars in compartmented cartons
II	2.0	Double triwall cartons with steel liner
III	3.0	Paper jars in compartmented cartons
IV	4.0	Polystyrene and paper jars in compartmented cartons
Cartonated Group B Unexpanded Plastic	5.0	
Cartonated Group A Unexpanded Plastic	6.0	Polystyrene jars in compartmented cartons
Cartonated Group A Expanded Plastic	7.0	

3.1 The Product Rank according to FMRC is based on four parameters, V1-V4

The Product Rank is based on results of the Industry Calorimeter measurements. FMRC choses four parameters to characterize the level of hazard which is referring to both the total heat release rate and the convective part of the heat release rate as both these play a major part regarding the sprinkler operation and the protection of the building construction. The four parameters are:

V1 Maximum one minute average of the total heat release rate
V2 Maximum one minute average of the convective part of the heat release rate
V3 Effective convective heat release rate, defined as the convective heat release rate averaged over the five minute interval of most intensive fire
V4 Convective energy, defined as the amount generated during the ten minute period of most intensive fire

These are considered to be important variables, which can be measured with accuracy and which give differences in the measured values from one hazard level to the next, large enough to provide a credible assessment of the hazard. The significance of each variable is discussed in detail by Chicarello and Troup [7] and can be summarized as follows.

V1 Maximum one minute average of the total heat release rate

The maximum total heat release rate is an important measure of the potential for fire spread and as well as an overall fundamental measure of fire severity. The total heat release rate can be divided in two parts, convective and radiative. Normally one-third of the energy is released by radiation. Radiation is the primary mechanism for fire spread across aisles and other open spaces to adjoining combustibles and also, in part, responsible for lateral fire spread throughout a large fuel array. The total heat release rate is based on gas analysis of the combustion gases and the one minute average value is used to avoid influence of spikes during the measurements due to environmental changes, nonuniformity of fuel packages, electrical noise, etc.

V2 Maximum one minute average of the convective heat release rate

The maximum convective heat release rate is one of the most important measures for characterizing fire severity. Approximately two-thirds of the energy generated from a fire is released through convection. Both the gas velocity and temperature within a fire plume is related to the convective heat release rate and these two are very important for the operation of the first sprinklers and the penetration of the water droplets. The higher the velocity and temperature are, the lower will the portion of water which penetrates the fire plume be. In the early stages of a fire, when the sprinklers just have operated, the amount of penetration will determine how quickly the fire is controlled. The one minute average is used for the same reason as mentioned above.

V3 Effective convective heat release rate

The convective energy released from the fire is to a great deal responsible for heating the ceiling construction and operation of sprinklers. For this purpose, the maximum rate of heat release is not relevant, as it is a matter of heat transfer where duration will be very important. A very intensive but short-lived fire might be less severe than a fire of lower intensity but with a longer duration. When assessing the fire severity it is therefore necessary to determine the heat release rate for a longer period of time. The effective convective heat release rate is therefore defined as the convective heat release rate averaged over the five minute interval of most severe fire.

V4 Convective energy

The total convective energy released during a fire is an important measure of the potential for causing thermal damage to a construction. The higher the convective energy, the greater the damage potential. Once again, a product with a lower intensity but with a long duration and thereby releasing more energy in total might cause the most severe damage to a construction. The convective energy reported from these classification tests is defined as the amount generated during the ten minute period of most severe fire or during the entire test if the fire duration is less. The 10 minute value is based on experience, that most of the energy from the commodities used in the tests will be released during this period of time.

3.2 Analysis of the test results and calculation of the Product Rank

The reference tests using the FMRC standard commodities and tested at three different water densities forms the base for the correlation between the existing commodity classification system, the four parameters V1-V4, to the Product Rank value. The results from these tests are summarized in metric units in table A1 (Annex A) which also can be used as test protocol during classification tests.

Commercial commodities fall normally more or less between the values of the standard commodities. In order to interprete such test results and to give the commodity a representative classification, Chicarello, Troup [7] present a correlation, both in form of mathematical expressions and four tables where the Rank values are listed in one-quarter increments for the four parameters V1-V4 at each of the four delivered water densities. These tables, B1-B4, are presented in Annex B with all values converted to the metric system.

Tables B1-B4 are therefore used together with table A1 in order to classify commodities. As an example (see Annex A and B), if a test is conducted at 12.6 mm/min, the test results of V1 to V4 are entered in table A1 in the column "Test Product" at the lines corresponding to 12.6 mm/min. The corresponding Rank values are then taken from table B3 and entered into table A1. The same procedure is then used for the tests with the other two water densities. The arithmetic mean of the Rank values is calculated for each delivered water density which is defined as the "Mean Unit Rank". The "Mean Total Rank" is then the arithmetic mean of the Mean Unit Rank values. As an example, if the Mean Total Rank is calculated to 3.25, the commodity shall be protected as a class III commodity.

If a tested commodity gives a Mean Unit Rank value which exceeds the Mean Total Rank value by more than 1.00, the commodity should be classified according to the highest Mean Unit Rank value.

It is important to note that this classification procedure and the Products Rank system have been developed for ordinary combustible hazards. Many commodities, e.g. containing exposed plastics, will create a fire hazard exceeding Product Rank 7.0 and should then be classified as an Extra Hazard commodity, "Ex". There are no generic protection guidelines for these commodities and in general, larger scale fire testing is needed to develop sprinkler protection guidelines for these products.

However, the test method might still be used also for certain "Ex" commodities to achieve a relative product ranking. This procedure is used by FMRC for approval of plastic pallets, where the measured results are compared with reference tests on wood pallets. As long as the fire and suppression behaviour are equal or less severe compared to wood pallets, the plastic pallets can get FMRC approval [15,16].

4 Classification test procedure

The commodity classification tests are conducted below a large-capacity calorimeter as shown in figure 1. The commodity is placed on pallets and placed in a double row rack storage segment. In each test, 8 pallet loads placed in a configuration 2 x 2 x 2 pallets, are used as shown in figure 2. The commodities are ignited in the center flue space using standardized ignition sources and the generated heat release rate is measured continuously. When the fire has reached such an intensity that a sprinkler system would have come into operation, the water application onto the fuel array starts. This is achieved by using a special water application system which applies an even water density on the fuel array, simulating the delivered water density coming from the sprinklers in a real situation.

The measurements of the heat release rate continuos until the fire either has been suppressed or the commodities have been consumed by the fire. A series of three tests is conducted, in which only the delivered density is changed. Normally, water densities of 4.5, 8.5 and 12.6 mm/min or 8.5, 12.6 and 15.9 mm/min, depending on hazard level of the tested product, are used. Based on the measurements from these three tests, the four parameters, V1-V4, are calculated and the classification is then determined as described in chapter 3.

In order to obtain similar, and realistic conditions for all tested commodities, the water application has to be started as in a real sprinkler installation. The conditions simulated during the tests are that the fuel array would be protected by a sprinkler system installed 3.05 m above the top of the fuel array with the following data, figure 1 (left): Standard upright sprinklers in a 3.05 by 3.05 m spacing, with deflectors located 178 mm below a smooth ceiling, with a temperature rating of 141 °C, a response time index (RTI) of 276 $m^{1/2}s^{1/2}$ and the point of ignition centered below four sprinklers. Using a computer model developed by FMRC, the link temperature of these simulated sprinklers is calculated on-line during the test using the convective rate of heat release as input. When the computer program calculates that the link temperature would be 141 °C, the water applicator is activated, figure 1 (right).

A sprinkler which might be considered as an "old type", with both a high temperature rating and a slow response, is simulated as it emphasizes the conditions which could occur in sprinkler systems designed to control a fire. This means that not only the packaging material would be involved in the fire but also the goods inside. This is a situation which could occur also in a situation when Quick Response Sprinklers are used and some of the first operating sprinklers malfunction.

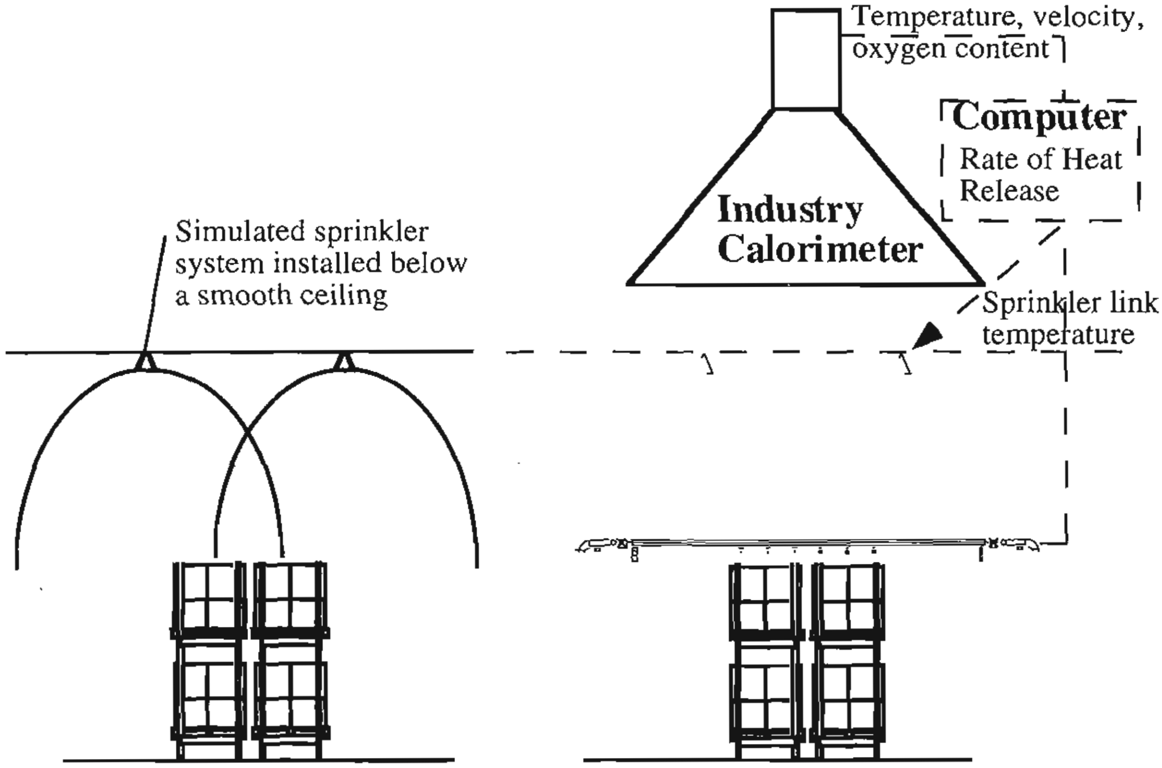


Figure 1 *The figure shows the principle of the test set-up for a commodity classification test. In the tests, a real sprinkler installation is simulated (left) by measuring the Rate of Heat Release and based on this, the link temperature of the simulated sprinkler is calculated (right). When "sprinkler activation" is achieved, a water application system is activated which distributes water on top of the tested commodity. The density is adjusted before each test to one of the four densities, 4.5, 8.5, 12.6 or 15.9 mm/min.*

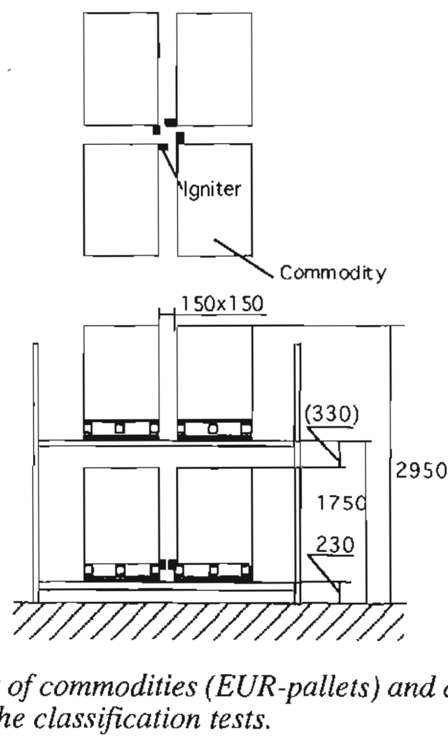


Figure 2 *Arrangement of commodities (EUR-pallets) and approximate measures in mm used in the classification tests.*

5 Test equipment

5.1 Industry Calorimeter

The Industry Calorimeter is a large hood connected to an evacuation system capable of collecting all the combustion gases produced by fires of an intensity up to about 10 MW. The hood is 6 m in diameter with its lower rim normally 8 m above the floor as shown in figure 1. The height of the rim might easily be varied up to 12 m by a telescopic arrangement of the duct system. The Industry Calorimeter is designed in a similar way as the Fire Products Collector (FPC) at FMRC [9,10]. The evacuation capacity is 22.5 m^3/s at room temperature which is approximately 20 % less compared to the FPC at FMRC. In the duct of the evacuation system, measurements of gas temperature and velocity, the generation of gaseous species such as CO_2, CO and the depletion of O_2 is made. The generation of smoke is also measured with a photocell equipment. Based on these measurements both the convective and total heat release rate can be calculated.

5.2 Water applicator

The water applicator consists of six parallel, double-jacketed, steelpipes fitted with six spray nozzles along each pipe, forming a matrix of nozzles 450 mm apart, see figure 3. The nozzles produce a full-cone, wide angle spray, resulting in an even water density over a maximum area of 2.7 m by 2.7 m. When a commodity stored on normal European wood pallets (1.2 m x 0.8 m) is tested, only four of the pipes are used while the two outer pipes are disconnected.

The suppression water is fed from both ends into the pipe. In order to reduce the fill-up time as much as possible, air relief devices are installed at the midpoint of the pipes. This allows the air in the pipes to bleed. The relief devices are automatically shut 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 as 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.

The applicator is water cooled in the annular area of the double jacketed pipes to protect it from the flames. The cooling water is feeded from one end and discharged through the other.

The water applicator has been calibrated for the various storage configurations to deliver the predetermined water density on top of the tested commodity.

Four types of spray nozzles, manufactured by Lechler and Spraying Systems Company, are used to achieve a wide range of delivered density:

- Lechler model 460.408.30.CA for a water density of 4.5 mm/min
- Lechler model 460.448.30.CA for a water density of 8.5 mm/min
- Spraying Systems model 1/8 GG 5.6W for water densities 10-25 mm/min
- Spraying Systems model 1/4 HH 14 W for water densities above 25 mm/min

The design of the applicator is basically identical with the one FMRC uses. However, the distances between the double-jacketed pipes and the number of nozzles have primarily been designed to fit European pallets and storage configurations. This new design has been constructed with guidance from FMRC [18].

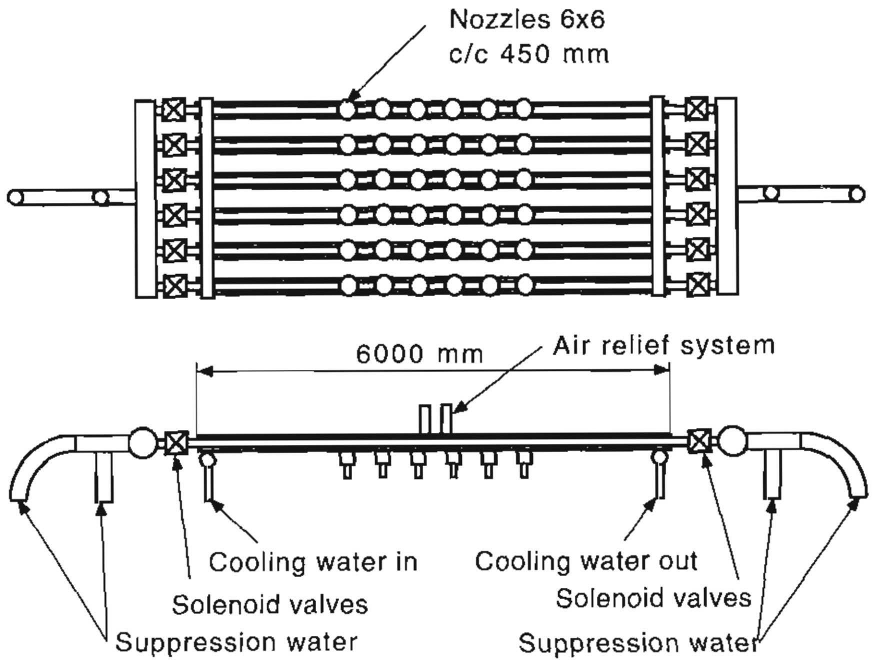


Figure 3 *The desired water density is achieved using a water applicator giving an even water distribution on top of the fuel array and the figure shows the principal design of the applicator used at SP-Fire Technology.*

As reported later on in chapter 7, it was noted that there are some important differences between the SP applicator for US pallets and the FMRC applicator which influence the classification results. The principal design of the two applicators are shown in figure 4.

The "ideal" water coverage surface of the FMRC applicator is 5.95 m^2 (2.44 x 2.44 m) which covers a fuel area of 5.24 m^2 (2.29 x 2.29 m) including the flue spaces.

The SP applicator for US pallets has an ideal water coverage area of 7.29 m^2 (2.7 x 2.7 m) which covers the same fuel area, 5.24 m^2

This means that the overshoot of water is 12 % for the FMRC water applicator while it is 28 % for the SP applicator on US pallets. Assuming a completely even distribution from each nozzle, this means that the total water flow is 22.5 % higher from the SP water applicator compared to the FM version in order to obtain the same delivered density. Even though this extra water is not hitting the fuel array, it might influence the measured convective RHR as it cools the flames and combustion gases. It should not influence the total RHR although a cooling effect directly in the vicinity of the fuel array might also reduce the fire development and thereby also the classification.

The SP applicator for the EUR pallets has a better agreement with FMRC. The water coverage area is 4.86 m^2 (1.8 x 2.7 m) and the fuel area is 4.46 m^2 (1.75 x 2.55 m) including the flue spaces. This means that the overshoot of water is 8 %.

In an attempt to avoid any influence on the fire from the higher overshoot and thereby total water flow from the SP water applicator when testing US pallets, some tests were conducted with a system of steel chutes mounted around the top of the commodity to collect the overshoot of water.

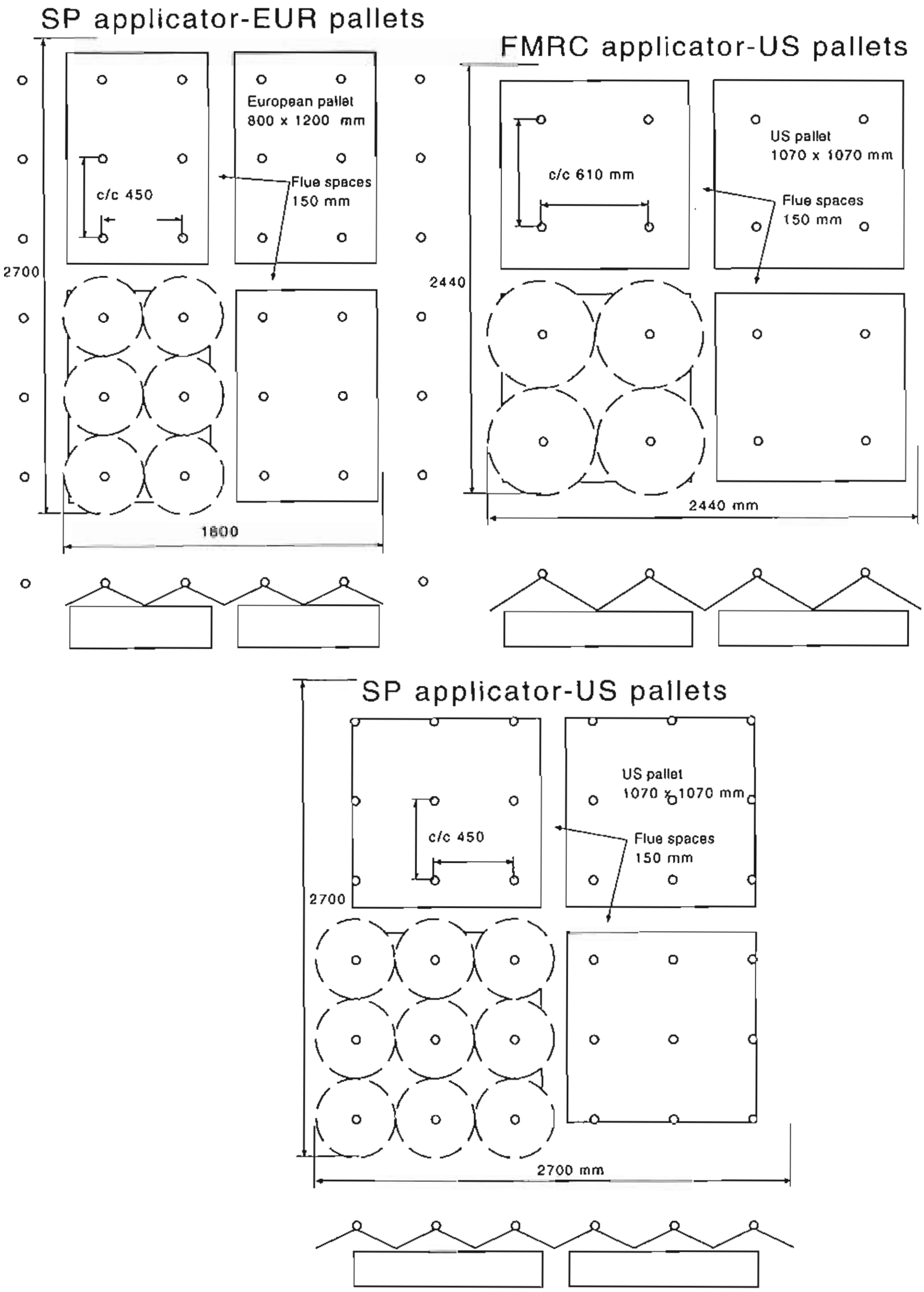


Figure 4 *The figures show the water application system used at SP (top left and bottom) and FMRC (top right) . As can be seen from the figure, the overshoot of water is considerably higher for the SP applicator on US pallets compared to the FMRC-applicator.*

5.3 Ignition source

Four igniters made of pieces of insulating fibre board were used in each test. They were 60 mm in square and 75 mm long, soaked in 120 ml of heptane and wrapped in a polyethylene bag. The ignitors were placed near the centre flue space at the bottom of the pallet loads of the lowest tier.

6 Test commodities

A series of 18 tests were conducted to gain experience of the commodity classification test procedure and to study how the Product Rank system proposed by FMRC fits into the European classification system.

The commodities were chosen, so that they by definition could clearly be classified into one of the four storage categories, L1-L4, used in Sweden [17]. No commodity classified as L1 was tested as commodities of category L2-L4 were considered more interesting. Two FMRC standard commodities were used to study the correlation with the results achieved by FMRC.

A general description of the tested commodities is given below and in table 2, respectively.

1) Unassembled, single wall corrugated paper cartons stored horizontally on wood pallets. 16 pallets were used in two tests.

2) Magazine files and letter trays made of polystyrene, stored in paper cartons on wood pallets. 24 pallets were used in three tests.

   Each test consisted of three types of pallet load and in all three tests these were mixed in order to get as equal composition as possible. The data for the most frequent pallet load, type I (13 pallets), is presented in table 2 and the two other types below:

   Magazine files, type II; 380x285x350, 24 pcs, 2x4x3, 770x1150x1220, corrugated paper 9.4 kg, plastic 67.4 kg, total weight 100 kg incl pallet (9 pallets).

   Magazine files, type III; 380x370x260, 24 pcs, 2x3x4, 770x1110x1180, corrugated paper 9.1 kg, plastic 58 kg, total weight 90 kg incl pallet (2 pallets).

3) Cushions stored in paper cartons on wood pallets. 16 pallets were used in two tests.

   Each test consisted of three types of pallet load and in both tests these were mixed in order to get as equal composition as possible. The data for the most frequent pallet load, type A (12 pallets), is presented in table 2 and the two other types below:

   Cushion, type B; 780x320x880, 4 pcs, 1x4, 780x1300x1040, corrugated paper and plastic material 33 kg, total weight 56 kg incl pallet (2 pallets)
   Cushion, type C; 780x590x500, 4 pcs, 1x2x2, 780x1200x1170, corrugated paper and plastic material 40 kg, total weight 63 kg incl pallet (2 pallets).

4) Polystyrene chips stored in paper cartons on wood pallets. 24 pallets were used in three tests.

5) 1.5 litre empty PET-bottles stored in plastic crates on wood pallets. 24 pallets were used in three tests. (Some tests with filled PET-bottles were also conducted but are not reported here.)

6) "EUR Plastic", a repacked version of the FMRC Standard Plastic commodity, in order to obtain cartons which fits to the European pallet system, 1200x800 mm. 16 pallets were used in two tests.

Original FMRC material was used except for the paper carton. In order to achieve this size of the cartons, the cups were stored 4x5x5. This resulted in 100 cups in each carton in the EUR Plastic compared to 125 cups in the FMRC carton.

7) FMRC Standard Plastic commodity on US wood pallets. 16 pallets were used in two tests.

   The commodity consists of 125 polystyrene cups packed in compartmented, single wall corrugated cartons. (See also [7])

8) FMRC Standard Class II commodity on US wood pallets. 16 pallets were used in two tests.

   The commodity consists of double triwall cartons, containing a steel liner. (See also [7])

Table 2   Commodity components and pallet load weights

Test commodity	1) Paper cartons	2) Magazine files, Type I	3) Cushion Type A	4) PS Chips	5) PET-bottles	6) EUR Plastic	7) FMRC Plastic	8) FMRC Class II
Swedish classification	L2	L3	L4	L4	L3	L3	L3	L2
Commodity components on one pallet load (measures in mm)								
Cartons, size	300x 400x 8	260x 395x 330	780x 400x 600	395x 575x 390	270x 300x 400	390x 585x 510	530x 530x 510	1070x 1070x 1040
No of cartons	720	27	4 1/2	12	36	8	8	1
Arrangement,no	6x120	3x3x3	1x3+ 1x1 1/2	2x2x3	3x4x3	2x2x2	2x2x2	-
Pallet size WxLxH	800x 1200x 1090	790x 1175x 1150	780x 1200x 1240	780x 1150x 1340	810x 1210x 1340	800x 1200x 1180	1070x 1070x 1040	1070x 1070x 1190
Pallet load weights (kg)								
Pallet	23	23	23	23	23	23	26	26
Corr paper	95	11	ND	8.4	-	15.2	22	38
Plastic material	-	70	44 (incl carton)	5.1	83	26.4	33	-
Total	118	104	67	36.5	106	64.5	81	64

ND Not determined

The moisture content of the paper cartons and wood pallets were in the order of 10-12 % in all tests. However, the US wood pallets used during the tests with the FMRC standard commodities were slightly less, 6-9 %.

7 Test results

In total 18 tests have been conducted using the 8 different types of commodities as described in chapter 6.

A summary of the test conditions and the results obtained are presented in table 3-4.

Table 3 presents some basic data from the tests. In table 4, the four parameters V1-V4 from each test are presented together with the Rank value for each parameter based on the figures in table B1-B4. More detailed information about the tests and the indicated classification of each type of commodity are given in chapter 7.1-7.8.

Most commodities were tested only at two water densities due to lack of test goods. Some tests were also terminated because the capacity of the Industry Calorimeter was exceeded. Further on and due to the behaviour of some of the tested commodities, some tests were conducted using a water density which is not specified by FMRC. Consequently, no "real" Rank values exist for these tests.

Table 3 Summary of fire tests.

Test commodity	Test no	Delivered Density (mm/min)	Nozzle operation (min:s)	Conv RHR at nozzle operation (kW)	Test duration (min:s)	Commodity consumed (%)
Paper cartons	6	8.5	2:08	3760	21:00	50
	16	12.6	2:04	3850	21:00	40
Magazine files	5	8.5	1:56	3730	6:07 *	95
	18	10.5	1:44	3760	23:00	75
	4	12.6	1:52	3850	19:00	30
Upholstery cushions	1	15.9	1:38	4050	16:00	90
	17	20.8	1:44	4110	16:15	70
PS Chips	13	15.9	1:08	5830	8:20	99
	14	20.8	1:08	5240	8:45	99
	15 **	20.8	0:40	1140	6:00	25
PET-bottles	8	12.6	5:40	4060	12:10*	80
	12	14.5	5:56	3710	10:30*	95
	9	15.9	5:12	3910	15:15	15
EUR Plastic	19	12.6	1:28	4550	5:40 *	80
	22	15.9	2:00	4090	18:00	80
FMRC Plastic	3	12.6	1:40	4190	22:45	70
	2	15.9	1:32	4030	23:00	60
FMRC Class II	21	8.5	2:48	2580	24:00	35
	20	12.6	2:25	2650	18:15	25

*) The test was terminated as the capacity of the Industry Calorimeter was exceeded

**) Test simulating a Quick Response sprinkler

One very important experience from the tests and from communication with FMRC [24] is that the tests have to represent a situation where the fire is controlled in order to be relevant for classification. The fire will be affected by water application in a certain way which is principally shown in figure 5. If the peak heat release rate (RHR) is plotted as a function of delivered water density, this will form an "inversed S-curve".

If no water is applied, there will be a completely freeburning fire resulting in a certain peak RHR. If only a low water density is applied, the fire will hardly be affected and the peak RHR will be almost the same. At a certain water density, the fire will start to be controlled resulting in a lower peak RHR. This is the beginning of the "controlled region". Further increased water density will reduce this peak RHR even more and at a certain water density the fire is suppressed rather than controlled. In the "suppressed region" the effect of a further increased water density on the peak RHR will be marginal as this is controlled by the time when water is applied. A slow response sprinkler will result in a higher peak RHR compared to a quick response sprinkler.

The most significant difference between the "controlled region" and "suppressed region" can be seen from the RHR development during a test. A test in the controlled region is recognised by the fact that the fire is first reduced at nozzle operation (simulated sprinkler operation) but the fire then redevelops and the peak RHR is higher compared to the RHR at nozzle operation (except for commodities with very low fire hazard). Most of the commodities are consumed by the fire in such a test. A test representing the suppressed region is recognised by the fact that the RHR is quickly reduced at the time of nozzle operation and the fire is then not redeveloping and the RHR is decreasing more or less until the fire is extinguished. The commodities are only consumed to a certain extent in these tests.

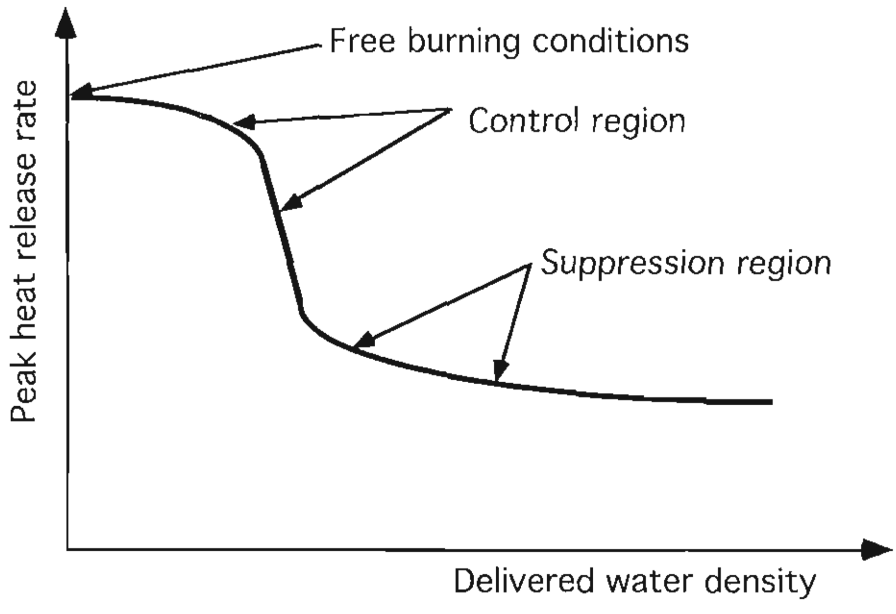


Figure 5. The figure shows the principle for how the peak heat release rate is affected of various delivered water densities and what could be defined as the "control region" and the "suppression region".

As the commodity classification system is based on, and only valid for, the controlled fire situation, it is important that the test also represent the controlled region. This is the reason that FMRC specified to conduct three tests at the prescribed water densities. That gives a good chance to achieve at least two tests in the controlled region which then can be used for ranking purpose. A test which turns out to be in the suppression region is therefore not appropriate to use, as the ranking values will not be relevant.

In the tests conducted in this project, several of the tests were conducted in or close to the suppression region which unables a classification. In some cases, tests in the controlled region could not be completed as the capacity of the Industry Calorimeter was exceeded.

Table 4 Summary of the obtained values of the parameters V1-V4 and the correlating Rank- and Mean Unit Rank values .

Tested commodity	Delivered Density	V 1 (kW)	Rank	V 2 (kW)	Rank	V 3 (kW)	Rank	V 4 (MJ)	Rank	Mean Unit Rank
Paper cartons	8.5 12.6	5050 5200	2.0 3.0	2840 3210	2.0 3.5	2770 3110	2.75 5.25	1300 1250	2.5 4.5	2.3 4.1
Magazine files	8.5 10.5 12.6	9700* 5570 4860	>4.75 ** 3.0	4900* 2700 2330	>4.0 ** 1.5	ND 2490 1400	ND ** 2.5	ND 1280 300	ND ** 1.0	ND ND** 2.0 1)
Cushions	15.9 20.8	6180 4800	5.5 **	3100 2580	5.0 **	2610 1770	7.0 **	1280 640	EX(7+) **	6.1+2) ND**1)
PS Chips	15.9 20.8	8770 7810	EX(7+) **	3280 2910	5.5 **	2190 1500	6.25 **	730 490	5.0 **	5.9+2) ND**
PET-bottles	12.6 14.5 15.9	9800* 11000* 5760	>7.0 ** 5.25	5900* 6100* 2150	EX ** ND(3-)	ND ND 910	ND ND 4.25	ND ND 300	ND ND 3.5	ND ND 4.0-1,3)
EUR plastic	12.6 15.9	10400* 5910	EX 5.25	5300* 2600	EX 3.25	ND 2330	ND 6.5	ND 970	ND 6.0	ND 5.25
FM plastic	12.6 15.9	6420 5780	4.25 5.25	3150 2670	3.25 3.75	2740 1800	4.75 5.75	850 500	3.5 4.0	3.9 4.7
FM II	8.5 12.6	3340 3230	0.5 0.5	2050 2140	0.75 1.0	1060 1080	1.0 1.5	390 380	1.25 1.5	0.9 1.1

V1 Maximum one minute average of the total heat release rate
V2 Maximum one minute average of the convective heat release rate
V3 Effective convective heat release rate, defined as the convective heat release rate averaged over the five minute interval of most severe fire
V4 Convective energy, defined as the amount generated during the ten minute period of most severe fire

* Higher value expected; the test was terminated as the capacity of the Industry Calorimeter was exceeded. The Rank values given for V1 and V2 are based on the heat release rate at termination.

** A "non-standard" water density was used. An indication of Rank values can be obtained in the diagrams for V1-V4 in sections 7.1-7.8.

ND Not determined

1) The fire was rather suppressed than controlled and the rank values might therefore not be relevant. Further tests using lower water density are needed.

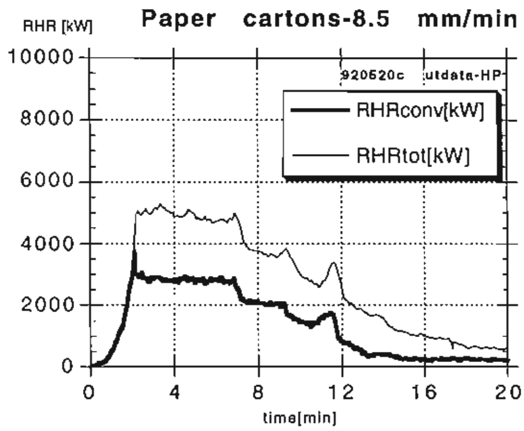
2) One of the four parameters, V1-V4 gave EX classification. However, the Mean Unit Rank calculation is based on Rank value 7.0 (indicated as 7+).

3) Lowest Rank value given by FMRC at 15.9 mm/min is 3.0. As the V2 value (2150 kW) was below the corresponding limit, the Mean Unit Rank calculation is based on Rank value 3.0 (indicated as 3-).

4) SP water applicator for tests of US-sized commodities (36 nozzle configuration) was used in the tests. The different design compared to the FMRC applicator. results probably in a too high water density and a too low ranking.

5) SP water applicator for tests of US-sized commodities (36 nozzle configuration) was used in the tests, but with steel chutes arranged around the commodity to collect overshooting water. Although this measure, the different design compared to the FMRC applicator results probably in a too low ranking.

7.1 Test results-Paper cartons



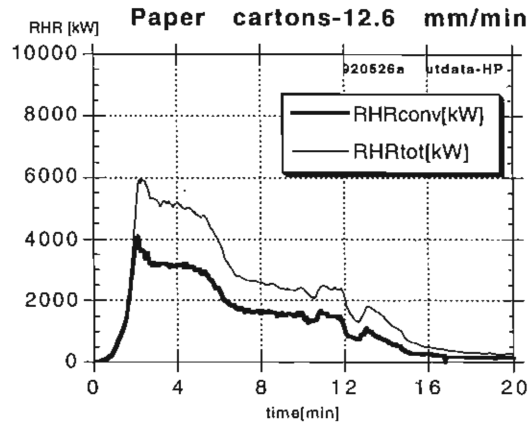


Figure 6 Total and convective RHR as a function of time for the unassembled, horizontally stored paper cartons.

Two tests with the horizontally stored paper cartons were conducted at 8.5 and 12.6 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 6.

Both tests resulted in a slowly decreasing RHR and the change in delivered water density gave only slightly different results. In the later part of the tests, some collapse of the fuel array decreased the RHR in steps.

Based on the RHR measurements, it is likely to assume that the test at 12.6 mm/min was more close to the "suppression region" than the "controlled region" and a third test at the lowest prescribed water density, 4.5 mm/min, is therefore necessary for a definite classification.

As shown in table 4 and figure 7, the two tests gave different Rank values at the two water densities. The more severe classification obtained using the delivered density of 12.6 mm/min is probably not relevant as this test not surely can be considered to be in the "controlled region".

Although a definite classification is not possible without a third test, the result from the test at 8.5 mm/min indicate that the commodity should have a Product Rank value of approximately 2. It should then be protected as a Class II commodity according to the FMRC classification system.

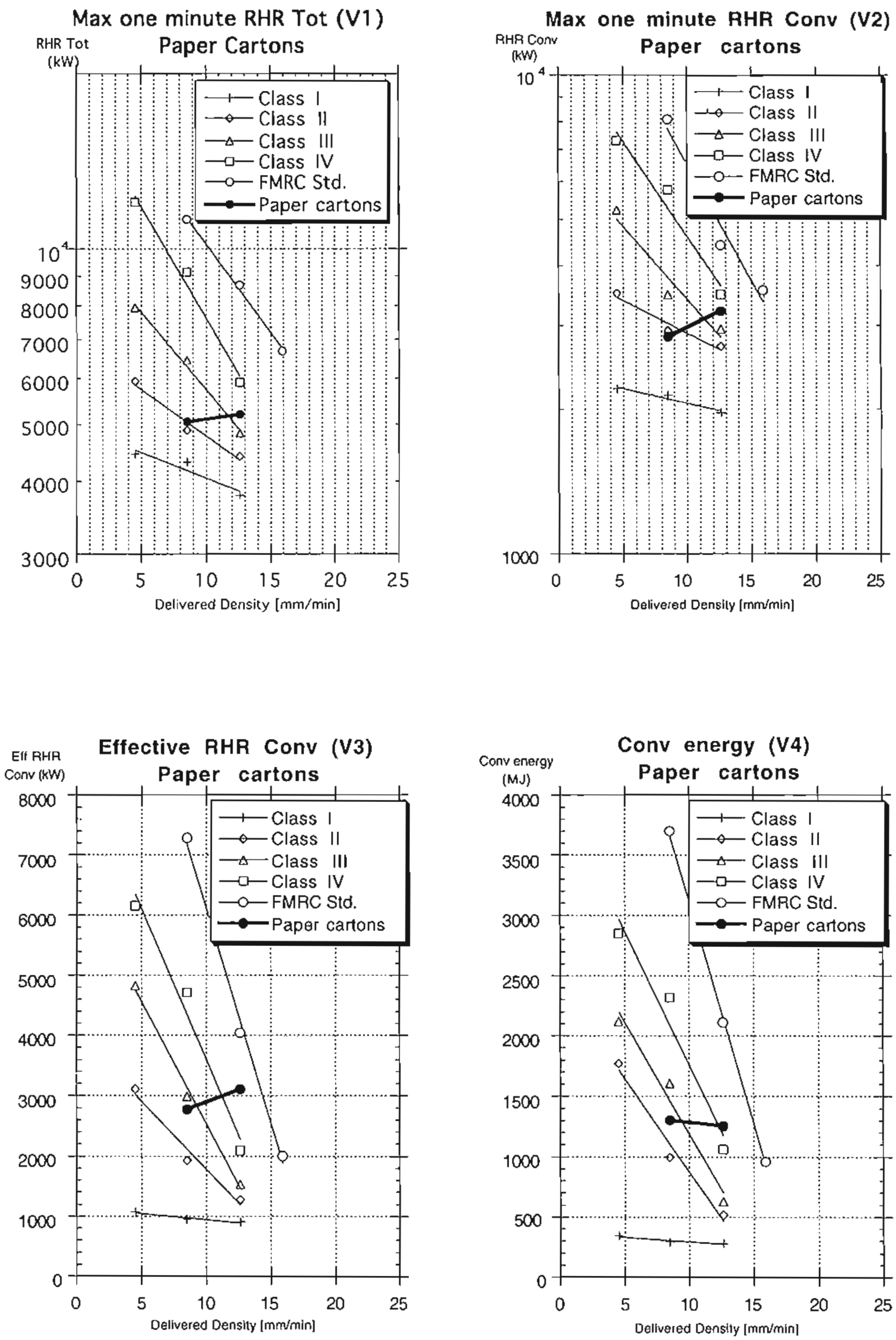


Figure 7 The measured values V1-V4 for paper cartons in comparison with the results obtained with the FMRC standard commodities.

7.2 Test results-Magazine files

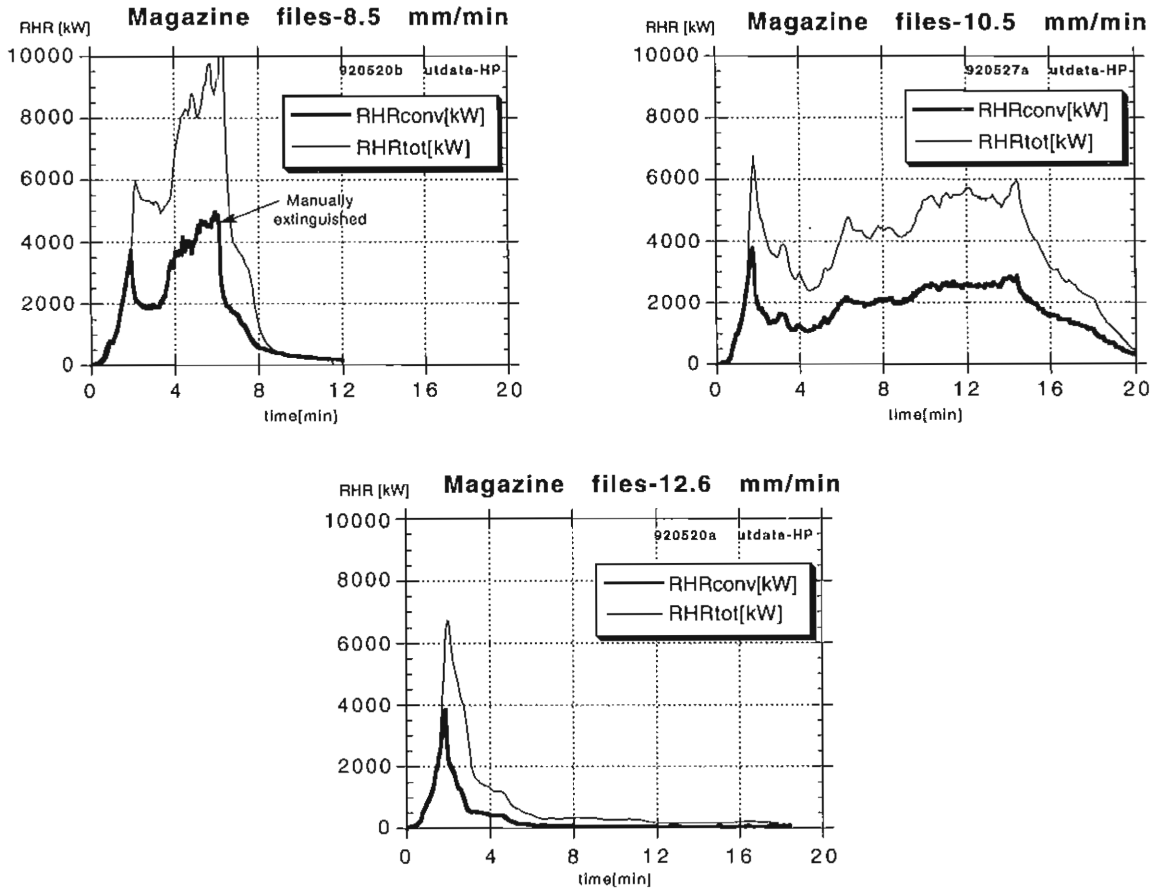


Figure 8 Total and convective RHR as a function of time for the magazine files

Three tests with the plastic (polystyrene) magazine files and letter trays in paper cartons were conducted at 8.5, 10.5 and 12.6 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 8.

During the test at 8.5 mm/min the fire was first reduced by the water application but increased then in intensity and was extinguished manually as the capacity of the Industry Calorimeter was exceeded. The next test was conducted at 12.6 mm/min which resulted in a relatively fast suppression of the fire. Based on these results it was considered of no use to run a third test lower than 8.5 mm/min as the capacity of Industry Calorimeter would not be sufficient. The third test was therefore conducted at a "non-standard "water density, 10.5 mm/min, which resulted in a well controlled fire with almost constant RHR until the commodity was consumed.

Unfortunately is it impossible to give any definite ranking based on the three tests conducted. Two further tests have to be conducted at 4.5 and 8.5 mm/min as this will represent the "control region". Measures will then have to be taken to assure an increased capacity of the Industry Calorimeter. The test at 12.6 mm/min is clearly in the "suppression region" and is not relevant for ranking.

A definite classification can not be given, but at the time of termination of the test at 8.5 mm/min, the values of V1 and V2 indicate Rank values more than 4 and the "non-standard" test at 10.5 mm/min approximately 3 (see figure 9). However, it is not unlikely that the final Product Rank value would be 4 to 6, corresponding to Class IV to unexpanded Plastic A.

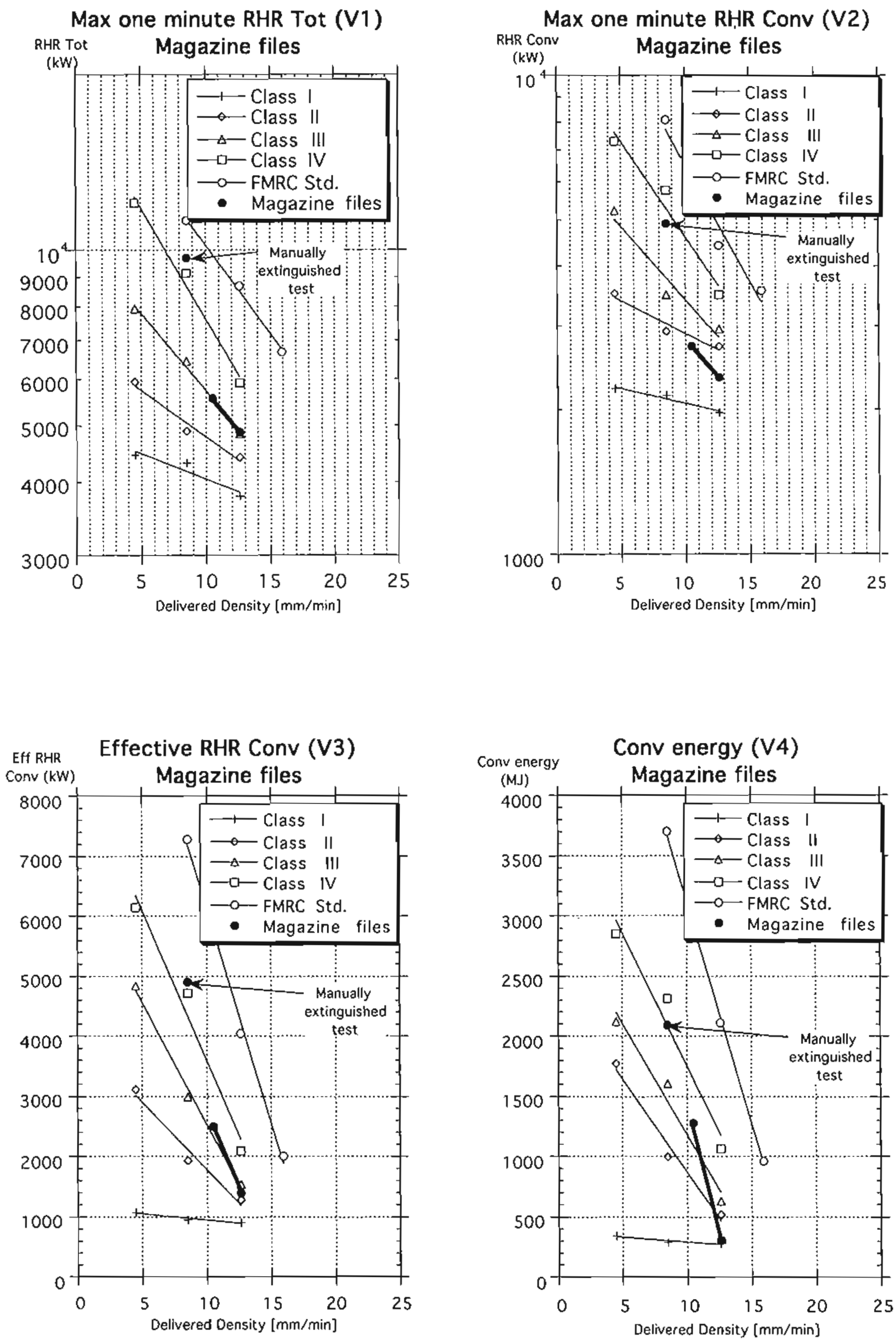
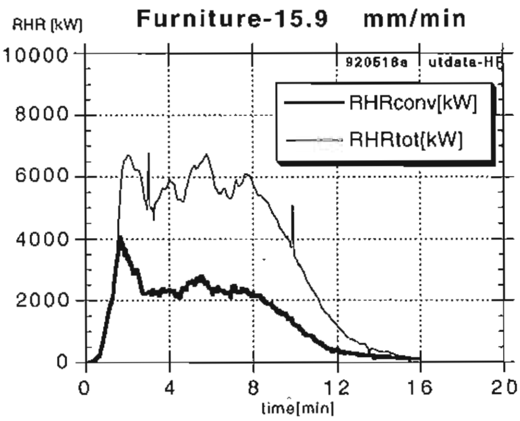


Figure 9 *The measured values V1-V4 for magazine files in comparison with the results obtained with the FMRC standard commodities.*

7.3 Test results-Upholstery cushions



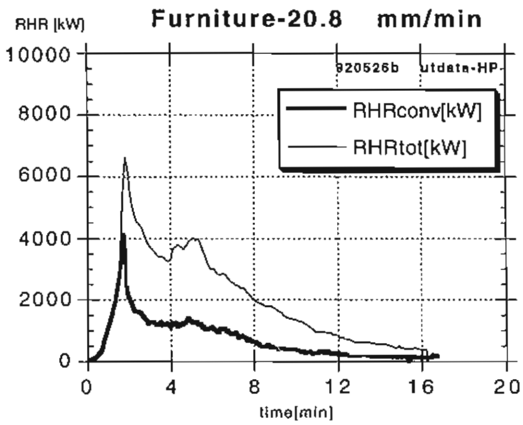


Figure 10 Total and convective RHR as a function of time for the upholstery cushions

Two tests with the upholstery cushions in paper cartons were conducted at 15.9 and 20.8 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 10.

During the test at 15.9 mm/min the fire was reduced and resulted in almost constant RHR until the commodity was consumed. As there were test goods for only two tests, the second test was run at the "non-standard water density, 20.8 mm/min. The reason was to avoid the possibility that the test had to be terminated. In this test, the convective RHR was reduced to about 1 MW initially and then more slowly until the fire was extinguished which indicates that the water density used is in the "suppression region" and is not relevant as a base for ranking.

A definite classification is not possible to give without running two further tests at 12.6 mm/min and 8.5 mm/min, which both for sure would be in the "control region". However, it is possible to get an indication based on the Rank values from the 15.9 mm/min test. As shown in table 4 and figure 11, the test indicates a Mean Unit Rank value higher than 6 (6+as the V4-value is falling into the "Ex" category).

As an indication, it is possible to assume that a final Product Rank value would be 6 or more which means that the commodity should be protected at least as an unexpanded Plastic A commodity according to the FMRC classification system. However, it is not unlikely that it might fall into the Extra Hazard category.

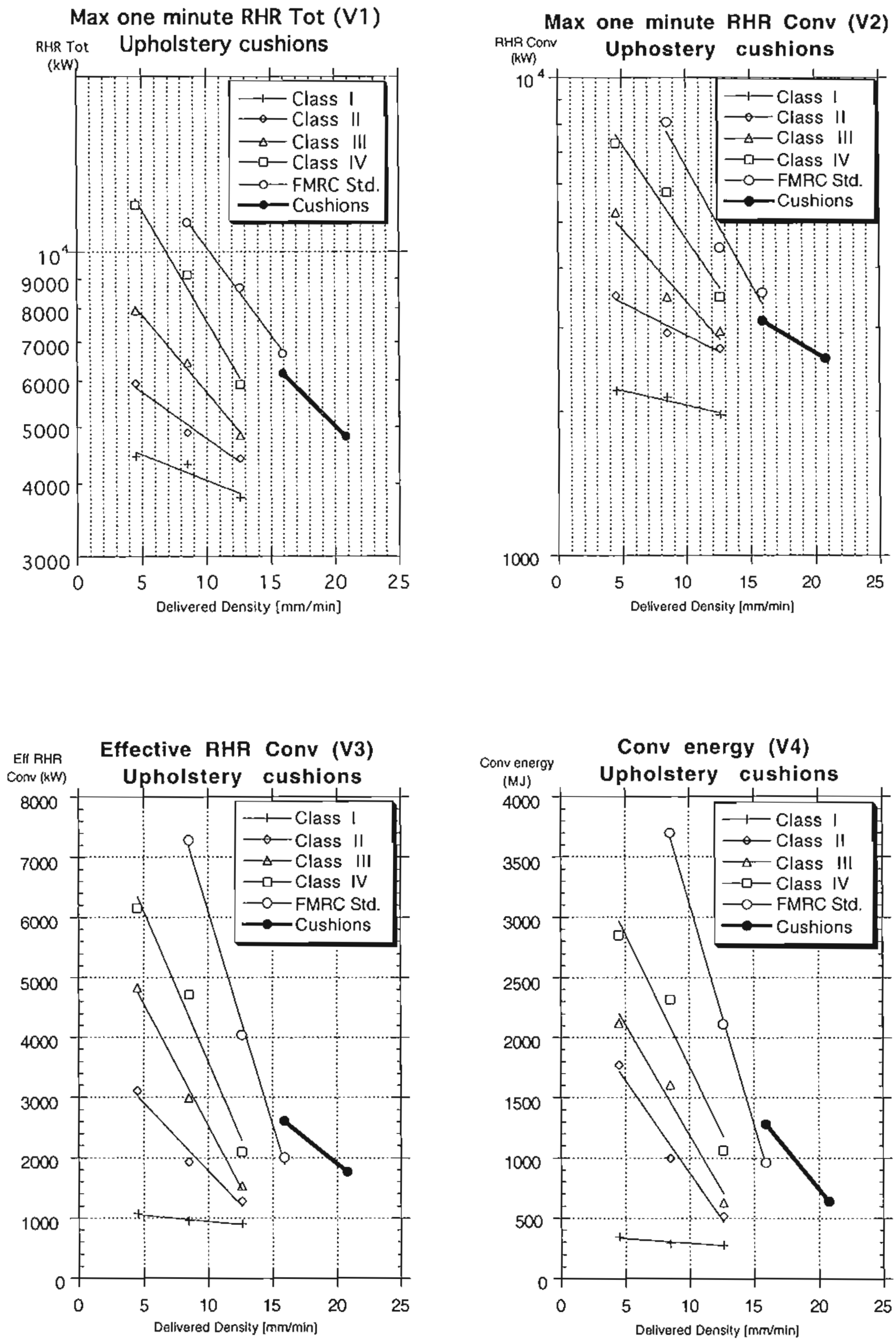


Figure 11 The measured values V1-V4 for upholstery cushions in comparison with the results obtained with the FMRC standard commodities.

7.4 Test results-Polystyrene chips

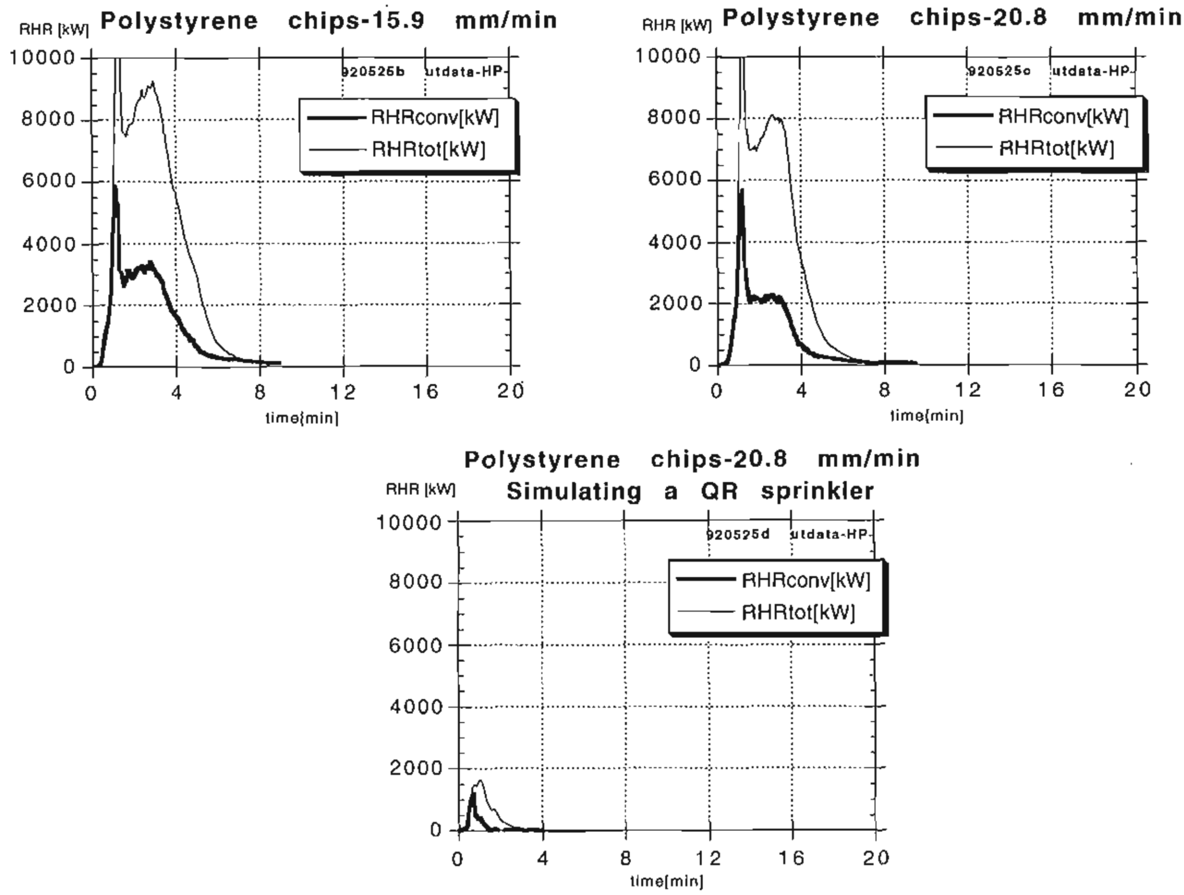


Figure 12 Total and convective RHR as a function of time for the polystyrene chips

Three tests with the polystyrene chips in paper cartons were conducted, one at 15.9 and two at 20.8 mm/min. The heat release rate (RHR) measurements obtained during the tests are presented in figure 12.

In the first test at 15.9 mm/min the commodity was completely consumed. The water density was therefore increased to the "non-standard" water density, 20.8 mm/min in the next test. The reason was to avoid the possibility that the test had to be terminated. The RHR was reduced slightly more but the commodity was still completely consumed. A further increase of the delivered water density was considered to be of limited interest. Instead a third test was run where a quick response sprinkler was simulated. As shown in figure 11, the result was completely different, leading to a very quick suppression of the fire. The result is however not relevant for ranking.

Also for this commodity, it is only possible to give specific Rank values from one of the tests. As shown in table 4 and figure 13, the test at 15.9 mm/min indicates a Mean Unit Rank value higher than 5.9 (5.9+ as the V1-value is falling into the "Ex" category). Even though it is not possible to give any Rank values from the test at 20.8 mm/min, it can not be considered to be in the "suppression region" as the commodity was completely consumed and the results plotted in figure 13 indicates that the classification should be "Ex".

A definite classification is not possible, but as an indication, it is very likely to assume that a final Product Rank value would be above 7.0 which means that the commodity falls into the Extra Hazard category.

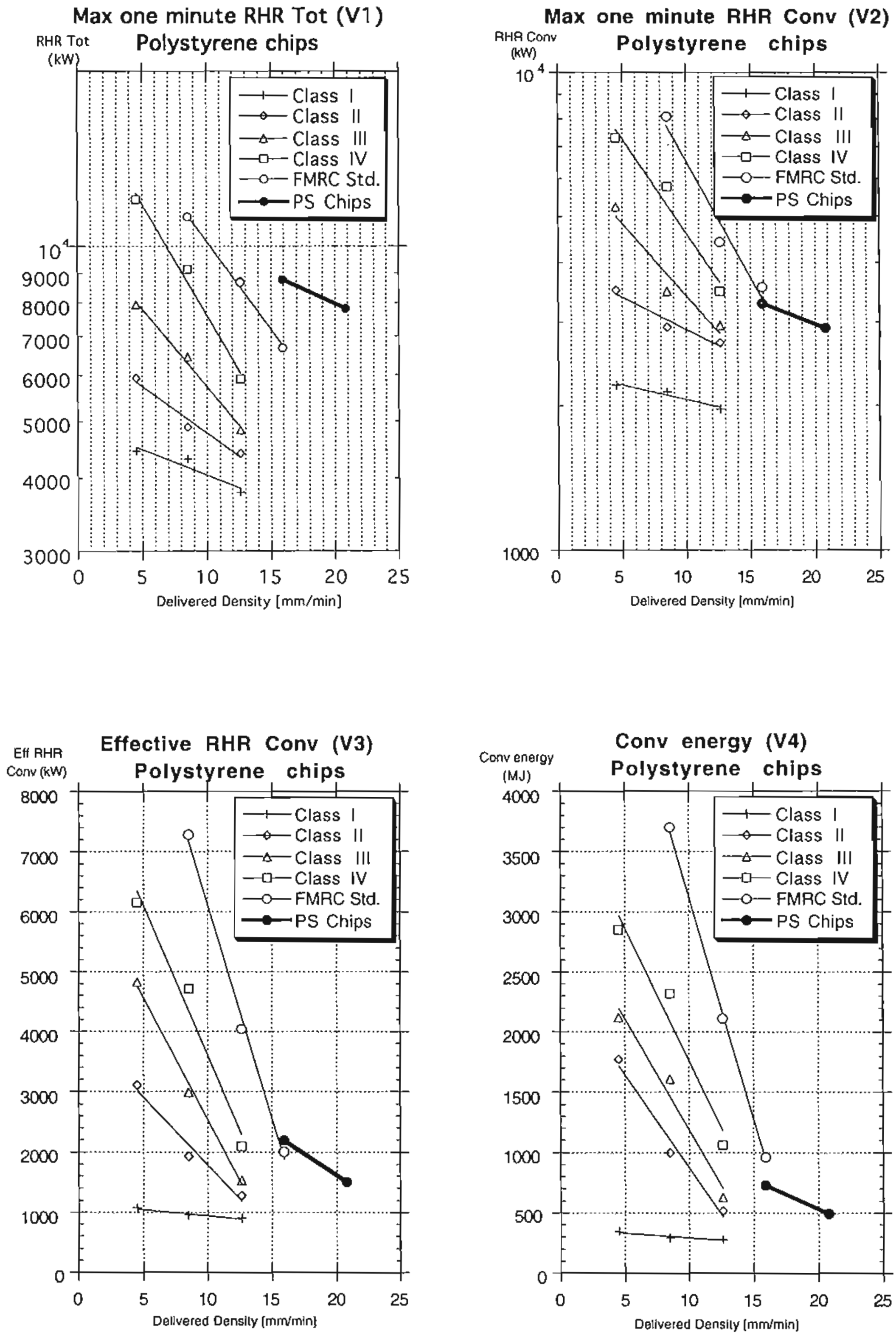


Figure 13 The measured values V1-V4 for polystyrene chips in comparison with the results obtained with the FMRC standard commodities.

7.5 Test results-PET bottles

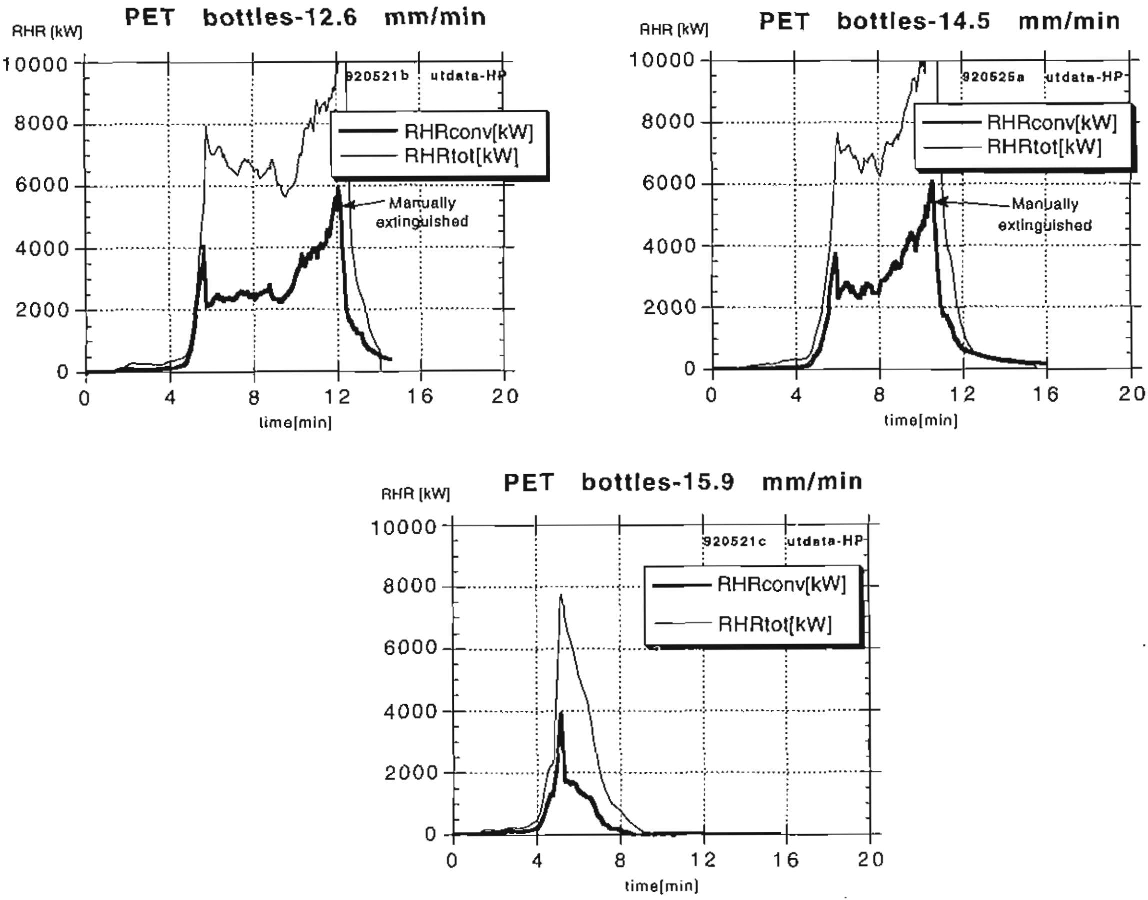


Figure 14 Total and convective RHR as a function of time for the PET bottles

Three tests with the PET bottles were conducted at 12.6, 14.5 and 15.9 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 14.

During the test at 12.6 mm/min the fire was first reduced by the water application but increased then in intensity and was extinguished manually as the capacity of the Industry Calorimeter was exceeded. The next test was conducted at 15.9 mm/min which resulted in a relatively fast suppression of the fire. Based on these results it was considered of no use to run a third test lower than 12.6 as the capacity of the Industry Calorimeter would not be sufficient. The third test was therefore conducted at the "non-standard" water density, 14.5 mm/min. Also in this test the fire was first reduced by the water application but increased then in intensity and was extinguished manually as the capacity of the Industry Calorimeter was exceeded.

Unfortunately is it impossible to give any definite ranking based on the three tests conducted. Two further tests have to be conducted at 12.6 and 8.5 mm/min as this will represent the "control region". Measures will then have to be taken to assure an increased capacity of the Industry Calorimeter. The test at 15.9 mm/min is clearly in the "suppression region" and is not relevant for ranking.

A definite classification can not be given, but at the time of termination of the test at 12.6 mm/min, the values V1 and V2 indicate Rank values more than 7 and "Ex", respectively.

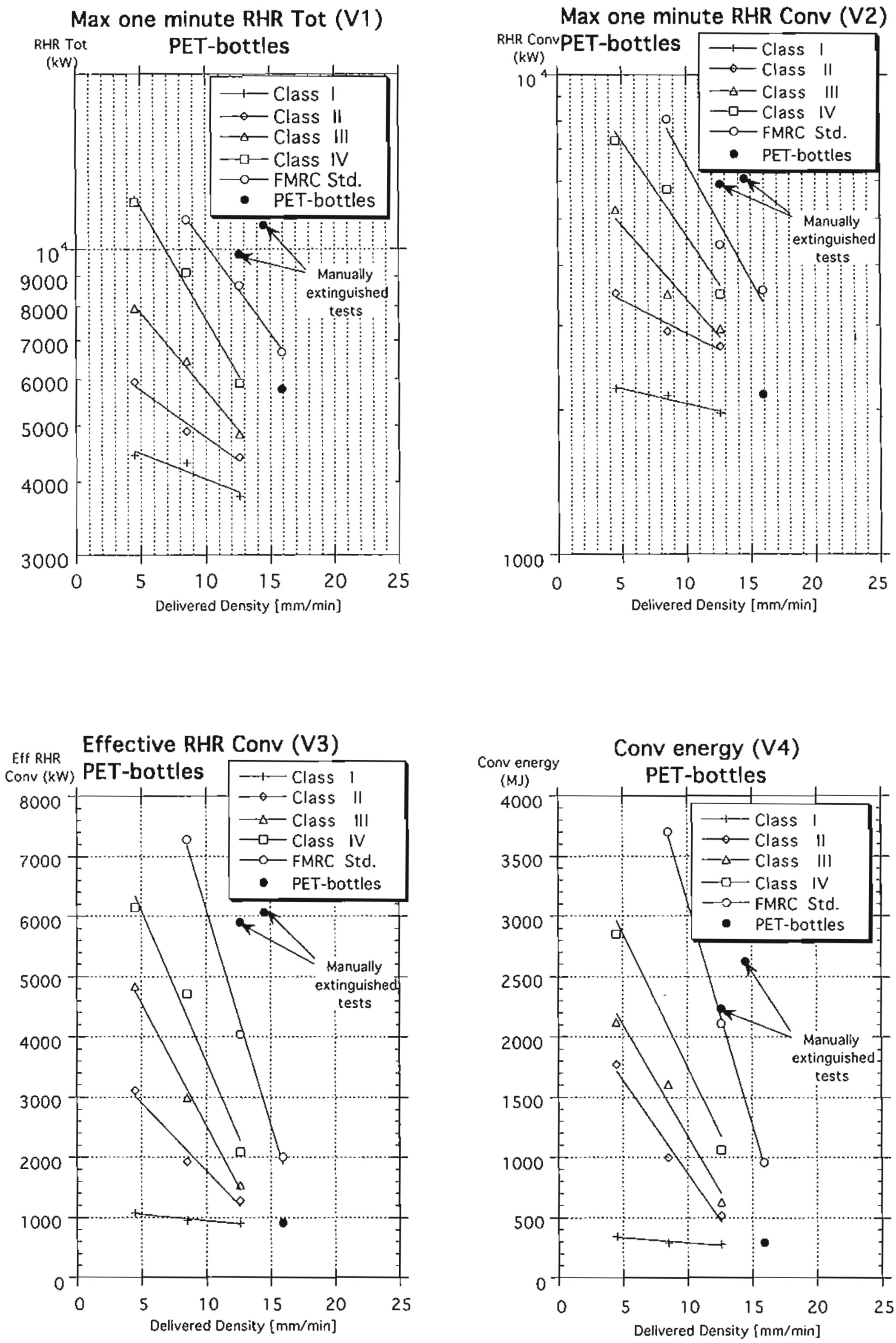


Figure 15 The measured values V1-V4 for PET bottles in comparison with the results obtained with the FMRC standard commodities.

7.6 Test results-FMRC Plastic

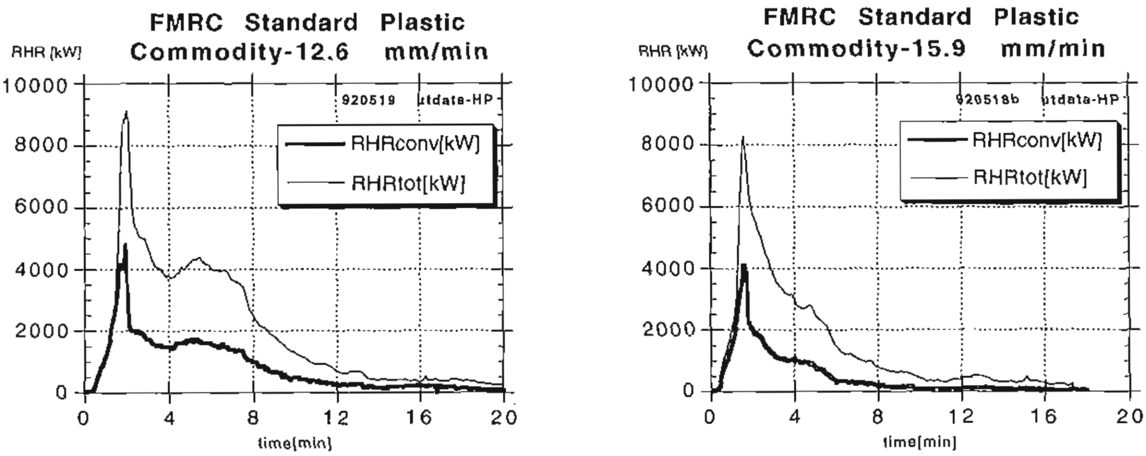


Figure 16 Total and convective RHR as a function of time for the FMRC Standard Plastic

Two tests with the FMRC Standard Plastic commodity were conducted at 12.6 and 15.9 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 16. The aim was to study the correlation between the test results and ranking obtained at FMRC and at SP. In these tests, the SP water applicator for US-pallets was used.

Both tests resulted in a considerably greater reduction of the RHR compared to the results obtained at FMRC. As shown in table 4 and figure 17, the Rank values obtained are therefore also considerably lower than those achieved at FMRC, especially at 12.6 mm/min.

The most likely reason for this difference is the difference in the design of the water applicator. As described in chapter 5.2, the overshoot of water is considerably higher for the SP applicator, 28 % versus 12 %, resulting in about 20 % higher total flow rate of water compared to the FMRC version to achieve the same delivered water density. According to FMRC experience [24] this overshoot may approach 0 % under fire conditions due to the effect of fire plume entrainment. The results might therefore be compared based on the total water flow, in other words, our results at 12.6 mm/min (92 l/min) could be compared to the FMRC results at 15.9 mm/min (approx 95 l/min). The effect of such a correction is most easy to study in figure 17. The plotted results would then "move to the right by one step", which indicates a much better correlation. If such correction is made, the correlation is much better and the Mean Unit Rank would be approx. 6.0 which corresponds to a correct classification.

The test at 15.9 mm/min (which in practice was higher) is clearly in the "suppression region" and is not relevant for ranking.

The influence of the water application design in relation to the commodity measures is also shown in the tests with the "EUR Plastic" (see chapter 7.8). However, further tests have still to be conducted to verify the correlation between the test results and ranking obtained at FMRC and at SP and a proposal for such a work is further discussed in chapter 9.4.

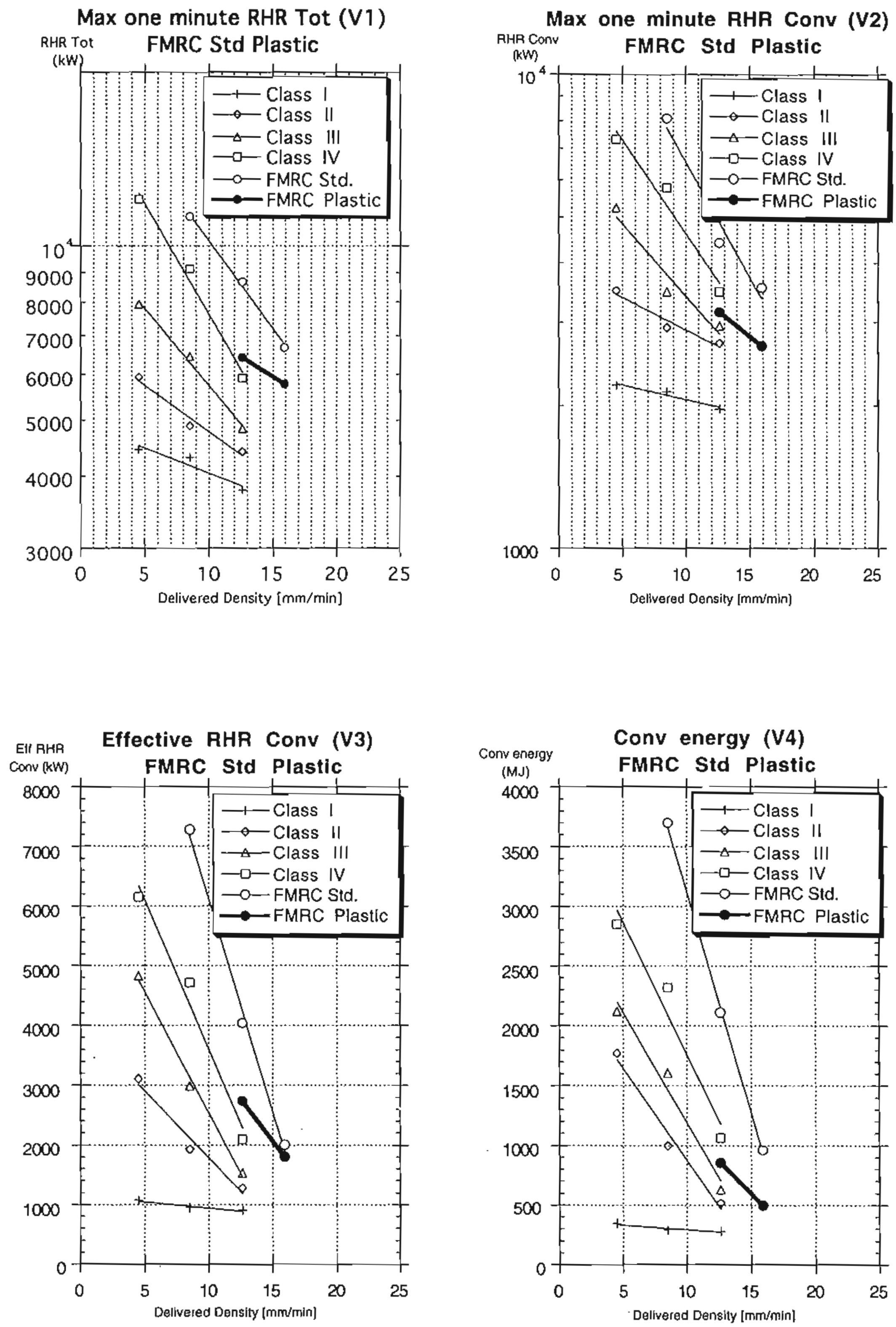
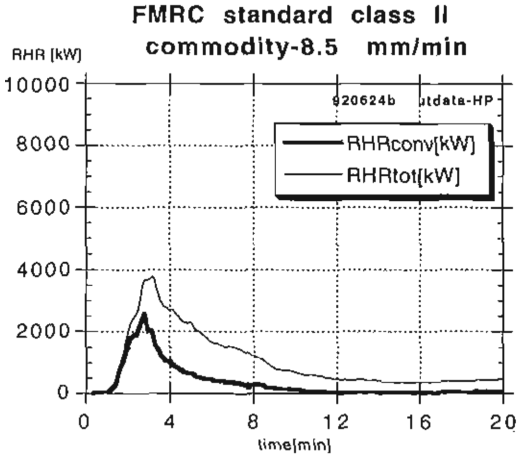


Figure 17 The measured values V1-V4 for the FMRC Standard Plastic commodity tested at SP in comparison with the results obtained with the FMRC standard commodities. A correction of the results due to the design of the water applicator would "move the results to the right" resulting in a better correlation than shown in the figure.

7.7 Test results-FMRC Class II



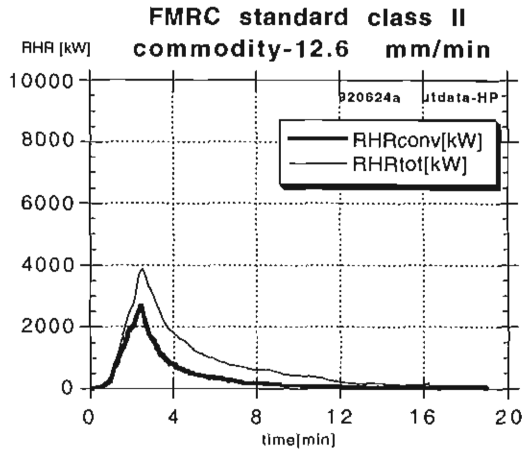


Figure 18 Total and convective RHR as a function of time for the FMRC Class II

Two tests with the FMRC Class II standard commodity were conducted at 8.5 and 12.6 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 18.

Also here, the aim was to study the correlation between the test results obtained at FMRC and at SP. Based on the experience from the tests with the Standard Plastic commodity, it was decided to modify the water applicator in order to reduce the effect of the overshoot of water and thereby the influence of the higher total flow rate of water. Steel chutes were mounted around the top of the commodity in order to collect most of the overshoot water which otherwise would have been sprayed outside the commodities, see chapter 5.2.

Both tests resulted in a fast decrease of the RHR and the change of delivered water density gave only slightly different results.

As shown in table 4 and figure 19, the Rank values obtained are considerably lower than those achieved at FMRC, especially at 8.5 mm/min and for the parameters V1 and V2.

Although the use of the steel chutes, the true delivered water density during the tests is very uncertain. As mentioned for the Standard Plastic tests, the entrainment during fire conditions might change the spraypattern, reducing the effect of the steel chutes and result in an increased delivered density.

Another factor contributing to the different results might be the humidity in the cartons. According to Chicarello and Troup [7] the humidity was about 7 % in the FMRC tests, while in our tests, the humidity in the cartons was around 11 %. In the FMRC tests the nozzle operation (calculated sprinkler operation) was achieved after about 1:50 to 2:00 minutes. In our tests the corresponding time was 2:25 minutes (12.6 mm/min) and 2:48 minutes (8.5 mm/min), respectively. This indicates a slower fire development, especially in the 8.5 mm/min test, which in turn results in a nozzle operation at a lower heat release rate. This effccts directly the values of V1 and V2 which explains the too low Rank values considering these two parameters. Further on, the smaller the fire is at water application, the easier the fire is to extinguish. This might of course also contribute to the differences between the FMRC and SP test results.

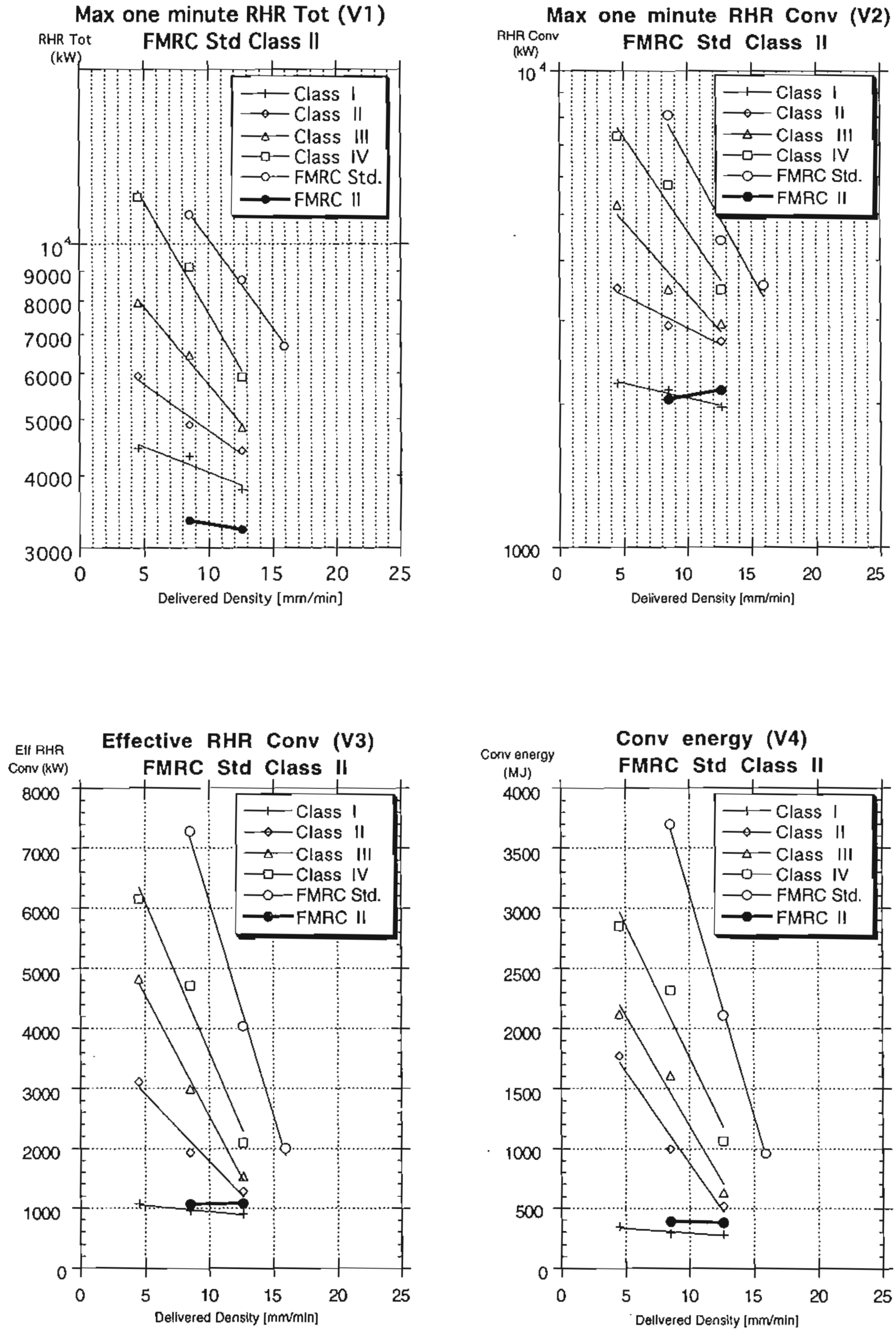


Figure 19 The measured values V1-V4 for the FMRC Class II commodity tested at SP in comparison with the results obtained with the FMRC standard commodities. The water applicator design and different humidity in the cartons is two probable reasons for the different classification.

7.8 Test results-"EUR" Plastic

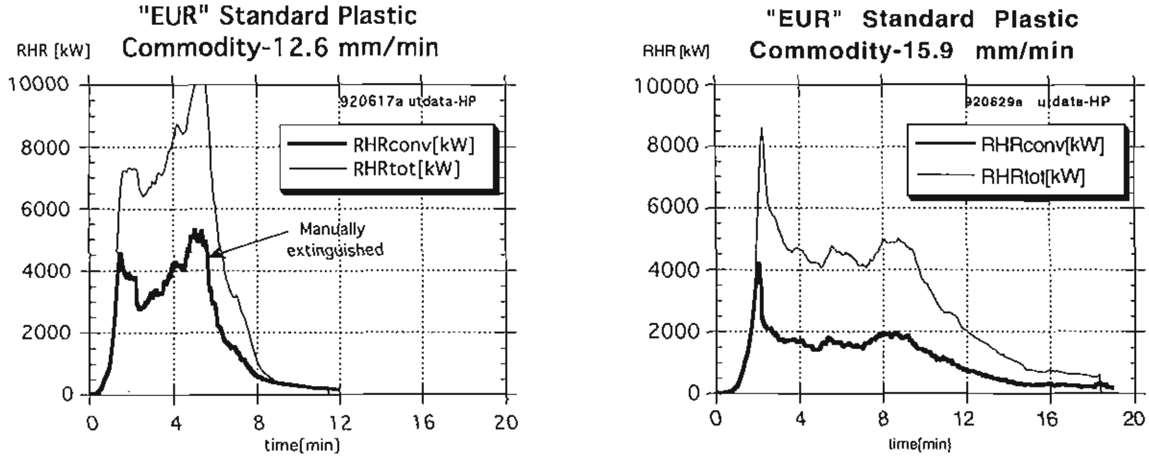


Figure 20 Total and convective RHR as a function of time for the "EUR" Plastic

Two tests with the "EUR" Standard Plastic commodity were conducted at 12.6 and 15.9 mm/min and the heat release rate (RHR) measurements obtained during the tests are presented in figure 20.

In order to verify the influence of the water applicator design, it was decided to repack the remaining Standard Plastic commodities in paper cartons fitting the European pallet size, 1200x800 mm, as the SP water applicator primarily is designed for this pallet size. The overshoot of water is then reduced from 28 % to 8 % which correlates reasonable well with the 12 % overshoot from the FMRC water applicator.

During the test at 12.6 mm/min the fire was first reduced by the water application but increased then in intensity and was extinguished manually as the capacity of the Industry Calorimeter was exceeded. The next test was conducted at 15.9 mm/min which resulted in a well controlled fire with almost constant RHR until most of the fuel was consumed.

Unfortunately, it is only possible to give specific Rank values from the second test, but as shown in table 4 and figure 21, both tests verified the influence of the water applicator design. In the 15.9 mm/min test, the correlation of the Rank values based on the V3 and V4 parameters are very good while the Rank values based on the V1 and V2 parameters were too low. As for the Class II commodity tests, this can be explained by the somewhat slower fire development in this test. Both in the FMRC tests [7] and in the 12.6 mm/min test, the nozzle operation was achieved between 1:26 and 1:40 minutes, while it was 2:00 in the 15.9 mm/min test. As previously mentioned, slower fire development results in a nozzle operation at a lower RHR which in turn results in a lower Rank value for the V1 and V2 parameters. The reason for this slower fire development is, however, not known.

The test at 12.6 mm/min indicates a slightly more severe ranking compared to the FMRC tests. One possible reason for this might be that the cartons were not perfectly rectangular in shape. As the cups were a little too large in diameter in order to fit in the cartons, this resulted in slightly "swollen" cartons, giving small flue spaces between the cartons which in turn could increase the fire severity. This effect is of course more pronounced, the lower the water density is.

A general conclusion of the tests is that the correlation with the FMRC test results is much better and the tests verify the influence of the water applicator design. However, further tests are needed to verify a full correlation and a proposal for such tests are mentioned in chapter 9.4.

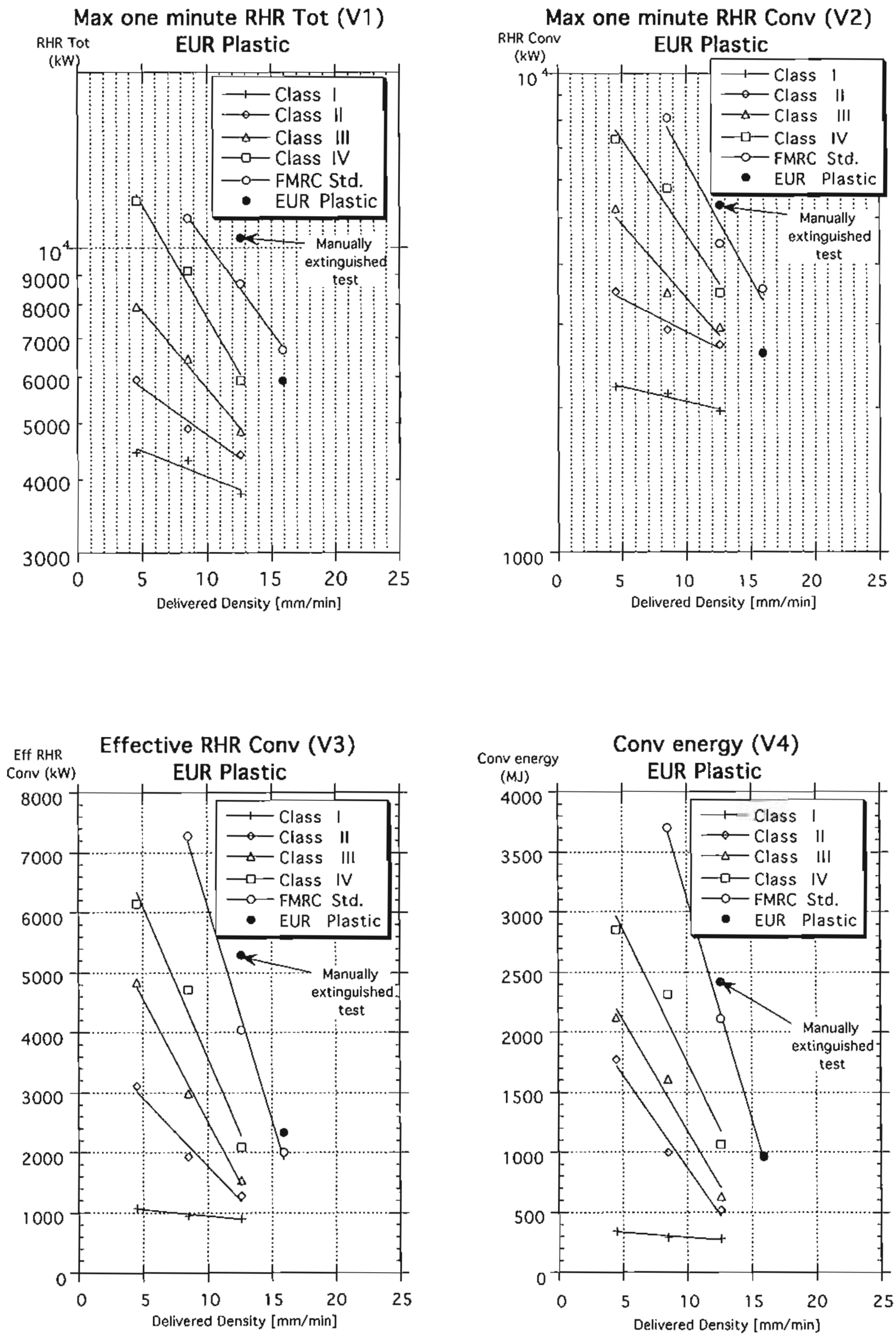


Figure 21 The measured values V1-V4 for the "EUR" Standard Plastic commodity in comparison with the results obtained with the FMRC standard commodities.

8 Comparison of classification and level of protection between US and European standards

The test commodities for this project were chosen based on their classification according to the Swedish sprinkler standard, RUS 120 [17] while the classification achieved from the tests are based on the FMRC commodity classification [14]. In order to evaluate the results achieved, the classification system used at FM and in Sweden together with the required level of protection (minimum design water density and operation area) for the various classes must be compared.

A complete comparison is probably impossible to make as the US and European standards differ in many technical aspects. For the purpose of this project, we have chosen to compare a certain storage configuration (which is not to complex), a 6.1 m high palletized storage protected by ceiling sprinklers only. Only ordinary combustibles and plastics have been included in the comparison. Both FM and NFPA have separate standards for certain products such as rubber tires, roll paper storage, aerosols, flammable liquids, etc, which are not included in this comparison.

As US-sprinkler installations can be based on standards both from FM and NFPA, standards from both these organisations have been used [14, 20, 21, 22]. In Europe most countries have their national sprinkler standards, very often quite similar as they all are based on the CEA sprinkler standard. Within CEN, work is under way to develop a common standard which is supposed to replace all the national standards. In our comparison, reference has therefore been made both to the existing Swedish sprinkler standard [17] and to a draft European standard [23].

It is important to understand that this is not a complete comparison and there might be limitations and additions which are not fully covered. Other storage conditions, e.g. where in-rack sprinklers are required might have given other results and conclusions.

8.1 Commodity classification

The commodity classification in all standards are based on descriptions and examples of various commodities falling into the various classes. A commodity is here defined as the combination of products, packing material and container. The European sprinkler standards normally covers all types of commodities and hazards and the classification and required level of protection is based on four classes or categories, 1-4. Various plastic materials are classified based on whether expanded or not. They are, however, not separated in any other form depending on e.g. composition.

In the Swedish standard, the final classification of a commodity is based on a separate classification of the product and the packing material. The highest classification of these two gives the final storage category according to table 5.

Table 5 The Swedish commodity classification is based on separate classification of the product (V1-V4) and packing material (F1-F4). The worst classification gives the final classification, Storage Category L1-L4.

	Packing category			
Product category	F1	F2	F3	F4
V1	L1	L2	L3	L4
V2	L2	L2	L3	L4
V3	L3	L3	L3	L4
V4	L4	L4	L4	L4

In US there are four classes for ordinary combustibles, I-IV, plus two basic classes of plastics, unexpanded and expanded. The plastics are then divided into group A, B and C depending on the generic type of plastic which influence the required level of protection. However, the definition of these groups is not identical between FM and NFPA and e.g. some plastics defined as a group B plastic by FM is defined as a group A plastic by NFPA. In addition, certain types of products are also covered by separate standards as mentioned above.

A general comparison of the list of commodities given in the FM standard [14] and the Swedish sprinkler standard [17] gives the following conclusions;

- Category L1 in Sweden might include commodities I-III according to FM
- Category L2 compares normally to class III and IV but some commodities would also be classified as Unexpanded Plastic
- Category L3 compares normally to Unexpanded Plastic
- Category L4 compares normally to Expanded Plastic

In all standards, the total content of plastic material is used to judge which classification should be used. The draft to CEN standard seems to correlate well with the existing limits used by FM as shown in figure 22. The Class I-III used by FM corresponds to Material Factor 1 by CEN, FM Class IV corresponds to Material Factor 2, FM Unexpanded Plastic to Material Factor 3 and FM expanded Plastic to Material Factor 4. The final classification in the CEN draft, Category 1-4, is based on the Material Factor but also on the commodity configuration.

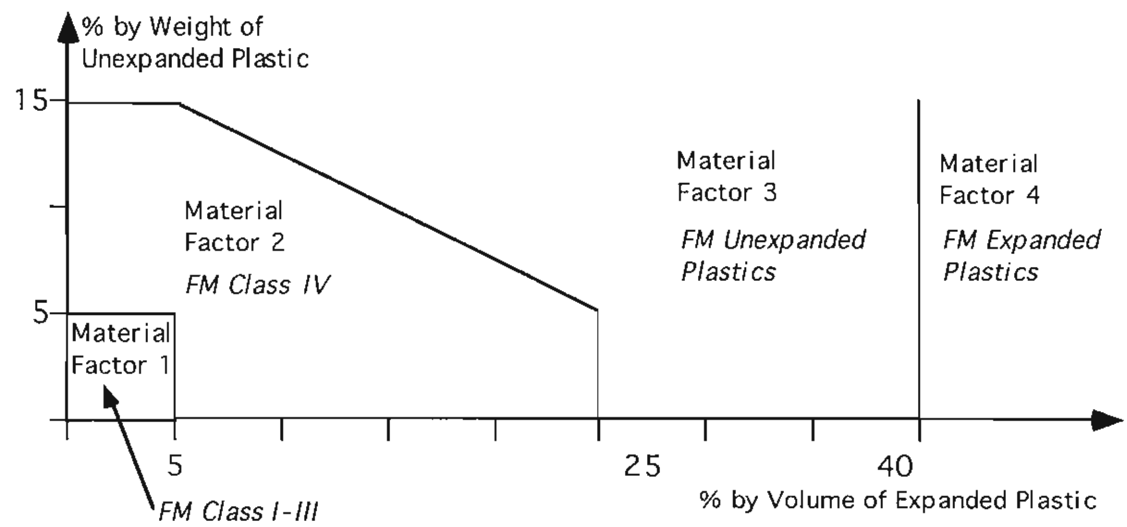


Figure 22 Classification according to the CEN draft and FM based on the content of plastics in the commodity in percent of volume and of weight.

The Swedish standard is based on the same principles as the CEN draft but the limits for plastic content are different. For L1 commodities, 10 % unexpanded or 5 % by volume expanded plastic is allowed. L2 commodities might only contain 15 % of expanded plastic. L3 commodities might be entirely made of unexpanded plastic but might not include more than 15 % expanded plastic. Any commodity having more than 30 % of expanded plastic should be a L4 commodity. However, the proposed level of protection, water density and operating area, is the same in the Swedish standard and the CEN draft, despite these differences.

The NFPA standard does not give any specific limits for the plastic content in a commodity, but the classification and level of protection is judged with aid of a decision tree according to figure 23. Depending on type of plastic, expanded or not, and on packing and storage, there are various requirements on level of protection. If there is a mixture of Group A and B plastics in a commodity, serious considerations have to be made in each case.

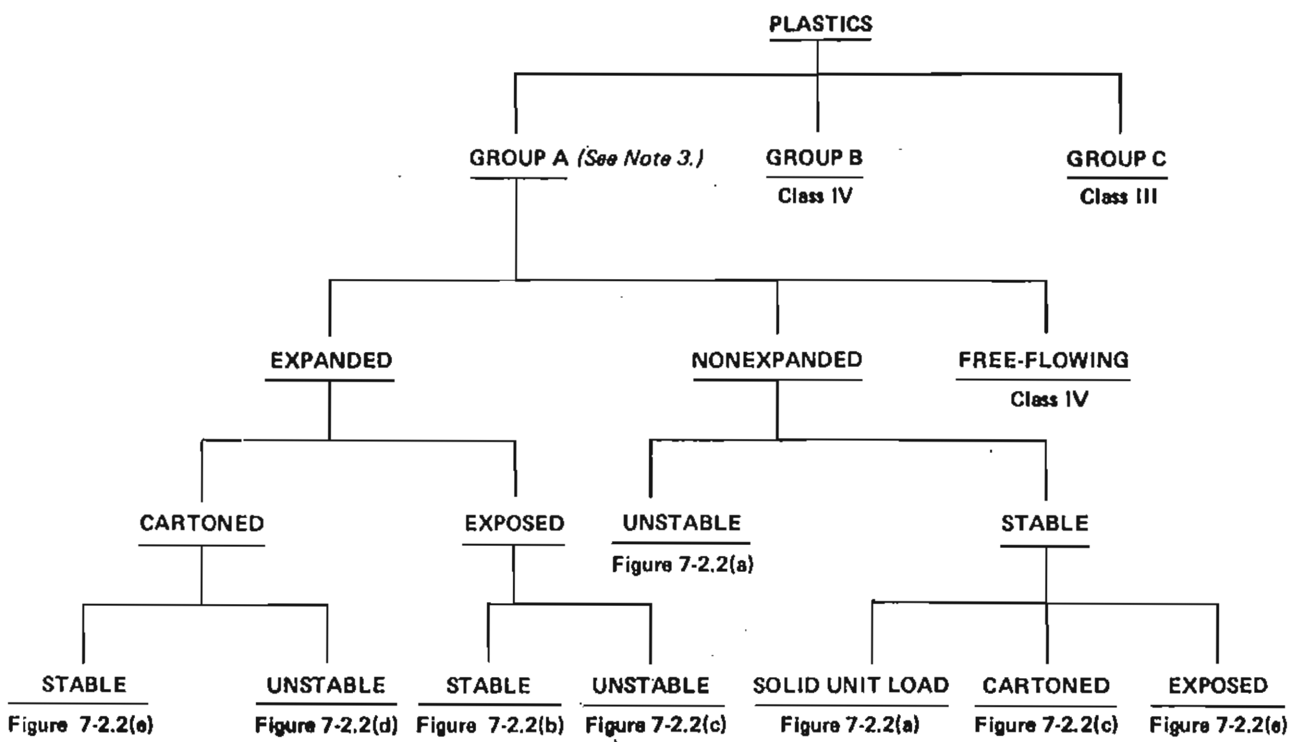


Figure 23 Decision tree used in the NFPA standard for general storage of plastics [22]. A similar decision tree is used for in-rack sprinkler protection.

8.2 Required level of protection

A general difference between the European and US standards is that in Europe there is only one single requirement for each type of storage. A certain commodity, storage and storage height gives one single value on design density and operation area as shown in table 6 [17]. There is no differentiation in the requirements between different temperature ratings on the sprinklers, although the rating assumed in most situations is 68°C-74 °C. It is mentioned that special considerations should be made if the clearance between the top of the storage and the ceiling sprinkler deflectors is more than 3.0 m, but without any specific guidance.

Table 6 Required level of protection for e.g. palletized commodities according to the Swedish standard. The requirements according to the CEN draft is almost identical.

Maximum storage height for the storage categories L1-L4 (m)				Water density (mm/min)	Operating area (m^2)
L1	L2	L3	L4		
5.3	4.1	2.9	1.6	7.5	250
6.5	5.0	3.5	2.0	10.0	250
7.5	5.9	4.1	2.3	12.5	250
	6.7	4.7	2.7	15.0	250
	7.5	5.2	3.0	17.5	250
		5.7	3.3	20.0	300
		6.3	3.6	22.5	300
		6.7	3.8	25.0	300
		7.2	4.1	27.5	300
		7.5	4.4	30.0	300

Both FM and NFPA uses the principle of "sprinkler demand design curves" which means that the required design density depends on the operation area. The requirements depend also on temperature rating, requiring higher density or larger operating area or both for 68-74 °C sprinklers. For the protection of plastics, NFPA recommends only the use of 141 °C sprinklers. There are also certain additions to the operating area depending on the clearance. If the clearance is more than 1.4 m, the operation area will be increased by a factor 1.0-2.5 depending on clearance and storage height.

For the protection of plastics, NFPA also requires an initial and a secondary water density and operation area, respectively. An example of such a design curve is shown in figure 24a). Depending on the classification according to the decision tree shown in figure 23, various design curves should be used. Both the initial and secondary requirements shall be met and the secondary density shall be at least 10 mm/min (0.25gpm/ft^2) less than the initial density. The diagrams show the requirements for 6.1 m storage height and a clearance of 0.5-1.4 m. Compensation factors for other conditions are given in additional diagrams, figure 24b)-c).

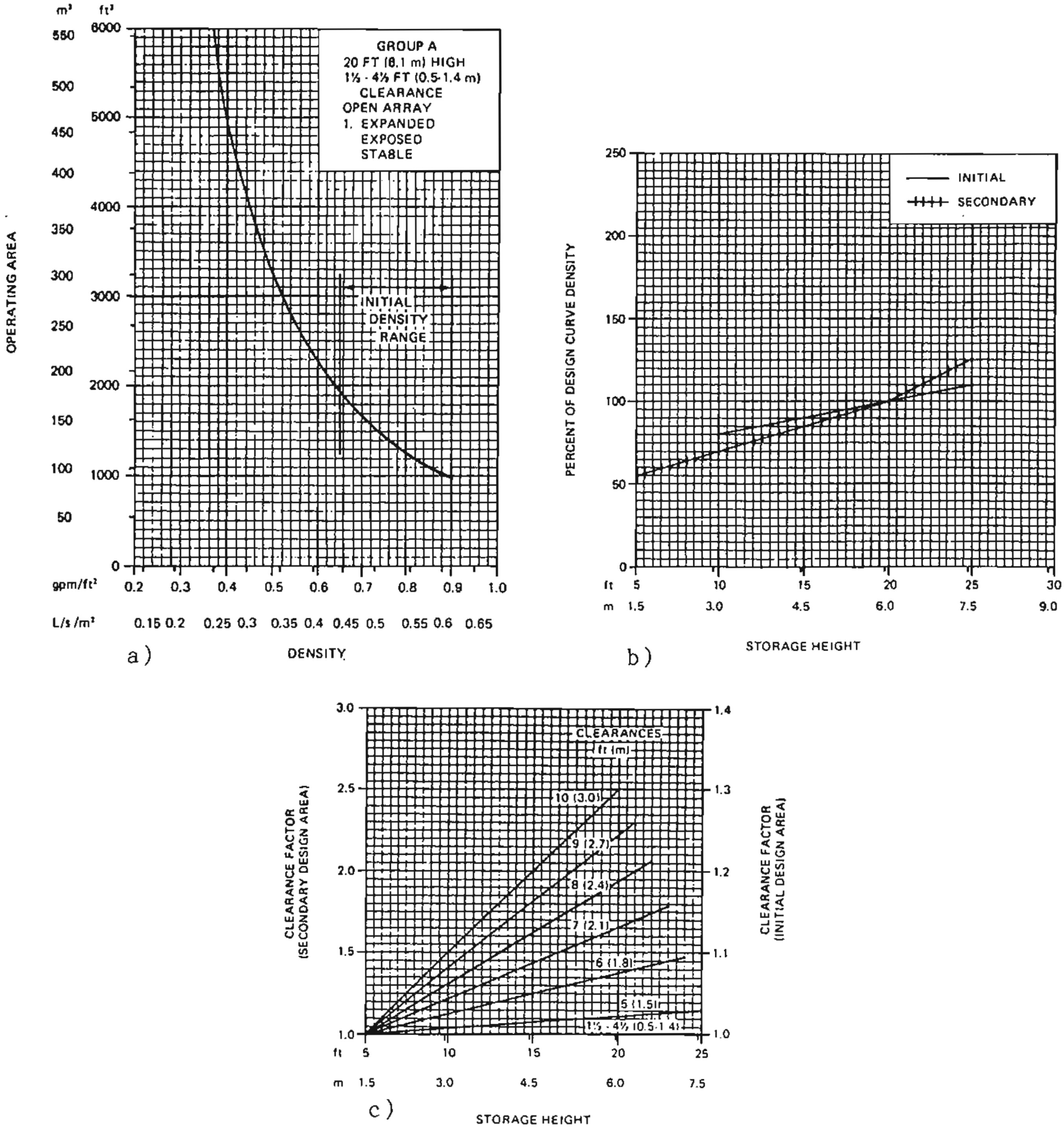


Figure 24 Example of a design curve, a), according to NFPA [22]. If storage height and clearance conditions differs, compensation should be made according to diagramme b) and c).

A comparison of the required level of protection has been made for palletized commodities classified as L1-L4 in the Swedish system and Class I-IV up to Expanded Plastic A in the FM- and NFPA systems, respectively, as shown in tables 7-9. The storage height was chosen to 6.1 m (20 ft) as this is the base height specified in the US standards. Where design curves are used by FM and NFPA, the operation area has been chosen to 250 and 300 m^2, respectively, as this is specified in the Swedish standard. To make the comparison possible, the water densities specified in the Swedish standard has been interpolated to 6.1 m storage height. 3.0 m clearance is assumed if no other notes are given.

Table 7-9 Required level of protection for various commodities according to RUS 120-3 [17], FM [20,21] and NFPA [22]. Basic conditions for the tabulated data are a palletized storage, storage height 6.1 m, operation area 250 or 300 m^2 and a clearance of 3 m.

Table 7	Swedish sprinkler standard, RUS 120-3*		
Storage category	Water density (mm/min)	Operation area (m^2)	Total water flow (l/min)
L1	9.2	250	2300
L2	13.1	250	3275
L3	21.7	300	6510
L4	30.0 **	300**	9000*

* The requirements are equal to the CEN Draft [23]
** Water density required for 4.4 m, which is max storage height allowed

Table 8	FM Datasheet 8-25 and 8-9		
Commodity class	Water density (mm/min)	Operation area (m^2)	Total water flow (l/min)
I	6.0*	190	1140
II	6.0*	250	1500
III	7.1*	250	1775
IV	9.7*	250	2425
Plastic A and B nonexpanded	24** 24**	279 (141°C) 464 (74°C)	6700 11140
Plastic A and B expanded	24***	464***	11140***

* Only 100 °C and 141 °C sprinklers specified
** Only 0.9 m in clearance allowed (DS 8-9, table 1)
*** Only 141 °C sprinklers specified. Water density required for 4.6 m, which is max storage height (DS 8-9, table 1)

Table 9	NFPA 231		
Commodity class	Water density (mm/min)	Operation area (m^2)	Total water flow (l/min)
I	7.0*	250	1750
II	7.7*	250	1925
III	9.8*	250	2450
IV	13.2*	250	3300
Plastic A, nonexpanded, exposed, stable	36.6-Initial** 18.3-Secondary (Figure 7-2.2(e))	75 98*** 300 750****	2750 3590 5490 13730
Plastic A, expanded, exposed, stable	36.6-Initial** 20.4-Secondary (Figure 7-2.2(b))	90 117*** 300 750****	3300 4280 6120 15300

* Requirements for 74 °C sprinklers. The NFPA requirements for 141 °C sprinklers are almost identical to the FM requirements shown in table 8.
** Highest specified density/lowest operation area used. Only 141 °C sprinklers recommended
*** 0.5-1.4 m clearance normally assumed. Operation area corrected to 3 m clearance for comparison purpose (Operation area x 1.3 acc to Figure 7-2.2.2.)
**** 0.5-1.4 m clearance normally assumed. Operation area corrected to 3 m clearance for comparison purpose (Operation area x 2.5 acc to Figure 7-2.2.2.)

A comparison of the required level of protection based on the total water flow shows that;

L1 requirements cover approx. Class I-III according to the NFPA standard. A strict comparison with the FM standard is not possible as only 100-141 °C sprinklers are specified. However, assuming that the differences between 74 °C and 141 °C sprinkler protection specified in the NFPA standard also would be valid for the FM standard, L1 also corresponds to FM Class I-III.

L2 requirements correspond well with NFPA Class IV and assuming the same correction of the FM requirements as mentioned for L1 above, it also agrees to the FM Class IV.

L3 requirements are considerably lower than the FM requirements for unexpanded Plastic A when 74 °C sprinklers are used. The FM requirements for 141 °C sprinklers are however almost the same with respect to the total water flow but differs in water density and operation area. NFPA specifies only 141 °C sprinklers and a strict comparison is not possible. However, the total water flow is considerably higher than those specified in the Swedish and FM standards depending on the compensation factor for 3 m clearance.

L4 requirements seem in general to be considerably lower than those specified by FM and NFPA even though a strict comparison is not possible. The FM standard for expanded Plastic A specifies a maximum storage height similar to the Swedish standard but requires 141 °C sprinklers and also a higher total water flow. NFPA allows a storage height of 6.1 m also for the expanded Plastic A, but requires still 141 °C sprinklers and a considerably higher total water flow. A large portion of this high water demand is based on the 3 m clearance. A correction to a storage height of approx. 4.5 m reduces the initial and secondary water density to 90 % and 85 %, respectively, of that specified for 6.1 m and the corrected secondary operating area from 750 m^2 to 600 m^2. The water demand based on the secondary density will then be 10400 l/min, still based on the use of 141 °C sprinklers, which is slightly less than required by FM but still is higher than required by the Swedish standard.

9 Summary and conclusions

9.1 Classification method

The general conclusion from the tests, is that the FMRC classification test method will have a great potential to form the basis for an international accepted procedure to classify commodities. The method is able to provide a better and more reliable classification which of course will give a more reliable sprinkler protection. The tests have shown the importance of using identical test equipment and test procedure and to use test commodities as close to the specifications as possible. This information will be very valuable in the work to specify the test procedure more in detail which will be required for such a test method.

The commodity classification procedure enables a much more accurate commodity classification compared to the possibilities in the past. The fire tests, which is the base for the classification, give quantitative information on the behaviour of various commodities which in many cases is very difficult or even impossible to gain by personal judgements. The fire tests also enables the possibilities to gain general experience how various commodities behave during a fire by visual observation of the tests. Such valuable information is e.g. the tendency to collapse, melt, form pool fires, etc. The visual observations in combination with the RHR measurements give a good information of the fire development until the water is applied. This information can also be used as input to computer models in order to calculate temperatures, smoke filling, time to response of fire detectors or sprinklers, etc in various buildings.

Even though it has not been possible to fully verify the reproducibility of the method within this project, the tests have still been very valuable. Based on the experience gained in the project, more detailed technical specifications of test equipment and test set-up are proposed which are believed to solve the problems with the reproducibility. For verification purposes, some additional tests are also suggested.

The most important factors which have caused problems with the reproducibility are the design of the water application system in combination with the pallet size of the tested commodities. Earlier RDD-tests [11, 12, 13], using the same test equipment, showed a very good correlation between tests at FMRC and SP, respectively, contrary to the classification tests conducted in this project. The reason for this difference seems to be that in the RDD-tests, quick response sprinklers and fire suppression conditions were simulated. However, the classification tests simulates a slow response, high temperature sprinkler under fire control conditions. This latter scenario seems to emphazise the difference in the design of the water applicator design and the differences in the size of the commodities used at SP and FMRC, respectively.

Another factor which have shown to be critical in these tests is the capacity of the large scale calorimeter used for the heat release rate measurements. The Industry Calorimeter used at SP has an evacuation capacity about 20 % less compared to the FMRC calorimeter. This difference showed to be critical as the simulated controlled conditions during the test requires at least the evacuation capacity of FMRCs calorimeter. This was especially pronounced for the various plastic commodities which resulted in such a large spill of smoke from the Industry Calorimeter that the judgement to terminate some of these tests was taken.

These problems in combination with limited amount of commodities made it impossible to determine a final classification of the commodities used in the project. However, the tests have given certain indications of possible classifications which are presented in 9.3.

9.2 Comparison of classification and protection

In order to facilitate an evaluation of the classification results achieved, there has been a need to compare the classification system used at FM and in Sweden. Not only the classification has been compared but also the required level of protection (design density and operation area) for the various classes using standards from FM, NFPA, Sweden and the draft to an European (CEN) standard [14, 17, 20-23]. A complete comparison is probably impossible to make as the US and European standards differ from technical point of view. For the purpose of this project, we have chosen to compare a storage configuration with a 6.1 m high palletized storage protected by ceiling sprinklers only. Only ordinary combustibles and plastics have been included in the comparison.

In Sweden, and also in the proposed CEN standard, all commodities are classified into four categories. In Sweden these are defined as L1-L4, which each requires a certain level of protection. In US, there are six basic categories, Class I-IV plus unexpanded and expanded plastics. In addition to this, there are several specific standards for commodities containing flammable liquids, rubber tyres, roll paper, aerosols, etc.

A more detailed study of the classification and the level of protection indicates that a Swedish L1 commodity equals to commodities in Class I-III according to the US standards. This means that the required level of protection for low hazard commodities, corresponding to Class I and II, is higher in Sweden (Europe) than in US.

L2 commodities seem to correlate well with a US Class IV commodity, both from classification and required level of protection point of views.

Plastics are classified as L3 and L4 in Sweden and this classification corresponds reasonably well to Unexpanded and Expanded plastics, respectively, in the US standards. In Sweden there is no separation made for various generic types of plastic materials, while in US, the plastics are divided into three categories; Plastic A, B and C, where Plastic A is considered most hazardous.

The required level of protection for L3 and L4 commodities seems to be considerably lower in the Swedish and draft CEN standards compared to both US standards. There are also several basic differences. In US, 141 °C sprinklers are normally recommended or required for this type of hazard while 68-74 °C sprinklers are normally used in Europe. In the cases where both alternatives are given in the US standards, the lower temperature rating requires a considerably larger operation area and thereby total water capacity. In the Swedish standard, there is only one single requirement on water density and operation area for each commodity class. In US the water density and operation area may be varied according to certain "design curves" for each commodity class. In the NFPA standard regarding the protection of plastics, the design curves include requirements on both an initial and secondary water density and related operating area and both these requirements have to be met. The NFPA requirements are also based on a clearance of 0.5-1.4 m. If the clearance is more, like 3 m which is generally accepted in the Swedish standard, the initial and secondary operating areas have to be increased, e.g. by a factor 1.3 and 2.5, respectively, for a storage height of 6.1 m.

9.3 Results from classification tests

Eight various types of commodities have been tested in this project. The commodities were chosen, so that they by definition could clearly be classified into one of the four classes, L1-L4, used in Sweden [17]. No commodity classified as L1 was tested as commodities of class L2-L4 were considered more interesting. Two FMRC standard commodities were used to study the correlation with the results achieved by FMRC.

A detailed summary of the tests and the results are given in table 3 and 4 (chapter 7). A deviation from the test procedure proposed by FMRC was that most commodities were tested only at two water densities due to lack of test goods. Some tests were also terminated because the capacity of the Industry Calorimeter was exceeded. Further on and due to the behaviour of some of the tested commodities, some tests were conducted using a water density which is different from FMRC standard values. Consequently, the tests conducted within this project are not enough to form the basis for a final classification. Even though further tests would be required for all of the tested commodities to achieve a final classification, the tests give a reasonable indication of classification. Further on, the tests have also provided a lot of useful information and experience which will be of great importance for the future use and application of the method.

Table 10 gives a summary of the indicated classification based on the tests and a comparison to the traditional classification according to the Swedish standard. The translation of the "Product Rank value" to the present commodity categories is based on the comparison of classification based on descriptions as summarized in chapter 9.2.

As the tests can only indicate a possible classification, it is hard to give any final comments to the comparison. In general there seems to be a reasonable correlation even though the tests indicate that the classification for some commodities might be both lower and higher compared to the present Swedish classification.

The reason for these differences is not based on any fundamental error in the present classification system. It is rather showing the fact that when using a more accurate "instrument" for the classification it is suddenly possible to identify different behaviour and properties of various commodities even though they belong to the same generic group of commodities. The reason for the differences in classification that might show up during these classification tests can depend on the fact that the commodity contains products with various geometry, the products are packed in different way, e.g. horizontally or vertically, etc. All these kind of detailed differences are not fully recognised in the traditional classification even though it might have an important impact in the fire behaviour and suppressability of a commodity.

It is also important to realize the consequences of the classification as this directly influences the level of protection. Even if the classification by the traditional system and by testing only differs by one class, this will have a major influence on the design of the sprinkler system, especially when dealing with the higher classes e.g. concerning plastics. A commodity containing unexpanded plastics is normally classified and protected as a L3 commodity in Sweden. If the tests show that this commodity corresponds to a L4 commodity, this will require a much higher level of protection. As an example, a L4 palletized commodity may be stored to 4.4 m and the design criteria is 30 mm/min and 300 m^2. A L3 commodity might either be stored to 7.5 m using the same protection, or requires only 15 mm/min over 250 m^2 at 4.4 m storage height. The total required flow capacity might consequently differ with more than 100 %.

Table 10 Comparison of the indicated classification based on the tests and present classification according to the Swedish sprinkler standard (RUS 120-3)

Commodity	Indicated Product Rank according to the tests	Corresponding FM Class	Corresponding RUS category**	Present category according to RUS 120-3
Paper cartons	2	II	L1	L2
Magazine files	4 - 6	IV- Unexp Plastic A	L2-L3	L3
Cushions	>6 to Ex	Unexp Plastic A to Ex	L3-L4*	L4
PS Chips	Ex (>7)	Ex	L4*	L4
PET-bottles	>7 to Ex	Exp Plastic A to Ex	L4*	L3
EUR Plastic	5 - 6	Unexp Plastic B to Unexp Plastic A	L3	L3

* L4 is the highest possible classification according to RUS 120-3
** Based on description of the commodities, not on corresponding level of protection.
Ex Extra Hazard commodity

The indicated classification shows that the paper cartons are classified as L2 according to the Swedish standard while the tests indicate a slightly lower classification. However, one further test at a lower water density, 4.5 mm/min, is required.

Two tests with commodities containing expanded plastics were conducted. The classification tests of the cushions indicates Rank 6 up to Extra Hazard ("Ex") and the polystyrene chips "Ex". However, both commodities requires further tests at a lower delivered density to give a final classification. In the Swedish standard, both commodities are classified as L4 which must be considered as correct as this is the highest possible classification. A traditional classification according to the FM standards, shows that these commodities should have been "Expanded Plastic A" commodities (Rank 7).

The tests with the commodities containing unexpanded plastics, magazine files, PET-bottles and EUR Plastic shows clearly the need for a more accurate classification method. Although the commodities are all unexpanded plastics (L3), the classification tests indicate different classification, both lower and higher. However, also here it is important to emphasise the need of further tests at lower water densities.

A characteristic which is worth noting for the magazine files and PET-bottles was the sensitivity to the delivered water density. Both commodities showed different but very sharp limits between suppression and almost freeburning conditions. At higher densities the fire was suppressed, while when the delivered density was only slightly reduced, they formed a pool fire of melted plastic on the floor which considerably increased the fire severity. This condition did not appear for the FMRC Standard Plastic commodity, probably because the plastic is better contained by the compartmented paper cartons, prohibiting the formation of a pool fire.

It should also be noted that, according to Chicarello and Troup [7], the classification method is only valid for ordinary hazards and that commodities with exposed plastic very well might exceed the classification system. This seems to be the fact for the PET-bottles commodity which consisted of exposed plastic, empty PET-bottles in plastic crates.

The EUR Plastic consisted of a repacked version of the FMRC Standard Plastic commodity in order to obtain a commodity which fit the European pallet size and the water applicator used in the tests. A correct classification should have been Rank 6 while one of the tests indicated slightly lower classification and one test, which was terminated, a possible higher classification. There are some possible reasons for these deviations, one is that the cartons were slightly "swollen" resulting in small flue spaces between each carton which in turn could increase the fire severity. Another factor is that the initial fire development were slower in one test, resulting in lower peak heat release rates and thereby lower classification.

The tests with the original FMRC standard commodities did not fully correlate with the test results achieved by FMRC. Possible reasons for this deviation are that the design of the water applicator used in the tests did not fit to the US pallet size and different humidity in the tested cartons.

Both the tests with the EUR plastic and the original FMRC standard commodities were, as mentioned, not fully successful in terms of verifying that the same ranking could be achieved in the tests in this project as achieved by FMRC. Some possible reasons for these differences have been mentioned and further tests to verify the classification of these standard commodities are therefore suggested below.

9.4 Proposal for future tests and research

Although the experience of this classification test method in general is very positive, both at FMRC and from the tests conducted in this project, there are as mentioned certain areas where further tests and research would be valuable.

The base for the classification is the results obtained by FMRC using their standard commodities. The tests conducted here at SP using two of their standard commodities did not give satisfactory correlation. The most probable reason is that the SP water applicator is designed for EUR-pallets while the standard commodities have measures corresponding to US standard pallets. Two tests with "EUR Standard Plastic" commodities which consisted of repacked FMRC Standard Plastic commodities in order to fit the EUR-pallets showed better correlation. However, the correlation was still not perfect and a possible reason for this was that the shape of the packed cartons was not perfect cubic.

In order to reach an international acceptance for the method, efforts to solve these problems must be given highest priority. The actual problem is not related to the test method but rather to the various standards for pallets and packing materials in USA and Europe, respectively. However, as this fact has a direct influence on the test equipment and on the results, some form of solution has to be found. As it is not possible to influence the standards for pallets and packing materials, one has to realize that some form of compromise has to be included in the test method.

Based on the experience from the tests and discussions with experts at FMRC [24], the most optimal solution is to specify a water applicator identical to the one used by FMRC. The commodities tested must then be as close to the optimal pallet size for this water applicator design as possible, which is 1.07 x 1.07 m. Based on the European standards for pallets and packing materials, the most optimum pallet size would then be 1.0 x 1.2 m. This commodity will be somewhat to large in one direction and smaller in the other direction in relation to the water applicator design, but this is although considered to be the best solution.

In order to verify the correlation and reproducibility, some further tests are required. Commodities, e.g. as equal as possible to the FMRC Standard Plastic commodity is made up to fit this proposed European pallet size, 1.0 x 1.2 m. This commodity is then tested both at SP and at FMRC in order to, both be able to study the reproducibility, and to correlate the results with the classification results achieved by FMRC using their Standard Plastic commodity.

The tests suggested above is most important to be able to use the classification method on a wide, international basis. However, it has also been possible to identify the need for other research efforts on a more long term basis and some proposals are given below.

The results from this project indicates that certain commodities might be classified too low following the recommendations in the sprinkler standards. Further classification tests with commodities which can be considered as "strategic" and of common interest should therefore be conducted. Special concern should be given new "environmental friendly" packing materials which are introduced on the market and which might have different fire behaviour compared to existing materials.

The comparison of level of protection between US and European standards show that there are significant differences in some parts. In this project, no attempt has been made to verify which of these requirements and recommendations are to be considered most correct. In cases where the basis for the protection requirements may be questioned, e.g. by lacking full scale tests for verification, both commodity classification and full scale tests ought to be made. From this point of view, commodities might also be considered "strategic" if they have been used in various full scale tests but where there is no definite classification made. As classification and required protection can be considered as fundamental information, such a project should be made on an international basis. The ultimate goal would of course be to achieve the same requirements in all standards.

Some commodities create a hazard which is exceeding that of Expanded Plastic A (Rank value 7) and will then be categorized as Extra Hazard. Typical commodities which can be expected to fall into this classification is commodities with exposed plastic or where the plastic content is very dominant as shown in this project. These commodities might have different fire behaviour and suppressability and thereby require different sprinkler protection. An extension of the classification procedure to give some further relative ranking would therefore be valuable.

At present the classification is a relative measure of a commodity's fire behaviour and suppressability. The level of protection for various storage configurations is then given in the sprinkler standards. An ultimate goal for the commodity classification method would of course be to create absolute figures on the required level of protection. In such a method one must also consider the difference between sprinkler systems designed to give suppression and systems which are intended to control the fire. The present classification method represents only the controlled fire situation.

In general, all classification of commodities is only related to fire behaviour and suppressability. During recent years, the impact on the environment from fires has been focused and many companies must today make precautions to minimize such damage in case of a fire. One major problem is however lack of reliable information of what kind of combustion products that might be produced in the fire and also what products can be expected in the spill water from e.g. the sprinkler system. An extended classification from environmental/toxicological point of view would therefore be valuable for the future. SP is currently participating in a STEP project (Science and Technology for Environmental Protection) sponsored by the European commission where the combustion gases have been analyzed from various products. The tests have been made in the Industry Calorimeter and the analysis technique could probably be incorporated in the test procedure for commodity classification as well.

10 References

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Annex A

Commodity Classification Fire Test Analysis

Client:	Date:
Description of Test Product:	

Calibration tests conducted with commodities of various classes have been included for comparison purposes. Rank values are taken from Table V. (* PS & Ppr = Polystyrene & Paper.)		CLASS I		CLASS II		CLASS III		CLASS IV		FMRC Std. Plastic		TEST PRODUCT	
		Glass Jars in Compart-mented Cartons		Double Triwall Cartons with Steel Liner		Paper Jars in Compart-mented Cartons		PS & Ppr Jars Com-partmented Cartons*		PS JARS in Compart-mented Cartons			
DELIVERED DENSITY (mm/min)	VARIABLE	Test Results	Rank	Test Results	Rank	Test Results	Rank	Test Results	Rank	Test Results	Rank	Test Results	Rank
4.5	Maximum Total Heat Release Rate (kW)	4450	1	5940	2	7940	3	12040	4				
	Maximum Convective Heat Release Rate	2210	1	3500	2	5220	3	7290	4				
	Effective Convective Heat Release Rate (kW)	540	1	3110	2	4830	3	6150	4				
	Convective Energy (MJ)	344	1	1773	2	2122	3	2853	4				
	Mean Unit Rank		1		2		3		4		6		
8.5	Maxiumum Total Heat Release Rate (kW)	4310	1	4890	2	6450	3	9140	4	11230			
	Maximum Convective Heat Release Rate (kW)	2140	1	2920	2	3480	3	5760	4	8080	6		
	Effective Convective Heat Release Rate (kW)	950	1	1930	2	2990	3	4710	4	7280	6		
	Convective Energy (MJ)	291	1	997	2	1606	3	2316	4	3699	6		
	Mean Unit Rank		1		2		3		4		6		
12.6	Maximum Total Heat Release Rate (kW)	3780	1	4410	2	4830	3	5910	4	8680	6		
	Maximum Convective Heat Release Rate (kW)	1970	1	2710	2	2950	3	3480	4	4410	6		
	Effective Convective Heat Release Rate (kW)	900	1	1280	2	1530	3	2090	4	4040	6		
	Convective Energy (MJ)	279	1	517	2	628	3	1064	4	2111	6		
	Mean Unit Rank		1		2		3		4		6		
15.9	Maximum Total Heat Release Rate (kW)									6680			
	Maximum Convective Heat Release Rate (kW)									3550			
	Effective Convective Heat Release Rate (kW)									2000	6		
	Convective Energy (MJ)									960	6		
	Mean Unit Rank		1		2		3		4		6		
	Mean Total Rank		1		2		3		4		6		

Notes:

Annex B1

Rank values for evaluation of ordinary combustible products

Delivered Density = 4.5 mm/min

Rank	V1 Maximum (2) Total Heat Release Rate kW	V2 Maximum (2) Convective Heat Release Rate kW	V3 Effective Convective Heat Release Rate kW	V4 Convective Energy MJ
0.50	0 - 3830	0-1970	0-620	
0.75	3840 - 4150	1980 - 2180	630 - 1040	199
1.00	4160 - 4520	2190 - 2410	1050 - 1460	200 - 589
1.25	4530 - 4910	2420 - 2660	1470 - 1880	590 - 940
1.50	4920 - 5310	2670 - 2940	1890 - 2300	941 - 1232
1.75	5320 - 5770	2950 - 3240	2310 - 2730	1233 - 1481
2.00	5780 - 6260	3250 - 3590	2740 - 3170	1482 - 1773
2.25	6270 - 6800	3600 - 3960	3180 - 3590	1774 - 1894
2.50	6810 - 7380	3970 - 4360	3600 - 4010	1895 - 2068
2.75	7390 - 7930	4370 - 4820	4020 - 4430	2069 - 2121
3.00	7940 - 8700	4830 - 5330	4440 - 4850	2122 - 2371
3.25	8710 - 9460	5340 - 5870	4860 - 5280	2372 - 2504
3.50	9470 - 10270	5880 - 6490	5290 - 5700	2505 - 2628
3.75	20280 - 11140	6500 - 7170	5710 - 6120	2629 - 2744
4.00	11150 - 12090	7180 - 7910	6130 - 6560	2745 - 2853
4.25	12100 - 13110	7920 - 8740	6570 - 6980	2854 - 2954
4.50	13120 - 14240	8750 - 9650	6990 - 7400	2955 - 30 51
4.75	14250 - 15470	9660 - 10650	7410 - 7820	3052 - 3142
5.00	15480 - 16780	10660 - 11760	7830 - 8250	3143 - 3228
5.25	ND (3)	ND (3)	ND (3)	ND (3)
5.50	ND	ND	ND	ND
5.75	ND	ND	ND	ND
6.00	ND	ND	ND	ND
6.25	ND	ND	ND	ND
6.50	ND	ND	ND	ND
6.75	ND	ND	ND	ND
7.00	ND	ND	ND	ND
EX (4)	Over 16780	Over 11760	Over 8250	Over 3228

Annex B2

Rank values for evaluation of ordinary combustible products

Delivered Density = 8.5 mm/min

Rank	V1 Maximum (2) Total Heat Release Rate kW	V2 Maximum (2) Convective Heat Release Rate kW	V3 Effective Convective Heat Release Rate kW	V4 Convective Energy MJ
0.50	0 - 3340	0 - 1970	0 - 530	0 - 32
0.75	3350 - 3730	1980 - 2110	540 - 790	33 - 204
1.00	3740 - 4310	2120 - 2270	800 - 1060	205 - 373
1.25	4320 - 4470	2280 - 2430	1070 - 1320	374 - 543
1.50	4480 - 4840	2440 -2600	1330 - 1600	544 - 713
1.75	4850 - 4870	2610 - 2780	1610 - 1880	714 - 883
2.00	4880 - 5590	2790 - 2970	1890 - 2180	884 - 1052
2.25	5600- 5980	2980 - 3180	2190 - 2460	1053 - 1222
2.50	5990 - 6330	3190 - 3410	2470 - 2760	1223 - 1392
2.75	6340 - 6430	3420 - 3460	2770 - 2970	1393 - 1561
3.00	6440 - 7100	3470 - 3900	2980 - 3380	1562 - 1731
3.25	7110 - 7450	3910 - 4190	3390 - 3680	1732 - 1901
3.50	7460 - 7840	4200 - 4490	3690 - 3990	1902 - 2071
3.75	7850 - 8210	4500 - 4800	4000 - 4310	2072 - 2315
4.00	8220 - 9140	4810 - 5770	4320 - 4710	2316 - 2411
4.25	9150 - 9180	5780 - 5800	4720 - 4960	2412 - 2581
4.50	9190 - 9320	5810 - 5890	4970 - 5290	2582 - 2750
4.75	9330 - 9700	5900 - 6310	5300 - 5610	2751 - 2920
5.00	9710 - 10090	6320 - 6750	5620 - 5940	2921 - 3090
5.25	10100 - 10440	6760 - 7240	5950 - 6280	3091 - 3260
5.50	10450 - 10830	7250 - 7750	6290 - 6610	3261 - 3429
5.75	10840 - 11220	7760 - 8070	6620 - 6950	3430 - 3599
6.00	11230 - 11570	8080 - 8880	6960 - 7300	3600 - 3768
6.25	11580 - 11950	8890 - 9490	7310 - 7630	3769 - 3938
6.50	11960 - 12320	9500 - 10180	7640 -7980	3939 - 4108
6.75	12330 - 12690	10190 - 10900	7990 - 8320	4109 - 4278
7.00	12700 - 13080	10910 - 11670	8330 - 8690	4279 - 4448
EX (4)	Over 13080	Over 11670	Over 8690	Over 4448

Annex B3

Rank values for evaluation of ordinary combustible products

Delivered Density = 12.6 mm/min

Rank	V1 Maximum (2) Total Heat Release Rate kW	V2 Maximum (2) Convective Heat Release Rate kW	V3 Effective Convective Heat Release Rate kW	V4 Convective Energy MJ
0.50	0 - 3470	0 - 1900	0 - 810	0 - 264
0.75	3480 - 3610	1910 - 1950	820 - 860	265 - 277
1.00	3620 -3780	1960 - 2130	870 - 930	278 - 321
1.25	3790 - 3910	2140 - 2250	940 - 1000	322 - 354
1.50	3920 - 4080	2260 - 2380	1010 - 1090	355 - 391
1.75	4090 - 4260	2390 - 2480	1100 - 1180	392 - 431
2.00	4270 - 4430	2490 - 2710	1190 - 1290	432 - 517
2.25	4440 - 4610	2720 - 2740	1300 - 1360	518 - 526
2.50	4620 - 4780	2750 - 2850	1370 - 1460	527 - 580
2.75	4790 - 4820	2860 - 2940	1470 - 1510	581 - 627
3.00	4830 - 5220	2950 - 3080	1520 - 1690	628 - 707
3.25	5230 - 5430	3090 - 3200	1700 - 1810	708 - 781
3.50	5440 -5680	3210 - 3310	1820 - 1950	782 - 861
3.75	5690 - 5890	3320 - 3460	1960 - 2880	862 - 951
4.00	5900 - 6150	3470 - 3550	2090 - 2270	952 - 1065
4.25	6160 - 6420	3560 - 3680	2280 - 2430	1066 - 1157
4.50	6430 - 6700	3690 - 3780	2440 - 2620	1158 - 1278
4.75	6710 - 6980	3790 - 3910	2630 - 2810	1279 - 1411
5.00	6990 - 7260	3920 - 4030	2820 - 3030	1412 - 1556
5.25	7270 - 7580	4040 - 4130	3040 - 3250	1557 - 1718
5.50	7590 - 7890	4140 - 4260	3260 - 3520	1719 - 1896
5.75	7900 - 8230	4270 - 4380	3530 - 3780	1897 - 2110
6.00	8240 - 8680	4390 - 4500	3790 - 4060	2111 - 2309
6.25	8690 - 8930	4510 - 4610	4070 - 4380	2310 - 2549
6.50	8940 - 9320	4620 - 4710	4390 - 4710	2550 - 2627
6.75	9330 - 9700	4720 - 4850	4720 - 5060	2628 - 3105
7.00	9710 - 10020	4860 - 4960	5070 - 5450	3106 - 3428
EX (4)	Over 10020	Over 4960	Over 5450	Over 3428

Annex B4

Rank values for evaluation of ordinary combustible products

Delivered Density = 15.9 mm/min

	V1	V2	V3	V4
Rank	Maximum (2) Total Heat Release Rate kW	Maximum (2) Convective Heat Release Rate kW	Effective Convective Heat Release Rate kW	Convective Energy MJ
0.50	ND (3)	ND (3)	ND (3)	ND (3)
0.75	ND	ND	ND	ND
1.00	ND	ND	ND	ND
1.25	ND	ND	ND	ND
1.50	ND	ND	ND	ND
1.75	ND	ND	ND	ND
2.00	ND	ND	ND	ND
2.25	ND	ND	ND	ND
2.50	ND	ND	ND	ND
2.75	ND	ND	ND	ND
3.00	3850 - 4030	2460 - 2550	50 - 200	60 - 159
3.25	4040 - 4200	2560 - 2610	210 - 360	160 - 254
3.50	4210 - 4380	2620 - 2660	370 - 500	255 - 342
3.75	4390 - 4570	2670 - 2690	510 - 640	343 - 424
4.00	4580 - 4780	2700 - 2830	650 - 810	425 - 501
4.25	4790 - 4990	2840 - 2920	820 - 970	502 - 574
4.50	5000 - 5200	2930 - 2990	980 - 1130	575 - 642
4.75	5210 - 5450	3000 - 3080	1140 - 1290	643 - 707
5.00	5460 -5700	3090 - 3170	1300 - 1450	708 - 768
5.25	5710 - 5940	3180 - 3270	1460 - 1600	769 - 826
5.50	5950 - 6190	3280 - 3360	1610 - 1760	827 - 882
5.75	6200 - 6470	3370 - 3470	1770 - 1900	883 - 936
6.00	6480 - 6750	3480 - 3570	1910 - 2060	937 - 987
6.25	6760 - 7050	3580 - 3680	2070 - 2220	988 - 1036
6.50	7060 - 7370	3690 - 3780	2230 - 2380	1037 - 1083
6.75	7380 - 7680	3790 - 3890	2390 - 2530	1084 - 1129
7.00	7690 - 8010	3900 - 3990	2540 - 2690	1130 - 1173
EX (4)	Over 8010	Over 3990	Over 2690	Over 1173

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