Publication No 11/96 Sprinklers for Life Safety in Shops: Survey of Shops

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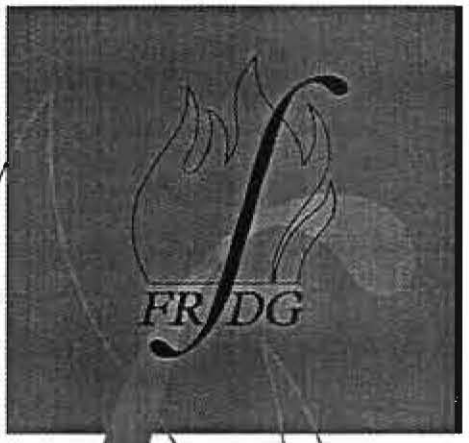

Sprinklers for Life Safety in Shops: Survey of Shops

Report prepared for the Home Office

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MANAGEMENT SUMMARY

There are concerns within the Home Office about the adequacy of life safety measures in shops in case of fire. Of particular concern are those shops found in the High Street which may have a high fuel load and which are not at present required to have sprinklers.

To help in this consideration, it was decided to carry out a survey of High Street shops to find out the range of compartment sizes and hazardous materials present and to identify the situations of greatest concern. It was decided that small shops of floor area less than 280 square metres (this is the definition of a small shop used in BS5588) would not be included as the hazard in these shops was considered to be of less concern.

FRDG let a contract to the Fire Protection Association (FPA) to carry out this survey. The survey was carried out between October 1995 and January 1996. Over 90 shops were visited in a number of towns in England, Scotland and Wales. A survey report form was completed for each shop recording the floor area and ceiling height of each sales floor, the types and arrangements of materials present and any other relevant information. Over 500 photographs and 5 hours of video recordings were taken showing the conditions in the shops visited. Once they had completed the survey, the FPA analysed the data collected and drew up a list of materials and arrangements presenting the greatest hazards.

The FPA then carried out small-scale fire tests on 18 samples of products to find out their fire behaviour. During each test the mass loss, plume temperature and radiation were recorded and from these an estimate was made of the anticipated maximum fire size from a full-size display of the product.

From the results of the FPA work, FRDG produced a shortlist of six arrangements of materials which gave cause for concern and which could be considered for large-scale fire testing. These were:-

- toys in blister packs, on hanging arms against the wall
- tights in cartons, on hanging arms against the wall
- soft toys, arranged in a large pile
- video cassette displays, either on metal shelves or a plastic rack
- crisps, displayed on open wire mesh shelving
- lightweight sportswear jackets, on metal hanging arms against the wall.

Conclusion. The survey identified a number of shop display arrangements which gave cause for concern in the event of a fire. The most serious ones found were displays of sportswear, soft toys, plastic toys, video displays and crisps or similar products.

CONTENTS

1. BACKGROUND

The Home Office is considering life safety in shops in the event of a fire, the adequacy of the fire protection measures currently used and whether a sprinkler system should be required. The shops considered are those typically found in the High Street as opposed to out of town developments or in sprinklered shopping malls. The size of the shops being considered are those over 280 square metres.

2. SUMMARY

Over ninety shops were visited in a number of towns and cities in England, Scotland and Wales. A survey report form was completed for each shop and an example is shown in Appendix D. Over 500 photographs were taken at 87 locations and video recordings taken at 42 locations amounting to some five hours of viewing.

Certain shops clearly present more of a concern than others and these can be summarised as:

a) those where combustibles are present in such a configuration that they could be readily ignited with minimal effort either accidentally or maliciously;

b) those where the quantity and arrangement of combustibles is such that a fast growing and rapidly spreading fire could occur;

c) those where the means of escape could rapidly become untenable.

Shops selling toys, particularly in blister packs on hanging arms were identified as fulfilling category a).

Heavily stocked discount stores selling a large range of products, which frequently included fancy goods, fell into category b).

Long narrow shops, shops with stock in aisles and those with directional funnelling of customers out via tills fell into category c).

Some shops fell into all three categories. Although the level of combustibles was found to be extensive in a number of shops, it was only considered worthy of special note on 7 of the survey report forms.

The photographs and video sequences give graphic evidence of the situations encountered.

Of the 20 shops that were sprinklered, 7 had some shielded or otherwise obstructed sprinkler heads.

3. THE SURVEY

The objective of this exercise was to obtain data from high street shops regarding their fire loading. Specific concern was expressed regarding the potential for rapidly spreading fires that could put customers and staff in untenable conditions prior to a warning and safe evacuation being completed.

Towns to visit were chosen at random to provide a cross-section of sizes, geographical locations and socio-economic well-being. The survey period was during the run up to Christmas which accounted for some excessive stock inventories, resultant high fire loadings and congested shops.

Shops were selected individually and independently, also on a random basis, but bearing in mind the size limitation and similarity to others already surveyed. Shop managers were asked for permission for the survey to be carried out and if appropriate permission to take photographs and video sequences was also requested. With the encapsulated Home Office letter of introduction, complete with a colour photograph of the surveyor, few problems were encountered.

During the survey it was quickly established that some shops, freezer centres for instance, have a limited combustible loading, which is extremely well spaced. It also quickly became apparent that discount stores tended to pack a vast range and quantity of combustible goods into their shops, some more proficiently than others. This accounts for there being survey reports on only 2 freezer centres but 22 discount stores.

Some of the older discount stores appeared to present a severe fire loading and congestion problem. Although the problem might have been recognized by local management, they seemed resigned to having to make do with the facility they had. An example of a congested discount store and a better arranged discount store are shown in Appendix F.

Nation wide discount stores are challenging the more up-market stores by providing purpose built or better refurbished stores capable of displaying their wide and ever changing range of products.

4. PHOTOGRAPHS

Photographs were taken to provide an overall impression of the size of shops, the distribution, layout and arrangement of stock and close-ups of the stock items itself.

One set of photographs has been produced, identified with small labels and is presented in six albums in easy to locate alpha-numeric order.

5. VIDEO RECORDINGS

The video recordings were aimed to enhance the photographs. However, by the very nature of taking the video sequences, the impression of congestion, particularly when customers were present in any numbers, was conveyed more readily. After all, a photograph of the back of a customer shows very little, where as a video sequence of trying to get from one part of a congested shop to another is quite revealing.

6. SPECIFIC CONCERNS

a) Obstructed sprinklers

It was disturbing that in 7 out of the 20 sprinklered shops surveyed, obstructed sprinklers were noted. Obstructions included: light fittings so close to sprinkler heads that the water discharge pattern would be adversely affected; shelving arrays close up to the ceiling totally obstructing sprinkler heads; display systems with "tops" of one form or another that would

interfere with sprinkler water reaching the goods below; electrical or mechanical services above gridded ceiling tiles, but below the sprinklers that would interfere with the sprinkler water discharge pattern; and light fittings in suspended gridded ceilings that would interfere with the water discharge from the sprinklers above.

b) Fire loads

Most shops stock combustible items. However some stock vast quantities of readily ignitable items in storage arrays that would support rapid fire growth and thus cause an early hazard to life in the shop.

c) Combustible display systems

The majority of display systems appeared to be based on steel, however some browsers were of timber or plastic construction. The provision of combustible display systems when non-combustible alternatives are available would seem to be a retrograde step.

Shelving on the most part was of steel with isolated instances of timber or timber substitutes being used for effect.

Timber pallets were found in use singly in a couple of shops more for effect than for anything else. They do not appear to constitute a significant combustible loading problem used in that fashion.

d) Congestion and narrow or obstructed aisles

The ability of people to locate the fire exits in an emergency situation and then to actually progress rapidly to and through them is of paramount importance. In a number of instances, particularly in some of the discount stores which were bulging at the seams with stock, the escape routes were far from ideal.

If when fire tests are carried out, dense smoke is produced very rapidly, the whole question of the adequacy of escape routes may need to be addressed. It is not so much the distance of travel that is of concern, but the ability of mothers and children, probably with pushchairs and shopping bags, to negotiate the obstacle course encountered in the shop. Customers away from the immediate incident will naturally take a time to react and allow people to push by them.

7. SHORT LIST OF MATERIALS AND ARRANGEMENTS CONSIDERED SUITABLE FOR FIRE TESTING

Displays of materials likely to support rapid fire growth and thus cause an early hazard to life in the shop would include but not necessarily be limited to the following. These could probably be considered as forming the basis of suitable fire test arrays:

a) Large vertical stacks of blister packs of frequently plastic toys in any of a number of arrays. These were found against walls, at the end of storage gondolas or racks and around columns.

b) As above but tights or other small items of clothing.

c) Kiddies' fluffy slippers, free hanging or in wire baskets against a wall or cuddly toys in wire basket storage systems.

d) A congested fancy goods and discount store. Some of the parameters might include a ceiling height of 2.5 to 3.0m; narrow or congested aisles; solid stacks of goods on the floor; walls of hanging arms of goods from the floor to the ceiling; wire shelving of goods.

e) Plastic CD/tape/video browser.

f) Bags of sweets on hanging arms and crisps in wire racks or plastic bins.

g) Displays against the wall of three high soccer kits on plastic hangers or sports tops also three high, some with polyurethane.

8. SMALL SCALE AD HOC FIRE TESTS

8.1 Decision to test

Following a meeting at the Home Office it was decided to purchase some sample items from some shops and to carry out some small scale ad hoc fire tests. The idea was to concentrate on a few items that had caused some concern during the survey of shops from the standpoint of a rapidly developing fire.

The items that were obtained for testing were scrutinized and the individual components weighed. The materials of the components were determined such as cardboard, plastic, nylon and potato chips.

8.2 Test protocol

The Loss Prevention Council's Specialist Fire Analysis Rig was used under the supervision of Dr Jim Glockling. The rig consisted of a closely sealed and instrumented room measuring 8m x 4m x 3m high. The sample was contained in chicken wire netting held in a clamp by a retort stand which stood on a load cell. This allowed the weight to be measured throughout the fire. The sample was ignited by a mini-blow lamp.

It was decided to record mass loss, plume temperature and radiation, all of which were data logged against time in seconds. The results were produced in the form of three curve graphs.

A total of eighteen fire tests were carried out. Each test is written up as a self-supporting piece with the following information provided:

a) Weight analysis, sometimes including reference to photographs.

b) Stacking arrangement in the shop where purchased.

c) Observations, including reference to photographs and video.

d) Heat release calculations.

e) Conclusions.

8.3 Items tested with anticipated maximum fire sizes

Test 1	Quavers	3.2 MW
Test 2	Housewife collection - plastic cups and saucers etc in polythene bag	6.6 MW
Test 3	Tights - four pairs in a carton	5.2 MW
Test 4	Mighty Max Werewolf - Plastic toy in blister pack	1.25 MW
Test 5	Power Ranger - Plastic toy in blister pack	0.35 MW
Test 6	Dekkertoys - plastic cups and saucers in blister pack	5.8 MW
Test 7	Permanent marker in blister pack	2.7 MW
Test 8	Papermate pen in blister pack	Not determined
Test 9	Ink cartridges in blister pack	Not determined
Test 10	Tights - single pair in cardboard sleeve	Not determined
Test 11	Soft toy	22.6 MW
Test 12	Walkers crisps - 10 pack	2.7 MW
Test 13	Girls short socks - three pairs	1.2 MW
Test 14	Lightweight sportswear jacket on a rigid nylon hanger	28 MW
Test 15	Knee high socks for girls - one pair	1.2 MW
Test 16	Mint creams - bag of sweets	Not determined
Test 17	VHS video cassette - empty	0.8 MW or 4.3 MW
Test 18	Audio tape cassette - empty	0.26 MW

8.4 Heat of combustion figures

The following figures have been used for heat of combustion:

Cardboard packaging and paper inserts	18 MJ kg^{-1}
Nylon	30 MJ kg^{-1}
Plastic (Polyethylene/polypropylene)	43 MJ kg^{-1}
Potato crisps and similar products	40 MJ kg^{-1}
Sweets (sucrose)	15 MJ kg^{-1}

The majority of the blister pack bubbles themselves tended to exhibit signs of being flame retardant.

9. CONCLUSIONS

General

The survey of shops and subsequent small scale ad hoc fire testing has resulted in a number of shop display arrangements giving cause for concern. The survey concentrated on High Street shops with normal situations.

Probably the situation that causes greatest concern is lightweight sportswear in sports shops due to the sheer quantity of goods close to the normal entry/exit route and the ease of ignition of the product. A number of these shops are two storey, with the added possibility of blocked escape routes.

The other hazard that could result in a massively large rapidly developing fire which could possibly over tax a standard sprinkler system is a large piled display of soft toys. The calculation for one large pile showed a potential 22.6 MW fire.

The other three main areas of concern are plastic toys, wire mesh or plastic video browsers and large concentrations of crisp like products. Any of these can produce rapidly developing fires easily ignited with large quantities of smoke.

Summary

In Section 8.3 there is a list if the items tested with anticipated maximum fire sizes that might occur in a real fire scenario. To predict these fire sizes a number of assumptions have had to be made which have generally been explained in each test result write-up. Readers of this report will probably form their own conclusions regarding the validity of and possible variations to these assumptions. The assumptions have tried to concentrate on the potential for rapidly developing fires in High Street shops that could quickly make a shop untenable to its occupant.

Lightweight sportswear jackets on plastic (nylon) hangers

The ease and speed with which this fire was started and developed had to be seen to be believed. Vast arrays of such lightweight sportswear are commonly found in sports shops. They frequently form the entire side wall display from floor to ceiling and are frequently adjacent to the main customer entry/exit door. The opposite wall may consist of shiny football club kits and jogging suits, formally termed track suits. All these products are almost certainly both readily ignitable and combustible. It is considered therefore that sports shops should be the prime target for further research on the subject of rapidly developing fires in shop.

Display of Soft Toys

Large heaps of soft toys which in the test proved so easy to ignite and so highly combustible, emitting large quantities of thick smoke would cause havoc if ignited in a shop. A larger scale test would determine just how much of a problem they represent.

Blister Packs

One of the most surprising results was the apparent low fire risk associated with a significant proportion of the blister packs on hanging arms. Further tests of larger arrays may be considered necessary, but the slow fire growth and the fire retardant nature of many of the blisters themselves would tend to indicate the improbability of a rapidly developing fire. Blisters that closely enclosed small items such as single small toys like the Power Ranger or the Papermate pen basically didn't catch fire. On the other hand, the permanent marker had a far more combustible blister, which was not at all apparent simply from seeing the different products hanging side by side on the same wall display. It would therefore be premature to say blister packs are not a problem without some further research into the practices and intentions of the product packaging industry.

Other plastic toys

Tests 2 and 6 involved other plastic toys and these indicated the potential for rapidly developing sizeable fires in the region of 6 MW. These tend to be the toys at the cheaper end of the market and although they are found in some main stream toy shops they would more often be found in the fancy goods or bargain basement type of outlet. The narrow aisles and vast arrays of other combustibles produces an ideal situation for a rapidly developing fire situation.

Quavers and potato chips

Tests 1 and 12 indicated how extremely easy it was to ignite this type of product and how very rapidly an intense and prolonged fire developed. In a situation where a large quantity of such product was displayed in an arrangement which allowed for both upward flaming and downward dripping impingement onto adjacent product, a fire of over 3 MW might well develop in a matter of only a few minutes. Certainly the fire safety aspects regarding the arrangement of large quantities of this type of product deserves closer scrutiny.

Video, audio tape and CD browsers

Single empty VHS and audio tape cassettes were tested in Tests 17 and 18. These tests did not realistically demonstrate a real situation of a fire in a browser. The ease with which the two items were ignited and their rapid fire development, both upwards and downwards, indicates the potential for a serious and large fire. A fire over 4 MW was predicted for an incident involving 100 cassettes and part of a plastic browser. the quantity of thick smoke that was given off by these products should not be overlooked when assessing the fire safety implications of such an incident.

Tights

Cartoned tights represent a potentially serious fire hazard almost simply on the basis of the very large quantity of product on display. It came as quite a surprise when it was calculated that each metre of wall display comprised around 43 kg of combustible stock. Certainly there appears to be the potential for a 5 MW fire although the particular store in question was sprinklered. The single pair of sleeved tights did not burn well in Test 10. Whether a display of a large number of such sleeves, which are frequently found, would behave very differently may deserve further investigation.

Appendix A

Distribution of shops surveyed by town/city visited

Town/City Visited	Number of shops Survey attempted	Number of shops Survey completed	Photos Taken	Video Sequences
England				
Aylesbury	6	5	31	5
Bicester	1	1	11	0
Bristol	14	13	70	10
Chester	10	7	16	4
Halifax	11	10	25	5
Huddersfield	6	5	12	1
Lincoln	6	6	41	3
Mansfield	6	6	38	4
Warrington	6	4	26	2
Scotland				
Clydebank	5	4	38	2
Falkirk	6	5	43	3
Glasgow	8	6	43	4
Grangemouth	5	5	29	0
Paisley	3	2	22	0
Wales				
Cardiff	4	4	24	2
Carmarthen	3	3	23	0
Llanelli	2	2	6	0
Swansea	3	3	21	1
Totals	105	91	519	46

Appendix B

Distribution of types of shops surveyed

Books/stationary:	7
Camping/outdoor:	3
Carpets:	2
Catalogue/Warehouse store:	3
Clothes, childrens:	4
Clothes, designer:	4
Clothes, discount:	3
Department store:	11
Discount store:	22
Electrical/electronic:	1
Food:	2
Footwear:	2
Freezer stores:	2
Home decoration:	1
Kitchenware:	2
Ladies fashions:	3
Market, covered:	5
Miscellaneous:	3
Music:	2
Pharmacy/drug store:	8
Portal frame buildings:	5+
Sports:	2
Supermarket:	2
Textiles/home furnishings:	1
Theme:	3
Toy shop:	2

Appendix C

Dictionary of terms used in the report

Blister packs: Packaging system typically for small items such as toys or sports equipment hut sometimes for lingerie or underwear. The packet normally consists of a card backing with a moulded or shaped "blister" of clear plastic over the product permitting full visual effect. The clear plastic is glued, stapled or simply crease-folded over the card. On hanging arms these form a high concentration of readily ignitable combustibles.

Browsers: Typically used for displaying tape cassettes, CDs and videos. They are frequently made of steel, can be of timber and hardboard and also infrequently of plastic construction. The display items are usually empty plastic containers with the actual tape, CD or video cassette held in a secure manned area near-by.

Gondola: A free standing display usually for garments on hangers. They can be circular, oval, rectangular, linear, cross or swastika shaped. Some of their protruding arms are angled to improve the display of goods.

Hanging arm: Normally a single or double stiff wire projection from a vertical surface on which small goods can be hung.

Portico: A display system or arrangement that consists of a semi-enclosed archway or cupboard without doors.

Showline: The top of the sales floor boundary wall storage arrangement.

Stock to stock: The distance between gondolas or other floor mounted displays or between floor and wall mounted displays.

Appendix D

Example Survey Report Form

Date of Survey: 7/11/95
Shop/Survey Ref No: CHESTER.3
FPA Surveyor: Bill Piers
Name of Town: Chester
Type of Town: Northern Tourist
Name of Shop:
Nationwide:
Address:
Type of Shop: Sports shop
Size of Shop: 16m x 22m
Local Contact/Manager:
Tel No:
Head Office Contact:
Tel No:
Sales Floors: Ground
No of Storeys: 3
Approx no of staff on duty on sales floors: 6
Sprinklers installed: No
AFD installed: Yes

Floor No.	Area (m^2)	Ceiling Height (m)	Hazard, Fire Load Factors, Arrangement, Stacking
G	352	3.0	Hanging sports garments on plastic hangers, three high, to the ceiling. 6 ceiling fans running might disperse smoke and effect the efficiency of the 2 smoke detectors covering the sales floor. Small sports accessories mostly in individual plastic packs hung on pillars. Good gaps and spaces between stock.

Any other relevant information: Intruder alarm system.

Photos: Yes (2)
Video: No
P1 Shiny jackets
P2 Clear aisles, plastic hangers holding garments on free standing gondolas

Appendix E

Small scale ad hoc fire tests - Results and calculations

Items tested with anticipated maximum fire sizes

Test 1	Quavers	3.2 MW
Test 2	Housewife collection - plastic cups and saucers etc in polythene bag	6.6 MW
Test 3	Tights - four pairs in a carton	5.2 MW
Test 4	Mighty Max Werewolf - Plastic toy in blister pack	1.25 MW
Test 5	Power Ranger - Plastic toy in blister pack	0.35 MW
Test 6	Dekkertoys - plastic cups and saucers in blister pack	5.8 MW
Test 7	Permanent marker in blister pack	2.7 MW
Test 8	Papermate pen in blister pack	Not determined
Test 9	Ink cartridges in blister pack	Not determined
Test 10	Tights - single pair in cardboard sleeve	Not determined
Test 11	Soft toy	22.6 MW
Test 12	Walkers crisps - 10 pack	2.7 MW
Test 13	Girls short socks - three pairs	1.2 MW
Test 14	Lightweight sportswear jacket on a rigid nylon hanger	28 MW
Test 15	Knee high socks for girls - one pair	1.2 MW
Test 16	Mint creams - bag of sweets	Not determined
Test 17	VHS video cassette - empty	0.8 MW or 4.3 MW
Test 18	Audio tape cassette - empty	0.26 MW

Test 1 (T1) - Quavers

T1 - Weight analysis (g):
6 pack of Quavers 124.0

T1 - Stacking arrangement in the shop where purchased:
Can be stacked in a number of different ways such as in an open basket, on sloped shelves with wire edges, or on hanging arms. In a commonly found free standing open wire mesh free standing basket or shelving arrangement there could be between twenty and fifty packs.

T1 - Observations:
Total burn time 6min 01s Ignition near instantaneous. Burned furiously.

T1 - Heat release calculations:
Heat of combustion is based upon animal fat or lard at approximately 40 MJ/kg.
Potential heat of combustion of 6 Pack of Quavers would be in the order of:

0.124 kg x 40 MJ/kg
= 4.96 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

(130-10)g/(120-60)s = 120/60 = 2.0 gs^{-1}

Thus the maximum anticipated heat release rate from the Quavers six pack would be in the order of:

2.0 gs^{-1} x 40 x 10^6 J kg^{-1} x 10^{-3} kg g^{-1}
= 80 kW

An arrangement where between twenty and fifty such packs (eg 40) could be involved in a fire would consist of say:

40 x 0.124 kg = 4.96 kg of product.

Thus the potential heat of combustion of such an array would be in the order of:

4.96 kg x 40 MJ kg^{-1}
= 198 MJ

The maximum anticipated heat release rate from such an array of 4.96 kg of Quavers, if the mass loss/time rate is similar to that for a single 6 pack, would be in the order of:

40 x 80 kW = 3.2 MW

T1 - Conclusions:
Quavers and similar products are extremely easy to ignite and burn rapidly and furiously with high flames releasing a lot of heat quickly. They are naturally well aerated and a fire would quickly spread to adjoining goods. Video evidence showed that the fire appeared to be fully developed in less than 30s, that maximum flaming occurred at around 45s but that surprisingly the fire continued to burn for some six minutes. Such loosely packaged edible products can be considered to be highly combustible and readily ignitable and therefore represent a real hazard..

Test 2 (T2) - Housewife Collection.

T2 - Weight analysis (g):

Plastic dishes in a tray	Plastic components	267.0	(Appeared to be polypropylene).
	Polythene sleeve/bag	16.0	
	Cardboard top	9.0	
	Combined weight	292.0	

T2 - Stacking arrangement in the shop where purchased:
4 rows of toys against the wall, mostly Blister Packs (BPs) on Hanging Arms (HAs), 2.4m wide x 1.27m high x 420mm deep.

Top row:	10HAs; 6-11/HA depending on thickness. Items included:		
	250g pop ball gun in polythene bag		
	2HAs; 6/HA 195x370x70:	=	3.0kg
	300g Housewife collection in polythene bag		
	2HAs; 7/HA 205x360x55:	=	4.2kg
	110g Blister pack of plastic toys		
	6HAs; 11/HA 190x370x30:	=	7.2kg
Second row:	Dekkertoys - plastic items in typical 215x290x35 BP.		
	3HAs; 9 items/HA @ 100g/item	=	2.7kg
	3HAs; 10 items/HA @ 150g/item	=	4.5kg
	4HAs; 17 items/HA @ 50g/item	=	3.4kg
Third row:	13HAs of assorted BPs		
	150g 185x260x35 10/HA		
	300g 150x250x80 4/HA		
	Average 1.2kg/HA	=	15.6kg
Fourth row:	15HAs		
	80g 14/HA		
	50g 10/HA		
	Average 0.8kg/HA	=	12.0kg
Thus total weight of goods:		=	52.6kg

(This equates to 40.5kg/m^3).

T2 - Observations:
Total burn time 22 min.
Ignition not difficult. Flame took easily. Timing started about 30 secs after initial approach. Hard brown residue.

T2 - Heat release calculations:
The Housewife Collection consisted of toys made of what appeared to be polypropylene.
Single set of toys weighed 292g.
Plastic content 283/292 or 97% of product.
(The cardboard component of this item has not been included as being relatively insignificant.)

Thus potential heat of combustion of this single toy would be in the order of:

$0.283 \text{ kg} \times 43 \text{ MJ kg}^{-1} = 12.2 \text{ MJ}$

During the small scale ad hoc fire test the maximum mass loss/time gradient from test printout:

$= (325\text{-}30)\text{g}/(480\text{-}100)\text{s} = 295/380 = 0.78 \text{ g s}^{-1}$

Thus the maximum anticipated heat release rate from this single toy would be in the order of:

$0.78 \text{ g s}^{-1} \times 43 \times 10^{6} \text{ J kg}^{-1} \times 10^{-3} \text{ kg g}^{-1}$

$= 35.5 \text{ kW}$

An arrangement such as the one found in one store in consisted of a calculated 52.6kg of similar products. The array was 2.4m wide x 1.27m high and 420mm deep.
Thus potential heat of combustion of this array would be in the order of:

$52.6 \text{ kg} \times 43 \text{ MJ kg}^{-1}$

$= 2{,}262 \text{ MJ}$

The maximum anticipated heat release rate from this array of 52.6 kg of toys, if the mass loss/time rate is similar to that for the single toy, would be in the order of:

$52.6/0.283 \times 35.5 \text{ kW} = 6.6 \text{ MW}$

T2 - Conclusions

Plastic toys can be readily ignited. They do not necessarily produce high flames particularly quickly but drip down onto goods below or onto carpets and fittings thus causing a rapidly spreading fire. The maximum burning rate of 0.78 gs^{-1} was achieved within 200s of ignition and thence settled to a 600s long "pool" fire at a burning rate of approximately 350/1100 or 0.32 gs^{-1}. This prolonged mobile fire has the potential of spreading in all directions particularly across aisles which are commonly around 1m wide in many toy shops.

Test 3 (T3) - Tights

T3 - Weight analysis (g):

Four pairs of superfit tights in cardboard carton	Tights	52.0
	Inner card	5.0
	Carton	19.0
	Combined weight	77.0

T3 - Stacking arrangement in the shop where purchased:

4m run of wall of cartoned tights.

Tights, 3 or 4 pairs, in 90x210x40 cardboard cartons on HAs over a 4m wide (34 HAs) section of wall with approximately 28mm vertical flue spaces between HAs.

7 rows of 34 HAs. 8 cartons/HA @ 90g(4 pack). Weight: 7x34x8x90g = 171.36kg
i.e. an average weight of 42.8kg/1m run of wall
which by volume equates to 1m x 1.89m x 0.24m (0.45m^3) or 95kg/m^3

T3 - Observations:

Total burn time 9 min

Carton difficult to ignite and went out twice. As soon as top opened allowing slight draft through, then went well. Black brittle residue.

T3 - Heat release calculations:

Heat of combustion is based upon cardboard at 18 MJ kg^{-1} and Nylon at 30 MJ kg^{-1}.

Potential heat of combustion of 4 pack of tights would be in the order of:

(0.005 + 0.019)kg x 18 MJ kg^{-1} + 0.052 kg x 30 MJ kg^{-1}
= 0.43 MJ + 1.56 MJ
= 1.99 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

(125g/(600-200)s = 125/400 = 0.31 gs^{-1}

Thus the maximum anticipated heat release rate from the four pack of tights would be in the order of:

0.31 gs^{-1} x 25* x 10^6 J kg^{-1} x 10^{-3} kg g^{-1} (* Average between 18 and 30 MJ kg^{-1})
= 7.75 kW

The arrangement of these four packs, eight deep in seven horizontal rows, with numerous flue spaces, could result in a fire started almost anywhere, quite rapidly spreading both upwards from flaming and downwards from dripping. It is estimated that the size of the fire might well be in the order of the full height of the display, approximately 1.8m, and a width of around 1.5m. This would represent around 7 rows of 12 HAs. There would therefore be approximately 7 x 12 x 8 = 672 cartons of 4 packs involved in the fire after ten minutes or so. This represents :

672 x 0.077 kg = 51.7 kg of stock

Thus the potential heat of combustion of this particular section of the 4m wide display would be in the order of:

51.7 kg x 25 MJ kg^{-1}
= 1292 MJ

The maximum anticipated heat release rate from such an array of 51.7 kg of nylon tights in cartons, if the mass loss/time rate is similar to that for a single carton, would be in the order of:

672 x 7.75 kW = 5.2 MW

T3 - Conclusions:

It should be noted that is was in fact quite difficult to get the carton of tights alight. This appeared to be due to the fact that the inside of the carton became smoke logged and acted as a self-extinguishing device. Once the top of the carton was deliberately and manually opened it was much easier to ignite the base of the carton and a self-sustaining and accelerating fire took off.

It was noticed during the survey of shops that some of these cartons of tights, including this one, have a small cellophane window at their tops near the hanging arm. If these windows melted or caught fire then a through draft should result. Estimating how many cartons would become involved in a fire simultaneously within a realistic period is quite difficult, due to the above reference regarding the difficulty with ignition. However, if similar but slightly different cartons were found which ignited more readily, then we believe a 5 MW fire could result. In a real situation, adjacent cartons and their flue spaces would tend to assist ignition and growth of a fire.

Test 4 (T4) - Mighty Max Werewolf

T4 - Weight analysis (g):

Plastic model in double blister pack	Plastic model	35.0
	Cardboard centre piece	22.0
	Double blister	12.0
	Combined weight	70.0

T4 - Display arrangement in the shop where purchased:
On hanging arms about twelve deep along with an assorment of other similar toys on up to six rows and several metres wide. With each pack measuring around 150 mm to 200 mm wide, there could be in the region of 12 x 6 x 8 = 576 packs in a display width of between 1.0 m and 1.5 m.

T4 - Observations:
Total burn time 3 min 18 s
Surprisingly difficult to ignite. Blister & toy burnt very slowly. Toy did not burn through at all readily.

T4 - Heat release calculations:
Heat of combustion is based upon approximately 43 MJ kg^{-1} for the plastic toy and 18 MJ kg^{-1} for the cardboard centre piece. The double blister itself seemed to be fire retardant and therefore did not contribute to the fire.
Potential heat of combustion of the Mighty Max Werewolf double blister pack therefore would be in the order of:

0.035 kg x 38* MJ kg^{-1} (* Average between 18 and 43 MJ/kg)
= 1.5 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

(73-40)g/(510-0)s = 33/510 = 0.065 gs^{-1}

Thus the maximum anticipated heat release rate from the Mighty Max blister pack would be in the order of:

0.065 gs^{-1} x 38* x 10^{6} J kg^{-1} x 10^{-3} kg g^{-1}
= 2.5 kW

An arrangement where up to 500 of these packscould be involved in a fire would consist of say:

500 x 0.057 kg** = 28.5 kg of combustible product.

(** The weight of the blister portion of the toy as a whole is ignored).
Thus the potential heat of combustion of such an array would be in the order of:

28.5 kg x 38 MJ kg^{-1}
= 1083 MJ

The maximum anticipated heat release rate from such an array of 28.5 kg of toys in blister packs, if the mass loss/time rate is similar to that for the single pack tested, would be in the order of:

500 x 2.5 kW = 1.25 MW

T4 - Conclusions:
The reluctance of Mighty Max to ignite, due to his secure envelopment in what can only be described as a fire retardant double blister, was surprising. Large quantities of extremely odorous smoke were given off by the smouldering product.

How a large display of such products with all its attendant flue spaces would behave in a full scale situation is hard to estimate. However, the fire retardant nature of the blisters appears to result in these toys not being the hazard they were originally thought to be. For these reasons the figures calculated above of a 1.25 MW fire need further refinement and examination. The reluctance of blisters to ignite has been observed by others previously.

Test 5 (T5) - Power Ranger

T5 - Weight analysis (g):

Plastic toy, (model man) in blister pack	Plastic man	26.0
	Plastic weapons	1.0
	Cardboard backing	19.0
	Plastic blister	32.0
	Combined weight	79.0

T5 - Display arrangement in the shop where purchased:

Various different shapes and sizes of Power Ranger toys in blister packs were displayed against a wall. Typically these consisted of three sizes and therefore weights of toys:

150g Cardboard backing - 305x185 Blister - 155x135x50
Plastic model.
Approx 2HAs; 7BPs/HA
Weight = 2 x 7 x 150g = 2.10kg

100g Cardboard backing - 305x185 Blister - 145x105x30
Smaller plastic model.
Approx 1HA; 7BPs/HA
Weight = 1 x 7 x 100g = 0.70kg

70g Clear plastic backing making a plastic heatsealed pack.
Overall size - 250x160 Blister - 120x65x25
2HAs; 8BPs/HA
Weight = 2 x 8 x 70g = 1.12kg

In the 79g Power Ranger that was purchased for testing, the only readily combustible component, the plastic man himself, weighed only 27g, i.e. 35%. The display weighed a total of 3.92 kg from the above information. The readily combustible components would therefore have weighed in the order of 0.35 x 3.92 kg = 1.37 kg.

T5 - Observations:

Power Ranger in double sided blister pack. Total burn time 2 min 7 s.
Blister difficult to ignite. Blister & toy burnt very slowly. Toy did not burn through at all readily.

T5 - Heat release calculations:

Heat of combustion is based upon a figure of 43 MJ kg^{-1} for the plastic man which eventually burnt readily. The double sided blister packaging did not burn well and is therefore not considered to have contributed to the fire. Neither did the cardboard insert burn well.

Potential heat of combustion of this Power Ranger double blister pack therefore would be in the order of:

0.027 kg x 43 MJ kg^{-1}
= 1.2 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

(100-10)g/(750-200)s = 90/550 = 0.16 gs^{-1}

Thus the maximum anticipated heat release rate from the Power Ranger blister pack would be in the order of:

$0.16\ gs^{-1} \times 43 \times 10^{6}\ J\ kg^{-1} \times 10^{-3}\ kg\ g^{-1}$
$= 6.9\ kW$

An arrangement such as the one encountered where this Power Ranger was purchased consisted of approximately 1.37 kg all of which might be involved in a fire ignited in the display due to the upward flaming and downward dripping of the plastic components.

Thus the potential heat of combustion of such an array would be in the order of:

$1.37\ kg \times 43\ MJ\ kg^{-1}$
$= 58.9\ MJ$

The maximum anticipated heat release rate from such an array of 1.37 kg of plastic toys in blister packs, if the mass loss/time rate is similar to that for the single pack tested, would be in the order of:

$1.37/0.027 \times 6.9\ kW = 50.7 \times 6.9 = 350\ kW$

T5 - Conclusions:

The Power Ranger was difficult to ignite, due to its secure envelopment in what can only be described as a fire retardant double blister. It was not until the plastic model itself was ignited through the blister pack that the fire took hold. Large quantities of extremely odourous smoke were given off by this really very small smouldering product.

As with the Mighty Max Werewolf blister pack it is difficult to predict how a large display of such products with all its attendant flue spaces would behave in a full scale situation is hard to estimate. However, the Power Ranger did burn out much more readily than the Mighty Max model which self enclosed itself.

The reason that the maximum anticipated heat release is a relatively conservative 350 kW is that the weights of the models are low and the particular display encountered was quite small. If larger versions of these Chinese made models were to be displayed in a larger quantity then obviously the resultant fire would be considerably larger.ay then the Mfire retardant nature of the blisters appears to result in these toys not being the hazard they were originally thought to be. For these reasons the figures calculated above of a 1.25 MW fire need further refinement and examination.

Test 6 (T6) - Dekkertoys

T6 - Weight analysis (g):

Plastic cups & saucers	Plastic components	58.0
	Plastic blister	9.0
	Cardboard backing	25.0
	Combined weight	92.0

T6 - Display arrangement in the shop where purchased:
As for T2.

T6 - Observations:
Blister pack of cups and saucers. Total burn time 15 min
Cardboard backing ignited easily but blister did not. Plastic components eventually burned well.

T6 - Heat release calculations:
Heat of combustion is based upon 43 MJ kg^{-1} for the plastic components and 18 MJ kg^{-1} for the cardboard backing piece. The single blister itself seemed to be fire retardant and therefore did not contribute to the fire.
Potential heat of combustion of the Dekkertoys cups and saucers would be in the order of:

0.083 kg x 38* MJ kg^{-1} (* Average between 18 and 43 MJ/kg)
= 3.15 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

(120)g/(700-200)s = 120/500 = 0.24 gs^{-1}

Thus the maximum anticipated heat release rate from the Dekkertoys pack would be in the order of:

0.24 gs^{-1} x 38* x 10^6 J kg^{-1} x 10^{-3} kg g^{-1}
= 9.1 kW

An arrangement such as the one found in one shop consisted of a calculated 52.6kg of similar products. The array was 2.4m wide x 1.27m high and 420mm deep.
Thus potential heat of combustion of this array would be in the order of:

52.6 kg x 38* MJ kg^{-1}
= 2,000 MJ

The maximum anticipated heat release rate from this array of 52.6 kg of toys, if the mass loss/time rate is similar to that for the single toy, would be in the order of:

52.6/0.083 x 9.1 kW = 5.8 MW

Consideration should be given to adjusting this figure by about 90% to take into account the percentage weight of product that is considered to be fire retardant.

T6 - Conclusions:
This was the first blister pack that readily ignited because the cardboard backing readily ignited. However as the video showed the initial fire went out and the plastic components were very slow to take off. Once ignited the plastic components did burn well and dripped. Large quantities of smoke produced.

A large display of such products with all its attendant flue spaces would probably result in a sizeable fire, but once again the products did not show up to be the very serious hazard they were initially expected to be.

Test 7 (T7) - Permanent Marker

T7 - Weight analysis (g):

Marker in blister pack	Marker itself	23.0
	Blister	2.0
	Cardboard backing	5.0
	Combined weight	30.0

T7 - Display arrangement in the shop where purchased:
Wall of small items mostly in bister packs on hanging arms (HAs). Eight 1m wide sections by 1.85m high.

Markers section:
Giant markers:

1 row of 9 HAs.	5 per HA @ 50g each.	Weight: 1x9x5x50g	=	2.25kg
Paper Mates:				
5 rows of 12 HAs.	10 per HA @ 10g each.	Weight: 5x12x10x10g	=	6.00kg
Dry markers (40g each) and Berol markers (30g each):				
2 rows of 11 HAs.	8 per HA @ av. 35g each.	Weight: 2x11x8x35g	=	6.16kg
Section total weight:			=	14.41kg

T7 - Observations:
Total burn time 5 min 30s
Fell off hanging arm support in well under a minute. Blister burned. Both cardboard and permanent marker ignited quickly and burned readily. At 3 min 30s markerwas a running dripping fire which was quite intense. Liquid pool residue left.

T7 - Heat release calculations:
Heat of combustion is based upon 43 MJ kg^{-1} for the plastic components and 18 MJ kg^{-1} for the cardboard backing piece. This time the single blister did not appear to be as fire retardant as those experienced in Tests 4, 5 and 6.
Potential heat of combustion of the Permanent Marker would be in the order of:

0.030 kg x 38* MJ kg^{-1} (* Average between 18 and 43 MJ/kg)
= 1.14 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

40g/(400-125)s = 40/275 = 0.15 gs^{-1}

Thus the maximum anticipated heat release rate from this single Permanent Marker would be in the order of:

0.15 gs^{-1} x 38* x 10^6 J kg^{-1} x 10^{-3} kg g^{-1}
= 5.7 kW

An arrangement such as the one found in one shop consisted of a calculated 14.41 kg of similar products. The particular section of the display was 1.0 m wide x 1.85 m high and approximately 150 to 200 mm deep.
Thus potential heat of combustion of this array would be in the order of:

14.41 kg x 38* MJ kg^{-1} = 548 MJ

The maximum anticipated heat release rate from this section of 14.41 kg of stationary items, if the mass loss/time rate is similar to that for the single permanent marker, would be in the order of:

14.41/0.030 x 5.7 kW = 2.7 MW

T7 - Conclusions:

This stationary item in a blister pack was much easier to ignite than the toys in blister packs which would tend to classify it as a serious hazard.

However, as the cardboard caught fire so quickly, the hole in the cardboard for supporting the item on the hanging arm was very vulnerable, and the item fell off its hanging arm within about half a minute. This would tend to suggest that a fire might not progress well. But if a buring item was to fall down on top of non-burning items on hanging arms below, the fire might grow quite quickly both from upward flaming and downward dripping of burning plastic. The numerous flue spaces would encourage rapid fire growth. Only a full scale test of such a display would reveal the answers.

Test 8 (T8) - Papermate

T8 - Weight analysis (g):

Papermate pen in blister pack	Pen	8.0
	Blister	2.0
	Cardboard backing	4.0
	Combined weight	15.0

T8 - Display arrangement in the shop where purchased:
Wall of small items mostly in bister packs on hanging arms (HAs). Eight 1m wide sections by 1.85m high.

Markers section:
Giant markers:

1 row of 9 HAs.	5 per HA @ 50g each.	Weight: 1x9x5x50g	=	2.25kg
Paper Mates:				
5 rows of 12 HAs.	10 per HA @ 10g each.	Weight: 5x12x10x10g	=	6.00kg
Dry markers (40g each) and Berol markers (30g each):				
2 rows of 11 HAs.	8 per HA @ av. 35g each.	Weight: 2x11x8x35g	=	6.16kg
Section total weight:			=	14.41kg

T8 - Observations:
Total burn time 50s.
Cardboard backing burnt quickly but blister did not catch. Burned through hanging arm support in 28s. Fire quickly petered out and pen remained almost undamaged.

T8 - Heat release calculations:
Heat of combustion is based upon 43 MJ kg^{-1} for the plastic components and 18 MJ kg^{-1} for the cardboard backing piece. This time the single blister appeared to be just as fire retardant as those experienced in Tests 4, 5 and 6.
Potential heat of combustion of the Papermate would be in the order of:

0.030 kg x 30* MJ kg^{-1} (* Average between 18 and 43 MJ/kg - larger proportion of cardboard to plastic)

= 1.14 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was so low that it was virtually meaningless at.

T8 - Conclusions:
This stationary item, a Papermate pen in a blister pack, was easy to ignite initially as the cardboard backing caught fire readily. However, from thence onwards it failed to gain a hold either with respect to the blister itself or the Papermate pen within the blister, and quickly went out.

Such staionary items in what can only be described as flame retardant blisters cannot be considered as a potentially serious fire threat.

Test 9 (T9) - Ink Cartridges

T9 - Weight analysis (g):

Ten cartridges in blister pack	Ten full cartridges	23.0
	Blister	1.0
	Cardboard backing	3.0
	Combined weight	27.0

T9 - Display arrangement in the shop where purchased:
Wall of small items mostly in bister packs on hanging arms (HAs). Eight 1m wide sections by 1.85m high.
Fountain Pens section:
Ink eradicators:

2 rows of 10 HAs.	12 per HA @ 150g/HA.	Weight: 2x10x150g	=	3.00kg

Ink cartridges:

2 rows of 14 HAs.	10 per HA @ 250g/HA.	Weight: 2x14x250g	=	7.00kg

Fountain pens in gift boxes:

5 rows of 10 HAs.	8 per HA @ 60g each.	Weight: 5x10x8x60g	=	12.00kg

Section total weight: = 22.00kg

T9 - Observations:
Total burn time 1 min
Blister burned through instantly and all the ink cartridges fell on floor. Cardboard backing burned but blister did not. Just charred.

T9 - Heat release calculations:
Since the only part of this item to burn, and that only slowly, was the small cardboard backing piece, heat release calculations would not be meaningful. During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was extremely low .

T9 - Conclusions:
This stationary item, ten ink cartridges in a blister pack, was easy to ignite initially as the cardboard backing caught fire readily. With all the ink cartridges fallen out onto the floor, the empty packaging failed to gain a hold,particularly since once again the blister itself can only be described as flame retardant. Certainly this particular stationary item cannot be considered as a potentially serious fire threat.

Test 10 (T10) - Tights - Single pair 15 denier tights in cardboard sleeve

T10 - Weight analysis (g):

Single pair 15 denier tights in cardboard sleeve	Tights	24.0
	Inner card	6.0
	Outer sleeve card	27.0
	Polythene inner sleeve	2.0
	Combined weight	60.0

T10 - Stacking arrangement in the shop where purchased:
Sleeved tights, single pairs, in 165x240x10 cardboard sleeves on HAs on the end of a gondola in an arrangement approximately 0.8m wide, 1.0m high and 0.4m deep (0.32m^3).
4 rows of 8 HAs. 40 sleeves/HA @ 60g/sleeve. Weight: 4x8x40x60g = 76.80 kg.
(Material density of arrangement = 240 kg/m^3).

T10 - Observations:
Total burn time 5 min 15 secs
Cardboard burned quite slowly. Contents eventually became involved. Fully developed fire never happened.

T10 - Heat release calculations:
Ignition of this single cardboard sleeve containing one pair of tights was possible but the resulting fire growth was painfully slow. Carrying out heat release calculations would not be meaningful. During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was extremely low.

T10 - Conclusions:
The actual ignition of the item was not too difficult and it is likely that an array such as the one described above would encourage fire growth. However since the progress of the fire through the cardboard and into the tights themselves was so slow, it is considered that this product is an unlikely contender for a rapidly developing fire scenario. We believe that only a larger scale ad hoc fire test would provide a more realistic indication.

Test 11 (T11) - Soft Toy

T11 - Weight analysis (g):

Mini Mouse 260mm long -	Mouse	100.0
Felt outer with what appears	Card tag	2.0
to be a polypropylene wool	Combined weight	102.0

T11 - Stacking arrangement in the shop where purchased:
A large pile of soft toys, consisting of between 500 and 600 soft toys on a 3m x 3m dias piled to a height of around 1.5m above floor level. The dias consisted of stepped shelves with different sized toys mixed together. Typical toys included:

Mickey and Mini Mouse -	smallest 260mm long weighing 80g medium 450mm long weighing 350g largest 700mm long weighing 1.2kg	Complies with the upholstered & stuffed articles act.

Poohbear -	550mm height in sitting position weighing - 650mm	1.4kg 2.8kg	- Polyester fibres

Purchase: One 260mm Mini Mouse @ £7.75.

T11 - Observations:
Total burn time 5 min
Very easy to ignite. Quickly became totally involved - at around 48s. Both flamed and dripped. Burnt out completely to a brittle black mess.

T11 - Heat release calculations:
The soft toy appeared to consist of a highly combustible outer covering of plush material and polypropylene wool filling:

The single soft toy weighed 100g.
Plastic content estimated at close to 100% of product.

(The 2g cardboard tag component of this item has not been included as being relatively insignificant).
Thus potential heat of combustion of this single toy would be in the order of:

$0.100 \text{ kg} \times 43 \text{ MJ kg}^{-1}$
$= 4.3 \text{ MJ}$

During the small scale ad hoc fire test the maximum mass loss/time gradient from test printout:

$= (75+8)\text{g}/(325-50)\text{s} = 83/275 = 0.30 \text{ g s}^{-1}$

Thus the maximum anticipated heat release rate from this single toy would be in the order of:

$0.30 \text{ g s}^{-1} \times 43 \times 10^{6} \text{ J kg}^{-1} \times 10^{-3} \text{ kg g}^{-1}$
$= 12.9 \text{ kW}$

One arrangement of soft toys found in the survey consisted of between 500 and 600 similar toys of the three different sizes as described above.

To calculate the approximate weight of the soft toys it was assumed that the average weight of the 500 toys was that of the medium sized one i.e. 350g.
Thus the approximate size of the risk was $500 \times 0.350 \text{ kg} = 175 \text{ kg}$.

Thus the potential heat of combustion would be in the order of:

175 kg x 43 MJ kg^{-1}

= 7,525 MJ

The maximum anticipated heat release rate from this array of 175 kg of soft toys, if the mass loss/time rate is similar to that for the single toy, would be in the order of:

175/0.100 x 12.9 kW = 22.6 MW

T11 - Conclusions

The ease with which the soft toy was ignited surprised those attending the fire test. The rapid involvement of the entire toy and its total burn out to a hard brittle mess indicated a severe fire hazard. With the ease of ignition and the subsequent dripping and flaming fire, rapid involvement of the entire pile could be expected in a real scenario.

The calculations indicate a massive 22 MW fire resulting. Working purely on the rule of thumb of that 10 kg represents approximately 1 MW, then this 175 kg pile would be expected to produce a very large fire.

The evolvement of very large quantities of toxic smoke would add to the resultant hazard to people in the shop and shopping mall as a whole. Sprinkler protection might find a fire such as this difficult to contain and control. Consideration should be given to investigating this particular hazard and its need for fire protection. The store found in the survey which featured a similar pile of soft toys had automatic smoke detection but did not have a sprinkler system.

Test 12 (T12) - Walkers Crisps

T12 - Weight analysis (g):

10 pack of crisps	Single packet crisps	30.0
	Single empty packet	2.0
	Total weight x 10	318.0
Thus:	Total weight crisps	300.0
	Total weight packaging	18.0

T12 - Stacking arrangement in the shop where purchased:
Can be stacked in a number of different ways such as in an open basket, on sloped shelves with wire edges, or on hanging arms. In a commonly found free standing open wire mesh free standing basket or shelving arrangement there could be between twenty and fifty packs.

T12 - Observations:
Total burn time 7 min 14 secs.
Very easy to ignite. Quickly became totally involved. 1.5m high flame.

T12 - Heat release calculations:
Heat of combustion is based upon animal fat or lard at approximately 40 MJ/kg.
Potential heat of combustion of 10 Pack of Walkers Crisps would be in the order of:

0.300 kg x 40 MJ/kg
= 12.0 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

425g/(290-40)s = 425/250 = 1.7 gs^{-1}

Thus the maximum anticipated heat release rate from the Walkers ten pack would be in the order of:

1.7 gs^{-1} x 40 x 10^6 J kg^{-1} x 10^{-3} kg g^{-1}
= 68 kW

An arrangement where between twenty and fifty such packs (eg 40) could be involved in a fire would consist of say:

40 x 0.300 kg = 12.00 kg of product.

Thus the potential heat of combustion of such an array would be in the order of:

12.00 kg x 40 MJ kg^{-1}
= 480 MJ

The maximum anticipated heat release rate from such an array of 4.96 kg of Quavers, if the mass loss/time rate is similar to that for a single 6 pack, would be in the order of:

40 x 68 kW = 2.7 MW

T12 - Conclusions:
As was seen with the Quavers in Test 1, similar products such as these crisps are extremely easy to ignite and burn both rapidly and furiously with high flames releasing a lot of heat quickly. They are naturally well aerated and a fire would quickly spread to adjoining goods. Video evidence showed that the fire appeared to be fully developed in less than 30s, that maximum flaming occurred at around 45s but that surprisingly the fire continued to burn for over seven minutes. Such loosely packaged edible products can be considered to be highly combustible and readily ignitable and therefore represent a real hazard.

Test 13 (T13) - Girls Short Socks

T13 - Weight analysis (g):

Three pairs of short socks for girls attached to cardboard loop with tiny plastic fastener	Socks	58.0
	Cardboard	7.0
	Combined weight	65.0

T13 - Stacking arrangement in the shop where purchased:

Childrens socks against "L" shaped wall layout.

Av. weight 70g. Socks mostly in cardboard holder.
6 rows; 14HAs/row; 6items/HA over a 1.9m run of wall.
6 rows; 28HAs/row; 6items/HA over a 3.35m run of wall.
Large variation of constituents e.g.:
80% Nylon/20% Cotton
60% Cotton/40%Nylon
95% Cotton/5% Nylon
99% Nylon/1% Lycra

T13 - Observations:

Total burn time 10 min

Easy to ignite, dripped well and fell off hanging arm at 50s. Burned steadily for a long time, although not furiously. Continued to burn on floor.

T13 - Heat release calculations:

Heat of combustion is based upon cardboard at 18 MJ kg^{-1} and Nylon at 30 MJ kg^{-1}

Potential heat of combustion of 3 pack of socks would be in the order of:

0.007 kg x 18 MJ kg^{-1} + 0.058 kg x 30 MJ kg^{-1}
= 0.126 MJ + 1.74 MJ
= 1.87 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

80g/600s = 0.13 gs^{-1}

Thus the maximum anticipated heat release rate from the three pack of socks would be in the order of:

0.13 gs^{-1} x 25* x 10^{6} J kg^{-1} x 10^{-3} kg g^{-1} (* Average between 18 and 30 MJ kg^{-1})
= 3.25 kW

It was assumed that a fire might readily involve a section of display some ten hanging arms wide. Thus with six rows and six items per hanging arm there would be approximately 10x6x6 items i.e. 360 similar items.

This represents :

360 x 0.065 kg = 23.4 kg of stock

Thus the potential heat of combustion of the ten hanging arm wide section of the corner display would be in the order of:

360 x 1.87 MJ = 673 MJ

The maximum anticipated heat release rate from such an array of 23.4 kg of socks, if the mass loss/time rate is similar to that for the single pack of three pairs of socks, would be in the order of:

360 x 3.25 kW = 1.2 MW

T13 - Conclusions:

The socks were easy to ignite and the location of the display in a corner might encourage both a malicious ignition and rapid fire growth. Although the item both flamed and dripped, the actual fire was small in size. To estimate the actual fire growth pattern in such a display a larger test array should be tested. It is considered likely that the size of the fire estimated at just over 1 MW would produce copious quantities of smoke.

Without additional testing, it is not considered possible to determine whether or not this particular product, in this sort of storage arrangement, constitutes a particularly serious hazard.

Test 14 (T14) - Lightweight Sportswear Jacket on a rigid nylon Hanger

T14 - Weight analysis (g):

Nylon hanger with metal hook	102.0
Lightweight sportswear jacket	448.0

T14 - Stacking arrangement in the shop where purchased:
The particular jacket used for the fire test was a John Player Special Grand Prix style jacket donated by Adair Lewis. It was about one year old, but was typical of the kind of jackets that are sold in numerous outlets, particularly sports shops. Jackets can be up to 12 deep on three rows of around fifteen hanging arms basically from floor level to the ceiling along one wall. There can, therefore, be in the region of 12 x 3 x 15 = 540 jackets on display.

T14 - Observations:
Total burn time
Ignited very easily. On hanger for quite a time.

T14 - Heat release calculations:
Heat of combustion is based upon the jacket being nylon with what appeared to be a kind of polyurethane shower proofing at approximately 30 MJ kg^{-1}. The hanger was suspected to be a rigid nylon type of material.
Potential heat of combustion of the hanger and jacket would be in the order of:

$0.550\ kg \times 30\ MJ\ kg^{-1}$
$= 16.5\ MJ$

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

$(600\text{-}225)g/(160\text{-}60)s = 375/100 = 3.75\ gs^{-1}$

Thus the maximum anticipated heat release rate from the lightweight sportswear jacket would be in the order of:

$3.75\ gs^{-1} \times 30 \times 10^{6}\ J\ kg^{-1} \times 10^{-3}\ kg\ g^{-1}$
$= 112.5\ kW$

An arrangement where perhaps several hundred of these sort of jackets, say 250, which could rapidly become involved in a fire, would consist of:

$250 \times 0.550\ kg = 137.5\ kg$ of product.

Thus the potential heat of combustion of such an array would be in the order of:

$137.5\ kg \times 30\ MJ\ kg^{-1}$
$= 4{,}125\ MJ$

The maximum anticipated heat release rate from such an array of 137.5 kg of lightweight sportswear jackets, if the mass loss/time rate is similar to that for the single jacket, would be in the order of:

$250 \times 112.5\ kW = 28\ MW$

T14 - Conclusions:
This type of jacket, hung in the way they are on plastic hangers, along an entire wall, frequently adjacent to the main entry and exit door, constitutes one of the most serious hazards recognised from the survey of shops. The ease of ignition and the very rapid fire development together with the high flaming and dripping fire would encourage rapid involvement of the entire stock.

The calculation above, which resulted in a 28 MW fire, assumed only half of the potential of 500 jacket were involved at one time.

Video evidence showed that the fire which was lit at the base of the jacket had reached up inside the jacket and was appearing at neck level within 25s. By 40s the flames were 0.5m above the top of the jacket and the hanger melted in just over one minute with the jacket continuing to burn on the floor. Even a sprinkler system might find it difficult to reduce the quantity of smoke evolved in the first few minutes of a fire in such a shop, since much of the stock would be shielded from direct water discharge by other stock.

Test 15 (T15) - Knee High Socks for Girls

T15 - Weight analysis (g):

1 pair knee high socks for girls	Socks	37.0
attached to cardboard loop	Cardboard	3.0
with tiny plastic fastener	Combined weight	40.0

T15 - Stacking arrangement in the shop where purchased (Similar to T13):
Childrens socks against "L" shaped wall layout.

Av. weight 70g. Socks mostly in cardboard holder.
6 rows; 14HAs/row; 6items/HA over a 1.9m run of wall.
6 rows; 28HAs/row; 6items/HA over a 3.35m run of wall.
Large variation of constituents e.g.:
80% Nylon/20% Cotton
60% Cotton/40%Nylon
95% Cotton/5% Nylon
99% Nylon/1% Lycra

T15 - Observations:
Total burn time
Ignited readily. Burned slowly almost like a wick.

T15 - Heat release calculations:
Heat of combustion is based upon cardboard at 18 MJ kg^{-1} and Nylon at 30 MJ kg^{-1}
Potential heat of combustion of pack of one pair of knee high socks for girls would be in the order of:

0.003 kg x 18 MJ kg^{-1} + 0.037 kg x 30 MJ kg^{-1}
= 0.054 MJ + 1.11 MJ
= 1.16 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

32.5g/150s = 0.22 gs^{-1}

Thus the maximum anticipated heat release rate from pack of one pair of knee high socks would be in the order of:

0.22 gs^{-1} x 25* x 10^6 J kg^{-1} x 10^{-3} kg g^{-1} (* Average between 18 and 30 MJ kg^{-1})
= 5.5 kW

As with Test 13, it was assumed that a fire might readily involve a section of display some ten hanging arms wide. Thus with six rows and six items per hanging arm there would be approximately 10x6x6 items i.e. 360 similar items.
This represents :

360 x 0.040 kg = 14.4 kg of stock

Thus the potential heat of combustion of the ten hanging arm wide section of the corner display would be in the order of:

360 x 1.16 MJ = 418 MJ

The maximum anticipated heat release rate from such an array of 23.4 kg of socks, if the mass loss/time rate is similar to that for the single pack of three pairs of socks, would be in the order of:

360 x 5.5 kW = 1.2 MW

T15 - Conclusions:

The socks were easy to ignite and the location of the display in a corner might encourage both a malicious ignition and rapid fire growth. Although the item both flamed and dripped, the actual fire was small in size. To estimate the actual fire growth pattern in such a display a larger test array should be tested. This single pair of socks burned slightly more rapidly but over a shorter period of time than the ones in Test 13 quickly dying down to a relatively low heat release smoldering fire. To get a 1 MW fire involving socks such as these might in fact be quite difficult if not impossible.

Without additional testing of a larger number of goods, it is not considered possible to determine whether or not this particular product, in this sort of storage arrangement, constitutes a particularly serious hazard.

Test 16 (T16) - Mint Creams

T16 - Weight analysis (g):

Individually wrapped	21 sweets @	10.0
sweets in a bag	Bag	10.0
	Combined weight	220.0

T16- Stacking arrangement in the shop where purchased (Similar to T1):
Can be stacked in a number of different ways such as in an open basket, on sloped shelves with wire edges, or on hanging arms. In a commonly found hanging arm display there could be several hundred packets of different but similar sweets.

T16 - Observations:
Total burn time
Cellophane bag ignited readily. The sugar content of the sweets burned slowly.

T16 - Heat release calculations:
Heat of combustion is based upon sucrose at 15 MJ kg^{-1}
Potential heat of packet of sweets would be in the order of:

0.220 kg x 15 MJ kg^{-1}
= 3.3 MJ

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

9.0g/700s = 0.013 gs^{-1}

Thus the maximum anticipated heat release rate from one packet of sweets would be in the order of:

0.013 gs^{-1} x 15 x 10^6 J kg^{-1} x 10^{-3} kg g^{-1}
= 0.2 kW

T16 - Conclusions:
It is considered probable that in a fire situation the bags would tend to fall off their hanging arms quickly, probably resulting in a relatively slow fire.
Without a more detailed and accurate assessment of what would happen in a real full scale fire situation, it is not considered possible to predict how such a fire would develop.

With several hundred packets of sweets on hanging arms in highly combustible cellophane bags we believe there is the potential for a large fire. However, we further believe that it would in fact burn in a significantly different way to how the single packet in Test 16 did. We have not therefore carried out the heat release calculations for the larger fire scenario based upon Test 16 results..

Test 17 (T17) - Video Cassette - Empty

T17 - Weight analysis (g):

Empty VHS	Paper insert	8.0
Video cassette	Plastic case	90.0
	Combined weight	98.0

T17 - Stacking arrangement in the shop where purchased:
Empty video cassettes are displayed in a number of ways, but mostly in a way that would tend to inhibit rapid fire spread from one tape to another. This is simply achieved by the cassette being flat against a shelving system, known in the trade as a video browser. Browsers tend to be made of steel, occasionally of timber, hardboard or plastic.

T17 - Observations:
Total burn time
Burned rapidly with both flaming and dripping onto floor. Produced a lot of black smoke and copious quantities of soot in the air.

T17 - Heat release calculations:
Heat of combustion is based upon the cassette being predominantly made of plastic at approximately 43 MJ kg^{-1}.
Potential heat of combustion of the empty video cassette would be in the order of:

$0.090 \text{ kg} \times 43 \text{ MJ kg}^{-1}$
$= 3.87 \text{ MJ}$

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

$130\text{g}/(375-100)\text{s} = 130/275 = 0.47 \text{ gs}^{-1}$

Thus the maximum anticipated heat release rate from the video cassette would be in the order of:

$0.47 \text{ gs}^{-1} \times 43 \times 10^{6} \text{ J kg}^{-1} \times 10^{-3} \text{ kg g}^{-1}$
$= 20.2 \text{ kW}$

Arrangements of several hundreds of these sort of cassettes are readily found. However it is considered unlikely that more than 40 or so would rapidly become involved in a fire. Without additional testing on actual browsers this number would be difficult to predict accurately:

$40 \times 0.090 \text{ kg} = 3.6 \text{ kg}$ of product.

Thus the potential heat of combustion of such an array would be in the order of:

$3.6 \text{ kg} \times 43 \text{ MJ kg}^{-1}$
$= 155 \text{ MJ}$

The maximum anticipated heat release rate from such an array of 3.6 kg of empty video cassettes, if the mass loss/time rate is similar to that for the single cassette, would be in the order of:

$40 \times 20.2 \text{ kW} = 0.8 \text{ MW}$

Let us consider a plastic browser caught fire and a hundred video cassettes plus the browser itself were involved in a rapidly developing fire. The size of the fire would be in the region of:

$100 \times 0.090 \text{ kg} = 9.0 \text{ kg}$ of product plus an estimated 10 kg of plastic browser.

Thus the potential heat of combustion of such an array would be in the order of:

$19.0\text{kg} \times 43 \text{ MJ kg}^{-1} = 817 \text{ MJ}$

The maximum anticipated heat release rate from such an array of 19.0 kg of empty video cassettes and plastic video browser, if the mass loss/time rate is similar to that for the single cassette, would be in the order of:

19.0/0.090 x 20.2 kW = 4.3 MW

T17 - Conclusions:

Predicting the fire scenario of a full scale video browser fire is difficult. The cassette was easy to ignite and burned intensely and rapidly with upward and downward flaming that would readily encourage fire spread. The fact that browsers tend to consist of narrow shelving, frequently for cassettes only one deep, means that the browsers feature a degree of intrinsic firesafety. Without a full scale fire test of some of the different sorts of loaded browsers commonly found in use, or some more detailed analysis of the information gathered, it is not possible to suggest any firm guidance on the potential fire hazard empty video cassettes pose.

In some shops the browsers are of open wire mesh. In that situation the fire spread would tend to be far more rapid and extensive.

The actual valuable contents of the cassettes are normally stored in a manned secure area. Although the actual tapes tend to be stored closely packed together on shelves, should a fire develop there, the outcome would almost certainly be extremely serious.

The turning away from plastic browsers to steel ones by a number of stockists is to be commended.

Test 18 (T18) - Audio Tape Cassette - Empty

T18 - Weight analysis (g):

Empty Audio	Paper insert	2.0
Tape cassette	Plastic case	27.0
	Combined weight	29.0

T18 - Stacking arrangement in the shop where purchased:
Empty audio tape cassettes are displayed in much the same way as empty video cassettes on browsers. These browsers would tend to inhibit rapid fire spread from one tape to another. This is simply achieved by the cassette or cassettes being flat against the shelving system, known in the trade as a browser. Browsers tend to be made of steel, occasionally of timber, hardboard or plastic.

T18 - Observations:
Total burn time: Not timed.
Readily ignited. Flamed and dripped producing a lot of smoke with a lot of soot in the air.

T18 - Heat release calculations:
Heat of combustion is based upon the cassette being predominantly made of plastic at approximately 43 MJ kg^{-1}.
Potential heat of combustion of the empty audio tape cassette would be in the order of:

$0.027 \text{ kg} \times 43 \text{ MJ kg}^{-1}$
$= 1.16 \text{ MJ}$

During the small scale ad hoc fire test the maximum mass loss/time gradient from the test printout was:

$39\text{g}/320\text{s} = 0.12 \text{ gs}^{-1}$

Thus the maximum anticipated heat release rate from the audio tape cassette jacket would be in the order of:

$0.12 \text{ gs}^{-1} \times 43 \times 10^{6} \text{ J kg}^{-1} \times 10^{-3} \text{ kg g}^{-1}$
$= 5.16 \text{ kW}$

Arrangements of several hundreds of these sort of cassettes are readily found. However, it is considered unlikely that more than 50 or so would rapidly become involved in a fire. Without additional testing of an actual loaded browser, this number would be difficult to predict accurately:

$50 \times 0.027 \text{ kg} = 1.35 \text{ kg}$ of product.

Thus the potential heat of combustion of such an array would be in the order of:

$1.35 \text{ kg} \times 43 \text{ MJ kg}^{-1}$
$= 58 \text{ MJ}$

The maximum anticipated heat release rate from such an array of 1.35 kg of empty audio tape cassettes, if the mass loss/time rate is similar to that for the single cassette, would be in the order of:

$50 \times 5.16 \text{ kW} = 0.26 \text{ MW}$

T18 - Conclusions:
Predicting the fire scenario of a full scale audio tape browser fire is difficult. The cassette was easy to ignite and burned intensely and rapidly with upward and downward flaming that would readily encourage fire spread. The fact that browsers tend to consist of narrow shelving, frequently for only a few cassettes deep, means that the browsers are almost certainly inherently reasonably firesafe. Without a full scale fire test of some of the different sorts of loaded browsers commonly found in use,

or some more detailed analysis of the information gathered, it is not possible to provide any firm guidance on the potential fire hazard empty audio tape cassettes pose.

In some shops the browsers are of open wire mesh. In that situation the fire spread would tend to be far more rapid and serious.
The actual valuable contents of the cassettes are normally stored in a manned secure area. The cassettes contents are stored closely packed together on shelves but should a fire develop there the outcome could possibly be serious.

APPENDIX F

Photographs from Survey

Photograph 1. Congested Discount Store.

Photograph 2. Better Arranged Discount Store.

APPENDIX F

Photograph 1 Congested discount store

Photograph 2 Better arranged discount store