FIRE SAFETY OF TV-SETS AND PC-MONITORS

Prepared for:
European Brominated Flame Retardants Industry Panel
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SUMMARY

The objective of Electrical and Electronic (E&E) fire safety standards is limited to protecting users of consumer appliances and office electronic equipment from fires which might start within those appliances. No account is taken of external fire sources.

Enclosures for most electronic office equipment, like PC-monitors, meet high fire safety levels world wide. The use of flame retarded plastics provides protection against both internal and external fire sources.

For TV-sets, fire safety standards vary by country or region. Higher fire safety levels exist in Japan and the USA than in Europe, where IEC 65 (the international standard for most mains operated electronic equipment) only requires low fire safety levels for materials used to make backplates and housings. In the past, high fire safety materials were used voluntarily by most producers of televisions sold in Europe. For several years this practice has been largely abandoned, and today the majority of television housings and backplates available on the European market meet only the lowest level of materials fire safety performance, the HB (horizontal burning) rating. In the USA, UL 1410 (the standard for Television Receivers and High Voltage Video Products) requires one of the highest levels of materials fire safety performance for TV-set enclosures, V0 (vertical burning). The Japanese standards for backplates are thought to be equivalent to those in the USA.

The objectives of this study were to determine the different fire safety levels of old and new TV-sets and PC-monitors from Europe, USA and Japan, to look at their ignition and post-ignition behaviour in test series with ignition sources of growing intensity to observe their fire behaviour in real life full scale room fire tests and to determine the ability of small scale fire testing of plastic specimens taken from the backplates to

predict the results of full scale tests. Another objective was to determine the ability of a typical TV-set to spread fire to the furnishings in a dwelling.

The study was structured as follows:

First, elemental analysis of the plastics was done to identify the plastics themselves and the nature of the flame retardant systems used.
Second, the materials used in backplates were tested to the standards used in the USA and Europe and their classification established.

Third, in a series of fire tests with ignition sources of growing intensity, the behaviour of backplates and entire TV-sets and PC-monitors was investigated.

Finally, two full scale fire tests were carried out in a fully furnished room, one with a TV-set representative of the US market and one with a TV-set representative of the European market.

The results of the test programme showed that:

- TV-sets backplates are made of polystyrene and high impact polystyrene, whereas ABS, PC/ABS and PVC are used for the PC-monitors tested.
- For meeting highest fire safety performance, the flame retardant systems used in TV-sets backplates are all based on brominated flame retardants combined with an antimony oxide synergist. For PC-monitors, brominated and phosphorous-containing flame retardants are used, depending on the polymer.
- The materials flammability tests carried out showed that sufficiently flame retarded plastics meet the high requirements of vertical tests (UL94 V). The low flame retardancy and non flame retarded plastics only meet the lower horizontal tests (UL94 HB) requirements.
- The tests with ignition sources of growing intensity showed that flame retarded UL94 V plastics generally do not burn, whereas HB-rated plastics readily ignite when exposed to the lowest energy ignition source typical of a short-circuit or to accidental contact with an open flame.
- Older model European TV-sets and backplates generally have higher fire safety levels than new TV-sets currently available in Germany
- New TV-sets and backplates purchased in Germany can in most cases be ignited by the lowest energy ignition source
- TV-sets bought in Japan and the USA have high to very high fire safety levels.
- In two simulated real life fire tests in a fully furnished room, a new TV set purchased in Germany, was ignited by the smallest ignition source, the methenamine tablet, and led to flashover in the room after about 7 minutes. A USA TV-set did not ignite and did not burn when exposed to even the highest intensity ignition sources.
- While new PC-monitor enclosures have high fire safety levels and did not burn when exposed to the different ignition sources, three of the six old PC-monitors tested burnt when exposed to the smallest energy ignition source, the methenamine tablet.

This study has confirmed previous findings that the use of plastics parts with higher fire safety levels are needed to ensure adequate consumer protection. External fire sources, inadequate design, manufacturing faults or defects, simple wear and tear and consumer misuse may lead to flashover and fully developed fires in a very short period of time if housings and backplates are not adequately flame retarded.

To optimise the fire safety level of TV-sets in Europe, housings and backplates should be made resistant against ignition sources of lower intensity like methenamine tablets and household candles. This could be achieved by harmonising European fire safety standards for consumer electronics with the requirements applied in other parts of the world. This would involve changing IEC 65 to require V-0 performance for housings and backplates.

1. INTRODUCTION

Fire safety is an integral part of fire precautions. Fire precautions have the objective to minimize the number of and damage from fires. Preventing fires or slowing their growth makes escape possible over a longer period of time. As a result, life, health and property are efficiently protected.

In order to reduce the fire risk of combustible materials and products, fire safety requirements exist in virtually all applications. The most important are building, transportation (road and rail vehicles, ships, aircraft), electrical engineering and electronics, furniture, textiles and mining.

Modern fire precautions guarantee a high level of fire safety and virtually exclude catastrophic fires which razed entire towns only one century ago. However, even today, fire statistics show a high death toll and huge losses for the economy [1].

New legislation is an essential influence for increasing the fire safety level in many fields. One striking example is the introduction of the UK regulations for flame retarded upholstered furniture in 1988. It shows a dramatic drop of fires and deaths from upholstered furniture (comparison 1988 to 1993: 4,818 to 3,746 fires; 247 to 146 fire deaths) [2].

One basic fire protection measure is to interfere with the course of a fire. Basically, the course of a fire is always the same. It consists of the phases initiating, fully developed and decreasing fire [3]. Fire protection measures for combustible materials and products can only apply to the early stage of a fire, i.e. the initiating fire phase, by preventing ignition and, if ignition occurred, by preventing or reducing fire propagation and minimising heat release. For example, flame retarded plastics and wood are materials which can prevent a fire or delay its development to flashover and the subsequent phase of a fully developed fire. In this way, flame retarded materials make a decisive contribution in saving lives, protecting property and the environment.

2. BACKGROUND OF THE STUDY

Plastics are widely used in electrical engineering and in electrical and electronic (E&E) equipment, particularly for office and consumer electronics. They have to meet flammability and fire safety requirements which may be different in various parts of the word.

In the USA, office and consumer electronics have to meet high fire safety requirements. This applies not only for internal plastics parts, but also for enclosures, housings and backplates. In Europe different requirements are applied to these product groups. The requirements for office equipment are the same as those in the USA.

This study was planned and carried out in order to determine how the fire safety levels of consumer and office electronics can be influenced by the materials performance ratings of housings and backplates.

The main objectives were to determine the flammability and fire behaviour of plastics materials, backplates and housings, TV-sets and PC-monitors as well as the fire contribution of TV-sets in a fully furnished room. Further, the aim was to find out whether the materials flammability test classifications specified in regulations and standards are in accordance with results obtained from larger scale and real life tests carried out with backplates and end-products.

Finally, the aim of the study was to investigate the effects of material flammability classification on enclosure response to selected ignition sources.

Because of public concern about a number of fire accidents due to TV-sets and the safety of the standby function, the fire safety of E&E equipment and particularly of TV-sets has already been studied in the past. One study compared the fire hazard of fire-retarded and non-fire-retarded products and showed that housings containing flame retardants meet higher fire safety requirements and better resist ignition, delay the flame propagation and the involvement of the whole apparatus in the fire [4]. A more recent study dealt with television fires and concluded that TV-sets bought in Europe are basically safe, but that they burn fiercely once ignited. Here, the role of external fire sources leading to quick ignition and sustained burning of the TV-sets is particularly referred to [5].

3. EXISTING REGULATIONS AND STANDARDS FOR E&E EQUIPMENT FIRE SAFETY

The fire safety of electrical and electronic (E&E) equipment is governed by rules and standards for product safety mainly set up by professional bodies like Underwriters' Laboratories (UL) in the USA and used world-wide. The UL standards were very often taken over by other bodies and standards organisations like the International Electrical Commission (IEC). However, the fire safety requirements in IEC standards may differ from those contained in UL standards.

Plastics used in E&E equipment have to meet materials and finished components fire safety requirements. They are part of product safety standards like UL 1950, CSA 22.2, IEC 950, EN 60950 for the safety of business equipment [6-9] and UL 1410, UL 746, IEC 65, EN 60065 for the safety of consumer electronic equipment [10-13].

The flammability tests for plastics materials described in the above mentioned standards and their annexes were developed by Underwriters Laboratories to evaluate their performance with respect to resistance to ignition and flame propagation. They can be found in UL 94 "Tests for flammability of plastic materials for parts in devices and appliances" [14]. Depending on the fire safety requirements, materials have to meet horizontal burning tests (Class UL 94 HB) or the more stringent vertical burning tests (Class UL 94 V2, V1, V0 or 5V). These tests simulate ignition sources which may occur in E&E equipment and impinge on plastics parts of electrical components.

Materials meeting these vertical tests confer higher fire safety to E&E equipment, against internal as well as external fire sources.

In the USA, plastic materials used in the manufacture of enclosures for office and consumer electronic products are virtually always required to pass one of the vertical flammability tests. In Europe, IEC 65 allows major plastics parts in TV-set backplates and housings to be made from materials that only fulfil the requirements of the much less demanding horizontal test.

A new IEC 65 draft would allow the use of TV backplates and housings without any fire safety classification. In a Draft for the revision of IEC 65, recently approved for publication, there will be basically no flammability requirements for plastics materials if they exceed a certain distance from specified potential ignition sources. The same is true if the specified potential ignition sources are contained in separate fire enclosure [15]. This approach relies solely on the technical design of the TV-set against internal fire sources and ignores the fire safety level of the materials which would cover both internal and external fire sources.

This compares with the recent past in Europe, when plastics used for backplates and housings in office and consumer electronics virtually all complied with the stringent UL 94 V specifications. This guaranteed a high fire safety level of materials against internal and, in addition, against external fire sources like candles. For TV-sets, this took place on a voluntary basis, since IEC 65 requires only low fire safety levels for materials.

4. TEST PROGRAMME FLAMMABILITY AND FIRE BEHAVIOUR OF TV-SETS AND PC-MONITORS

In 1997, a comprehensive fire testing programme aiming to evaluate the fire safety level of TV-sets and PC-monitors was commissioned by the European flame retardants associations EFRA and EBFRIP. Both associations are sector groups of CEFIC, the European Chemical Industry Council located in Brussels, Belgium. The UL 94 flammability tests were carried out at the UL certified laboratory of General Electric (GE)

Plastics, Bergen op Zoom, the Netherlands, and the actual fire testing programme was performed at the State Materials Research and Testing Establishment MFPA in Leipzig, Germany.

As already said, the main objectives were to study the ignition and post-ignition behaviour of TV-sets and PC-monitors. Backplates and housings are the biggest plastics parts in these appliances (25" TV-sets: Backplates 2 to 4 kg; Housings 1 to 1.5 kg). Therefore, it was essential to determine how the flammability ratings of different backplates influence the fire behaviour of these appliances. The program used fire sources of growing intensity.

To this aim, a series of TV-sets, PC-monitors and spare backplates available on the market were purchased.

In March 1997, a random selection of 5 PC-monitors (15") in triplicate and 6 TV-sets (28",25",14") in duplicate as well as spare TV-sets backplates was purchased in the Frankfurt area at major retailers. As older spare TV-sets backplates were still available, the corresponding backplates or enclosures produced from 1989 to 1991 were also purchased. Inquiries at retailers for spare PC-monitors backplates were unsuccessful.

Two 25" TV-sets of different brands were purchased in duplicate at retailer shops in the USA and one 25" TV-set in Japan.

In general, leading brands were selected to obtain a representative cross-section of the market. The same brands are available across Europe. The models selected in the USA and in Japan were made by the same manufacturers as some of the models purchased in Germany. The identity of the brands selected will not be disclosed in this report as the focus of the study is the IEC 65 standard, not the performance of individual models.

Seven old TV-sets, 10 old TV-sets backplates and six old PC-monitors were selected in a collecting point for old consumer and office electronics near Frankfurt with a view to determining their flammability and fire behaviour in range-finding tests. The tests were carried out before the start of and parallel to the main programme and helped to optimise the test protocols, as well as providing some valuable information on the fire behaviour and safety levels of old consumer and office equipment.

4.1 FIRE SOURCES

Various low energy ignition sources of growing intensity were selected in order to study their influence on the behaviour of backplates and housings alone and as parts of the original TV-sets and PC-monitors. In order to simulate conditions which may occur in practice, ignition sources which simulate events happening in real life were used. With the exception of the methenamine tablet, which can be used for simulating both internal electrical faults like a short circuit and a small external open flame like a match, all the other ignition sources simulated external open flames.

In order of increasing intensity, the ignition sources selected were the following:

- Methenamine tablet (standardised solid fuel pellet) to simulate a low energy fire source like an internal electrical fault (short circuit) or an external open flame (match)
- Small candle (plate warmer, also called ”tea light” or ”night light”)
- Household candle (often used as background lights on TV-sets)
- Piece of cloth soaked with isopropanol (secondary ignition source)
- Isopropanol fuel as fire accelerator (to simulate possible arson).

Ignition sources were selected on the grounds of their accepted use in standardised testing protocols and for their real-life significance. In order of increasing intensity, the ignition sources selected were the following:

The **methenamine tablet** (solid fuel pellet) was placed under the lower edge of the backplate (worst case situation) to allow the flame to attack the material on top of it and on the side in a vertical position. In the room fire tests, a hole was cut into the bottom of the casing of the TV-sets and the methenamine tablet placed in the hole so that the flame impinged on the plastic. This arrangement was chosen in order to simulate both an internal and an external ignition source, and to monitor the development of the fire from ignition onwards.

The methenamine tablet is comprised of hexamethylene-tetramine ($C_6H_{12}N_4$), with a diameter of 6 mm and a height of 4 mm, a mass of 0.15 g and a burning time of around 100 s. It has a combustion energy of 4.5 kJ and produces a 40 W flame as described and used in a previous TV-set study [5]. It is used as an ignition source placed on enclosures of TV-sets and high voltage video products according to UL 1410 [10]. This test procedure is much less demanding than the vertical test procedure we used in our real life fire test series. In addition, the methenamine tablet is applied as an ignition source to determine the reaction to fire of floor coverings to ISO 6925 [16] and has been retained by the European Commission as a harmonised test for the reaction of fire of floor coverings in the European Union.

The flame of the **small candle** was placed under the bottom edge of the backplate to simulate a steadily burning ignition source vertically impinging on the plastic in a worst case situation. The small candle flame simulates a small oil lamp flame or a wax candle often used in some countries when watching TV (some consumer believe the light relieves stress from their eyes).

The small candle is a plate warmer commonly used in households in Germany and elsewhere. The candle is 18 mm high with a diameter of 38 mm and has a mass of 14 g. It is contained in a small aluminium cup (mass 0.6 g). The mass loss of the small candle is 0.04 g/min. It produces a flame of around 30 W.

The **household candle** was leaned against the vertical part of the backplate or housing so that the flame impinged on the surface of the plastic. This simulated the worst case situation where a candle next to an appliance comes in contact with the housing or backplate. Candles are often placed on and near TV-sets in particular in Germany and the Nordic countries.

The household candle is commonly used in Germany and elsewhere, 185 mm high with a diameter of 21 mm and has a mass of 53 g. The mass loss of the household candle is 0.08 g/min. It produces a flame of around 60 W.

The **piece of cloth soaked with isopropanol** was positioned on the top of the housing or backplate to simulate a secondary fire source, for example a burning decoration article. In many countries, particularly in the Nordic countries and Germany, such articles supporting candles are placed on top of TV-sets.

In addition, in order to simulate a worst case situation, the cloth soaked with isopropanol was placed at the bottom of the edge of the backplate.

The pieces of cloth made of mixed cotton fabric had the dimensions of 120 x 60 mm and a mass of around 4 g. The cloth was soaked with 13 g of isopropanol. It released an energy of 1.6 to 1.9 kW during combustion.

Finally, in cases were the housings/backplates did not contribute to flame propagation with the other fire sources mentioned above, 200 ml (or 200 cm^3 x 0.8 g/cm^3 = 160 g), and in one case additional 500 ml (= 400 g) of **isopropanol** was poured on the appliance. The combustion of the isopropanol releases an energy of 27 to 40 kW. This scenario was designed to simulate possible arson.

Table 1: Characteristics of the ignition sources used in the test programme1 Characteristics of the ignition sources used in the test programme Characteristics of the ignition sources used in the test programme Characteristics of the ignition sources used in the test programme Characteristics of the ignition sources used in the test programme Characteristics of the ignition sources used in the test programme Characteristics of the ignition sources used in the test programme

Ignition Source	Mass [g]	Flame height range [mm]	Burn time [s]	Net heat of combustion* [MJ/kg]	Mass loss [g/min]	Heat release [W]
Solid fuel pellet (methenamine tablet)	0.15	5 – 10	80 – 105	30.0	0.08 – 0.11	40 – 55
Small candle (plate warmer)	14	10 – 15	n.a.	46.2	0.04	30
Household candle	53	15 – 30	n.a.	46.2	0.08	60
Piece of cloth soaked with isopropanol	413	200 – 300	210 – 240	30.4	3.25 - 3.7	$1.6 - 1.9 \cdot 10^3$
Isopropanol (200 ml)	160	600 – 800	120 – 180	30.4	53 - 80	$27 - 40 \cdot 10^3$

n.a.: not applicable. The candle flames were usually applied for 5 min
*: The values for the net heat of combustion were taken from [17]

4.2 ANALYSIS OF MATERIALS

4.2.1 Determination of polymers

As part of the programme on fire testing of TV-sets and PC monitors, samples for UL 94 testing were analysed in the General Electric (GE) Plastics analytical laboratory in Bergen op Zoom, the Netherlands, with the aid of a Fourier Transform Infra Red (FTIR) spectrometer. The equipment used was a Perkin Elmer 2000 FT-IR unit.

The identification test is made on a small plaque of unknown material. An infrared scan (4,000 – 500 cm^{-1}) is made and absorption peaks are registered. With the aid of a computerised library the unknown material is identified.

The results are summarised in Table 2.

Table 2: Determination of polymers2 Determination of polymers Determination of polymers Determination of polymers Determination of polymers Determination of polymers Determination of polymers

Sample Identification	Year of Manufacture	Nature of Plastic
TV-sets and old spare backplates purchased in Germany		
TV01-28	New*	HIPS
TV01-28-BP91	1991	HIPS
TV02-25	New	HIPS
TV02-25-BP90	1990	HIPS
TV03-25	New	PS
TV03-25-BP90	1990	Not available
TV04-25	New	PS
TV04-25-BP90	1990	PS
TV05-25	New	HIPS
TV05-25-BP91	1991	HIPS
TV06-14	New	HIPS
TV06-14-BP89	1989	HIPS
TV-sets purchased in the USA and Japan		
TV07-25-US	New	HIPS
TV08-25-US	New	HIPS
TV09-25-JAP	New	HIPS

PC-monitors purchased in Germany		
PC 1	New	ABS
PC 2	New	PC/ABS
PC 3	New	PC/ABS
PC 4	New	PC/ABS
PC 5	New	PVC

New* = Purchased in 1997

The TV-sets backplates all consisted of polystyrene, most of them of high impact polystyrene (HIPS). Only the TV-sets 03 and 04, as well as the 1990 backplate of TV set 04 were made of polystyrene.

The materials used for PC-monitors backplates consisted of ABS (PC 1), PC/ABS (PC 2, PC 3, PC 4) and PVC (PC 5).

4.2.2 Determination of flame retardants

The elemental analysis of polymer samples was conducted in duplicate by the analytical laboratories of Albemarle S.A. and Great Lakes Chemical Corporation. The analyses focused on the detection and quantification of elements typically used in the manufacture of flame retardant polymer formulations. Samples were obtained from the actual televisions, backplates or monitors that were subjected to small and large scale fire testing.

Elemental analysis indicates that a wide range of materials are used in the manufacture of televisions and monitors. Analysis of some samples were typical of UL 94 V materials (>10% Br and ~2.5% Sb) while some TV set housings did not contain any flame retardant. Materials containing intermediate levels of flame retardants were also observed.

Analysis of all samples from televisions purchased in Japan and the USA contained Br and Sb at levels typical of UL 94 V materials. Samples from old (1989-1991) European television backplates generally contained similar levels of Br or Cl and Sb, while new European televisions contained either much lower levels of flame retardants or none at all. Analysis of personal computer monitor housings indicates that, depending on the polymer, halogen/antimony and phosphorous flame retardant systems are both being used commercially today.

4.2.2.1 Analysis protocol

As a preliminary screening tool to detect all elements of interest, all samples were first subjected to elemental analysis by x-ray fluorescence spectroscopy. Using these results as a guide, additional tests were conducted to quantify the levels of specific elements of interest. Since nitrogen is not detected by x-ray fluorescence spectroscopy, tests for extractable melamine and derivatives were conducted on all samples which were seen to contain phosphorous.

4.2.2.2 Method description

Preliminary elemental analysis

X-ray fluorescence spectroscopy (general laboratory technique)

A sample is bombarded with high energy electrons, causing ejection of electrons from the inner shells of sample atoms. By a series of transitions, electrons from the outer shells of that atom fill the vacancy created by ejection of the inner shell electron. Each of these electron transitions emits a characteristic x-ray spectral line. X-ray fluorescence spectroscopy is limited to detection of elements that are heavier than magnesium.

Total bromine and chlorine content

Schöniger flask method (GLCC method GM-82-03)

A sample is burned completely in an oxygen-rich atmosphere in a specially designed flask, converting all bromine and chlorine in the sample to elemental bromine/chlorine or hydrogen bromide/chloride. These gases are absorbed into a potassium hydroxide/hydrazine sulphate solution, in which bromine/chlorine are reduced to bromide/chloride. The bromide/chloride levels are then determined by potentiometric titration with silver nitrate.

Total antimony and phosphorous content

ICP Inductively coupled plasma (GLCC preliminary method dated 13 June 1996)

A sample is placed inside a microwave-transparent vessel containing concentrated sulphuric and nitric acids and subjected to rapid heating. This breaks down even highly stable organic structures so that subsequent oxidation by nitric acid and peroxide can provide complete digestion of the sample. Antimony and phosphorous levels are determined by inductively coupled plasma atomic emission spectrometry.

Total extractable melamine and derivatives

FTIR Fourier transform infrared analysis (general laboratory technique)

A sample is held in boiling water for 30 minutes. The water, containing any extracted material, is dried to constant weight. Residues are formed into a potassium bromide pellet for identification of constituents by Fourier transform infrared analysis.

4.2.2.3 Results

The results of the analytical work are summarised in Table 3

Table 3: Identification of flame retardants in the samples from TV-sets backplates, TV-sets and PC-monitors.

Sample Identification	Sb [%]	Br [%]	Cl [%]	P [%]	Extractable Melamine+ Derivatives [%]	ICP ScanScanningScanningScanningScanningScanningScanning Results
Old TV-sets from consumer electronics collection point						
OLD TV-BP01	0.5	<0.1	8.0	<0.1	- - -	Zn,Pb,Mn,Fe,Al,Na
OLD TV-BP02	3.5	11.0	<0.1	<0.1	- - -	Fe, Ti, Al
OLD TV-BP03TV-BP03TV-BP03TV-	3.0	8.0	<0.1	<0.1	- - -	Zn
BP03TV-BP03TV-BP03TV-BP03	<0.1	2.5	<0.1	<0.1	- - -	Zn, Fe, Ba
OLD TV-BP04	1.0	3.5	<0.1	<0.1	- - -	
OLD TV-BP05	4.0	<0.1	12.0	<0.1	- - -	
OLD TV-BP06	<0.1	<0.1	<0.1	<0.1	- - -	Ba, Ti, Fe, Zn, Cd
OLD TV-BP07	3.0	6.5	<0.1	<0.1	- - -	
OLD TV-BP08	5.0	<0.1	6.5	<0.1	- - -	
OLD TV-BP10						
TV-sets and old spare backplates purchased in Germany						
TV01-28*	<0.1	3.0/<0.1	<0.1	<0.1/0.4	- - -/<2	Zn
TV01-28-BP91	2.5	9.5	<0.1	<0.1	- - -	
TV02-25	<0.05	<0.1	<0.1	0.4	<2	P, <Ti, Zn
TV02-25-BP90	4.0	<0.1	12.0	<0.1	- - -	
TV03-25	<0.1	<0.1	<0.1	<0.1	- - -	
TV03-25-BP90	<0.05	<0.1	<0.1	<0.1	- - -	Ti, Zn
TV04-25	<0.1	<0.1	<0.1	<0.1	- - -	Zn, <Ti
TV04-25-BP90	3.5	11.5	<0.1	<0.1	- - -	
TV05-25	2.0	11.0	<0.1	<0.1	- - -	Zn, Ba
TV05-25-BP91	2.5	10.5	<0.1	<0.1	- - -	
TV06-14	0.1	<0.1	<0.1	0.2	<2	Zn
TV06-14-BP89	3.0	9.0	<0.1	<0.1	- - -	Zn
TV-sets purchased in the USA and Japan						
TV07-25-US	2.0	10.0	<0.1	<0.1	- - -	Zn
TV08-25-US	2.5	9.5	<0.1	<0.1	- - -	Zn
TV09-25-JAP	1.5	9.0	<0.1	<0.1	- - -	Ti, Si, Zn, Mg
PC-monitors purchased in Germany						
PC 1	1.5	9.5	<0.1	<0.1	- - -	B, Ti, Al
PC 2	<0.1	<0.1	<0.1	0.8	- - -	P, Ti
PC 3	<0.1	<0.1	<0.1	1.0	- - -	P, Ti
PC 4	<0.1	<0.1	<0.1	1.0	- - -	P, Ti, Cd, Al
PC 5	<0.1	<0.1	45.0	<0.1	(0.3%Sn)	P

TV01-28*: The analytical results for new backplates of the TV-set were different. Reason unknown

Old TV-sets from consumer electronics collection points

The results showed that the backplates of the old TV-sets from the collecting point for old consumer electronics, with the exception of old TV-BP07 with no flame retardant, all contained halogenated flame retardants (backplates 01, 06, 10 chlorinated, and the rest brominated flame retardants) in various amounts.

TV-sets and old spare backplates purchased in Germany

The old spare TV-sets backplates from 1989 to 1991 all contained (halogenated) flame retardants with one exception, TV03-25-BP90, which contained no flame retardants.

Among the TV-sets purchased in Europe in 1997, sets 03 and 04 did not contain any flame retardants. The two spare backplate obtained for set 01 contained different flame retardants (3 % Br and 0.4 % P), the sets 02 and 06 contained low amounts of phosphorous flame retardants (0.4 and 0.2 % P, respectively). Brominated flame retardants, at levels common in 1989 to 1991, were found in set 05.

TV-sets purchased in the USA and Japan

All TV-sets contained brominated flame retardants and antimony oxide.

PC-monitors purchased in Germany

The PC-backplates all contained flame retardants, with the exception of PC 5 being a PVC backplate. PC 1 contained brominated, and PC 2 to 4 phosphorous flame retardants.

4.3 MATERIALS FLAMMABILITY TESTS ACCORDING TO UL 94

4.3.1 Introduction

As part of the programme on fire testing of TV-sets and PC-monitors, UL 94 testing on samples taken from the TV-sets and PC-monitors were conducted by the flammability laboratory of General Electric (GE) Plastics in Bergen op Zoom, the Netherlands. The flammability laboratory is a certified UL test laboratory under the Client Test Data Programme.

Flammability requirements for TV-sets are covered by EN 60065, clause 20. The standard requires for backplate materials a horizontal flame test with max. 40 mm/min burning speed. Samples 125 mm in length by 12 mm in width are to be cut from the thinnest part of the backcover.

In Europe, this IEC 65 standard has been in use for a long period of time.

Flammability requirements for PC-monitors are covered by EN 60950. As a monitor is in most cases less than 18 kg, the requirements is to use a UL 94 V1 material or to conduct an end-product test as described in Appendix A2 of the standard.

4.3.2 Test programme

Samples cut from the TV-backplates and PC-monitor housings were tested in the General Electric Plastics UL-Recognised flammability laboratory according to UL 94.

The following ratings were investigated:

UL 94-HB Horizontal burning with 50 W flame
For thickness < 3.2 mm a burning rate ? 75 mm/min is allowed
For thickness ? 3.2 mm a burning rate ? 40 mm/min is allowed

UL 94-V Vertical burning with 50 W flame

Criteria	**94 V-0**	**94 V-1**	**94 V-2**
Individual flame time, s	? 10	? 30	? 30
Total flame time, s (5 specimens)	? 50	? 250	? 250
Glowing time, s (individual specimen)	? 30	? 60	? 60
Particles ignite cotton	No	No	Yes

According to IEC 65, in the horizontal burning test a burning rate of max. 40 mm/min is allowed independently of thickness. This is different from the UL 94-HB classification because there two burning speeds are allowed depending on the thickness. In fact a UL 94-HB material is not automatically suited for TV-backplates.

All samples were tested in the vertical mode for V-classification, in case of failure for the V-class, they were tested in the horizontal mode (HB) and the burning speed was reported.

The results of the test programme are summarised in Table 4.

Table 4: Results of the UL 94 test programme 4 Results of the UL 94 test programme Results of the UL 94 test programme Results of the UL 94 test programme Results of the UL 94 test programme Results of the UL 94 test programme Results of the UL 94 test programme

Sample Identification	Fire Rating	Thickness [mm]	Remarks on UL94-V*/HB-testing
TV-sets and old spare backplates purchased in Germany			
TV01-28	HB	3,2	30 mm/min
TV01-28-BP91	HB	3,6	22 mm/min
TV02-25	V-2	2,6	Burning drips
TV02-25-BP90	V-0	2,9	
TV03-25	HB	3,2	25 mm/min
TV03-25-BP90			Backplate not available for testing
TV04-25	HB	3,2	30 mm/min
TV04-25-BP90	HB	1,8	0 mm/min in HB-test, glow time >60 sec in V-test
TV05-25	V-1	2,9	
TV05-25-BP91	V-0	3,6	
TV06-14	V-2	2	Burning drips
TV06-14-BP89	V-2	2,4	Burning drips
TV-sets purchased in the USA and in Japan			
TV07-25-US	HB/V2	3	Test 1: 0 mm/min, V2 missed for 2 of 5 samples too long burning time, but total burning time OK Test 2: V2
TV08-25-US	V-0	3,2	
TV09-25-JAP	V-2	2,4	Burning drips, stops before 1st mark in HB test
PC-monitors purchased in Germany			
PC 1	V-0	3,1	
PC 2	V-2	3,2	Burning drips
PC 3	V-0	2,4	
PC 4	V-1	3,2	
PC 5	V-0	3	

4.3.3 Results

In general, the results show that UL 94 V ratings are obtained when flame retardants are used. However, this was not the case for TV01-28-BP91 where the presence of flame retardants was identified and only the rating UL 94 HB was reached. For TV07-25-US in a first test, The HB rating was due to the >30 s afterglow. The other criteria would have allowed a V2 rating. In a second test, V2 rating was achieved.

The reason for these differing results may be that UL 94 is a materials test and heavily depends on properties like thickness, stress, orientation of the polymer and sample orientation relative to flow. While small scale flammability tests results obtained using samples cut from final products were not always consistent, analyses suggest that flammability ratings of materials correlate well with the ignition resistance and post-ignition behaviour of end-products in real life fire tests.

4.4 SMALL FIRE ROOM TEST PROGRAMME

The test program with old and new backplates, TV-sets and PC-monitors exposed to the different ignition sources of growing intensity was carried out in the small fire test room at the Fire Testing Centre of the German State Research and Materials Testing Establishment (MFPA) in Laue near Leipzig.

The small fire test room is 2.600 m long, 2.300 m wide and 3.125 m high. The products to be tested were placed on a table 0.8 m high. The top and side view of the small fire test room are shown in Figures 1 and 2.

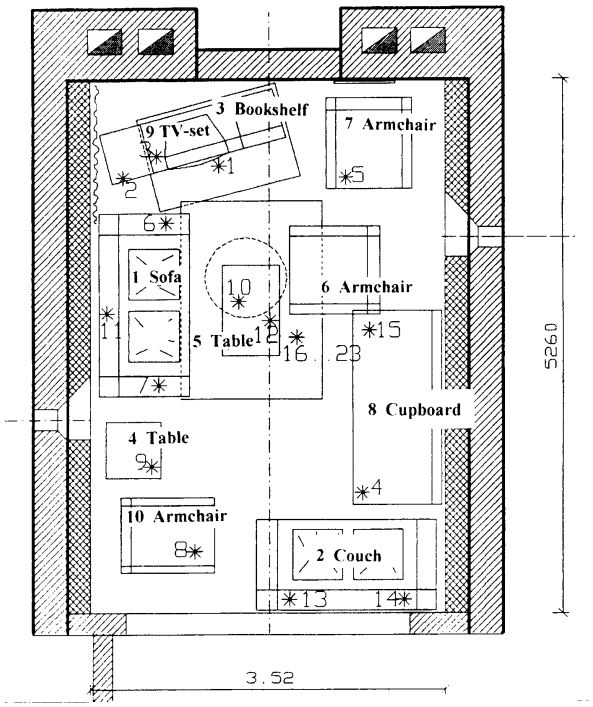

Figure 1 – top view

Figure 2 – side view

4.4.1 Tests on old TV-sets backplates, old TV-sets and old PC-monitors with ignition sources of increasing intensity

4.4.1.1 Test programme

Ten old TV-sets backplates, seven old TV-sets and six old PC-monitors from electronic waste collection points were subjected to the various ignition sources: a methenamine tablet, a small candle, a household candle, a piece of cloth soaked with isopropanol and 200 ml of isopropanol, to study their flammability and fire behaviour in indicative tests. The other objective of the tests series was to learn about the fire retardancy of the polymers used for the backplates and housings in the past.

The ten old TV-sets backplates were analysed for their flame retardants contents (see Table 3). The results of the fire tests programme is summarised in Table 5.

Table 5: Fire tests with ignition sources of growing intensity with old TV-sets backplates, old TV-sets and old PC-monitors

Sample Identification	Ignition source					
	Methenamine Tablet	Small Candle	Household Candle	Isopropanol Cloth on top	Isopropanol Cloth below	Isopropanol 200 ml
Old TV-sets backplates						
Old TV-BP 01	- (extin.)	-	- (extin.)		- (extin.)	n.d.
Old TV-BP 02	- (extin.)	- (extin.)	- (extin.)		+	
Old TV-BP 03	- (extin.)	- (extin.)	- (extin.)		- (extin.)	n.d.
Old TV-BP 04	+ (after 70s)					
Old TV-BP 05	+ (slow)					
Old TV-BP 06	- (extin.)	-	n.d.	n.d.	n.d.	n.d.
Old TV-BP 07	+					
Old TV-BP 08	- (extin.)	- (extin.)	- (extin.)	- (extin.)	- (extin.)	n.d.
Old TV-BP 09	- (extin.)	- (extin.)	- (extin.)	- (extin.) n.d.	- (extin.)	n.d.
Old TV-BP 10	- (extin.)	- (extin.)	- (extin.)		n.d.	n.d.
Old TV-sets						
Old TV 1TV 1TV	- (extin.)	+ (slow)				
15TV 1TV 1TV	+ (quick)					
1TV 1	-	-	-	-	+	
Old TV 2	-	-	-	+ (v. slow)		
Old TV 3	-	-	-	-	-	- (extin.)
Old TV 4	-	-	-	-	+	
Old TV 5	+ (after 35s)					
Old TV 6						
Old TV 7						

Old PC-monitors						
Old PC 1	-	-	-	-	-	n.d.
Old PC 2	-	-	-	- (extin.)	- (extin.)	n.d.
Old PC 3	+ (after 10s)					
Old PC 4	-	-	-	-	+ (slow)	
Old PC 5	+ (quick)					
Old PC 6	+ (quick)					

-: no sustained burning
+: sustained burning leading to fully developed fire
n.d.: not determined

4.4.1.2 Results

The first series of tests carried out with the old TV-sets backplates show that, with the exception of the Old TV-BP 04, 05 and 07, they extinguish when exposed to the different ignition sources of growing intensity. It is interesting to note that all the backplates which did not sustain flame spread after ignition contained flame retardants (BP 09 was missing for analysis). It also emerged that low amounts (2.5 and 3.5% Br for BP 04, 05) or no flame retardants (BP 07) lead to ignition and sustained burning by the lowest intensity ignition source, the methenamine tablet.

The indicative tests with the old TV-sets 01 to 07 showed that two of them (TV 02 and 07) started to burn very quickly with the methenamine tablet, whereas TV 01 burned when exposed to the small candle flame. All the others only burnt with the cloth soaked with isopropanol or not at all (TV 05).

The majority of the older TV sets and backplates were flame retarded and test results found them to be protected against lower intensity internal and external primary ignition sources and secondary fire sources.

The tests with the old PCs revealed that three (PC 3, 5, 6) of the six monitors did ignite very quickly with the methenamine tablet and completely burned out while PC 4 burned with the isopropanol cloth and PC 1 and 2 did not burn at all.

Contrary to the European TV-sets, where the overall fire safety of backplates is now relatively lower, newer PC-monitors were generally shown to possess a higher level of fire safety.

4.4.2 Tests on new and spare old TV-sets backplates, new TV-sets and new PC-monitors with ignition sources of increasing intensity

4.4.2.1 Test programme

Six TV-sets of different brands from Germany (with ten spares: four new and six old backplates), two TV-sets of different brands from the USA and one from Japan were placed in the small fire test room and subjected to the various ignition sources. In a series of tests, methenamine tablets, small candles, household candles, pieces of cloth soaked with isopropanol and isopropanol were used to study ignition and post-ignition behaviour.

In addition, five PC-monitors (spare backplates were not available) of different brands were tested under the same experimental conditions.

The results of the test programme is summarised in Table 6.

Table 6: Fire tests with ignition sources of growing intensity with new and spare old TV-sets backplates, new TV-sets and new PC-monitors

Sample Identification	Ignition sourcesourcesourcesourcesourcesource					
	Methenamine Tablet	Small Candle	Household Candle	Isopropanol Cloth On top	below	Isopropanol 200 ml
New and spare old backplates purchased in Germany						
TV01-28-BP91	-	-	-	-	-	n.d.
TV01-28-BP97	+ (slow)					
TV02-25-BP90	-	-	-	-	+	
TV02-25-BP97	+					
TV03-25-BP90	-	+				
TV03-25-BP97	+					
TV04-25-BP90	-	-	-	-	-	n.d.
TV05-25-BP91	-	-	-	-	-	n.d.
TV06-14-BP89	-	-	-	-	-	-
TV06-14-BP97	+ (quick)					
New TV-sets purchased in Germany						
TV01-28-28-28-28-	+ (quick)					
28-28-28	+ (quick)					
TV02-25	+ (quick)					
TV03-25	+ (quick)					
TV04-25	-	-	-	-	-	n.d.
TV05-25	+ (quick)					
TV06-14						

New TV-sets purchased in the USA and Japan						
TV07-25-US	-	-	-	-	-	-
TV08-25-US	-	-	-	-	-	-
TV09-25-JAP	-	-	-	-	-	n.d.
New PC-monitors purchased in Germany						
PC1	-	-	-	-	+	
PC2	-	-	-	-	-	+
PC3	-	-	-	-	-	+
PC4	-	-	-	-	-	(+)
PC5	-	-	-	-	+	

-: no sustained burning
+: sustained burning leading to fully developed fire
n.d.: not determined

4.4.2.2 Results

New and spare old TV-sets backplates and new TV-sets

Among the TV-sets and spare backplates bought in Germany, TV03 and the old spare backplate TV03-25-BP90 as well as TV04 did not contain flame retardants and burned when exposed to the methenamine tablet or the small candle.

The TV-sets TV01, 02, 04, 06 and the respective new backplates all burned quickly (one exception: slow burning) with the lowest intensity ignition source, the methenamine tablet. They all contained no or only small amounts of flame retardants.

TV05 and the old 1989-1991 spare backplates contained brominated (TV01, 04, 05, 06 BP) and chlorinated (TV02 BP90) flame retardants in such amounts that they did not burn when exposed to the low intensity ignition sources and the secondary isopropanol cloth fire source. Only TV02 BP90 burned with the isopropanol cloth placed below.

TV-sets purchased in the USA and Japan

The TV-sets from the USA did not burn when their backplates were exposed to the different ignition sources.

A detailed description of these growing intensity ignition sources tests conducted with TV07-25-US is given in the following. This TV-set was first exposed to the three smaller ignition sources (methenamine tablet, small candle and household candle) in the fully furnished room fire test described under 4.5.3. As it did not burn, it was then exposed to the other sources in the small fire room as shown hereunder:

The TV-set was exposed to the piece of cloth soaked with isopropanol placed on top and in the middle of the housing and ignited. The housing material melted, ignited, but extinguished rapidly. The housing itself did not contribute to the flames. A hole of ca. 70 mm diameter was formed. The flames extinguished after 5-6 min.

In the following test, the TV-set was exposed to the piece of cloth soaked with isopropanol placed under the housing. The housing material melted, ignited, but extinguished rapidly. The flames were 0.5 m high and also appeared in the interior of the TV-set. Again, there was no evidence of the housings themselves contributing to the flames. A hole of ca. 0.3 m height was formed. The flames extinguished after 6 min.

In the final test, 200 ml of isopropanol were poured on the TV-set and ignited. After a flash of 2 m high flames in the first seconds, the isopropanol burnt with 0.5 m flames over and in the TV-set. Due to the high temperature developed, the backplate melted away in the flame area. The picture tube imploded. Following consumption of the isopropanol after around 5 min, the fire extinguished itself. No sustained burning of the material could be observed during the test.

The series of tests showed that is was not possible to sustain a fire in the TV07-25-US set by any of the ignition sources of increasing intensity used.

The TV-set purchased in Japan did not burn when its backplate was exposed to the different ignition sources.

PC-monitors

All the PC-monitors backplates tested contained flame retardants or consisted of PVC (PC5). They all resisted ignition sources up to the isopropanol cloth. In two cases (PC1 and 5), the isopropanol cloth placed under the backplate set the PC-monitors on fire.

The results show that the use of flame retardants increases the fire safety level of the PC-monitors tested.

4.4.3 Comparison between tests on materials, backplates, TV-sets and PC-monitors

The UL 94 materials tests correlated in most cases with the test programme's results obtained from TV-sets and backplates with ignition sources of increasing intensity. In some cases however, the results were different. As UL 94 is a materials test, it heavily depends on materials properties like thickness, orientation of the polymer after processing and cutting of the sample in flow or cross direction as well as homogenous distribution of the additives in the polymer matrix.

The fire behaviour of backplates tested alone and attached to the original TV-sets was basically identical. There were apparently no significant deviations due to possible heat sink or chimney effects.

When the TV-sets and PC-monitors enclosures contained sufficient levels of flame retardants, they extinguished when exposed to the different ignition sources of increasing intensity and did not sustain flame spread.

It is interesting to note that contrary to the backplates, the housings of TV05-25 and TV09-25-JAP were set on fire with the methenamine tablet. Following the experience gained from the test programme, this implies that these housings did not contain high levels of flame retardants.

All the results of the test programme obtained for old and new TV-sets backplates and TV-sets as well as old and new PC-monitors (Tables 5 and 6) are summarised in the following two diagrams. The low energy ignition source referred to is the small candle.

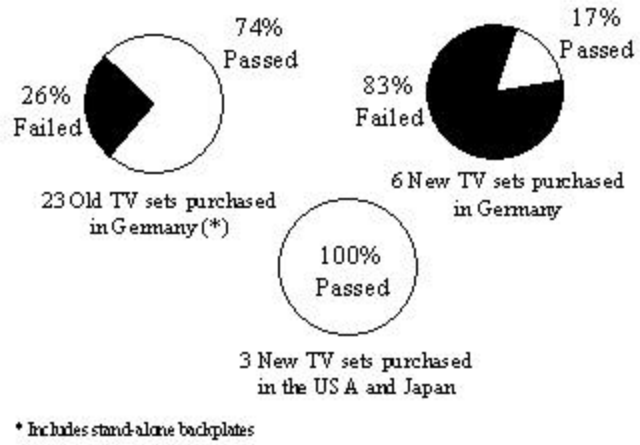

Figure 2: TV-set testing with low energy ignition source (small candle)

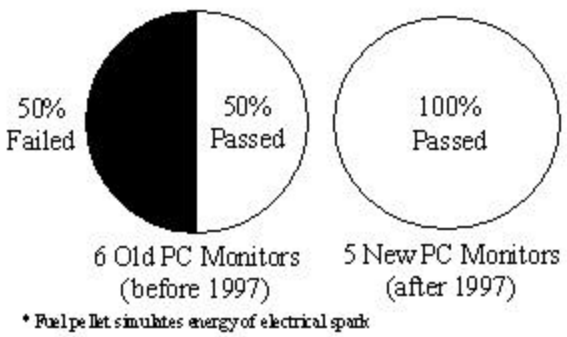

Figure 3: Testing of German PC-monitors with low energy ignition source (solid fuel pellet)

The TV-sets diagram shows that the majority of the old European sets pass the tests, while the sets purchased recently do not. This demonstrates a trend to lower fire safety performance of new equipment against external fire sources. All TV-sets purchased in the USA and Japan passed the tests. It is interesting to note that half of the old PC-monitors failed, while the new monitors all passed the tests. Here, the trend goes to better fire safety performance.

4.5 FULLY FURNISHED LARGE ROOM FIRE TEST PROGRAMME

4.5.1 Introduction

The fire tests in the fully furnished large test room were carried out in order to compare the fire behaviour of TV-sets with housings made from materials with different flammability ratings and their contribution to fire development and flashover.

Therefore, two TV-sets were selected. The first one, TV07-25-US from the USA, had been shown to extinguish after exposure to all the test programme's ignition sources. The second one, TV02-25 from Germany, rapidly led to sustained combustion after the methenamine tablet extinguished itself, and burned completely.

4.5.2 Test Arrangement

The fire test room was 3.52 m wide, 5.26 m long and 2.80 m high and fitted out with furniture typical for continental Europe. The pieces of furniture were one couch, one sofa, three armchairs, one cupboard, two tables, two carpets and one bookshelf with the TV-set. The arrangement of the furniture in the fire test room is shown in Figure 4.

Figure 5: Fire test room arrangement

Figure 6: t = 1min after ignition

Figure 7: t = 4min after ignition

Figure 8: t = 6 min 30 s after ignition

Figure 9: t = 7 min 30 s after ignition (flashover)

The test room was fitted out with 24 thermocouples distributed throughout the room in different positions on the TV-set, the book shelf, the pieces of furniture, in different heights in the centre of the room and under the ceiling.

The fire load of the combustible materials placed in the room is summarised in Table 7.

Table 7: Calculation of fully furnished room fire load7 Calculation of fully furnished room fire load Calculation of fully furnished room fire load Calculation of fully furnished room fire load Calculation of fully furnished room fire load Calculation of fully furnished room fire load Calculation of fully furnished room fire load

Item	Material	Position Fire Room No.	Mass [kg]	Heat of Com-bustion [kWh/kg]	Energy [kWh]
Floor covering	Textile material with Latex backing		24.4	7.6	185.44
Sofa	Wood	1	22	4.8	105.6
			30	6.4	192
Couch/Mattress	Foam	2	2.15	6.4	13.76
			3	6.4	19.2
Shelf	Wood	3	34	4.8	163.2
Table, yellow	Wood	4	4.5	4.8	21.6
Table, white	Wood	5	6	4.8	28.8
Wood parts, shelf	Wood		18	4.8	86.4
Armchair	Mixed fire load	6	10	5.4	54

			22	4.8	105.6
Armchair	Mixed fire load	7	17	5.4	91.8
Rug	Mixed fire load		4.7	5.4	25.38
Picture frame	Wood and paper		2	5	10
Cupboard	Wood	8	79	4.8	379.2
			9.5	4.8	45.6
TV-set	Mixed fire load	9	29.5	5.6	165.2
Armchair, old	Mixed fire load	10	26	5.6	145.6
Textiles	Mixed fire load		12	5	60
			15	5	75
			9	5	45
Shoes	Leather		3	5.3	15.9
Books	Paper		25	4.2	105
			59	4.6	271.4
			13.2	4.2	55.44
				Sum:	2,466.12

Weighed back: 32 kg or 172.8 kWh

Fire energy	2,293.3 kWh	Total mass wood and chipboard	197 kg
Fire load	127 kWh/m²	Total mass foam	32.2 kg
Fire load	457.2 MJ/m²	Total mass Textiles	66.4 kg
in Wood Equivalents	26.3 kg Wood/m²	Total mass paper	97.2 kg

The tests were filmed with two cameras, one in front of the room through the front opening (2.30 m wide, 1.50 m high) simulating a window, the other from a hole protected with a fire resistant pane allowing a view on the lateral right side of the TV-set, where the ignition sources impinged on the enclosure.

Photographs were taken of the most important events during the test.

In addition, a thermovision (IR) camera was used for obtaining supplementary information on the temperature distribution during the test.

4.5.3 Test with TV-set bought in the USA

The first fire test was carried out with the TV07-25-US set. A hole of 20 x 20 mm was cut in the lateral front right side of the housing in such a way that the tablet could touch the bottom of the backplate behind. Thus, the tablet impinged on the housing on top of it and on the edge of the backplate. This arrangement simulated both an external and internal low intensity ignition source.

The tablet was ignited and extinguished after 1 min and 40 s. The flame height was 5-10 mm. The plastic material did not ignite and housing and backplate were only slightly damaged on the surface.

The second test was carried out with the small candle (plate warmer) also placed in the hole, so that the flame impinged on the housing on top of it. The material ignited briefly but extinguished immediately after. The test was stopped after 6 min. The surface of the housing was damaged in a height of 20 mm following flame impingement.

The third test was performed with the household candle leaned against the housing. Here too, the material ignited briefly but extinguished soon after. The candle was removed after 10 min. The plastic was degraded in a height of 40 mm following flame impingement without forming a hole and the surface blackened over the degradation zone.

These tests showed that ignition sources of small intensity do not set on fire the housing or the backplate of a TV-set purchased in the USA.

4.5.4 Test with TV-set bought in Germany

The fire test was carried out with the TV02-25 set. A hole of 20 x 20 mm was cut in the lateral right front side of the backplate adjacent to the housing.

After ignition, the methenamine tablet flame impinged on the backplate on top of it and later on the edge of the housing. This arrangement simulated an external and internal low intensity ignition source.

24s after ignition of the methenamine tablet, the backplate began to burn. After 1 min, the flames on the backplates were 8-10 cm high and reached around 1 m after 2 min 30 s, involving the shelf ~~into~~ in the fire. Flashover with all furniture burning occurred after around 7 min with flames 6-8 m high coming out of the front of the fire room. The observations during the test are summarised in Table 8.

Table 8: Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set8 Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set Room fire test MFPA Leipzig/Laue on 25 June 1997 with European made TV-set

Time [min]	Observations
00:00	Ignition with solid fuel pellet
00:24	Backplate begins to burn
01:00	Flames at backplate 8-10 cm
01:10	Burning drips on shelf surface
02:00	Flames around 1 m high. Shelf involved in flames
02:30	Shelf burns in full height. Strong smoke development
04:02	Shelf burns in full width. Burning drips on the floor. Shelf begins to burn from the bottom Picture tube implodes
04:48	Strong burning flow off from housing/backplate material. Dark smoke layer about1.5 m under
05:30	the ceiling Lamp falls down
05:57	Curtain burns
06:35	Couch at the window burns on top
06:50	Flashover, all furniture burns
06:52	Flames blaze out of the whole window opening. Flame height at the facade 8m
07:05	Flames in front of the facade about 6 m. Strong black smoke Strong black smoke. Flames hardly visible
09:00	Flames visible again
10:00	Flames of about 2-3 m out of the window opening, less smoke development, steady burning
11:00	Steady, smooth burning
12:00	
15:00	

4.5.5 Results

The time temperature curves of the fire test with the European TV02-25 set are shown in Figure 5 (temperatures near the ceiling), Figure 6 (temperatures in different heights in the fire room), Figure 7 (temperature of the furniture) and Figure 8 (top of the window opening).

It can be seen that after flashover in the 7th min, the temperatures rose to 800-900°C and reached over 1,100°C near the ceiling after 12 min. This is characteristic of a fully developed fire.

Figure 9 shows the gas concentration distribution of oxygen (O_2), carbon monoxide (CO) and carbon dioxide (CO_2) in the fire room. After flashover, the oxygen concentration decreases within one minute from 21 to 3 %, whereas at the same time CO (short peak with 8% at 8 min) and CO_2 (11-13%) concentrations dramatically increase. This is also typical of a flashover situation in which virtually the whole oxygen available in the room is suddenly consumed. A major amount of the gases formed from the decomposition of the combustible contents of the room cannot be consumed due to the lack of oxygen in the room and ignite outside the front window opening where enough oxygen is available. This leads to the 8 m high flames just after flashover.

The fire tests carried out in the fully furnished room confirmed what was found in the test series conducted with ignition sources of increasing intensity. The American TV07-25-US set extinguished in all fire tests and

did not spread the fire. The European TV02-25 set quickly started to burn when exposed to the methenamine tablet, the lowest intensity ignition source used in the fire testing programme and led to flash-over of the room after 7 min.

These two real life fire tests have clearly shown the difference in the fire behaviour between TV-sets with housings made using materials that have high flammability ratings and those using materials with low flammability ratings.

5. CONCLUSIONS

The test programme has shown that both internal and external fire sources may cause fully developed fires in a very short period of time if housings and backplates are not flame retarded sufficiently to fulfil vertical materials flammability UL 94 V tests. TV-sets sold in the US and Japanese markets, and PC-monitors sold worldwide, are flame retarded and fulfil these vertical flammability test requirements.

To improve the fire safety level of TV-sets in Europe, housings and backplates must resist external ignition sources of lower intensity like methenamine tablets and household candles. This can be achieved by harmonising European fire safety standards for consumer electronics with requirements applied in other parts of the world. This would require improving the requirements of the IEC 65 standard used in Europe.

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