Flammability and Fire Behaviour of TV Sets

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ABSTRACT

A study carried out at the State Materials Testing Establishment MFPA in Leipzig, Germany, on the ignition and post-ignition behaviour of TV-sets has shown that housings and backplates made of plastics only meeting low fire safety levels will dramatically contribute to the development of a fire and may lead to flash-over in a very short period of time. The role of fire safety in electrical and electronic (E&E) standards and the protection of consumer electronics against potential external fire sources of growing intensity are discussed. In a comprehensive fire testing programme including tests in a fully furnished room, TV-sets used in the USA and Japan complying with UL 94 V fire safety levels did not lead to fire propagation, whereas TV-sets of European origin with low UL 94 HB fire safety levels already ignited when exposed to the lowest intensity ignition source. High fire safety levels for all plastics used in E&E devices are necessary in order to protect them against internal as well as external ignition sources of lower intensity. They need to be introduced in standards like IEC 65 which allow the use of non flame retarded, low fire safety level plastics for housings and backplates.

KEYWORDS: Fire safety of TV sets, Standard IEC 65, Plastics, Housings, Backplates, Flame retardants, UL 94 flammability test, External ignition sources, Ignition, Post ignition behaviour, Large scale fire tests

INTRODUCTION

Fire safety is an integral part of fire precautions. Fire precautions have the objective to minimise the number of and damage from fires by measures hindering their initiation, limiting their propagation and if possible excluding flash-over. Preventing fires or delaying them makes escape possible over a longer period of time. As a result, life, health and property are efficiently protected.

Electrical appliances are a major cause of fires in dwellings. In the UK, in 1993, they caused 5,764 fires, which is around 14% of all household fires. 441 fires were caused by TV sets [1]. In Sweden, in 1994, the Swedish Insurance Federation reported 5,231 fires due to electrical appliances in private homes. The Swedish Electrical Equipment Control Office SEMKO indicated that 150 to 250 TV set fires take place every year in Sweden [2].

In the fire statistics, no indication is made whether the TV set is ignited by internal or external fire sources. Candles and night lights placed on or next to the TV set – this is particularly popular in the Nordic countries – may play a more important role than one would expect.
In order to protect the consumer against fires, fire safety requirements for electrical and electronic (E&E) equipment are part of rules and standards for product safety. 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 [3-6] and UL 1410, UL 746, IEC 65, EN 60065 for the safety of consumer electronic equipment [7-10].

The flammability tests for plastics materials described in the a.m. 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" [11]. 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 of lower energy 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 ignition sources of lower energy.

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 fulfil the requirements of the much less demanding horizontal test.

In a Draft for the revision of IEC 65, recently approved for publication, there will be basically no flammability requirements for plastics materials like TV set backplates and housings 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 [12]. This approach relies solely on the technical design of the TV set against internal ignition sources and ignores the fire safety level of the materials used which would cover both internal and external ignition 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 ignition sources like candles. For TV sets, this took place on a voluntary basis, as only the IEC 65 low fire safety requirements for materials had to be met.

Starting in 1993, German consumer magazines depreciated TV sets containing brominated flame retardants. As a consequence, now the majority of TV sets available in Europe do no more contain flame retardants at all in backplates and housings.

Backplates and housings comprise a major part of the plastics used in TV sets. The use of lower fire safety level materials in such appreciable amounts could affect the overall fire safety level of E&E equipment with, as a consequence, a lower degree of protection of life and property. In addition, as more fires would occur, the environment may also be more affected. Therefore, fire safety should be enhanced and introduced as a criterion in environmental considerations.

BACKGROUND OF THE STUDY

Because of concern from fire brigades, authorities, consumer organisations and ongoing reports in the media about 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 [13]. 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 ignition sources leading to quick ignition and sustained burning of the TV sets is particularly referred to [14].

In 1997, a new study with a comprehensive fire testing programme addressing the concern of lower fire safety of TV sets was commissioned by the European flame retardants associations EFRA and EBFRIP. The author was entrusted with the preparation and completion of the whole programme. The fire tests were carried out at the State Materials Research and Testing Establishment MFPA in Leipzig, Germany, and the final reports completed [15-17].

OBJECTIVE OF THE STUDY, TV SET FIRE TEST PROGRAMME AND RESULTS

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 objectives of this study were to determine the different fire safety levels of old and new TV sets 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 was investigated.
- Finally, two full scale fire tests were carried out in a fully furnished room, one with a TV set for the US market and one with a TV set for the European market.

The influence of different backplates flammability grades on the ignition and post-ignition behaviour of TV sets was studied. The program focussed on external ignition sources of growing intensity which are basically not covered by IEC 65. The ignition sources used were:

- Solid fuel pellet (standardised methenamine tablet) for simulating a lowest 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)

The characteristics of the fire sources are summarised in Table 1. Samples of the items tested were taken for chemical analysis in order to determine the polymers and the nature of the flame retardant systems used. The results showed that all TV sets backplates consisted of polystyrene (mostly high impact grades). The materials used in backplates were then tested to the standards used in the USA and Europe and their classification established according to UL 94 (Table 2). Table 3 summarises the flame retardant systems identified.

In a first series of tests, backplates from older and new TV sets were exposed to the different ignition sources. The second test series was carried out on older and new TV sets. The results from the different test series are shown in Tables 4 and 5.

TABLE 1: Characteristics of Ignition Sources Used in 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	0.15	5 – 10	80 – 105	30.0	0.08 – 0.11	40 – 55
Small candle	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	4 13	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 [18]						

The results of the various test programmes showed that:

- The TV sets backplates are made of polystyrene and high impact polystyrene.
- For meeting highest fire safety performance, the TV sets backplates all contain brominated flame retardants combined with an antimony oxide synergist.
- The materials flammability tests showed that flame retarded plastics usually meet the high requirements of vertical tests (UL94 V). The non flame retarded plastics only meet the lower horizontal tests (UL94 HB) requirements. The reason why in one case a different result was obtained may be that the UL 94 test 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 tests with external ignition sources of growing intensity showed that flame retarded UL94 V plastics generally do not burn, whereas non flame retarded, 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. Compared to UL 94, these ignition sources appear to better assess the flammability and fire risk of E&E equipment.
- 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.

TABLE 2: 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

TABLE 3: Identification of flame retardants in the samples from TV sets backplates and TV sets

Sample Identification	Sb [%]	Br [%]	Cl [%]	P [%]	Extractable Melamine+ Derivatives [%]	ICP Scan 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-BP03	3.0	8.0	<0.1	<0.1	- - -	Zn
OLD TV-BP04	<0.1	2.5	<0.1	<0.1	- - -	Zn, Fe, Ba
OLD TV-BP05	1.0	3.5	<0.1	<0.1	- - -	
OLD TV-BP06	4.0	<0.1	12.0	<0.1	- - -	
OLD TV-BP07	<0.1	<0.1	<0.1	<0.1	- - -	Ba, Ti, Fe, Zn, Cd
OLD TV-BP08	3.0	6.5	<0.1	<0.1	- - -	
OLD TV-BP10	5.0	<0.1	6.5	<0.1	- - -	
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
TV01-28*: Analytical results for new backplates of the TV set were different. Reason unknown						

TABLE 4: Fire tests with ignition sources of growing intensity with old TV sets backplates and old TV sets

Sample Identification	Ignition source					
	Solid Fuel Pellet	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.)	- (extin.)	n.d.
Old TV-BP 10	- (extin.)	- (extin.)	- (extin.)	n.d.	n.d.	n.d.
Old TV sets						
Old TV 1	- (extin.)	+ (slow)				
Old TV 2	+ (quick)					
Old TV 3	-	-	-	-	+	
Old TV 4	-	-	-	+ (v. slow)		
Old TV 5	-	-	-	-	-	- (extin.)
Old TV 6	-	-	-	-	+	
Old TV 7	+ (after 35s)					

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

TABLE 5: Fire tests with ignition sources of growing intensity with new and spare old TV sets backplates and new TV sets

Sample Identification	Ignition source					
	Solid Fuel Pellet	Small Candle	Household Candle	Isopropanol Cloth		Isopropanol 200 ml
				On top	Below	
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	+ (quick)					
TV02-25	+ (quick)					
TV03-25	+ (quick)					
TV04-25	+ (quick)					
TV05-25	-	-	-	-	-	n.d.
TV06-14	+ (quick)					
New TV sets purchased in the USA and Japan						
TV07-25-US	-	-	-	-	-	-
TV08-25-US	-	-	-	-	-	-
TV09-25-JAP	-	-	-	-	-	n.d.

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

FULLY FURNISHED LARGE ROOM FIRE TEST PROGRAMME

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. 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 solid fuel pellet extinguished itself, and burned completely.

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 1.

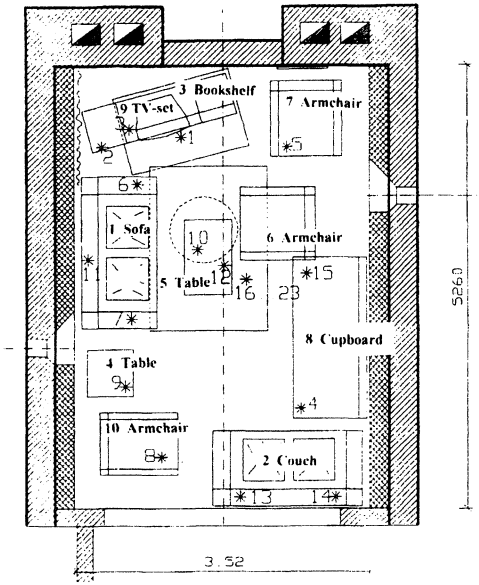

FIGURE 1: Fire test room. Furniture arrangement and thermocouples location

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

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 solid fuel pellet 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 pellet 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.

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 solid fuel pellet 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.

24 s after ignition of the pellet, 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 in the fire. A pre-flashover situation developed in the following 4 min 30 s with the curtain left of the book shelf burning after 6 min 30 s, the back rest of the sofa after 6 min 45 s and the table in front of the book shelf starting to give off smoke and igniting after 6 min 50 s. Flashover with all furniture burning occurred after 7 min with flames 6-8 m high coming out of the front of the fire room.

Results

The time temperature curves of the fire test with the European TV02-25 set show 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. The gas concentration distribution of oxygen (O_2), carbon monoxide (CO) and carbon dioxide (CO_2) in the fire room was measured. 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.

In order to have a better approach of the temperature distribution during the room fire test with the TV02-25 set, a numerical fire simulation was carried out [19]. The field model KOBRA-3D 3.7b was used [20]. The temperature distribution and velocity of the fire gases were calculated. The calculated temperature distribution is in good accordance with the temperatures measured with the thermocouples.

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 solid fuel pellet, the lowest intensity ignition source used in the fire testing programme, and led to flashover 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.

CONCLUSIONS

This study has confirmed previous findings and shown that there is a need to use plastics parts like housings and backplates with higher fire safety levels meeting the requirements of UL 94 V tests so as to ensure adequate consumer protection. External fire sources, inadequate design, manufacturing faults or defects due to 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 flame retarded and do not fulfil these vertical flammability test requirements.

To optimise the fire safety level of TV sets in Europe, housings and backplates should be made resistant against external ignition sources of lower intensity like solid fuel pellets and household candles. This could be achieved by harmonising fire safety standards for consumer electronics with the American requirements by upgrading the IEC 65 standard used in Europe.

Fire safety plays a key role in our society, because it helps to meet fire precaution requirements and, as a consequence, to prevent fires. It contributes to save human lives, to protect property and eventually the environment. Therefore, our objective should be to hold and improve fire safety levels in all fire and environmental regulations and standards.

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