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Urban Mass Transportation Administration

The Current State of European Railway Fire Safety Research

Transportation Systems Center
Cambridge MA 02142

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16. Abstract

This report describes the recent fire safety research and practical fire experience of the major European railways. It includes a summary of the main causes and characteristics of railway vehicle fires, general approaches to the problem, and existing European fire protection requirements.

The report outlines a variety of methods currently used to test and formally approve materials and structural items, including techniques for measuring material properties like smoke emission, ignitability, and surface spread of flame. Full-scale facilities like British Railway's "Phoenix" fire test vehicle are described. Detailed drawings for test apparatus and facilities accompany the text.

Also included are the formulas used in the classification of materials, as well as the fire safety standards for vehicle construction adopted by individual railways and the international Office for Research and Experiments (ORE). Finally, the report looks at two recent projects in fire detection technology and rescue procedures, along with several current or projected developmental activities.

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PREFACE

The purpose of this report is to inform the American transit industry and fire protection agencies of recent and ongoing fire safety research and training projects conducted in Europe, either by individual railways or by multinational regulatory organizations like the International Union of Railways (UIC).

Information on Polish State Railways (PKP) fire research is based on projects headed by the author or in which the author participated. Information concerning other European railways is based on data provided by railway officials during on-site visits or during meetings of the Office of Research and Experiments (ORE) and the Organization for the Cooperation of Railways (OSZD) - including joint meetings - from 1979 to 1984. The views and conclusions expressed in the document should not necessarily be interpreted as representing the official policies or opinions, either stated or implied, of the railways in question.

This report was prepared under the sponsorship of the Urban Mass Transportation Administration (UMTA), Office of Technical Assistance, Safety and Security Staff. The author would like to thank Lloyd G. Murphy of UMTA and William T. Hathaway of the Transportation Systems Center for assistance and encouragement while completing this paper and for providing the opportunity to present it in public. The author is also indebted to the United States Information Agency and to the Council for International Exchange of Scholars for their financial support.

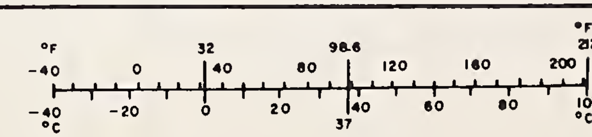
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ABBREVIATIONS USED IN TEXT

BDZ - Bulgarian State Railways

BR - British Railways

CNOBP - Fire Science and Research Center of Poland

CSD - Czechoslovakian Railways

DB - West German State Railways

DR - East German State Railways

DSB - Danish State Railways

FRS.E - Fire Research Station at Elstree, U.K.

FS - Italian Railways

IMCO - Intergovernmental Maritime Consultative Organization

ISO - International Standardization Organization

MAV - Hungarian State Railways

NS - Dutch Railways

ORE - Office for Research and Experiments

OSZD - Organization for the Cooperation of Railways

PKP - Polish State Railways

RENFE - Spanish Railways

SJ - Swedish Railways

SNCB - Belgian National Railways

SNCF - French National Railways

SZD - Soviet Railways

UIC - International Union of Railways

1. INTRODUCTION

The purpose of this paper is to describe in brief the recent research and practical fire safety experience of the major European railways. Only the experiments carried out in the past five years are considered; earlier tests are discounted as being outdated. The information is, with a few exceptions, based on reports which have not been widely available since, for a variety of reasons, only a few of them have been published.

The need for railway fire safety research has been confirmed by a number of serious accidents. In 1977, six German citizens died and others were severely injured in a sleeping car in Poland when an international train in transit from Paris caught fire at night. The fire, caused by a dropped cigarette, spread so rapidly that the victims were trapped in their compartments with no real chance of escape. Although the vehicle was not Polish, Polish State Railway (PKP) Fire Brigades rescued the survivors. This accident demonstrated the hazards of fire in transit railway vehicles, and revealed the need for a wide range of research in this field.

In 1978, twelve people died in Taunton, Great Britain, when a sleeping car of a London-Glasgow night train caught fire. The bodies of all the victims were found in the corridor. The cause of fire has not been determined, though manufacturer, crew, or the victims themselves have been suggested as possible sources. The accident alarmed British Railways (BR) fire safety specialists because at the time BR was already using some two hundred of these particular vehicles and because the vehicle involved was a new one, built according to protective standards developed by BR during twenty years of research and laboratory tests. This disastrous experience was the source of wide-spread criticism from journalists and even some Members of Parliament, which resulted in BR making simulated and full-scale fire safety experiments.

It should be mentioned that the victims of both accidents died from inhalation of toxic gases and combustion products, except for two British Railways passengers who died as a result of heart attack.

In addition to these accidents, fires have occurred on French high speed trains (TGVs). No formal report on casualties or investigational findings has been released.

Tragic though these accidents were, the real threat to all railways lies in smaller fires occurring in commuter trains and intercity vehicles. The total damage due to these small fires can be enormous. A typical vehicle in Europe costs the equivalent of 0.5-1 million dollars, up to 80 percent of which can be lost in a fire. Statistics on fires occurring over the last 10 years at the most important European railways are given in Table 1-1. BR, PKP and West German State Railways (DB) reported that the severest damage to their vehicles is due to vandalism. Other European railways, including the Bulgarian (BDZ), Czechoslovakian (CSD), East German (DR), Italian (FS), Hungarian (MAV) and Soviet (SZD) Railways, also reported fires but no reliable statistical data are yet available.

To permit closer cooperation in fire safety research, the international Office for Research and Experiments (ORE), a branch of the International Union of Railways (UIC), decided in 1983 to form a new Working Group (No. B106.2) entitled "Vehicle Fire Safety" in which specialists from BR, DB, Danish State Railways (DSB), Dutch Railways (NS), PKP, Spanish Railways (RENFE), Swedish Railways (SJ), Belgian Railways (SNCB) and French Railways (SNCF) would take part.

TABLE 1-1. INQUIRY INTO RAIL VEHICLE FIRES IN EUROPE - 1974-1984

Railway	Cause of fire						Total Number of Incidents
	Electrical		Inattention or carelessness		Other		
	No. of Incidents	Percent. of Total	No. of Incidents	Percent. of Total	No. of Incidents	Percent. of Total	
BR[1]	247	23.7	0	0	794	76.3	1041
DB[2]	86	25.4	176	52.1	76	22.5	338
NS[2]	15	9.2	84	51.5	64	29.3	163
PKP[2]	47	25.7	104	56.8	32	17.5	183
RENFE	43	47.3	12	13.2	36	39.5	91
SJ[2]	54	36.0	28	18.7	68	45.4	150
SNCB[3]	19	24.3	27	34.7	32	41.0	78
SNCF[3]	11	17.0	41	62.0	14	21.0	66

1. Includes minor fires
2. Only fires which damaged at least 15% of vehicle
3. Only fires which damaged more than 50% of vehicle

2. GENERAL FIRE SAFETY RESEARCH AND PREVENTION PROGRAM

No fire safety research would be reliable without properly defined fire-prevention aims. This is a very complicated task which may be open to different approaches, depending on a railway's specific needs.

A lively discussion on this topic took place at one of the ORE "Vehicle Fire Safety" meetings. Some specialists held that their railways need 100 percent fire protection. It was pointed out, however, that this would lead to concrete floors, steel ceilings and walls, and seats with glass fiber cushioning, which would not be in the interest of passenger comfort. Others argued that common sense suggests that prevention should be aimed at saving passengers' lives under normal railway performance conditions, since it is impossible to stop a person determined to set fire to a vehicle with oil or even fire bombs at their disposal. It was finally agreed that efforts should be directed only at such technical failures as electrical arcing and sparks, and at unintentional ignition by lit cigarettes. Vehicles must likewise be designed in such a way that the spread of fire is minimal enough to allow the evacuation of passengers, though what constitutes emergency egress time has yet to be determined.

In response to these concerns, PKP established its own general fire safety research and prevention program (Figure 2-1). A similar program exists at BR. To collect data for the development of material property requirements and structural guidelines, a special scientific emergency group headed by the author has been formed. For a period of two years, this group took part in all railway fire investigations conducted after each rescue action. The group held its own investigations throughout Poland parallel to official investigations performed

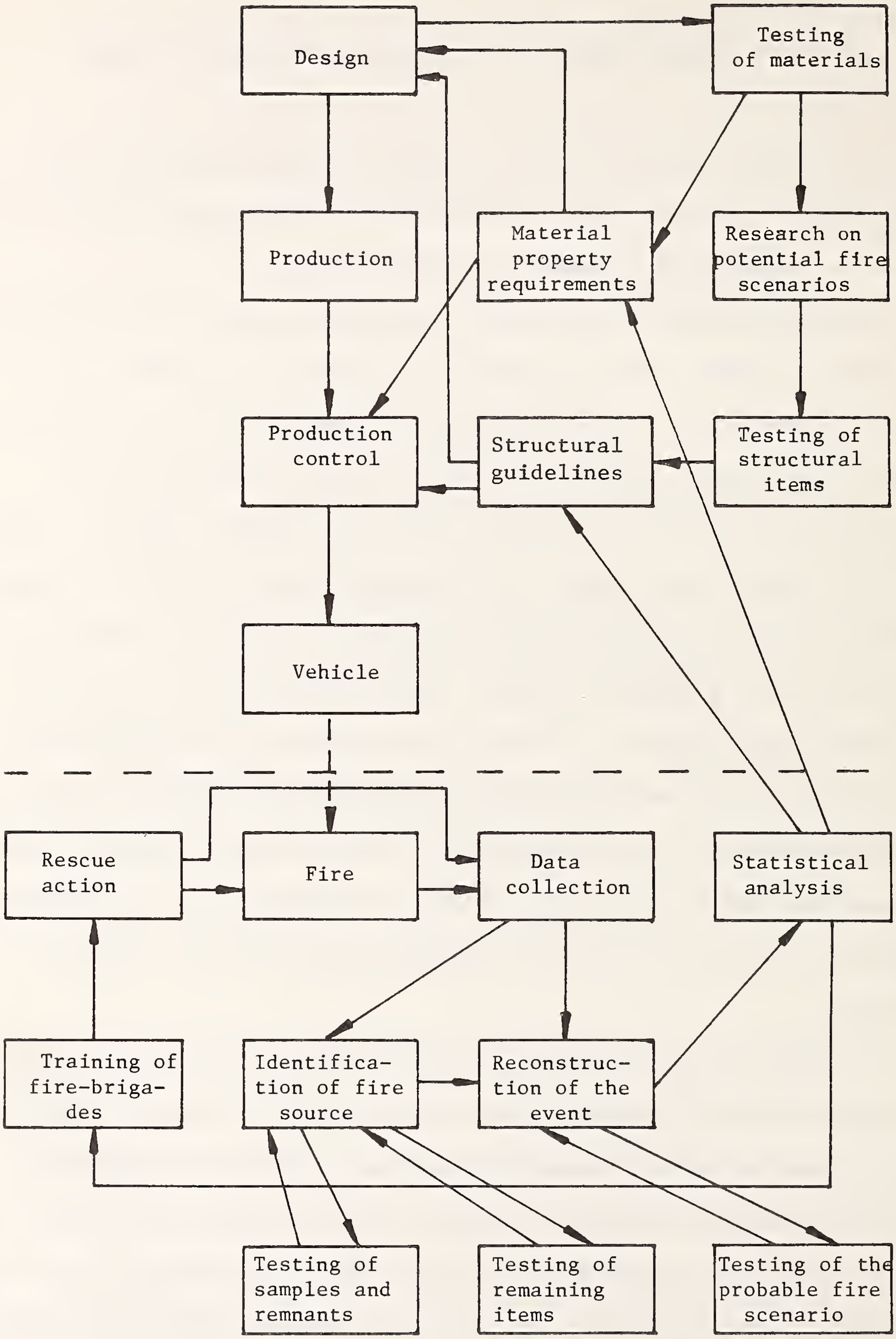


FIGURE 2-1. FIRE SAFETY RESEARCH AND PREVENTION PROGRAM AT PKP

by local police and fire brigades. These investigations focused mainly on data collection, identification of fire source, testing of samples and remnants and, finally, attempting a reconstruction of the event. Statistical analysis followed. These investigations yielded unexpectedly large amounts of useful data on the spread of fire in railway vehicles, and permitted the development of the full-scale tests and fire brigade training schemes that are described later in this paper.

3. DESCRIPTION OF A TYPICAL FIRE IN RAILWAY VEHICLES

The typical fire starts on or under seats, benches or berths as a result of a cigarette igniting upholstery or randomly dispersed paper rubbish. In some cases, overheating due to electrical component failure can also cause rubbish to ignite. The fire edge, consisting of the buoyant plume and hot gases, spreads to the seat backrests, which are covered with a textile or polyvinal chloride-coated upholstery and are easily ignited. The fire then grows quickly because of the ignition of foam cushioning under the textile of the backrests. This cushioning ignites easily, regardless of the material used (latex foam rubber, polyurethane sponge, etc.). This is due to the vertical position of the backrests, which allows for an easy exchange of heat between the combustion products and backrest upholstery and cushioning. Next, wall linings above the seat level ignite, and the fire soon spreads to the ceiling. Critical conditions for ceiling flashover can be reached in less than five minutes because of the vehicle's interior geometry and the lack of relatively cool fresh air.

Analysis of fires performed by the PKP scientific group and full-scale tests by BR (to be described later) revealed that at this stage the plume at the ceiling forms a wave which travels at the rate of 2 to 6 m/sec. This creates the danger of passenger entrapment especially in compartment vehicles like sleeping and intercity cars. Ceiling temperatures above the original ignition point reach from 900° to 1000°C.

After 7 to 10 minutes the fire can either burn through glass-fiber-reinforced polyester (GRP) or any other plastic ceiling, or can melt a hole through an aluminum ceiling structure. The plume and hot gases then enter into a gap between the ceiling and the roof. This gap is often used for electric cables or is filled with foam plastic thermal insulation. Electrical insulation of cables is rapidly destroyed in places, often resulting in sparking or arcing which may become an additional source of fire. Thermal roof insulation melts or burns depending on the foam compound, allowing the fire to spread even further. At this stage huge amounts of smoke and soot are generated, due to lack of sufficient oxygen for the combustion of thermal insulating materials such as polyurethane foam.

Light diffusers start to melt or burn and in some cases flaming material falls down, along with burning pieces of the ceiling and thermal insulation or aluminum, igniting additional seats and even flooring material. Temperatures in the vicinity of windows and roof reaches 1200°C and window glass melts. At this point the fire could easily spread to adjacent vehicles, if they have not already been disconnected by the train crew from the burning one. Such disconnection, however, is sometimes not possible for electrically powered trains because of other emergency regulations or automatic power shut-off devices.

The vehicle's body loses mechanical stiffness and stability, and starts to bend, shrink or break. Modern aluminum bodies may almost completely disintegrate within 10 minutes, as happened to an underground vehicle in Munich, W. Germany, in 1982.

The mechanics of fire spread as described above demonstrate the need for the creation of fire protection requirements as regards material properties, structural items and vehicle geometry.

4. EXISTING INTERNATIONAL RAILWAY FIRE PROTECTION REQUIREMENTS

The basic international fire protection requirements relating to passenger vehicles are specified in International Union of Railways (UIC) Leaflet No. 564-2, "Regulations Relating to Fire Precautions and Fire-Fighting in Vehicles Used on International Services." The document contains directives which apply in particular to:

- acoustic and thermal insulating materials,
- wall and ceiling linings,
- upholstery and cushions,
- floor linings,
- carpets in the aisles and elsewhere,
- curtains and bedding, and
- paints and varnishes.

In general, no material is tolerated which has an oxygen index less than 28 and the "I" coefficient for surface spread of flame (see section 5.2) higher than 65. For flooring materials, the International Standardization Organization's (ISO) draft methamine test is recommended. The leaflet also specifies that each vehicle must have at least two fire barriers less than 11 meters apart. Electrical wiring must be protected as far as possible by metal tubing. There are also safety requirements for the use of portable extinguishers and the protection of liquid gas installations. Two methods for fire testing of seats are presented in the figures that follow. The UIC and SNCF-recommended method shown in Figure 4-1 entails two separate tests. The first consists of igniting a standard source of fire - in this instance a 70 gram newspaper rolled into a "pillow". The "pillow" burn-time is usually 3 minutes. After ignition, the fire must go out in at most 10 minutes. The second test used in this method is

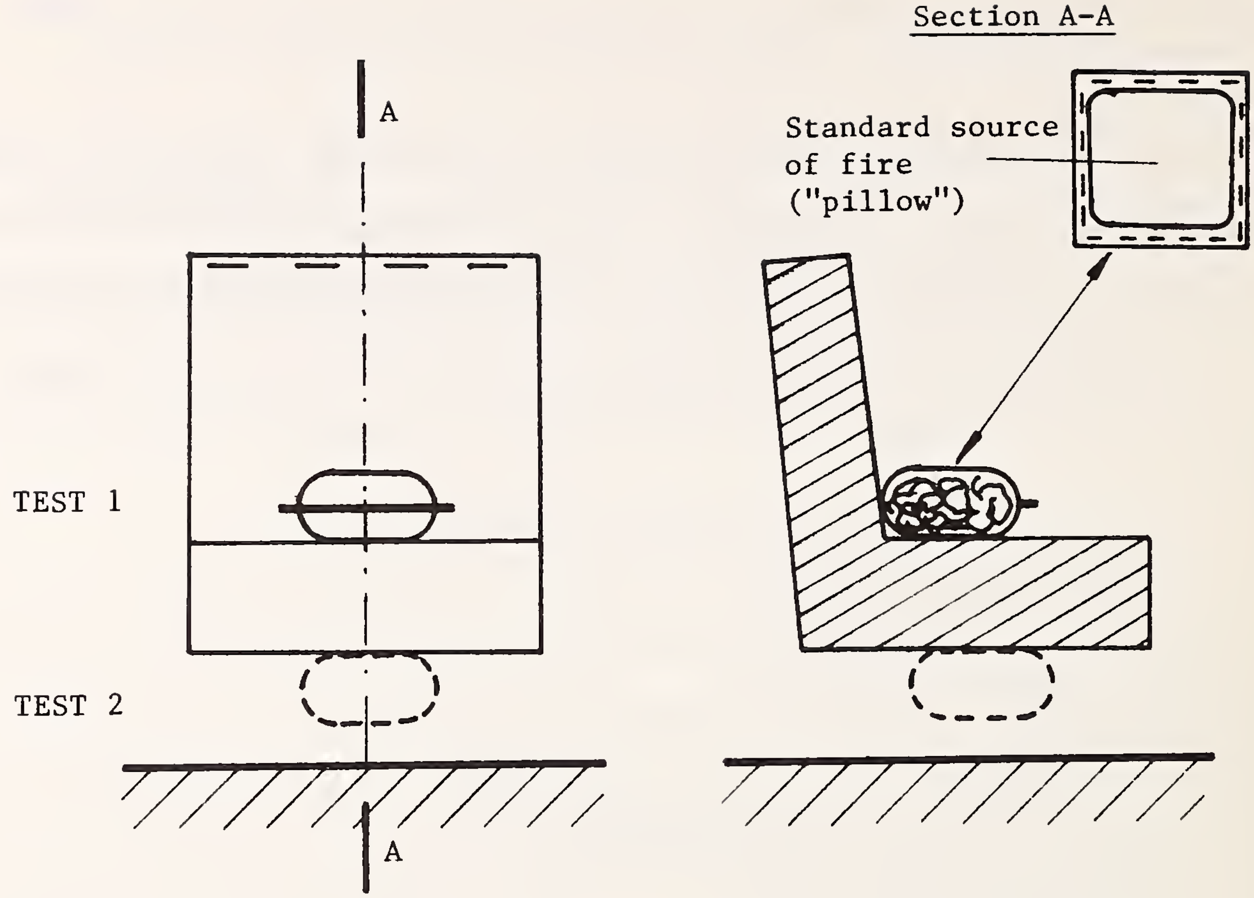


FIGURE 4-1. UIC AND SNCF RECOMMENDED SEAT SHELL IGNITION TEST

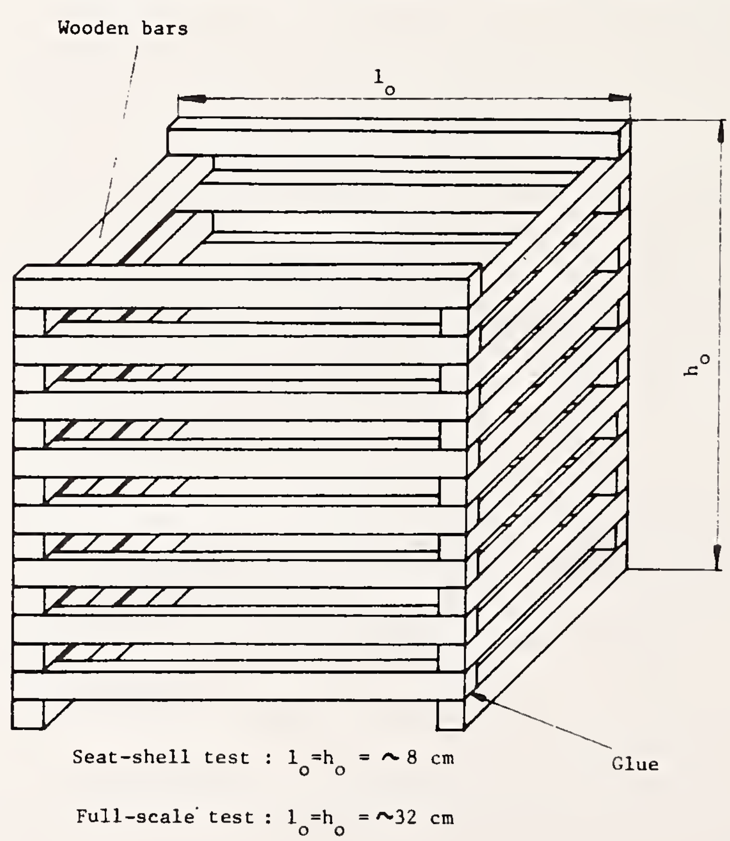


FIGURE 4-2. BR-PREFERED STANDARD SOURCE OF FIRE FOR SEAT SHELL IGNITION AND FULL SCALE TESTS

performed in the same way, but now the "pillow" is located underneath the seat. Instead of the "pillow" technique, BR prefers to use its standard source of fire (see Figure 4-2). The second method is based on seat model testing as shown in Figure 4-3. This method, preferred only by DB, uses a standard Bunsen burner as the source of fire.

Additional requirements are specified in UIC Leaflet No. 895, "Technical Specifications for the Supply of Insulated Electrical Cables for Railway Vehicles." Two testing methods are described, one for ignitability (see Figure 4-4) and the other for long term fire resistance, which consists of simultaneous heating and igniting of cable insulation.

Some requirements are also specified in UIC Leaflet No. 845, "Technical Specifications for the Supply of Tubular Rubber Seals for Corridor Gangways." It is expected that these will be soon changed and that the ORE test for rigid materials discussed in section 5-5 will be adopted. This is supported by BR, which suffered from rubber seal fires in the newest series of Advanced Passenger Train vehicles brought into service in 1982.

Requirements for power units are defined in two UIC Leaflets: No. 617, entitled "Regulations for Electric Motive Power Units for International Traffic in Regard to Fire Prevention," and No. 625-I, entitled "Regulations Relating to Precautionary and Fire-Fighting Measures on Diesel Motor Stock."

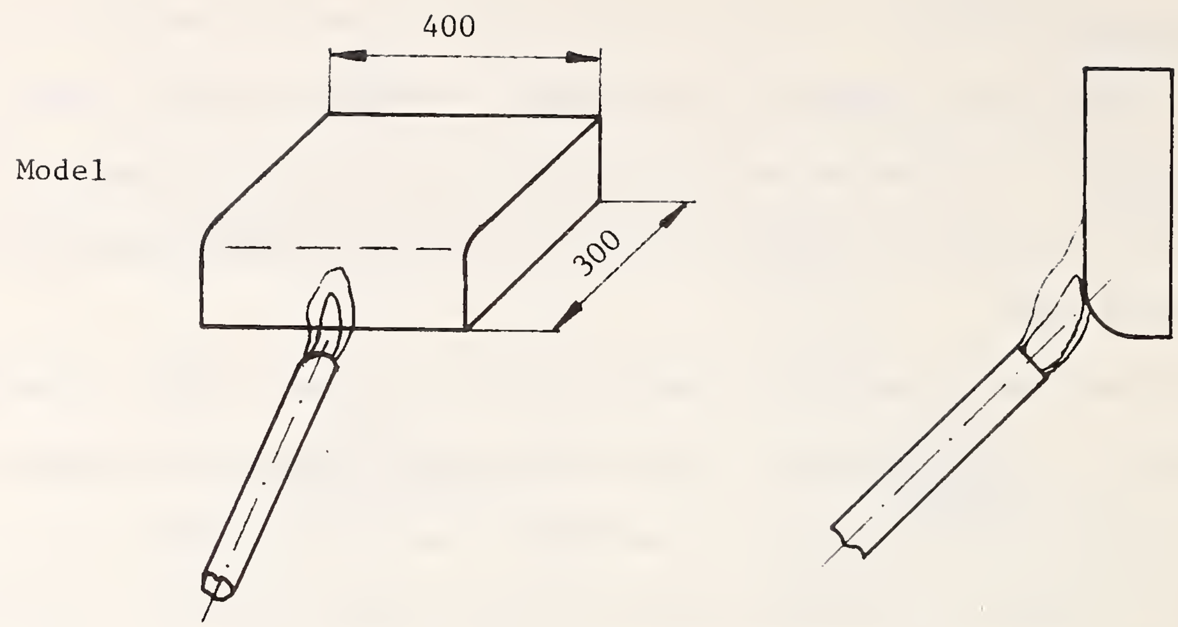


FIGURE 4-3. UIC AND DB RECOMMENDED REDUCED-SCALE SEAT SHELL IGNITION TEST

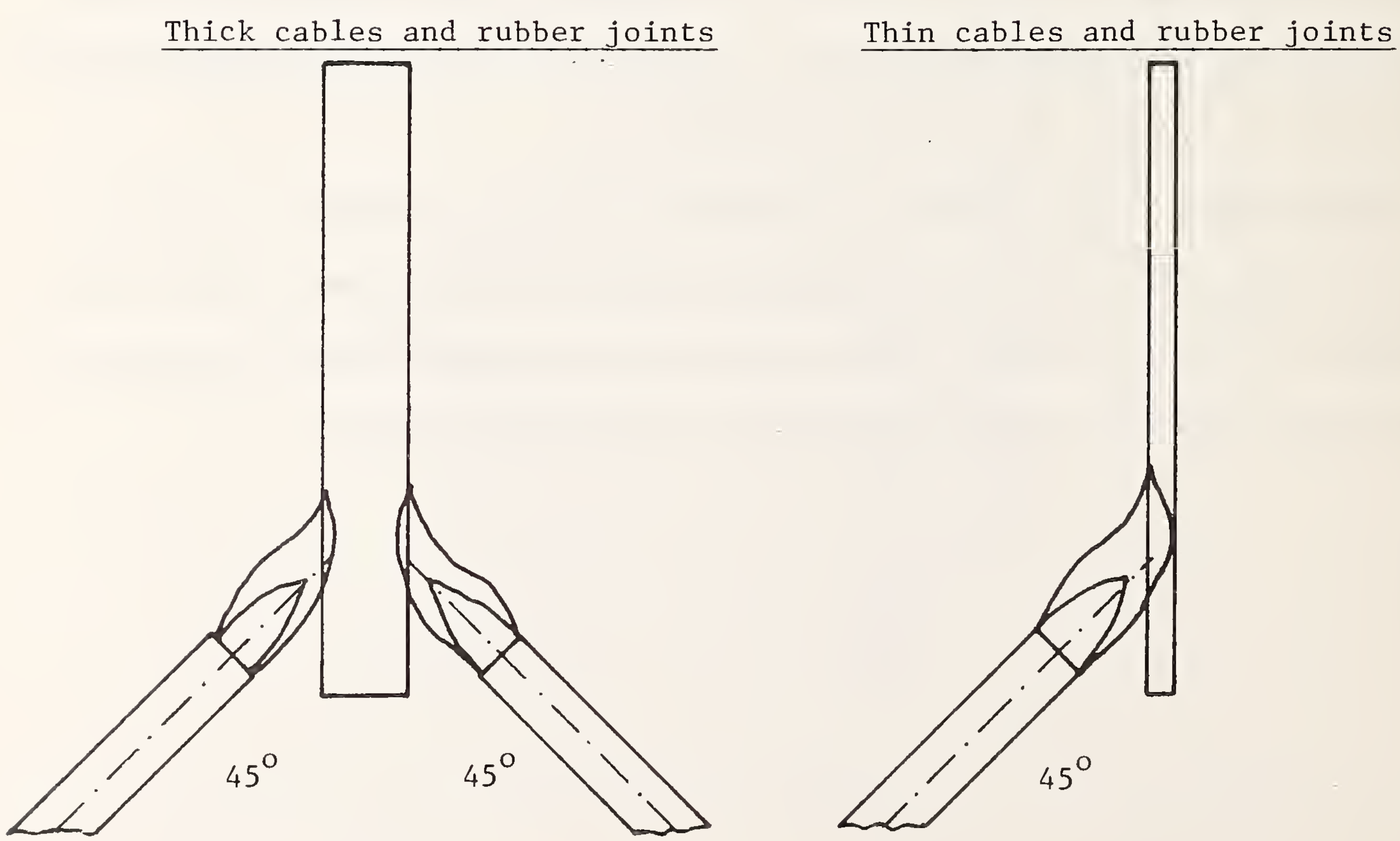


FIGURE 4-4. ORE TESTS FOR CABLES AND RUBBER JOINTS (ADOPTED UIC METHOD)

5. MATERIAL PROPERTIES TESTING METHODS

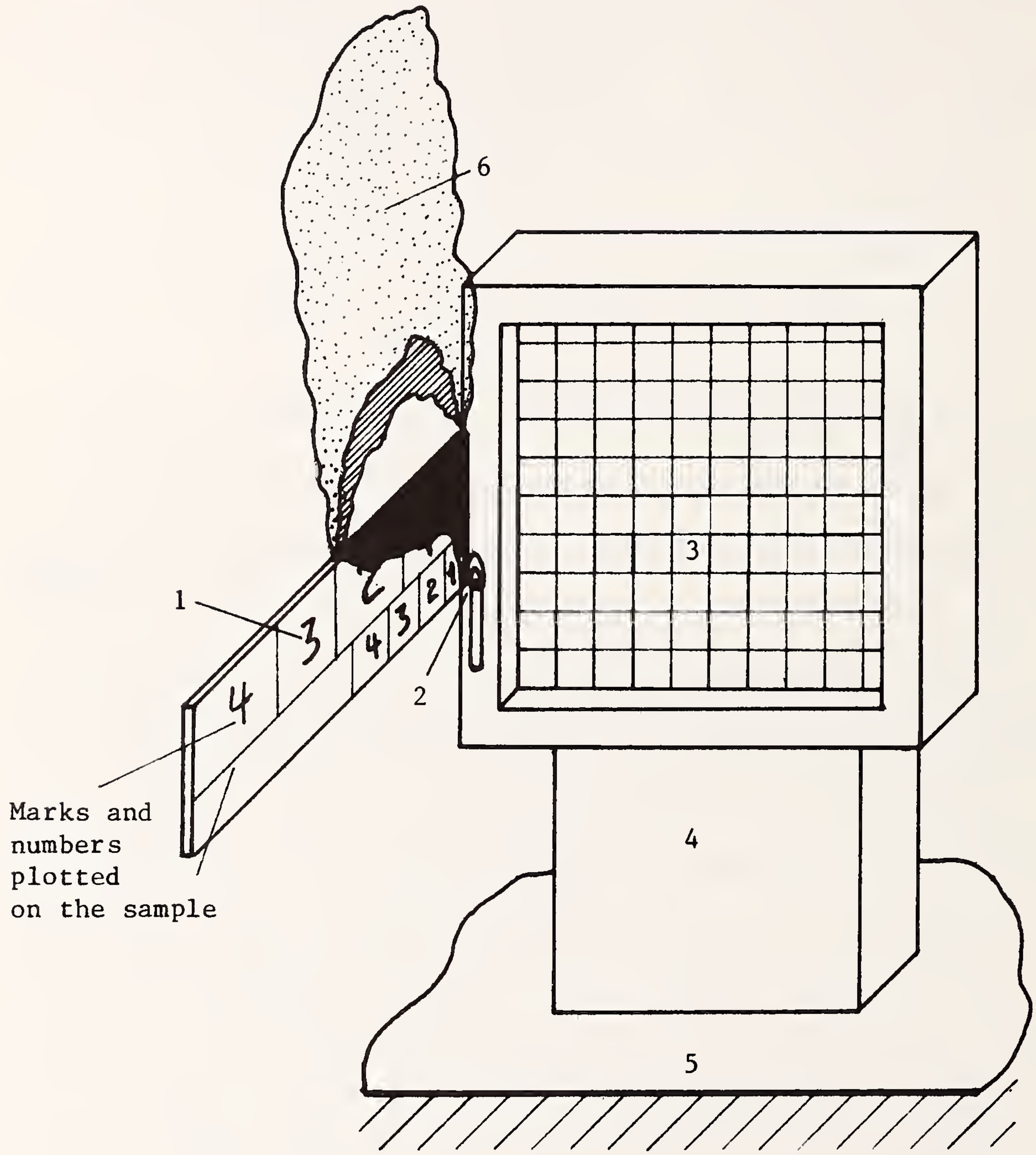
5.1 BRITISH RAILWAYS (BR) SURFACE SPREAD OF FLAME AND OXYGEN INDEX TESTS

The schematic drawing of the apparatus for measuring surface spread of flame according to British Standard BS 476 Part 7 adopted by BR is shown in Figure 5-1. The method was developed at the Fire Research Station in Elstree (FRS.E) in the early 1960s for building purposes. Materials are divided into four classes numbered 1 to 4, where class 4 designates the material most prone to fire spread.

BR assumes as a rule that only class 2 or better materials can be used in vehicle construction. In the case of sleeping cars, since 1980 the so-called "class 0" materials have been preferred. Class 0 material is not precisely defined; in the existing British Building Regulations, however, it is stated that class 0 material should have better properties than the class 1 material.

The apparatus used to measure the surface spread of flame is large, testing procedures are expensive and considerable laboratory space is needed. BR therefore found it more convenient and economical to have these measurements taken by the privately owned Warrington Research Center, either at BR's own or the manufacturer's expense. However, this procedure is carried out only for the formal approval of materials. For preliminary material selection BR has chosen an oxygen index test. As this method is widely known, only a very schematic diagram is given in Figure 5-2. Based on many tests, BR has found an approximate correlation between both methods, which is given in Table 5-1.

Material as shown in this drawing
is classified as Class 2
according to BS 476 Part 7



1 - sample
2 - pilot flame
3 - radiating panel
4 - stand
5 - floor
6 - decomposition products

FIGURE 5-1. SURFACE SPREAD OF FLAME PER BS 476 PART 7, ADOPTED BY BR

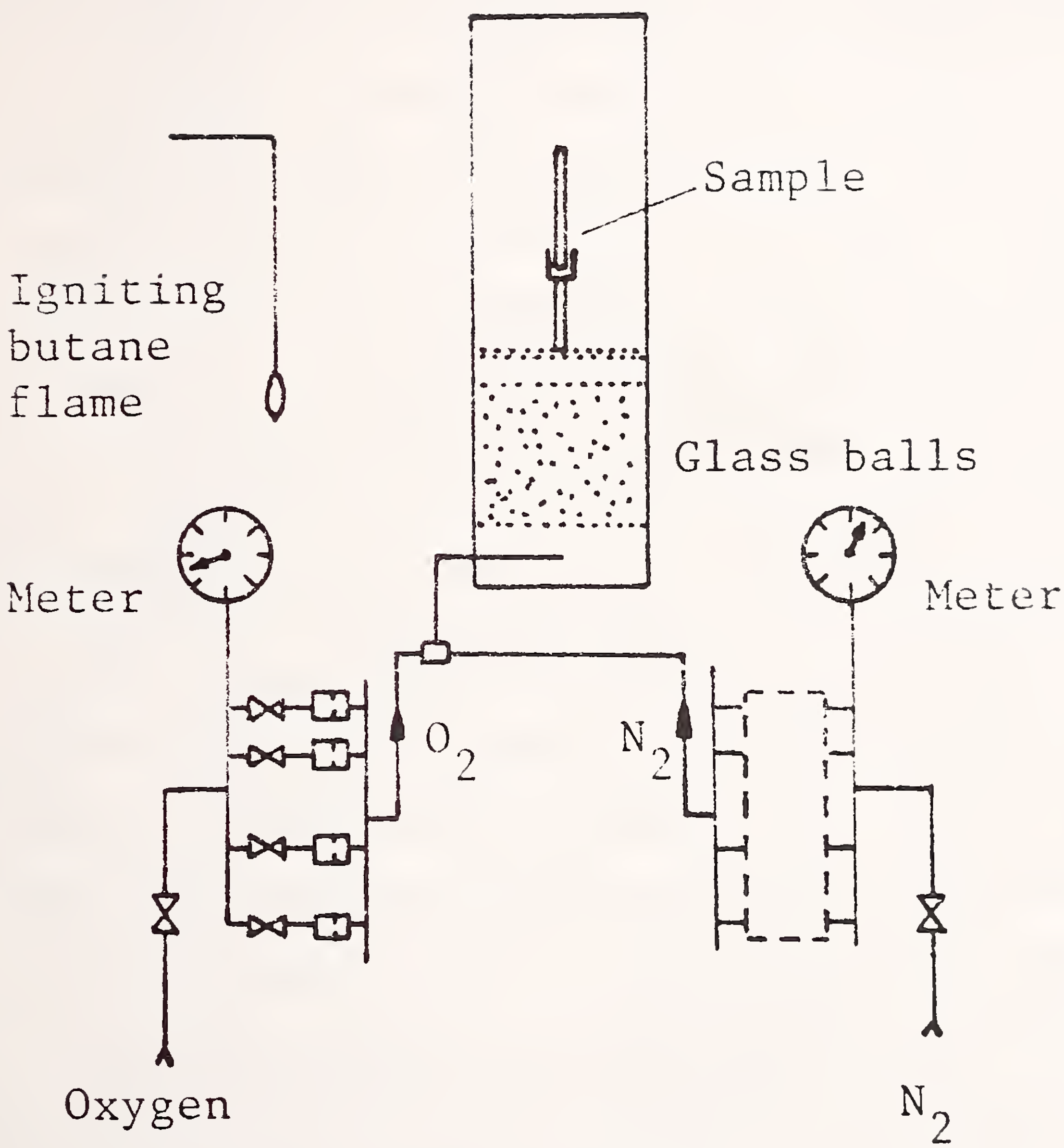


FIGURE 5-2. OXYGEN INDEX TEST

TABLE 5-1. CORRELATION OF SURFACE SPREAD OF FLAME AND OXYGEN INDEX TEXT

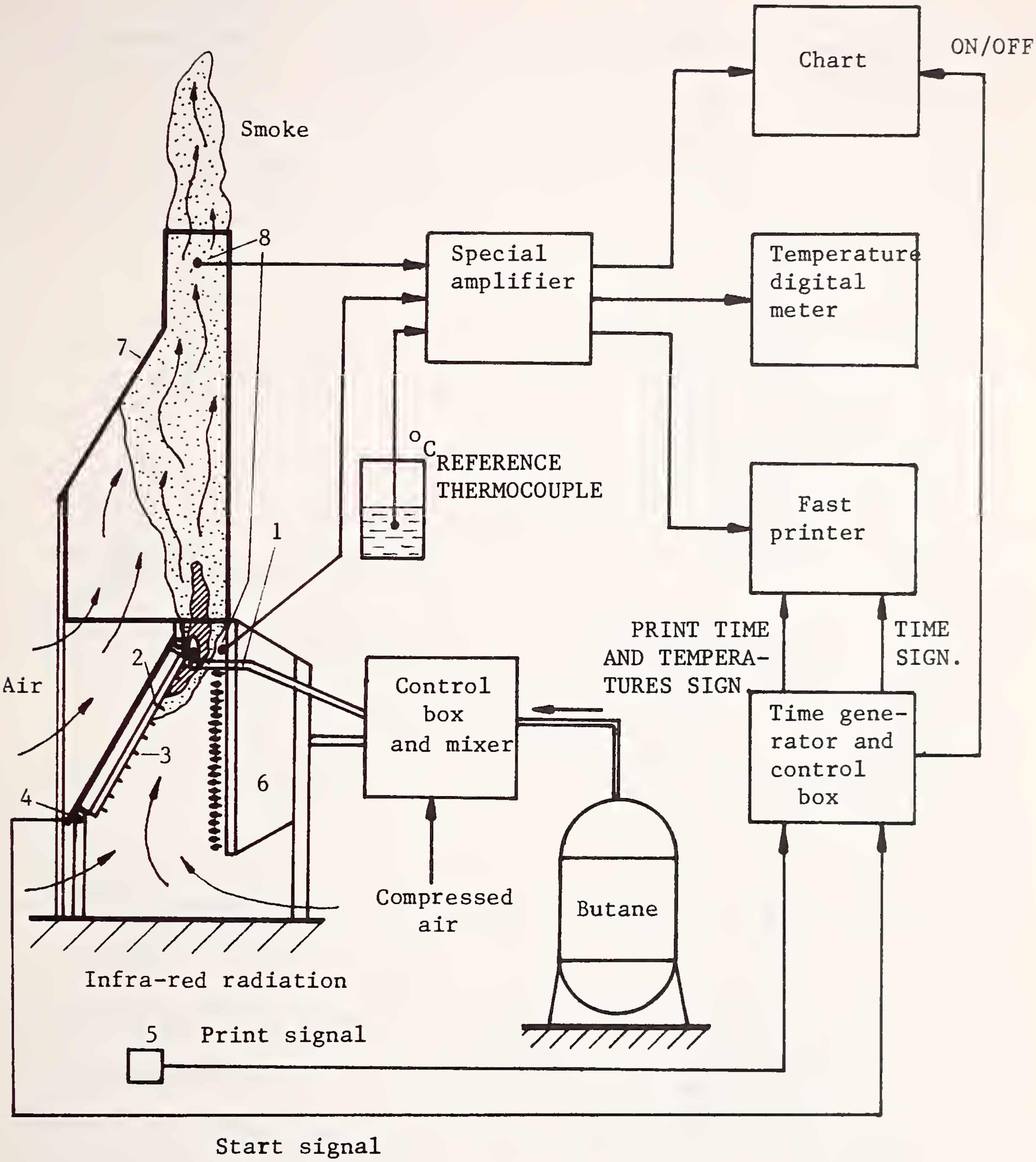
Class per BS 476 Part 7	4	3	2	1	-
Class per Building Regulations	NA	NA	NA	0	1
Oxygen Index (% oxygen)	≦ 21	21,1-28	28,10-35	35,1-42	>42

NA - Not applicable

It is assumed that the surface spread of flame test according to BS 476 Part 7 is the most severe testing method, to some extent approximating fully developed fire conditions. It has however been widely criticized for being applicable to wall materials only, for its nonadaptability to textile testing, and for its high cost and outmoded methods. In fact, the method requires no measuring equipment except for a ruler and stop watch.

5.2 POLISH STATE RAILWAYS (PKP) TESTS AND ADOPTED CLASSIFICATION AND REQUIREMENTS

The schematic diagram of the apparatus for measurement of surface spread of flame according to Draft Polish National Standard PN-74/K-02500 adopted by PKP is shown in Figure 5-3. This enhanced testing equipment is designed according to Intergovernmental Maritime Consultative Organization (IMCO) requirements. The apparatus permits the testing not only of wall and ceiling materials but also of flooring and textile materials, as shown in Figure 5-4. The radiating panel of the apparatus is designed so that, for wall and ceiling materials, the intensity of irradiation at the upper edge of the sample is 35 kW/m^2, while for textile and flooring materials it is 14 kW/m^2. The testing procedure is semi-automatic. One only needs to put a sample into the apparatus, which then switches the measuring equipment from stand-by to operating mode. When the front edge of the fire, spreading along the sample, reaches a particular distance marked on the frame, one pushes the print signal button. The results



1 - pilot flame
2 - sample
3 - distance marks on the frame
4 - on/off switch
5 - on switch
6 - radiating panel
7 - chimney
8 - thermocouples

FIGURE 5-3. ENHANCED IMCO EQUIPMENT ADOPTED BY PKP FIRE LABORATORY

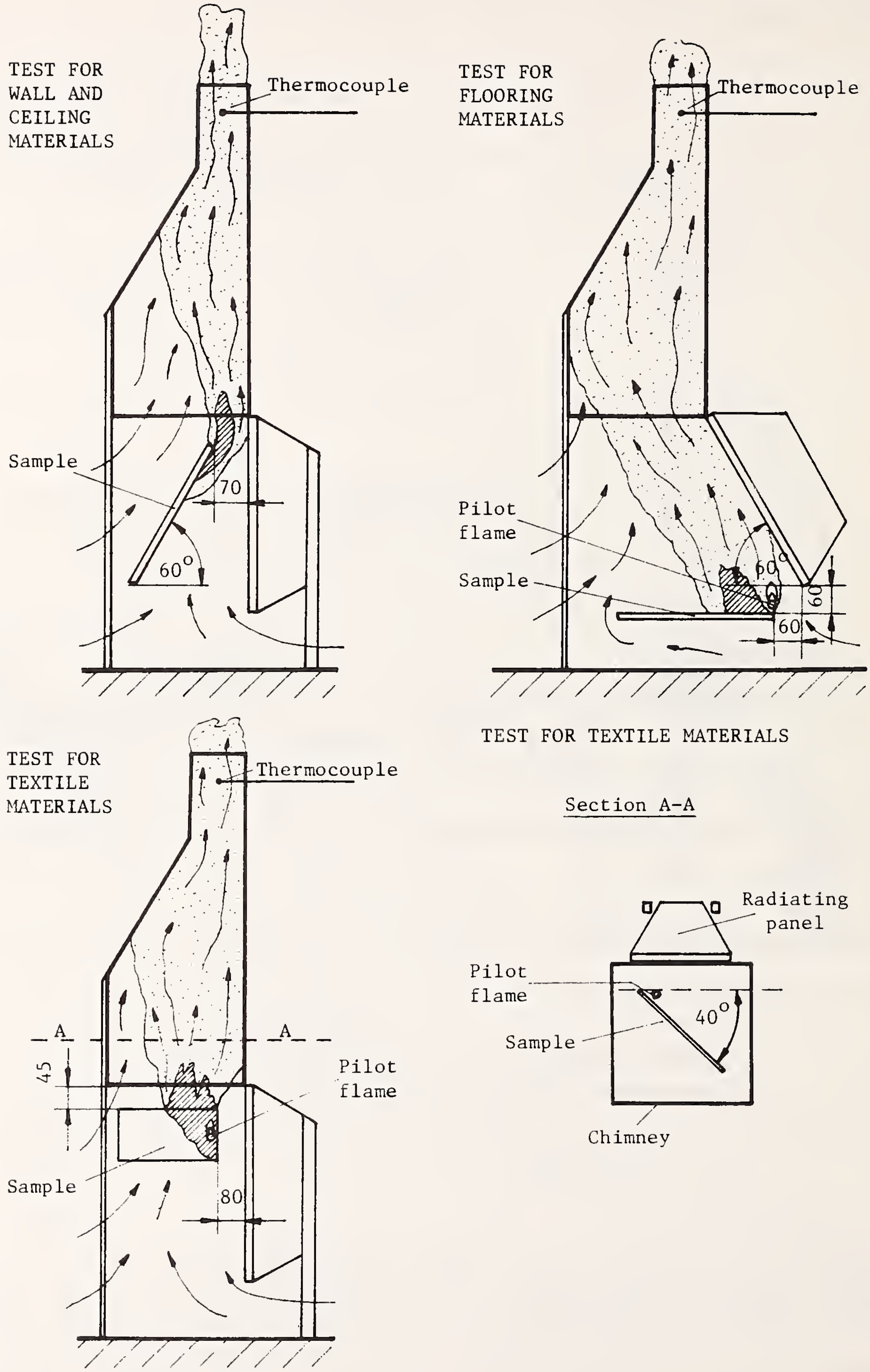


FIGURE 5-4. SURFACE SPREAD OF FLAME TESTS ADOPTED BY PKP

are expressed in the form of the surface-spread of flame coefficient "I", calculated by the following formula:

$$I = \sqrt{AB(T_{max} - T_o)(t_{max} - t_z)t_z^{-1}(1 + L_r C \sum_{i-1}^{n} \Delta t_i^{-1})}$$

where

A = energy exchange by means of radiation between the radiating panel and sample's surface (approximately equal to 11.5 kW^{-1});

B = a thermal constant for the apparatus (in kW K^{-1}), i.e., thermal power released from sample's surface increasing the chimney thermocouple temperature for 1K;

C = 200 s m^{-1};

t_i = time it takes the edge of flame to travel between distance marks "i - 1" and "i" on frame;

t_{max} = elapsed time from sample ignition to maximal temperature level;

t_2 = time to ignition;

L_r = maximal distance on sample reached by flame (i.e. burned surface length);

T_{max} = maximal chimney thermocouple temperature (K); and

T_o = initial temperature of chimney thermocouple (K).

The oxygen index test (Figure 5-2) is also applied by PKP to analyze material ignitability.

The schematic drawing of the PKP glow test is shown in Figure 5-5. In this test the heated bar touches a sample of material used in the production of

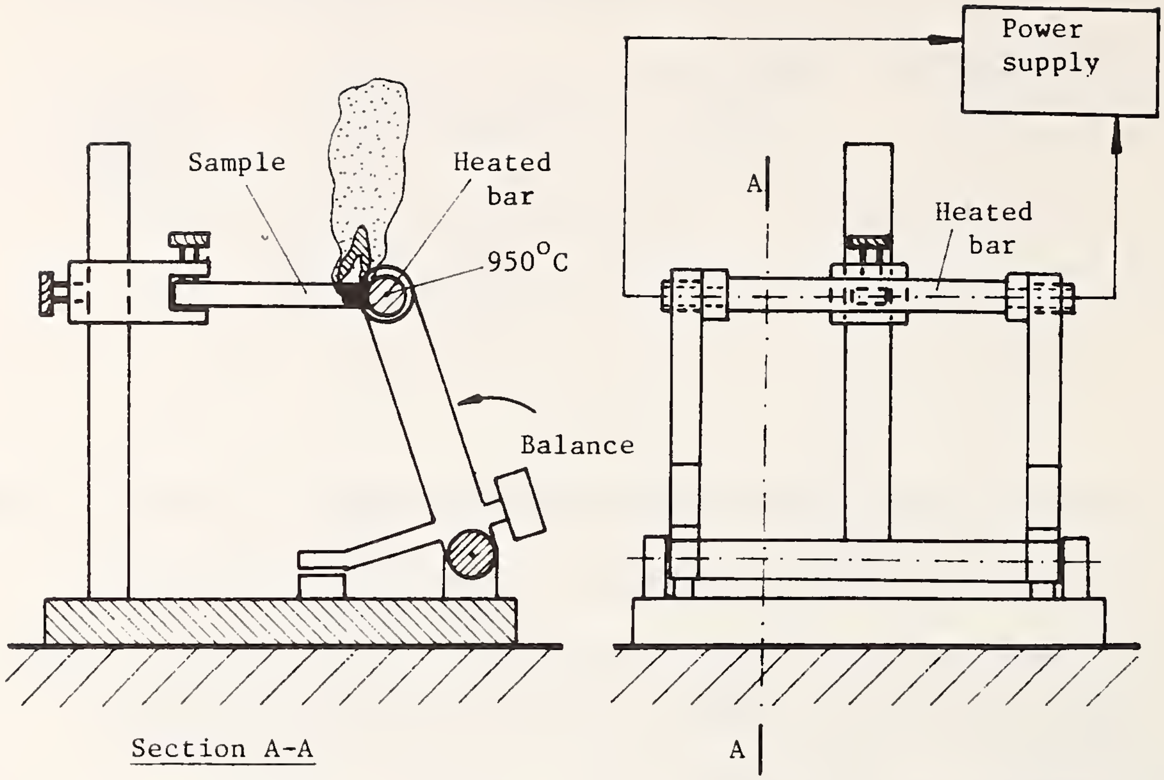


FIGURE 5-5. PKP GLOW TEST

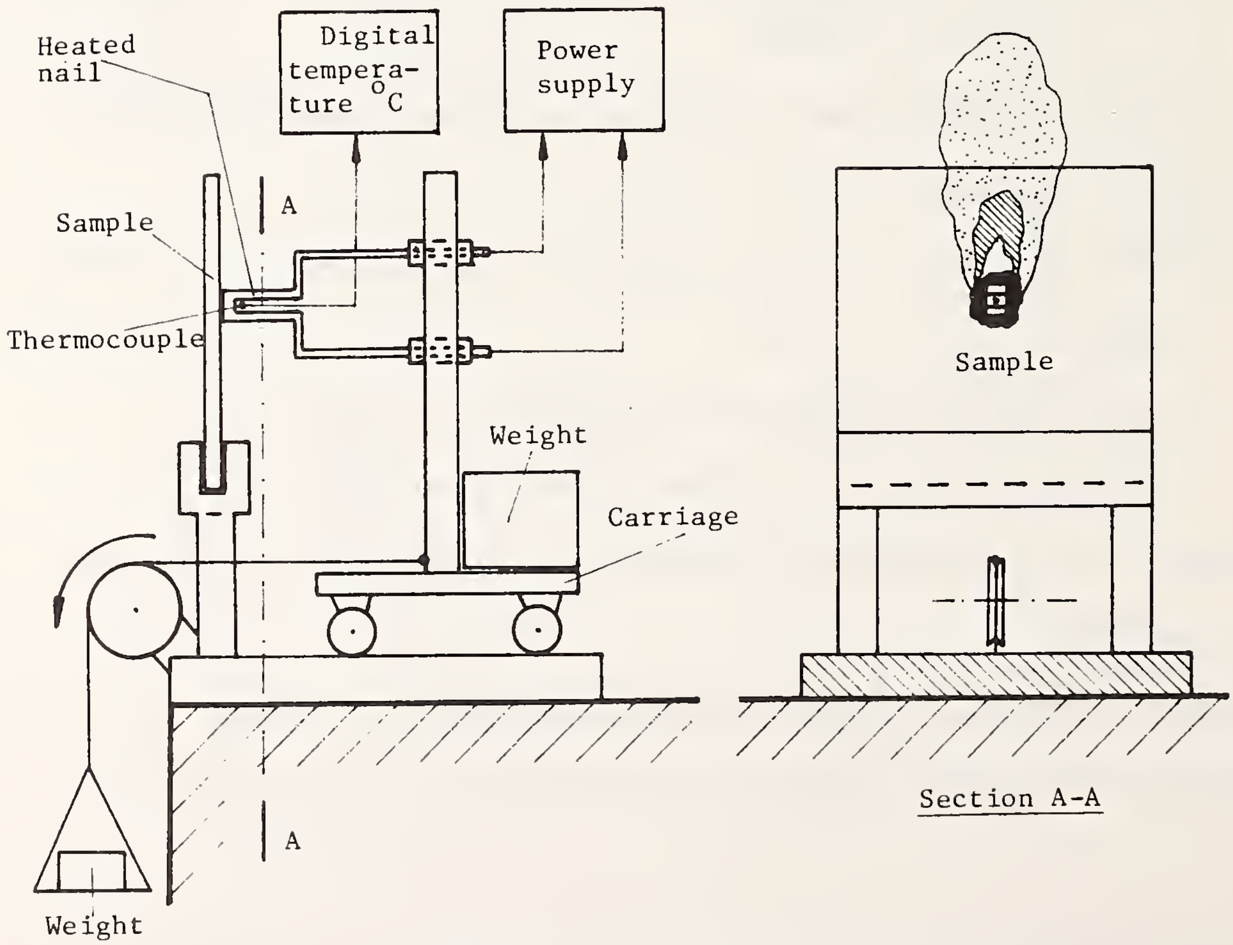


FIGURE 5-6. SNCF GLOW TEST

structural and insulating items in electric circuit components. Burn-time and length of burned surface are measured.

On the basis of extensive comparative fire testing, the classification of materials shown in Table 5-2 has been adopted. Nonburning (N) denotes a material which can pass the 750°C ISO building test. Other materials are classified as burning (P). Noninflammable (P 1) denotes a material which has an oxygen index higher than 28. Hardly inflammable (P 2) denotes a material which has an oxygen index within the 21-28 range. Easily inflammable (P 3) denotes a material which has an oxygen index of lower than 21. Low surface spread of flame (R 1) denotes a material which has an I coefficient of lower than 20 or, in cases of porous insulating materials, has a burn time shorter than 5 seconds and a burned surface length of less than 25 mm when tested according to the ISO method shown in Figure 7. Medium surface spead of flame (R 2) denotes a material which has an I coefficient within the 20-65 range or, in cases of porous insulating materials, has a burn time of shorter than 30 seconds and a burned length of less than 125 mm. High surface spread of flame (R 3) denotes a material which cannot be classified as either an R 1 or an R 2 material. Glow-resistant (Z 1) denotes a material which stops burning before the heating bar is removed and which has a burned surface length equal or less than 3.5 mm. Medium glow-resistant (Z 2) denotes a material which stops burning before the heating bar is removed and which has a burned length within the 3.5 - 35 mm range. Non-glow-resistant (Z 3) denotes a material which cannot be classified as either a Z 1 or a Z 2 material.

Property requirements for various materials used in commuter and intercity vehicles and sleeping cars are given in Table 5-3.

TABLE 5-3. PKP REQUIREMENTS FOR MATERIAL PROPERTIES

Description of material	Classification
Nonburning	N
Burning	P
Noninflammable	P 1
Hardly inflammable	P 2
Easily inflammable	P 3
Low surface spread of flame	R 1
Medium surface spread of flame	R 2
High surface spread of flame	R 3
Glow-resistant	Z 1
Medium glow-resistant	Z 2
Non-glow-resistant	Z 3

TABLE 5-3. PKP REQUIREMENTS FOR MATERIAL PROPERTIES

Application	Commuter vehicles	Inter-city vehicles	Sleeping cars etc.
Parts of ceiling and walls directed to the inside of the vehicle	P 1 or R 1	P 1 and R 1	
Compartment doors	P 2 or R 2		P 1 and R 1
Structural floor items		P 3 or R 3	
Seats/benches/beds (if applicable)	P 1 and R 1	P 2 or R 2	P 2 and R 2
Doors connecting with next Vehicle		N	
Rubber joints		P 2 or R 2	
Thermal and acoustical insulation		P 2 or R 2	
Rubber gangway items		P 2 or R 2	
Electrical insulation of cables			
low-voltage	R 2	R 1	
high-voltage		R 1	
Structural and insulating items in electric circuit appliances			
low-voltage		R 2 or Z 2	
high-voltage		R 1 or Z 1	
Flooring materials, carpets, etc.		P 2 or R 2	
Light diffusers		P 1 or R 1	
Blankets, bed materials			P 2 and R 2
All items at 0.5 m distance from self-heating system (coal and oil)		N	
All items in service compartment (if equiped with kitchen facilities)		P 1 and R 1	

5.3 FRENCH RAILWAYS (SNCF) GLOW RESISTANCE AND IGNITABILITY TESTS

A schematic drawing of the SNCF glow resistance test is given in Figure 5-6. In this test, a heated nail touches the surface of a sample. Burn-time, mass loss and burned surface area are measured. This test will probably be approved as a European Economic Community standard.

A schematic drawing of the SNCF ignitability test (the so-called "epiradiateur" test) is given in Figure 5-7. The frame and the sample holder are positioned at a 45° angle to the floor. A sample of a rigid structural material is fitted to the holder and heated from underneath by an electric radiator. Two pilot flames on both sides of the sample serve to ignite decomposition products. Temperatures of incoming fresh air and outgoing fumes are measured, along with burned surface area. Materials are classified from M 1 to M 4, where class M 4 denotes the most ignitable material. Although this test is less severe than those of BS 476 Part 7 and of PN-84/K-02500, it is generally agreed that the classifications are similar. For fusibles, like thermoplastic materials, an additional test is performed, as depicted in Figure 5-8. In this test the total mass of pieces dropping from the burning sample is measured. The falling of burning strips, drops, etc., is also detected. For flexible materials, an oxygen index test has been adopted. For porous materials the ISO test method is used, as shown in Figure 5-9.

5.4 WEST GERMAN STATE RAILWAYS (DB) TEST METHOD

The schematic drawing of DB standard fire test method for various materials is shown in Figure 5-10. A sample in the holder is subjected to a Bunsen burner flame. Burn-time, mass lost, falling of burning particles and smoke emission are measured. This is the oldest and simplest method available for testing

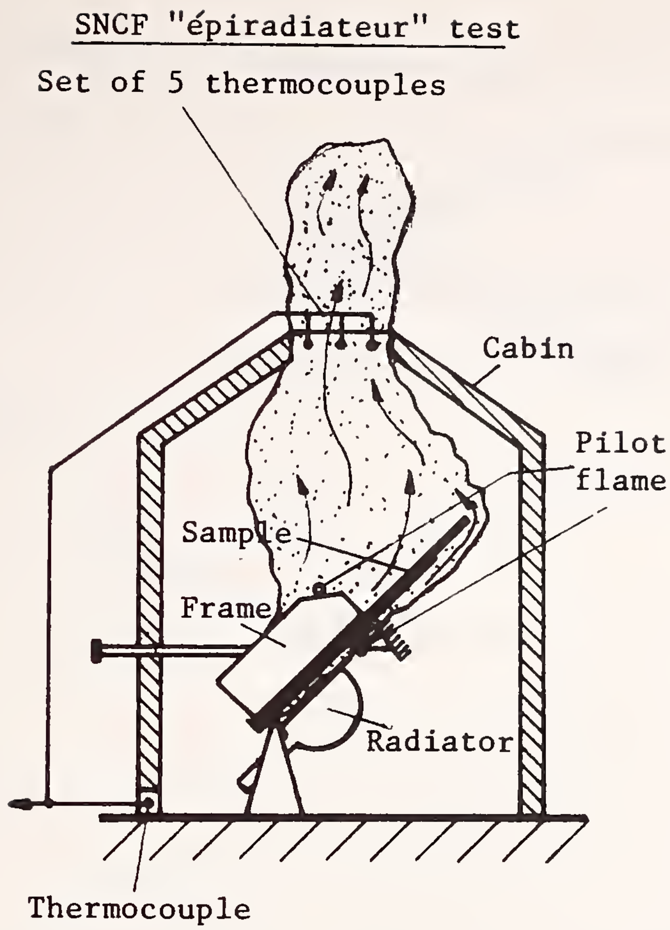


FIGURE 5-7. SNCF "EPIRADIATEUR" TEST

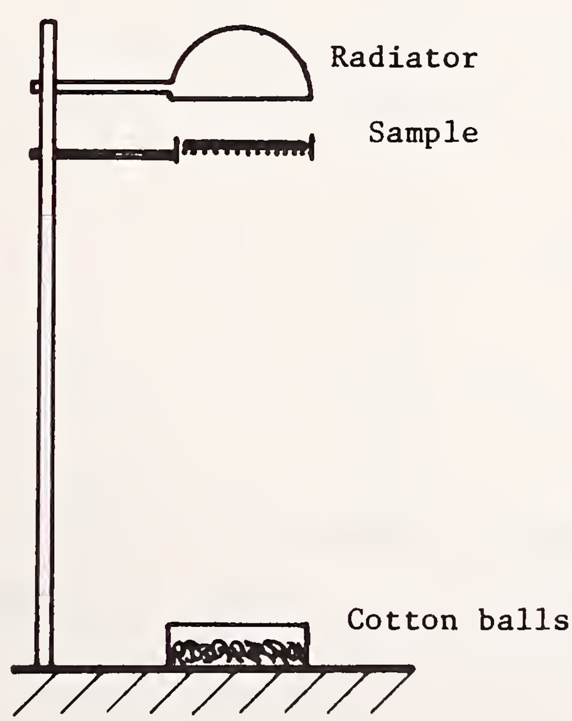


FIGURE 5-8. SNCF TEST FOR FUSIBLE MATERIALS

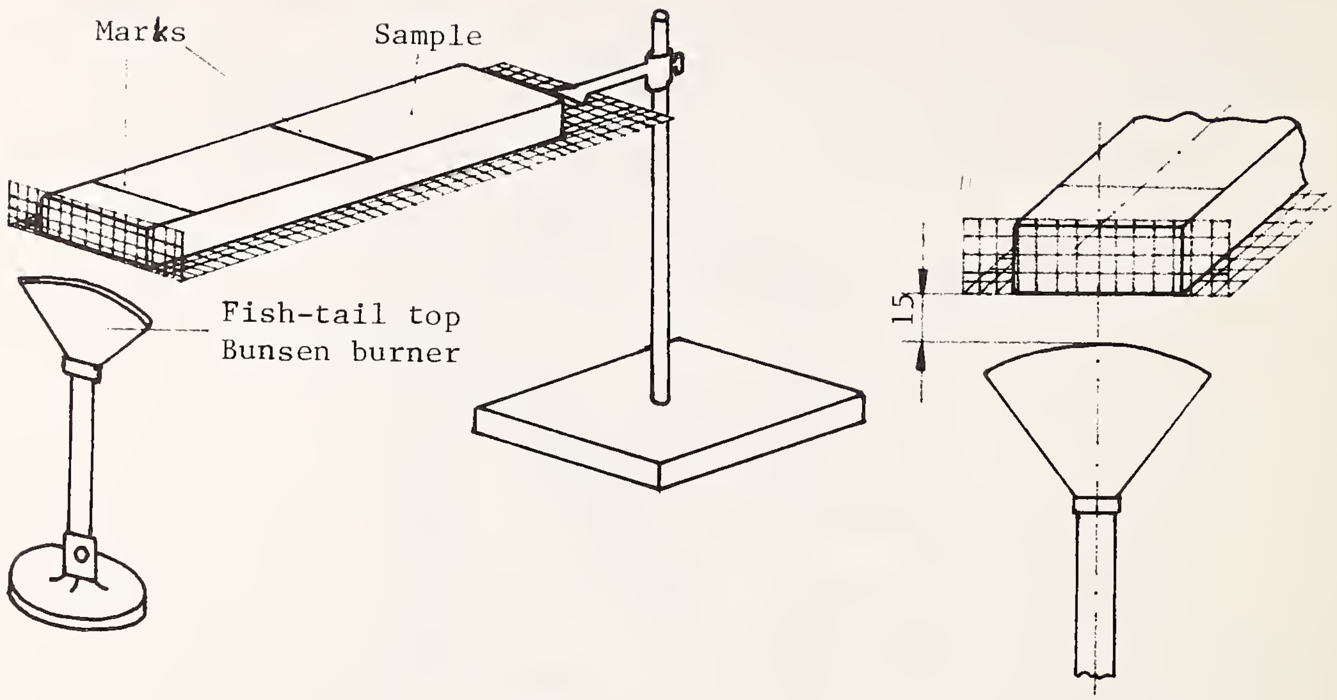


FIGURE 5-9. ISO TEST METHODS ADOPTED BY ORE FOR TEXTILES AND CELLULAR PLASTICS

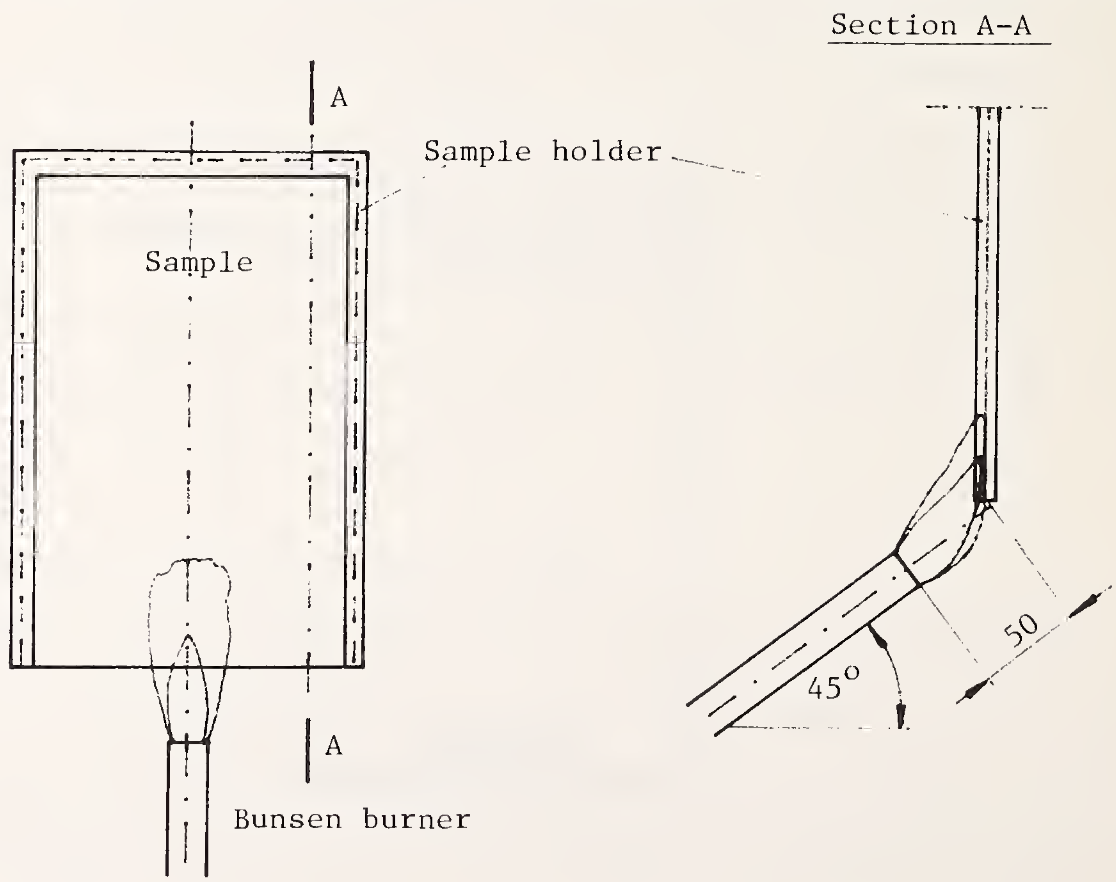


FIGURE 5-10. DB STANDARD FIRE TEST (ORE METHOD FOR TEXTILES)

rigid materials, but it has been rejected by all European railways except DB because the results are difficult to reproduce and the method's relation to actual transit fire conditions is uncertain.

A new German Industrial Standard (DIN) test is being developed in W. Germany. Entitled "Protection of Railway Vehicles against Fire," it will be applicable to all railway vehicles.

5.5 TEST METHODS DEVELOPED AND ADOPTED BY ORE

The basic ignitability test method developed by ORE Working Group B 106.2 is shown in Figure 5-11. A material sample is mounted on the frame shown in Figure 5-12. The frame is positioned on the sample stand at a 45° angle to the floor. A brass cup filled with 4 cm^3 of 96 percent alcohol rests on the cup mounting plate. The alcohol is ignited and the flame touches the upper surface of the sample. Burn-time after the alcohol flame is extinguished and burned surface area are measured. Materials are divided into three groups (A, B and C) according to the following table, which is based on two years of interlaboratory testing of materials supplied by all railways participating in the work group.

TABLE 5-4. MATERIAL CLASSIFICATION APPLIED BY ORE

Burn-time (sec) / Burned surface (cm^2)	≦2	≦10	>10
≦ 100	A	B	C
≦ 150	B	B	C
>150	C	C	C

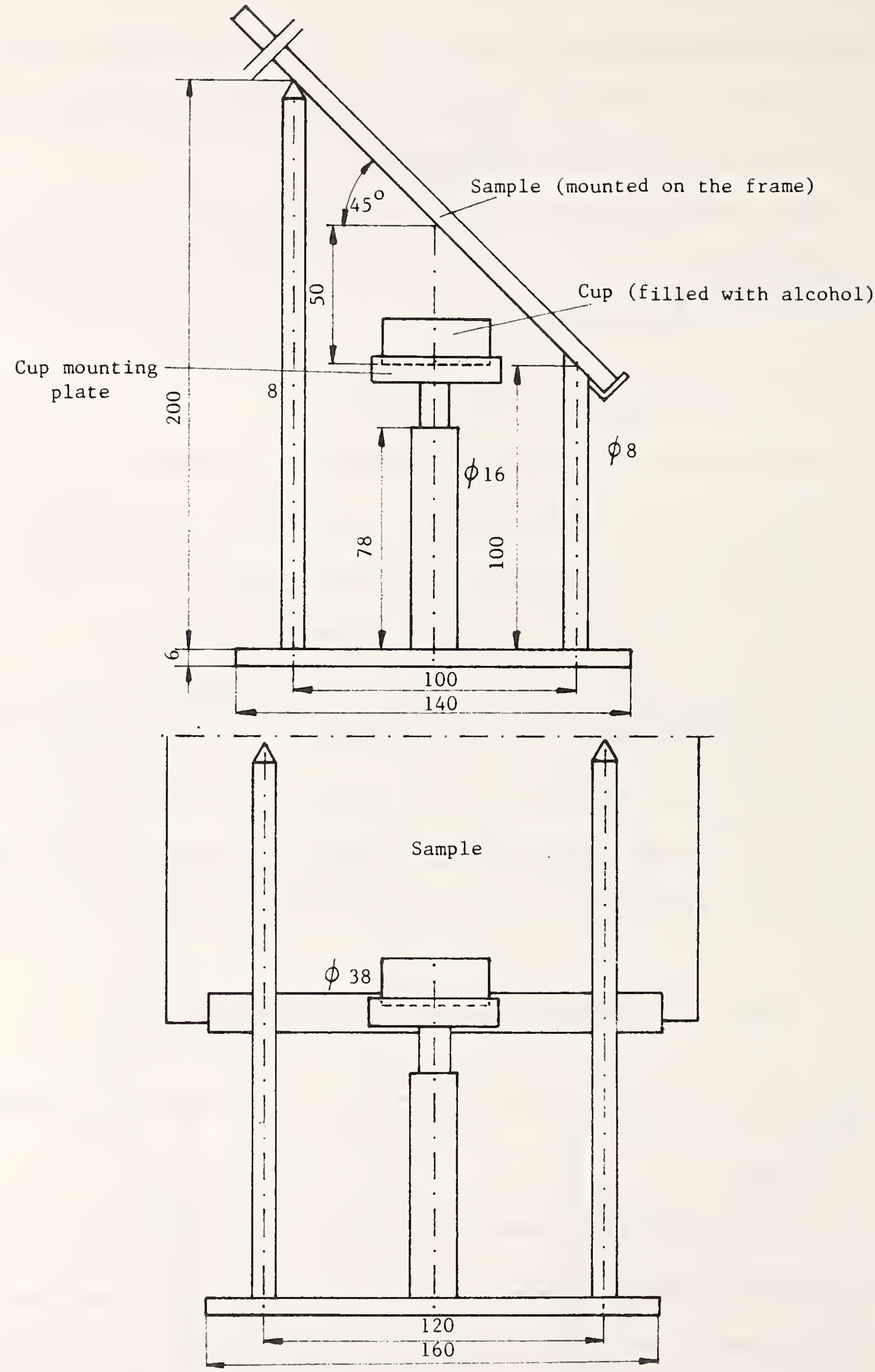
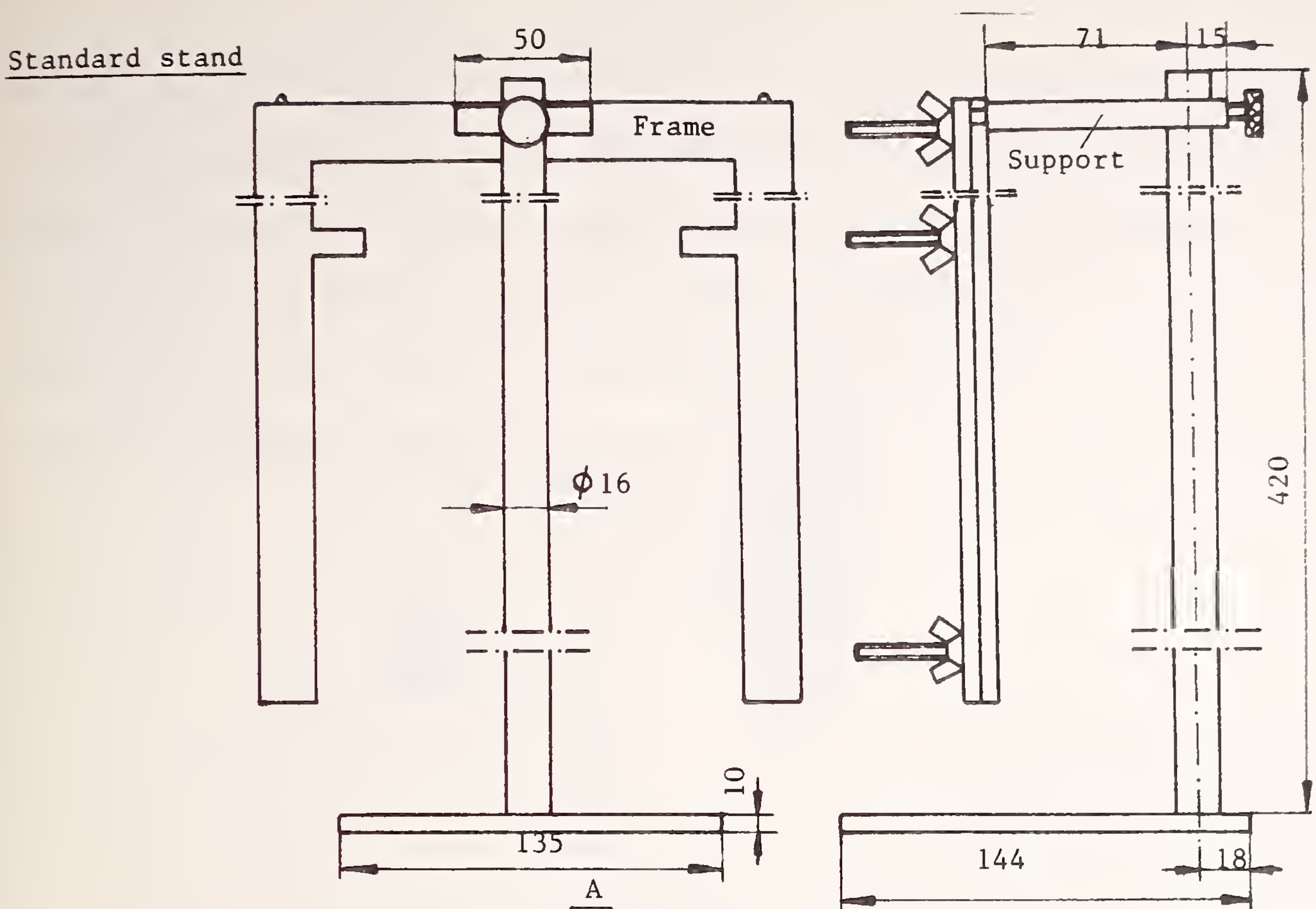


FIGURE 5-11. ORE METHOD FOR TESTING RIGID MATERIALS



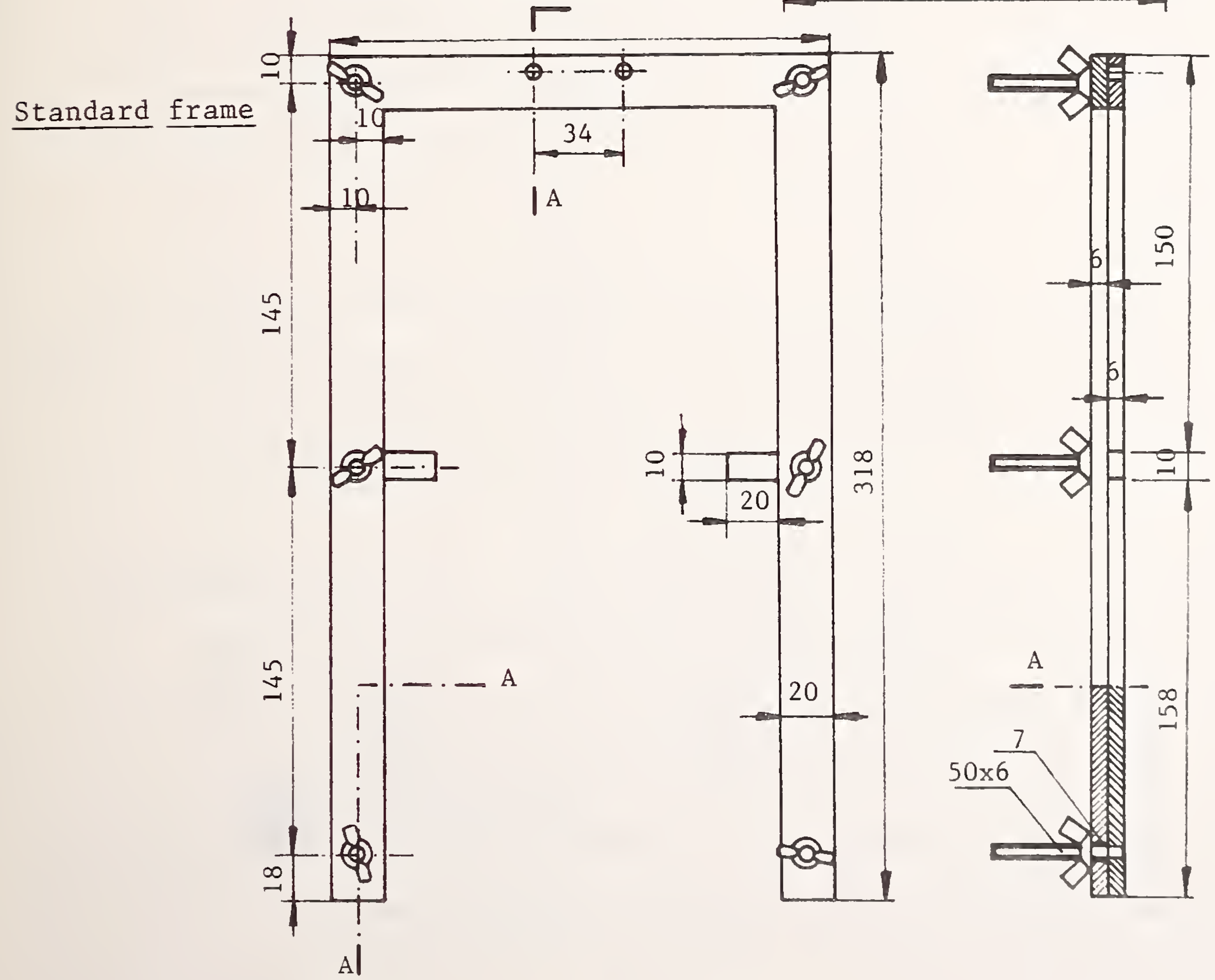


FIGURE 5-12. STAND AND FRAME FOR ORE TESTING METHODS

For textile materials, however, it has been found that the results vary due to the difficulty, in the case of thin materials, of stretching samples to fit the frame. The vertical test as shown in Figures 5-10 and 5-12 has been adopted for these materials. The difference between this ORE method and the DB method mentioned above lies in the different burners used. DB uses a DIN burner which ORE considers too weak. For these textile materials ORE has adopted a similar classification system as shown in the following table:

TABLE 5-5. ORE CLASSIFICATION OF TEXTILE MATERIALS

Burned surface (cm^2) \ Burn-time (sec)	≤ 2	≤ 10	>10
≤ 80	A	B	C
≤ 200	B	B	C
>200	C	C	C

Typical material samples after both ORE tests are shown in Figure 5-13. Samples to the left of this figure are classified as class A materials, samples in the middle as class B materials, and samples to the right as class C materials.

PKP tested 70 rigid and textile materials with the methods described in section 5.2 and with both ORE methods. It found that there is a good correlation between PKP and ORE classifications. In the case of textile materials, however, the PKP method appears to be more severe.

BR and SNCF also reported a good correlation between their method and that of ORE. DB has released no information as of September 1984.

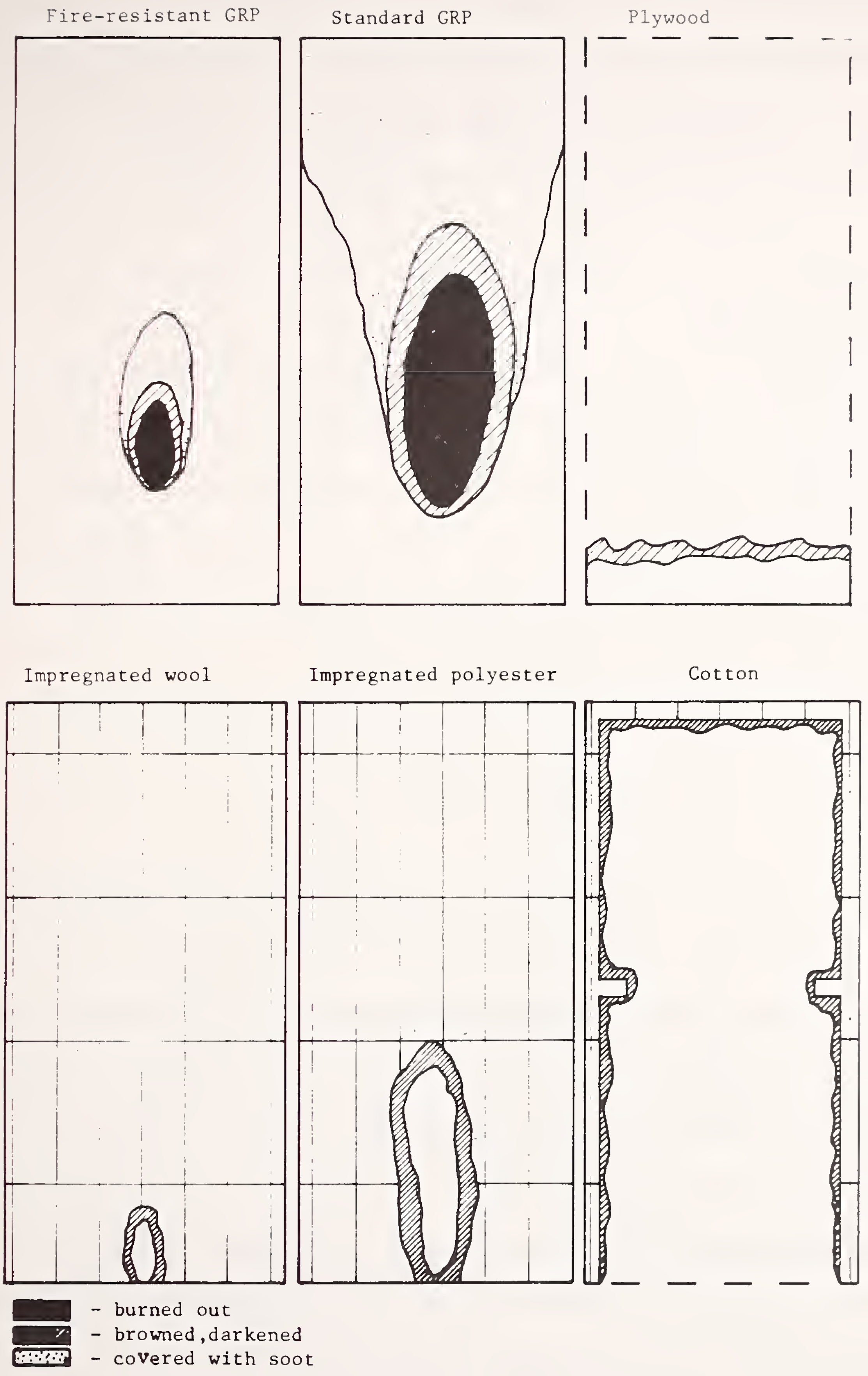


FIGURE 5-13. TYPICAL MATERIAL SAMPLES TESTED WITH ORE METHOD

For porous materials ORE adopted the ISO method already shown in Figure 5-9. For electric cable insulation and for rubber window and door joints, the UIC method is currently being tested by ORE. The report is due in 1985. It is expected however that the UIC method already shown in Figure 4-4 will be adopted.

5.6 TOXICITY AND SMOKE

BR measures toxicity of combustion products in accordance with British Maritime Standard No. 713 entitled "Determination of Toxicity Index for Combustion Products based on Small Material Samples." This method can be used for calculating toxicity based on concentrations of each toxic gas produced when 100 grams of a given material are burned in one cubic meter of air. The following formula is used for this calculation:

$$C_{si} = \frac{100c}{MV}$$

where

C_{si} = a normalized concentration of toxic gas "i" (in parts per million),

c = concentration of toxic gas "i" in the test chamber,

M = mass of the burned sample (in grams), and

V = test chamber volume (in cubic meters).

The toxicity index is calculated from the following formula:

$$TI = \sum_{i=1}^{n} \frac{C_{si}}{C_{pi}}$$

where i = 1, 2, 3, etc., represents different toxic gases and C_{pi} represents lethal concentrations at 30 minutes of exposure.

The corresponding values for common toxic gases are as follows:

TABLE 5-6. Cp VALUES FOR COMMON TOXIC GASES

Gas	C_p (in parts per million)
CO_2	100,000
CO	4,000
HCN	150
HCl	500
NO_2, NO_3	250
SO_3	400
H_2S	750
HF	100
HBr	150
NH_3	750
HCHO (formaldehyde)	500

It is assumed that materials having a toxicity index of less than 8 are safe. However, materials with far higher values are acceptable if the nature of a given material makes a lower value impossible, as in the case of wood and wood-based products.

PKP is conducting comparative tests of two methods for measuring the smoke-generating properties of materials. The first method is based on the NBS smoke chamber method enhanced with a laser light source and an optometric two-bar reference. This permits the measurement of the contrast-decrease factor, which relates to the panic level in humans. The method combines the smoke-generating properties of materials with the visual characteristics of the human eye. The second method is based on smoke mass optical density (MOD) measurements, and uses the test chamber described in a draft standard of the Council for Mutual Economic Assistance. Several samples of a material are decomposed by being subjected to ten different degrees of irradiation ranging from 15 to 50 kW/m^2. Percent of obscuration is measured with conventional lamp-light cell equipment. The results obtained at different irradiation levels are averaged together. The MOD for wood is around 100; for various plastics it usually ranges from 50 to 1500. Further information will be available after all testing has been completed. The latter method will probably be adopted as an Organization for Cooperation of Railways (OSZD) standard, and will be used by BDZ, DR, CSD, MAV and SZD.

Another study of toxicity and smoke evaluation techniques and related vehicle protection problems is being carried out by the ORE Working Group. It should be completed in 1987.

6. TESTS FOR STRUCTURAL ITEMS

6.1 POLISH STATE RAILWAYS (PKP) SEAT AND WALL FIRE TESTS

A rig used for PKP seat and wall fire tests according to UIC Leaflet No. 564-2 is shown in Figure 6-1. It was also used for the fire scenario tests discussed in section 6-3. Recording and measuring equipment varied depending on the test, but usually consisted of video camera, cameras, thermocouples, etc.

For wall testing, a standard PKP vehicle litter bin full of paper was used as a source of fire. The tests have not yet been completed.

On the basis of the seat tests, a new polyvinal chloride (PVC) coated textile material for upholstery was developed in early 1984. This material, which meets all present PKP fire protection requirements, melts rather than burns in a fire. In August 1984 the first supplies of this material were used for commuter vehicle seat repair and production.

6.2 BRITISH RAILWAYS (BR) CORRIDOR TEST

After the Taunton incident described in Chapter 1, BR began a series of tests at FRS.E to determine the probable cause of passenger deaths. Since, as has already been mentioned, the bodies were found in the corridor, BR designed the corridor test shown in Figure 6-2. The numbers in this diagram indicate the following components:

1 - test corridor built of a noncombustible silicate material,

2 - test sample,

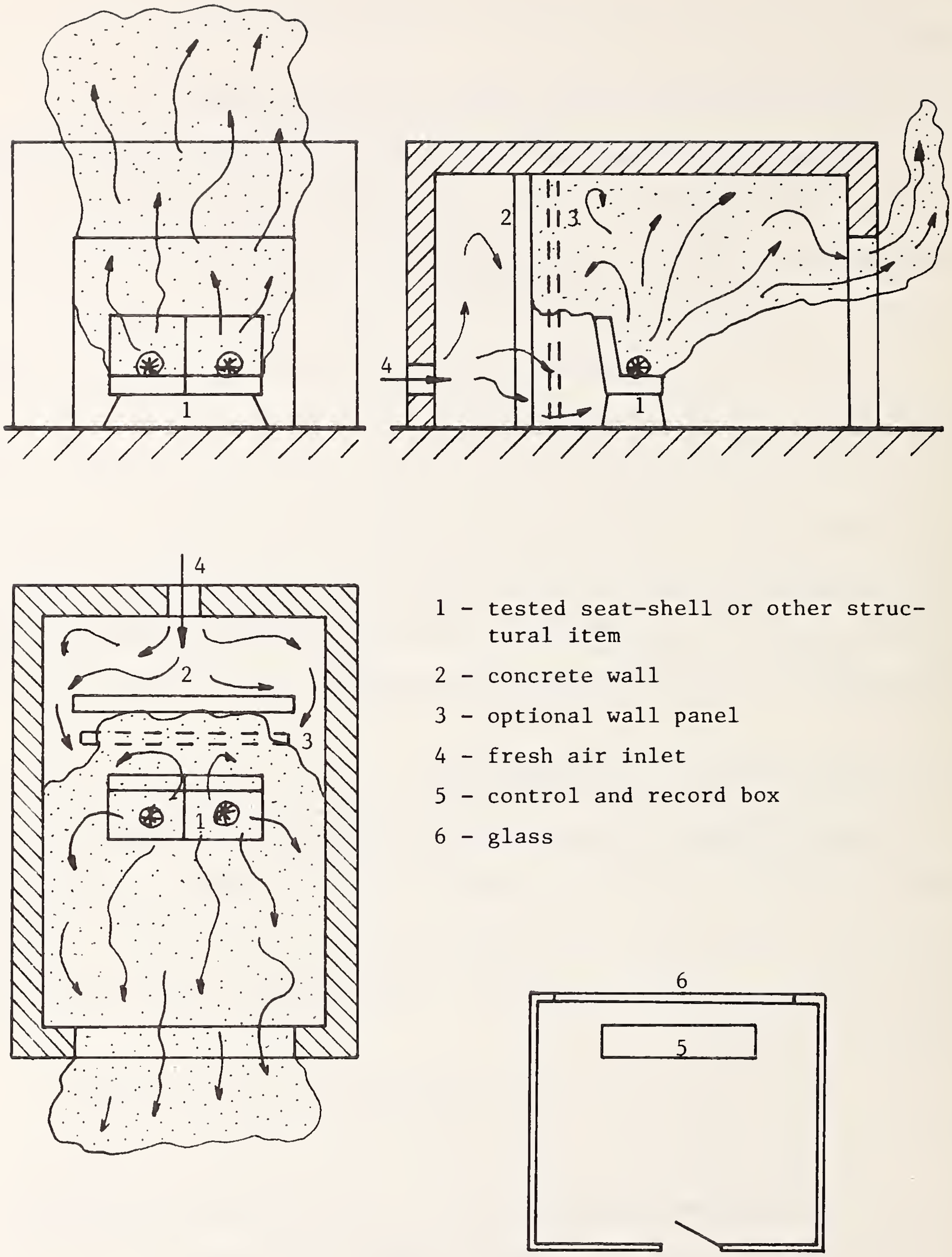
3 - BR full-scale standard source of fire (as shown in Figure 13),

4 - heat flux meter to measure irradiation of sample,

5 - light detector for smoke obscuration measurement,

6 - visible light lamp,

7 - scale to detect mass loss,



1 - tested seat-shell or other structural item

2 - concrete wall

3 - optional wall panel

4 - fresh air inlet

5 - control and record box

6 - glass

FIGURE 6-1. PKP FIRE TEST FOR WALL PANELS AND SEAT SHELLS

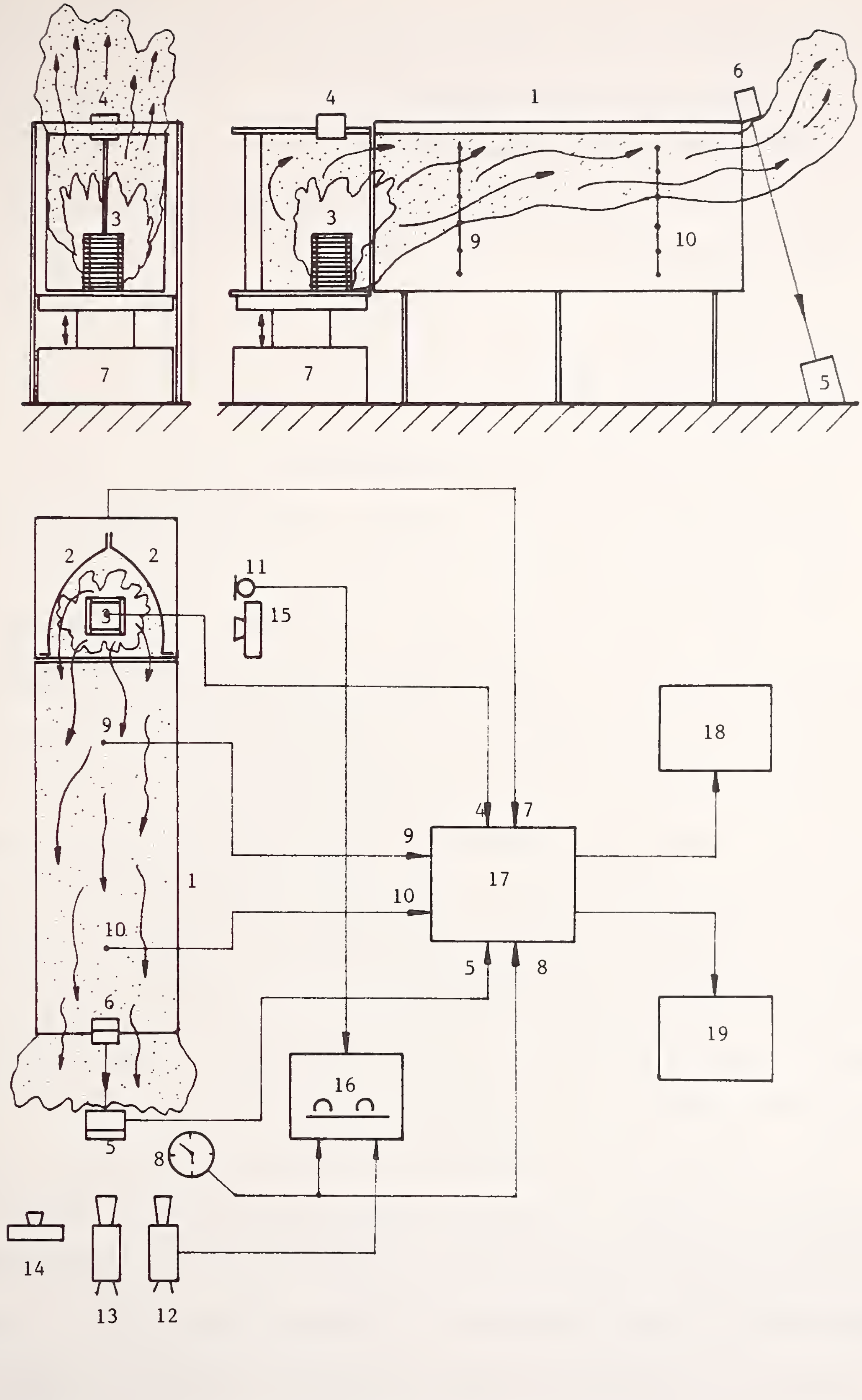


FIGURE 6-2. BR SIMULATED CORRIDOR FIRE TEST CONDUCTED AT FRS.E

8 - clock,

9 - first set of thermocouples,

10 - second set of thermocouples,

11 - microphone to record any sounds that may be produced,

12 - video camera,

13 - movie camera,

14/15 - high quality cameras,

16 - video recorder,

17 - recording and control microcomputer,

18 - printer, and

19 - advanced multichannel x-y plotter.

Two sets of samples were prepared. The first set consisted of six different formulations (doubled) of fiber-glass-reinforced polyester laminates using three different surface coating systems. One was of the same type as that used in the interior corridor wall lining of the Taunton vehicle and the others were of the type currently used by BR for other vehicle applications (HST driver's cabin, MK IIa intercity coach door, seat shells, etc.). The second set of doubled samples was prepared from two different types of fiber-glass-reinforced phenolic laminates with two different surface coating systems. The phenolic resins used in the preparation of the samples were of the latest design, supplied by the French Company CdF Chimie.

The purpose of testing the phenolic laminates was to verify findings both in the literature and in some preliminary tests sponsored by the Simca-Matra Automobile Company and conducted by the Laboratory for Industrial Hygiene in Nancy, France. These preliminary tests suggested lower levels of smoke emission and toxicity of combustion products in phenolic laminates as compared to polyester laminates.

Samples have also been prepared using polyester and phenolic laminates and all surface coating systems. These were used for testing the surface spread of flame, the oxygen index, and mechanical properties. Some of the results of this study have already published (reference 1). On the basis of these tests, all laminates have been classified as at least class 1 materials in accordance with BS 476 Part 7.

In the corridor fire tests, the standard source of fire was always located in such proximity to the samples that the maximal irradiation of sample surfaces averaged 50 kW/m^2. This value was calculated by FRS.E specialists on the basis of data from the Taunton incident. The doubled sample represented corridor wall moldings located in the vicinity of the lavatory. They were equal in mass and similar in shape to these moldings.

The polyester laminate results shocked all who were involved in the testing procedure, including FRS.E personnel who are accustomed to full-scale fire testing of buildings. It was found that in just 5 to 8 minutes a flashover occurs on all samples. Pictures taken during testing are presented in Figure 6-3. It was also found that in the case of polyester laminates an enormous amount of dense smoke was generated. Although the tests were conducted in a large building, a former movie studio with a ceiling height of 150 feet and a fully retractable roof, it was impossible for the test crew to remain inside for more than 15 minutes without gas masks after fire tests with polyester laminates had commenced.

On the other hand, it was found that the phenolic laminates do not generate significant amounts of smoke (reference 2). On the basis of these findings, a new generation of phenolic laminating resins was developed by the aforementioned French company. A production technique for vehicle doors using these resins has also been developed.

Phenolic laminate (foreground) and polyester laminate samples used for BR corridor fire test.

Emission of dense smoke during polyester laminate test.

No emission of smoke was found during phenolic laminate test.

FIGURE 6-3. SCENES FROM THE BR CORRIDOR TEST

The latest and most advanced generation of the Norsophen resins presents excellent overall fire performance (for instance, its oxygen index - 7.90 percent - is close to that of metals). Because of this, the resins have been approved for application in civil aircraft (FAA Part 25), the Paris Rapid Transit System (RATP), SNCF, Merchant Marines (IMCO), and construction. They are also used as ceiling and wall linings in San Francisco Bay Rapid Transit's (BART) C-vehicles, which will be supplied in the next few years by the French company Alsthome Atlantique. The results of fire performance tests of these materials conducted by the French Building Institute (CSTB) and the Warrington Research Center in England are given in brief in the following table.

TABLE 6-1. FIRE PERFORMANCE OF NORSOPHEN PHENOLIC RESIN-BASED SHEET MOLDING COMPOUNDS

TEST	CHARACTERISTIC	CLASSIFICATION
French "Epiradiateur" Test	Class	M1
BS 476 Part 7	Surface spread of Flame - Class	1
W. German Test DIN 4102	Ignitability - Class	1
Oxygen Limit Index Test NFT51071	Oxygen Content	7.90%
ISO R 1210	Class	1
Opacity of Fumes (NBS Smoke Chamber Test)	Time for D^{S}	3 min 5 sec
	Time for Dmax	20 min
	Dmax corrected	69
	Dm c/g	1.4

The following year British Petroleum (BP) Laboratories developed similar products. The BP resins are now commercially available under the trade name "Cellobond" and are used by BR in the production of several glass-fiber-reinforced items for passenger vehicles.

6.3 POLISH STATE RAILWAY (PKP) ELECTRIC COMPONENT FAILURE TEST

One of the heritages of Poland's railway system is the existence of three overhead catenary dc voltages (750 volts, 1500 volts and 3000 volts dc), each located in a different part of the country. All intercity rail vehicles must be equipped with a heating system capable of operating when voltage is being changed between the different zones. This is accomplished by means of a fully electronic and automatic control box (ACB) located under the vehicle body. The dc current from the ACB supplies individual heaters located in compartments. Circuits are equiped with fuses and a thermal barrier has been built between the seats and heaters. The question arose, however, whether a seat could ignite when the ACB or its fuses are out of order, or when there is an accumulation of paper rubbish between the heater and the seat. This possibility was supported by some 15 fire incidents which otherwise proved difficult to explain. To verify this, a series of tests was conducted. A schematic diagram of these tests is provided in Figure 6-4. It has been found in some rare cases that the ignition of seats, paper rubbish or both could occur due to a slow reaction time in about 5 percent of the fuses. It was also observed that in the case of some foamed cushion materials, auto-ignition occurred not during tests but some hours later. This was attributed to a semiglow state caused by overheating, and to the resulting heat accumulation in foamed material of poor thermal conductivity.

On the basis of this investigation the fuses were improved, the heater construction changed, and the ACB redesigned.

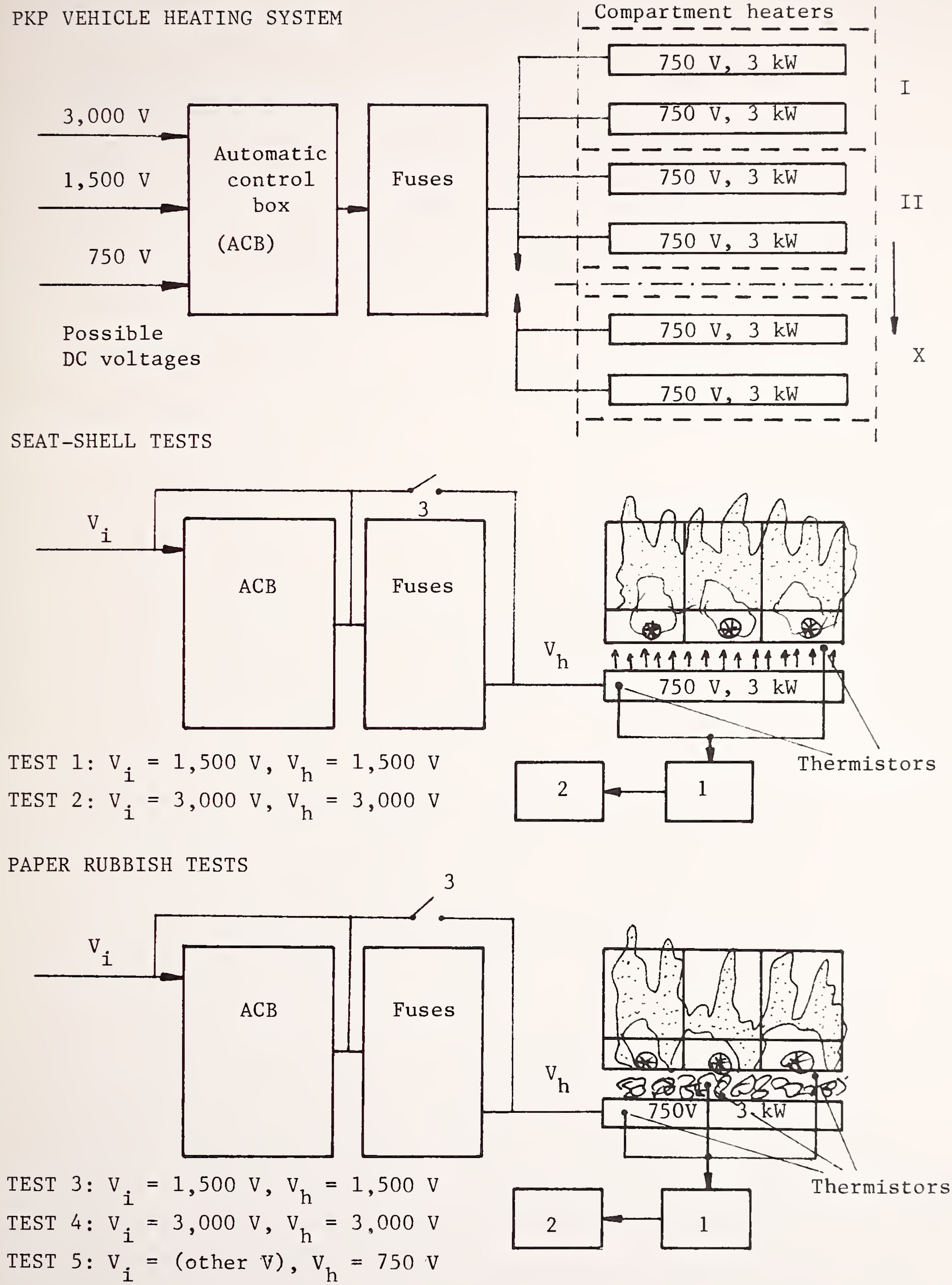


FIGURE 6-4. PKP FIRE SCENARIO TESTS

7. FULL-SCALE FIRE TESTS

7.1 BRITISH RAILWAYS (BR) TEST FACILITY

The experience gained from the corridor fire tests described in section 6.2 has led BR to develop the full-scale fire testing facility shown in Figure 7-1. This figure uses the following code to designate facility components:

1 - platform,

2 - movable platform,

3 - vehicle access track,

4 - concrete wall,

5 - stairs,

6 - watch window,

7 - constant humidity storeroom for samples and standard sources of fire,

8 - general control and record booth,

9 - fresh air inlet,

10 - service door,

11 - movable noninflammable wall equipped with an observation window,

12 - control and record box,

13 - tested structural item (e.g., a seat),

14 - test wall or ceiling,

15 - heaters,

16 - parallel service and emergency track.

The "Phoenix" fire test vehicle shown in Figure 7-2 possesses real potential as a fire test facility. Aside from stationary tests, the "Phoenix" vehicle can be used for tunnel tests and in-track fire research. The smoke stratification unit shown in Figure 7-3 is used for toxicity, smoke and temperature distribution measurements. In 1983-84 numerous tests were conducted

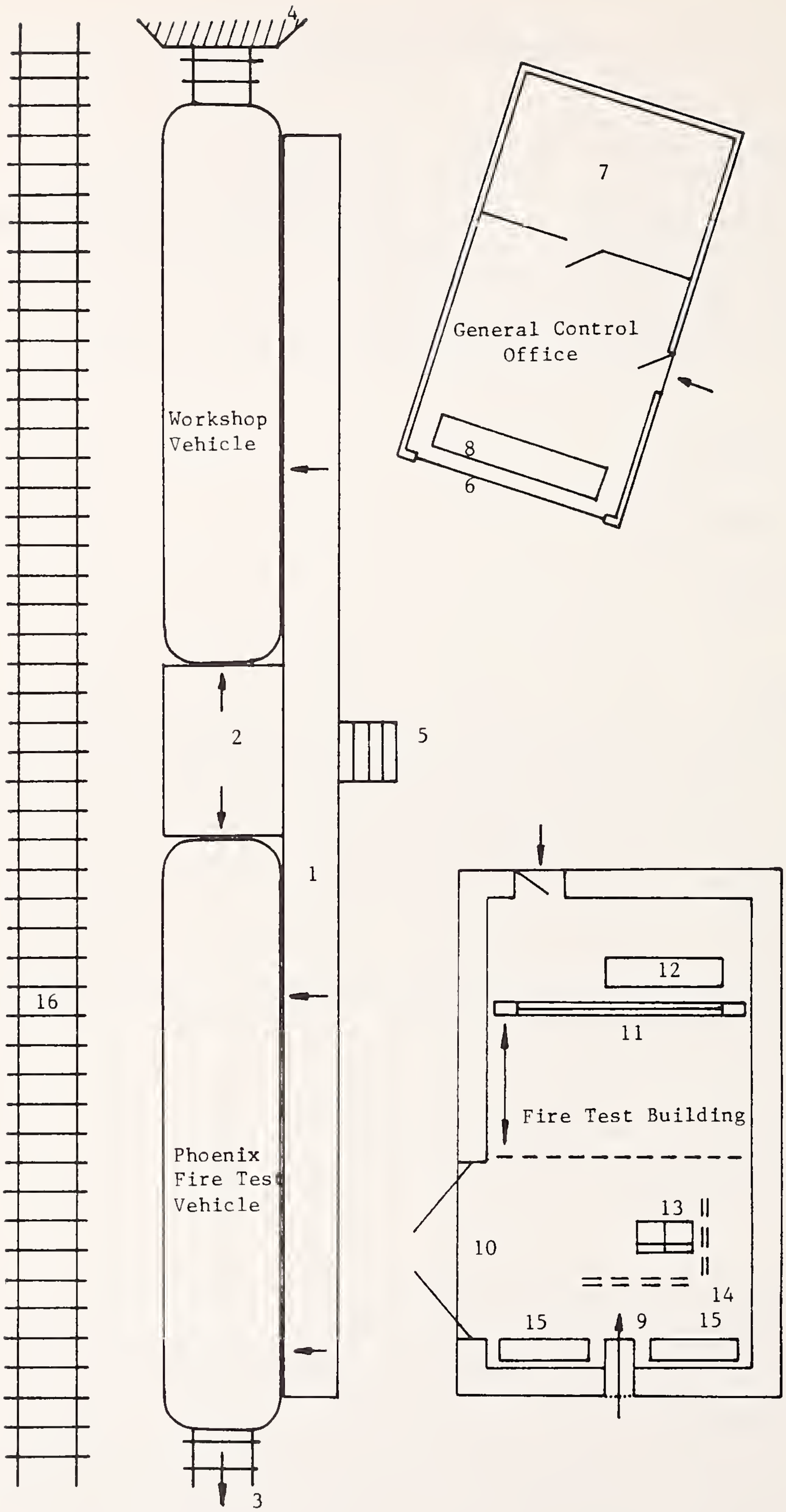
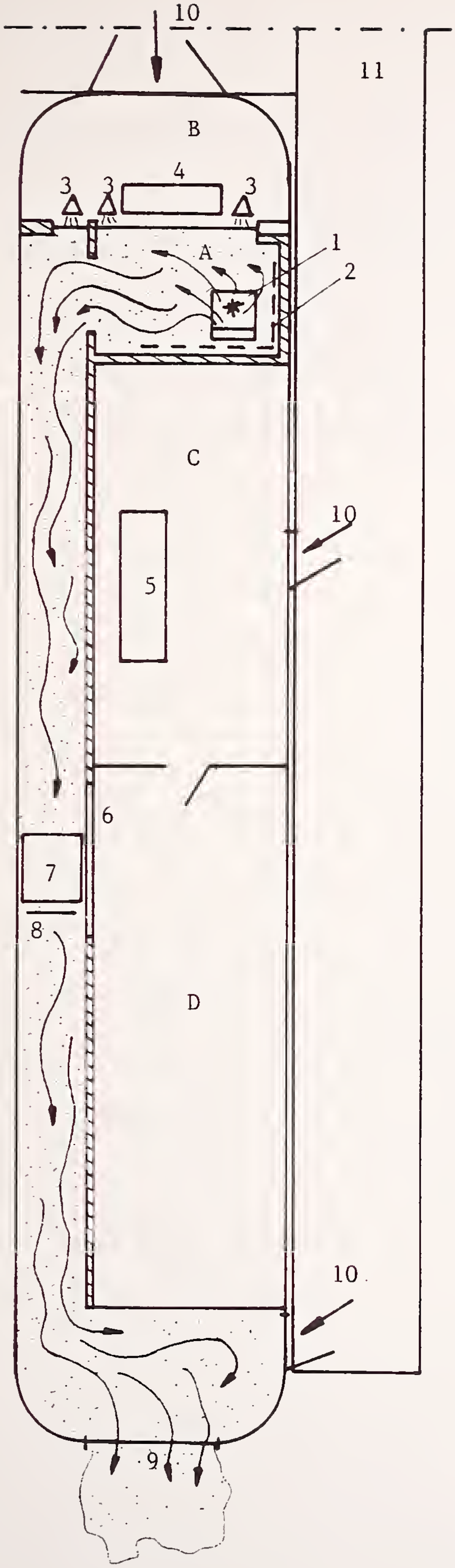


FIGURE 7-1. GENERAL VIEW OF THE BR FIRE TESTING FACILITY



A - Test compartment

B - Crew room

C - Recording equipment storage room

D - Crew lounge

1 - tested structural item

2 - tested wall or ceiling

3 - high power lamps

4 - recording and control box

5 - general recording facility

6 - corridor observation window

7 - smoke stratification unit

8 - thermocouples

9 - smoke outlet

10 - service door

11 - platform

FIGURE 7-2. DETAILS OF THE BR "PHOENIX" FIRE TEST VEHICLE

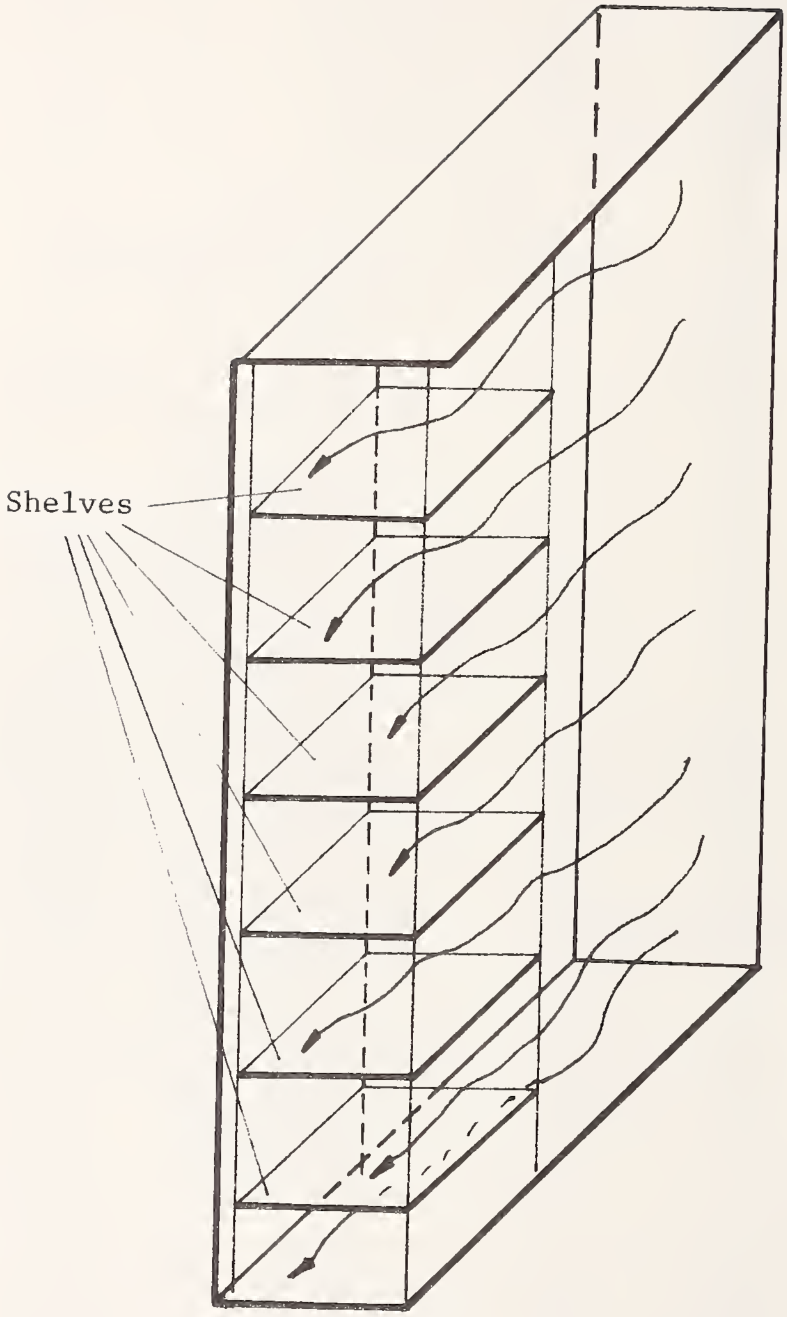


FIGURE 7-3. "PHOENIX" SMOKE STRATIFICATION UNIT

by BR at the facility. A final report is in the process of completion.

7.2 POLISH STATE RAILWAYS (PKP) CURTAIN IGNITION TEST

Although PKP full-scale testing began in 1975, it was limited to the collection of data during the burning of old vehicles provided for scrap. A 1982 case involving arson on intercity coaches, however, afforded an excellent opportunity to perform the full-scale test shown in Figure 7-4. The numbered items here correspond to the following components:

1 - folded curtain,

2 - unfolded curtain,

3 - water sprinkler,

4 - water tank car,

5 - clocks,

6 - video cameras,

7 - cameras,

8 - thermocouples,

9 - optical pyrometer,

10 - video recorders,

11 - digital multimeters,

12 - printers,

13 - wind direction indicator,

14 - wind speed meter, and

15 - central control box.

The textile material currently used for the curtains - which had been chosen on the basis of fire-resistance tests - was found to be difficult to ignite when unfolded. When folded, however, it could be ignited with a certain amount of effort, producing fires which in each case developed quickly.

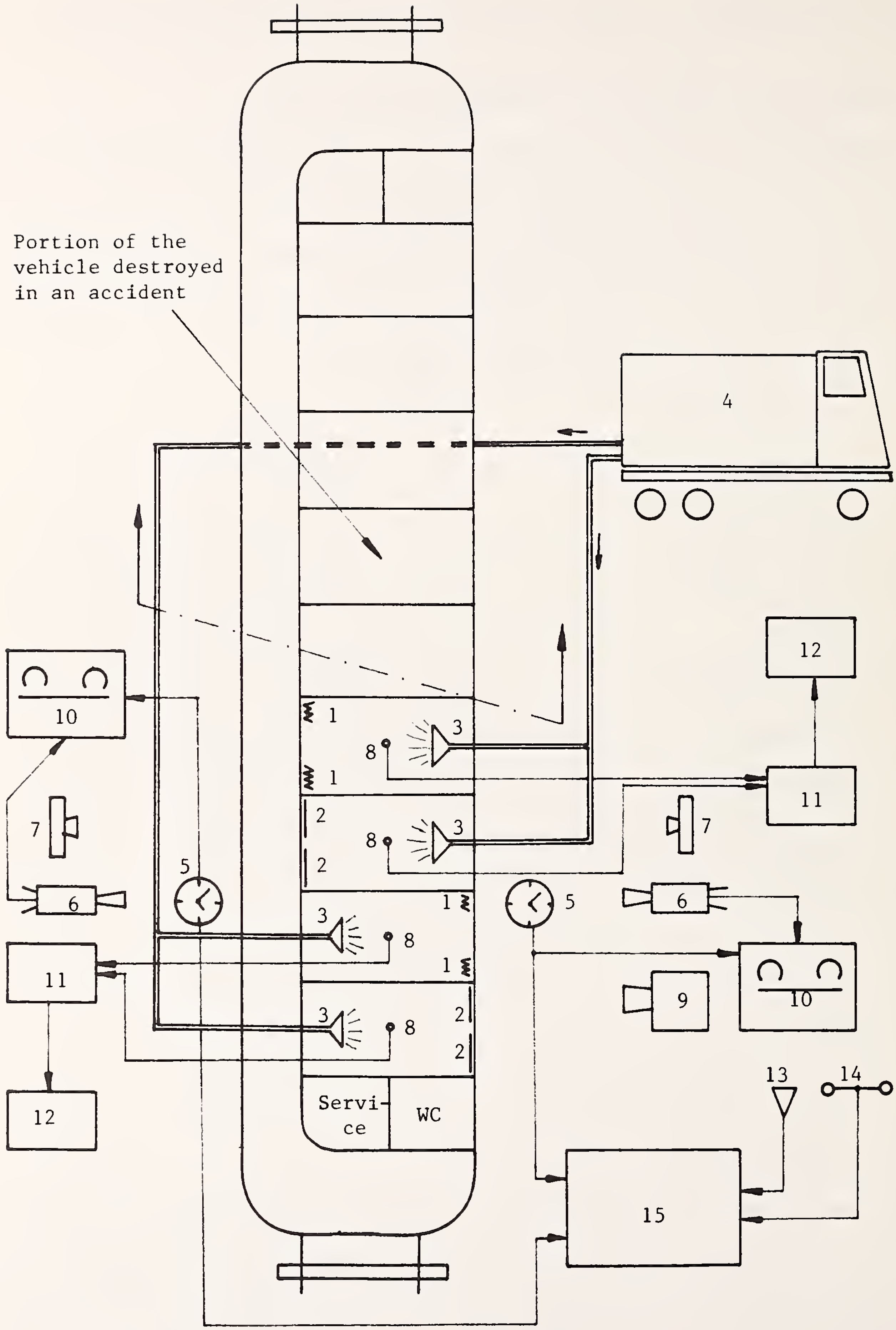


FIGURE 7-4. PKP CURTAIN IGNITION TEST (CONDUCTED WITH CNOBP)

7.3 EVACUATION OF PASSENGERS

West German Railways (DB) is quite concerned about passenger evacuation time. Some preliminary tests conducted in 1983 gave the following general indications of emergency egress time:

TABLE 7-1. PASSENGER EVACUATION TIMES

Type of train	In tunnel		In track
	without braking; exit at a station in tunnel	with emergency braking in the middle of a tunnel	
Intercity train	15 minutes	130 minutes	5 minutes
Commuter train	10 minutes	75 minutes	5 minutes

Based on these findings DB is considering the development of procedures and equipment which would prevent a train from stopping in a tunnel in the case of fire, even if an emergency brake handle is pulled by a passenger.

BR is considering the use of professional actors to simulate passenger behavior in the event of vehicle fires. The tests would include the evacuation of elderly and handicaped passengers, incidents of panic, night fire conditions, etc.

SNCF completed its passenger egress tests in 1983. The purpose of these tests was to measure the time it takes passengers to leave a vehicle at an underground station at peak hours. The results vary from 2 to 5 minutes. The principle of these tests was strongly criticized however by all members of the ORE Working Group in May 1984 for its lack of correlation to real fire emergency or panic conditions. One example can be cited in this connection. A time estimate made by SNCF research laboratories for passenger egress from a certain bus of French manufacture was 2 minutes. In 1982, however, 15 people died in Poland in a fire on a bus of this type, either struck down by other, panicking passengers or unable to leap over emergency exit windows due to physical limitations. On the basis of calculations made by the Fire Science and Research Center of Poland, it can be assumed that lethal conditions in that incident were only reached after 15 minutes.

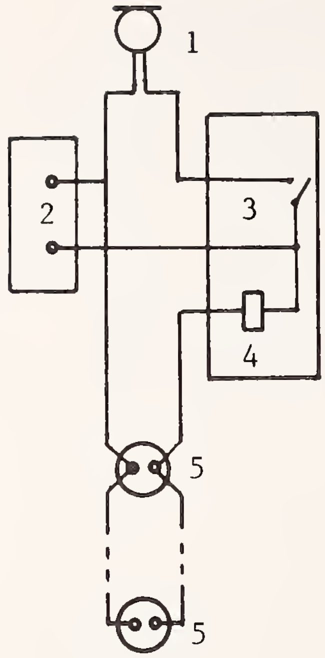
8. FIRE DETECTION AND RESCUE

8.1 EAST GERMAN STATE RAILWAYS (DR) FIRE DETECTION SYSTEM

DR is interested in different fire detection and alarm systems. It designed the simple alarm device for sleeping cars shown in Figure 22. A series of tests has been conducted to find out where in the train compartment fire detectors should be installed. The testing procedure was simple: A certain amount of alcohol or a piece of wood was ignited in a fully furnished compartment and detection time was measured. It was found unexpectedly that standard thermostats already installed in the compartments could play the role of additional fire detectors. Some measurements of the temperature increase in vehicle compartments are given in Figures 8-2 and 8-3. On the basis of these investigations, a fire detection system was developed as shown in Figure 8-4.

8.2 POLISH STATE RAILWAYS (PKP) FIRE BRIGADE TRAINING

The great majority of local fire brigades called upon to respond to a transit fire emergency are doing so for the first time. Thus, no special emergency plan or techniques applicable to fighting fires on rail vehicles have been established. In order to provide an arena for hands-on experience and to promote the development of specific rescue guidelines, a damaged commuter vehicle was adapted for training and research purposes (Figure 8-5). This was also seen as an opportunity to establish a permanent training facility for PKP fire personnel. Firemen from different cities were divided into five groups, each assigned to a different task. Groups 1 and 2 simulated a tunnel rescue. Group 3 simulated station-platform and off-station rescue through vehicle doors. Group 4a simulated an off-station rescue without access to the inside of the



1 - speaker

2 - vehicle battery

3 - relay on/off switch

4 - amplifier

5 - ionized gas detector

FIGURE 8-1. DR FIRE ALARM DEVICE FOR SLEEPING CARS

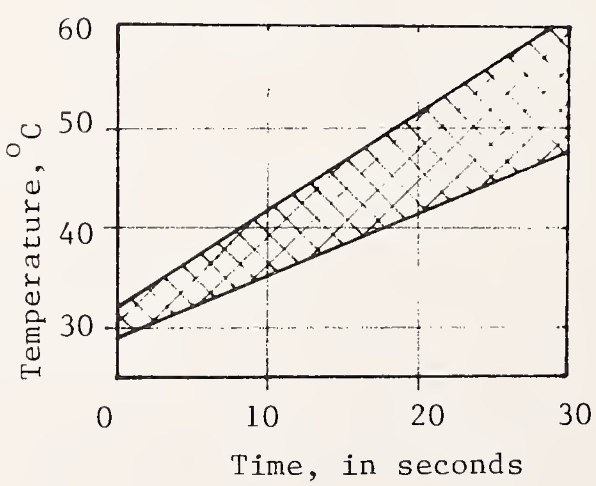


FIGURE 8-2. COMPARTMENT TEMPERATURE INCREASE WHILE BURNING 50 CCM OF ALCOHOL

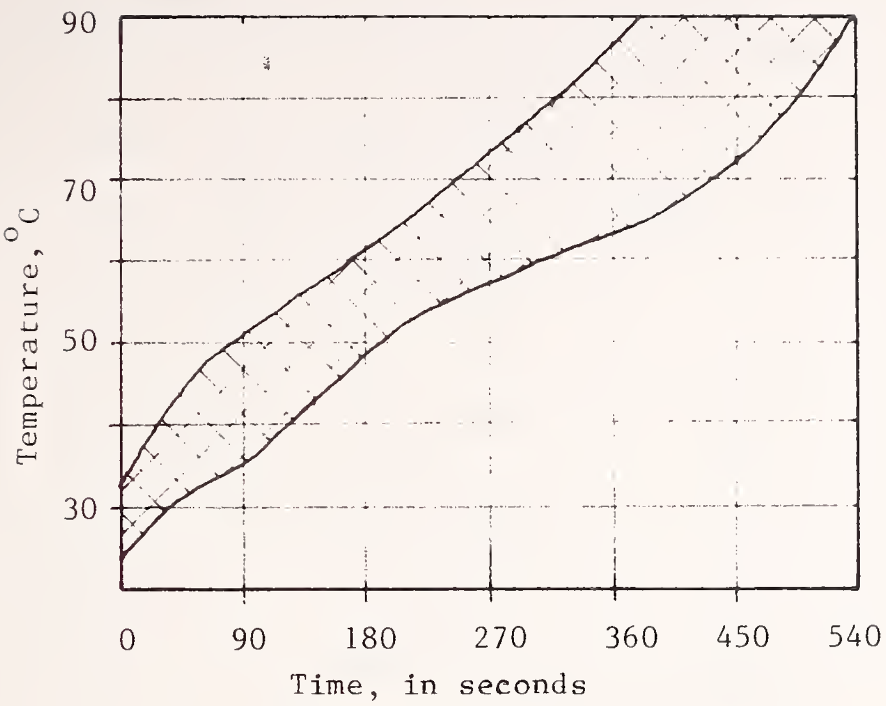


FIGURE 8-3. COMPARTMENT TEMPERATURE INCREASE WHILE BURNING A PIECE OF WOOD

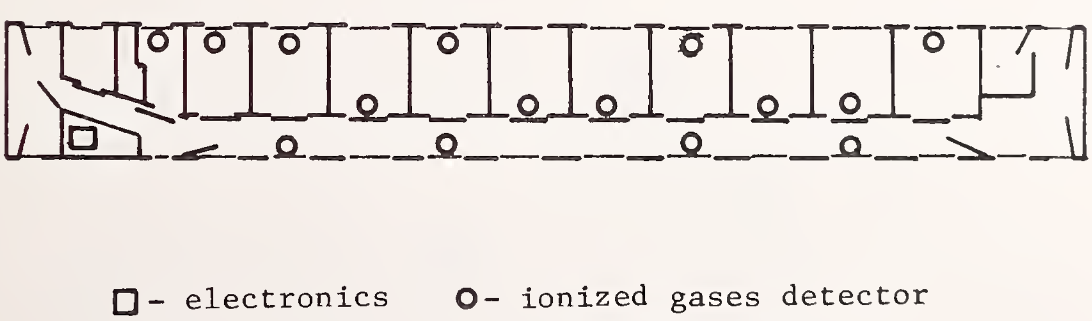


FIGURE 8-4. DR FIRE DETECTION SYSTEM FOR SLEEPING CARS

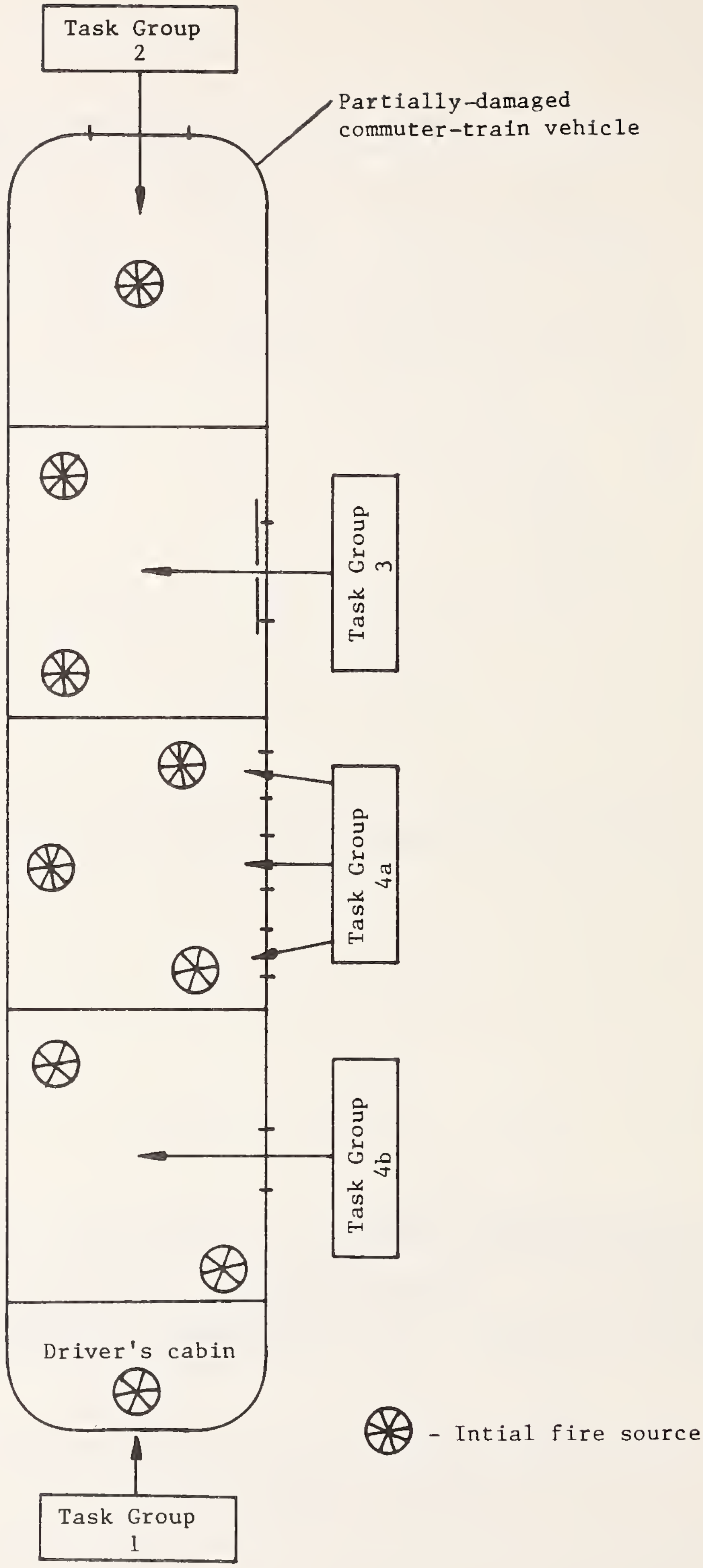


FIGURE 8-5. FIRE BRIGADE TRAINING AND RESEARCH AT PKP

vehicle, and group 4b simulated an off-station rescue with access through windows. Each group performed at least twice, using different extinguishing equipment. Rescues did not begin until the fires were fully developed. The vehicle was refurnished following each action.

It was found that existing rescue tactics were not sufficient. For example, standard water nozzles proved ineffective and in some cases even intensified the fire. Rescue action through windows was also found to be ineffective because smoke issuing from the windows prevented firefighters from directing extinguishing solutions to the necessary points. The most efficient technique for putting out vehicle fires involved firemen wearing respiration masks and light fire resistant clothing entering the vehicle through the door. The fireman in front was equipped with a hose nozzle spraying a full 180° jet which produced a shield of water protecting firefighters from excessive heat.

9. OTHER ACTIVITIES

In September 1983, Poland's first national Scientific and Technical Conference was held on "Problems of Rolling Stock Protection Against Fire." Twelve reports were presented. The next conference on this subject is expected to be held in 1986, with international participation.

In October 1983 a group of Bulgarian State Railways (BDZ) engineers visited the PKP fire laboratory in Warsaw to learn about fire testing methods, procedures, and requirements, etc. At the same time, a joint research project on small fires was conducted. This provided useful experience in close bilateral cooperation, and good working and personal relations were established.

10. FURTHER DEVELOPMENTAL TRENDS

10.1 FIRE LOAD FORMULA

To be effective, a fire prevention program cannot be based solely on the analysis of material properties or the measurement of smoke and toxicity of combustion products. Some structural requirements for railway vehicles must also be considered. For this purpose the following formula has been developed:

$$Q_p = \frac{1}{S} \sum_{i=1}^{n} k_i \, m_i \, Q_i$$

where

Q_p = vehicle fire load (MJ/m^2),

S = vehicle floor surface area (m^2),

k_i = dimensionless coefficient related to the placement of an "i" material in the vehicle,

m_i = mass of an "i" material in that placement (in kilograms),

Q_i = the calorific value of an "i" material (MJ/kg), and

n = total number of different materials in the vehicle.

The application of the dimensionless coefficient k_i is based on practical observation. In real fire situations, even fire-resistant plastics and other combustible synthetic materials used for ceiling and wall linings can contribute to the rapid spread of fire in the vehicle, while materials relatively susceptible to ignition used for flooring applications do not burn at all.

Research is being carried out to estimate values of k_i coefficients for all possible material applications in transit vehicles. Although this study is still in progress, the following values will probably be adopted:

TABLE 10-1. k_i VALUES FOR SOME MATERIAL APPLICATIONS

Application	k_i
Ceiling	1.5
Wall lining	1.2
Seat	1.0
Floor	0.25

According to the author's data, the fire load (Q_p) for a typical European transit vehicle calculated from the above formula ranges from 1,000 to 1,800 MJ/m^2, depending on vehicle type and manufacturer. These values are extremely high. For example, building regulations in France allow the use of combustible materials whose Q_p value, if calculated from the above formula, would be approximately as follows:

TABLE 10-2. ALLOWABLE Q_p VALUES OF BUILDING MATERIALS - FRANCE

Building application	Q_p (MJ/m^2)
External wall lining	25
Structural materials	230
Furniture	400
Total	655

As compared to these estimates, the estimated fire load of transit vehicles is from 130 percent to 280 percent greater.

10.2 SEAT IMPROVEMENT

The SNCF fire laboratory in Levallois-Perret outside of Paris is investigating the possibilities for further improvement of seat fire resistance by means of an elastic fire screen inserted between the textile upholstery and the synthetic foam cushion. The most promising material for this purpose seems to be a textile made of fiberglass completely covered with a PVC coating containing a special fire retardant additive and a latent foaming agent. This textile is resistant to mechanical damage and, due to glass-fiber reinforcement, is difficult to cut even with a knife-blade. When the upholstery textile catches fire, the released heat plasticizes the PVC coating and decomposes the foaming agent, producing a thin sponge-like layer. Further heat release cures and carbonizes the layer to produce a rigid, glass-fiber-reinforced, highly fire-resistant foam. The foam protects the cushion from fire and excessive heat, due to its low thermal conductivity.

The tests have not yet been completed, and some problems exist with the chemical composition of the PVC coating. However, SNCF expects to overcome these obstacles and predicts that its seats using the screen described above will be the best fire- and vandal-proof seats available in Europe in the coming years.

BR is also concentrating its research efforts on seats. Based on the phenolic resins described in section 6.2, a new construction of passenger seat shell is under development.

10.3 FIRE BARRIER EVALUATION

BR is considering using the method from BS 476 Part 8, developed for building applications, to test transit vehicle fire barriers. The method includes the evaluation of the stability, integrity and insulating properties of a barrier during 30 minutes in standard fire conditions. A similar test is being developed by DR.

PKP is considering the use of naval, Lloyd-approved standards for fire barrier testing.

10.4 BATTERY EXPLOSION TEST

In some cases, an electrical failure on a passenger vehicle or Diesel locomotive can produce an explosion in a battery box. This is due to overcharging of the battery which results in the rapid generation of hydrogen and oxygen. If not quickly dispersed, these gases can form an explosive mixture. Arrangements have been made by PKP to study this phenomenon in 1985.

11. CONCLUSIONS

In light of the foregoing summary of current European railway fire safety research it can be concluded that a considerable amount of practical experience has been gained. The resulting modifications in materials and structural items have by and large been successful in limiting ignition from common fire sources. Less successful has been the attempt to impede the spread of fully developed fires and prevent flashover. This issue has become increasingly important in view of the rapid rise in the number of fires due to vandalism at all the major railway systems of Europe. Progress in this area depends on the development of scientific theories dealing with fire spread in the rail vehicle interior.

REFERENCES

1. A. Kaminski, "Interlaminar Shear Properties of Some Glass-Fiber-Reinforced Phenolic and Polyester Laminates," J. Applied Polymer Sci. 27 (1982).

2. A. Kaminski, "Evaluation of Glass-Fiber-Reinforced Phenolic Resins for the Production of Items for Railway Rolling Stock," Technical Memorandum for the British Railways Board, Derby, U.K., 1981, TM PDU 90.

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