



INSTRUCTION DE SÉCURITÉ SAFETY INSTRUCTION

Mandatory as defined in SAPOCO/42

IS41
Rev. 1

Issued by: SC-GS

Date of revision: November 2005

Original: English

The Use of Plastic* and other Non-Metallic Materials at CERN with respect to Fire Safety and Radiation Resistance

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* The word 'plastic', as used in this document, means all thermosetting and thermoplastic polymers and elastomers. These terms are defined in the Glossary (Annex 3).

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1 Introduction

This Safety Instruction is published by the Safety Commission under the procedure set out in the CERN Safety Policy document SAPOCO 42 and in application of the CERN Staff Rules and Regulations. It updates and replaces Safety Note No. 11 and is based on:

- The CERN Fire Code E
- Standards and publications of the IEC and other nationally and internationally recognized bodies
- The CERN Safety Instruction No. 23 (Criteria for the selection of electrical cables)
- Recommendations of the inter-divisional Materials and Cable Working Group on fire and radiation resistant properties

It is complemented by Annex 1 ‘Guidelines for the Use of Plastics at CERN: Fire Considerations’, Annex 2 ‘Trade Names and Abbreviations’, Annex 3 ‘Glossary of Terms’ and Annex 4 ‘Standards’. These Annexes are intended to help the user make a choice of suitable materials while avoiding those which are prohibited.

N.B. These annexes will be updated as necessary.

This Instruction is intended to ensure a very high level of safety and must be applied to all new installations at CERN, including modifications to existing installations. CERN attaches great importance to the hazards associated with the density, toxicity and corrosiveness of smoke from burning plastics.

2 General Considerations

The use of plastics has increased enormously over the last 50 years, not only for consumer goods (e.g. furniture, wall and floor coverings etc.), but also for industrial goods (e.g. cable insulation, tubes, conduits, insulating materials, structural components etc.). The increase in the use of such materials has been accompanied by a marked increase in the severity of fires, and particularly in the number of deaths and the amount of material damage caused by the density, toxicity, and corrosiveness of the smoke produced.

CERN has experienced a number of fires in which severe material damage has been caused, particularly by the hydrochloric acid resulting from PVC insulated cables. Many fires have occurred in industrial installations throughout the world where the principal damage has been the corrosion from the acidic fire gases.

As accelerator tunnels have become longer and deeper and escape routes more complicated, personnel may be exposed to smoke from a fire for considerably longer periods than in surface installations, and therefore every effort must be made to use

materials which do not burn easily and evolve smoke of low optical density, low corrosiveness, and low toxicity.

It is evident that, while the safety aspects of the material must be acceptable, it must also be mechanically and chemically suitable, be resistant to the environment in which it will be installed (e.g. ionizing radiation), be available in sufficient quantities and at a price that makes it economically acceptable.

3 Scope

The scope of this Safety Instruction is to give criteria for the choice of plastics for use at CERN, taking into account their overall fire performance including the optical density, corrosiveness and toxicity of the smoke evolved, and also their radiation resistance.

This Instruction applies to all equipment or installations consisting of or containing substantial amounts of plastics. It is of particular importance in experimental areas and all underground areas. It does not apply to small parts (such as knobs, handles, rollers, gaskets, fasteners, clips, grommets, rub strips, pulleys or small electrical parts) which would not contribute significantly to smoke, toxic, or corrosive gas emissions. Reference should also be made to the CERN Safety Code E, 'Fire Protection', Appendix IV, 'Safety standards for furniture and other contents of rooms and buildings', for all such items.

4 The Problem

All plastics, and indeed all substances containing carbon (including wood, wool and other natural materials), give off carbon monoxide (CO) when involved in a fire. It has been shown that inhalation of this gas is the primary cause of death in fires. Halogenated plastics, such as PVC, polychloroprene (Neoprene®) and PTFE (Teflon®), as well as producing CO, give off irritating, thick, acidic and often highly narcotic smoke which can cause persons caught up in a fire to be exposed to concentrations of CO for longer than might be the case with less narcotic smoke, and in fact long enough to be killed. Halogenated fire retardants used to improve the fire resistance of some plastics such as polyethylene and polypropylene confer to the latter similar, undesirable properties.

Other, halogen-free, plastics which have been shown to produce thick, toxic, and corrosive smoke are acrylonitriles, acrylonitrile-butadiene-styrene (ABS) copolymers, and polyurethanes, especially foams based on the latter. Plastics containing organo-phosphorus compounds as flame retardants can also be problematical in that corrosive phosphoric acid is evolved in addition to the unchanged fire retardant which may itself be toxic.

Sulphur may also be present in plastics either as a component in the monomer (e.g. polyether sulphones and polyphenylene sulphide) or as a curing or vulcanizing agent. In a fire the smoke will contain sulphur dioxide and sulphur trioxide, gases which, as well as being toxic and highly irritating, condense on cold surfaces, with water vapour, to form the highly corrosive sulphurous and sulphuric acids.

5 Required Properties of Plastics and other Non-Metallic Materials

The requirements for all plastics and other non-metallic materials are:

- Mechanical, chemical, thermal and environmental resistance properties suitable for the desired application, and conforming to the appropriate standards;
- Satisfactory fire performance (ease of ignition, rate of flame spread, rate of heat release, etc.) to specified standards;
- Free from halogens and sulphur;
- Low smoke density of fire gases;
- Low toxicity of fire gases;
- Low corrosiveness of fire gases;
- Adequate radiation resistance.

It should be noted that the requirements of this Safety Instruction proscribe the use of many plastics. These include polyvinyl chloride (PVC), chlorosulphonated polyethylene (Hypalon®), polychloroprene (Neoprene®), fluorinated plastics (Teflon®), and plastics which contain halogenated fire retardants. It also proscribes natural and synthetic rubbers containing sulphur as the curing agent.

6 Criteria for the Specification and Selection of Plastics and other Non-Metallic Materials

6.1 Applicable Standards

Wherever possible, internationally accepted standards shall be used. Where these are not available, national standards may be used but this raises the problem of the equivalence of standards and, where there is conflict in the interpretation, SC will be the final arbiter. The standards are described in this section and are summarized in Table 1. A list of independent laboratories capable of carrying out the specified tests is given in Table 2.

6.2 Fire Performance

6.2.1 *Classification of the fire performance of building materials, elements and components*

The classification of the fire performance of building materials and components differs in each country. Although national ‘fire philosophies’ differ from one another in certain respects, they are based on the same concepts. Building materials are usually divided into four levels of fire contribution:

- Minimal
- Low
- Normal
- High

Minimal (meaning none or very low) contribution to fire of building materials is usually determined, in the different countries, by a combustibility test based on International Standards. The ‘minimal contribution to fire’ is subdivided in some countries such as Germany and Switzerland to enable totally inorganic building materials to be differentiated from those with low (usually < 1%) organic content such as mineral fibre panels containing binders.

The classifications ‘low’, ‘normal’, and ‘high’ contribution to fire of a building material are a measure of its behaviour in an initiating fire. Materials which make a low contribution to initiating a fire usually start to participate at a later stage of the fire. Those that make a normal contribution resist medium- and low-intensity ignition sources for a short time (of the order of minutes) and those which make a high contribution are set on fire by practically any ignition source and are therefore not permitted to be used as building materials. Many national classification systems contain intermediate classes in order to be able to differentiate materials more clearly.

Table 3 gives the classification of the fire performance of building materials in national building regulations in terms of the four levels of fire contribution outlined above, but it should be understood that strict comparisons are impossible and that the original standards should be consulted before any choice is made.

It should be noted that the words used have no meaning unless they are accompanied by a classification by a specific test, such as ‘low fire contribution, German classification B1’. **A material should never be accepted on the basis of a description without a classification to an accepted standard.**

Only building materials with ‘minimal’ and ‘low’ levels of fire contribution, as given in Table 3, will be accepted (see also the CERN Safety Code E—Fire Protection).

6.2.2 *Classification of the fire performance of plastics for general purposes including particle detectors and ancillary equipment*

The use of plastics for the construction of particle detectors has increased enormously owing to the desirable properties of these materials, for instance ease of construction, relatively low cost and high strength/weight ratio. For an initial study of possible materials, the IEC 60695-11-10 or UL 94V tests are very useful and can be carried out at CERN. Moreover specific tests according to the form of the material (e.g. tube, sheet etc.) can be performed or can be taken into consideration. Finished items can be tested by the needle-flame test, IEC 60695-2-2.

6.3 **Smoke Density**

Samples of materials proposed for buildings and experimental installations shall be tested according to ASTM E 662 or ISO 5659-2. The value of the specific optical density, D_s , shall not exceed 250 in both the flaming and non-flaming modes.

Where very large quantities of particular materials, or mixtures of materials, are to be used, the Safety Commission may demand that the smoke density be evaluated by other, larger scale, tests for instance by adapting the IEC 61034 large-scale smoke emission test for cables.

6.4 **Toxicity of Fire Gases**

The IEC 60695-7 part 50 and 51 shall be applied. The principle of this method is to calculate the fractional effective dose of toxic products accumulated by exposure to the effluent from a fire.

All the results must be analysed with the Gas and Chemistry Section of the CERN Safety Commission.

6.5 **Corrosiveness of Fire Gases**

All plastics must conform to the IEC standard 60754-2, with a pH > 4.3 and a conductivity < 100 $\mu\text{S}/\text{cm}$.

6.6 **Cone Calorimeter Test**

The Cone Calorimeter test, ISO 5660, is at present one of the most advanced methods for assessing the fire behaviour of a material on a relatively large scale. Measurements of the smoke density and toxic gas production can be performed during the test. It also allows the possibility to evaluate the heat release with respect to time and to compare the fire behaviour of different materials by measuring such parameters.

The Gas and Chemistry Section of the CERN Safety Commission can request that this test be performed to evaluate the performance of a material when it is used in large quantities (e.g. tonnage quantities) or when the fire risk is considered significant.

The test conditions must be agreed with the Safety Commission which will issue its conclusions on receipt of the test results.

6.7 Radiation Resistance

The radiation resistance and Radiation Index are assessed according to IEC 60544-4.

This standard recommends as the relevant critical properties:

- for rigid plastics—the flexural stress at maximum load,
- for flexible plastics and elastomers—the percentage elongation at break.

The end-point criterion may be expressed as an absolute value or as a percentage of the initial value, e.g. 50%.

The Radiation Index (RI) is defined as the logarithm ($\log_{10}$) of the absorbed dose in gray (Gy), rounded off to two significant figures, above which the value of the appropriate critical property has reached the end-point criterion under the specified conditions. For example, a material which satisfies a particular end-point at 2×10^4 Gy has a radiation index of 4.3 (i.e. $\log 2 \times 10^4 = 4.301$).

The value of RI will be specified in relation to the application.

The CERN Safety Commission can arrange for radiation tests to be carried out.

7 Procurement of Materials

Materials satisfying the requirements of this Safety Instruction can be obtained for virtually all purposes in the Member States. Technical specifications for items known or suspected to contain plastics should be clearly written to ensure that the delivered product has the required properties. This Instruction, or at least Table 1, should be attached to enquiries where this is thought to be useful.

Exceptions can be authorized only by the Leader of the Safety Commission and only on condition that compensating preventive measures have been studied and agreed.

Table 1: Test Standards and Specifications for the Selection of Plastics

Test	Standards (1)	Requirements
Flame propagation		
a) Needle-flame test	IEC 60695-2-2	Duration of flame application 60 s unless otherwise stated according to Clause 5. Time to extinction: 30 s* Damaged length (mm) must be measured*
b) General flammability test	UL 94V IEC 60695-11-10	94 V0, 94V1
Or flammability test for:		
– plastic film/sheet	ISO 12992	} Results of the test have to be acceptable to SC-GS-GC.
– rubber and plastic hoses	ISO 8030	
– cellular plastics	ISO 9772	
– thermoretractable tube	UL 224 (flame test)	The specimen shall not burn for more than 60 s following any of five 15 s applications of the test flame.
Smoke density	ASTM-E-662 or ISO 5659-2	$D_s < 250$ for flaming and non- flaming modes
Toxicity Toxicity of fire gases	IEC 60695-7 50 and 51	The conditions of the test have to be agreed with SC, and the results must be acceptable to all parties.
Corrosivity Corrosivity of fire gases	IEC 60754-2	pH > 4.3 conductivity < 100 $\mu\text{S/cm}$
Radiation resistance	IEC 60544 Parts 2 and 4	At the specified absorbed dose, rigid plastics must retain 50% of their initial flexural strength, and flexible plastics must retain 50% of their initial elongation at break.

* Full details and numerical values must be supplied by the manufacturer.

(1) **Standards** (Alternative ISO, IEC and other International Standards or National Standards may be considered in agreement with CERN, and should preferably be selected from the survey of test methods listed in IEC 695-3-1 section 5 and Appendix A, or in the IEC Safety Handbook.)

**Table 2: A Selection of Independent Laboratories Capable of Carrying Out
Fire, Smoke or Toxicity Tests**

1.	FRS, BRE Garston Watford WD 259 XX UK Tel: +44 (0) 1923 664982 Fax: +44 (0) 1923 664910 Web: www.bre.co.uk
2.	Warrington Fire Research Centre Holmesfield Road Warrington Cheshire WA1 2DS UK Tel: +44 (0)1925 655 116 Fax: +44 (0)1925 655 419 Web: www.wfrc.co.uk
3.	Laboratoire National d'Essai LNE TRAPPES-ELANCOURT ZA de Trappes-Élancourt 29, avenue Roger Hennequin F-78197 TRAPPES Cedex France Tel: +33 (0)1 30 69 10 00 Fax: +33 (0)1 30 69 12 34 Web: www.lne.fr
4.	Laboratoire Central des Industries Electriques 33, avenue du General Leclerc F-92260 Fontenay-Aux-Roses France Tel: +33 (0)1 40 95 60 60 Fax: +33 (0)1 40 95 60 95 Web: www.lcie.fr
5.	ISSEP 200 rue du Chera B-4000 Liège Belgium Tel: + 32 41 229 83 11 Fax: + 32 41 252 46 65 Web: www.issep.be

6. Kema

Utrechtseweg 310, 6812 AR Arnhem
P.O.Box: 9035, 6800 ET Arnhem
The Netherlands

Tel: +1 7036316912
Fax: +1 7036314119
Web: www.kema.nl

7. VDE

Testing and Certification Institute
Merianstrasse 28
63069 Offenbach
Germany

Tel: + 49 69 83 06 0
Fax: + 49 69 83 08 555
Web: www.vde-institute.com

8. Danish Institute of Fire and Security Technology

Jernholmen 12
DK-2650 Hvidovre
Denmark

Tel: +45 36349000
Fax: +45 36349001
Web: www.dift.dk

Table 3: Classification of Fire Resistance of Building and Structural Materials in Various Countries

(Taken from the ‘Plastics Flammability Handbook, 3rd edition’,
J. Troitzsch, Hanser Publishers, Munich, 2004)

Fire contribution of building material	Minimal	Low	Normal	High
European Union	A1/A2	B/C	D	E/F
Austria	A	B1	B2	B3
Germany	A1/A2	B1	B2	B3
France	M0	M1/M2	M3	M4
United Kingdom	0	1	2/3	4
Italy	0	1	2/3	4/5
Norway	nc*	A20	A30	
The Netherlands	nc*	1	2/3	4/5
Switzerland	VI/VIq	V	IV	III/II/I
Belgium	A0	A1/A2	A3	A4
Spain	M0	M1/M2	M3	M4
Czech Republic	A	B	C1/C2	C3
Sweden	nc*	1	2	
Denmark (1)	nc*	A (1)	B (2)	
United States of America (2)	nc*	A (I)	B (II)/C (III)	

* *nc* = *non combustible*.

(1) Classes 1, 2 for linings.

(2) Classes A, B, C or I, II, III for linings depending on Model Building Code.

Annex 1

Guidelines for the Use of Plastics at CERN: Fire Considerations

1 Introduction

It is impossible to ban certain plastics and unreservedly accept others in any quantity since, although simple, it would be too restrictive in the first case and possibly too dangerous in the other. These guidelines are intended to help users to choose materials which are likely to be acceptable for use at CERN. It is of necessity a brief document and before choosing any material more complete information must be obtained.

The mechanical, electrical, and chemical resistance properties of the materials are not given as these vary considerably with the polymer grade and modifications such as the charge (filler). Information on these topics should be obtained from the supplier. However, the Safety Commission often has a sufficiently large amount of information to enable a preliminary selection to be made. It can also often provide details of various suppliers of the basic materials.

The terms used to indicate the contribution to a fire, 'minimal', 'low', 'normal' and 'high' are defined in Section 6.2.1 of this Safety Instruction.

Information on the radiation resistance of materials can be found in the CERN 'Yellow Reports' 79-08, 82-10, 85-02 and 89-12.

2 Materials

It should be noted that the requirements of this Safety Instruction prohibit the use of many plastics which hitherto have been in general use. These include polyvinyl chloride (PVC), chlorosulphonated polyethylene (Hypalon®), polychloroprene (Neoprene®), fluorinated plastics (Teflon®), and plastics that contain halogenated fire retardants. It also excludes natural and synthetic rubbers containing sulphur as the curing agent.

2.1 Fibre Reinforced Plastics

2.1.1 *Standard polyester systems*

These materials are the most widely used in this class and can be adapted to give 'low' contribution to fire. However, this adaptation may take the form of the addition of antimony oxide and halogen containing fire retarding organic compounds and then the end product will emit dense, toxic and corrosive smoke in a fire situation and is unsuitable for use at CERN. If aluminium hydroxide is used as a fire retarding agent the material will probably give 'low' contribution to a fire and emit

smoke of sufficiently low density, toxicity and corrosiveness to enable widespread use to be envisaged.

The gel coat often used on such material can be a major producer of smoke and fume and thus render its use unacceptable. In cases like this the gel coat should be left off or other coatings applied after moulding.

2.1.2 *Phenolic systems (PF)*

These resins can be adapted to give ‘low’ contribution to fire. Their smoke density emission is lower than the best, aluminium-hydroxide-filled, polyester systems. They generally emit small amounts of toxic and corrosive fume, mainly oxides of sulphur, but the levels are usually low. Polyester gel coatings are often used which can increase the fume emission drastically and therefore these should be avoided. Decorative coating systems have been developed which have satisfactory fire performance.

Phenolics must be fully post cured to achieve the correct fire properties. The curing agent and the manufacturing processes affect the fire performance of the finished material.

2.1.3 *Furan systems*

These resins can be adapted to give ‘low’ contribution to fire. However, the base materials are black and they emit significant quantities of toxic and corrosive gases when involved in a fire and thus are unlikely to be of use at CERN.

2.1.4 *Epoxies (EP)*

Certain epoxies, such as those based on Bisphenol A, emit dense smoke in a fire situation. Novolac-based resins emit less dense smoke but in any case great care should be taken in choosing epoxy systems since halogenated (and in particular brominated) organic compounds are often used as fire retardants, which drastically increase the density, toxicity and corrosiveness of smoke emitted in a fire.

Base materials for the manufacture of printed circuit boards and finished printed circuit boards are now available without the addition of brominated fire retardants. Some of these alternative materials exhibit better fire behaviour (i.e. low smoke, low corrosivity of fire gases) than the standard FR-4 (‘brominated’) materials and should be used in preference whenever possible. A list of suppliers for the alternative non-brominated materials can be had from SC-GS-GC.

2.1.5 *Others*

Other plastics can be reinforced with fibres. The fire properties are similar to the plastic base material, but they have not found such widespread use as the previously mentioned systems. The ‘flowing away’ from a fire of these base materials (thus a type of self-extinguishing behaviour) may not occur with filled grades.

2.2 Coated Metals

2.2.1 *Melamine-coated steel or aluminium*

These resins, and especially the flame retardant grades, can be adapted to give 'low' contribution to fire. The melamine resin normally forms only the top layer of a composite consisting of several layers of phenolic resin. There is virtually no danger of fire spread and when exposed to a strong fire source they char with low smoke development. The fire gases contain ammonia and formaldehyde and smell of burnt milk and fish. The stability of the bond between the melamine and the substrate is of importance, since smoke emission and flame spread can increase dramatically if extensive delamination occurs. They can be used, but each should be tested individually.

It should be noted that aluminium, unlike steel, will not protect materials behind it in a fire to any great extent, because of its low melting point, 660°C, a temperature easily exceeded in most fires. Whatever coating may be used, the applications of coated aluminium should be restricted to those areas where it is not required to give any protection in a fire.

2.2.2 *Bitumen-coated steel*

These materials can burn very easily and produce dense smoke in a fire. They were the major cause of the severity of a fire at a London Underground station some years ago and their use should be prohibited.

2.2.3 *'Thin' coatings*

These are coatings of resins or paints, usually on a steel substrate, where the thickness is measured, at most, in a few hundreds of microns. They are not normally very flammable but in a fire situation surface spread of flame can occur and, depending on the coating material, the smoke density, toxicity and corrosiveness may be unacceptable. Tests should be carried out where there are doubts on the behaviour of the coatings used.

2.2.4 *Plastic/plastic and metal/plastic laminates*

These materials are coming more and more into use, especially in particle detector construction, as they combine light weight with good strength and stiffness. They are normally of three-ply construction with metal or plastic outer ply and a plastic inner layer. The plastic may be in the form of a cast sheet or a honeycomb which is hollow or filled. The metal coating is often aluminium and therefore will give little protection in the event of a significant fire. Sometimes the outer plies are plastic with a metal honeycomb filler. Many combinations are available and some are acceptable for use. In all cases no extensive use of any product should be envisaged until tests have been carried out and have shown satisfactory characteristics.

2.2.5 *Intumescent coatings*

These coatings are systems which act by puffing up to form an insulating layer. Because of this characteristic they are used to protect materials such as wood and plastics which are combustible and those like steel which lose their strength when exposed to high temperatures. The foam is typically some 50 to 100 times as thick as the original intumescent layer resulting in good thermal insulation, thus protecting the substrate from the effects of heat and decomposition. However, there is a very large difference in smoke emission between the best and the worst and some of the systems available commercially evolve toxic and corrosive hydrochloric or phosphoric acids as well as dense smoke. Before specifying the systems, tests should be carried out as a limited number of intumescent paints are now available combining acceptable flame retardance and good intumescent performance with low smoke and toxic fume emission.

2.3 **Wood and Coated Wood**

Wood is included here as it is extensively used in systems which are similar to those using plastics, especially in building components and is often used as part of a composite material in combination with plastics.

2.3.1 *Uncoated wood and soft wood*

Untreated soft wood should not be used in locations where there is a serious fire risk. Plywoods are available which give good resistance to fire but these vary tremendously in smoke and toxic fume emission due to the different glues, fire retardants and wood used. Tests should be carried out before specifying the grade to be used.

2.3.2 *Melamine-coated plywood*

These materials can give adequate fire resistance especially if a fire resistant grade of plywood is used. However, they can be high smoke emitters and tests should be carried out before use.

2.3.3 *Urea-resins-coated plywood*

Urea based resins have been used to replace melamine and the same comments apply.

2.4 **Glazing Materials**

Fire resistant glass is available in several different forms and is by far the best material for use in situations where fire and or radiation are serious problems, and where it is technically suitable.

PVC SHEET MUST NOT BE USED.

2.4.1 *Acrylics*

Standard acrylics, including polymethyl methacrylate (PMMA-Plexiglas®, Perspex® etc.), are highly flammable and thus are unsuitable for general use. The flame retardant types will burn with quite small fire sources and they emit dense and toxic fume in a fire. They should only be considered for small items in insensitive locations.

2.4.2 *Polycarbonates (PC)*

Even standard polycarbonates (e.g. Makrolon®) are considered to be better than flame retardant acrylics. They are high smoke emitters and some fire retardant grades may give even greater smoke and fume emission if the polycarbonate stays in the fire area. Most grades do not drip and tend to melt away from a fire, thus exhibiting a kind of ‘self-extinguishing’ behaviour limiting the spread of fire and reducing the smoke and fume emission. They may be used in some less critical areas where acrylics would not be allowed, but any large scale use should be avoided.

2.4.3 *Polyarylates (PAr)*

These relatively new products have good fire resistance (UL 94 V-0) and a working temperature of up to 300°C. They are said to be susceptible to stress corrosion cracking by hydrocarbon solvents and so their performance in particle detectors where hydrocarbon gases and vapours are present should be carefully checked before specification.

2.5 *Moulding and Extrusions*

PVC MUST NOT BE USED.

2.5.1 *Polyamides (PA)*

Some standard grades (e.g. Nylon®) burn readily exhibiting dripping and should not be used. Flame retardant grades are available which resist ignition from moderate fire sources but the smoke and toxic fume emission should be controlled before use. Polyamide gas tubing is often used in experimental gas systems but polyurethane tubing has been shown to be safer and has the added advantage of being more supple (see 2.5.16).

2.5.2 *Polypropylene and polyethylene (PP & PE)*

Standard grades are not suitable for use in other than very small quantities in insensitive situations. Flame retardant grades are available but those using organic halogen or phosphorus fire retardants must not be used because of the high smoke and toxic and corrosive fume emission, but grades using aluminium hydroxide as the fire retardant are produced which give acceptable fire performance and which are extensively used in the cable industry.

2.5.3 Polyphenylene oxide (PPO)

This material is available in grades (e.g. Noryl®) with suitable fire resistance (UL94V-0 or V-1 depending on the grade). It is a high smoke emitter in a fire situation but the fume is less toxic and corrosive than PVC. In many cases it can be substituted for PVC as, although it is not perfect, it has mechanical and processing properties which cannot be found in other reasonably priced alternatives.

2.5.4 Polyetheretherketone (PEEK)

This is a recent and relatively expensive material which has good heat resistance (up to 250°C) and very good fire retardance (UL94 V-0), as well as low smoke and toxic and corrosive fume emission, without resort to the use of additives. It is used in applications where its relatively high price is not a problem and, as the price comes down with increased consumption, it will find more extensive use in many more fields.

2.5.5 Polyetherimide (PEI)

Another relatively recent material with very good heat resistance (up to 200°C) and very good fire retardance (UL94 V-0), including low smoke and toxic and corrosive gas emission without resort to the use of additives. Can be considered for many applications where its still relatively high cost is outweighed by its desirable properties.

2.5.6 Polyether sulphones (PES)

The polyether sulphones (PES), and the related polysulphones (PSO or PSU) and polyaryl sulphones exhibit very good temperature resistance and can be exposed for long periods to temperatures up to 160–250°C. Polyether sulphones are rated as UL94 V-0 and polysulphones UL94 V-1. They are difficult to ignite but when involved in a fire situation they can, at high temperatures, emit sulphur dioxide. Nevertheless their high temperature resistance may make them useful for limited application and each case should be considered on its merits.

2.5.7 Polyphenylene sulphide (PPS)

Exhibits very good resistance to temperatures up to about 260°C and is only ignited with difficulty (UL94 V-0), but extinguishes immediately on removal of the ignition source. It is available only in dark colours as it is very difficult to pigment and also is available only in modified form, i.e. glass or carbon fibre filled. Its high temperature resistance may make it useful for limited application and each case should be considered on its merits.

2.5.8 Polyphenylene ether (PPE)

The pure product is resistant to temperature up to 110°C and is only ignited with difficulty (UL94 V-0). However, it is usually modified with high impact polystyrene (HIPS) in order to achieve better processability and thus the modified products are

less fire resistant. Each case should be considered on its merits. This is the most commonly used heat resistant plastic.

2.5.9 Polyarylates (PAr)

These relatively new products (e.g. Isaryl®) have good fire resistance (UL 94 V-0) and a working temperature of up to 300°C. They are said to be susceptible to stress corrosion cracking by hydrocarbon solvents and so their use in particle detectors where hydrocarbon gases and vapours are used should be carefully checked.

2.5.10 Polystyrene (PS)

Although this is a cheap and easily processed material, its high flammability coupled with dense and toxic smoke emission make it unsuitable for use. Its tendency to de-polymerize at relatively low temperatures makes it doubly unsuitable for use in particle detectors. Fire retardant grades, using halogenated organic compounds as retardants, are available but must not be used.

2.5.11 Acrylonitrile butadiene styrene (ABS)

These are flammable materials and are particularly high smoke emitters. Fire retardant grades, using halogenated organic compounds as retardants, are available but are high smoke and toxic and corrosive fume producers and must not be used.

2.5.12 Polyimides (PI)

These materials have excellent heat resistance, up to 260°C as well as inherent fire resistance (UL94 V-0) and low smoke and toxic and corrosive smoke emission.

2.5.13 Polyamide imides (PAI)

These materials have properties approaching those of polyimides with a working temperature of up to 210°C and good fire resistance (UL94 V-0) while being melt processable.

2.5.14 Polytetrafluorethylene (PTFE)

Although PTFE (Teflon®) only melts and decomposes at temperatures exceeding 500°C, it emits, under these conditions, highly toxic and corrosive smoke containing hydrogen fluoride and highly toxic fluorides of carbon. Although it is a very useful material with unique properties its large scale use should be avoided also because of its very poor radiation resistance.

2.5.15 Polyurethanes (PUR)

These materials should not be used as they are flammable (do not conform to UL94V requirements) and emit dense smoke. However polyurethane tubing has been shown to be less flammable than polyamide tubing hitherto used as gas tubing in experimental systems. Although it does not conform fully to the requirements of this Instruction, it has been allowed in limited quantities as it is more supple than

polyamide tubing and gives less dense, toxic and corrosive smoke. It may be used in limited quantities in places where it would be impossible to use metal tubing, especially for 'tight' bends.

2.5.16 Polyacetals-polyoxymethylene (POM)

These materials which are designated as polyoxymethylene have mechanical properties which make them very useful. They are more creep resistant than the polyamides and have excellent abrasion resistance. However, they burn very easily (although with low smoke emission), are radiation sensitive, and fire retardants cannot be incorporated into the polymer. They may be used in limited quantities only.

2.6 Foam Plastics

It is possible to obtain foams from practically any plastic and there is a vast range of these materials although only a few have achieved real importance. Here they are divided into two categories: rigid foams which usually have a closed cell structure and flexible foams which are mainly open celled. At CERN they are mainly used for thermal (and occasionally acoustic) insulation and for 'cushioning', but they are also used in furniture construction, especially the flexible foams in furniture upholstery, and thus care should be taken when specifying furniture.

2.6.1 Rigid foams

PVC MUST NOT BE USED.

2.6.1.1 Polyurethane (PUR)

These foams have the advantage of being able to be 'foamed' in place, but they are flammable and are high smoke emitters. Preformed panels may contain flame retardants but as these are often halogenated organic compounds the panels emit dense, toxic and corrosive smoke when involved in a fire. Unprotected foams should not be used.

2.6.1.2 Polyisocyanurates (PIR)

These foams are similar to the polyurethane foams but exhibit better flame resistance and emit much less dense smoke when involved in a fire. However, the pure compounds are extremely brittle and in practice they are modified with polyurethane foams to give products which are less brittle, while exhibiting better heat stability and lower combustibility than pure polyurethane foams. They are available in sheets, blocks and preformed pieces for pipe insulation. The properties of individual foams should be investigated before being considered for use.

2.6.1.3 Phenolics (phenol-formaldehyde) (PF)

These foams exhibit excellent flame resistance (UL94 V-0), emit very little smoke in a fire, and have a maximum operating temperature of 120°C. However, they are

often acid cured and in a fire at high temperatures they emit toxic and corrosive fumes and may smoulder when the ignition source is removed. They tend to be brittle but can be supplied with an aluminium foil for reinforcement. They are available in sheets, blocks and preformed pieces for pipe insulation. The properties of individual foams should be investigated before being considered for use.

2.6.1.4 *Ureas (urea-formaldehyde) (UF)*

These foams exhibit excellent flame resistance (UL94 V-0), emit very little smoke in a fire but have a maximum operating temperature of only 90°C. In a fire, at high temperatures, they emit toxic and corrosive fumes but do not smoulder when the ignition source is removed. They tend to be brittle but can be modified with additives such as polyethylene glycol to reduce the brittleness but this results in an increase in flammability. They are available in sheets, blocks and preformed shapes for pipe insulation. The properties of individual foams should be investigated before being considered for use.

N.B. These foams have been used as 'foam in place' for insulation in cavity walls in domestic premises and have given problems with the emission of formaldehyde (an eye and throat irritant and suspected carcinogen) from the badly cured resins.

2.6.1.5 *Polyimides (PI)*

Foams with excellent high temperature (up to 200°C) and flame resistance (UL94 V-0) can be manufactured but they are very expensive and have only found limited use in, for example, sound proofing of jet engines.

2.6.1.6 *Polystyrene (PS)*

These exist as structural foams, for electronic and business machines and for replacing wood in furniture, and as the expanded polystyrene for sound and thermal insulation panels and food containers. In both cases the unmodified products are highly flammable and flame retardant grades contain halogenated compounds which dramatically increase the density, toxicity and corrosiveness of the smoke produced in a fire situation. They should not be used in significant quantities.

2.6.1.7 *Glass*

Foam glass is available as an insulating material in panels and preformed shapes for pipe and duct insulation. It has excellent fire resistance.

2.6.2 *Flexible foams*

PVC MUST NOT BE USED.

2.6.2.1 *Polyurethanes (PUR)*

The unmodified foams exhibit very poor fire resistance and are high smoke producers. They are less stable to high temperatures than the rigid foams and burn more intensely. Foams using halogenated compounds as fire retardants are available

which have better fire performance but which emit dense, toxic and corrosive smoke when involved in a fire. Halogen-free flame retardant grades using aluminium oxide as retarding agent have been developed and have been classed as making 'low' contribution to a fire as well as satisfying the requirements for toxicity and corrosiveness. These were used in some LEP experiments and since then improvements have been made in their mechanical properties which make them useful candidates for future use. Any foam should be fire tested before use.

2.6.2.2 *Natural rubber*

These foams burn easily with high density, toxic and corrosive fume emission and must not be used.

2.6.2.3 *Polychloroprene*

Must not be used.

2.6.2.4 *Polyolefines (PP & PE)*

Polyethylene and polypropylene foams are available but either their flame resistance is very low or, if halogenated flame retardants are used, the smoke and toxic and corrosive fume emission is unacceptable. Foams using aluminium hydroxide as flame retardant are becoming available and may be suitable if their fire performance is acceptable.

2.6.2.5 *Silicones (SI)*

Silicone foams are available which are classed as having 'low' contribution to a fire and are even used as fire stops in, for instance, cable passages.

2.7 **Films**

Many plastics can be made into flexible films, some of which are transparent or translucent. Some which are in general use, such as polyethylene, polyester or polyethylene terephthalate (Mylar®) are very flammable while others such as PVC and polyethylene, containing halogenated flame retardants, are prohibited for reasons already stated.

Films which conform to the requirements of this Instruction are available in the following materials:

- polyetheretherketone (PEEK)
- polyimide (PI, Kapton®)
- polyarylate (PAr)
- polyetherimide (PEI)
- polyaryl amide (PAA)

- polyethylene (PE) and polypropylene (PP) with aluminium oxide trihydrate flame retardant.

2.8 Flooring Materials

PVC MUST NOT BE USED.

2.8.1 Polyamides (PA)

Fire resistant grades of polyamide carpeting are available but, where these are proposed, consideration should be taken of the fire retardants used, as these can increase the smoke and toxic and corrosive fume emission.

2.8.2 Polypropylene (PP)

As for polyamides.

2.8.3 Low smoke elastomers

Materials are now available which can meet the fire safety requirements in terms of flammability, smoke and toxic and corrosive fume emission. Their wear-life is good as they are used in public transport applications, especially in railway and metro passenger trains.

2.8.4 Wood

Wooden and laminated wood parquet blocks, sheets and boards are available in various forms, many of which may be suitable for use. All products should be tested before use.

2.8.5 Others

Low organic asphalt has been shown to have low fire spread and low smoke emission. Any proposal to use these materials should be carefully examined before application.

Marble chip/cement tiling is suitable but care must be taken to test resin-bonded materials before application.

3 Suitability of Plastics for Use at CERN

Table 1 of Annex 1 gives an indication of the suitability of plastics for use at CERN classified as follows:

- materials which are likely to be suitable **with** or without fire retarding agents,
- materials which are likely to be suitable only with the incorporation of fire-retarding agents **not** containing halogen, sulphur or phosphorus,
- those materials which are prohibited.

This table is for preliminary selection only and in all cases materials should be tested before use or specification.

The trade names are classified in the same way in Annex 2.

Table 1: Classification of Plastics for Use at CERN

Suitable base materials	Melamine formaldehyde Phenol formaldehyde Polyamide imide Polyarylate Polybenzimidazole Polyether ether ketone Polyether imide Polyimide Urea formaldehyde
Suitable only with incorporation of fire retardant NOT containing halogen, sulphur or phosphorus	Epoxy resin Ethyl acrylate rubber Ethylene propylene diene Ethylene propylene rubber Ethylene vinyl acetate High density polyethylene Low density polyethylene Polyamide Polyaryl amide Polybutylene Polybutylene terephthalate Polycarbonate Polyethylene terephthalate Polyisocyanurate Polyphenylene ether Polyphenylene oxide Polypropylene Polyurethane Polyvinyl acetate Polyvinyl alcohol Silicones
Prohibited materials	Acetal Acrylonitrile Acrylonitrile butadiene styrene copolymer (ABS) Acrylonitrile styrene acrylic ester copolymer Ethylene tetrafluoroethylene copolymer Natural rubber Perfluoroethylene propylene Polychlorotrifluoro ethylene Polymethyl methacrylate Polyoxymethylene Polystyrene Polytetrafluoroethylene (PTFE) Polyvinyl chloride (PVC) Polyvinyl fluoride Polyvinylidene chloride Polyvinylidene fluoride Styrene acrylonitrile copolymer Styrene butadiene copolymer

Annex 2

Trade Names and Abbreviations

1 Trade Names (® is the registered trade name of a producing company)

1.1 Materials likely to satisfy the requirements of this Instruction without recourse to flame retarding agents

Trade name	Product description
BAKELITE	Phenolic moulding compound
ISARYL®	Polyarylates
KAPTON®	Polyimide
STABAR®	Polyetheretherketone films
TORLON®	Polyamide-imide
ULTEM®	Polyetherimide
VICTREX-PEEK	Polyetheretherketone

1.2 Halogen- and sulphur-free materials which are likely to conform to the fire performance requirements of this Instruction only by the incorporation of fire retarding agents FREE OF halogen, sulphur and phosphorus

Trade name	Product description
ALKATHENE®	Polyethylene
ALTUGLAS®	Cast acrylic sheets
ARALDITE®	Epoxy resin
AXXIS PC®	Polycarbonate sheets
BAYLON®	High density polyethylene
CELMAR®	Polypropylene
DELFIN®	Acetal (POM)
ECCOFOAM®	Polyurethane foam-in-place resins
EPIKOTE®	Epoxy resin
EPOPHEN®	Epoxy resins
FEREX®	Fire retarded polyurethane foams
HYTREL®	Polyester elastomer
LEVAPREN	Ethylenevinyl acetate
LEXAN®	Polycarbonate
MAKROLON®	Polycarbonate
MIL-ENE®	Polyester film
MYLAR®	Polyethylene terephthalate film

Trade name	Product description cont.
NORDEL [®]	Hydrocarbon rubber
NORYL [®]	Polyphenylene oxide
NYLON	Polyamide
SILASTIC [®]	Silicone mastics
SYLGARD [®]	Silicone elastomers
VALOX [®]	Thermoplastic polyester
VAMAC [®]	Ethylene acrylic elastomer
VITEC [®]	Fire retarded polyurethane foams

1.3 Prohibited Materials

Trade name	Product description
BETAGLAS[®]	Rigid PVC films
DARVIC[®]	PVC
FIBERLOC[®]	Glass-fibre-reinforced PVC
FLUON[®]	Polytetrafluoroethylene
HYPALON[®]	Chlorosulphonated polyethylene
NEOPRENE[®]	Polychloroprene rubber
PLEXIGLAS[®]	Polymethyl methacrylate
SARAN[®]	Polyvinylidene chloride
TEFLON[®]	Polytetrafluoroethylene
VITON[®]	Fluorinated elastomer

2 Abbreviations

Prohibited materials are in bold.

Abbreviation	Chemical name
ABS	Acrylonitrile butadiene styrene copolymer
AN	Acrylonitrile
ASA	Acrylonitrile styrene acrylic ester copolymer
CPE	Chlorinated polyethylene
EAR	Ethyl acrylate rubber
EP	Epoxy resin
EPDM	Ethylene propylene diene monomer
EPR	Ethylene propylene rubber
ETFE	Ethylene tetrafluoroethylene copolymer
EVA	Ethylene vinyl acetate copolymer

Abbreviation	Chemical name cont.
FEP	Perfluoroethylene propylene
FRP	Fibreglass-reinforced polyester
FRTTP	Fibre-reinforced thermoplastic
HDPE	High-density polyethylene
HIPS	High-impact polystyrene
LDPE	Low-density polyethylene
MF	Melamine formaldehyde resin
PA	Polyamide
PAI	Polyamide imide
PAr	Polyarylate
PB	Polybutylene (Polybutene)
PBI	Polybenzimidazole
PBT	Polybutyleneterephthalate
PC	Polycarbonate
PCTFE	Polychlorotrifluoroethylene
PE	Polyethylene (Polyethene)
PEEK	Polyether ether ketone
PEI	Polyether imide
PES	Polyether sulphone
PET (PETP)	Polyethylene terephthalate
PF	Phenol formaldehyde resin
PI	Polyimide
PIR	Polyisocyanurate
PMMA	Polymethyl methacrylate
POM	Polyoxymethylene (Acetal)
PP	Polypropylene
PPE	Polyphenylene ether
PPO	Polyphenylene oxide
PPS	Polyphenylene sulphide
PS	Polystyrene
PSO	Polysulphone
PSU	Polysulphone
PTFE	Polytetrafluoroethylene
PU	Polyurethane
PUR	Polyurethane rubber
PVA	Polyvinyl alcohol
PVAC	Polyvinyl acetate
PVC	Polyvinyl chloride
PVCC	Chlorinated polyvinyl chloride

Abbreviation	Chemical name cont.
PVDC	Polyvinylidene chloride
PVDF	Polyvinylidene fluoride
PVF	Polyvinyl fluoride
SAN	Styrene acrylonitrile copolymer
SB	Styrene butadiene copolymer
SBR	Styrene butadiene rubber
SI	Silicone
SIR	Silicone rubber
UF	Urea formaldehyde resin
UP	Unsaturated polyester resin

Annex 3

Glossary of Terms

ACCELERATOR

A material that, when mixed with a catalyst or a resin, speeds up the chemical reaction between the catalyst and the resin. Also called a promoter.

ANTIOXIDANT

A substance that, when added in small quantities to the resin during mixing, prevents its oxidative degradation and contributes to the maintenance of its properties.

CATALYST

A substance that changes the rate of a chemical reaction without itself undergoing permanent change in composition or becoming a part of the molecular structure of the product. A substance that speeds up the cure rate of a compound when added in minor quantity, compared to the amounts of primary reactants (see also accelerator and hardener).

COMBUSTION

The exothermic reaction of a substance with an oxidizer (in most cases air) generally accompanied by flames and/or glowing and/or emission of smoke.

COMPOSITE MATERIAL

A combination of two or more materials, reinforcing elements and composite matrix binders, differing in form or composition on a macro scale. The constituents retain their identities, that is they do not dissolve or merge completely into one another although they act in concert. Normally the components can be identified and exhibit an interface between one another.

CROSS LINKING

With thermosetting and certain thermoplastic plastics, the setting up of chemical links between the molecular chains. When extensive, as in most thermosetting plastics, cross linking makes an infusible supermolecule of all the chains. In rubbers the cross linking is just enough to join all the molecules into a network.

EASE OF IGNITION

The ease with which a material can be ignited under specified test conditions.

ELASTOMER

A generic term for all substances having the properties of natural, reclaimed, vulcanized or synthetic rubber, in that they stretch under tension, have a high tensile strength, retract rapidly, and recover their original dimensions fully. Typical elastomers contain long polymer chains.

FILLER

A relatively inert substance added to a plastic to alter its physical, mechanical, thermal, electrical or other properties, or to lower cost or change density. Usually means a particulate additive.

FIRE PERFORMANCE

The physical and/or chemical changes that take place when a material, product and/or structure is exposed to an uncontrolled fire.

FIRE RETARDANT

A substance added, or a treatment applied to a material in order to suppress, significantly reduce, or delay the combustion of the material.

FLAMMABILITY

The ability of a material or product to burn with flame under specified test conditions.

FUME

Synonymous with smoke (in this note).

GLOW COMBUSTION

Combustion of a material in the solid phase without flame but with emission of light from the combustion zone.

HALOGEN

A halogen is a member of the Group VII A of the periodic table of chemical elements which contains fluorine, chlorine, bromine and iodine.

HARDENER

A substance or mixture added to a plastic composition to promote or control the curing action by taking part in it.

HEAT RELEASE RATE

The calorific energy released per unit time by a material during combustion under specified test conditions.

IEC

International Electrotechnical Commission.

INTUMESCENT

Swelling up. Refers to coatings of paint or mastic which are applied to surfaces and puff or swell up in a fire, thus protecting the underlying material.

MONOMER

A single molecule that can react with like or other molecules to form a polymer. The smallest repeating structure of a polymer.

NARCOTIC (adj.)

Of substances etc. Having the effect of inducing stupor, sleep or insensibility.

OLEFIN

A group of unsaturated hydrocarbons of the general formula C_nH_{2n} and named after the corresponding paraffins by the addition of -ene or -ylene to the root (e.g. ethene or ethylene from ethane).

OPTICAL DENSITY OF SMOKE

Measure of the degree of opacity of smoke, usually expressed as the common logarithm of the ratio of the incident light to the transmitted light.

PLASTICIZER

A material incorporated into a plastic to increase its workability, flexibility or distensibility. Normally used in thermoplastics.

PLASTICS

A group of organic materials which, though stable in use at ambient temperatures, are plastic at some stage in their manufacture and then can be shaped by the application of heat and/or pressure.

POLYMER

A member of a series of polymeric compounds. A substance composed of very large molecules, which consist essentially of recurring long-chain structural units, which distinguish polymers from other types of organic molecules and confer on them tensile strength, deformability, elasticity and hardness.

POLYOLEFIN

Plastics based on a polymer made with an olefin as essentially the sole monomer. The most important polyolefins used as standard plastics are low-density polyethyl-

ene (LDPE), high-density polyethylene (HDPE) and polypropylene (PP). Less common materials are polybutene (polybutylene) and polymethylpentene.

PYROLYSIS

Irreversible chemical decomposition of a material due to an increase in temperature without oxidation.

RATE OF FLAME SPREAD

Distance travelled by a flame front during its propagation per unit time under specified test conditions

RESIN

In this document it is taken to mean the viscous liquid that can be cross-linked into its final solid form by means of a chemical reaction with a variety of catalysts, hardeners and accelerators, with or without heat.

SMOKE

A visible suspension of solid and/or liquid particles in gases resulting from combustion or pyrolysis.

SMOULDERING

The slow combustion of a material without light being visible and generally evidenced by an increase in temperature and/or smoke.

STABILIZERS

Chemicals used in plastic formulations to help maintain physical and chemical properties during processing or service life. For instance an ultraviolet stabilizer is designed to absorb ultraviolet rays and prevent them from attacking the plastic.

THERMOPLASTICS

A class of plastic materials that is capable of being repeatedly softened by heating and hardened by cooling. ABS, PVC, polystyrene, polyethylene and polypropylene are all thermoplastic materials.

THERMOSETTING PLASTICS

A class of plastic materials that will undergo a chemical reaction by the application of heat, pressure, catalysts etc., leading to a relatively infusible, non-reversible state. Phenolics and epoxies are typical thermosetting plastics.

Annex 4

Standards

The standards cited in this Safety Instruction are issued by the following organizations:

ABD

Airbus Industrie Directive
31707 Blagnac Cédex, France.

ASTM

American Society for Testing and Materials
Philadelphia, Pennsylvania, United States.

BS

British Standards Institution
2 Park Street, London WA1 2BS, U.K.

IEC

International Electrotechnical Commission
1–3, rue de Varembé, 1211 Geneva 20, Switzerland.

ISO

International Organization for Standardization
1–3, rue de Varembé, 1211 Geneva 20, Switzerland.

UL

Underwriters Laboratories Inc.
333 Pfingsten Road, Northbrook, Illinois 60062, United States.