

## Guidance Document

# G085

# Code of practice - Fire Safety of Materials and Fire Safety of Specific Items and Materials Used in the Underground

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## 1 Purpose

The purpose of this Manual of Good Practice is to detail the background to London Underground's philosophy behind the use and controls of flammable and specific items and materials in underground locations (including rolling stock). This Code of Practice of Materials Used in the Underground, details the underlying risk-based approach to materials fire safety which remains constant, whilst the specific tests and requirements in 1-085 may change when National and European Standards are updated.

## 2 Scope

- 2.1 This document should be read in conjunction with standard 1-085, which details specific test requirements, together with current legislation and the specific Guidance Notes in Section 3.2. It applies to the locations defined in that Standard, which includes sub-surface stations, tunnels, certain depot locations and some surface stations.
- 2.2 As additional guidance on specific items and materials is progressively incorporated into Section 3.2 of this Manual of Good Practice, the new entry is added to the Contents and the Manual is issued as an up-dated version.

## 3 Guidance

### 3.1 Code of Practice - Fire Safety of Materials Used in the Underground

#### 3.1.1 Materials and Requirements

Ideally, all solid materials used in the underground locations (including rolling stock) should be made of either non-reactive metal or ceramic. This is not always practicable, but where materials are used which are not inert, such as paper, polymer or cloth, they have to meet strict requirements, detailed in 1-085. The controls associated with flammable liquids and gases are also detailed in 1-085. Materials which do not meet the above requirements may be conceded in accordance with LU procedure S1641, if accompanied by an acceptable risk assessment.

#### 3.1.2 Combustibility/Heat Release

##### 3.1.2.1 General Principles

The combustibility of a material or composite, and the related rate of heat emission, are the principal parameters which determine how fast, and to what extent a fire will spread, once ignited. The quantification of combustibility and heat release are therefore the usual starting points for any fire risk assessment. Testing usually involves a larger scale test to assess flame spread across a defined area, accompanied by a smaller scale heat release test. Other factors to consider are detailed below:

- a) profile of the material (vertical, horizontal, floor, ceiling, chimney etc);
- b) the effects of draughts and ventilation;
- c) sources of ignition;
- d) flaming drips, debris or delamination, which could spread the fire to other areas;
- e) amount of material present.



### 3.1.2.2 Fire Regions

A fire region is defined such that a fire cannot spread from one fire region to another within the timescale designated for escape. The defined size of the fire region depends upon the combustibility of the materials present and the size and intensity of the fire source. For the purposes of this Code of Practice, the initial fire source for stations and tunnels has been defined as:

- a) the base of the fire not having an area in excess of  $1.0 \text{ m}^2$ ;
- b) having an average irradiance of not more than  $35 \text{ kW m}^{-2}$ .

This represents a typical small garden bonfire or a region of trackside smouldering. Assuming the  $1.0 \text{ m}^2$  fire does not spread, through the appropriate use of surrounding materials, this implies a fire region of roughly  $1.25 \text{ m}^2$  to be designated for fire compliant materials in stations and tunnels. Rolling stock interiors have more onerous requirements, due to the potential increased escape time from a train stopped in a tunnel, and therefore the fire region has been defined as  $0.5 \text{ m}^2$  for rolling stock interiors. In summary:

| Location               | Size of fire region for compliant materials |
|------------------------|---------------------------------------------|
| Station or tunnel      | $1.25 \text{ m}^2$                          |
| Rolling stock interior | $0.5 \text{ m}^2$                           |

### 3.1.3 Smoke Emission

#### 3.1.3.1 General Principles

**3.1.3.1.1** Smoke consists of tiny particles emitted from burning material, and smoke emission is quantified by the degree of obscuration of an optical beam in a confined space, which can be related to the visual impairment of the escape route in a particular circumstance. The hazard connected with smoke is therefore a reduction in the visibility distance, which can be defined as follows:

- a) general Visibility Distance  $D_G$  - the distance from a light source at which objects can just be seen;
- b) specific Visibility Distance  $D_S$  - the distance from a light source at which the light source can be seen.

**3.1.3.1.2** This Code of Practice is based upon the assumption that a person escaping from a fire should be able to see the immediate surroundings when 10 metres from a light source, and also should be able to see the light source itself from a distance of 10 metres. Calculations in risk assessments therefore should ensure that  $D_G$  and  $D_S$  should not fall below 10m. Which parameter to use depends upon circumstances: if an internally illuminated emergency exit sign is provided then  $D_S$  should be used, but where no internal illumination is present  $D_G$  should be used in calculations. The key parameters which affect the values of  $D_G$  and  $D_S$  are:

- a) dispersal volume;
- b) lighting level;
- c) total smoke production;
- d) ventilation.

**3.1.3.1.3** The colour of smoke is related to the nature of the material being burnt - generally the greater the carbon content, the blacker the smoke. White smoke is believed to affect visibility to a greater extent than black smoke, because the lighter coloured particles reflect light, therefore increasing the 'signal to noise' ratio, whereas incident light tends



to be absorbed by darker particles. This guidance does not differentiate between different coloured smokes.

### 3.1.3.2 Measurement of Smoke

**3.1.3.2.1** The starting point for the quantification of smoke emission from a burning material is the optical density or measured absorbance.

$$A_m = \log_{10}(I_o/I_T) - \text{equation (1).}$$

- a)  $I_o$  = Light intensity before passing through smoke;
- b)  $I_T$  = Light intensity after passing through smoke.

**3.1.3.2.2** The  $A_m$  parameter is measured by shining a light into a chamber or cube of known volume. The nature of the fire source and the beam will vary depending upon the test method. The measured absorbance is converted into, what is termed 'standard absorbance  $A_o$ ' as follows:

$$A_o = A_m v / (nL) - \text{equation (2).}$$

- a)  $A_m$  = Measured absorbance;
- b)  $v$  = volume of the cube;
- c)  $L$  = Optical path length;
- d)  $n$  = number of units comprising the specimen being burnt (eg cables in bunches).

**3.1.3.2.3** There are several test methods and standards for static smoke emission tests using light beams and cubes, and the nomenclature will vary, depending upon the test method. The duration of the test will also vary, depending upon the test method and the nature of the sample. Some standards only specify a minimum % transmittance of the light beam ( $I_o/I_T$ ), but the standard absorbance ( $A_o$ ) can still be calculated if the parameters in equation (2) are known. The units of  $A_o$  will also change depending upon the nature of the sample being burnt, as detailed below:

- a) per unit surface area (for flat surfaces) with units  $m^2/\text{burn area}$ ;
- b) per unit mass with units  $m^2/g$ ;
- c) per area of fire source with units  $m^2/m^2$ ;
- d) per single unit of whatever is under test with units  $m^2/\text{unit}$ ;
- e) per unit length (for cables and other linear components) with units  $m^2/\text{burn length}$ .

**3.1.3.2.4** Some tests are termed 'two phase tests' where there is a clear distinction between the recorded  $A_o$  values during the burning and smouldering phases, and this is typically a characteristic of tests where not all the material has been consumed during the flaming phase, such as for some bunched cable tests. The standard absorbance recorded during the burning and smouldering phases are termed  $A_o(\text{ON})$  and  $A_o(\text{OFF})$  respectively. The  $A_o(\text{OFF})$  figure is usually larger than  $A_o(\text{ON})$ . In both cases the quoted figure for standard absorbance is usually the maximum value recorded during the duration of the test. Sometimes the  $A_o(\text{ON})$  parameter will peak and then dip, before reaching a new maximum at  $A_o(\text{OFF})$  - where this happens, the  $A_o(\text{OFF})$  value is corrected as follows:

$$A_o(\text{OFF}) = A_o(\text{OFF})_{\text{end}} + (A_o(\text{ON})_{\text{max}} - A_o(\text{ON})_{\text{end}}).$$

**Note:** Also that the gradient of the standard absorbance  $v$  time curve can also be of interest, because a very rapid smoke build-up can have implications for escape, and can also indicate intense flame spread.



**3.1.3.2.5** The optical density per metre of smoke in an actual location is termed the 'Expected Absorbance' or  $A_E$ , which is derived from  $A_o$  as follows:

$$A_E = A_o(n/V) - \text{equation (3)}$$

- a)  $n$  = number of units being burnt (same as in equation (2) above);
- b)  $V$  = dispersal volume in  $m^3$ .

**3.1.3.2.6** Not all smoke emission testing is undertaken in a static cube or chamber. Some standards measure smoke emission using what is termed a 'dynamic or flow method' where the smoke is sucked through an extraction hood above the burning sample, and the smoke stream analysed by a light beam. This method measures smoke emission rate, and to reach an equivalent figure to the static build-up of smoke in a cube, the dynamic smoke data has to be integrated with respect to time. There is no known firm correlation between static and dynamic smoke emission results, and dynamic methods are not specified by London Underground.

### 3.1.3.3 Dispersal Volumes

**3.1.3.3.1** Smoke generated from a fire is mobile, and can be disrupted by natural air flow and forced ventilation. Smoke will become diluted the further it spreads from the fire source and, hence, the volume available for it to disperse is critical to assessing risk. It is assumed that smoke generated in a fire in a large volume, as detailed in clause 3.1.3.1.2 above, will not travel faster than an escapee. It is therefore possible to calculate the approximate volume that the smoke will encompass, within 10 metres of the fire source, for different locations, as detailed below:

- a) Station environment - A typical tube station platform tunnel has a diameter of 6.7m, equating to a cross-sectional area of  $35m^2$ . The dispersal volume for a fire on such a platform, encompassing 20m (10m each side of the fire) is therefore  $700m^3$ ;
- b) Tube tunnel environment - A typical tube tunnel has a diameter of 3.6m, equating to a cross-sectional area of  $10m^2$ . The dispersal volume encompassing a 20m length of tunnel is therefore  $200m^3$ ;
- c) Rolling Stock Interior - It is assumed that a car interior will confine the smoke within itself, thus the dispersal volume can be equated to the interior volume of the car, which varies between  $80m^3$  and  $120m^3$ , depending upon the type of stock. The dispersal volume for rolling stock interiors is therefore usually approximated to  $100m^3$ .

**3.1.3.3.2** In summary, for reference purposes, LU defines dispersal volumes as follows:

| Location               | Size of smoke dispersal volume |
|------------------------|--------------------------------|
| Station                | $700m^3$                       |
| Tube tunnel            | $200m^3$                       |
| Rolling stock interior | $100m^3$                       |

**3.1.3.3.3** The above values are generally assumed for all of the above locations, although there will be some variation, especially for the Sub-Surface Lines, which need to be taken into consideration when undertaking risk assessments and considering concession applications.

### 3.1.3.4 Lighting Level

**3.1.3.4.1** For a given dispersal volume and smoke density, the visibility distance will vary depending upon the intensity of the lighting; the brighter the lighting the greater the visibility distance. The precise correlation between visibility distances and lighting



types and levels is very complex for real locations, such as station platforms, but the process can be approximated using the Lighting Parameter K, where:

**$K = A_E D$  - equation (4)**

- a)  $K$  = Lighting parameter;
- b)  $A_E$  = Expected absorbance (Optical density per metre);
- c)  $D$  = Dispersal volume.

**3.1.3.4.2** For a light source, such as an internally illuminated emergency exit sign, the following is a rough approximation:

| $K_s = A_E D_s$ | Intensity of internally illuminated sign |
|-----------------|------------------------------------------|
| 3.6             | 2000 lux                                 |
| 3.4             | 1000 lux                                 |
| 3.1             | 500 lux                                  |

**3.1.3.4.3** For an escape route in ambient lighting, the following is also a rough approximation:

| $K_G = A_E D_G$ | Intensity of ambient lighting |
|-----------------|-------------------------------|
| 1.6             | 2000 lux                      |
| 1.1             | 1000 lux                      |
| 0.75            | 500 lux                       |

**3.1.3.4.4**  $K_s$  is usually approximated to 3 and  $K_G$  is usually approximated to 1.

**Note:** That the visibility distance varies logarithmically with intensity of illumination (a direct consequence of the Beer-Lambert Law), and hence increasing the lighting level has only a small effect on visibility. The above relationship does not hold for very low lighting levels, but it is relevant for the emergency lighting conditions likely to be found in London Underground stations and tunnels, using SL18 900 lumen fluorescent lighting.

### 3.1.3.5 Calculation of Visibility Distances

**3.1.3.5.1** The specific visibility distance for a light source, such as an illuminated sign can therefore be calculated as follows:

**$D_s = 3/A_E$  - equation (5)**

**3.1.3.5.2** The general visibility distance for viewing an escape route under ambient lighting conditions can also be calculated as follows:

**$D_G = 1/A_E$  - equation (6)**

### 3.1.3.6 Multiple Sources of Smoke Emission

**3.1.3.6.1** If the smoke emission from two or more separately burning items in the same area is to be assessed, it is important to realise that it is the individual expected absorbance that must be summed, and only then the overall visibility distance calculated:

**$A_{E(Total)} = \Sigma A_E$  - equation (7)**

**3.1.3.6.2** This summation cannot be undertaken with the standard absorbance  $A_o$ , because the  $A_o$  parameter has not been normalised with respect to amount.



### **3.1.4 Toxic Fume Emission**

#### **3.1.4.1 General Principles**

**3.1.4.1.1** The principle applied to toxic fume emission in this Code of Practice is that the concentration of combustion gases released into the atmosphere should not exceed the level where a person exposed for 30 minutes will not experience any effects that will unacceptably impair escape, or which is likely to cause irreversible health effects.

**3.1.4.1.2** Toxic fumes are usually the principal direct cause of death in fire fatalities. The most effective way to reduce toxic fume emissions from burning materials is to reduce the material's combustibility, thereby reducing the amount of the material that actually burns. Toxic fumes are either gases or vapours, unlike smoke which is particulate, and can be sub-divided into three categories:

- a) Irritants;
- b) Asphyxiants;
- c) Nerve sensitisers.

**3.1.4.1.3** Irritants are usually acidic and turn to acid when breathed into the lungs. Examples of irritant gases are hydrogen halides and oxides of sulphur and nitrogen. Asphyxiants displace oxygen in the blood stream and therefore lead to suffocation. Examples of asphyxiants are carbon monoxide and hydrogen cyanide. Nerve sensitisers attack the central nervous system. This Code of Practice does not differentiate between the different mechanisms of toxicity.

**3.1.4.1.4** The 30 minute incapacitation criterion, detailed above, is met by considering the eight gases which are most commonly encountered as products of combustion. The presence of the eight gases detailed below may also indicate the presence of other gases with more complex, chemical groupings:

- a) Carbon Monoxide (CO);
- b) Carbon Dioxide (CO<sub>2</sub>);
- c) Hydrogen Fluoride (HF);
- d) Hydrogen Chloride (HCl);
- e) Hydrogen Bromide (HBr);
- f) Hydrogen Cyanide (HCN);
- g) Nitrogen Dioxide (NO<sub>2</sub>);
- h) Sulphur Dioxide (SO<sub>2</sub>).

**3.1.4.1.5** There are several options for assessing materials for toxic fume emission as detailed below.

#### **3.1.4.2 Exclusion Clauses**

**3.1.4.2.1** To produce the above gases (with the exception of CO and CO<sub>2</sub>) a material must contain nitrogen, sulphur or a halogen (fluorine, chlorine or bromine). Materials can therefore be excluded through chemical analysis. Such an approach may however exclude materials that pose no hazard, such as rock salt (sodium chloride), due to its non-combustibility. A more specific analysis is required to assess organically or covalently bound sulphur, nitrogen or halogen. The specific bonds to be excluded are:



- a) C-Halogen;
- b) C-S;
- c) C-N;
- d) C-O-S.

**3.1.4.2.2** The above approach does not include CO and CO<sub>2</sub>. It is not generally practicable to exclude carbon, which is the basis of virtually all polymeric and all organic materials. It is therefore necessary to include a risk assessment to accompany the exclusion clauses detailing the environment in which the material in question is to be installed. The ratio of CO to CO<sub>2</sub> produced will depend upon the environment: A well ventilated or oxygen rich environment will favour the production of CO<sub>2</sub> whereas an oxygen deficient environment, such as a smouldering fire in a compartmented area, will favour the production of CO. By contrast, the conversion of C-Halogen to hydrogen halide is always high, regardless of environment.

### 3.1.4.3 Numerical Assessment - General Principle

**3.1.4.3.1** The use of exclusion clauses has the disadvantage of requiring a separate risk assessment relating to the production of CO and CO<sub>2</sub>, together with being often impractical with material profiles, such as multi-layered composites, where each layer would need to be separately tested. The majority of modern toxic fume measurement test methods therefore involve the actual burning of the material concerned under specific conditions, and analysing the fumes emitted. Each of the 8 gases, detailed in clause 3.1.4.1.4 above is given a weighting related to its toxicity, hence the term 'numerical', and the sum of the weighted gases detected is deduced. (Note the nomenclature will vary with different standards, but the principle remains constant). There are several internationally accepted standards for weighting the 8 gases, and for a risk assessment to be compliant with this Code of Practice, it must be stated which standard is being used. The IDLH (Immediately Dangerous to Life or Health) method, detailed in the NIOSH Pocket Guide to Chemical Hazards, is used to explain principles in this Code of Practice. The IDLH level for incapacitation is quoted, as opposed to the level of lethality. The values were arrived at by testing rats, and it should be noted that the figures should only be taken as guide for humans - the values are normalised for an average healthy human, and not for example babies or anyone predisposed to respiratory problems.

| Gas 'x'         | IDLH Level 'fx' |                    |
|-----------------|-----------------|--------------------|
|                 | (ppm)           | mg.m <sup>-3</sup> |
| CO              | 1200            | 1400               |
| CO <sub>2</sub> | 40000           | 73000              |
| HF              | 30              | 25                 |
| HCl             | 50              | 76                 |
| HBr             | 30              | 101                |
| HCN             | 50              | 56                 |
| NO <sub>2</sub> | 20              | 38                 |
| SO <sub>2</sub> | 100             | 270                |

**3.1.4.3.2** The sum of the contributions of each gas detected is calculated by:

$$r_x = c_x / f_x - \text{equation (8)}$$

$$R = \sum r_x - \text{equation (9)}$$

- a)  $c_x$  = detected level of each combustion gas 'x';



- b)  $f_x$  = IDLH of each gas 'x' relating to toxicity (or parameter given in relevant standard).

#### 3.1.4.4 Numerical Assessment - Mass and Area Based Methods

3.1.4.4.1 Toxic fume emission can either be expressed in:

- a) mg of each gas detected per g of material burnt (mass based);  
b) g of each gas detected per  $m^2$  of material burnt (area based).

3.1.4.4.2 Area based testing is usually deemed more appropriate for surface profiles, such as panelling or coatings, because the test generally gives a more realistic indication of reaction to fire and flame spread behaviour. Area based testing is also more realistic where a large percentage mass of non-combustible fillers are used. Mass based tests are usually undertaken in a furnace, where the whole sample is consumed, and therefore measure toxic potency, rather than the actual fumes likely to be emitted in a fire as detailed in Clause 3.1.4 above. Miscellaneous moulded shaped items are usually tested using the mass based method. The above approach is analogous to the different units of standard absorbance for smoke emission detailed in Clause 3.1.3.2 above. In either case the weighting values 'f' for each gas remains the same, although the overall summated 'R' value will vary depending upon whether a mass or area based calculation is used for a specific sample. It is possible to convert from mass to area and area to mass 'R' values, so long as the test methods use the same weightings 'f' for each gas detected:

- a) calculated area based value = Measured mass based value x (mass per unit surface area of sample  $[g/m^2]/1000$ );  
b) calculated mass based value = Measured area based value x (1000/mass per unit surface area) assuming a 100% depth of burn in the area based test.

#### 3.1.4.5 Numerical Assessment - Expressing Results

3.1.4.5.1 The summated 'R' toxic fume emission results are usually normalised to a specific mass of material burning in a specific volume, or a specific surface area of material burning into a specific volume. The values of mass, surface area and volume will vary with the application.

**Note:** The dispersal volume for toxic fumes need not be the same as for smoke emission, because it are not related to the 10m optical visibility requirement although for most applications, the dispersal volume for toxic fume can be assumed to be the same as detailed for smoke in Clause 3.1.3.3 above.

3.1.4.5.2 Results expressed in this way are called a CIT (Critical Index of Toxicity), where:

**CIT = N x R - equation (10)**

- a) N = normalising factor;  
b) R = Weighted sum of toxic gases detected.

3.1.4.5.3 The normalising factor is based upon the mass or area of the sample being burnt and the dispersal volume available for the fumes produced, as detailed in the worked examples in Section 3.1.6. The key result is that a CIT of 1.0 would lead to incapacitation in 30 minutes, and therefore the CIT value should be less than 1.0.

#### 3.1.4.6 Multiple Sources of Toxic Fume Emission

If the toxic fume emission from two or more separately burning items in the same area is to be assessed, a separate R value is calculated for each fire and then summed - equation 10 therefore becomes:



$$CIT = N (\Sigma R)$$

### 3.1.4.7 Numerical Assessment - Additional Points to Consider

**3.1.4.7.1** Continuous Monitoring - Some toxic fume standards call for continuous gas monitoring over the duration of the test. Such an approach gives a comprehensive picture of what is happening during all phases of the combustion process. The presentation format of the results usually involves the time to be calculated for the summated gases to reach the incapacitation level of CIT =1.

**3.1.4.7.2** Single Point Monitoring - The advantage with such an approach is that the equipment and presentation of results is simpler than with continuous monitoring. The principal disadvantage is that a less complete picture of the total toxic emissions with respect to time is available. The key is to sample at the correct point, and this varies with different standards.

**3.1.4.7.3** Static or dynamic monitoring - This is analogous to the smoke emission testing detailed in clause 3.1.3.2, where the fumes are either measured in a static chamber (cube) or in the dynamic air flow of an extractor hood. For the purposes of this Code of Practice, dynamic methods are not considered, because of the lack of correlation with the results from the longer established static systems.

**3.1.4.7.4** Temperature - It is accepted that a toxic fume emission test will only test the toxic fume emission of a material under one defined set of conditions, as do smoke and combustibility tests. However, the temperature will have an effect on the cocktail of gases produced and detected, and care needs to be taken to ensure that the temperature quoted in the standard to be used is relevant to the application.

### 3.1.5 Fire Risk Assessment

#### 3.1.5.1 General Principles

**3.1.5.1.1** Risk assessments must be performed in accordance with the relevant London Underground requirements, including any applicable Standards. When assessing the particular risks associated with the matters being considered in this Manual, the assessment should include consideration of all the following factors:

- a) ease of escape;
- b) level and integrity of lighting;
- c) fire compartmentation and to what time rating?;
- d) ventilation;
- e) dispersal volume for smoke and toxic fumes;
- f) suppression systems available, and their effect upon visibility when discharged;
- g) detection systems available and ease of detection;
- h) potential ignition sources;
- j) risk of vandalism;
- k) risk of explosion;
- m) existing logged non-fire compliances on site and fire load of non-fire compliant material;
- n) effect of fire on other safety critical equipment and balance of other non-fire risks;
- o) operational effect;



- p) spaces and cavities for air behind surfaces, and areas for combustible rubbish to accumulate;
- q) training and operating practices
- r) persons at risk.

**3.1.5.1.2** The four worked examples of risk assessments detailed below are all fictitious, although they closely resemble real installations and their associated risk assessments that have been undertaken.

### **3.1.6 Examples of Risk Assessments**

#### **3.1.6.1 Example 1 - Cash Machine in Station Ticket Hall**

**3.1.6.1.1** This is an example of a typical 'front of house' installation of the type becoming increasingly common across the network:

**3.1.6.1.2** A single cash or ATM machine is proposed for installation in every station ticket hall. The machine may be free standing or buried in a wall, depending upon location. Each machine has a fire resisting 1 hour rated non-combustible enclosure, apart from the screen and key pad, which are made of polycarbonate plastic. The principal non-fire compliance is the electronics within the machine, together with the key pad and screen, and the paper money. The machines are positioned so as not to restrict escape or passenger flow, but they are located in the only escape route from some deep stations. The machines are fitted with internal fire detection equipment, but suppression is deemed impractical.

**3.1.6.1.3** A materials parts list has been provided, and the principal non-fire compliance is 300g of polycarbonate thermoplastic in the screen, key pad and electronics together with a further 200g of assorted polymer based electronics materials. The fire performance data for the polycarbonate is detailed below:

- a) flame spread: BS 476-7 Class 2;
- b) smoke emission: BS 6853 D8.3  $A_o = 0.12 \text{ m}^2/\text{g}$ ;
- c) toxic fume: Assessed by the exclusion clauses method, with 0.5% bromine detected by weight (w/w).

**3.1.6.1.4** The polycarbonate component is the principal factor in the fire risk assessment, because it is the major component by mass, and because it is all together in one lump (screen and key pad assembly). The other 200g of polymer components are all made of different materials, for which specific fire data is not available, and have physical separation from the polycarbonate within the cash machine. The other 200g of non-fire compliant material is therefore treated as additional fire load, but with precise properties undefined. The paper money is assumed to be well compartmented for security reasons.

**3.1.6.1.5** The principal fire risks are deemed to be arson and internal ignition from an electrical fault.

**3.1.6.1.6** Considering smoke emission, the  $A_o$  value of  $0.12 \text{ m}^2/\text{g}$  will give an  $A_o$  value of  $300\text{g} \times 0.12 = 36$  if all the polycarbonate is available for combustion.

$$A_E = A_o(n/V) = 36(1/700) = 0.051$$

- a)  $n$  = number of units being burnt = 1 (i.e. one piece of material);
- b)  $V$  = dispersal volume =  $700 \text{ m}^3$ .

**3.1.6.1.7** The general visibility distance :  $D_G = 1/A_E = 19.44\text{m}$ , which is in excess of the 10m requirement, but will be further reduced if the other 200g of polymer components are also involved in any fire.



**3.1.6.1.8** Considering toxic fume emission: The principal concern is the 0.5% (w/w) bromine in the 300g of polycarbonate. Because the analysis is undertaken using the exclusion clause method, it has to be assumed that there is 100% conversion of the bromine to hydrogen bromide gas.

- a) the mass of bromine present =  $0.005 \times 300\text{g} = 1.5\text{g} = 1.5/80 = 0.01875$  moles. (atomic mass of Br=80);
- b) one mole of bromine produces one mole of hydrogen bromide (HBr);
- c) one mole of any gas occupies a volume of  $0.0244 \text{ m}^3$  at standard temperature and pressure, which implies that 0.01875 moles of gas occupies  $4.575 \times 10^{-4} \text{ m}^3$ ;
- d) ticket hall has as assumed volume of  $700 \text{ m}^3$  implying the hydrogen bromide gas produced occupies  $4.575 \times 10^{-4} / 700 = 3.8 \times 10^{-7} = 0.65$  parts per million;
- e) the incapacitation level of hydrogen bromide = 30 parts per million.

**3.1.6.1.9** The amount of toxic fume produced is well within safety limits for the station ticket hall in this exercise. Note this is a worst case scenario, assuming all the bromine present is converted to toxic fume, and that it is all produced at once, with no ventilation. In reality, the concentration of hydrogen bromide would be lower. Note no assessment of carbon monoxide has been made, but the limited amount of combustible material in the station ticket hall environment, together with a well ventilated environment implies that the risk is very low.

#### **3.1.6.1.10 Overall Assessment:**

Smoke and toxic fume emission are well within acceptable safety limits, with smoke being the most critical parameter. The ventilation of the immediate area will therefore be a critical mitigating factor.

The limited mass of material, combined with the compartmentation provided makes the risk of a fire spreading beyond the immediate  $1.25 \text{ m}^2$  fire region negligible, assuming there are no other fire non-compliances in the immediate vicinity.

#### **3.1.6.2 Example 2 - Electrical Equipment, Including Batteries, Located in a 1 Hour Rated Equipment Room**

This is an example of a typical 'rear of house' installation, of the type becoming increasingly common in signalling and communications equipment rooms across the network. The room has a 1 hour fire compartmentation rating for smoke and flame spread, together with smoke detection, but no suppression. The principal concern is therefore the build-up of hydrogen gas from the batteries over-charging, which is covered in the separate Section of this document.

#### **3.1.6.3 Example 3 - Use of Train Wheel/Rail Lubrication Grease in Tunnels**

**3.1.6.3.1** This is an example of a typical tunnel installation, which is non-fire compliant, but which has important operational, safety and reliability implications for the railway. The grease to be used is optimised for the wheel/rail interface lubrication application, and does not compromise other safety critical systems such as signalling track circuits or train position detectors. The grease and dispenser are considered together as one system, with the grease contained in a metal tank, with a single precise shot delivered with the passing of each train wheel onto the flange of the rail. The grease is also bio-degradable, so it will not accumulate long term in tunnels or under trains. The known fire data associated with the grease is detailed below:

- a) combustibility (time taken to consume 25g of grease by mass loss rate method) = 1.2 minutes;
- b) smoke emission to BS 6853 D8.3:  $A_o = 0.11 \text{ m}^2/\text{g}$ ;