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NFCC
National Fire
Chiefs Council



National
Operational
Guidance

National Operational Guidance: Scheduled review

National Operational Guidance topic	
National Operational Guidance: <i>Foundation for firefighting</i>	
Change originator	
NFCC Portfolio – National Operational Guidance content team	
Change requested	
<p>A pre-review survey was carried out in mid-2021; the feedback included comments such as:</p> <ul style="list-style-type: none"> • This has mixed up information for policy writers with background technical knowledge and so makes the document hard to read and digest • It would be easier to read and digest if it were in the style of a foundation document like BA • Consideration to the size of the document; would smaller documents be more user friendly? <p>The question was asked: Should the <i>Firefighting equipment knowledge sheets</i> be incorporated within guidance, remain as supplementary information or be archived. 75% of consultees opted for the option for the content to remain as supplementary information.</p> <p>The approach has been taken to develop a <i>Foundation for firefighting</i>. To avoid multiple publications, this publication includes the firefighting equipment knowledge sheets.</p>	
Changes proposed	Rationale for change
Create a <i>Foundation for firefighting</i>	<p>Foundation content relating to firefighting currently published in the <i>Foundation for hazardous materials</i>. There is also a publication <i>Firefighting equipment knowledge sheets</i>.</p> <p>These should be pulled together into a single foundation publication, along with other foundation-type content currently published in the <i>Fires and firefighting guidance</i>.</p>
Incorporate the <i>Firefighting equipment knowledge sheets</i> into the <i>Foundation for firefighting</i>	To consolidate the publications that users need to refer to, incorporate the required content about firefighting equipment into the <i>Foundation for firefighting</i> .
Change in term from <i>fire gas explosion</i> to <i>smoke explosion</i>	Subject matter expert confirmed that the original term is inaccurate and had historically been adopted in error.
Consultation process	
Pre-consultation focus group: 16 February 2022	

Open consultation: xx March 2022 to xx April 2022

Governance process

- Recommended by NFCC Operational Guidance Forum Click or tap to enter a date.
- Approved by NFCC Operations Committee Click or tap to enter a date.
- Approved by NFCC Steering Group Click or tap to enter a date.

Impacts on other guidance and National Operational Guidance products

- Removal of the relocated foundation content that relates to the *Foundation for firefighting* from the *Foundation for hazardous materials*
- *Firefighting equipment knowledge sheets* incorporated into the *Foundation for firefighting*



National
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Foundation for firefighting

The link to the consultation survey is

<https://www.smartsurvey.co.uk/s/Firefighting2022/>

2021

For consultation

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1 **Introduction**

2 This publication, Foundation for firefighting, has been developed to address two topics:

- 3 • High-level scientific information about fires, to support the Firefighting guidance
- 4 • Generic information about firefighting equipment, which falls outside the scope of guidance

5 **Scientific information about fires**

6 The aim of this publication is to provide the scientific information that would support understanding about
7 fire dynamics and fire behaviour, rather than providing complete knowledge about the topic.

8 There are many publications and training courses that can be used to gain a wider understanding or
9 professional qualifications, and it is recommended that these are referred to if required.

10 Another aspect of understanding fire is recognising the chemical reactions that are occurring. This is also
11 provided by many publications and training courses, with a summary being provided in the Foundation
12 for hazardous materials.

13 **Generic information about firefighting equipment**

14 As this information is generic, further or more technical information should be obtained from the
15 manufacturer of the equipment if required.

16 **Relevance to firefighting**

17 A sound understanding of the physics and chemistry of combustion will help with accurately identifying
18 the type of fire.

19 This knowledge, combined with experience, will enable firefighters to understand the relationship
20 between the types of combustion, phases of fire and the products of combustion, and how these are
21 likely to interact in a fire situation.

22 The situational awareness informed by this knowledge assists with decision-making and determining
23 tactical actions, to ensure that any fire is appropriately, safely and efficiently extinguished.

24 In summary, personnel should have an understanding of what a fire is and the conditions required for it
25 to start (ignite) and grow (develop) so that they can tackle and extinguish the fire and be safe and
26 effective in their role.

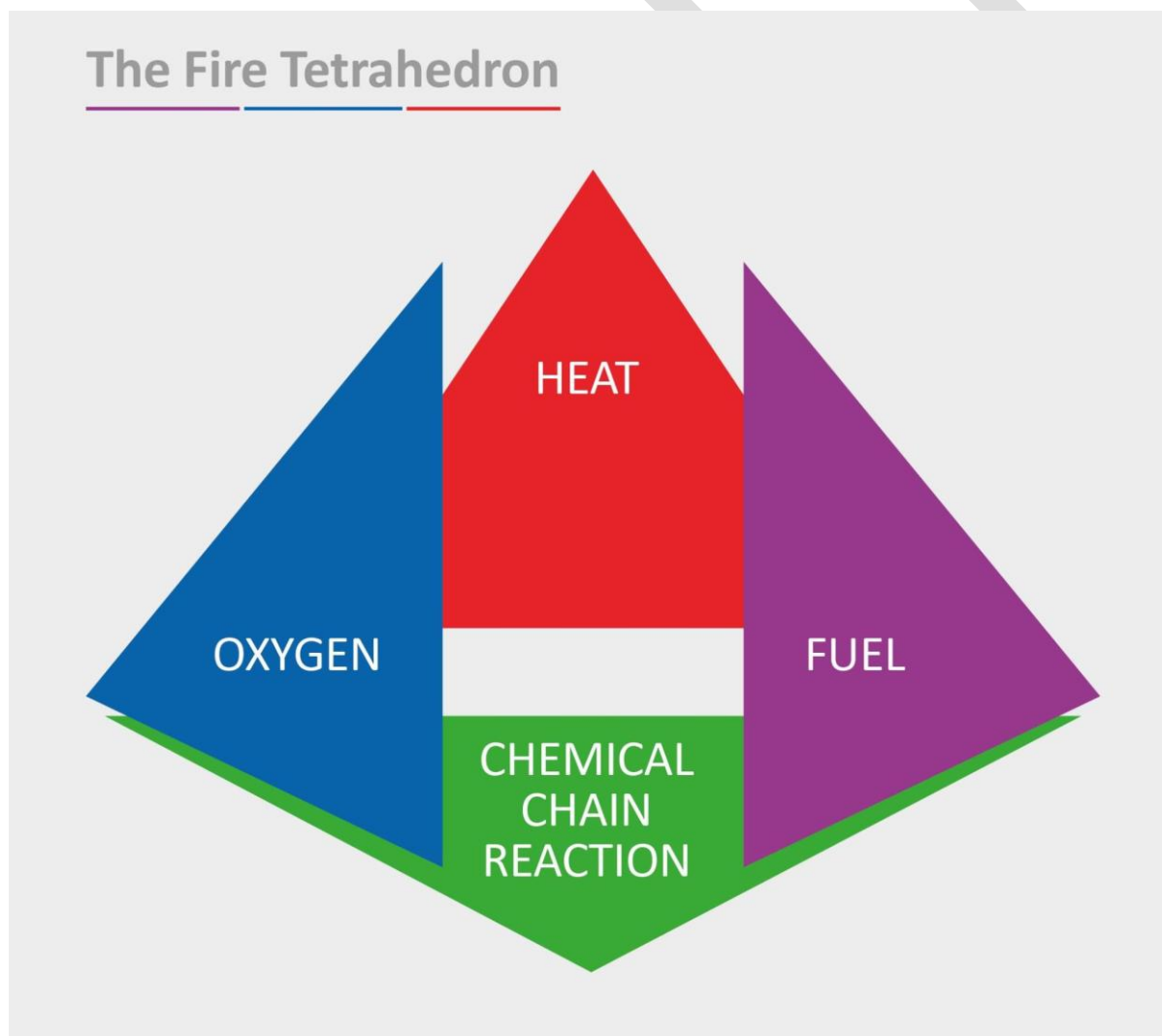
27 Science of fire and combustion

28 Fire is the result of a chemical reaction called combustion. Combustion is a chemical reaction between
29 oxygen and a fuel source that produces chemical energy in the form of heat and light.

30 To understand the process of combustion and the subsequent behaviour of a fire, personnel should have
31 a basic understanding of the elements required for combustion to occur. In the first instance, a
32 combustible fuel must be present, along with a sufficient quantity of oxygen and a source of ignition or
33 heat.

34 This is commonly referred to as the 'triangle of fire'. For many years, this simple triangle of fire (heat, fuel
35 and oxygen) has been used to illustrate our basic understanding of fire. While it remains useful from a
36 technical perspective, there is a fourth component in the chemical chain reaction, which is extremely
37 important for fire suppression and extinguishment.

38 The three elements of heat, fuel and oxygen need to be sufficiently balanced for combustion to occur.
39 They must then continue to interact in such a way that they create a self-supporting chemical chain
40 reaction to maintain the combustion process. This is described as the fire tetrahedron. Each component
41 of the tetrahedron must be in place for self-sustaining combustion to continue.



42

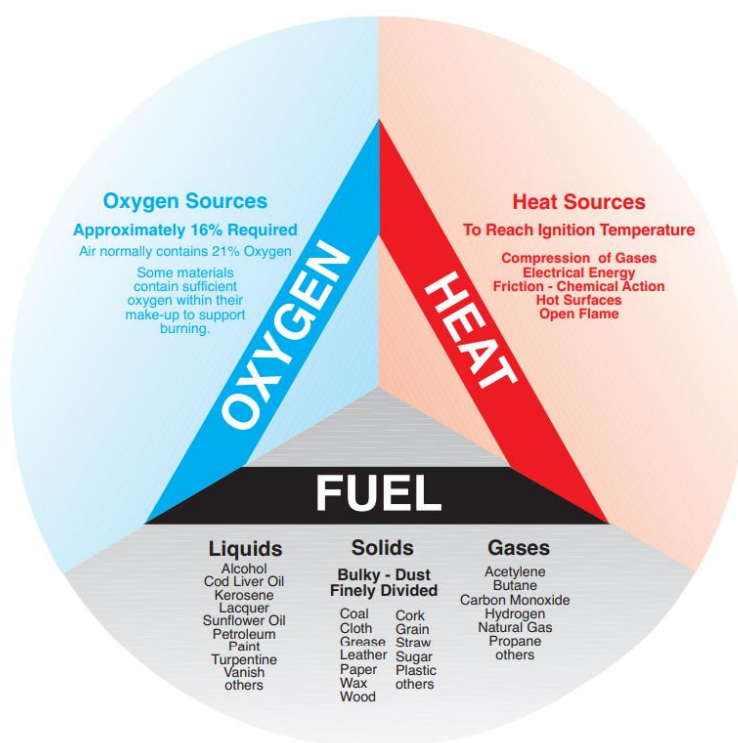
43 Figure: Diagram showing the fire tetrahedron

44 Combustion

45 For combustion or burning to occur, oxygen (usually from the air) must combine with a fuel. A fuel may
46 be in any one of the three states (gas, liquid or solid) initially. Flaming combustion involves a solid or
47 liquid fuel being converted into a vapour, which then mixes with air and reacts with oxygen. Smouldering
48 combustion involves a reaction between oxygen (from the air) and the surface of the fuel; this is a
49 complex process and usually occurs with solid fuels that char on heating.

50 A flame is a region in which a sustained, heat-releasing reaction between a fuel in the vapour state and
51 oxygen takes place. This region also emits light, usually with a strong yellow colour, although there are
52 substances, such as methanol, which burn with a weak blue flame that cannot be seen in strong light.

53 Combustion will continue as long as all three triangle of fire elements (heat, fuel and oxygen) are
54 present. Removing one of them leads to the collapse of the fire triangle and combustion stops.



55
56 Figure: Diagram showing the typical sources of oxygen, heat and fuel

57 Heat of reaction and calorific value

58 All combustion reactions release heat energy and are called exothermic reactions. The quantity of heat
59 produced per unit weight of fuel can be calculated and is known as its calorific value. For example, if 12g
60 of carbon (the gram atomic mass) are burned to carbon dioxide, 392,920 joules of heat are produced.
61 This is the heat of combustion; it refers to a standard amount of the fuel (the mole) and has units kJ/mol
62 (kilojoule per mole).

63 The calorific value for carbon is: $392,920 / 12 = 32,743$ joules per gram (J/g), as one mole of carbon
64 contains 12g.

65 Besides calorific value, the rate of heat release is also important. For example, burning magnesium
66 produces less heat than burning carbon, but when rates of reaction are considered, as magnesium has a
67 much higher rate of combustion than carbon, the heat is released much more rapidly. Heat release rate

68 is a major factor in whether a fire will spread over materials; a device called a 'cone calorimeter' can
69 measure this quantity for wall linings and building materials, as part of the assessment of their
70 flammability and suitability for their intended use.

71 **Flammability**

72 With a flammable material, a region exists above its surface where the evaporating fuel vapour is mixed
73 with air. At certain temperatures, this well-mixed region will become flammable; that is, the vapour
74 concentration in air is above its lower flammable limit (LFL), or lower explosive limit (LEL). The lowest
75 temperature at which this occurs is called the flashpoint; the temperature at which the application of an
76 ignition source will cause a flame to flash across the surface of the material.

77 This is a premixed flame moving through the vapour and air mixture but, just above the flashpoint, it
78 burns out, or self-extinguishes, because it has consumed the entire vapour. If heating continues, a
79 temperature will be reached at which ignition of the vapours will lead to a flash, followed by the
80 development of a sustained diffusion flame at the surface flame. This temperature is known as the fire
81 point, the lowest temperature at which the rate of supply of fuel vapours, by evaporation, can sustain the
82 flame.

83 **Flammable range**

84 The flammable range is the range of concentrations of a substance in air when it is flammable.
85 Flammable limits are also referred to as flammability limits or explosive limits. The lower flammable limit
86 (LFL) or lower explosive limit (LEL) describes the leanest mixture that is still flammable, while the upper
87 flammable limit (UFL) or upper explosive limit (UEL) describes the richest flammable mixture. Increasing
88 the fraction of inert gases in a mixture raises the LFL and decreases the UFL.

89 Substances with wider flammable ranges are more hazardous than those with narrow ranges. For
90 example, isopropyl alcohol has a flammable range of 2 to 12 per cent in air, whereas acetylene has a
91 flammable range of 2.5 to 100 per cent. This makes vapour clouds of acetylene much more likely to be
92 flammable in air.

93 For example, mixtures of methane and air will only burn if the concentration of methane in air is between
94 5 and 15 per cent, whereas hydrogen will burn in air at concentrations between 4 and 76 per cent.

Flammable range (% fuel/air by volume)		
Substance	Lower flammable limit (LFL)	Upper flammable limit (UFL)
Hydrogen	4.0	76.0
Carbon monoxide	12.5	74.2
Methane	5.0	15.0
Butane	1.5	9.0
Ethylene	2.7	28.6
Acetylene	2.5	100
Propane	2.4	9.5

95

96 The figures quoted for flammable limits (LFL and UFL) may vary as a number of factors may slightly alter
97 the value, such as pressure, temperature, direction of flame propagation and moisture content of the
98 mixture. In general, the range between limits widens with increased temperature.

99 Vapour monitoring at an incident can determine if the vapour cloud is within the flammable range. If the
100 values found are above the UFL, there will be a risk of ignition when the vapour has further dispersed,
101 resulting in the concentration falling into the flammable range.

102 **Auto-ignition temperature**

103 The auto-ignition temperature (AIT), sometimes called the kindling point, refers to the lowest temperature
104 at which a substance will ignite without a flame or ignition source.

105 The AIT decreases as the pressure increases or where oxygen concentration increases. An application
106 of this is the automotive diesel engine, where the mixture of fuel and air is compressed sufficiently for the
107 diesel to self-ignite and power the vehicle.

108 Pyrophoric substances such as silanes and phosphorus have low auto-ignition temperatures.

109 **Flashpoint and fire point**

110 An ignition source, such as an electrical spark, static electricity or naked flame, can trigger a fire where
111 there are flammable liquids present. However, the likelihood of this occurring also depends on the
112 flammable limits of the flammable liquid.

113 Flammable liquids have a flashpoint of 60°C or lower. Liquids that have a flashpoint above 60°C are
114 termed combustible. Highly flammable or extremely flammable liquids have flashpoints lower than 23°C,
115 which is close to normal ambient temperatures.

116 In a dish of flammable liquid, such as paraffin, a region will exist above the liquid surface in which the
117 evaporating fuel vapour is well mixed with air. If the paraffin is heated above about 40°C, this region will
118 become flammable; the vapour concentration in air is above its lower flammable limit (LFL).

119 The lowest temperature at which this occurs is called the flashpoint; the liquid temperature at which
120 application of an ignition source will cause a flame to flash across the surface of the liquid.

121 This is a premixed flame moving through the vapour-air mixture but, just above the flashpoint, it burns
122 out or self-extinguishes because it has consumed all the vapour. If heating is continued, a temperature
123 will be reached at which ignition of the vapours will lead to a flash, followed by the development of a
124 sustained diffusion flame at the surface flame.

125 This temperature is known as the fire point, the lowest temperature at which the rate of supply of fuel
126 vapours, by evaporation, can sustain the flame.

127 **Oxidation reactions**

128 An oxidation reaction involves a combination with oxygen or other oxidising agents. Oxidation reactions
129 are found in the following typical examples of combustion:

- 130 • The oxygen may be supplied by the air
- 131 • The combustion may take place using oxygen contained within the burning material, where the
132 combustible material and the supporter of combustion are present in the same compound

- 133 • Oxygen may be provided by one of the materials in a mixture of compounds; the thermite
134 reaction illustrates this principle, with thermite being a pyrotechnic composition of metal powder
135 and metal oxide
- 136 • Elements other than oxygen may be considered as oxidising agents, such as chlorine and
137 fluorine; combustion may occur with these substances, for example, hydrogen will burn
138 explosively with chlorine
- 139 • Many organic materials, which are based on carbon, will burn readily in halogen gases
- 140 • Nitrogen is not usually thought of as an oxidising agent or even a reactive element, but some
141 metals will burn vigorously in this gas; magnesium, aluminium and their alloys form nitrides in
142 combustion reactions

143 **Toxic products of combustion**

144 When a material burns or combusts, it undergoes a chemical reaction that usually involves atmospheric
145 oxygen. This results in products of combustion, some of which may present particular hazards to health.
146 Hydrocarbons and many common materials such as paper, wood and plastic contain carbon. When
147 burned they produce oxides of carbon, including carbon dioxide and carbon monoxide. If smoke is
148 produced in a fire, it will contain particulates, usually of carbon. As carbon monoxide is a toxic gas, it can
149 be assumed that all smoke is toxic. Products of combustion will either be toxic or asphyxiant.

150 Particular concern needs to be taken if the products of combustion are corrosive or acutely toxic. These
151 tend to be produced when the chemical products undergoing combustion contain certain elements, such
152 as:

- 153 • Halogens:
 - 154 ○ Fluorine
 - 155 ○ Chlorine
 - 156 ○ Bromine
 - 157 ○ Iodine
- 158 • Metals and particularly alkali metals:
 - 159 ○ Lithium
 - 160 ○ Potassium
 - 161 ○ Sodium
- 162 • Certain non-metallic elements in their compound structure, specifically:
 - 163 ○ Nitrogen
 - 164 ○ Sulphur
 - 165 ○ Phosphorus
 - 166 ○ Arsenic)

167 Compounds containing these non-metallic elements are commonly found in products such as
168 detergents, fertilisers and pesticides. If in any doubt about whether fumes are likely to contain these
169 compounds, consult the [Safety Data Sheet \(SDS\)](#) or seek further advice from the manufacturer,
170 hazardous materials adviser or scientific adviser.

171 For example, chlorinated hydrocarbons produce hydrochloric acid (HCl) fumes when they decompose at

172 high temperatures, such as when exposed to a fire or hot surfaces. Inhalation of toxic or corrosive fumes
173 may lead to acid forming in and affecting the lungs and could lead to more serious health effects..

174 **Toxicity**

175 Toxicity is the intrinsic capacity of a chemical to adversely affect an organism.

176 The level of toxicity is distinguished in legislation and, according to the United Nations Economic
177 Commission for Europe (UNECE) Globally Harmonized System of Classification and Labelling of
178 Chemicals, can be highly-toxic, toxic, harmful, and so on, based on the lethal dose.

179 The most common ratings concern acute toxicity, which is a short-term but potentially high exposure.
180 Substances can also have chronically toxic effects, from repeat and cumulative exposure over time. The
181 differences between acute and chronic toxicity are reflected in the criteria for classifying products for
182 transport and supply. For example, cancer is much more likely to develop from repeated occupational
183 exposure to a carcinogen than a one-off acute exposure. There is no necessary correlation between
184 acute and chronic toxicity.

185 The dose-effect relationship is the relationship between dose and effect on the individual level. An
186 increase in dose may increase the intensity of an effect, or a more severe effect may result. Some toxic
187 effects, such as death or cancer, are not graded but are 'all or none' effects.

188 A dose is often expressed as the amount of a substance entering an organism (such as a person) and is
189 expressed in units such as mg/kg body weight. A dose threshold is a dose level below which no
190 observable effect occurs. Thresholds are thought to exist for certain effects, like acute toxic effects, but
191 not for others, like carcinogenic effects or exposure to radiation.

192 The lethal dose (LD₅₀) is the dose causing 50 per cent death in an animal population. LD₅₀ is given as a
193 measure of the acute toxicity of the chemical substance. The lower the LD₅₀ the higher the acute toxicity.
194 The lethal concentration (LC₅₀) is the concentration of the chemical in the air or water that will kill 50 per
195 cent of the test animals with a single exposure.

196 **Eco-toxicity**

197 Further information on eco-toxicity and how to interpret the various values such as biochemical oxygen
198 demand (BOD), toxicity, bioaccumulation and persistence can be found in the [Foundation for
199 environmental protection](#).

200 **What makes a flame a flame?**

201 If a pool of paraffin is heated, its temperature will rise and combustible vapours will evaporate from the
202 surface. When the temperature of the liquid surface reaches about 50 to 55°C, the rate of evaporation is
203 high enough for the vapours to be ignited by a small flame or spark, and support continuous flaming
204 above the surface. After the paraffin has been burning for some time, the surface of the fuel will be close
205 to its boiling point, supplying flammable vapours to the flame.

206 Once a flame has been established and flammable vapours are rising from the fuel surface, heat and
207 what are called chain carriers are produced, where the flame reactions are occurring. A proportion of
208 these will pass into the next layer of gas and start the oxidation and heat release processes there, rather
209 like a relay race. Chain carriers are believed to be atoms or fragments of molecules, known as free
210 radicals, which are extremely reactive. The type of chemical reaction that occurs in the flame is known
211 as a chain reaction.

212 There are two distinct types of flame:

- 213 • Premixed flame
- 214 • Diffusion flame

215 The types of flame have different properties, although both are familiar from everyday experience.
216 Understanding that each behaves differently is important. Under different circumstances, fuel and air can
217 combine in different ways to produce very different results.

218 **Turbulent flow and laminar flow**

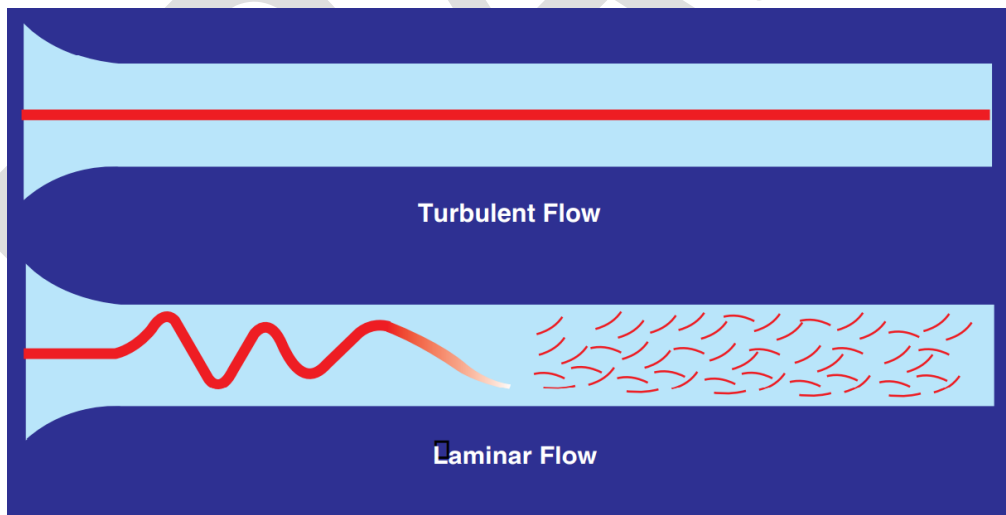
219 Before discussing flames, it is useful to define two types of gas flow.

220 **Turbulent flow**

221 There are random changes in velocity and direction of the flow, although the flow as a whole is moving in
222 a definite direction. When wind blows down a street on a windy day, leaves and litter may be blown up,
223 down, across and around, revealing local changes in the flow, but the general direction of the wind is still
224 down the street. Turbulent flow tends to occur in fast flows over rough surfaces and around obstacles.

225 **Laminar flow**

226 There is a steady flow in which two particles starting at any given point follow the same path. Particles
227 never cross each other's paths, so the particle paths are bunched together, like uncooked spaghetti in a
228 packet. At any given time, the velocities of all particles on one path are the same, but the velocities of
229 particles in different paths might be different. Laminar flow is associated with slow flow over smooth
230 surfaces.



231
232 Figure: Diagram showing turbulent flow and laminar flow

233 **Premixed and diffusion flames**

234 A flame is the region in which chemical reactions take place and turn unburnt fuel vapours into burnt
235 gases. The combustion products, for example methane and oxygen, react to give carbon dioxide and
236 water vapour.

237 A certain amount of heat energy is required to start this reaction, but as more heat is produced by the
238 reaction than it takes to initially start it, the burning process is self-sustaining.

239 Premixed flames

240 Premixed flames occur when a fuel is well-mixed with an oxidant, for example, 10% methane mixed with
241 air. For ignition to occur, energy must be supplied in the form of a spark or small flame. A self-sustaining
242 flame will then be established around the ignition source and will propagate outwards in all directions.

243 The flame consists of a zone where cold, unburnt gas (reactants) is transformed into hot burnt gas
244 (products). The flame zone of a premixed flame may be less than 1mm thick. As the volume of the hot
245 burnt gas is greater than that of the same mass of cold unburnt gas, the flame front is pushed outwards
246 from the ignition point, like the skin of an inflating balloon.

247 Not every mixture of air and fuel will burn. Depending on the type of fuel and oxidant involved, for
248 example, air or pure oxygen, a mixture initially at room temperature and pressure will only burn if the
249 concentration of fuel is between a well-defined [flammable range](#).

250 For each mixture of fuel and air between the flammable limits (LFL and UFL), there is a characteristic
251 burning velocity at which a premixed flame will propagate through a stationary gas. Burning velocity is
252 dictated by the chemical processes involved; how quickly the fuel reacts with the oxygen. The methane
253 and oxygen molecules do not simply combine instantly to form carbon dioxide and water vapour, but
254 form free radicals and intermediates such as formaldehyde and carbon monoxide along the way to
255 completing the reaction.

256 If the premixture flows into a flame with a laminar flow whose velocity is equal to the burning velocity of
257 the mixture, the flame can be held stationary. This is how premixed flames on equipment such as gas
258 cooker hobs and Bunsen burners are held steady.

259 Local air currents, and turbulence caused by obstacles, can cause a flame to move at speeds much
260 higher than the burning velocity. The speed at which a flame moves relative to an observer is the flame
261 speed, which is different to the burning velocity. For example, the burning velocity of a methane-air flame
262 is about 0.45m/s. If the unburnt gases are no longer stationary, the flame propagates at the local flow
263 speed plus the burning velocity. As the flame gets faster, the flame front wrinkles as turbulence is
264 produced in the unburnt gas, increasing the surface area of the flame front. This increases the reaction
265 rate, increasing the rate at which burnt gas is produced, so pushing the flame front forward faster.

266 In explosions, flame speeds of hundreds of metres per second can be achieved in gas-air mixtures,
267 though the burning velocity of the mixture will be much lower than this. It is possible to achieve
268 supersonic flame speeds, in which the combustion region is strongly coupled to a shock wave; this
269 phenomenon is called detonation.

270 Diffusion flames

271 Diffusion flames occur at the interface where fuel vapour and air meet. Unlike premixed flames, the fuel
272 vapour and the oxidant are separate prior to burning. The dominant process in the diffusion flame is the
273 mixing process. The fuel vapour and oxygen mix by molecular diffusion, which is a relatively slow
274 process, though the high temperatures associated with flames increase the rate at which diffusion
275 occurs.

276 Because diffusion flames exist only at the fuel-air interface, there is no equivalent of burning velocity,
277 and no equivalent to rich or lean mixtures, or flammable limits.

278 Diffusion flames fall into two broad types:

- 279
- 280
- Laminar diffusion flame – in slow-burning diffusion flames, such as candle flames, the fuel vapour rises slowly from the wick in a laminar flow, and molecular diffusion dominates
- 281
- Turbulent diffusion flame – in industrial burners, fuel is injected into the air at high velocity, as a spray or jet. Turbulence is induced at the interface where mixing takes place. This gives the flame
- 282
- 283
- 284
- 285

286 In a large fire of more than 1m diameter, the flames are turbulent diffusion flames, with the turbulence
287 generated by the strong buoyancy of the flames themselves. Inside the flame, there are regions of high
288 temperature and low oxygen concentration, where the fuel vapour is subjected to a mixture of pyrolysis
289 (chemical decomposition in the absence of oxygen) and partial oxidation. This leads to the formation of
290 soot particles and products of incomplete combustion, in particular carbon monoxide. These are the
291 source of smoke and fire gases that make fire products toxic.

292 **Vapour cloud fires**

293 **Flash fires**

294 The term flash fire is used to describe what happens if the temperature of the fuel is much greater than
295 the fire point and a flammable vapour-air zone exists at some distance from the liquid surface. This may
296 happen if there is a spillage of petrol, with a fire point of approximately -40°C, that forms a large pool. If
297 an ignition source is introduced into the flammable zone, a premixed flame will flash back, igniting the
298 fuel in the fuel-rich mixture above the liquid surface and giving rise to a large fire with a turbulent
299 diffusion flame.

300 In a sustained fire of this type, flames burn continuously above the surface until the fuel is consumed or
301 the fire is extinguished. In principle, combustible solids burn in the same way, although the formation of
302 fuel vapours involves chemical decomposition of the solid, which requires more energy than simple
303 evaporation. For this reason, solids tend to burn much slower than combustible liquids.

304 **Fireballs**

305 A fireball can occur when a mixture of vapour and mist droplets forms a cloud containing very little air;
306 the oxygen concentration is too low for premixed combustion to take place. However, if there is an
307 ignition source at the boundary between the fuel and surrounding air, a premixed flame will flash through
308 the flammable zone at the boundary, producing a diffusion flame. A fireball is established and rises as it
309 burns; as burning continues, instabilities at the surface of the flame increase surface area and the fireball
310 will increase in size until it uses up the fuel.

311 **Vapour cloud explosions**

312 After ignition, any obstacles will create turbulence in the vapour mixture, increasing the amount of
313 burning and flame spread. This may lead to overpressures that can, in certain circumstances, cause
314 blast damage. An overpressure is the difference between the highest instantaneous pressure at a point
315 subjected to a shock wave and the ambient atmospheric pressure.

316 **Ignition**

317 For ignition to occur, sufficient heat energy is supplied to gaseous fuel and an oxidant, either mixed to
318 within flammable limits or at the interface between the fuel and the oxidant, to start a self-sustaining

319 chemical reaction. This energy is generally supplied by a flame, spark or a hot surface, but ignition can
320 occur in other ways including:

- 321 • Spontaneous ignition temperature – this is the lowest temperature at which the substance will
322 ignite spontaneously, that is the substance will burn without the application of a flame or other
323 ignition source. This is sometimes referred to as the [auto-ignition temperature](#).
- 324 • Self-heating and spontaneous combustion – certain materials may react with oxygen at room
325 temperature. Compounds that contain carbon-carbon double bonds, such as linseed oil, are very
326 prone to this reaction, but any organic material in bulk quantities may be suspect, especially if it
327 has been stored at an elevated temperature. Sometimes the action of bacteria on organic
328 materials can cause a rise in temperature that will eventually lead to active combustion; haystacks are one example of this. Powdered material can lead to spontaneous combustion. In
329 the manufacture of some plastics, such as polyurethane foams, the crosslinking process that
330 creates the final molecular structure of the material is exothermic, and can lead to spontaneous
331 combustion if slabs of foam are stored before the process is complete.
- 332 • Smouldering – this only occurs in porous materials that form a solid carbonaceous char when
333 heated. Paper, sawdust, fibreboard and latex rubber can all undergo smouldering. Smouldering is
334 the combustion of a solid in an oxidising gas, such as air, without the appearance of a flame. The
335 process is very slow, but smouldering fires can be hidden for a very long time and can produce a
336 large amount of smoke. The smoke is flammable, but it must accumulate and reach its lower
337 flammable limit before it can be ignited. Smouldering will undergo a transition to flaming under
338 favourable conditions. As the mechanism is not fully understood, it is impossible to predict how
339 long after smouldering commences that the transition will occur.
- 340

341 **Heat transmission**

342 Heat energy always flows from an object with a higher temperature to an object with a lower
343 temperature. Heat will always flow if there is a temperature difference, no matter how small that
344 temperature difference is.

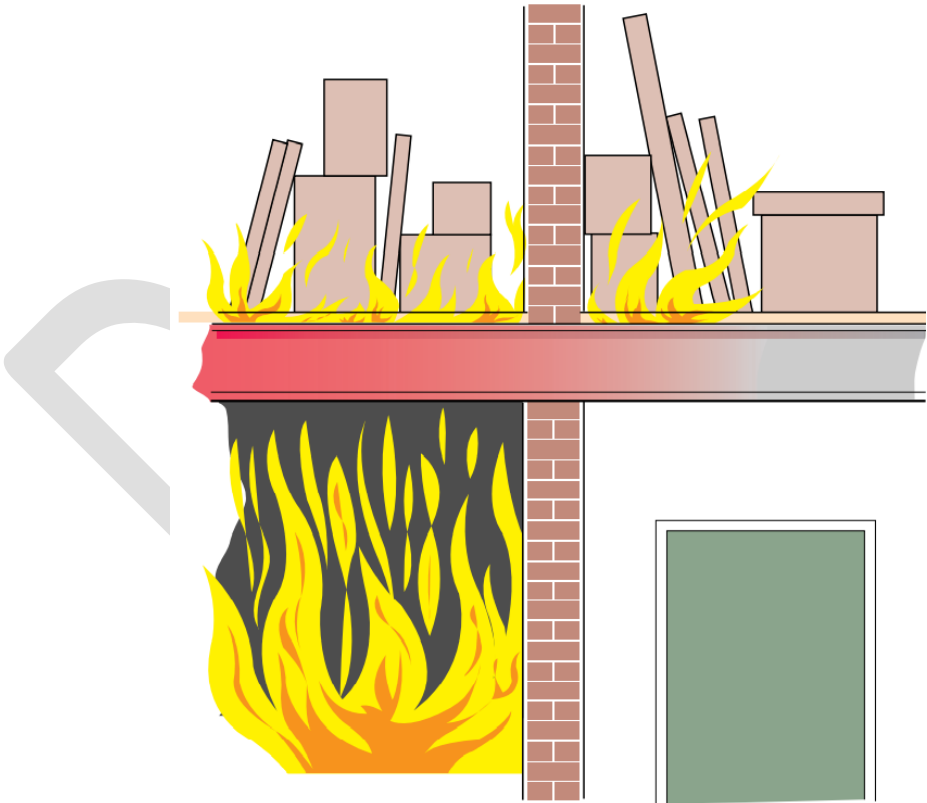
345 There are three methods by which heat may be transmitted:

- 346 • Conduction
- 347 • Convection
- 348 • Radiation

349 **Conduction**

350 Conduction may occur in solids, liquids or gases, although it is most clearly present in solids; heat
351 energy is passed on from each molecule to its nearest neighbour.

352 Thermal conductivity is important at most stages of a fire, but during a fully developed fire there is the
353 hazard of firespread. As steel conducts heat very well, a steel girder passing through a fire wall may
354 conduct sufficient heat through to the neighbouring room or compartment to start a fire there. It is not
355 necessary for flames to spread through the fire wall itself, as shown in the illustration below.



356
357 Figure: Illustration showing how fire may be spread in a building due to the conduction of heat along an unprotected steel girder

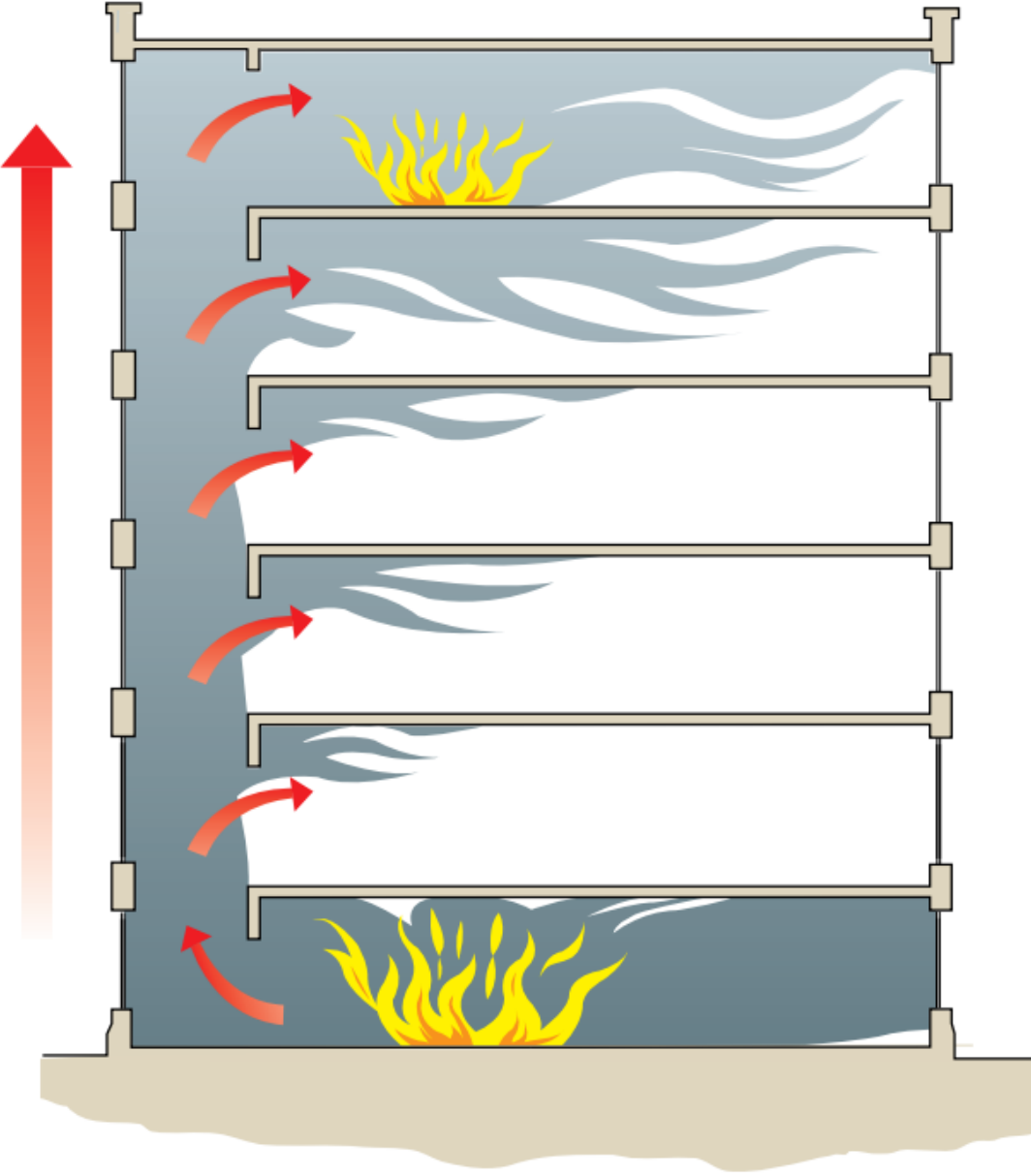
358 **Convection**

359 Convection only occurs in gases and liquids. The term convective heat transfer is used to describe the
360 transfer of heat between a gas or liquid and a solid. For example, a hot object in air loses heat partly by
361 convection; the layer of air next to the hot surface becomes heated, and buoyant with respect to the

362 surrounding cold air. It then rises, carrying away the heat, which is replaced by cold air. This in turn
363 becomes heated, and a convection current is set up that cools the solid.

364 Convection is used in domestic hot water systems and many heating systems use 'radiators'. Most of the
365 heat from radiators is carried away by convection. Convection also causes the updraft in chimneys.
366 Thermosyphons use this principle for the circulation of liquids and volatile gases in heating and cooling
367 applications such as heat pumps, water heaters, boilers and furnaces.

368 If a fire occurs in a building, convection currents can convey the hot gases produced upwards through
369 stairwells and open lift or service shafts, as shown in the illustration below, thereby spreading the fire to
370 the upper parts of buildings.



371
372 Figure: Illustration showing how fire on a lower floor can spread to upper floors by convection.

373 **Radiation**

374 All objects give out and take in thermal radiation, which is also called infrared radiation. The hotter an
375 object is, the more infrared radiation it emits. It is a type of electromagnetic radiation that involves waves;

376 no particles are involved, unlike conduction and convection. Because no particles are involved, radiation
377 can even work through the vacuum of space.

378 Thin or flat objects will radiate heat energy faster than a thicker object. Surfaces vary in how they reflect
379 and absorb infrared radiation, with some high-level examples shown in the following table:

Surface	Absorption	Emission	Reflection of infrared radiation
Dull, matt or rough	Good	Good	Poor
Shiny	Poor	Poor	Good

380

381 Many fires are caused by radiation, with one of the most common causes being laundry placed too close
382 to a source of radiated heat, such as an electric fire.

383 Radiant heat from the sun passing through a window can be concentrated by an object inside the
384 building which acts as a lens, such as a magnifying glass, glass ornament or a mirror. Old-fashioned
385 'bottle glass' used in windows can also concentrate the sun's rays and could cause a fire. Sunlight being
386 concentrated by a discarded bottle onto flammable material, such as dry grass or leaves, could create a
387 fire in the open.

388 When radiant energy falls on an object, there are three possibilities:

- 389 • **Transmission** – if energy passes through the object without warming it, it has been transmitted
390 through the object; for example, transparent materials transmit light
- 391 • **Absorption** – the energy is absorbed by the object, whose temperature is raised
- 392 • **Reflection** – the energy may be reflected back from the surface in the way that light is from a
393 shiny surface; reflected energy does not enter the object, it just 'bounces off' the surface

394 **Fire dynamics**

395 Fire dynamics is the study of how fire behaviour is influenced by the interaction of:

- 396 • Chemistry
- 397 • Fire science
- 398 • Material science
- 399 • Mechanical engineering disciplines of fluid mechanics and heat transfer

400 Fire dynamics is the study of how fires start, spread and develop. This helps to inform the effective
401 application of firefighting media, which for a building would be based on information such as:

- 402 • Construction and occupancy
- 403 • Fire load
- 404 • Compartment size, in terms of area and height
- 405 • Sizes of openings
- 406 • External environmental conditions, including wind speed and temperature differentials

407 **Heat**

408 This is the thermal energy that is transferred from one body to another. It is measured in the metric units
409 of joules (J) or kilojoules (kJ). Heat energy is always transferred from an object with a higher temperature
410 to an object with a lower temperature.

411 **Fire load**

412 The fire load (or fuel load) is the total amount of heat energy that is available to be released in a fire. In a
413 time dependent heat release rate (HRR) fire growth curve, the area under the curve represents the fire
414 load. The weight (mass) of the fire load may be measured in kilograms (kg).

415 The fire load can be measured in megajoules per square metre (MJ/m²). In a building this represents the
416 heat energy that could be released per square metre of floor area, including combustion of the contents
417 and the structure itself.

418 High density fire loads can be very difficult to extinguish and the higher the fire load, the more firefighting
419 media will be required.

420 **Heat release rate**

421 The heat release rate (HRR) is the rate at which a fire releases energy (or power). HRR can be
422 measured in watts (W), kilowatts (kW) or megawatts (MW), and demonstrates the intensity of the fire at
423 any point in time. One watt is equivalent to one joule per second. The peak heat release rate (PHRR) is
424 the measure that determines when a fire is burning at its greatest intensity.

425 The HRR can only be an estimation, based on the fire load and ventilation profiles, but is useful to gain
426 an understanding about the intensity of the fire. Approximations of HRR can inform:

- 427 • The likely burning duration
- 428 • A prediction of how difficult it may be to extinguish the fire

- 429
- The quantity of water required to extinguish the fire

Typical peak heat release rates (fire intensity/power)	
Fire type	Typical peak heat release
Lighted match	80W (0.08kW)
Office waste bin	4 to 18kW (0.004 to 0.018 MW)
Bedroom fire	3 to 13MW
Single car fire	5 to 9MW
Fully involved flat of 70m ²	10 to 20MW
Office of 240m ²	30 to 35MW
Warehouse of 500m ²	>100MW

430

431 Research estimates that 24.42L/min of water is able to absorb one MW of heat energy release in a
 432 building fire. Therefore, a fire generating 10MW of heat energy would require an applied flow rate of at
 433 least 245L/min. This further suggests that fires releasing heat energy of around 20MW or 30MW are the
 434 largest size that may be handled by a 500L/min or 750L/min jet respectively. These sizes of fires can
 435 occur if there are large open floor spaces, such as open plan offices or retail stores, or high vertical fire
 436 loads, such as storage warehouses or large retail DIY superstores.

437 **Temperature**

438 Temperature is a measure of the average thermal energy, with the most common measurement being
 439 the centigrade scale. For more information refer to [Thermometric scales](#).

440 **Heat flux**

441 The term 'heat flux' refers to the quantity of heat as thermal radiation, and measured in kW/m², that is
 442 received at a particular point. The level of heat flux will impact on the amount of time that personnel can
 443 work for safely and effectively, and is a consideration for the performance of personal protective
 444 equipment (PPE) for firefighting, as described in [BS EN 469:2020 Protective clothing for firefighters: Performance requirements for protective clothing for firefighting activities](#).

446 **Pyrolysis**

447 Pyrolysis is the chemical decomposition of organic carbon-based materials due to the application of
 448 heat. Pyrolysis, which is also the first step in gasification and combustion, occurs in the absence or near
 449 absence of oxygen. This differentiates it from combustion, which requires sufficient oxygen for it to occur.
 450 The rate of pyrolysis increases with temperature.

451 Pyrolysis is used in large industrial applications at temperatures of around 400°C or higher, or at lower
 452 temperatures for smaller-scale operations. Pyrolysis products always produce a solid, such as charcoal
 453 or biochar, a liquid, and non-condensable gases, such as hydrogen, methane, hydrocarbons, carbon
 454 monoxide, carbon dioxide and nitrogen.

455 **Fires in compartments**

456 **British Standards information**

457 The British Standards publication, *Application of fire safety engineering principles to the design of*
 458 *buildings – Part 5: Fire and rescue service intervention (PD 7974-5:2014+A1:2020)*, provides useful
 459 background information about fires in compartments. Section 8 of the publication provides a *Quantitative*
 460 *analysis of the effectiveness of fire and rescue service intervention*, with section 8.5 of the publication

461 stating:

462 *The fire service has a statutory responsibility under the Fire and Rescue Services Act, to take all*
463 *reasonable measures to ensure that an adequate supply of firefighting water is available. It is important*
464 *therefore that effective fire-fighting access, facilities and other fire protection measures are provided to*
465 *support a safe and extended firefighting operation, for what is considered a “reasonable” time period.*

466 Annex A of the publication provides many examples of research carried out on fire growth rates and
467 firefighting flow rates.

468 **Phases of fire development in a compartment**

469 The development of a fire in a compartment is influenced by the available fuel and air. Modern materials
470 can provide an abundant amount of fuel and as the available oxygen is soon consumed, thereby
471 preventing combustion, this is referred to as ventilation-controlled. The following diagrams show how a
472 fire in a compartment can be influenced.

473 ***Editor’s note: Diagrams will be reviewed and added prior to publication***

474 **Flashover**

475 In a fire in a compartment there can come a stage when the total thermal radiation from the fire plume,
476 hot gases and hot compartment boundaries causes the generation of flammable products of pyrolysis
477 from all exposed combustible surfaces within the compartment. Given a source of ignition, this will result
478 in the sudden and sustained transition of a growing fire to a fully developed fire. This is called flashover.

479 A room fire with adequate ventilation, may reach the flashover stage within a very short timescale, but
480 will generally reach the greatest level of fire intensity at around 15 to 20 minutes. After this, the fire may
481 enter a short period of steady state burning before entering a decay stage of fire growth, gradually
482 declining until almost the entire fuel load has been consumed.

483 According to this definition, a backdraught can be considered as a special case of a flashover. If the
484 backdraught results in a sustained fully developed fire, a flashover has occurred. However, it is important
485 to be able to draw a distinction between the two because the implications for personnel are very
486 different.

487 The primary requirement for a flashover to occur is that there should be significant thermal radiation from
488 above. This will be felt by personnel as a rapid increase in the temperature in the compartment, and in
489 the heat from the hot gases at ceiling level, forcing them down low. If they can see above them, tongues
490 of flame may be seen running through the gas layer. In addition, other combustible materials within the
491 compartment will be giving off visible smoke and flammable gases.

492 **Backdraught**

493 Limited ventilation can lead to a fire in a compartment producing fire gases containing significant
494 proportions of partial combustion products and unburnt pyrolysis products. If these accumulate, the
495 admission of air when an opening is made to the compartment can lead to a sudden deflagration. This
496 deflagration moving through the compartment and out of the opening is a backdraught.

497 The first clue to the possibility of a backdraught is the history of the fire. If the fire has been burning for
498 some time, has generated lots of smoke which is now leaking out from the building, and has apparently
499 died down without major areas of flame being visible from outside, the possibility is that it has died down
500 from oxygen starvation.

501 When the building is viewed from outside, it is likely that the windows of the compartment concerned will
502 be blackened, with no obvious flames within. If part of a window is broken, it is possible that this will not
503 provide sufficient oxygen to feed the fire. In this case it is likely that smoke will be pulsing out of the hole.
504 Fresh air is drawn in as the fire cools slightly and the hot gases contract. This produces a local explosive
505 mixture which burns, resulting in a mini-backdraught. The expansion of the hot gases in turn drives some
506 smoke out of the compartment.

507 This cycle repeats itself at a frequency which depends on the size of the hole and the location of the fire
508 relative to it.

509 If there is a gap under the compartment door, there may be smoke pulsing there due to the mini-
510 backdraught effect already described. There may be a whistling noise if air is being drawn into the
511 compartment through very small gaps around the door, but this could be difficult to hear. The door may
512 be hot on the outside. In particular, the door handle may be hot if there is a metal rod linking it to the
513 door handle on the other side.

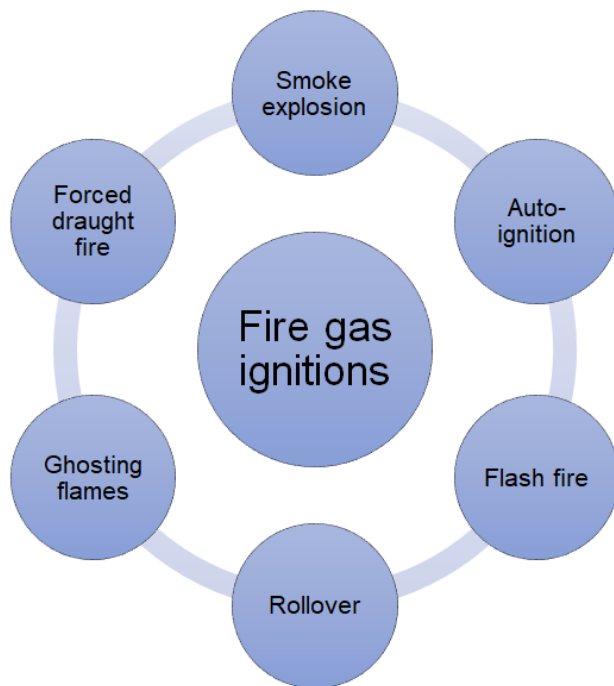
514 If the compartment has been left long enough for it to cool down, air will no longer be drawn in, and the
515 smoke pulsing effect will not be evident. However, if the compartment has not been ventilated and there
516 are still flammable gases present, a backdraught is still possible.

517 If the decision is taken to open the door, there may be an in-rush of air as soon as the door is ajar,
518 showing either that there is a shortage of oxygen in the compartment, or that the compartment has been
519 much hotter and is starting to cool. Small flames may appear where the gases from the room are
520 meeting the relatively fresh air outside, indicating that there are flammable gases in the room that are
521 sufficiently hot to ignite given a source of fresh air, even without any other source of ignition. In either
522 case, it may still be possible to close the door before sufficient air has entered the compartment to trigger
523 any possible backdraught.

524 **Fire gas ignition**

525 The products of combustion include fire gases, especially when the combustion process is compromised
526 due to lack of oxygen. These fire gases can be influenced and lead to fire gas ignitions in the form of:

- 527 • Smoke explosion (previously referred to as fire gas explosion)
- 528 • Auto-ignition
- 529 • Flash fire
- 530 • Rollover
- 531 • Ghosting flames
- 532 • Forced draught fire



533

534

Figure: Diagram showing the types of fire gas ignition

535

Each type of fire gas ignition has its own warning signs, variation of intensity and threat in the combustion process.

537

A fire gas ignition is an ignition of accumulated fire gases and combustion products existing in, or transported into, a flammable state. Any such ignition is usually caused by:

538

539

- The introduction of an ignition source into a pre-mixed state of flammable gases
- The transport of such gases towards a source of ignition
- The transport of a fuel-rich mixture of gases into an area containing oxygen and an ignition source
- An accumulation of heated fire gases transporting through an opening and mixing with air to auto-ignite

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Fire gas accumulations can occur in voids or reservoirs formed under a ceiling or a roof. In some instances, these accumulations of gases will be dispersed at a lower level to entirely fill a compartment or space. If they are pre-mixed with air within the flammable limits, they can ignite or explode as soon as an ignition source makes contact with the fire gases.

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Similarly, very hot gases can auto-ignite as soon as they meet with sufficient air. In this case, the gases move towards the air supply. If the air is moved towards the gases due to a negative pressure in the room or compartment, this is known as a backdraught. If the air is forced into the gases by an external positive pressure, such as wind, the resulting blowtorch fire is called a forced draught.

550

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A fire gas ignition may occur at any stage of a fire without any warning signs. This can even occur sometime after the main fire has been extinguished. The flammability of the fire gases produced from a fire is widely variable, but fires that have smouldered for long periods may produce the most flammable mixtures. A situation can occur where hot gases have cooled to ambient temperatures and been transported into areas remote from the fire. These gases, although cooled, can retain their flammability level.

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559 It is very difficult to predict a fire gas ignition and the conditions may appear to be manageable. However,
560 the following indicators point to the potential for this phenomenon to occur:

- 561 ▪ A ventilation-controlled fire has led to inefficient combustion, producing substantial amounts of
562 unburned pyrolysis products and flammable products of incomplete combustion
- 563 ▪ Presence of void spaces, particularly if they are interconnected
- 564 ▪ Combustible structural elements
- 565 ▪ Infiltration of significant amounts of smoke into uninvolved rooms or compartments in the building
566 or structure

567 The transportation of fire gases into other parts of the building is driven by density, with hot air rising, and
568 pressure from the fire compartment forcing fire gases into, or through, low-pressure areas or openings. It
569 may also be driven by external wind currents or building stack effect.

570 The areas that can be affected include high ceilings, adjacent rooms (on the same floor level or above or
571 below), corridors, stair shafts and hidden voids, especially behind false ceilings.

572 An ignition can occur in varying ways, for example:

- 573 • A flashover in the fire compartment could force flaming combustion into adjacent areas containing
574 flammable smoke
- 575 • If a fire has burned through to an upper level, where there is smoke that has travelled or
576 pyrolysed, on ignition the burning gas layers could travel across and down the stairs, involving all
577 levels within 3 to 4 seconds

578 **Smoke explosion**

579 Fire gases from a smouldering fire could accumulate at a high level, near the ceiling. If a burning ember
580 develops and rises on a thermal current into the gas layer, an ignition could occur that may accompany
581 an explosive pressure wave.

582 **Auto-ignition**

583 Smoke may not need the introduction of an ignition source if the smoke exiting an opening is so hot, that
584 it auto-ignites as it reaches air containing adequate oxygen.

585 **Flash fire**

586 In some cases, the mix with air will cause the fire gases near the ceiling to ignite; it will last a few
587 seconds before disappearing.

588 **Rollover**

589 Where sustained burning exists in a smoke layer existing near the ceiling and generally occurs before a
590 full compartment flashover.

591 **Ghosting flames**

592 The event associated with 'ghosting flames' refers to tiny pockets of fire gases that may exist within a
593 flammable range in the fire compartment. They can auto-ignite in short pops or bursts of flame, which
594 are often blue, that may last 3 to 4 seconds. The smoke surrounding these brief ignitions is generally too
595 rich a mix to ignite. However, ghosting flames serve as a warning sign for an impending ignition of the

596 entire fire gas layer. They are sometimes referred to as dancing angels.

597 **Forced draught fire**

598 A forced draught fire is one resulting from a high-velocity wind (wind driven) or a positive pressure
 599 ventilation (PPV) airflow. It forces flaming combustion several metres out of an opening, which ignites on
 600 meeting outside air. It can also occur through mixing from a forced internal airflow. The event can appear
 601 as a 'flame-thrower' type flame emitting from an opening, as it is a rapid burn-off of fire gases as they
 602 meet air.

603 *Summary of key fire behaviour indicators*

	Fire behaviour indicator	Hazard information
1	Slow-moving light-coloured smoke issuing from an opening	Early-stage fire development or smoke issuing some distance from the fire compartment
2	Fast-moving darkening smoke issuing from an opening	Impending flashover
3	Heavily darkened or heat-crazed windows	Under-ventilated fire conditions threatening backdraught or smoke explosion
4	Pulsing (in and out) darkened smoke movements around closed doors and windows	Fire development heading towards backdraught
5	Very hot doors or windows (feel with back of the hand)	Under-ventilated fire conditions threatening backdraught, smoke explosion or thermal runaway (flashover)
6	Sudden reversal of smoke issuing from an opening, causing smoke to head back into the compartment or building	The fire is rapidly developing and in need of more oxygen (impending flashover or backdraught), or a gusting wind-driven fire event is occurring
7	A rapid lowering of the smoke layer (previously referred to as the neutral plane)	Impending flashover
8	A rising of the smoke layer (previously referred to as the neutral plane)	A vent opening may have occurred at another location in the compartment or building

9	Turbulence or rising and falling (bouncing) in the smoke layer (previously referred to as the neutral plane)	Rapid fire development may be occurring
10	Heat radiating down from the smoke layer (previously referred to as the neutral plane)	Impending flashover
11	Detached 'ghosting' tongues of flame moving around the fire compartment	Impending flashover
12	Flaming combustion seen near the ceiling or at the smoke interface	Impending flashover
13	Smoke seen issuing from closed windows, doors or roof eaves, as if under pressure	Under-ventilated fire and impending backdraught

DRAFT

604

605 **Firefighting equipment notes**

606 **Hose layers**

607 Hose laying vehicles can be used to deliver large-capacity hoses over distances up to 2km.

608 Hoses ranging from 70mm to 150mm diameter are stored in a number of ways. They are deployed using
609 vehicles at low speeds and retrieved using mechanical or physical retrieval systems.

610 **High-volume pumping units**

611 A high-volume pumping (HVP) unit consists of two demountable modules transported on prime movers.
612 Each module consists of two further sub-units, a hose retrieval system and all associated ancillary
613 equipment. The sub-units carry either 1km of hose or the HydroSub.

614 A hook arm attached to the prime mover is used to dismount the modules for use. The sub-units are also
615 removable from the main module for placing as required at an incident.

616 Hose can be deployed using the 1km hose boxes at a maximum speed of 40km per hour.

617 **HVP vehicle equipment**

618 The **HydroSub** is one of the four sub-units transported on the main modules; it weighs three tonnes and
619 is placed in position using the prime mover. It consists of the submersible pump unit, 60m hydraulic hose
620 lines, 60m winch cable for pump deployment and recovery, control panel and the turbo-diesel engine
621 that drives both the hydraulic and electrical systems.

622 The **submersible pump** is a portable centrifugal pump with a high-flow impeller and flotation chamber,
623 which is deployed into the water supply. The submersible pump is capable of deployment up to 60m
624 from the HydroSub. It is used either to supply water to a fireground or to pump out floodwater to a
625 minimum depth of 15cm. It is approximately the size and weight of a light portable pump and is fairly
626 easy to manoeuvre. It has a maximum pumping capacity of 7,000 litres per minute, but has the capability
627 of delivering large volumes of water at great distances, using additional pumps as boosters in a relay
628 system.

629 The HydroSub also has scene lighting and flashing blue lights to allow it to be placed on roads if
630 required.

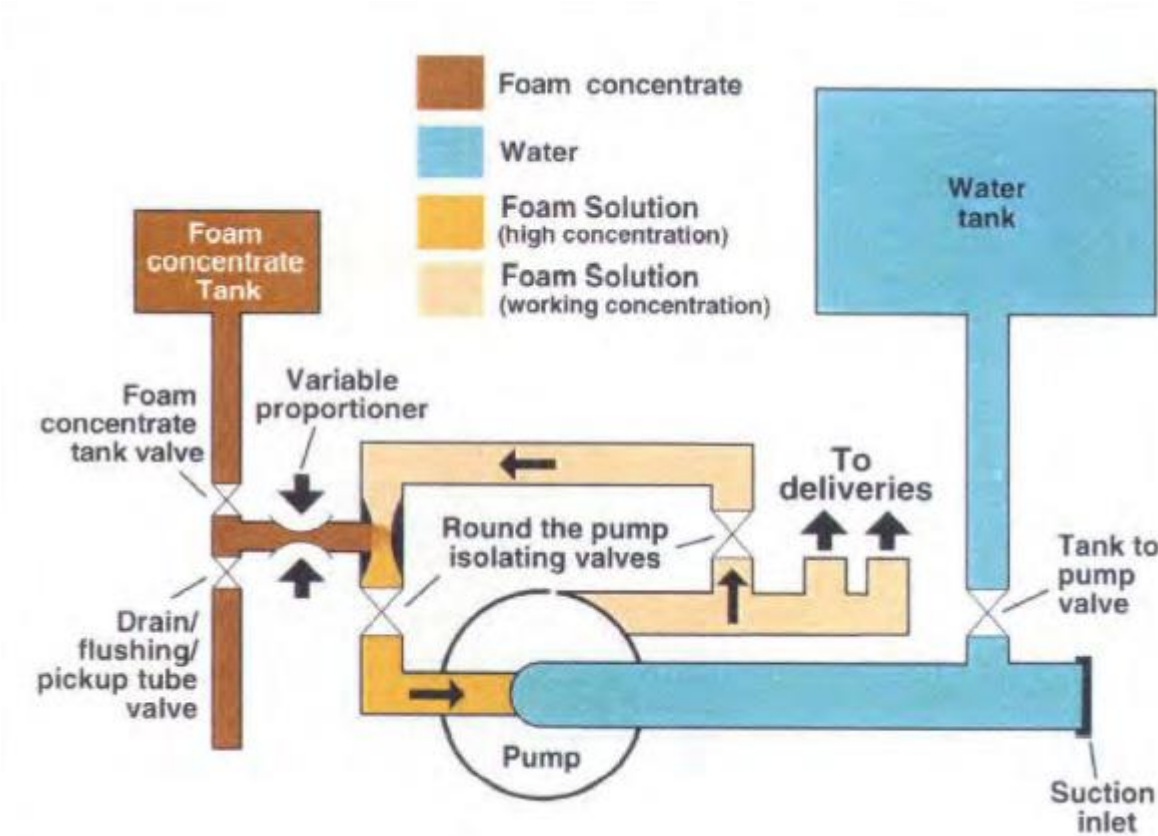
631 Each HVP module has a **mechanical hose retrieval unit**. Driving at a maximum speed of 4km per hour,
632 it assists two people located in the hose box to retrieve the hose, which is flaked back into the hose box
633 ready for redeployment.

634 The HVP module carries a variety of **ancillary equipment**, including hose adaptors, five-way manifolds,
635 Y-pieces, gate valves, non-return valves, water safety equipment, harnesses and lanyards, hose ramps,
636 change of direction equipment, edge protection, sack trolley and lighting, cones and tape.

637 **Foam-making equipment**

638 There are usually two stages in its production. The first stage is to mix the correct proportion of foam
639 concentrate with water to produce a foam solution. This proportioning is carried out by the use of
640 inductors, proportioners or other similar equipment to produce a 'premix' foam solution prior to be
641 delivered to the branch. In addition, some types of foam-making branches are fitted with a means of
642 picking up foam concentrate; these are known as 'self-inducing' with the mixing taking place in the foam-

643 making equipment itself.

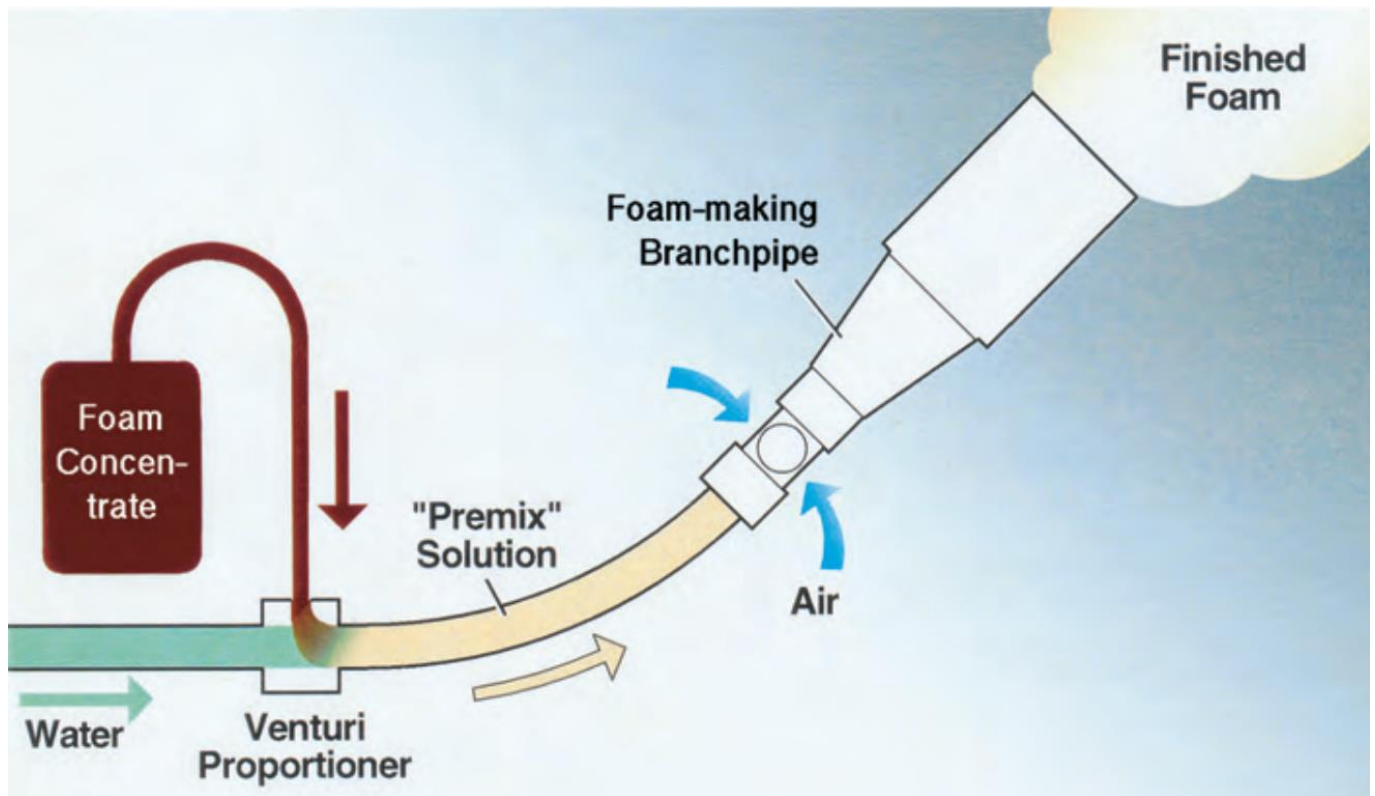


644

645 Figure: Diagram showing the layout of a round-the-pump proportioner system where there is a built-in foam tank

646 The second stage is the addition of air to the foam solution to make bubbles, known as aspiration, to
647 produce the finished foam. The amount of air added depends on the type of equipment used. Hand-held
648 foam-making branches generally only mix relatively small amounts of air into the foam solution.

649 Consequently, these produce finished foam with low expansion (LX) ratios, that is to say, the ratio of the
650 volume of the finished foam produced by the nozzle, to the volume of the foam solution used to produce
651 it, is 20:1 or less. Other equipment is available which can produce medium expansion foam (MX) with
652 expansion ratios of more than 20:1 but less than 200:1, and high expansion foam (HX) with expansion
653 ratios of more than 200:1 and possibly in excess of 1000:1.



654

655 Figure: Diagram showing the production of finished foam

656 When using firefighting foam, consideration should be given to the technique and equipment for delivery.
 657 In general, foam is made by mixing a foam concentrate with water to create a foam solution, which is
 658 then aspirated through equipment. The mixing can use a premix solution in which the foam concentrate
 659 is introduced into the water stream at an earlier stage, usually by some form of induction or injection
 660 equipment. Alternatively mixing can take place in the foam-making equipment as it is aspirated. This
 661 type of foam-making equipment is fitted with a means of picking up foam concentrate through a length of
 662 tube, known as self-inducing.

663 Two main types of foam equipment are described here:

- 664 • Foam-making equipment, including foam-making branches and foam-making generators
- 665 • Foam concentrate induction and injection equipment, including inline inductors

666 The primary aspirating foam-making equipment used by fire and rescue services can be divided into the
 667 following main categories:

- 668 • LX (low-expansion foam) handheld foam-making branches
- 669 • LX handheld hose reel foam unit
- 670 • LX foam generators
- 671 • LX foam monitors
- 672 • MX (medium-expansion foam) handheld foam-making branches
- 673 • LX and MX handheld water branch attachments
- 674 • MX foam pourers
- 675 • HX (high-expansion foam) generators

676 The following equipment is available in various sizes, ranging from those needing less than 50 litres per
677 minute to over 15,000 litres per minute of foam solution.

678 **LX (low-expansion foam) handheld foam-making branches**

679 These branches are intended to produce relatively low quantities of fully aspirated foam using either:

- 680 • Concentrate through a foam pickup tube, connected and inducted at the branch
- 681 • A premixed solution, supplied either through a fire pump with an around-the-pump foam
682 proportioner or an inline foam generator

683 Essentially, turbulence in the foam solution is created in the branch, which draws large quantities of air
684 through air inlet holes, producing the finished foam.

685 At the outlet, the branch is reduced in diameter to increase the exit velocity, thereby helping the finished
686 foam to be thrown an effective distance. The design here is crucial as if the outlet is too narrow it will
687 produce back pressure, which results in less air being drawn and a finished foam of very low expansion
688 ratio and very short drainage times. If the outlet is too large, the expansion is higher, but the throw is
689 reduced. Some branches may also contain flow-straightening sections at the nozzle to reduce turbulence
690 at the outlet of the branch. These assist in forming a coherent 'rope' of finished foam, with little fallout of
691 foam along its trajectory.

692 **LX handheld hose reel foam unit**

693 This consists of a portable handheld unit, similar to an extinguisher, which can contain up to 11 litres of
694 foam concentrate. A fire and rescue service vehicle hose reel is connected to an adaptor at the top of the
695 unit and water is supplied at between 2 and 10.5 bars.

696 A small proportion of the water is diverted to fill a completely deflated flexible bag in the container.
697 Inflation of the bag displaces the foam concentrate through a siphon tube, the concentrate entering the
698 main water stream, passing to an integral LX foam-making branch to give a jet of primary aspirated
699 foam.

700 **LX foam generators**

701 As an alternative to a foam-making branch, an LX foam generator may be used. When inserted into a
702 line of hose, this induces appropriate amounts of foam concentrate and air into the water stream to
703 generate finished foam. This is then delivered through the hose to a water-type branch for application as
704 finished foam. The foam concentrate is induced using the same principle as that of an inline inductor,
705 and the air is drawn in through orifices adjacent to the water inlet.

706 **LX foam monitors**

707 Primary aspirating LX foam monitors are larger versions of foam-making branches, which cannot be
708 handheld. They may be free standing and portable, mounted on trailers or mounted on fire and rescue
709 service vehicles. They usually have multiple water connections, and may be self-inducing or used in
710 conjunction with other methods of foam concentrate induction. They can be found in fixed installations at
711 oil tanker jetties and refineries, or as oscillating monitors in aircraft hangers. Similar monitors are fitted to
712 airport foam tenders, often with adjustable jaws that allow the option of a flat fan-shaped spray.

713 **MX (medium-expansion foam) handheld foam-making branches**

714 With MX foam-making branches, an inline inductor is generally used to introduce the foam concentrate as
715 a premix. The branch then diffuses, aerates the stream of foam solution and projects it through a gauze

716 mesh to produce bubbles of a uniform size.

717 **LX and MX handheld water branch attachments:** Attachments are available for use with some hose
718 reel and mainline water branches, which enable primary aspirated LX and MX foam to be produced.
719 Generally, the foam produced by these attachments is not very well worked, making it less stable, with
720 much shorter drainage times, and less effective than that produced by purpose-designed primary
721 aspirating foam branches.

722 **MX foam pourers:** In addition to the MX handheld foam-making branches, some freestanding MX foam
723 pourers are also available. These are much larger than the handheld models, have higher flow
724 requirements and so produce greater volumes of foam. However, as their name suggests, finished foam
725 pours out of them rather than being projected. They have been designed to stand on integral legs for the
726 unattended delivery of MX foam into banded areas, such as those surrounding fuel storage tanks. They
727 operate in a similar way to the handheld MX foam branches described above.

728 **HX (high-expansion) foam generators**

729 High-expansion foam generators are designed to be used with particular foam concentrate only and
730 usually produce finished foams of expansion ratios of 200:1 to 1,200:1.

731 Air is blown through the generator by a fan and foam solution is sprayed into the airstream, which is
732 directed onto the surface of a fine-net screen. The air blowing through the net wetted with foam solution
733 produces finished foam with a mass of bubbles of uniform size, which is 'poured' rather than 'projected',
734 similar to the MX foam pourers.

735 **Compressed air foam systems**

736 Compressed air foam systems can deliver a range of useful foam consistencies, labelled from type 1
737 (very dry) to type 5 (wet), which are controlled by the air-to-solution ratios and, to a lesser extent, by the
738 concentrate-to-water percentage. Types 1 and 2 foams have long drain times, meaning the bubbles do
739 not burst and give up their water quickly. Wet foams, such as types 4 and 5, drain more quickly in the
740 presence of heat.

741 Compressed air foam systems can produce a wide range of foam qualities or foam types, providing the
742 most appropriate foam response to individual fire situations. Generally, the environmental effects of
743 foams are considered in terms of their toxicity and their biodegradability. It is the total volume of the foam
744 concentrate that is released into the environment that is of concern; it does not matter by how much it
745 has been diluted. For more information refer to Environmental protection - Use, containment and
746 substitution of firefighting foam.

747 **Fire extinguishers**

748 While there still may be a number of old types of fire extinguisher, which expel the extinguishing medium
749 by chemical reaction or by a self-contained hand pump, these have been superseded by extinguishers
750 that use an internal charge of pressurised gas. These are more efficient, less damaging to materials and
751 easier to refurbish.

752 BS EN 3 details fire extinguisher characteristics, performance requirements and test methods. The
753 colour coding, as provided by BS 5306-10, is shown below.

Type	BS EN 3 colour (RAL colour	Description	Suitable for use on fire classes
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	reference and name)							
Water	Red (RAL 3000 – flame red)	Red	A					
Foam	Pale cream (RAL 1014 – ivory)	Red with a cream panel above the operating instructions	A	B			Electrical (if dielectrically tested)	
Dry powder	Blue (RAL 5002 – ultramarine)	Red with a blue panel above the operating instructions	A	B	C		Electrical	
Carbon dioxide CO ₂	Black (RAL 9005 – jet black)	Red with a black panel above the operating instructions		B			Electrical	
Wet chemical	Canary yellow (RAL 1023 – traffic yellow)	Red with a yellow panel above the operating instructions	A	B (sometimes suitable)				F
Specialist powder	Signal violet (RAL 4008 – signal violet)	Red with a violet panel above the operating instructions				D		
Halon	Green (RAL 6016 – turquoise green)	No longer produced – illegal in the UK with exceptions	A					

754

755 **Water-type extinguishers**

756 **Water (gas cartridge) extinguisher**

757 The water content of this plastic-lined steel cylinder is generally six or nine litres and the expellant gas,
758 usually carbon dioxide, is contained in a cartridge fitted inside the body of the extinguisher. The removal
759 of a safety pin or plug and pressure applied on the operating lever of the extinguisher causes a pressure
760 disc on the cartridge to be pierced and at the same time opens a control valve. The release of gas exerts
761 pressure on the surface of the water, forcing it up through a discharge tube and out through a hose and
762 nozzle.

763 **Water (stored pressure) extinguisher**

764 This is of similar construction to the gas cartridge type and available in similar capacities, the difference
765 being that the whole container is pressurised. Air or nitrogen is pumped into it through a special adaptor
766 in the opening head. The extinguisher is operated by removing a safety pin or plug and squeezing an
767 operating lever. This opens the control valve and allows pressurised air to expel the water. Again, the
768 discharge can be controlled by the lever.

769 **Foam extinguishers**

770 Most types of foam concentrate in common use can be found in extinguishers. These include aqueous
771 film-forming foam (AFFF), alcohol-resistant aqueous film-forming foams (AR-AFFF) and film-forming
772 fluoroprotein (FFFP).

773 **Chemical foam extinguishers**

774 These have now largely been replaced by more modern types. The chemical reaction in the extinguisher
775 produces a foam containing carbon dioxide bubbles and the gas pressure itself causes the discharge.

776 **Self-aspirating foam extinguishers**

777 A foam solution is stored in a container, usually of six or nine litre capacity, and either discharged by a
778 gas cartridge of carbon dioxide fitted in the body of the extinguisher or by compressed air or nitrogen,
779 which has been pumped into the container. In both cases, the solution is forced out through the delivery
780 hose and aspirated by the specially designed branch of the low-expansion type.

781 **Non-aspirating aqueous film-forming foams AFFF extinguisher**

782 This is usually a gas cartridge-operated type with a modified nozzle that sprays the AFFF onto the fire.

783 **Dry powder extinguishers**

784 The dry powder used to extinguish or control fires is composed of very small particles of an appropriate
785 chemical or chemicals. This is treated with flow additives to give resistance to moisture absorption and
786 caking during storage, and to give a free flow when discharged through hoses and nozzles. Different
787 chemicals are effective on different classes of fire, and powders are classified according to their potential
788 application.

789 The primary mechanism through which dry powders extinguish a class B fire is a 'chain breaking' action,
790 by changing the behaviour of free radicals, which are formed in the combustion process.

791 Dry powder extinguishers are available in sizes ranging from 1kg to 12kg of powder content. The
792 methods of expelling the powder from the container are similar to those of water and foam extinguishers,
793 either by stored pressure or gas cartridge. The pressurised gas, when released, 'fluidifies' the powder
794 and ejects it through a discharge tube and nozzle.

795 **Carbon dioxide extinguishers**

796 Carbon dioxide extinguishers consist of a pressure cylinder, a control valve for releasing the gas and a
797 discharge horn for applying the gas onto the fire. The carbon dioxide is retained in a liquid condition in
798 the cylinder, which is usually filled to approximately two-thirds of its total capacity. A small amount of
799 carbon dioxide evaporates and fills the top third of the cylinder, and it is this gas which acts as the
800 expellant.

801 On actuation, the discharging gas expands at a ratio of 450:1 and this mostly takes place in the
802 discharge horn, which is used to direct the gas onto the fire. The design of the horn is a very important

803 feature; its main purpose is to stop the entrainment of air with the carbon dioxide by reducing the velocity
804 of the gas. Without this horn, the jet of carbon dioxide gas and air would act like a blowtorch and
805 increase the intensity of the fire.

806 Touching a carbon dioxide extinguisher horn during use can result in a severe frost burn, unless it is a
807 fire extinguisher with an insulated 'frost-free' horn.

808 **Halon extinguishers**

809 Due to legislation, [Commission Regulation \(EU\) No 744/2010](#), halon extinguishers can only legally be
810 used in specific contexts, including:

- 811 • Military:
 - 812 ○ Ground vehicles
 - 813 ○ Surface ships
 - 814 ○ Submarines
- 815 • Aircraft
- 816 • Land-based command and communications facilities essential to national security

817 Each of these exceptions have scheduled end dates, by which time halon extinguishers need to be
818 decommissioned. If a fire and rescue service believes they may encounter and need to use halon
819 extinguishers, they should liaise with the site about their location, application and operation.

820 **Firefighting hose**

821 The main characteristics of good firefighting hose are:

- 822 • Flexibility – hose should be sufficiently flexible to enable it to be handled easily and without
823 knotting when in use, and for it to be made up into a smooth roll whether wet or dry
- 824 • Durability – the durability and wearing qualities should be as high as possible and the materials
825 used, particularly in the warp, should have high resistance to abrasion and be able to withstand
826 the rough usage which hose inevitably receives in service. A tough plastic outer cover gives
827 additional protection to the jacket and prolongs the life of the hose.

828 It is also essential that the hose is easily repairable. However good a hose may be initially, bursts do
829 occur through damage or other reasons.

830 **Change in length and diameter**

831 Any increase in the length or diameter of hose when under pressure indicates that the materials are
832 stretching. Unlimited stretch would tend to weaken and burst the hose. Moreover, lengthwise stretch or
833 extension causes hose to 'snake' when under pressure.

834 **Frictional loss**

835 The internal surface should be as smooth as possible to reduce to a minimum loss of pressure through
836 friction.

837 **Weight**

838 The weight of hose is important, not only from the point of view of handling at fires and drills, but also for
839 stowing on fire and rescue service vehicles.

840 **Hose pressure and acceptance tests**

841 Hose has to stand high internal pressures. During firefighting these pressures may be as high as 10.5
842 bars and shock pressures may be even higher. Hose should be designed to give an adequate margin
843 over pressure likely to be encountered and it is usually constructed to withstand at least twice the
844 pressure to which it is likely to be subjected in use. Manufacturers sometimes indicate the average burst
845 pressure of their various hoses. This is referred to as the 'short length burst pressure' and may be as
846 high as around 40 bars, depending on the type and quality of the hose.

847 **Storage of hose**

848 Many different methods have been developed for storing hose, which may be referred to as:

- 849 • The roll (or coil)
- 850 • Dutch roll (or roll on the bight)
- 851 • Flaking
- 852 • Figure of eight
- 853 • The Cleveland coil

854 **Deterioration of hose**

855 **Mildew:** Synthetic materials are not affected by mildew, but fungus may grow on them if damp and dirt is
856 present. Although mildew has no detrimental effect on synthetic yarn, proper care should still be
857 exercised.

858 **Shock:** Shock is a frequent cause of hose failure. Hose should always be treated with care and rolls of
859 hose should never be thrown roughly to the ground, even though they may be dry and in good condition.

860 Shock may also occur if water is allowed to flow too rapidly into a line of hose that is badly kinked; the
861 sudden straightening out of hose under pressure and the ensuing rush of water that flows, only to be
862 checked by the next kink, set up a series of pressure waves, which may lead to a burst at a weak point.
863 Similarly, a burst may also occur if a hand-controlled branch is shut off suddenly, or a line is charged too
864 rapidly after a temporary shutdown.

865 **Acids, oils, grease and petrol:** Some types of fire hose are liable to damage by contact with products
866 such as acid, oil, grease or petrol, and hose should be stored well away from these substances. Care
867 should also be taken when working at oil installations and industrial sites to ensure that, as far as
868 possible, hose has minimal contact with oils and other contaminants. For example, petrol may cause the
869 rubber lining to separate from the fabric of a hose.

870 **Suction hose**

871 Suction hose or hard suction hose refers to hose designed to resist external pressure. It is used
872 exclusively between the water supply and the pump. As it will withstand internal or external pressure, it
873 can be used when working a pump either from pressure-fed mains or from open water supplies. It is an
874 essential part of the equipment of every pumping fire and rescue service vehicle. The diameter of the
875 hose should be sufficient to enable the pump it is used with to operate at maximum capacity, according
876 to the rated output of the pump.

877 Although the lengths and diameters of suction hose vary with the fire and rescue service vehicle on
878 which it is carried, the construction is substantially the same. The principal feature is that it should

879 possess sufficient strength to withstand, without collapsing, the pressure of the external air when a
880 vacuum has been created inside. It should also be strong enough to resist the maximum hydrant
881 pressure normally encountered, and at the same time possess lightness and flexibility compatible with its
882 strength.

883 **Care of firefighting hose**

884 Firefighting hose should be cared for in line with manufacturer's guidelines, which are likely to include:

- 885 • Hose should be stored in a cool, dry, well-ventilated place
- 886 • Hose unused for long periods should not remain on fire and rescue service vehicles but should
887 be removed and placed on racks or towers
- 888 • Rubber-lined hose should have water passed through it from time to time to keep the lining in
889 good condition, after which it should be thoroughly drained and dried in towers or by hanging in a
890 warm room
- 891 • If hose becomes frozen it should on no account be bent as it will be liable to crack
- 892 • Great care should be taken of rubber-lined hose, especially when cooling down after large fires,
893 as it may have been stretched over debris. As bricks and stone retain heat for a long time, the
894 outer covering is liable to scorch, weakening it and shortening its life.
- 895 • Hose should never be bent or kept at an acute angle, especially under pressure, since this
896 causes a severe strain on the fibres. This is a frequent source of breakage, particularly if the
897 edge under strain is rubbed sharply or knocked against a hard surface.
- 898 • Hose laid across roads should always be 'ramped' to prevent damage by moving vehicles
- 899 • Hose known to have been contaminated with acids or alkalis should be thoroughly washed
900 immediately with clean water
- 901 • Hose should be drained by under-running. When under-running it is essential to see that kinks do
902 not form at the bends, which may lead to the formation of pockets of water or pockets of vacuum
903 and thereby prevent the complete removal of the water.
- 904 • Personnel should not be allowed to walk on hose to flatten it out or rid it of water before rolling.
905 This may drive stones or grit into the fabric and also impose a heavy strain on the fibres on either
906 fold, which considerably weakens the hose. In practice, it is found that bursts almost invariably
907 appear at the two opposite points on the hose where it has been flattened.
- 908 • With lined hose, avoidance of such treatment is of even greater importance. The fibres of the
909 jacket are weakened and the lining itself becomes fretted, with particles of dirt lodging in these
910 frets and causing a rapid deterioration of the rubber. The correct method of clearing water by
911 under-running is to raise the hose shoulder-high while avoiding kinks, which will trap the water.
- 912 • When making up hose on the roll, the female coupling should not be doubled down onto the hose
913 too tightly and the first coil should be somewhat loose. This will minimise the possibility of the
914 coupling edge cutting into the hose and, in the case of lined hose, the lining becoming separated
915 from the jacket due to strain. In this connection, it is advisable to examine couplings periodically
916 and remove 'burrs' that might cause damage.
- 917 • Care should be taken when hose is stowed on fire and rescue service vehicles to avoid the
918 possibility of hose chaffing against the locker sides due to vibration
- 919 • Fire and rescue service vehicle locker doors should be opened at frequent intervals to allow air to
920 circulate and condition the hose

921 **Branches**

922 **Branches without control facilities**

923 The standard type of branch and nozzle has been used for many years. However, with technological
924 advancement, the majority of fire and rescue services now use various configurations of modern types of
925 hand-controlled branches.

926 **Branches with control facilities**

927 There are many different patterns of hand-controlled branch, all designed to enable branch operators to
928 control or change the formation of the water stream, by the operation of levers, triggers or various forms
929 of attachment. With most hand-controlled branches, the pattern of the water stream can be a jet, a
930 diffused spray or the flow completely stopped.

931 **Hose reel branches**

932 There are many different types of hose reel branch, which have the dual-purpose function of providing
933 either a straight jet or a spray, which can be adjusted by the operator to give a dense mist of fine
934 intensity or coarse spray. With some models, both jet and spray can be used.

935 **Monitors**

936 Many monitors are permanently fixed to pipework and designed to protect specific installations.
937 However, it is sometimes more convenient to mount monitors on trailers that can be moved from hazard
938 to hazard. Smaller monitors can be moved by hand and placed on the ground to provide a rapid
939 response in the event of a fire. However, mobile monitors require a water supply, usually provided by
940 hoses or portable pumps.

941 The jet reaction force of a portable monitor can vary from a few kilograms for a small ground monitor to
942 over a tonne for a larger trailer-mounted unit. Any portable monitor should be secured so that it cannot
943 move once the full water flow and pressure is applied.

944 Small hand wheel portable monitors are specifically designed to be easy to manoeuvre or carried over
945 rough terrain. To resist the jet reaction forces, portable ground monitors are provided with a method of
946 stabilising them on soft ground.

947 Larger monitors are usually mounted on trailers. The trailer is also often fitted with outriggers to provide
948 stability. Water tanks on the trailer can be filled to provide additional weight for stability. Extra tanks can
949 also provide foam concentrate.

950 In many applications, it is necessary to operate a monitor remotely. To do this, motors are fitted to move
951 the monitor body in the horizontal and vertical planes. If the monitor is fitted with an adjustable nozzle,
952 this will also need to be moved with a motor or actuator. Some applications require a master control
953 panel and slave control panel arrangement, while others require feedback to show the operator where
954 the monitor is pointing, so that it can be operated even if smoke reduces visibility.

955 Supporting equipment

956 Thermal imaging and scanning equipment

957 Thermal imaging cameras (TIC) and other thermal scanning equipment are devices that form an image
958 using emitted infrared radiation, as opposed to normal visible radiation. They can gather information
959 when normal observation may be restricted due to smoke or lack of light.

960 Thermal imaging or scanning can be used to search for specific points of interest, such as seats of fire,
961 or to detect firespread, which may not be visible to the naked eye.

962 There is a range of thermal imaging and scanning equipment, with varying specifications. However, the
963 equipment often has a numerical and gradient temperature scale, either in colour or black and white.

964 The heat energy radiated from the objects in the form of infrared waves is picked up by the equipment,
965 which is then able to identify the energy differences from the objects being scanned and convert the
966 readings into visual images. The image displayed is based on the temperature differential.

967 The manufacturer's information for the equipment should be referred to for descriptions of how higher or
968 hotter temperatures will be displayed.

969 Operators of thermal imaging or scanning equipment should be aware that:

- 970 • The equipment may not have an appropriate ATEX classification, which may limit its use in some
971 hazardous environments; more information is provided in [Utilities and fuel – Use intrinsically safe
972 equipment](#)
- 973 • Some surfaces can reflect or absorb infrared radiation, causing images to be misleading. For
974 example, the devices often depict areas of the same temperature in the same shade or colour,
975 which can obscure some hazards such as pits, surface liquid or unsafe ground.
- 976 • Equipment using a different spectrum should not be relied on as a total replacement for normal
977 vision. Fire and rescue service procedures for moving in smoke and darkness should be
978 maintained, with care taken to ensure that personnel remain safe.
- 979 • Battery power may be lost rapidly with little warning
- 980 • As images displayed on the devices are computerised images created from the sensor
981 equipment, allowances should be made for alterations to the actual size and distances involved
982 for the objects displayed
- 983 • Images may be misleading as sensors may not differentiate between the heat of a fire versus the
984 reflected heat from the sun on some surfaces, such as glass or polished metal. Well-insulated
985 structures, such as buildings with sandwich panels, do not readily allow for the passage of
986 infrared radiation.
- 987 • Images may indicate weaknesses in a structure but may not give any indication about the internal
988 conditions