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HEALTH & SAFETY LABORATORY

A review of installations, standards and design requirements of fixed and on-board fire suppression systems

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EXECUTIVE SUMMARY

OBJECTIVES

The aim of this report was to obtain information on the current situation regarding design and use of fixed fire suppression systems on vehicles, fixed and mobile equipment. It is intended that this will be used to advise/inform a standard or other suitable guidance on system design requirements.. This was to be achieved through study of the following areas.

1) Review of fixed fire suppression systems used on vehicles, transport systems, fixed and mobile equipment.
2) Obtain details of relevant incidents, in particular those involving vehicles.
3) Report on any guidance – UK, European, or international.
4) To review commercially available fire suppression systems and design/installation philosophy.

MAIN FINDINGS

1) Fire protection is a specialised field, as there are many types of fire and many situations in which fire could occur. If this is not complex enough, each situation, e.g. vehicle, type of railway rolling stock etc., will have a large number of models, each with their own specific geometry. Incident data suggests that fires occur on a wide range of vehicles for a variety of reasons and that installed fire protection systems are not always fully effective in dealing with the incident.

2) As a result the development of a generic standard covering system specification for all situations (fixed, mobile, on vehicles, in static compartments/buildings etc.), is probably almost impossible. It may be possible, however, for recommendations to be produced, for example, on the quantity of agent required and the number of discharge nozzles, based on the volume or dimensions of a fire-affected volume - as recommended in the NIST post-collision vehicle fires study: or to adopt a modified version of guidance produced by the Dept of Minerals and Energy, Western Australia. Some suggested approaches are discussed in Section 6.

   There is, however, merit in clearly defining the need for fixed fire protection systems and summarising existing legislation/guidance.

3) The provision/consideration of fire protection is required in UK legislation on equipment where risk of fire is recognised/possible. Statutory instruments are reported, along with a number of international codes/standards. These are discussed in Section 3.

4) Few standards identified covered fire suppression systems for vehicles and mobile equipment, the original scope of this review. The most detailed is that of the Dept. of Minerals and Energy, Western Australia. This could be extended to other diesel engined vehicles or hydraulic power systems, but a blanket extension of the use of aqueous film forming foam (AFFF), as used in this standard, would not be appropriate, as there are many other effective suppressants and there may be issues about aqueous media freezing at low temperature.

5) Again, due to the myriad of fire types, combustion products etc., no common means of fire detection was identified, with all common detectors being utilised. Thus standard

fire engineering principles should be employed when determining detector types/locations to ensure full coverage and prompt activation.

6) A wide range of extinguishing agents is used, including; halons, dry powder, carbon dioxide and foams. However, there has been an upsurge in the number of parties producing water mist suppression systems. These appear highly effective as they cool the protected area, reduce smoke obscuration and suppress through a combination of direct flame cooling and local inerting by steam/water vapour. Such systems are in use in turbine enclosures, ships engine rooms, electrical switch rooms, in underground railway stations and on railway rolling stock.

RECOMMENDATIONS

1) The opinion of relevant organisations, eg BSI, Systems Manufacturers, User Groups and Trade Associations etc, should be sought with regard to the production of some form of standard or guidance; possibly using the information contained in this report as an initial basis for discussion. The formation of a generic standard covering the specification of fixed fire suppression systems for all situations is not recommended due to the variety of situations and possible fires.

2) General, non-prescriptive guidance, which highlights the major points to consider when designing a fire protection system, could be considered. It may also be possible to address ‘packages’ or units of related equipment in more detail and, where appropriate, for recommendations to be produced using available information, for example on the quantity of agent required and the number of discharge nozzles, based on the volume or dimensions of a fire-affected volume - as recommended in the NIST post-collision vehicle fires study: or to adopt a modified version of guidance produced by the Dept. of Minerals and Energy, Western Australia.

3) There may be some benefit in giving consideration to the wider utilisation of water mist suppression systems where appropriate, for example in protection of enclosures such as turbine enclosures, plant rooms, low voltage electrical switch rooms or other such spaces. Water mists appear highly effective and have the added benefits of removing asphyxiation risks for personnel and are environmentally friendly. However, the compatibility of extinguishant / suppressant with equipment must always be considered. This is particularly so wherever the use of water is considered for an ‘electrical’ situation and appropriate safety measures must be in place.

4) Consideration should be given to the development of guidance of the type produced by the Dept. of Minerals and Energy, Western Australia, on fire suppression systems for underground vehicles for surface and underground vehicles within the EU. This could possibly be combined with more analytical studies developed by the US National Institute of Science and Technology (NIST), on post-collision vehicle fires.

5) Such guidance could also apply to other equipment fitted with diesel engines such as pumps or compressors, or railway locomotives, and also to hydraulic power systems utilising flammable fluids.

6) If specific guidance is developed, the efficiency of designs or recommendations should be tested practically before finalisation of the standard. If more general guidance is produced the concept of performance testing of designed systems, before installation, should be promoted.

7) Where practical, or where ease of egress of personnel is difficult, both automatic and manual discharge systems should be installed.

8) For large items of plant or vehicles it is recommended that sprinkler systems should be fitted in all cases where egress is difficult and an operator may have to move past a fire-affected area. This recommendation is made following an incident where a vehicle driver suffered burns while trying to escape along an unprotected access route on a large vehicle.

1 INTRODUCTION

Fires involving static and mobile machinery are not uncommon, and HSL have been called to investigate a number of incidents involving compressors, conveyors or vehicles in the recent past. Depending on the circumstances, such fires may have serious consequences. Of particular concern and interest, from the life-safety point of view, are situations where access / egress may be difficult such as fires in underground workings; especially those involving vehicles or mobile machinery such as TBMs. For example, information provided to HSE indicates that in 'miscellaneous' mines (i.e. non-coal), during the period 1993-2003, incidents involving diesel-fuelled, steered vehicles were the main single cause of fires (17 out of 29 incidents); typically as a result of electrical faults, hydraulic fluids from ruptured lines spraying onto hot turbochargers, etc. One possible way of mitigating such events is the provision of some form of fire suppression system integral to the equipment. However, there appears to be no standard and little guidance to assist designers of such systems, and there are occasions where installed systems have been known to have failed to control potentially serious fires.

- The main aim of this study, therefore, is to obtain information on the current design, installation and use of integrated (fixed) fire suppression/extinguishing systems on vehicles and mobile equipment/machinery used above or below ground in order to confirm the need for and support a proposal for the production of a design standard, or other suitable guidance.

To obtain a 'broader' view the study will also consider systems installed on some relevant 'fixed' installations such as gas turbines, compressors etc., where similar fire hazards may exist. This should:

- Identify any overlap or differences in approach to design, vs, vehicles or mobile equipment.
- Eliminate the need for a duplicate study to consider fixed equipment.
- Give some indication as to whether, or not, it is possible to produce generic guidance which may be relevant to the range of situations considered.

To achieve these aims the study will –

- Review relevant incidents.
- Investigate fixed/integrated fire suppression systems either installed, or suitable for installation, on vehicles or mobile equipment above or below ground, and associated design philosophy
- Present a similar review of fire suppression systems on 'fixed' equipment installations
- Report and discuss relevant legislation, codes or guidance (UK, national, international) relevant to vehicles and fixed situations as above
- Identify any "gaps" in current knowledge and approach to design and installation which will lead to improved efficiency of installed systems and thereby facilitate production of a suitable standard.
- Consider/propose aspects for inclusion in any standard or guidance

2 FIRE INCIDENTS ON VEHICLES AND MOBILE EQUIPMENT

2.1 Incidents underground

2.1.1 UK incidents

During the 10 year period from 1993 - 2003, 19 fires were reported to HSE on underground vehicles in coal and no-coal mines. Where information is available a brief description of some of the individual incidents, along with other international examples are given below to illustrate the range of fires encountered.

Diesel transit van
Fire occurred on a vehicle used for personnel transport. After driving 13.5 km the vehicle was parked, and 10 minutes later glowing fragments were seen falling below the engine compartment. Attempts to fight the fire using portable extinguishers and attempts to activate the onboard extinguishing system failed. Investigations suggested the cause of the fire was due to an electrical fault, which could have been prevented if the battery had been isolated on parking.

Caterpillar 988 loading shovel
Fire broke out in engine compartment of a Caterpillar 988 diesel powered loading shovel during startup. Inspection found the starter motor solenoid to be the cause. Fire extinguished when driver initiated the onboard suppression system.

Fuchs descaler
Fire occurred in engine compartment when an escape of hydraulic mineral oil from a failed high pressure joint was ignited by a hot turbocharger. Fire extinguished by automatic activation of onboard powder extinguisher.

Roofbolter
Driver heard crackling noises from the engine compartment on trying to start diesel engine. He opened the rear cover and extinguished a small flame by blowing on it. Investigation found that the protective insulating cap over the starter motor terminal had been ignited by arcing.

2.1.2 Non-UK incidents

Large dump truck
In 1999 HSL investigated a fire in a non-UK mine. The cause was attributed to a burst hydraulic hose spraying oil in the vicinity of a hot turbocharger. Unsuccessful attempts were made to extinguish the fire with the onboard dry powder suppression system, and a handheld powder extinguisher. The delivery system comprised three nozzles in the engine compartment and three in the rear section of the truck.

In 1997 a similar fire had occurred in the same mine where the dry powder system knocked down the flames but failed to extinguish them, resulting in the loss of the vehicle. One possible cause of continued combustion could be due to the engine being left running. This would result in a continual oil spray over ignition sources and whilst the extinguishant may initially be effective, once expended re-ignition of the spray could occur. If switched off, oil pressure is lost, removing the initial fuel supply.

4x4 light vehicles - Department of Minerals and Energy (Western Australia)
Within a two month period in 1994 two vehicle fires were investigated. In each case the fire was caused by the engine being driven backwards as the vehicle rolled back after stalling on an incline while still in forward gear. This caused the air filter to ignite due to the combustion cycle

being reversed. Engine modifications have been made by the manufacturer to prevent reoccurrence and recommendations on the fitting of fire suppression systems made.

In addition to the above 4x4 incident, four further fires were investigated in the period 1984 - 1991. Two were caused when vehicles overturned spilling fuel, one caused by an electrical fault, and another by a hydraulic fluid spray into the engine compartment.

10 m^3 capacity wheel loader
A 1984 model 10m^3 capacity wheel loader burst into flames while reversing from a stockpile, the resulting explosion of flame surrounded the cabin in seconds. A truck driver who went to the loader to give assistance found the operator on the ground in shock. He had been burnt leaving the cabin. The ladder railings were so hot that he was forced to jump to the ground.

The cause could not be established conclusively due to the extensive damage to the machine, but it was suspected that a hydraulic hose had ruptured.

The following comments were made regarding the incident.

1. There was no automatic fire fighting system fitted to the machine.
2. The machine continued to idle for two hours after the fire commenced.
3. The only escape for the operator was through the flames.
4. Excess grease, oil and the routing of hydraulic hoses at the pivot point below the cabin provided additional fuel for the fire.
5. The fire was finally extinguished nine hours after it commenced.

Investigations are underway by the US Bureau of Mines on the control and suppression of mine fires, in particular methods of mitigating the effects of fires on conveyors, underground compressors, and large above ground vehicles.

2.2 Fires on road vehicles

The incidence of vehicle fires in the USA has been given by Hamins (2000) in a report prepared for the National Institute of Standards and Technology (NIST) on the evaluation of active suppression in simulated post-collision vehicle fires. It was reported that vehicle fires amounted to approximately a quarter of all fires attended by the fire services, (US Fire Administration 1997), and also that although fires represented a small portion of vehicle related injuries, they accounted for approximately 10 % of the 15,000 fire injuries in the US in 1994. According to the National Fire Protection Association (NFPA) there are an annual average of 425,000 fires in vehicles per year and 320,000 fires in passenger road transport vehicles (Stewart, 1996), although no information is included as to the type of fire, e.g. tyre, engine compartment, post-collision pool fire, etc.. This figure was updated in a review covering the period 1980-1999 (Ahrens 2001), showing the overall trend was falling with the number of fires reported in 1999 being 368,500, causing 470 deaths, 1850 injuries and $1,324M worth of damage.

A limited search for similar information for the UK/Europe did not produce any readily usable information.

2.3 Fires on railways

Fires on railway rolling stock are not uncommon. Many are deliberate, and others involving electrical components have been investigated by HSL. The most relevant incident to this review is a recent under-floor/engine compartment fire in the UK caused by a burst hydraulic hose ahead of the engine on a modern diesel multiple unit. In this incident the hose ruptured when the locomotive was braking, but still travelling at considerable speed. The spray of hydraulic fluid was confined between the track bed and the bottom of the carriage, with the majority probably being confined within the sub-floor body trim. This confinement, combined with the high airflow, carried the oil over the top of the hot engine where it ignited causing considerable damage. On stopping, the fire largely died out as the hydraulic system was no longer pressurised. The suppression system comprised a 22 kg tank of AFFF (foam) suppressant, to be discharged via a number of nozzles directed over the engine. No such nozzles were dedicated towards protecting parts of the hydraulic system away from hot engine components. However, as the wires leading to actuators to discharge the on-broad suppression system were damaged, the system failed to operate.

2.4 Fires on diesel driven compressors

Whilst not technically vehicles, fires are known to occur on diesel-driven air compressors, and as such it may be legitimate to consider them under the ‘vehicles’ heading.

In 2001 HSL investigated a fire in a large diesel-fuelled screw compressor on an oil platform in the North Sea. Initial findings cast suspicion on a failed compressed air/oil pipe which may have sprayed an oil mist into the vicinity of the turbocharger for the diesel engine driving the compressor pump. No fire protection was fitted and the compressor was almost completely burnt out. This example, along with US Bureau of Mines studies of underground compressor fires, serve to show that the issue of oil sprays within engine compartments is a widespread problem, not limited to vehicles.

As a result of known incidents and potential consequences, it is reasonable to treat compressors as presenting the same fire hazard as vehicles and fit them with a fire suppression system.

Compressors have the advantage that they are usually used in a fixed location and can therefore be protected by more standard systems such as the water mist system as developed by the US Bureau of Mines. This would prevent fire spread beyond the compressor, but would not tackle an internal fire, as would be the case with an internal discharge of foam or powder.

3 REGULATIONS, STANDARDS OR RECOMMENDED PRACTICES

A brief search of legal requirements relating to the provision of fire suppression (see footnote) systems has failed to find any that contain specific or detailed recommendations on such systems, instead only general statements are made. Relevant regulations found include:

1. Provision and Use of Work Equipment Regulations, 1998 (PUWER). Regulation 10: conformity with Community requirements

2. The Supply of Machinery (Safety) Regulations, 1992, Schedule 3, Clause 1.5.6: designed and constructed to avoid all risks of fire or overheating, (clause 1.5.7: regarding risks of explosions).

3. The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations, 1996. Regulations 12(2): protection against specified hazards – (c) work equipment catching fire or overheating, (e) explosion of work equipment or any article or substance reduced, used or stored in it.

4. The Mines Miscellaneous Health and Safety Provisions Regulations 1995. Regulation 4(1): requiring a risk assessment document, which must include – Regulation 4 (2)(b) a fire protection plan detailing the likely sources of fire, and precautions to be taken to protect against, to detect and combat the outbreak and spread of fire.

5. The Coal Mines (Owner's Operating Rules) Regulations 1993. The schedule to Regulation 4 requires, in the Owner's operating rules on mine fires, at Model Rule 26 – When considered necessary and where practicable, diesel-powered vehicles should be fitted with fixed fire-quenching systems containing sufficient outlets placed to drench the main vehicle components at risk. Such systems should be capable of manual operation from inside or outside the cab.

6. A general requirement to consider fire risks also occurs in a variety of other legislation including, for example;
- the Management of Health and Safety at Work Regulations 1999,
- the Construction (Health, Safety and Welfare) Regulations 1996,
- the Dangerous Substances and Explosive Atmospheres Regulations 2002.

Standards or recommended industry practices which cover fire suppression requirements are discussed in the following sections.

Before describing legal requirements or practices, it should be noted that in this review the strict fire safety definitions of suppression; extinguishing; or control, are not applied as many of the standards or information sources utilised use these terms interchangeably.

In practice the system installed will depend on how the fire is to be tackled:

- *Control - allow the fire to burn but prevent its growth outside a defined area;*
- *Suppress - control the fire, reduce its size, but not actually extinguish it completely; or,*
- *Extinguish - put out the fire.*

For the majority of systems described in this review it is thought that the intended purpose of the systems is actually to extinguish the fire, not suppress it.

3.1 General requirements only

3.1.1 ISO 6826 - Reciprocating internal combustion engines – fire protection

This standard is geared towards fire prevention, rather than methods of extinguishing a fire should one occur.

Engines covered are internal combustion engines for land, rail-traction, and marine use, excluding those used to propel agricultural tractors, road vehicles, road construction and earth moving machines and aircraft. The exclusion of road construction and earth moving machinery from the scope of this standard is significant as it means that the large items of machinery typically used in the quarrying and mining industry fall outside it's scope.
Despite these exclusions, the standard possesses many features which would serve to prevent fire. For example:

- manufacturers' instructions shall contain information on regular inspection of hoses and pipe connections for thermal or vibration-induced damage;
- all components which contain flammable liquids shall withstand exposure to flame for 30 minutes as determined by a test where the item is subjected to heating at 800 ^{o}C when water filled, and a 2.5 minute duration fire when fuel filled;*
- piping shall be designed to prevent flammable liquids coming into contact with high temperature surfaces, rotating parts, electrical components, or air inlets of compression ignition engines; and,
- the exhaust system and other parts of the engine shall be cooled and/or insulated so that no external temperature shall reach the autoignition temperature of leaking fluids.

* The shorter fire exposure when fuel-filled compared to water-filled is presumably due to it being deemed that small leaks during early stages will lead to rapid fire escalation.

Full details of the requirements are given in the standard.

3.1.2 BSEN 13478 Safety of machinery – Fire prevention and protection

In brief, fire risk is to be reduced through design and engineering measures, integrated fire detection and fire fighting systems, additional measures and information on use.

Apart from identifying the need for fire detection/fighting systems only general details are given. (The system should comprise equipment for: detection, control, alarm and extinguishing. Additional measures such as emergency shutdown, isolation of protected area are also covered.

3.1.3 BS 6853 1999 – Code of practice for fire precautions in the design and construction of passenger carrying trains

The need for fire detection and fire fighting equipment is covered, as is whether suppression should be manual or automatic. No details of exactly what should be provided are given.

3.2 Specific details of suppression systems

3.2.1 Department of Minerals and Energy, Western Australia. Foam fire protection systems on mine vehicles – guidelines

3.2.1.1 Heavy vehicles

The Department of Minerals and Energy (1997) has published a minimum standard of requirement for vehicles used underground in Western Australian mines which states:

> "The manager of an underground mine must ensure that each diesel unit at the mine that is turbocharged or rated at 125 kW or more, and each loader or grader at the mine is equipped with an effective (*the meaning of effective is undefined*) and properly maintained aqueous film forming foam (AFFF) or film forming fluoroprotein foam (FFFP) fire suppression system with a minimum of two actuators".
>
> "If a diesel unit in an underground mine is controlled by remote control, the manager of the mine must ensure that the unit is equipped with an automatically operated AFFF or FFFP fire suppression system that has the facility to be activated from the operator's remote control unit".

In addition to the above all underground vehicles are required to carry portable extinguishers to the minimum requirements given in Tables 1 and 2.

Table 1 Extinguisher ratings for different engine sizes

Engine rating	*Extinguisher rating*	*Approx. minimum weight (kg)*
Less than 100 kW	30 B (E)	2 - 3
101 kW to 200 kW	60 B (E)	4.5 - 8
More than 200 kW	80 B (E)	6 - 11

Where, B(E) designates a powder extinguisher, and the number codes 30, 60 and 80 refer to fire tray dimensions used in standard tests as below (AS/NZS 1850:1997).

The author has been unable to establish how these sizes were derived.

Table 2 Pool fire sizes used in standard tests to assign extinguisher ratings

Rating and classification	*Minimum effective discharge time (mins *)*	*Nominal tray size (mm)*	*Nominal heptane content (litres)*
30B	11	2650 x 2650	350
60B	17	3725 x 3725	695
80B	20	4300 x 4300	925

** Discharge time not explicitly stated in standard, from specified durations of test fires it is thought that the required discharge times will be in minutes.*

System specification

The system shall have a foam tank solution volume sufficient to provide a minimum discharge rate of 4.1 $l min^{-1} m^{-2}$ or greater, over the fire risk area for a nominal discharge time of 50 s. When activated the system should cover all electrical and hot areas in the engine compartment including any hydraulic lines, the turbocharger and catalytic converter if fitted in that area, together with any adjacent high risk areas.

The system shall have a minimum of two manual actuators, one within easy reach in the driver's cab, and the other accessible from ground level. Consideration shall be given to locating a ground level actuator close to the battery isolation switch if this is further than 3 m from the cab. No mention is made of automatic detection and activation.

Foam shall be discharged through solid cone non-aspirating nozzles with a suitable pressure rating, and suitably rated piping compatible with the foam solution used. The piping shall have a continuous fire rating of 100 ^{o}C or more and nozzles are to be fitted with protective blow-off caps to prevent clogging during normal operation of the vehicle.

Links to engine management systems shall also be fitted such that the engine is automatically shut down on system activation after a delay of 5 - 15 s to allow the operator to safely park the vehicle. Means to prevent the engine start-up during operation of the suppression system or the supply pressure drops below a critical value are also to be included.

Recommendations are also given on maintenance and service along with a 16-point maintenance schedule: Table 3.

It is not reported whether these requirements have been subject to practical performance testing.

Table 3 Maintenance schedule for foam suppression systems (Department of Minerals and Energy, Western Australia)

	Day	*Week*	*Month*	*3 mth or 250 hrs*	*6 mth or 500 hrs*	*Year or 1000 hrs*
1. Check pressure indicators are in the green operating zone						
2. Check anti-tamper/pull pin is in place and secure/ serviceable						
3. Inspect and ensure manual actuators are clean, undamaged and accessible.						
4. Check nozzle caps are in pace, and if not clean nozzle and replace caps.						
5. Check distribution pipework, hoses and fittings and ensure they are not damaged.						
6. Check pressure vessel is not damaged.						
7. Check pressure vessel and mounting bracket are secure.						
8. Check CO_2 cartridge mass is within limits (if fitted).						
9. Ensure CO_2 cartridge is in place, not loose and undamaged.						
10. Check the system including pipework to ensure components are not corroded or loose.						
11. Check all system labels are in place and legible.						
12. Check for free passage through the system by flushing with clean water.						
13. Manually discharge the system from an actuator, observe discharge to ensure risk areas are adequately covered, record discharge times and correct any deficiencies.						
14. Check pressure vessel and CO_2 cartridge (if fitted) for last inspection date, and retest if necessary.						
15. Check system for leaks						
16. Refill, pressure vessel and CO_2 cartridge (if fitted) reassemble and recommission						

This schedule is intended as a guide, in all cases the manufacturers' recommendations should be followed.

3.2.1.2 Light vehicles

Light vehicles (engine size < 125 kW and non-turbocharged) do not appear subject to the above requirements. Instead recommendations are made on possible system designs as described below.

Where it has been decided to fit a system to a vehicle, the following information is quoted as "being of value":

The discharge rate shall be a minimum of 4.1 $lmin^{-1}m^{-2}$ and have a foam solution charge of 9 l or more;

The minimum discharge time is normally 30 - 45 s;

Actuation may be manual from a single location, providing the actuator is accessible from ground level, and at < 3 m from the driver's point of exit from the vehicle; and,

Remote pressure indication is not required providing a cylinder mounted pressure indicator is visible from a position at ground level, and is < 3 m from the driver's point of exit.

3.2.2 NFPA 121 - Self-propelled and mobile surface mining equipment

This document by the NFPA covers general fire protection and fire risk assessment requirements for mining vehicles/equipment, but falls short of specific recommendations of the type required in this study.

The general requirements given are paraphrased below.

1) The system shall be of sufficient size to suppress possible fires. (No definition of sufficient is included)

2) It shall be approved for the purpose and located or guarded against physical damage.

3) The system can be manually or automatically activated. In the case of automatic activation a manual switch shall also be installed in the operators cab or other location.

4) On large equipment additional activation points may be required to provide quick access for manual activation.

5) Agent distribution hoses shall be protected against damage, corrosion etc..

6) Discharge nozzles shall be protected against entry of dirt, insects etc..

7) Activation of the system shall cause automatic shutdown of the equipment.

Further details are listed covering testing after installation, inspection and maintenance at least every 12 months (or according to manufacturers recommendations) and staff training.

The choice of suppressant, and specific details such as number and location of nozzles, quantity of suppressant required, etc., is dependant on the type of system installed and is left to the user's discretion.

3.2.3 National Coal Board (NCB) specification 702: 1986 – Fire extinguishing system for surface mobile plant

This specification is now obsolete as it requires the fitting of a 5 kg Halon 1211 (bromochlorodifluoromethane – BCF) cylinder to the vehicle. Further, the BCF is applied manually by the operator, who activates the extinguisher and then applies the extinguishant via a hand-held 6 m long hose. Application via a manual hose-line is out with the scope of this review looking at permanent, fixed systems

Requirements for halon extinguishants aside, there are still lessons to be learnt from the mining industry, in particular the requirement to limit surface temperatures to below 150 ^{o}C. Extension of this measure, in particular, would have great effect in removing potential ignition sources from many situations.

3.2.4 UK defence standards

Due to the range of vehicle types involved no generic UK Defence Standard exists for fixed fire suppression systems on military vehicles. Due to security considerations the exact specification of systems fitted cannot be obtained. Broadly speaking, however, it seems that systems for which at least some detail is available utilise either halon substitutes, water mists, or powder systems.

4 APPLICATIONS AND INSTALLED SYSTEMS

A literature search identified publications on fixed fire suppression systems in the following generic fields.

Area	Common means of suppression
Ship engine rooms	water mists CO_2 or halons
Railways	halons, CO_2, powder, water mist
Aircraft	halons
Military vehicles	halons, powder, water mist
Vehicles – mining	foam, powder
road transport	powder, foam, CO_2, pyrotechnic systems

Each of these areas is discussed separately.

In addition to these areas fixed fire suppression equipment are also used in the following generic areas.

Computer suites	halons
Electrical switch rooms	CO_2, halons
Adjacent to compressors	water mists
Gas turbines	CO_2, halons, or water mist

The design specification of such systems is often based on specialist experience and will usually be governed by factors such as the type of fire, whether the protected area is occupied or not, the volume of space to be inerted etc.. In the case of compressors, much work has been done by the US Bureau of Mines on use of water sprays, (Smith et al. 1995).

Total flooding, often used in all four of the above cases, also has the advantage that detailed consideration of possible fire locations on an item of plant need not be considered as protection is achieved by blanket inerting.

4.1 Ships engine rooms

Marine fire suppression systems all appear to take advantage of the confined nature of the environment to extinguish a fire by flooding the room with inert gases (CO_2 or halon alternatives), or water mist. No details are given as to locations of discharge nozzles, delivery rates etc. in the relevant publications, as fires are extinguished by indirect contact with the extinguishant, rather than by direct application of a jet/spray to the fire.

Whilst water mists are a highly effective means of suppression and would be suitable in many confined or restricted spaces, their widespread utilisation may not be suitable for all applications. For instance the use of water to control electrical fires in high voltage switch rooms, for example, would not be recommended, but they have apparently been used to control fires in low voltage telecommunications switchrooms (see Section 5.4).

Use of water presents different problems of a practical, rather than safety nature, in vehicle engine compartments. This time the difficulty can be water freezing if temperatures cannot be guaranteed to remain above 0 ^{o}C. It was reported by Hamins (2000) that the selection of an anti-freeze is not trivial as many are combustible or may alter the effectiveness of the suppressant.

HSL is also aware of the use of halon systems to flood engine rooms, however, it is known that this can cause problems after the fire as decomposition products are highly corrosive, possibly causing additional damage if the compartment is not ventilated and cleaned promptly.

4.2 Military systems

Details of systems on military vehicles are limited. Generally a range of extinguishants are used, powder, foam, water, or halon substitutes. What appears interesting, however is the use of fast-acting UV/IR flame detectors to ensure very rapid fire detection, in conjunction with fast-acting valves to give quick release. Details of one halon substitute system quotes a detection to delivery time of the extinguishing agent of 7 ms, with the capability of a second shot if the first fails to extinguish the fire. A slower time of 15 s is given using a linear heat detecting wire to give the activation signal.

It is thought that similar, rapid optical flame detection is employed in a system developed by Kidde-Graviner. The author of this report witnessed a demonstration test by Kidde in which around 3 l of sodium stearate solution was driven from a reservoir by rapid pressurisation from a small pyrotechnic charge. This was able to suppress the ignition of a pressurised diesel spray giving only transient (< 1 s) burning.

Such a system may be effective in situations where the fuel and ignition source are only present fleetingly, but its effectiveness against longer term fire hazards where a pressurised fuel spray could be directed onto a hot engine manifold, for instance, remain to be demonstrated.

4.3 Railways

In the UK several means of protection are utilised. For example, the author is aware of a foam fire suppression system installed on a modern diesel multiple unit and also of water mist systems fitted on older rolling stock.

The foam system comprised two 22 kg AFFF cylinders (one for a manual backup) which discharged via a number of nozzles located over the engine and beneath the sub-floor space. Fire detection was via the Kidde-Graviner metal hydride Fire Wire and a twisted wire pair insulated by plastic sheathing. The system was tested during development on a mock-up using small pool fires on the ‘engine’ surface. Further details of this system, are described in Section 2.3.

Water mist systems (Hi-Fog) are now installed on some of the Channel Tunnel vehicle carriers and on other items.

Hi-Fog water mist systems are also in use on the Madrid Metro where they provide protection for driver cabs and passenger compartments. They are not used in under-body applications as the main means by which the mist works involves development of a cool inerting atmosphere. This is only possible in a closed/semi-closed compartment.

The amount of information on systems fitted on railways is limited. However, one article (Pier 1996), referring to locomotives in the United States, describes the introduction of a dual wavelength (one frequency in near and one in far IR) optical detector as a means of providing rapid automatic discharge of halon (now replaced by carbon dioxide or powder) extinguishers in locomotives. (Two locomotives were trialled: Amtrak Turboliner dual mode turbine hydraulic / third rail electric traction power cars; and, an Amtrak AEM-7 electric locomotive).

Specific details, where given, are as follows.

Turboliner
Original specification, three 20 lb bottles of halon 1301, updated specification – unspecified quantity of CO_2.

Detection by - 16 heat detectors in 3 electrical cabinets
2 heat sensors in air compressor area
2 optical detectors.

Activation of suppression system is manual by driver on notification by heat/optical detectors, with automatic fuel shutdown on fire, rather than overheat, detection.

AEM-7
Only general details were published for this diesel-electric locomotive. Overheat detection in electrical cabinets was by heat detectors, and fire detection by optical sensors. Due to the large amount of fuel present, suppression would be by dry powder, with nozzles aimed under the loco near brakes and also in the main diesel engine area.

No details were included on the likely quantity of powder required for suppression.

4.4 Systems on vehicles

4.4.1 Cars

Again little information is available. See Sections 4.4.3.3 – FireTrak, 5.2 – Pyrogen (discussed below) and 5.3 – National Institute of Standards and Technology (NIST) post-collision vehicle fires study. This latter study was of a very high quality and covered both fires within the engine compartment and from fuel spilt under the car.

Of these, only FireTrak is utilised in the UK.

4.4.2 Buses

Only one manufacturer (Pyrogen Corporation) could be found who has published information on fire suppression systems for use in engine compartments on buses. Whilst this company appears to trade worldwide, it appears that it may not have been used in the UK as yet.

Similar systems are apparently used on most forms of transport including lorries, cars, cranes, railway locomotives and rolling stock, and are discussed in further detail in Section 5.2. Briefly, however, they utilise a pyrotechnic charge to generate and disperse the extinguishing agent, and are thus more compact than those requiring a pressurised container.

4.4.3 Mining (Coal and non-coal)

Systems installed on vehicles used in mining applications have already been discussed in Sections 3.2.1 – 3.2.4, where extinguisher ratings for different engine sizes are presented in Tables 1 and 2. However, in addition to equipment meeting the requirements of these standards/specifications, several UK fire suppression equipment manufacturers have provided details of on-board fire suppression systems utilised in non-coal mines. These are discussed below.

4.4.3.1 Ardent

Information provided by Ardent indicates they follow a combination of recommendations from the Western Australian specification (foam suppression) and NFPA 121 (powder suppression), as their belief is that a dual powder/foam system provides the best cover, with the powder providing the initial knockdown, followed by cooling and exclusion of air by the foam. The equipment installed is manufactured by Wormald (foam system) and Ardent (powder system).

Release of the agents can be by either manual or automatic actuation. Options for automatic detection are:

- temperature sensitive wire, the insulation of which melts in a fire completing a circuit;
- spot-type heat detectors fitted with internal contacts which close at a predetermined temperature;
- gas-filled stainless steel tubing, where a fire is detected through increased pressure in the tube through thermal expansion of the gas; and,
- a pressurised plastic tube which melts in a fire, releasing its pressure - the suppression system is activated on loss of pressure in the detector tube.

Depending on system specification there are two time delays before full activation and release of the fire suppression agent. The first pre-set delay is the shutdown time to allow the operator to either shutdown the vehicle or bring it to rest safely. After this automatic shutdown will occur (if that option is fitted). The second delay, the discharge time delay, may then begin. After the discharge time delay has expired the suppression system is activated. If the manual activation switch is operated the system may discharge immediately, or after a discharge time delay, depending on settings.

The use of pre-set time delays with a possible gap of 60 s between detection and activation of the system potentially introduces a considerable time delay before fire fighting begins. Depending on the nature of the fire and the amount of combustible material available, this could lead to the development of a fire which cannot be controlled by the installed systems. It must be assumed that the time delays set, if any, will take account of these considerations.

Additional information received advises of a dry powder system (mono-ammonium phosphate) fitted to vehicles and locomotives with diesel engines used in coal mines. It is manually activated via one of a number of firing positions.

4.4.3.2 Kidde

From discussions with Kidde the choice of system fitted can be driven to a large extent by the customer. Their recommendation for an optimum vehicle system would be a dual shot foam and powder system, with the powder knocking down the flames, and foam, delivered later, cooling surfaces. However, it should be stressed that the final choice of system, foam vs powder, number of nozzles etc., is made after consideration of the hazards presented by a particular vehicle and the location in which it is used.

In common with other suppliers the Kidde fire suppression system can be triggered by a variety of detectors including: infrared; linear heat sensing cable; or spot detection. The detection time quoted is 15 ms.

Kidde also fit suppression systems in the driver's cab and on escape routes from the vehicle to protect the driver. This measure has recently been added in response to a request from a customer following a fatality as a result of a fire.

4.4.3.3 *The FireTrak system*

The FireTrak system is used on small vehicles to control fires in the engine compartment. It comprises, a halon fire extinguisher, fitted with a monitoring device and take-off to a length of 6 mm nylon tubing. This tubing is permanently pressurised and will melt when heated by a fire, automatically releasing the extinguishing agent in the vicinity of the fire.

This should be a highly effective method of extinguishing small fires in the engine compartment, particularly as halons are highly effective extinguishants and release would occur close to the fire. There is also no need to open the vehicle bonnet which would disperse the halon. A possible shortcoming is the absence of a cooling effect, potentially leaving hot surfaces which could reignite on dispersion of the halon. However, the most likely fire to occur in smaller vehicles where this system is used, will be electrical. Fitting an automatic isolation system will prevent continued electrical discharge, and hence prevent reignition.

With the phasing out of halon, this system could be modified to use either CO_2 or more environmentally friendly halon alternatives.

5 EXPERIMENTAL TESTS ON SUPPRESSION SYSTEMS

5.1 US Bureau of Mines

The US Bureau of Mines (USBM) have completed a number of studies on fire suppression systems for vehicles or equipment such as conveyor drive systems or compressors used underground.

i) Dry powder systems

One study, ”Automatic fire protection for mobile underground mining equipment”, (Johnson, 1983), gives limited details of the design of pipework and agent delivery system and describes the outcome of fire tests performed on mock-ups and actual vehicles. Following a series of successful experimental trials on mock-ups and an actual vehicle, systems were installed on operational vehicles underground and run for periods up between 10 – 34 months. It is believed that this study and eventual system design formed the basis of requirements proposed in NFPA 121 (2001).
Only general details of the fire suppression systems tested in the USBM study are available. A summary is as follows.

Detection – linear wire heat detector

Activation – automatic or manual

Suppression – dry powder – small load-haul-dump vehicle, 30 lb powder
large load-haul-dump vehicle, 60 lb powder.

Discharge nozzles – two, of unspecified type.

Additional features were automatic engine shutdown and inclusion of a compressed air cylinder to set the brakes.

ii) Water sprinkler systems

Research on fires with conveyor systems or air compressors has shown that such systems can be protected effectively through installation of automatic water sprinkler systems, (Smith et al. 1995).

Two sprinkler systems were evaluated: standard response 100 °C, and 74 °C fast response sprinklers, both types discharging at least 10 $l.min^{-1}.m^{-2}$ of water. Ventilation rates between 1.1 to 4.6 $m.s^{-1}$ were investigated, as were the benefits of utilising two rows of sprinklers spaced at 2.4 m intervals to protect both the upper and lower portion of the belt.

It was found that each type of sprinkler was capable of extinguishing incipient fires, with the fast response type showing slightly improved performance. In propagating belt fire experiments the results indicated the systems could stop flame spread along the belts for fires up to 10.8 MW heat output. However, at the higher airflow of 4 $m.s^{-1}$ sprinklers activated later and resulted in larger fires.

5.2 Pyrogen Corporation

Work by this company is published on the internet. Unlike systems described previously, which use a stored gas pressure to disperse an extinguishant, the Pryogen system utilises a pyrotechnic charge to generate and disperse a fire suppressing solid aerosol.

Fire tests performed on a bus were apparently successful, but since the fire comprised a number of diesel soaked rags placed at various locations within the engine compartment, it is difficult to discern the type of fire this was intended to mimic. However, successful performance under authentic fire conditions is also reported for an accidental fire that occurred within the engine compartment of an operating bus.

The above tests, carried out in the engine compartment of a single decker bus in Hong Kong utilised two 200 g and one 100 g generators directed into different areas of the compartment to give full cover. Despite a considerable amount of the suppressing agent escaping through the open base of the compartment the test fires were extinguished.

No details are available on the determination of the quantity of suppressant required per unit volume of compartment, or for fire size.

References to pyrotechnic generators of this type have also been found for other applications such as bullet-proof limousines for VIPs and racing cars.

5.3 National Institute of Standards and Technology (NIST) post-collision vehicle fires study

This 170 page report covers the effectiveness of fire suppressants in simulated post-collision vehicle fires. In such cases the fires considered were either within the engine compartment, or pool fires beneath a crashed vehicle formed as a result of a ruptured/leaking fuel tank, thus two suppression systems were developed and tested. Agents used were:

- Engine compartments – HFC-125(C_2HF_5), HFC-227ea (C_3HF_7), ABC powder (mono-ammonium phosphate), BC powder (sodium bicarbonate), a tubular suppression system where powder is discharged via a plastic tube wound around the interior of the engine compartment, as well as two types of pyrotechnic systems - solid propellant generators, and aerosol generators.

- Under-body fires – HFC-125, ABC powder, BC powder, solid propellant generators and aerosol generators.

Considerable detail is given on a possible method of calculation of the amount of suppressant required to extinguish a given fire. However, due to uncertainties in the degree of mixing on discharge and how airflow affects this (and its distribution within the protected area), it is not clear how much reliance could be placed on such an analytical approach without practical tests to confirm predictions. Also it is worth bearing in mind the overall conclusions of the work which were.

“The results showed that it is highly improbable that an on-board fire suppression system will be able to extinguish all engine compartment and under-body fires, and many suppressant types were found to be impractical for post-collision engine compartment applications. The experiments have shown, however, that under certain conditions, fire suppression is feasible, with the solid propellant generator being the most effective suppressant for engine compartment

fires. Full-scale tests in an engine compartment (with the radiator fan off) showed a 500 g solid propellant generator could suppress a 200 ml/min petrol fire. This equates to a tray around 22 cm on an edge. Full-scale underbody tests showed the suppression of a 333 cm^3 (no indication of pool area given) petrol fire could be achieved using less than 300 g of a dry powder suppressant when the fuel was located under the vehicle in low wind conditions. If a fuel puddle extended beyond the vehicle footprint and moderate wind conditions were present, then the powder system failed to reliably extinguish the fire."
This summary, taken from the report, would appear to show that the size of fires used in the experimental tests were extremely small

As well as calculations on the quantity of agent required to control a fire, extensive information is included on:

- the performance of different nozzle types at differing driving pressures;
- the effect of wind on agent distribution patterns for under-body fires; and,
- effectiveness of different nozzles in two sizes of engine compartment and for two under-body types.

General information is also included on the type of piping required, with the suggestion of flexible braided tubing for systems which must function after a collision, and on the type of detectors. Again, emphasis is placed on operability after collision.

5.4 Water mist suppression systems – National Association of Fire Equipment Distributors

This internet publication (www.nafed.org/library/wmist.cfm) covers use of water mist in electronic switch rooms, gas turbine enclosures and gas well blowouts among others and quotes a number of source references listed in the references of this report. It confirms the effectiveness of water mist systems in total flooding applications and gives details of fire tests.

i) Telecommunications switchgear

Tests using telecommunications switchgear with vertically mounted circuit boards exhibited temperatures between 600-1000 ^{o}C (no indication as to where these were measured) and flame heights of 4 m without suppression. With suppression, temperatures dropped to 300-500 ^{o}C and flames were extinguished within 2 s. As would be expected, nozzles within the switchgear proved more effective than those at ceiling level.

No damage to electrical components was observed as a result of water application. This was attributed to the use of clean water, rather than salt or rusty water. It could also be said, however, that no electrical tracking occurred during water application as the switchgear could well have been low voltage.

No details of nozzles are given, but use of stainless steel tubing to prevent formation of rust is specified.

ii) Gas turbines

Test work on suppression of spray, pool or lagging fires in a mock-up of a gas turbine enclosure is also relevant.

These tests employed a specially designed air-atomising nozzle running at 60-90 psi. In most cases immediate extinguishment occurred with a 10 s application. However, in some tests using fuel-soaked lagging, the lagging was dislodged by the water mist, was extinguished, and then re-ignited. In these cases a second 10 s application permanently extinguished the fire.

6 DISCUSSION

6.1 Legal requirements

A limited study of legislation confirmed that it is a legal requirement to ensure that equipment and machinery do not present a fire risk. Relevant legislation includes:

- The Provision and Use of Work Equipment Regulations, 1998.
- The Supply of Machinery (Safety) Regulations, 1992, Schedule 3, Clause 1.5.6.
- The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations, 1996.
- The Mines Miscellaneous Health and Safety Provisions Regulations, 1995.
- The Coal Mines (Owner's Operating Rules) Regulations, 1993.

There is a general requirement to consider risk from fire in:

- The Management of Health and Safety at Work Regulations, 1999
- The Construction (Health, Safety and Welfare) Regulations, 1996.
- The Dangerous Substances and Explosive Atmospheres Regulations, 2002

6.2 Standards

A number of standards or recommended practices were identified:

a. ISO 6826 – Reciprocating internal combustion engines – fire protection. This is geared more towards fire prevention, rather than suppression.
b. BSEN 13478 – Safety of machinery, fire prevention and protection. General statements on requirements for fire detection/fighting equipment only.
c. BS 6853 1999 - Code of practice for fire precautions in the design and construction of passenger carrying trains. General statements on requirements for fire detection/fighting equipment only.
d. Department of Minerals and Energy, Western Australia - Foam fire suppression systems on mine vehicles – guidelines. A well specified document giving detailed requirements on the quantity of AFFF required for protection of a particular engine size.
e. NFPA 121– Self-propelled and mobile surface mining equipment. General requirements are listed, but the choice of agent, number of nozzles etc. is left to the user to specify.
f. NCB 702: 1986 – Fire extinguishing system for surface mobile plant. Requires the fitting of a 5 kg BCF extinguisher, fitted with a 6m application hose, to underground vehicles.

Of the above, the most detailed is (d). This could be extended to applications other than the intended large machinery used in mineral extraction, but a blanket extension of the use of AFFF would not be appropriate.

6.3 Types of suppression system

Table 4 summarises the means of suppression identified and the situations in which they are typically used.

Table 4 Means of suppression identified in fields reviewed

	Ships engine rooms.	***Military systems***	***Rail applications***	***Heavy equipment***	***Buses / other vehicles***
Exclusion of oxygen from atmosphere with possible chemical inhibition	Water mists* CO_2	Halon/halon alternatives, water mist	CO_2 Halons		Halon/halon alternatives (FireTrak system)
Exclusion of oxygen from burning surface, with possible chemical inhibition		Dry powder AFFF	AFFF Dry powder	Dry powder AFFF	
Active generation of extinguishing species					Pyrogen, Aerosol generators

** Water mists have the additional advantage of absorption of heat from the fire as well as exclusion of oxygen through formation of steam.*

The above table is subdivided according to the mode of agent operation, viz:

- exclusion of oxygen from atmosphere with possible chemical inhibition, for instance by halons or components in dry powders acting as free radical traps;
- exclusion of oxygen from fire surface, with possible chemical inhibition; or,
- active generation of extinguishing species.

It can be seen that for a confined environment such as a ship's engine room the chosen method of fire control is by suffocation. With other areas – rail, large vehicles, or military vehicles, suppression may be by either removal of oxygen if in a confined space, or by direct application of an agent such as AFFF to the fire surface. With the choice of agent being dictated partly by the nature of the fire and degree of ventilation, and also by whether it is a manned area.

The use of halons or halon alternatives also appears common. However, their use is now severely restricted under the Montreal Protocol, so alternatives are being developed. Environmental problems aside, systems such as FireTrak, which discharge into an area as a result of a discharge tube melting in the heat from a fire, are highly effective. This also holds for other systems where an agent is routed through the protected area in a plastic tube which melts/softens in a fire resulting in discharge over the hottest area.

The remaining agent types are those produced or dispersed by pyrotechnic effects. These appear highly effective and are particularly suitable for systems where a fast response is required such as oil spray fires. But excepting those that create an anoxic atmosphere, they may suffer from the same lack of cooling of hot surfaces as conventional dry powders meaning re-ignition of fires is a possibility if fuel and ignition source remain present.

6.4 Experimental or practical tests

Section 5 covers work of three organisations that have undertaken experimental work on fire suppression systems. The most detailed are those of the US Bureau of Mines, who examined large quarry vehicles, and NIST who studied post-collision vehicle fires. Both studies are of a high quality; that of the USBM was used as the basis for guidance produced by the NFPA. The NIST vehicle fires study comprises a high quality 170 page report providing considerable detail on a proposed method of calculation of the amount of suppressant required to extinguish a given fire. However, due to uncertainties in the degree of mixing on discharge, and how airflow affects this (and its distribution within the protected area), it is not clear how much reliance can be placed on this analytical approach without practical tests to confirm predictions.

Reference should also be made to the joint Australia/New Zealand standard (Section 3.2) on fixed suppression systems for underground vehicles where, without validating fire tests, the choice of agent capacity is set as the quantity required to control a pool fire of given dimension, with larger engine (and hence vehicle) sizes being represented by larger pool areas.

Practical tests have also been performed by the Pyrogen Company, who effectively demonstrated that fires in vehicle engine compartments can be controlled using pyrotechnically generated or dispersed agents. This is a relatively new development which bears further consideration.

6.5 Use of this report as the basis for possible guidance

The original scope of this report was to identify means of suppressing/fighting fires on vehicles and mobile machinery used above or below ground in order to establish a need for guidance on fixed fire suppression. As a part of this it was decided to review fixed fire suppression systems as a whole to establish whether methodologies existed in other applications which were readily transferable. Subsequently, it was decided to broaden the scope across all industries/applications reviewed, rather than solely on vehicles and mobile equipment.

How the information given in this report may best be utilised will ultimately be determined by the user, based on individual specific requirements. Given the range of applications, it is believed that production of a single, generic standard giving detailed or prescriptive design requirements would be unrealistic since one document could not sensibly encompass all possible situations. To address such a broad range in a single guidance document would need a very general approach, essentially highlighting the factors that need to be considered and subsequently tailored for individual specific situations by the user and/or system designer.

However, various approaches are possible and could be developed, including for example,

- produce general guidance that discusses the range of factors that need to be considered, possibly incorporating a risk assessment approach, to design a fire protection system,
- develop more detailed or prescriptive specification for individual, or groups of similar / related, items – based on the general guidance principles above or,
- develop detailed guidance for specific extinguishing systems or media.

6.5.1 Factors for consideration when designing a fire protection system

General factors that need to be considered when designing a fire protection system are discussed below. There may be additional aspects, specific to the equipment to be protected; eg type, use, configuration, particular hazards etc., that play an important part in the design and effective operation of the fire protection system and which need to be considered at the system design stage.

General requirements and type of system required

The suggested approach outlined below is typical of that which would be considered if general guidance was being prepared for equipment fitted with for example a diesel engine – it may not be fully comprehensive. With appropriate modification and adaptation for specific items, the overall philosophy and content is equally relevant to a wider range of equipment.
1. <u>Avoidance of fire - Detection of equipment malfunction</u>
It is preferable to avoid a fire starting rather than need to rely on fire suppression. Therefore some form of leak detection system, eg for flammable gas or vapour, oil mist etc., should be considered where appropriate as early warning of a potential problem that could be avoided.

2. <u>Purpose and design capability</u>

There is also the issue of the intended purpose of the fire fighting system. Two are commonly considered: fire suppression and fire extinguishing. Broadly, a system intended for extinguishing a fire may need to operate over a short period to completely douse and extinguish the fire: whilst a suppression system may do just that, gradually applying the agent, thus suppressing the fire and preventing further growth until outside assistance arrives.

The choice of what is required, or what a system is capable of providing in developing circumstances, will depend on a number of factors, including:

- the work location and environment, e.g. confined areas ease of access etc.;
- the fuel and potential severity both of the fire and its consequences;
- occupancy levels and personnel safety;
- the time taken for outside assistance to be summoned; and perhaps,
- potential asset or monetary losses.

Thus in a tunnel, extinguishing systems may be required as the tunnel could become smoke-logged, trapping personnel and hampering fire fighting, whereas above ground in the open air and where the situation does not present a risk of fire spread, or risks to personnel eg by smoke inhalation etc, it may be possible to merely suppress a similar fire until the fire brigade arrives. In this latter scenario, in situations where there are no risks of fire spread or danger to personnel, other factors, eg the potential loss of high cost equipment, may necessitate the installation of a system capable of extinguishing rather than suppressing a fire.

3. <u>Fuels and ignition aspects</u>

The following should be considered.

- Type of fuels present - diesel, pressurised hydraulic or brake circuits.
- Nature of fuel release – gas/vapour, spray, pool, absorbed on other materials, force / pressure.

- Combustion - amount of heat produced by the fire and type / quantity / toxicity etc of combustion products.
- Probability of ignition of releases. Identify the location and temperatures of hot surfaces – could they ignite a release. Are other ignition sources present.
- Can the fuel supply be isolated. Does the hazard persist when the engine is switched off. Hydraulic spray fires will die out when the engine is turned off as pressure is lost.
- Are any other combustible materials present which will be ignited as a result of a fire.

4. <u>Identify suppression agent and time of application</u>

Identify the type of fire to be extinguished/suppressed (see above) and the most appropriate means.

- Identify suitable extinguishants for the system and operating conditions. An important point for consideration is whether equipment or operational circumstances preclude a certain agent – e.g. by asphyxiation/toxicity risk, airflow or speed of movement of a vehicle which would carry agent away preventing effective fire fighting, water and electrical systems, freezing conditions are not ideal for water without additional measures, etc.
- Consideration must be given to cooling hot surfaces such as exhaust manifolds if fuel supplies will still be in contact with them after all extinguishant is exhausted – can the extinguishant used achieve this, eg aqueous foam.
- Is a dual extinguishant system necessary; eg one to knock down the fire, the second to follow up, cool the system, prevent re-ignition etc.
- Single shot / double shot,
- Means of delivery to the fire; nozzle type / size and blockage protection, pipework type and design, driving force etc.
- Quantity of agent(s) required
- Volume / dimensions etc of fire affected area.
- Protection of delivery hoses against damage.

Ensure full coverage of all areas where fire could occur including:

- Ignition sources
- Sources of leaks
- Areas where burning liquid could pool, for instance top of engine, floor pan in engine compartment etc.
- Also consider protection of other combustible items which may ignite.

5. <u>Method of fire detection and activation of system</u>

As with most other systems, the method of fire detection chosen will depend on the situation. Temperature monitoring equipment may be required to sound alarms before a fire starts to allow equipment shutdown, or there could be detection by smoke, temperature in the compartment, infra-red or optical flame detectors etc.. All of these methods will be equally effective and the best will depend on the situation and degree of congestion in the area. For instance, optical flame detectors might not work in a congested environment where they could not see all parts of the area. Likewise in a large open space, detectors based on temperature rise will not be as effective as the temperature rise might be small. Additional sensors might be required to ensure coverage.

Three methods/combinations of system activation are commonly employed.

- manual
- automatic
- manual and automatic

Again the method chosen and the number and location of activation points will vary depending on circumstances.

6. Additional factors

There may be a number of additional factors to consider. These will often be dependent on the specific nature of the equipment, location etc. For example,

- is explosion protection needed in addition to fire protection,
- are there any relevant building codes, specific standards etc,
- is there any other relevant guidance – eg that used on the London Underground forbidding the use of carbon dioxide due to the risk of asphyxiation.

7. Tests to determine effectiveness of chosen system

The final step before acceptance is to determine the effectiveness of any system by performance testing. Such tests could be:

- full scale fire tests;
- visualisation tests to ensure full coverage of protected areas by the extinguishant;
- fire detection tests; and,
- tests of activation systems.

7 CONCLUSIONS

1) Fire protection is a specialised field, as there are many types of fire and many situations in which fire could occur. To this complexity is added a wide range of applications e.g. vehicle, type of railway rolling stock etc., each with their own specific geometry. Incident data suggests that fires occur on a wide range of vehicles and equipment for a variety of reasons and that installed fire protection systems are not always fully effective in dealing with the incident.

2) The development of a single generic standard covering system specification for all situations (fixed, mobile, on vehicles, in static compartments/buildings etc.), is probably unrealistic, but general guidance, or guidance that considers groups of 'similar' equipment in more detail may be possible. There is, however, merit in clearly defining the need for fixed fire protection systems and summarising existing legislation/guidance.

3) A limited search on legislation requiring fire protection systems revealed a number of statutory instruments:

a. Provision and Use of Work Equipment Regulations, 1998 (PUWER). Regulations 10 and 12.
b. The Supply of Machinery (Safety) Regulations, 1992, Schedule 3, Clause 1.5.6: designed and constructed to avoid all risks of fire or overheating, (clause 1.5.7: regarding risks of explosions).
c. The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations, 1996.
d. The Mines Miscellaneous Health and Safety Provisions Regulations, 1995 (regulation 4(1) & 4(2)).
e. The Coal Mines (Owner's Operating Rules) Regulations, 1993 (Schedule to regulation 4),

With general requirements to consider risk from fire in:

f. The Management of Health and Safety at Work Regulations, 1999
g. The Construction (Health, Safety and Welfare) Regulations, 1996
h. The Dangerous Substances and Explosive Atmospheres Regulations, 2002.

In addition a number of relevant international standards were found.

4) Few of the standards identified covered fire suppression systems for vehicles. The most detailed is that of the Department of Minerals and Energy, Western Australia. This could be extended to other diesel engined vehicles or hydraulic power systems, but a blanket extension of the use of AFFF as used in this standard, would be inappropriate, as there are other effective suppressants and there may be issues about aqueous media freezing at low temperature.

5) As stated in (1) above the range of applications and types of situation, vehicle etc. mean that it is probably impossible to define a generic system for a particular situation. It may be possible, however, for recommendations to be produced on the quantity of agent required and the number of discharge nozzles, based on the volume or dimensions of a

fire-affected volume - as recommended in the NIST post-collision vehicle fires study: or to adopt a modified version of guidance produced by the Dept of Minerals and Energy, Western Australia.

6) Again, due to the myriad of fire types, combustion products etc., no common means of fire detection was identified, with all common detectors being utilised. Thus standard fire engineering principles should be employed when determining detector types/locations to ensure full coverage and prompt activation.

7) General recommendations are made on how this report could be used in the preparation of a standard or guidance on fixed suppression systems.

8) A wide range of extinguishing agents is used, including; halons, dry powder, carbon dioxide and foams. However, there has been an upsurge in the number of parties producing water mist suppression systems. These appear highly effective as they cool the protected area, reduce smoke obscuration and suppress through a combination of direct flame cooling and local inerting by steam/water vapour. Such systems are in use in turbine enclosures, ships engine rooms, electrical switch rooms, in underground railway stations and on railway rolling stock.

8 RECOMMENDATIONS

1) The opinion of relevant organisations, eg BSI, Systems Manufacturers, User Groups and Trade Associations etc, should be sought with regard to the production of some form of standard or guidance; possibly using the information contained in this report as an initial basis for discussion. The formation of a generic standard covering the specification of fixed fire suppression systems for all situations is not recommended due to the variety of situations and possible fires.

2) General, non-prescriptive guidance, which highlights the major points to consider when designing a fire protection system, could be considered. Alternatively, it may also be possible to address 'packages' or units of related or similar equipment in more detail and, where appropriate, for recommendations to be produced using available information, for example on the quantity of agent required and the number of discharge nozzles, based on the volume or dimensions of a fire-affected volume - as recommended in the NIST post-collision vehicle fires study: or to adopt a modified version of guidance produced by the Dept of Minerals and Energy, Western Australia.

3) There may be some benefit in giving consideration to the wider utilisation of water mist suppression systems where appropriate, for example in protection of enclosures such as turbine enclosures, plant rooms, low voltage electrical switch rooms or other such spaces. Water mists appear highly effective and have the added benefits of removing asphyxiation risks for personnel and are environmentally friendly. (Note: The compatibility of extinguishant / suppressant with equipment must always be considered. This is particularly so wherever the use of water is considered for an 'electrical' situation and appropriate safety measures must be in place.)

4) Consideration should be given to the development of guidance of the type produced by the Dept. of Minerals and Energy, Western Australia on fire suppression systems for underground vehicles, for surface and underground vehicles within the EU. This could possibly be combined with more analytical studies developed by the US National Institute of Science and Technology (NIST), on post-collision vehicle fires.

5) Such guidance could also apply to other equipment fitted with diesel engines such as pumps or compressors, or railway locomotives, and also to hydraulic power systems utilising flammable fluids.

6) If specific guidance is developed, the efficiency of designs or recommendations should be tested practically before finalisation of the standard. If more general guidance is produced the concept of performance testing of designed systems, before installation, should be promoted.

7) Where practical, or where ease of egress of personnel is difficult, both automatic and manual discharge systems should be installed.

8) For large items of plant or vehicles it is recommended that sprinkler systems should be fitted in all cases where egress is difficult and an operator may have to move past a fire-affected area. This recommendation is made following an incident where a vehicle driver suffered burns while trying to escape along an unprotected access route on a large vehicle.

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