Control of safety risks at gas turbines used for power generation

Guidance Note **PM84**

This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Guidance Notes are published under five subject headings:

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Environmental Hygiene
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General

INTRODUCTION

1 This guidance is aimed at manufacturers, suppliers and operators of gas turbines (GTs) used for electrical power generation. It is also applicable to the use of GTs in pumping and gas compression plant and other similar applications. Marine and other propulsion applications are not within the scope of this guidance. The guidance draws attention to hazards associated with GTs and describes ways in which the associated risks can be eliminated or reduced to an acceptable level.

2 The generation of electricity by a GT is implemented by several different systems. The simple cycle only generates electricity. In combined heat and power (CHP) plants the residual heat in the engine exhaust is used for a variety of purposes ranging from industrial process heating to domestic hot water. Combined cycle gas turbine (CCGT) plant uses the residual heat to raise steam, which drives a steam turbine producing further electricity.

3 GTs are used in the gas and petroleum industries to provide pumping and gas compression facilities, often in remote locations such as a pipeline. The GT may run on fuel taken from the pipeline. Electrical power can also be generated if required, for instance on an oil production platform.

4 GT-driven plant can be utilised for local or national power-generation requirements. Turbines up to about 50 megawatts (MW) may be either industrial or modified aero-engines, while larger industrial units up to about 330 MW are purpose-built.

FUELS

5 A variety of fuels can be used by a GT. While natural gas is the preferred fuel for most UK plants, liquefied petroleum gas (LPG), refinery gas, gas oil, diesel and naphtha may be used as main, alternate, standby or start-up fuels. Hydrogen and biogas derivatives are also increasingly being used and fuel can include waste streams produced on-site. The choice is dependent on commercial and environmental considerations. Each type of fuel has its own particular hazards arising from its physical and chemical properties.

HAZARDS

6 The fuel supply to a GT has to be at high pressure. Typically, industrial units require natural gas up to 30 barg and some machines require fuel up to 50 barg. The pipework supplying the fuel to the turbine combustion chambers is often highly complex since the fuel is supplied to one or more annular distribution manifolds connected to numerous individual burners. A combination of flanges, flexible pipes, valves and bellows may be used, each being a potential leak site. Leaks are therefore foreseeable. Leaks may be ignited immediately producing a flame, or may lead to the accumulation of a flammable fuel air mixture. The delayed ignition of such a mixture within a confined space, such as an acoustic enclosure, can lead to an explosion with potential for injury and major plant damage. A leak of liquid at high pressure can produce a mist, which is flammable at a temperature below the flashpoint of the liquid, so that leaks of liquid fuels, lubricating oils and hydraulic fluids may also result in fires or explosions.

7 The burning of fuel in the GT may produce high surface temperatures capable of igniting a leak. In the case of aero-engines the casings may glow dull red due to the heat produced. On larger plant, hot surfaces in excess of 520°C have been found during normal operation. In certain circumstances such temperatures are sufficient to ignite leaks of mist or vapour from liquid fuels, lubricating or hydraulic oils, as well as gaseous fuels.

8 GTs are a significant noise source capable of causing noise-induced hearing loss as well as producing environmentally unacceptable noise. For these reasons they are often installed within an acoustic enclosure.

9 Other explosion hazards may be present within the GT. An excess of flammable fuel/air mixture may accumulate within the turbine inlet or exhaust system, which can be ignited (especially at start-up).

10 Due to the high operating speeds mechanical failure can occur, in particular with turbine and compressor blades and discs. Such failures can lead to a loss of containment, mechanical damage, and fire and explosion risks from plant disruption.

11 Electric shock and electromagnetic field hazards may also exist on generators and turbine auxiliary systems.

RISK ASSESSMENT

12 Risk assessment should be undertaken by competent people at all stages of the design, manufacture, packaging and commissioning of the GT. This should also include the consequences of foreseeable abnormal operation impacting on nearby plant, for example on an offshore platform. Manufacturers and suppliers should not only use existing knowledge of hazards associated with GTs but should also maintain contact with the users of such plant to gain information on plant failures. The commissioning stage is particularly important as it necessarily includes the first admission of fuel to the equipment and also because the responsibility for managing the plant is being progressively transferred to the user.

13 Before handover the user should carry out a suitable and sufficient risk assessment on the operation of the GT. This should include the requirements of the Management of Health and Safety at Work Regulations 1999 (see paragraph 80) and of the Dangerous Substances and Explosive Atmospheres Regulations (see paragraph 91). For larger plants, which generally present a greater risk, a more detailed risk assessment may be required, including the use of qualitative or quantitative risk analysis techniques. As well as confirming that the safety features of the plant meet the agreed specification, the risk assessment should also pay particular attention to operational procedures. Third-party design appraisal may be used to demonstrate reduced risk by providing verification that relevant design standards have been met. The adequacy of the training and experience of those involved with the operation, maintenance, inspection and monitoring of the GT plant should also be confirmed. Consideration should be given to the site conditions in which the equipment is installed, in order to reduce the risk of environmental or third-party impact; for example weather related motion would affect performance and lifecycle of components and equipment installed on floating platforms. The risk assessment should be reviewed at appropriate intervals as operational experience develops.

PRECAUTIONS AGAINST FIRE

14 Minimising the risk of fuel and oil leakage and controlling the presence of sources of ignition will reduce the risk of fire. The presence of exposed hot surfaces during normal operation precludes complete control over sources of ignition.

15 The fuel supply should be interlocked in a fail-safe manner with the fire and gas detection systems. It should also be possible to manually isolate the fuel supply from a safe position outside any enclosure around a GT.

16 Many oil fires, in particular oil-soaked insulation fires, have occurred. Insulation materials in areas susceptible to oil leaks or likely to be exposed to such fluids during general maintenance can include a protective film or metal skin. This should be carefully installed to avoid puncturing, and seams should be taped or folded in such a way as not to collect fluids. Further protection of high-risk pipes can be achieved by the use of double-walled pipe systems to contain any leak. To minimise risk, lubrication and hydraulic oil systems should be designed and constructed to recognised engineering standards.

17 Once a GT is in service, a regular scheme of inspection for leaks of both fuel and oil should be developed and implemented. This should be carried out in accordance with a safe system of work to minimise the risk to those carrying out the inspection. Guidance on access to enclosures is given in paragraphs 54-57. Such an inspection scheme should be regularly reviewed and modified according to user experience. Results of inspections should be recorded. While visual inspections can help identify liquid leaks they will not detect gas fuel leaks.

18 A fixed fire protection system should be installed to mitigate the consequences of a fire on the GT. This should be to an appropriate standard, such as NFPA 750,[1] BS ISO 14520[2] or BS 5306[3] and, as a minimum, designed to be capable of at least suppressing a fire on the GT or within the GT enclosure. The design and installation of fixed fire protection systems is a specialist field and it is recommended that companies experienced in fire protection engineering are consulted.

19 In considering the design of a fire protection system, careful attention also needs to be given to its interactions with other parts of the installation and personnel. These may include:

(a) the ventilation system;

(b) the isolation of the fuel supply to reduce fire loading and the risk of explosion once the fire has been extinguished;

(c) the isolation of the electrical supply;

(d) the choice of extinguishant to minimise the risk of electrocution or asphyxiation;

(e) the environment in which the GT is installed; and

(f) the means of access to the enclosure and the location of emergency shutdown pushbuttons and fuel isolation devices.

20 The early and reliable detection of fire is critical to the successful performance of the fire protection system. Key to this is the careful choice and siting of fire detectors in the GT enclosure. No single type of fire detector is the best in all situations and typically a combination of thermal, flame and smoke detectors will be appropriate. The choice should be based on an analysis of the characteristics of the potential fires that might occur in the GT enclosure and their particular causes. Fire detectors should comply with the relevant part of BS EN 54[4] and should be installed in accordance with the recommendations of BS 5839[5] and BS 7273.[6] A manual release facility for the fire protection system should also be provided in accordance with the recommendations of BS 7273.[6]

21 Where a fixed fire protection system is installed it should be regularly inspected and properly maintained in accordance with BS 5839[5] and BS 7273.[6] The fire protection system should be periodically inspected and serviced by a competent person with the necessary skills and specialist knowledge of such systems. A suitable record should be kept of the inspection checks, servicing and maintenance work carried out. The user should carry out a daily check that the system is operational and other regular checks and tests detailed in the user instructions provided by the fire protection system installer. The user should ensure that those with responsibility for carrying out these tasks are adequately trained.

22 Exposure to extinguishants that are potentially hazardous should be prevented. This may be achieved by selecting a non-hazardous extinguishant, eg water mist. Alternatively, potentially hazardous extinguishants, such as gaseous fire extinguishants, can be used under carefully controlled conditions to prevent inadvertent exposure to the extinguishant. The control requirements depend on the particular extinguishant and its maximum concentration in the enclosure. Details and recommendations on this are contained in BS ISO 14520.[2] Extinguishing systems that may create an asphyxiation or toxic hazard should be isolated before entry into an enclosure. The isolation procedure should comply with BS ISO 14520[2] and BS 7273.[6] However, systems based on extinguishants such as water mist do not have to be isolated so the risk of inadvertent isolation is eliminated. Inadvertent exposure to extinguishants should be avoided, even with fire protection systems using concentrations at which there are no observed adverse toxicological or physiological effects, in accordance with BS 5839.[5] A suitable alarm should be incorporated into the fire protection control system to provide sufficient warning to people within the enclosure to make their escape before discharge of the extinguishant. Where there is a potential visibility hazard, the exits from the enclosure should be adequately illuminated. Any air exhausts or air inlet openings into the enclosure should be fitted with an automatic closing damper.

PRECAUTIONS AGAINST EXPLOSION

23 If an enclosure is provided, then precautions should also be taken against explosion hazards. These precautions should be based on risk assessment. The use of certain fuels having low auto-ignition temperatures (AIT) or ignition energies, such as naphtha or hydrogen enriched fuel, requires specialist advice because of their particular hazards. The risk assessment should identify the additional risks posed by such fuels and any measures necessary to reduce the risk to an acceptable level.

24 Ventilation was initially installed in acoustic enclosures to assist cooling of the GTs. Subsequently it has been shown that it can also be used as a basis of safety, if designed as dilution ventilation. In practice this means that the ventilation should ensure that there are no stagnant or poorly ventilated spaces and that any leak is effectively mixed with air. Re-circulation and re-entrainment should be minimised, further reducing any accumulation of flammable mixture. This may require a large number of air inlet positions to obtain adequate distribution and, in extreme cases, supplementary fans or air distributors. Dilution ventilation is only acceptable as a basis of safety when associated with the use of suitable gas detection. See paragraphs 43-45.

25 In most cases a GT cannot directly comply with the regulations made to implement the ATEX Directive (paragraph 88), because of the requirement to exclude hot surfaces from hazardous areas. The European Commission have published guidance on their website,[7] which confirms that the provision of dilution ventilation will, by preventing an explosion, enable GTs operating in an enclosure to be regarded as ATEX compliant. Conformity assessment of the ventilation design, in the UK, will be required to ATEX Equipment-Group II, Category 3 equivalence, and will therefore be the responsibility of the final supplier.

26 While dilution ventilation has now been accepted as the preferred basis of safety, explosion relief and explosion suppression may be used as additional risk reduction measures. However if either of these techniques were to be used as an alternative basis of safety, then appropriate justification would be required.

27 Explosion relief is easier and less costly to fit to new plant than to retrofit. It has the advantage of proven reliability as a basis of safety in many process industries. Strengthening of the enclosure can be used to reduce the vent area required. Modification of existing roof panels may provide sufficient explosion relief. All such relief panels should be restrained and should discharge to a safe place, preferably in the open air, in order to prevent injury to personnel and damage to adjacent plant. Any ductwork associated with the relief panels should be designed to contain the expected pressures.

28 Explosion suppression is a well established technique in other industries. A suitable suppressant is distributed within an enclosure at the onset of an

explosion with such speed that the explosion is quenched and the pressure rise is limited to a small acceptable value. It can be linked to a fire extinguishing system and will similarly preclude access to the plant during normal operation unless isolated. Ventilation, fuel controls and fire extinguishing systems may need to be linked to the suppression system to maintain safety following its operation.

29 Turbines within spacious halls are unlikely to present an explosion hazard, since foreseeable flammable mixtures are not sufficiently enclosed. Such an arrangement has significant advantages of accessibility for maintenance, although employees in the building are likely to need protection against exposure to noise. In turbine halls the use of dilution ventilation as a basis for safety and ATEX compliance is less applicable, and the focus shifts towards gas detection. However, the ventilation of such large halls should be designed, and checked, to ensure that large accumulations of flammable mixture would not arise from foreseeable leaks, and that such leaks can be detected.[8] Screens or baffles may assist the detection of leaks by restricting the spread of fuel/air mixtures. Access to hazardous areas in the vicinity of the GT should be restricted to mitigate the residual risk, as noted at paragraph 57.

30 GT enclosures may, in exceptional circumstances, be installed in a hazardous area. Their installation in zone 1 areas (see definitions of zones in BS EN 60079-10[9]) should be avoided. If installation is contemplated in zone 2 areas, expert specialist advice should be sought. Such advice should include consideration of the following precautions:

(a) combustion air and ventilation air should be drawn from a safe area, ie un-zoned, taking wind effects into account;

(b) fast-acting gas detectors should be placed in combustion air and ventilation air intakes to provide alarm and trip functions. These detectors should be set to the lowest levels compatible with a minimum of spurious operations;

(c) engine exhaust should discharge to a safe place outside any zoned areas, taking wind effects into account;

(d) ventilation should be forced, so as to maintain a positive pressure within the enclosure;

(e) a pressure detector should be used to interlock the enclosure pressure with the GT fuel trip;

(f) access to the enclosure should be prevented during GT operation and after engine shutdown until hot surfaces have cooled to a safe level. An assessment of the time required to achieve adequate cooling will be required;

(g) the enclosure should be constructed to minimise air loss to the outside;

(h) in general, the enclosure and associated equipment should comply with BS EN standards for equipment intended for use in hazardous atmospheres; and

(i) depending upon the regulations applicable to the installation site, certification of conformity and appropriate marking may also be required.

VENTILATION

31 If practicable for new plant, ventilation should be designed so that it passes from potential hydrocarbon leak sources away from surfaces which are at a high temperature, and not towards them. However, in doing so care should be taken not to expose other sensitive components, such as instrumentation and cable trays, to excessive temperatures. Also any modified ventilation flow should not generate component stresses in the GT casing that could lead to failure. It should be noted that the appropriate distribution of ventilation air is more important than its quantity, and that high ventilation rates may inhibit the detection of small leaks.

32 Dilution ventilation air movement should be monitored and interlocked to GT start and trip sequences so that the unit cannot start without sufficient ventilation and GT pre-purging. The gas shut-off valves should not open and any gas-line vent valves should not close until after the GT purge cycle is complete. Failure of the ventilation system during running should initiate a fuel trip, unless the ventilation is automatically restored from an alternate or emergency power supply. This should also supply the air movement detection instruments, gas detection instruments and associated engine trip systems. In the case of battery back-up systems a controlled shutdown should be initiated within the expected safe period of operation of the batteries. Reliance must not be placed on battery back-up systems to continue normal running. All types of electrical back-up systems involved in safe operation of the plant will require regular maintenance and testing to ensure their continued availability.

33 At turbine start-up, thermally induced flows that are present during normal operation may be absent. The possibility of gas leaks is also likely to be greater at start-up, for example following maintenance operations. The effectiveness of the ventilation under normal operating conditions and at turbine start-up should therefore be confirmed.

34 In smaller enclosures the effectiveness of the ventilation may be studied with the use of smoke combined with closed circuit television (CCTV). In larger enclosures (above about 50 m^3) tracer gas techniques have been used effectively. However, it has been found that in most cases ventilation and gas leakage in these larger enclosures are best predicted by modelling with computational fluid dynamics (CFD). Currently other available techniques may fail to take full account of the momentum of the leak. An additional benefit is that CFD permits a quantitative assessment against the criterion noted below. A CFD approach also has the advantage that ventilation modifications, if shown to be necessary, can be modelled without actual plant change, or even before the plant is built.

35 A quantitative criterion against which to assess dilution ventilation efficiency in enclosures has been proposed[10] and shown to be both conservative[8] and

attainable. It is based on the principle of limiting any foreseeable accumulation of flammable mixture, so that its ignition would not present a hazard to the strength of the enclosure or to people. The criterion proposes that the size of the flammable cloud, as defined by the iso-surface at 50% of the lower explosive limit (LEL), should be no larger than 0.1% of the net enclosure volume. This criterion has been developed to allow a common basis for assessment of ventilation effectiveness in enclosures. It is primarily applicable to a CFD-based approach. The results of any research into this field should be taken into account as they become available.

36 In adopting a CFD approach, the model should be representative of the plant. The geometry of the enclosure, turbine and associated equipment should be adequately resolved by the CFD grid. It may not prove possible to explicitly resolve small obstacles, such as pipework, fittings etc, in which case these should be taken into account by adopting a porosity-based approach. The number and location of ventilation inlets and outlets should be correctly represented, as should the flow rates. Consideration should be given to thermal boundary conditions, and the need to satisfy an overall heat balance for the turbine enclosure system. Where possible, the CFD model should be demonstrated as being representative of actual conditions, by comparison of simulated velocity and temperature fields with in-situ measurements.

37 The effects of buoyancy in a CFD model should be addressed, since thermally induced natural convection flows can be significant. While the main fuel, natural gas, is inherently buoyant, a high-pressure release will normally cause a substantial amount of mixing, and the resulting gas cloud may then be at relatively low concentration. In these circumstances the gas cloud could be more affected by the background ventilation, including any thermally induced flows, or flows induced by the momentum of the release.

38 The modelling of the gas leak in a CFD approach can be undertaken in one of two ways: either the leak source is resolved explicitly by the CFD grid, or the effects of the leak are introduced as sub-grid scale sources of mass, momentum, energy, and turbulence. In practice, it is usually not feasible to resolve the leak directly at its source, due to its small dimensions. In such cases it is acceptable to use correlations or a simple jet model to provide a larger pseudo-source a small distance downstream from the leak location, which can be resolved by the CFD grid. In general, this approach is more reliable than use of a sub-grid scale source.

39 The leak rate to be modelled in CFD simulations should be the largest leak that would just pass undetected. This can be calculated as that gas release rate which, when fully mixed in the ventilating air passing through the enclosure, just initiates the alarm for a detector located in the ventilation outlet. Larger leaks than this should be readily detected and appropriate action taken. Smaller leaks could pass undetected, but present no hazard if the ventilation design has been validated.

40 A CFD approach should aim to demonstrate that the ventilation is effective for a credible 'worst case'. The leak rate should be calculated using the above approach, and the leak location and orientation chosen to produce the largest flammable cloud predicted by CFD modelling. This can be best achieved by an approach which identifies poorly ventilated regions, ie re-circulating or stagnant flow. Identification of poorly ventilated regions can be achieved by analysing simulations or measurements. Since it is not possible to know, in advance, which combination of factors will lead to the largest flammable cloud, a small number of alternative leak locations and orientations should be simulated. These leak scenarios should be investigated separately to avoid interactions, rather than all modelled within a single simulation.

41 CFD results should be subject to sensitivity analysis regarding areas of modelling uncertainty. In particular, the sensitivity of the flammable cloud volume to the mesh resolution should be addressed. This can, for example, be achieved by local grid refinement. The numerical schemes that are used to estimate fluid flow across the boundaries of grid cells can also have a significant influence on the accuracy of the results. Simple schemes may result in over-rapid mixing, purely as a consequence of numerical errors. This effect is commonly referred to as false, or numerical, diffusion. More advanced numerical schemes should ideally be used to avoid excessive numerical diffusion.

GT PURGING

42 Explosions within fired plant at start-up, due to the ignition of accumulated fuel, are a well-recognized hazard, and measures should be adopted to control this hazard. Such measures should include adequate gas path purging (at least three volume changes) before start-up, a high standard of isolation to prevent leakage during shutdown and a controlled duration for attempted ignition based on flame or combustion detection. Arrangements should be provided to drain any accumulation of liquid fuel from the GT casing. These precautions are normally inherent within the GT control package provided by the manufacturer. Care should also be taken with the design of drain lines, to minimise risks when changing from a liquid fuel to gas, by preventing gas from entering sump tanks. Consideration should also be given to fitting gas detectors in such tanks.

GAS DETECTORS

43 At least one gas detector should always be installed if the GT has a gaseous fuel supply. The best location for gas detection is in the ventilation outlet because a leak will always reach it. The detector should be located sufficiently downstream to ensure adequate mixing within the outlet duct. Additional detectors can also be used within the enclosure to increase the probability of detecting small leaks. As well as considering the best location for such additional detectors, care needs to be taken that they are not exposed to temperatures above their operating range. Some large units have successfully used piped sampling systems to monitor for gas from potential leaks. The sampling regime of these systems means they are slow to respond but may be valuable as an additional source of warning of small leaks. In the case of a turbine hall, CFD modelling work suggests it is useful to model likely fuel dispersions around the GTs to identify

the best location for gas detectors.[8] The effectiveness of such detectors may also be improved by providing baffles, which will direct predicted flows towards them.

44 The settings for gas detectors placed around a GT should be dictated by their purpose. Gas detectors in the ventilation outlet from the enclosure should be set to alarm at the lowest reasonably practicable level, preferably below 5% of the lower explosive limit (LEL) but not exceeding 10%. Ventilation inlets should be located in a safe area, but if there is a possibility of a flammable mixture being drawn into the enclosure via the air inlets, then further fast-acting gas detectors will be required. In the event of a gas alarm safe plant rundown should be initiated. During this period, the ventilation should run at its maximum rate. The increase in ventilation may reduce the gas concentration, but this should not cancel the alarm or delay the rundown. It should only be possible to cancel alarms manually and preferably only after the plant has shut down. High-level trips should also be set as low as reasonably practicable, but no higher than 25% of the LEL and should initiate automatic GT trip with gas supply valves being fully closed. Intermediate detector settings, between the alarm and trip settings, may be valuable as a means of initiating automatic controlled shutdown of larger turbines. Very sensitive detectors may be valuable as a means of early warning of a gas leak, which may enable safe access to investigate the leak source.

45 Gas detectors should be selected in accordance with BS EN 50073[11] and installed and calibrated regularly in accordance with manufacturers' recommendations. In-situ calibration facilities are recommended if plant is expected to run continuously for long periods. The use of additional detectors or recalibration may be required for different fuels. However, recalibration must be strictly controlled to prevent the incorrect setting of detectors. Where spurious trips must be minimised, such as at larger plant or critical supply installations, a voting system based on a number of detectors in the ventilation outlet may be used. For example, activation of any one out of three detectors would initiate an alarm. However, any two out of three detectors above the trip level would be required to automatically shut down the fuel supply. Displays of gas levels, recording and trending facilities can also add to reliability and aid the diagnosis of faults.

CONTROL SYSTEMS

46 For those hazards identified by risk assessment and which are addressed by precautions inherent within the GT control package, safety-related systems should be identified, specified, implemented, tested and maintained in accordance with the principles of BS EN 61508[12] or IEC 61511[13] as appropriate. Interfaces between the GT and site control systems should be checked to avoid mismatch and subsequent failure. Strict controls should be in place to prevent unauthorised access to safety-related systems. Such systems may include, for example, the GT purge cycle, flame detection, fuel isolation, ventilation detection, fixed fire protection, engine trip, and gas detector alarm/trip settings.

47 A mechanism for control of software changes is recommended as part of the overall management of the software. This should also include copies of the software being held at secure locations and procedures being in place to audit and confirm that the copies are all to the same revision. Any changes to the hardware/software of safety-related control systems should be accompanied by an impact assessment to determine what effect such changes will have on the safety integrity of the control system. Any adverse effects identified by the assessment will require the design of the control system to be revisited, and possibly modified, to restore the safety integrity to its original level. BS EN 61508[12] describes a mechanism for this process. Any changes to the safety-related control system should be documented, including the reasons for the change, relevant technical details, the impact assessment, the design review, and any changes to the operating/maintenance regime. The asset owner or custodian should sign off all relevant documentation.

FUEL SUPPLY SYSTEMS

48 Fuel pipework should be designed, constructed, tested and installed to an appropriate recognised standard. Relevant references are given in Institution of Gas Engineers and Managers publication UP/9.[14] Replacement pipework should be subject to the same standards. Vulnerable pipework should be routed so as to avoid the likely disintegration plane of ejected turbine disks and blades. Fuel pipework should also be designed with the minimum of non-welded joints compatible with maintenance requirements. Assembly and maintenance requirements should be considered at the design stage.

49 All fuel pipelines should be assembled, and re-assembled following maintenance, under a quality assurance scheme. They should also be pressure tested, so far as practicable. All flanges and fittings upstream of any final flanges or connections at combustion chambers should be pressure and leak tested after assembly. Final flanges or connections should be tightened under recorded and controlled quality assured conditions, and leak tested so far as practicable. Adequate access to all such fuel pipework flanges is thus essential. Where it is possible to produce a small backpressure by spinning the gas turbine, techniques such as the use of proprietary leak detection spray or a tracer gas can be used to aid leak detection.[15]

GAS FUEL

50 A high standard of automatic isolation, based on two safety shut-off valves meeting class A performance standards, should be fitted to the gas supply to prevent gas from passing into downstream equipment while the GT is stationary. For systems where the fuel thermal energy input flow rate exceeds 1.2 MW, the valves should be fitted with a system to prove their effective closure, for example by the fitting of proving switches to detect mechanical overtravel, or by sequential pressure proving, which may use an intermediate vent valve. The latter system has the advantage that it effectively tests the valves for leakage at each start-up and shutdown. Further guidance on isolation is given in IGE/UP/9.[14]

51 For applications where gas supplied by a national gas transporter is further compressed by the end user, safety features will be required to prevent the back feed of high-pressure gas into the distribution system.

Appropriate measures to prevent this situation during upset conditions may be required by the gas transporter. Such measures could include:

(a) a plant inlet 'emergency shutdown valve' acting on rising pressure in addition to other plant safety requirements; and

(b) a 'non-return valve' at the suction side of the gas compressor package to prevent reverse flow.

Further details are given in IGE /UP/6.[16]

ADDITIONAL EXPLOSION PRECAUTIONS FOR LIQUID FUELS AND OILS

52 Liquid fuel leaks from high-pressure sources can produce a mist, which can be flammable at a temperature below the flashpoint of the liquid. Ignition of such a mist can have explosive effects similar to gas explosions. Effective ventilation should be provided but, because ventilation is less effective in diluting and removing liquid droplets, their formation should be avoided as far as possible. Vulnerable joints and fittings should be minimised. Consideration should be given to the use of welded joints or the use of double containment pipework, as well as to the use of proprietary mist eliminators (spray shields) or encapsulation to protect remaining vulnerable joints and fittings. Mist detection should be considered as a further risk reduction measure if practicable. So far as possible, joints should be positioned so that leaks do not drip or spray onto hot surfaces. In particular, for liquid fuels of very low AIT such as naphtha, segregation of risk areas, explosion relief or explosion suppression should be considered. This is because of the increased risk of ignition and the uncertainties of CFD modelling of such releases. Further guidance on liquid fuel installations is given in IGE/UP/9.[14]

53 High pressure leaks of lubricating oils and hydraulic oils may also produce a flammable mist with risks similar to those noted above for fuels. The properties of any such flammable fluids should be obtained from suppliers and taken into account in a risk assessment. Where necessary, additional precautions as described above should be considered to reduce the risk. Where other risk reduction measures against flammable oil mists do not provide an adequate level of safety, it will be necessary to use fire-resistant or non-flammable fluids.

ACCESS

54 The acoustic enclosure around a GT is likely to be a confined space (see paragraph 82) as there is a foreseeable risk of serious injury due to the leakage and subsequent ignition of a flammable fuel. Entry for maintenance when the GT has been shut down should be under the control of a suitable safe system of work, which may include a permit to work. Such a safe system of work should include the manual isolation of the fuel supply and the testing of the atmosphere within the enclosure to confirm the absence of flammable or toxic gases.

55 Strong justification will be required for entry to an enclosure during turbine operation. All other potential options for carrying out the work from outside the enclosure should be considered before allowing entry. Instrumentation with remote indication should be used to avoid routine entry. CCTV and/or viewing windows can be used where practicable to provide visual checks on machinery conditions. On new plant, both manufacturers and users should try to eliminate the need for entry. If there is no alternative then it should be restricted to a minimum duration and limited to authorised personnel carrying out specific tasks. The risk assessment should identify why such an entry is required, what the inherent hazards are, and the measures to be taken to reduce them. Thermal and noise hazards should also be considered in setting entry duration. A written safe system of work will be required which may include a permit to enter and to carry out specified work. Appropriate precautions should be taken to prevent the trapping of personnel inside the enclosure under any foreseeable circumstances.

56 Due to the increased risk while load and fuel changes are taking place, entry should be prohibited at these times. Such changes can occur automatically. However, entry should not be permitted to the enclosure when there is an imminent planned change. Load changes may increase the risk of a leak by an increase in fuel pressure when an idling GT is brought on load. The small variations that occur during normal running are not considered to increase risk. Changing from one fuel to another may increase the possibility of a leak occurring due to the increase in fuel system pressures or use of different pipework. Similarly, entry at start-up and under any ongoing uncontrolled emergency condition should not be permitted.

57 For GTs in a turbine hall, close approach to a running machine and access to hazardous areas in the vicinity of the GT should be kept to the minimum necessary for safe operation in accordance with risk assessment.

GAS COMPRESSOR STATIONS

58 Those concerned with the supply and operation of gas compressor stations used in UK should be aware that the foreword to BS EN 12583: 2000 *Gas supply systems - compressor stations - functional requirements* contains the following proviso:

'In the UK the national safety body, the Health and Safety Executive (HSE) (see CR 13737), has required additional precautions at gas turbine driven plant, eg compressors, combined heat and power (CHP) and combined cycle gas turbine (CCGT), in order to comply with the general provisions of the Health and Safety at Work etc Act (HSWA). These additional precautions are contained in HSE Guidance (*Control of safety risks at gas turbines used for power generation*)'.

EMERGENCY PROCEDURES

59 Actions to be taken in the event of fire or gas alarms should be written into emergency plans and regularly reviewed. Guidance from suppliers should be sought and applied. Training in emergency procedures should be given to operators. Instructions should be given on when to shut down under controlled conditions or to trip fuel

supplies immediately, when to summon the emergency services, control of the ventilation system, access limitation, and emergency communications. Emergency shutdown controls should be located within the control room and at other appropriate locations based on a risk assessment.

MECHANICAL FAILURES

60 The frequency of mechanical failures on GT plant is low. However, if it occurs in close proximity to other plant the consequences can be severe. This is a particular concern on offshore installations where other high-pressure pipework/plant containing flammable materials can be damaged.

61 On some thin-walled machines, blade failure can result in blades being ejected at high speed through the rotor housing. The casings of some machines are protected to withstand such failures. The need for additional protection should be considered as part of the risk assessment. Failures can occur for a variety of reasons such as overload, deterioration or damage incurred in use. To further reduce the risk of turbine failure, appropriate measures should be implemented to monitor blade condition for erosion, corrosion and damage. Air inlets may be screened to prevent the entry of foreign bodies into the turbine intakes. In such cases precautions should be taken to avoid hazards from ice formation where icing conditions can occur.

62 Turbines and their housings are precision components which run at high temperature. A vibration footprint at first run up/run down and steady state can provide a valuable reference point. To avoid damage, procedures need to be followed when starting and stopping the GT. These procedures are intended to mitigate the rate of expansion or contraction of the blades and housing. If they are not followed, the rates of expansion can differ and damage can occur.

63 While running, the rotational speed of GTs should be controlled within safe limits to prevent blades from being overloaded and damaged due to centrifugal force. Any safety features provided for this purpose, such as overspeed protection, need to be maintained in good working order and tested both off-line and on-line. For instance, overspeed testing can be achieved by causing a trip during recommissioning from an outage. On some machines a trip condition can be simulated by control software, while other machines can only achieve this by actually overspeeding the machine, when careful consideration needs to be given to any increased risks from carrying out such a test.

64 Blades erode and shaft bearings may wear in use and this can upset the balance of the GT. If the erosion and/or wear are allowed to progress beyond safe limits then mechanical failure can occur due to the lack of balance. GTs should be inspected and maintained at set intervals to protect against damage or wear which may lead to safety-critical failure. Periodic preventive maintenance should be carried out to set schemes to determine the levels of deterioration or damage on blades and shaft bearings. When formulating the inspection scheme or carrying out maintenance, the manufacturer's recommendations on inspection intervals or replacement criteria for parts should be taken into account.

65 Condition monitoring may be used to assess the condition of blades and bearings without resorting to costly strip-downs. However, periodic inspection still needs to be carried out at appropriate intervals and care needs to be taken over the correct interpretation of data obtained. This often means that condition-monitoring data needs to be collected over a period of time and compared with the results of periodic inspections before users can have sufficient confidence in its interpretation. Also, a history of data is often needed to measure vibration trends, which can indicate when blades or bearings need to be replaced. Only those who are competent to make judgments on its significance should undertake the interpretation of such data.

66 Airborne contaminants can enter via the air inlet and become deposited on the compressor blades. Compressor blade cleaning, as well as maintaining the efficiency of the GT, may also lessen any possible risk of blade failure. Air inlet filters should be cleaned and maintained regularly.

67 Gearboxes should be maintained, taking into account the manufacturer's instructions. The correct grade of oil should be used and replaced at the correct intervals specified by the manufacturer.

68 Major gearbox failures have been known to cause injury as the larger units transmit significant shaft power. Vibration monitoring and oil debris analysis can give early warning of damage. Continued contact with the supplier and participation in user networks can supply useful information on problems encountered in use, what to look for during inspection and the necessary frequency of inspection intervals.

ELECTRICAL ISSUES

69 When the initial tenders for new power generation are drawn up, care should be given to the consideration of the technical specifications for the electrical plant, equipment, installations and systems to be provided. It is essential to establish that what is to be provided and installed will comply with the relevant health and safety legislation in the United Kingdom and relevant national or international standards. The electrical protection system should minimise the risk of potentially damaging overload situations (that may result in catastrophic drive-train failure) in both island operation and when synchronised to the grid.

70 Hazardous area classification should be carried out for all plant items and pipework containing flammable substances such as fuel or oils, whether in an enclosure or otherwise. It should be carried out in accordance with relevant regulations (The Dangerous Substances and Explosive Atmospheres Regulations 2002), the associated Approved Codes of Practice[17,18,19] and current recognised standards.[9] Normally, enclosures would be expected to be classified zone 2. In some cases it may be possible to justify the reduction of zone sizes by making a conservative allowance for the effects of the ventilation in accordance with relevant standards and

guidance. This must take into account the extent of flammable areas from CFD predictions as described at paragraphs 35-41 above. Zoned areas may be safe when the plant has shut down, if the fuel and other flammables are adequately isolated, as described in paragraph 50, and sufficiently de-pressurised. Additional guidance relating to area classification for natural gas is given in IGE/SR/25.[20] All electrical equipment should be checked to confirm it is suitable for the area classification.

71 Before plant is taken into use, site safety rules and operational procedures should be carefully matched to the original specifications for the electrical installation, to avoid misunderstandings by the operators. Specific agreements between users/purchasers and manufacturers as required by some relevant standards, need to be checked to ensure full compliance.

72 Risk assessment should be carried out on all the electrical systems for the plant. The assessment should also include all the risks arising during system verification and commissioning tests. The user will be responsible for ensuring that the suppliers of electrical systems provide sufficient information to describe the safe use of their equipment.

73 Identification and labelling systems and the positioning of labels and notices on switchgear, transformers, control gear and plant have been used in the UK which differ from those normally used. It is essential that employees are fully conversant with alternative identification and labelling systems and that labels, notices and instructions are clearly displayed. Where this is a potential problem, systems will have to be replaced with more familiar ones or further training will be needed.

74 People carrying out commissioning or live work must be familiar with the plant and systems to be commissioned. They must be trained in using a permit-to-work system as described in the regulations referred to in paragraph 87. They must also consider the effects the work could have on other people and plant. Adequate documentation and drawings must be available at handover and final documentation must be completed as soon as practicable following completion of commissioning. For the purpose of commissioning activities, inhibits and overrides may need to be temporarily installed in order to prove the system controls. If this is the case, a log should be maintained to ensure that they are removed and the systems reinstated, prior to the equipment being made fully operational.

75 Existing safety rules and operating procedures may not address the requirements of the plant, for example live brush changing. It may be necessary to confirm before taking operational responsibility that the rules, procedures and all equipment, including where necessary personal protective equipment, are in place. Staff will also have to be familiar and practised in these matters.

ELECTROMAGNETIC RADIATION

76 Employers should use the guidance published by the National Radiological Protection Board[21] when assessing whether there is a risk to health.

77 Current flows greater than a few hundred amps are capable of producing a significant magnetic field risk at a distance of less than one metre. Bare HV conductors may lead to people being exposed to electric fields which exceed the NRPB investigation levels of 12 kV/m. On GT plant the HV conductors are normally phase segregated and insulated, which will prevent corona discharge. The only exception is the conductors from the transformer bushing to the banking compound where a visible corona may be present.

78 If the measured field strengths exceed the investigation level, more detailed investigation should be carried out to determine the induced currents arising from potential exposures. These should be compared with the published basic restrictions and, if necessary, preventative measures taken. Such measures could include limiting the proximity at which people may approach live conductors. Restricting the duration of exposure is not an acceptable control strategy. In this case suitable barriers and signs shall be in place to warn of the potential for danger.

LEGAL REQUIREMENTS

79 The Health and Safety at Work etc Act 1974 requires that an employer ensure the health safety and welfare at work of all employees and people affected by such work activities. Duties include the provision and maintenance of plant and systems of work that are, so far as is reasonably practicable, safe and without risk to health.

80 The Management of Health and Safety at Work Regulations 1999 (MHSWR) require a risk assessment to be carried out to identify and implement any necessary preventative and protective measures.

81 The Provision and Use of Work Equipment Regulations 1998 complement MHSWR. The risk assessment will help identify all the protective and preventative measures that have to be taken in order to select suitable work equipment and safeguard dangerous parts or features of that equipment.

82 The Confined Spaces Regulations 1997, together with the associated Approved Code of Practice,[22] define a confined space. An acoustic enclosure around a GT is likely to form such a confined space. The first consideration is to avoid entry when there is a reasonably foreseeable risk of serious injury from any hazardous substance or condition. Based on a risk assessment, measures can then be adopted to reduce the risk to an acceptable level.

83 The Noise at Work Regulations 1989 require an assessment of the exposure of employees to noise to be carried out when the first action level of 85 dB (A) or the peak action level of 200 pascals is exceeded. Hearing protection is only acceptable after all reasonably practical measures have been taken to reduce exposure at source.

84 The Supply of Machinery (Safety) Regulations 1992, which implement the Machinery Directive 89/392/EEC, places duties on the responsible person who supplies relevant machinery and/or relevant safety components in the UK market. Relevant machinery and safety

components are defined within the Regulations. The Regulations require machinery etc to satisfy the essential health and safety requirements (EHSRs), and to undergo the appropriate conformity assessment procedures to demonstrate that the equipment has met the EHSRs and is safe.

85 The Gas Act 1995 authorises the Public Gas Transporter to require the fitting of supply protection devices to protect against excess reverse pressures, low inlet pressures, large rates of change of flow and undue pressure/flow perturbations.

86 The Gas Safety (Installation and Use) Regulations 1998 mainly apply to domestic premises. However, regulation 38 covering the use of antifluctuators and valves applies to all gas users. This reaffirms the need to notify the Public Gas Transporter and carry out any requirements set by the Transporter in order to protect other consumers from danger.

87 The Electricity at Work Regulations 1989 set out the safety requirements for electrical installations and the safety of people working with or near such systems. They impose duties primarily on the occupier of the premises but also in certain cases on employees working on the system, including contractors.

88 The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996, which implement Directive 94/9/EC (the ATEX 'Equipment' Directive), are concerned with the supply of equipment and protective systems for use in potentially explosive atmospheres.

89 The Pressure Systems Safety Regulations 2000 set requirements for pressure systems containing a relevant fluid. A relevant fluid is defined as steam, at any pressure, a gas or a liquid which would have a vapour pressure greater than 0.5 bar above atmospheric. Gases dissolved under pressure are also considered relevant fluids. The Regulations impose requirements on designers, manufacturers, suppliers, owners and users of pressure systems, together with employers of people who modify or repair such systems. The intention of the Regulations is to prevent the risk of serious injury from stored energy as a result of a failure of the pressure system or part of it. The design requirements of the Pressure Systems Safety Regulations (regulations 4 and 5(1) and (4)) are specifically disapplied for equipment designed and supplied in accordance with the Pressure Equipment Regulations 1999.

90 The Pressure Equipment Regulations 1999, which implement the Pressure Equipment Directive 97/23/EC, put duties on the responsible person who places pressure equipment on the UK market or puts such equipment into service in the UK. The Regulations apply to the design, manufacture and conformity assessment of pressure equipment and assemblies of pressure equipment with a maximum allowable pressure greater than 0.5 bar. The Regulations require equipment (as defined) to satisfy the essential safety requirements and to undergo the appropriate conformity assessment procedures to demonstrate that the equipment has met the essential safety requirements and is safe. The conformity assessment procedures are based on the level of hazard, which is determined by classifying the equipment according to criteria laid down in the Regulations.

91 The Dangerous Substances and Explosive Atmospheres Regulations 2002, together with the associated Approved Codes of Practice,[17,18,19] implement Directive 1999/92/EC (the ATEX "Workplace" Directive) and are concerned with area classification and the selection and use of equipment for use in hazardous areas.

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