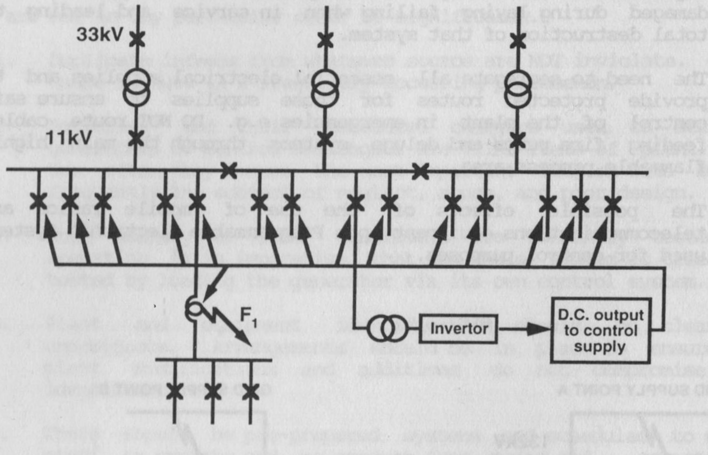
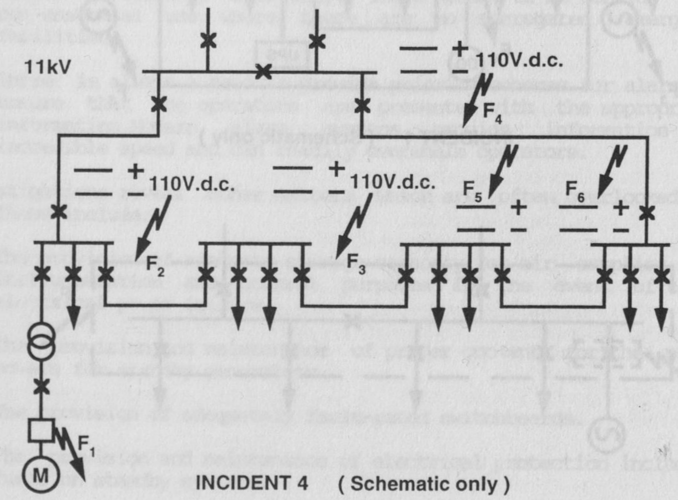


INCIDENT 3 (Schematic only)



INCIDENT 4 (Schematic only)

THE USE OF FIRE AND GAS DETECTION SYSTEMS AS PART OF THE SAFETY CONTROL PACKAGE

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The paper discusses those areas of industrial safety where the use of fire and gas detection systems are accepted as an alternative to the traditional standards of "passive" means of protection, eg the use of explosion protected electrical equipment in hazardous areas. This is illustrated by examples of the use of such systems in specific operations and processes.

Examples of industrial applications, where the use of such systems is in addition to traditional methods to enhance safety levels are also discussed.

Comment is made on the standards required for such systems when used as an alternative to other safety requirements, and those typically employed when these systems provide an additional safety feature.

Concluding remarks identify those areas which need further study to increase the acceptance of fire and gas detection systems as means of maintaining or improving current safety levels.

Key Words: FIRE DETECTOR, FLAMMABLE GAS DETECTOR, SAFETY CONTROL SYSTEM

INTRODUCTION

Fire and gas detection systems have been around for many years, yet many still question the safety benefits these provide. The objective of installing a fire or gas detection system is to give reliable warning of a developing hazard in sufficient time to prevent that hazard occurring. An obvious requirement, but one which is surprisingly sometimes overlooked. Unfortunately it is not unknown for a sophisticated detection system to be installed without sufficient regard for the emergency response to be taken once the alarm is raised, and indeed whether there is sufficient time for this action to be taken to prevent the hazard.

The views expressed are those of the author and do not necessarily reflect those or the policies of the Health and Safety Executive.

It is the purpose of this paper to consider the integration of fire and gas detection systems with the emergency response, to comprise a discrete safety or emergency control package, and in doing so, to demonstrate that a fire or gas detection system cannot by itself constitute an emergency control package.

The response to an alarm from a fire or gas detection system can be by either manual or executive (automatic) action. An example of executive action is where an electrical signal from the detection system either directly or via a programmable electronic system initiates the emergency action, eg shutdown of the plant by perhaps closure of valves etc.

The most common example of manual response to a signal from a detection system is that of the fire warning alarm in buildings. Here such a response is invariably acceptable because the standards of means of escape and other general fire precautions required by the Fire Precautions Act 1971 and similar legislation ensure that an adequate amount of time will be available from raising the alarm to complete safe evacuation of the building. However, it is important that, if it is to be left to a "responsible" person to decide on the emergency response to be taken, they know that it is their responsibility and by analysis and practice it has been demonstrated that sufficient time is available for safe evacuation from the time the fire is detected to it becoming untenable for survival. Unfortunately history reflects numerous incidents eg Woolworths, Manchester 1979; Stardust Disco, Dublin 1981; and Kings Cross, London 1987 where aspects of this response and hence the emergency control package itself broke down resulting in numerous fire deaths.

However there are numerous situations where evacuation cannot be the sole response to an alarm from a fire or gas detection system and, indeed, might not be appropriate. In the case of process plant for example, whether it is on or off shore, remedial action may need to be taken to attempt to control a fire or gas release to prevent a major hazard resulting. This could be by, for example, activation of the water deluge system and the emergency shut down valves on an LPG installation. In these situations it is easy to over extend the limits of what reasonably can be expected from human intervention to implement emergency action. As a result the operator can be presented with information that is imprecise and also have inadequate time to be able to take all the emergency actions necessary. An obvious way of overcoming this is to provide an emergency control package where the response to the alarm from the fire or gas detection system is on an executive (automatic) basis. Without this the adequacy of the overall emergency control package may be found wanting. An example of this being the Piper Alpha disaster, where the report of the public inquiry, Department of Energy [1] makes comment that the lack of proper integration of the gas detection system with the emergency shutdown system was a deficiency.

The weakness of not providing a fully integrated safety control package is clear and indeed this paper is not unique in recognising this, Bonn [2]. So why is there an apparent continuing tendency to treat fire and gas detection systems in isolation? There are perhaps two major generic reasons. One is the manner in which the requirements and design specifications for fire and gas detection systems are given in published guidance which, because of their complexity are invariably discussed in isolation of the emergency response; with the result that perhaps the plant operator does not connect the two. The other is the operational difficulty of achieving an acceptable balance between avoiding nuisance alarms, resulting in costly and

unnecessary plant shut downs and realising sufficiently early detection to be able to take emergency action. We will now consider these issues.

INDUSTRIAL APPLICATIONS OF FIRE AND GAS DETECTION SYSTEMS

Detection Systems Having a Primary Role in Protection

Guidance on fire and explosion precautions, involving the use of fire and gas detection systems for specific processes or applications, tends not to address the fire and gas detection systems in any detail, referring the reader to detailed guidance, such as the codes of practice on gas and fire detection systems. However, on reference to these, it is invariably found that discussion or direction as to how these systems are to be integrated with the emergency response is absent. For example, one of the definitive guides for gas detectors, BS 6959: 1989 [3] although it gives a list of possible applications, which includes reference to process shutdown, does not further discuss or develop this. Indeed, such application is perhaps consciously drawn back from via the statement "the use of combustible gas detection apparatus is to be regarded as a secondary means of protection and not as a substitute for the primary protection measures". Similarly, with the definitive guide for fire protection and alarm systems in buildings (the BS 5839 series) [4], the assumption is made that adequate time will be available to safely evacuate the building in the event of fire.

However, despite the comment made in BS 6959, there are situations discussed in published guidance, albeit in varying degrees of detail, where fire and gas detection systems play a primary role in fulfilling the safety requirements for some industrial processes. Further consideration of examples of this guidance is useful to provide a comparison of the extent to which fire and gas detection systems are integrated with the emergency response and whether the discrete safety control package so produced is adequate for the hazard it is designed to mitigate or control.

Brief examples of applications are presented at the end of this paper. Example 1, whilst a dissimilar process from the others discussed, does serve to illustrate a relatively simple application in which reliance on human intervention as the response constitutes an acceptable component of the safety control package. However as one moves towards more dynamic and rapidly changing situations such reliance becomes less tenable. Example 2 discusses automatic fire detection provision for offshore installations. This does not detail the emergency action required, but it is evident that a number of fire scenarios will be beyond the capacity of manual intervention to control, and executive action will be needed. To identify the necessary emergency actions the various incident scenarios require to be established and analysed. In doing so the capability of the detection system, along with the emergency action to prevent escalation of the incident, can be assessed. As a consequence of this assessment it may be found for some predicted scenarios that there is insufficient time from detection to implement the emergency response, even by executive action. These would then need to be addressed by taking other precautions eg to reduce the amount of fuel available by reduction of plant size and pipe diameters, or fitting further emergency shut-off valves etc. What is clear is that unless the role of the fire detection system as part of the overall safety strategy is established, it may become limited to being solely the harbinger of imminent disaster.

Examples 3, 4, and 5 illustrate cases where the incident scenarios have been considered and used to determine the emergency response on detector alarm so as to prevent or limit the likelihood of an ignition occurring. The limiting leakage rate that can be prevented from giving rise to a dangerous accumulation of flammable gas or vapour and ignition sources have been identified and used in arriving at the overall safety control package. Incidents resulting in leakage rates above this can then, where the risk of their occurrence so warrants, be addressed by additional safety controls.

Examples 6 and 7 illustrate the need for prior analysis of incident scenarios to establish what the emergency response should be and what equipment must be installed to accomplish this either by manual or executive action as appropriate.

Detection Systems Having a Secondary Role in Protection

Consideration of those areas where fire and gas detection systems are used to supplement safety levels show marked similarity with those applications where these systems play a primary safety role, but for which the emergency response is not described in the guidance. Namely the systems are specified, but how they are integrated into the safety control package is not, except where they are very site specific, eg over-temperature detectors on individual pieces of plant such as bearings on pumps. Where these detector systems provide a wider general coverage, eg of the premises, the emergency action is left to the operator. This is not to say that the purpose of installing such systems is questionable. For example, it might be argued that had such a system been installed on the Pemex Plant, Mexico City in 1984, the early detection of the initial leak and the appropriate emergency action may have prevented the subsequent disaster; when it is believed a leak of gas from a pipe manifold travelled a considerable distance to a flare stack and flashed back. What is questionable is the use of detection systems without regard to the emergency action they are to initiate.

RISK REDUCTION APPROACH

Comment has been made above that a reason for the limited integration of a fire or gas detection system into a safety control package is the belief, whether perceived or not, that adequate reliability cannot be placed upon the detection system to initiate the emergency action. Considering this further, it is not so much the possible failure of a detector to react to the stimulus, be it fire or gas when presented with it, since response is really quite reliable, but rather whether the detector is in the right place to detect the leak, and to do so in sufficient time to mitigate the consequences of that leak. Therefore a methodology needs to be developed to permit the analysis of the various facets of a safety control package, in this case one incorporating a fire/gas detection system.

Although still in its infancy a possible approach is the Safety Life Cycle, using System Integrity Levels currently under development by the IEC [16]. It is not the intention to develop this approach in this paper, but to introduce its application to fire and gas detection systems and specifically to show how detection systems need to be considered a part of a safety related system to bring equipment or a process to a safe state in the event of loss of normal control.

The safety of any industrial process or operation typically relies on a number of discrete safety features whose purpose is separately to mitigate the hazard. If one fails, then the ready availability and implementation of another maintains safety. For example a reaction vessel and associated pipework will be built to appropriate design codes to ensure containment during normal process control. However in the event of loss of control it may be that the hazard is mitigated either by emergency relief vents, or evacuation of the building. Each of these can be considered to be a Safety Related System, which combined achieve the necessary reduction of risk from the consequences of loss of normal control to one which is tolerable, ie the ALARP (as low as reasonably practicable) region.

For a fire or detection system to constitute a Safety Related System, then the response, as well as the detector and alarm needs to be considered. Developing the example above, if to achieve the risk which is deemed tolerable for the process the installation of gas detectors is felt appropriate to give early warning of loss of containment; then despite the likely high reliability of the electronic components of the gas detectors and associated electrical circuitry, they alone cannot achieve this. The risk reduction can only be achieved by, in addition to the detectors, their location to realise sufficiently early detection to initiate the response and the response itself. This may be solely to initiate an evacuation alarm, or close emergency valves. Whichever, the Safety Related System will have a certain risk of failure that by the IEC approach can be categorised into one of four Safety Integrity Levels. If the response is to be a manual one, such as closure of valves, the probability of failure of the Safety Related System might be determined to be in the range of $\geq 10^{-3}$ to $<10^{-2}$, which is System Integrity Level 2. If however closure of the valves is to be by executive action, the probability of failure might be reduced and fall in the range $\geq 10^{-5}$ to $<10^{-4}$, which is the highest System Integrity Level of 4.

The appropriate level depends on the importance and hence reliability of the other Safety Related Systems. If in the example above the emergency relief vents provide the primary risk reduction measure, then the prescribed tolerable risk could be realised by a gas detection system that has a System Integrity Level of 2. However if the primary risk reduction measure is provided by the gas detection system, a System Integrity Level of 4 might be necessary.

The benefit behind the suggested approach is that it permits for the systematic analysis of the various discrete Safety Related Systems for any process or operation and how these combine to achieve the tolerable risk appropriate to the process. Thus by including fire and gas detection systems in such study, their role and their reliability in performing that role can be assessed.

CONCLUSION

The part played by fire and gas detection systems in reducing risk is not usually quantified as part of an integrated safety approach, particularly when provided on larger plant and installations. It is evident that this can be and is carried out on the small scale as exemplified for the specific plant and processes detailed in this paper; but typically as the fire and gas detection system becomes less plant or process specific, there is a lack of consistency and coherent approach in its provision and function it serves. Before these detection systems can play a greater safety role, the systematic analysis of their role as part of the emergency control procedure needs to be carried out. An approach using a methodolody of broad categorisation of safety integrity levels appears capable of being developed for this analysis. Fire and gas detection systems would be required to achieve an appropriate level if they are to be given credit for reducing risk.

Until such an approach is fully developed and adopted the role of these detection systems in the overall safety control package will remain limited.

APPENDIX

Example Case 1: Use of gas detection equipment prior to carrying out hot work.

When plant has previously contained a flammable substance, then prior to hot work such as welding or cutting, the plant is required to be cleaned and the atmosphere checked with a flammable gas detector. Guidance published by HSE [5,6,7] discusses the safeguards required for these work activities including the use of gas detectors in possibly one of their simplest applications. The environment within the vessel or space would be expected to be relatively constant, the detector is a self - contained hand held unit and should be used by an experienced operator, who at the conclusion of his inspection pronounces whether it is safe to commence the activity or not. However, despite this, incidents often resulting in fatalities still periodically occur. There can be several reasons for this, including the most disappointing one of failing to even use a gas detector. Typically though, a substantial number of incidents also occur due to the failure to recognise the limitations of the gas detector. For example, it is extremely unlikely that it will detect anything from liquids such as heavy fuel oil where the danger from such materials becoming heated during the hot work is reliant upon the interpretive skills and knowledge of the gas detector operator. To make the obvious point the safety control package in respect of hot work on vessels that have contained flammable material includes, inter alia, the cleaning method, the gas detection equipment and human factors. The inadequacy of any one leaves the safety control package incomplete with the consequence that a potentially dangerous situation prevails.

Example Case 2: Automatic fire detection for Offshore Installations

There is a requirement for an automatic fire detection system under Regulation 5 of the Offshore Installations (Fire Fighting Equipment) Regulations 1978. An interpretation of what is required by the legislation has been published, Department of Energy [8]. However this is not, nor is it intended to be a design specification, and furthermore, it is discussed in isolation to the overall safety objective. What is implicit is that the installer needs to be knowledgeable of the types of fire detection equipment available and their limitations. More precisely, the installer needs to assess the type of fire to be detected to be able to specify the appropriate detector that will most reliably detect a fire with the minimum of nuisance alarms.

It is not the purpose of this paper to consider fire detection equipment in detail. This is to be found in numerous publications elsewhere, for example, an excellent introductory discussion is to be found in the NFPA Fire Protection Handbook [9]. But, for the purpose of illustrating the dilemma faced in installing a suitable fire detection system, it is useful to consider various fire scenarios. For example, flaming fires are most rapidly detected by optical detectors (UV and IR), these being capable of response within milliseconds, but care is needed on siting to avoid nuisance alarms, such as from arc welding triggering UV detectors and black body flickering radiation from hot machinery triggering IR detectors. With respect to smouldering fires, it may be that the most reliable indication will be given by a photo electric or ionization type smoke detector, though it is unlikely that they will detect a fire size below 250 kW, and will only do so where the smoke is contained and accumulates within an enclosure in which there are no significant air movements to negate the thermal currents transporting the smoke from the fire. Finally, it may be considered that the risk is one of a component overheating, eg a bearing, that might then result in a fire. In this case, a heat detector or rate of heat rise detector might be considered most appropriate located on the critical part of the equipment. The triggering thresholds can be set so that normal operating conditions are accommodated with alarm typically above $60^{o}C$ or greater than $7^{o}C$ per minute. Obviously, the benefit of early detection, possibly before any fire, has to be weighed against the site specific nature of the detector.

From the above discussion it can be seen that prior to the installation of any fire detection system it is necessary for the nature and size of possible fires to be assessed.

However, the operator having settled on the installation of a fire detection system after this careful analysis has still not provided adequate safety. For this the emergency action and time available to accomplish this are also of prime importance in establishing an adequate safety control package. If despite the early detection of a fire, its rate of growth is such that there is insufficient time for emergency action to be taken to prevent or mitigate the hazard, then alternatives, such as limiting the fuel available to the fire or its isolation from personnel, need to be considered. Conversely, it may be that any slowness in the response of the fire detection system is offset by this being fully integrated with the emergency action. For example, sprinkler systems have a relatively slow response, typically being triggered by a fire size of 1 to 1.5 MW (about half this with fast response sprinkler heads) but since they immediately start to cool the fire, and more importantly the fuel in its immediate vicinity, the rate of fire growth can be significantly retarded. It might be argued that this provides sufficient time for other emergency actions to be taken.

Example Case 3: Gas detector provision in aerosol filling rooms

The BAMA Code of Practice - Guide to Safety in Aerosol Manufacture [10] advises on the number of detectors and their location, their maintenance including the requirement for on-line self checking, the number of alarm settings and their levels. It also details the integration of the gas detection system by executive action with the emergency responses of increasing mechanical exhaust ventilation, stopping the aerosol filling machine and closing an emergency shutdown valve on the LPG supply pipe.

Example Case 4: Gas detector provision in ammonia filled refrigeration plant

A safety control package incorporating gas detectors is required for certain refrigeration plants using ammonia as detailed in BS 4434: Part 1: 1980 [11]. The number of detectors, their location and alarm level and the executive action on alarm is given; namely increasing the mechanical exhaust ventilation, the capacity of which is detailed, and isolation of "non-flameproof" electrical equipment.

Example Case 5: Gas detector provision for fork lift trucks in hazardous areas

In areas where it is considered there is potential for a flammable atmosphere to be formed, it is necessary for any powered plant within such areas to be protected to prevent it constituting an ignition source. Typically protection is provided by "passive" means when appropriate, eg flameproof enclosure; intrinsically safe circuitry etc. However, there may be a need for specific plant for which such means of "passive" protection is extremely difficult or expensive to provide. Fork lift trucks fall into this category, HSE [12], as does robotic plant which is increasingly used in hazardous areas. In such cases the gas detectors form part of an integrated safety control package to isolate the non-protected electrical components and other potential ignition sources such as the engine, in the event of flammable gas detection and alarm. Additional enclosure of the electrical components and other potential ignition sources is required to provide a period of 60s before the outside atmosphere reaches these. This provides sufficient time for their isolation before the flammable atmosphere reaches them, for the particular leak scenarios envisaged.

Example Case 6: Gas detector provision in LPG spillage catchment pit

The HSE guidance on the storage of LPG at fixed installations [13] requires gas detectors to be installed in any spillage catchment pit associated with a LPG storage installation. Whilst the catchment pit is separated from the LPG vessel(s) by a prescribed distance based on the potential fire size, the action on receiving an alarm is not given. This could vary depending on circumstances, but options need to be considered prior to any incident. Obviously, closure of valves on the import and export lines to the LPG vessel(s), preferably by executive action is to be provided for; but perhaps means for remote controlled ignition and activation of the water deluge system on the LPG vessels should also be provided. This may sound extreme and would require careful consideration , but the consequences of an uncontrolled leak continuing for some time and then igniting, giving rise to a fireball and explosion are potentially far more extreme. The LPGITA Guide to writing LPG Safety Reports [14] details the sizes and consequences of various leak scenarios.

Example Case 7: Gas detector provision for cryogenic LPG storage

The Institute of Petroleum Code of Practice for Refrigerated LPG [15] requires that tanks provided with a containment wall comprising a full height wall around the tank, should be provided with means for detecting and removing "liquid" leakage into the annular space. One of the objectives of this is, in the event of LPG leakage, to prevent the formation of an explosible atmosphere in the annular space. The location of gas detectors in this space will give warning of any leak, but this then needs to be linked to an emergency action to mitigate or prevent the danger. An option is to commence inerting of the space; but with the volume of such annular spaces often in excess of 1,000 m^3, such a process can take several hours to complete. The operation therefore needs to be taken in conjunction with other emergency operations.

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TRAINING PROCESS CONTROL SKILLS

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This paper discusses issues associated with operator training including emphasizing the importance of designing for human factors in general to provide a sensible context for training as well as discussing training methods themselves. The benefits of an analytical approach to identifying, designing for, and integrating these various training solutions is emphasised as this can lead to training which is effective whilst avoiding unnecessary expense. The paper emphasises the need to return to principles of learning to support practical training design.

Keywords: process control skills; training; simulation, human factors; task analysis

INTRODUCTION

Training is well established in the process industries. While much of this is well done there is scope for improvement, especially as new technologies offer new opportunities. An aim of this paper is to argue that training practice in these industries will be enhanced by training theory. Before turning to the nature of such theory, I shall first consider the different forms of training method currently in practice. Broadly, there are four main types of training commonly observed in the process industries, knowledge training, on-job instruction, simulator training and experience.

Teaching process knowledge

Teaching basic knowledge about plant, for example its structure and function, and about elementary physics and chemistry has long been regarded as an essential component of operator training. It can certainly help in teaching the names of parts of plant and equipment, justifying certain procedures and safety measures and is motivating if done well.

There is a danger that this form of training is over-emphasized because, firstly, it is relatively easy to generate content by presenting a diluted version of the chemistry and physics underlying the plant's design. Secondly, it is relatively easy to administer — all of the knowledge to be taught can be assembled and presented in a classroom session or in a computer-based learning package. Unfortunately the relationship between knowledge and skill is not so straightforward and administrative expedients often prevent training from fulfilling the real needs of learners.

On-job instruction

A second common form of training is on-job instruction, where a trainee watches activities on a real plant and is introduced to certain tasks under the scrutiny and control of an experienced colleague. There are some genuine benefits to be had from this sort of training. Firstly, it provides a very real