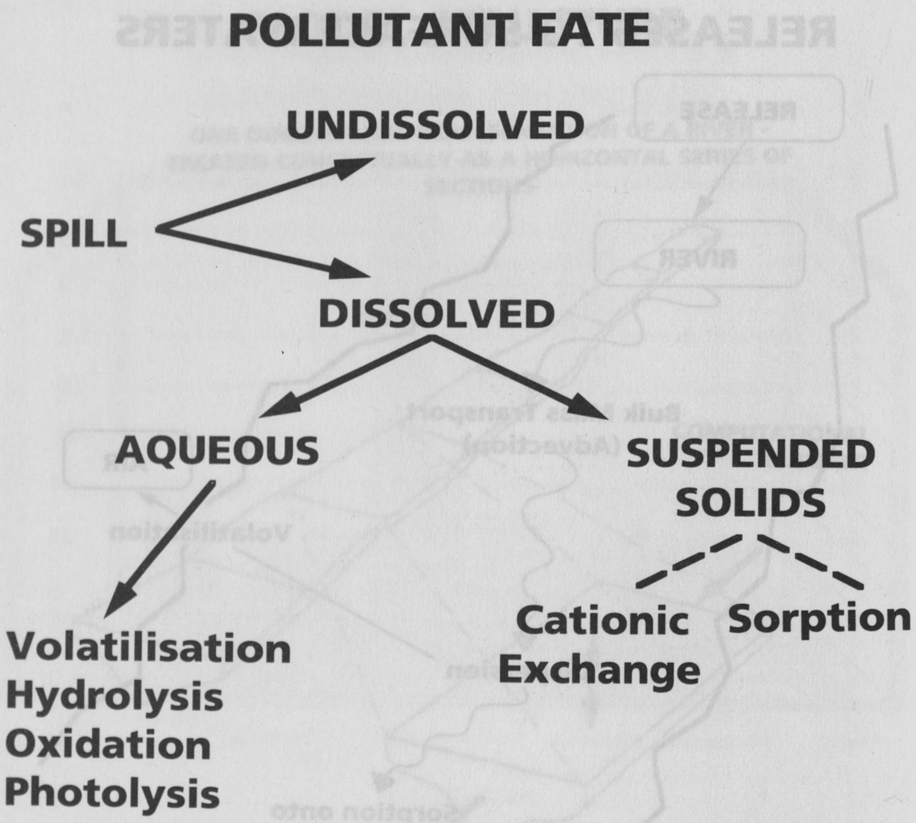

FIGURE 6

PERFORMANCE OF PASSIVE FIRE PROTECTION IN JET FIRES

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Emergency Shutdown Valves on offshore oil and gas risers must be protected from damage by fire. The most severe fire event to be protected against is considered to be an impinging jet fire from a high pressure gas leak. In the absence of any recognised jet fire test, a series of full-scale demonstrations have been carried out to provide assurance that candidate passive fire protection systems would provide protection in the event of a jet fire. These unique demonstrations are described, together with the supporting research and the findings which led to the selection of systems for installation offshore.

Offshore Safety, Fire Protection, Jet Fires

INTRODUCTION

One early consequence of the Piper Alpha disaster was new legislation, Statutory Instrument 1029(1), requiring all oil and gas risers in the North Sea to be fitted with Emergency Shutdown Valves (ESVs). This requirement was subsequently endorsed by Lord Cullen(2) in his inquiry into the disaster. An additional requirement of SI 1029 is that the ESV and its actuator shall, so far as is reasonably practicable, be protected from damage arising from fire, explosion and impact.

Shell Expro, who operate in the North Sea on behalf of Shell and Esso, decided to provide, where necessary, passive fire protection (PFP) to ESVs, actuators, adjacent risers and supporting structural members. The most severe fire event to be protected against was considered to be an impinging jet fire from a high-pressure gas leak. In the absence of any recognised test for jet fire resistance, a series of full-scale demonstrations have been carried out to provide assurance that candidate PFP systems would provide protection in the event of a jet fire. The jet fire demonstrations represented only one realistic event but its selection was underpinned by extensive research into the nature of jet fires.

These unique jet fire demonstrations will be described, together with the supporting research and the findings which led to the selection of systems for installation offshore.

BACKGROUND

Hydrocarbon fire tests

Passive fire protection materials for use on offshore facilities are currently subjected to fire resistance tests carried out in a furnace operating under time-temperature conditions defined by a fire curve(3). For facilities processing hydrocarbons, a fire curve to represent a hydrocarbon fire is used and this leads to an 'H' rating for a given length of time.

Surprisingly, there is no internationally recognised hydrocarbon fire test standard, although the Mobil and NPD time-temperature curves are widely used, as is the interim hydrocarbon fire standard adopted by the UK Department of Energy(4).

These hydrocarbon fire tests are based on furnace temperature rather than heat flux and, although the total flux may be similar to that generated within a fire, the wider range of fire variables, such as the balance of radiative and convective heating, high gas velocities and thermal shock are not specifically included or controlled. These are major factors with regard to the performance of passive fire protection in actual fires and, in particular, jet fires resulting from high pressure gas leaks.

In the absence of any specific test for jet fire resistance, the Shell Expro approach has been to carry out full-scale demonstrations of the ability of candidate systems to provide protection in the event of a jet fire. These demonstrations have been based on large-scale jet fire research.

Large-scale jet fire research

In order to assess the consequences of large-scale jet fires, Shell Research Ltd and British Gas plc conducted jointly a comprehensive experimental research project(5,6,7). This project was co-funded by the Commission of European Communities, under their Research Programme on Major Technological Hazards. Additional funding was provided by the UK Health and Safety Executive.

As part of this project, experiments were conducted in which natural gas and two-phase propane jet fires impinged horizontally onto either an empty, 0.9 m diameter, pipe or an empty, 13 tonne, LPG storage vessel, positioned over a range of distances relative to the release point.

A range of discharge orifice sizes were used. The natural gas releases had discharge pressures from 1.01 to 67 bara and flow rates from 2.5 to 10 kg/s, the lowest pressure discharges were sub-sonic and the others sonic. The propane releases were at pressures from 7 to 11 bara with flow rates of 1.5 to 22 kg/s.

Figure 1 shows a typical experiment, a 10 kg/s natural gas flame impinging on the pipe target.

Heat flux distributions over the structures were obtained directly using an array of forty total-heat-flux gauges located at their surfaces. The radiative flux to the impingement targets and the target metal temperatures were also measured. The direct heat flux measurements were supplemented by measurements of gas temperatures and velocities within the flame.

The heat flux density distribution was found to be complex and was dependent upon both flame type and position in the flame. Time-averaged heat fluxes in the flames studied were in the range 50 to 300 kW/m^2 for the sonic natural gas flames and 50 to 250 kW/m^2 for the propane flames. These total fluxes were lower than previously assumed literature values and the areas of maximum flux were small in comparison with the total engulfed area.

Performance of PFP in large jet fires

The very first tests of passive fire protection in a large high-pressure natural gas jet fire were carried out in the Shell Offshore Flame Impingement Protection Programme (SOFIPP)(8). The objective of the programme was to determine directly the response of full-size, unprotected and passively fire-protected, structural steel members to impingement for one hour by a large natural gas flame. The test flame, about 20 m long, was an ignited 3 kg/s sonic release of natural gas. This flame had been characterised in the jet-fire research programme described above, enabling the test specimen to be placed where there was known to be a representative total heat flux with substantial radiative and convective components and high gas velocities.

Two generic types of passive fire protection were evaluated, cementitious and intumescent coatings, on two types of structural member, tubulars and I-section columns. The tests demonstrated that both types can provide significant protection against an impinging jet fire.

Figure 2 shows the temperature response in the central region of the two tubular specimens, compared with the unprotected specimen. The temperature of the unprotected specimen rose to a equilibrium value of 1000°C in about 12 minutes. Both coatings kept the steel temperature below the target value of 300°C. The difference in performance between the two coatings does not necessarily indicate the superiority of one over the other. It reflects the thickness applied and, in the case of the cementitious coating, the water content, evidenced by the plateau at 100°C. The tests also highlighted the importance of features, such as erosion by the high-velocity jet, that are not present in furnace-based tests.

The jet fire demonstrations to be described in this paper closely followed the SOFIPP method. The main difference being the two-hour duration required for the ESV protection, based on maximum predicted event or evacuation times.

Since this work was carried out, some progress has been made towards a laboratory-scale test method for jet fire exposure(9). However, as we shall see, weaknesses in some fire protection systems may only be revealed by full-scale testing.

JET FIRE DEMONSTRATIONS

A series of seven jet fire demonstrations were carried out during Autumn 1990. Eleven products from five manufacturers were evaluated.

Specimens tested

The test specimens were 18 inch ball valves complete with dummy actuators and mounted between two pipe spools. The valve bodies and actuators were protected by various candidate enclosures and the pipe spools protected with epoxy intumescent coatings. The valve size was chosen such that the enclosure construction would be typical of that to be used to protect the larger ESVs. The smallest ESVs would probably have one enclosure protecting both valve and actuator. Shell Expro have ESVs in risers ranging in diameter from 4 to 36 inches.

The basic specimen configuration and its orientation to the jet flame is shown in Figure 3. Thermocouples were attached to the valve, the actuator, the inside of the enclosures and the inside of the pipe spools to monitor temperatures.

The enclosures tested covered a wide range of types and materials.

- soft tailored-jackets containing ceramic fibre

- a high-performance insulation encapsulated in stainless steel
- an all-metal insulation system comprising many layers of dimpled stainless steel foil
- a GRP composite insulation within a steel framework

The enclosures were designed and supplied by the manufacturers to meet the protection requirements set out below. All the systems had hydrocarbon fire ratings but none had been tested in a large jet-fire. Indeed, it is only fair to point out that the manufacturers were designing against an unfamiliar event.

Protection systems for risers and supporting steelwork in the form of removable shell and panel systems were also tested but these will not be reported in this paper.

Protection requirements

For the purpose of these two-hour demonstrations, a maximum temperature limit of 300°C was set for the valve and pipe spools. This was based on maintaining the integrity of the particular valves chosen. A different limit might be required for other designs or operating conditions.

The valve actuator must in practice be capable of closing the valve within the first 15 minutes of a fire. Having closed the valve, the actuator is no longer a critical component, although it may provide a heat path into the valve body. For the purpose of these demonstrations, a maximum temperature for the actuator of 100°C within 15 minutes was the only limit set. This was based on the operating limit of actuators in use by Shell Expro and a different limit might be required for other designs.

Test procedure

The test procedure used closely followed that described in the SOFIPP reports(8). The protected specimen was supported horizontally, 9 m away from the gas discharge orifice, on two insulated pillars 5 m apart. The jet flame, an ignited 3 kg/s, 60 bar release of natural gas, engulfed the specimen. Owing to a limited gas supply, the mass flow rate had to be reduced to 2 kg/s after the first hour. Figure 4 shows a test in progress. The discharge orifice, a 20 mm hole, is to the left of the picture.

Findings

Only the most interesting findings will be described here, with particular reference to the systems finally chosen for installation offshore.

Apart from the soft-jacket systems, all the enclosures gave worthwhile protection against the jet fire, although only one system, the GRP composite, achieved the protection requirements set. Both soft-jacket systems failed catastrophically within a few minutes and failed to provide any worthwhile protection, even for the actuator. One of these systems had a four-hour hydrocarbon fire rating.

Figure 5 shows one of the soft-jacket systems before and after testing, the test having been stopped after only 20 minutes. The jacket had been ripped apart by the jet exposing the valve and actuator. Figure 6 shows the temperature record at selected points on the valve and actuator. It was clear that the failure was the result of the high velocity jet penetrating the jacket and ripping it apart. The manufacturer subsequently modified the design by strengthening the outer material and eliminating some of the joints. This new design was successfully tested for actuator protection only and is one of the products that has been installed offshore.

Figure 7 shows the GRP composite enclosure before and after testing. The lower box is the valve enclosure. The upper box enclosing the actuator was the metal foil insulation system.

Figure 8 shows the temperature record at selected points on the valve and actuator. The 100°C temperature limit for the actuator was exceeded at one point after 12 minutes, although the bulk of the actuator was below the limit at 15 minutes. On the valve body, the maximum temperature reached at the end of the two-hour test was 170°C, well below the 300°C limit.

A general comment on all of the systems tested is that any weakness is invariably at joints, penetrations, fixings, etc. Tests carried out only on the materials from which enclosures are to be made, or on small versions having different construction details, may not reveal weaknesses to jet fire exposure.

CONCLUSIONS

1. The demonstrations revealed that some systems provided a significant amount of protection against an impinging jet fire, whereas others provided very little, even though all had a hydrocarbon fire rating.
2. Only one of the valve enclosure systems tested met the temperature criteria set for the two-hour test. This enclosure was constructed from a GRP composite within a steel framework.
3. The soft-jacket systems failed to provide any worthwhile protection against a jet fire. However, one of the systems was subsequently improved by the manufacturer, and successfully re-tested for 15 minute actuator protection.
4. The construction details are particularly important for jet fire exposure since the high velocity jet will penetrate any chinks in the armour.

IMPLEMENTATION

Based on the confidence gained from the jet fire demonstrations described in this paper, Shell Expro have installed, where necessary, passive fire protection systems to their ESVs, actuators, adjacent risers and supporting structural members.

The detailed results from these jet fire demonstrations have been shared with other offshore operators through the UK Offshore Operators Association.

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ACKNOWLEDGEMENT

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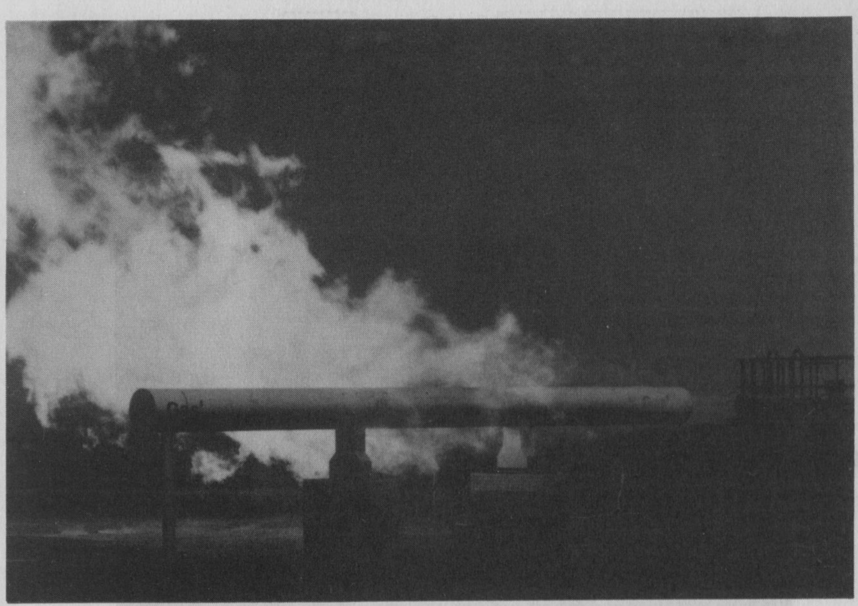

FIG. 1 - A 10 kg/s natural gas flame impinging on an instrumented pipe target

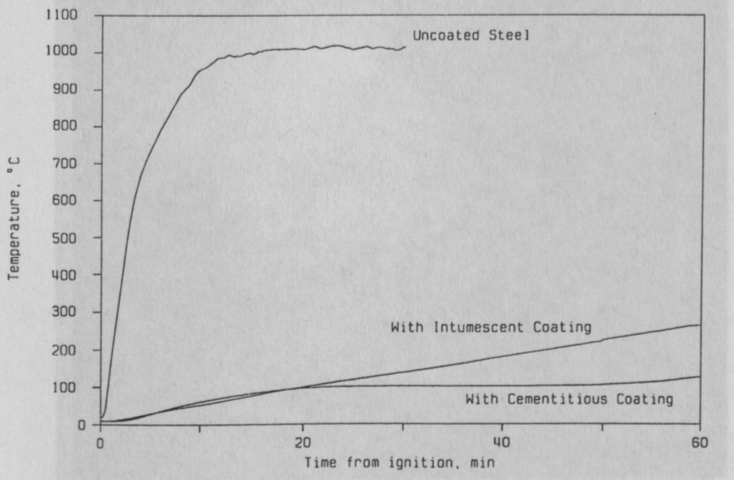

FIG. 2 - The temperature response of fire protected and unprotected steel tubulars in a jet fire

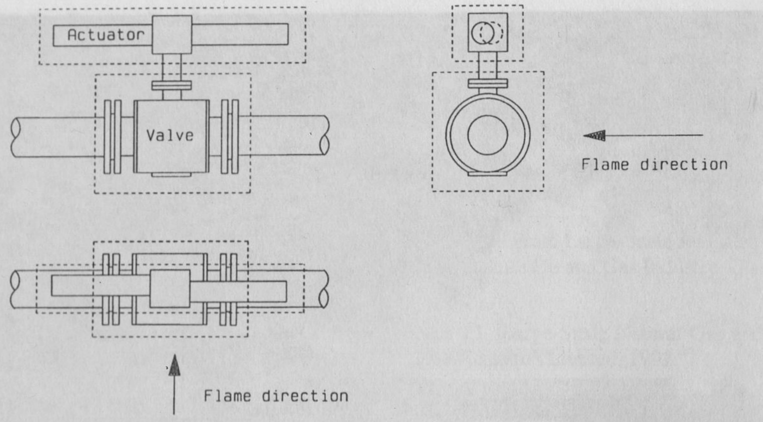

FIG. 3 - Configuration of the ESV enclosure specimens used in the Jet Fire demonstrations

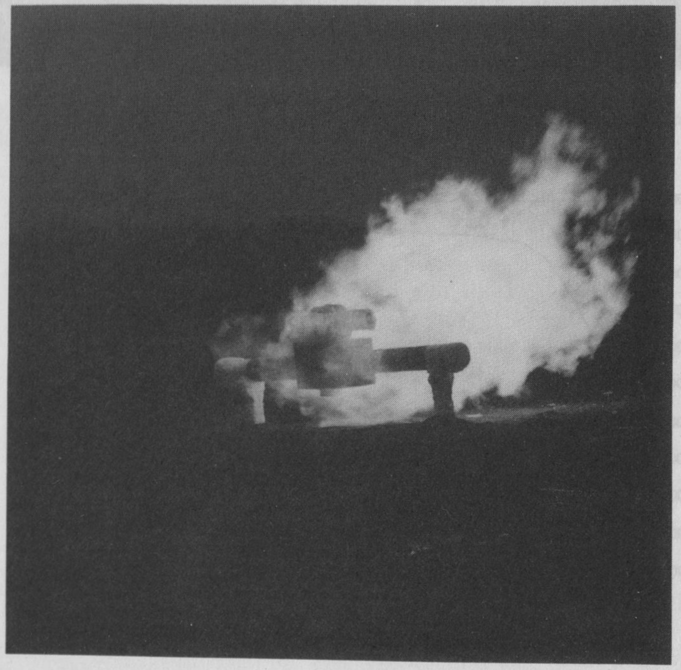

FIG. 4 - A jet fire demonstration in progress

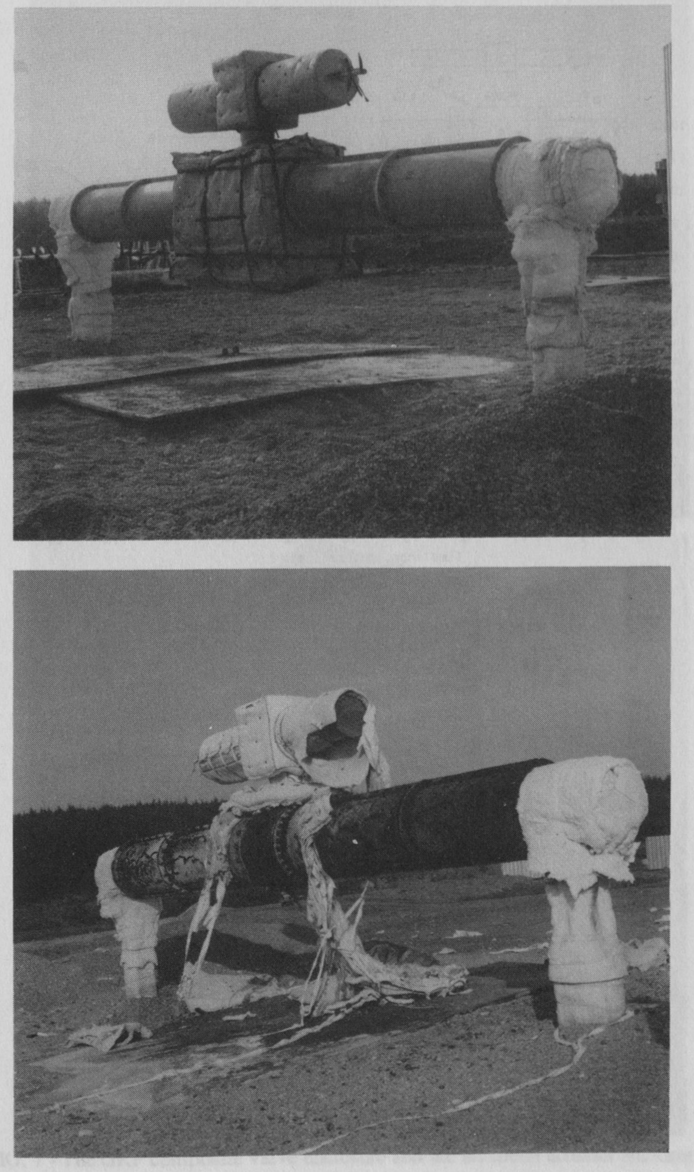

FIG. 5 - One of the soft-jacket protection systems, before and after testing

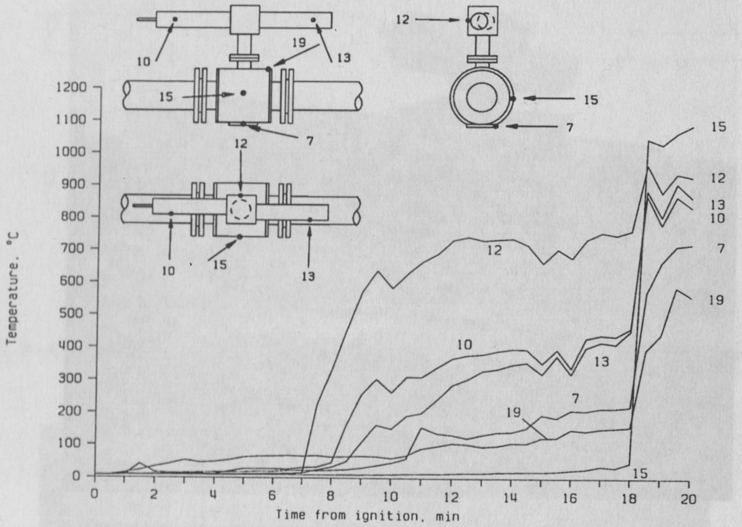

FIG. 6 - The temperature response of the soft-jacketed specimen

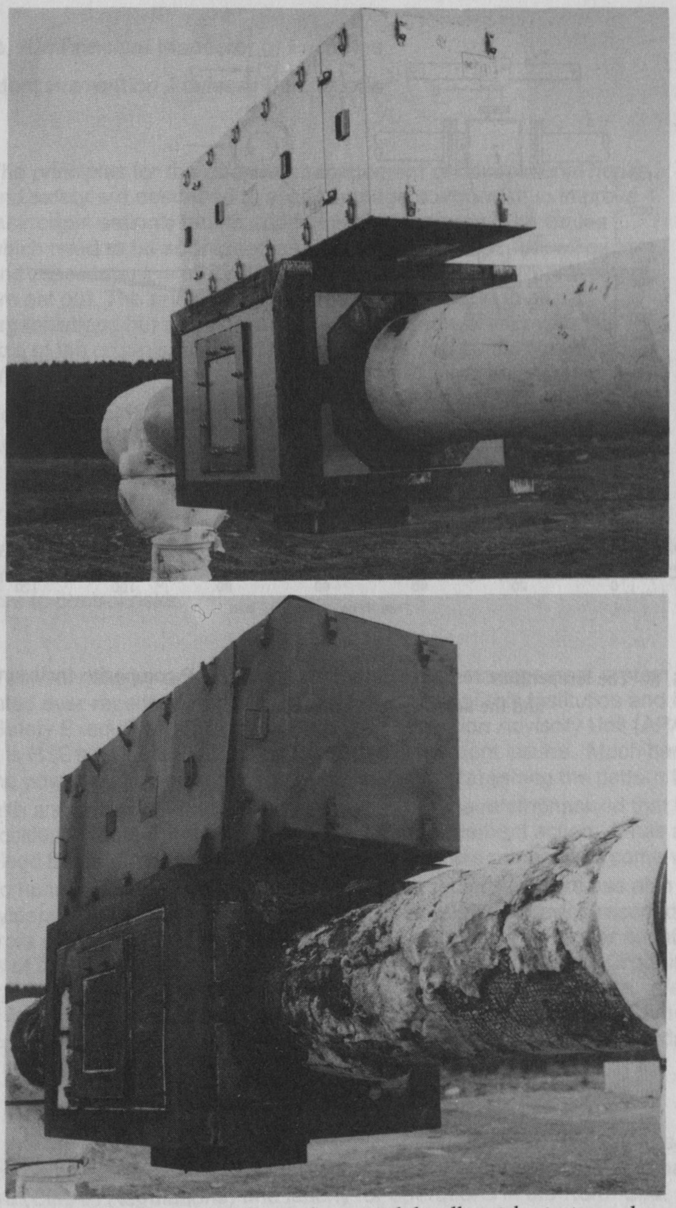

FIG. 7 - The GRP composite valve enclosure and the all-metal actuator enclosure, before and after testing

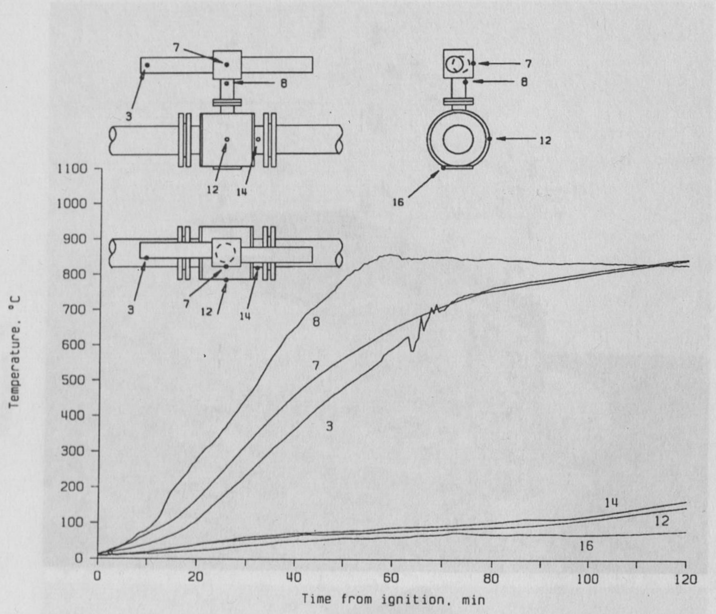

FIG. 8 - The temperature response of the valve in the GRP composite enclosure and the actuator in the all-metal enclosure

CRACKING HEALTH AND SAFETY MANAGEMENT

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The principles for the effective management of occupational health and safety are described to assist managers who wish to improve their organisation's health and safety performance. The issues which need to be addressed and which can be used for self audit and assessment, and for developing programmes for improvement, are set out. The principles described are applicable to all organisations but the extent of action required will vary with the size of the organisation, the hazards presented by its' activities, products or services and the adequacy of existing arrangements.

Policy; Planning; Organising; Measuring; Reviewing; Monitoring; Auditing.

A common feature of the onshore chemical industry and the oil industry is the likelihood of high hazard low probability events and the consequences both in financial and human terms of failure to control risks.

This need to control risks by an effective health and safety management system has been advocated over recent years by prominent members of this Institution and by the Health and Safety Executive (HSE). The Accident Prevention Advisory Unit (APAU) in which I work is HSE's focus for health and safety management issues. Much has been said about the power and influence of the boardroom in establishing the pattern to promote health and safety at work[1]. Many Publications[2-4] have emphasised that the vast majority of accidents could have been prevented by management action. It has also been recognised that the majority of accidents in industry are generally in some way attributable to human (behavioural) as well as technical factors[5]. There has also been increasing evidence from official reports of the public enquiries following recent disasters that while errors of an individual or individuals in the workplace may trigger events, the basic causes of accidents generally lie in flawed organisational systems. Organisations are encouraged to develop a safety culture which promotes and rewards the safe behaviour of employees, eliminating unacceptable practices and at the same time developing organisational structures and control measures which identify hazards, control risks and minimise losses.

In parallel to this the application of sound management principles to health and safety has been incorporated into legislative requirements, firstly with regard to major hazard sites on-shore (CIMAH Regulations) and latterly for operations in the North Sea. Safety