EXTENSION OF ONSHORE BASIS OF SAFETY PHILOSOPHY TO PERFORMANCE STANDARDS FOR PROTECTION MEASURES ON OFFSHORE PLATFORMS

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Application of the widely used Basis of Safety philosophy to operations on offshore platforms is discussed. The approach seeks to identify potential hazards associated with process operation and to define suitable safety measures to reduce risks to ALARP. This approach has been used in the offshore environment to identify critical safety systems and define performance standards for them in compliance with the new PFEER Regulations. The methodology entailed identification of credible fire and explosion scenarios, assessment of their consequences and the influence on the Emergency Response System, and finally definition of appropriate safety strategies and their performance standards.

Keywords : Basis of Safety, ALARP, PFEER, ERS, Fire & Explosion, Safety Systems.

INTRODUCTION

The Basis of Safety philosophy has become a widely used approach to defining the requirements for appropriate protective measures to ensure safety in process operations (Ref 1). This approach seeks to identify potential hazards associated with the processes being performed and to define suitable safety measures which, if correctly implemented, will reduce the risk of the hazard being realised to as low as reasonably practicable. The approach deliberately avoids the use of checklists, or standard protective measures for a given hazard, and instead assesses the hazards associated with each process on an individual basis, to define the most appropriate measures commensurate with the risk, the operating environment, cost and quality issues. The approach also avoids the use of multiple protective devices and focuses on simple concepts to allow a process to be safely and efficiently operated.

The approach is most usually applied to processes which have associated fire and explosion, or chemical reaction, hazards. In respect of fire and explosion hazards the best basis of safety is normally to modify the process to avoid the use of flammable material, this is rarely possible in practice however. Other bases of safety are :

(i) Operation below the lower explosive limit of the flammable material (e.g. by temperature control below the flash point, or dilution by forced ventilation)

(ii) Operation above the upper explosive limit of the flammable material (e.g. by exclusion of air, possibly utilising inert gas)
(iii) Provision of explosion relief facilities
(iv) Provision of explosion suppression facilities
(v) Design of equipment to withstand the maximum explosion pressure without sustaining damage
(vi) Elimination of ignition sources

In connection with the techniques outlined above it is normal to couple protective measures (i.e. (iii) to (v) above) with measures to avoid ignition sources even if elimination of ignition sources is not possible. This represents an attempt to minimise demands on the protective systems and to minimise plant down time as a result of fire or explosion events.

A simple example is a process which involves loading a flammable liquid into a reactor where the reactor temperature is above the liquid's flash point. Clearly if the reactor is initially full of air a flammable atmosphere may be generated in the reactor as it is filled and if an ignition source were to arise an explosion would result. Any of the measures listed above could be used as the basis of safety in this case i.e. :

(i) the reactor and liquid could be cooled or the reactor headspace force ventilated to avoid a flammable atmosphere
(ii) the reactor could be purged with nitrogen (or another inert gas) to exclude air and allow operation above the upper flammable limit
(iii) an explosion relief panel could be provided on the reactor
(iv) explosion suppression could be fitted to the reactor
(v) the reactor could be design to survive the maximum explosion overpressure (e.g. circa 8 bar)
(vi) potential ignition sources could be identified and measures taken to eliminate all of them

It is important to document which basis of safety is selected and the logic for that selection. It is also important to select only <u>one</u> basis of safety on which safe operation hinges e.g. if the basis of safety is explosion relief there is no need to inert gas blanket. All too often processes are erroneously designed with more than one basis of safety and such "over-design" may lead to complacency in operations such that critical systems are ignored or neglected in the mistaken belief that alternative systems will provide the necessary protection.

It was with this background that work was done with a major UK offshore Oil and Gas producing company to identify and evaluate those protective features on existing offshore production platforms which are critical to the ongoing safety of the operations. The work was commissioned with the new Prevention of Fire and Explosion and Emergency Response (PFEER) Regulations in mind. The work primarily addressed fire and explosion issues but also considered the effects of these hazards on emergency response.

THE PFEER REGULATIONS

These new regulations for the offshore industry form part of the new goal setting safety regime advocated in the Cullen Report (Ref 2). In 1992 the Offshore Installations (Safety Case) Regulations (Ref 3) were implemented which require a Safety Case to be prepared for each installation in the UK North Sea to demonstrate that all major accident hazards have been identified, their risks evaluated and reduced to a level that is as low as reasonably practicable.

The PFEER Regulations mirror the Safety Case Regulations while providing more details on specific requirements for assessment and systems. The PFEER Regulations replace the outdated prescriptive legislation on Fire Protection (SI 611, 1978). They require formal Fire and Explosion, and Evacuation, Escape and Rescue analyses, to be performed for each platform. These analyses must demonstrate the suitability of the facilities on the platform to provide prevention or control of fire and explosion incidents and to permit safe evacuation of the platform should a serious incident arise. As with the Safety Case Regulations the aim is to demonstrate that risks to personnel on the platform are as low as reasonably practicable.

At first sight therefore the PFEER Regulations appear to be a duplication of those parts of the Safety Case Regulations relating to Fire and Explosion hazards and Emergency Response, which is essentially true. However the PFEER Regulations go further than the Safety Case Regulations by requiring operators to identify those preventive and protective systems which are critical to the safety strategy on the platform and to define the performance standards required of these systems in order to ensure risks are as low as reasonably practicable (ALARP). For protective systems these performance standards need to consider the design capabilities required of the system, the external (normal and accidental) loads which the systems may be subjected to, and the availability of the systems required for ALARP to be demonstrable (the latter must recognise damage from accidental loads (e.g. fire and explosion) reducing the overall availability of systems).

It was with a view to identifying the truly critical protective systems, and defining performance standards required of these, that the Basis of Safety philosophy was applied to the Offshore environment. The studies were performed on existing (established) installations whose protective facilities had been specified under the SI 611 regime and it was recognised at an early stage that some protective facilities which existed were of limited value in relation to the hazards which may arise. The study took a fresh look at protective requirements to ascertain what type of systems would truly be of value, whether these currently exist, and which current systems warrant most attention in terms of improvement, modification and maintenance.

ASSESSMENT METHODOLOGY

The fundamental steps used in the assessment approach are :

(i) to identify potential fire and explosion scenarios

(ii) to assess the potential consequences of the identified scenarios

(iii) to define an appropriate safety strategy to prevent, or control/mitigate the consequences of the identified scenarios, taking into account the severity of the potential consequences

(iv) to define the required facilities to assure the chosen safety strategy and the required performance standards for these

Identification of Credible Scenarios

This initial stage of the study involved a multi-disciplined team of personnel, including offshore operations and maintenance representatives, onshore process and safety engineers and specialist combustion science consultants (i.e. Burgoynes). The team systematically assessed the operations in each area of the platform/complex, following the process streams from the wells through to the export risers. In this respect the process stream was broken down into discrete inventories for consideration, these inventories being agreed amongst the team members and determined by consideration of the process equipment, operating conditions and the physical location of equipment. As the studies all related to existing installations the chosen inventories were typically determined by the location of existing emergency isolation valves. In some cases however the location of such valves was such that the "isolatable" inventory could theoretically be released in more than one discrete location (e.g. consecutive isolation valves on different platforms of a multi-platform complex, or different modules of a platform, or different decks within a module). In such circumstances the causes and assessment of consequences of a release from the "isolatable " inventory were assessed for numerous different release locations covering the representative areas through which the inventory passed.

A brain-storming approach was used, calling on the experience of the team members, knowledge of loss of containment incidents on the platforms (or within the industry generally) and lateral thinking to define credible causes of release of process hydrocarbons, giving the potential for fire and/or explosion. Identified causes (and the logic behind them) were documented and passed forward for consequence analysis. (In the event the above work had been previously performed for each of the platforms in preparation of the Safety Cases, however the subsequent analyses had considered only the currently installed protective systems and had not looked objectively for a definition of an optimal safety strategy and of performance standards).

Assessment of Consequences

After identifying credible causes of loss of containment from the isolatable inventories the potential consequences of these events were assessed. In particular this assessment sought to assess whether a fire or explosion resulting from the release would be capable of causing escalation by, for example, giving rise to secondary failures of hydrocarbon containing equipment and failure of walls or decks. Potential consequences to facilities constituting the platform's Emergency Response System were also given significant attention. To facilitate this the key elements of the Emergency Response System and the proposed actions in the event of a major incident were documented.

Firstly the immediate consequences of ignition of the primary release were considered so far as they could influence the elements of the Emergency Response System. The results of this dictated whether or not protective measures were required to combat the potential effects of the primary event. The initial hydrocarbon release rates from the primary releases were assessed using standard (published) techniques for gas, liquid or two-phase releases as appropriate and assuming the normal operating conditions of the isolatable inventory. The presence and influence of existing emergency isolation and blowdown systems was not taken into account at this stage as the intention was to perform a fundamental assessment as to whether such facilities are necessary or not in the light of individual scenarios. Whether or not an explosion could occur as a result of the primary release was determined taking into account the release rate, the volume of confinement around the release (e.g.the module or enclosed deck volume) and any natural ventilation, ignoring at this stage potential influence of existing shut down systems. Gas accumulation calculations were performed to assess the maximum fraction of the confined volume which could be theoretically "gassed up" to a stoichiometric concentration, taking into account the release rate and the influence of natural ventilation. An assessment was then made of the maximum explosion overpressure which could arise if this volume of flammable mixture were to ignite. A simple explosion model was used based on the published results of one fifth scale tests, scaled up to full scale by a CFD model (Ref 4). The presence of any natural explosion relief areas was taken into account. An assessment was then made as to whether the predicted overpressure would be capable of causing structural failures or secondary failures of equipment. This determined the maximum explosion overpressure loads which protective equipment would be required to survive. Where overpressures capable of causing serious escalation by structural failure were identified (and particularly where elements of the Emergency Response System would be at risk) possible strategies to reduce the overpressure, or otherwise mitigate the consequences were considered. This approach reflects the Basis of Safety idea. Consequence analyses were then rerun assuming protective measures in place to evaluate the benefits which could be gained. Typically the protective measures considered in relation to explosion hazards were :

(a) automatic isolation (e.g. on gas detection) to minimise the quantity which could be released and thereby minimise the quantity of flammable volume available for an explosion

(b) automatic blowdown in conjunction with (a) to reduce the release period and further minimise the quantity of flammable volume (Figure 1 illustrates the potential benefits of (a) and (b))

(c) provision of forced or improved ventilation to dilute leaks and reduce the flammable volume

(d) provision of explosion relief area to minimise the explosion overpressure

(e) provision of strengthened walls to avoid structural damage or ensure any escalation is away from critical areas (e.g. TR) (normally in conjunction with (d))

Elimination of ignition sources was not normally viewed as a viable option but clearly all reasonable steps to minimise the probability of ignition must be taken.

As a result of the reanalysis of consequences an overall protection strategy in respect of explosion was defined for each scenario based on those protective measures for which significant positive benefits could be demonstrated.

The assessment then went on to look at the fire hazards, resulting either from immediate ignition of a release, or subsequent to an explosion. Consideration was given as to whether the release would be all gas, predominantly liquid or two phase and the fire resulting from ignition suitably modelled. Ventilation conditions were taken into account to determine whether the fire would be fuel or ventilation controlled and a suitable model used to determine the fire characteristics such as flame length, heat output, radiative and convective heat fluxes (Ref 5). The response of structure and equipment to the assessed heat fluxes were then considered to evaluate whether escalation would be possible or likely. In particular the potential for secondary failures of pipework and/or vessels was considered using a simple model to calculate the increase in wall temperature with time and the decreasing pressure containing capability with increasing wall temperature (see Figure 2).

Where escalation was identified as possible, potential protective measures were considered for example:

(i) emergency isolation facilities to minimise the duration of the primary fire and possibly reduce the exposure of structure and equipment to avoid escalation

(ii) emergency blowdown facilities to accelerate depletion of the flammable inventory (i.e. in conjunction with (i)) and also to depressurise process equipment to minimise the risk of secondary ruptures of pipework or vessels (Figure 3 illustrates the benefits of (i) and (ii))

(iii) deluge for protection of vessels, pipework and structure

(iv) passive fire protection for vessels, pipework and structure

(v) foam, halon, or carbon dioxide extinguishing systems

Consequences were reassessed in light of possible protective measures (and combination of measures) and a protection strategy defined based on those measures which illustrated significant benefits in terms of reducing the likelihood of escalation.

Influence on the Emergency Response System

The assessment of the influence of the scenarios on the ERS started with an identification of the key elements of the system and the maximum tolerable loadings for these elements. In essence this was a definition of the criteria under which "Impairment" of the ERS (including Temporary Refuge) would be deemed to have arisen. Typical maximum allowable loadings are shown below in the Tables below (example from a bridge linked multi-platform complex):

TABLE 1

ERS IMPAIRMENT CRITERIA
ESCAPE ROUTES

ESCAPE ROUTE AVAILABILITY	
CRITERION	**IMPAIRMENT VALUE**
Fire	Direct flame impingement
Thermal radiation	Incident heat flux exceeding $10kW/m^2$
Smoke and Gas	Envelopment of area - loss of access
Structural integrity	Collapse of supporting structure[1] (heat flux of $<100kW/m^2$ at supporting structure during initial 5 minutes to maintain structural integrity and allow passage of personnel).
BRIDGE ACCESS	
Fire	Direct flame impingement
Thermal radiation	Incident heat flux exceeding $10kW/m^2$
Smoke and Gas	Envelopment of area - loss of access
Structural integrity	Collapse of supporting structure[1] (heat flux of $<100kW/m^2$ at supporting structure during initial 5 minutes to maintain structural integrity and allow passage of personnel).
PROTECTED MUSTER POINTS	
Fire	Direct flame impingement
Thermal radiation	Incident heat flux exceeding $4kW/m^2$ [2]
Smoke and Gas	Envelopment of area
Structural integrity	Collapse of supporting structure (heat flux of $<30kW/m^2$ at supporting structure during initial 20 minutes to maintain structural integrity and allow personnel to muster, contact ECC and if necessary evacuate via TEMPSC).

[1] It is unlikely that open walkways and decks forming escape routes or bridges will require to be protected from fire. If they are engulfed in flames or exposed to radiation levels to the extent that they require protection to maintain structural integrity, they will not be passable and alternative routes shall be available.

[2] It should be noted that the Thermal radiation criteria for PMPs is more stringent than for escape routes and bridges as personnel will be transient on escape routes and bridges but may be stationary at PMP for a short time.

TABLE 2

ERS IMPAIRMENT CRITERIA
TEMPORARY REFUGE

TEMPORARY REFUGE - LIFE SUPPORT	
CRITERION	**IMPAIRMENT VALUE**
Smoke ingress	Visibility e.g. < 10 metres for evacuation from TR
Flammable gas ingress	60% LEL
Internal toxic fumes generation	Generation of toxic pyrolysis products
Oxygen depletion	Minimum 17% vol/vol 0_2
Carbon dioxide accumulation	Maximum 20,000 ppm CO_2
Heat	Internal air temperature exceeding 50 deg. C.
TEMPORARY REFUGE - STRUCTURAL SUPPORT	
Support frame	Collapse of jacket/supporting structure: - jet flame impingement of supporting structure for > 5 minutes; - radiant heat loading of supporting structure of >40kW/m^2 for 1 hour.
Envelope	Collapse or breach of TR structure or exterior fabric: - jet flame impingement for >5 minutes; - missile penetration of exterior fabric.
TEMPORARY REFUGE - COMMAND SUPPORT	
Communications	Not available or working
Emergency lighting	Not available or working
Control monitoring	Not available or working
Emergency power	Not available or working

The loadings (e.g. heat, overpressure, smoke etc.) which the key elements would be subjected to as a result of the primary (unescalated) events were then calculated and compared with the maximum tolerable loadings, to ascertain if impairment would occur. Where it had been identified that escalation of a primary event would be possible, the loadings on the key elements of the ERS from the escalated events were also calculated. In this way scenarios capable of causing TR impairment were identified and a picture of the consequences which would have to be mitigated against, or the type of escalation which would need to be prevented, was built up. This again followed the Basis of Safety principles by identifying events which potentially need to be avoided and an outline of the key measures required to achieve this.

cases these are combined inextricably with the explosion probabilities making comparisons difficult.

Such broad estimates are not particularly helpful.in identifying particular weaknesses in module layouts. There may be potential for relatively small-scale improvements to process pipe mountings and the like but this is not often addressed in Safety Cases. Vulnerability of emergency systems such as fire mains and personnel address cabling are however normally addressed qualitatively as one of the "forthwith" recommendations of Lord Cullen ([2], Recommendation 69).

Structural analysis codes are beginning to be applied to examining explosion resistance of piping [24,25]. Another aspect of structural response that merits more attention in future is the "strong vibration" resulting from the transient response of the platform to the impulsive reaction forces from venting of an explosion. Studies conducted for HSE [26] indicate that this vibration can have serious effects on emergency equipment remote from the site of the explosion unless suitable performance standards for design of equipment are applied. This is another factor rarely explicitly included in current explosion risk analysis studies.

Uncertainty in Explosion Risk Analysis for Fixed Installations

With the large number of factors involved there is potential for a large variation in predictions of explosion risks on offshore installations. Moreover, we have not considered additional aspects of evaluating risk to individuals such as human vulnerability factors and probabilities for successful evacuation and escape. Benchmark exercises on risk analysis for onshore installations have shown that differing assumptions and analysis methods can produce risk results differing by several orders of magnitude [27].

Our assessment of offshore Safety Cases indicates that differences in predictions of risk from loss of containment of hydrocarbons between platforms may reflect differences in methods, data and assumptions rather than real differences in safety levels. In some instances our discussions with operators have led to reworking of the analysis and significant changes in predicted risks.

To seek some further indication of the extent of this variability we have devised a simple hazard index for the hydrocarbon risk. Intuitively, this will be dependent upon the oil, gas and condensate inventories. In addition, compactness of an installation is considered to affect the risk. Consequences of explosions tend to be greater and escalation is more likely for compact installations, eg because of impingement of jet fires on neighbouring equipment or the temporary refuge. Accordingly, such an index was defined as a weighted sum (in the ratios 1:3:10 for oil:condensate:gas) of the inventories divided by the area of the installation excluding the accommodation.

Figure 2 shows a plot of this index versus the predicted individual risk from hydrocarbon releases extracted from a number of Safety Cases. The installations were all fixed jackets except for one FPSO as indicated. At the upper end of the hazard index range, where large integrated platforms tend to cluster, the variation in take into account the availability and reliability of the identified items of key protective equipment. This allowed the overall frequency of impairment of ERS to be assessed as a function of the availability/reliability of protective systems. By varying the availability figures in the event trees it was possible to define a minimum availability which would be required for the frequency of ERS impairment to be acceptably low. In this way a minimum availability performance standard was defined for each item of critical equipment. This can be used to optimise the preventive maintenance schedules for such equipment.

At the end of the assessment summary tables were prepared out lining the identified scenario, potential for escalation, potential for ERS impairment, protection philosophy (Basis of Safety) to avoid ERS impairment, equipment required to assure the Basis of Safety, and performance standards required of the critical equipment. These tables were intended as a reference point for future use when modifications are proposed as the succinctly spell out the logic of the protective measures and provide a framework against which it is possible to assess if modifications may compromise the Basis of Safety.

In the assessments perform it was frequently not possible to find a sound logic for items of protective equipment currently installed. In some areas dual protection was provided by different protection techniques but systems had not been suitably maintained and thus overall protection reliability was deficient. By identifying key protective measures and prioritising these for maintenance, inspection and testing, the protection reliability is improved and costs minimised.

In terms of availability performance standards it is necessary to use equipment failure rate data. Such data specific to the platforms considered was scarce and thus it was necessary to fall back on generic failure rates from published sources. Having identified the critical facilities and defined test schedules a database of equipment failure rates will be built up based on test results and performance in "demand" situations. Periodic cross reference of the database contents with data assumed in the event tress will allow the chosen availability performance standards to be verified in the future and maintenance schedules to be modified as appropriate to maintain the required equipment availability.

CONCLUDING REMARKS

The methodology developed and described above follows a logical development of accident scenarios on a platform and matches the chosen protection measures to the hazard and risk. In all cases the prime concern is for safety of personnel and thus the methodology focuses on potential consequences of identified accident scenarios on the Evacuation, Escape and Rescue facilities provided on the installation.

The approach allows protection facilities to be optimised and hence provides for cost effective design for a new installation (or modification to an existing one) and provides assistance in defining cost effective maintenance and inspection schedules for existing installations.

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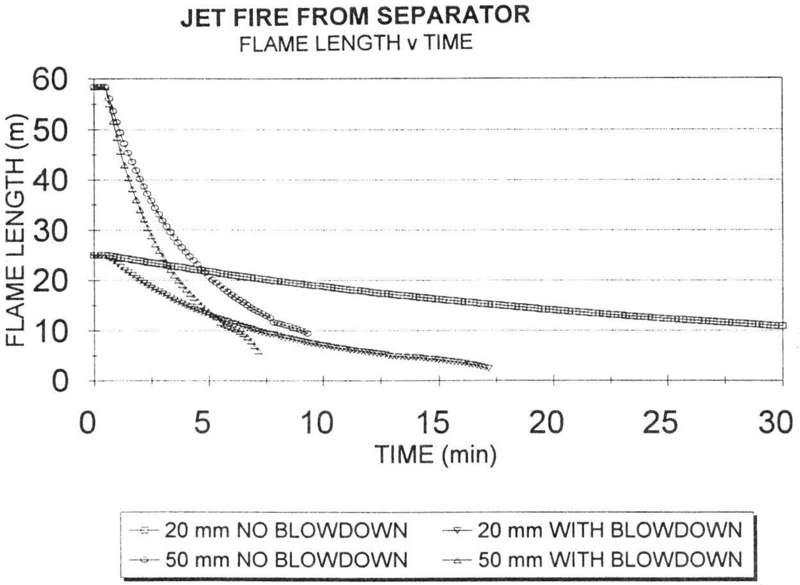

FIGURE 1

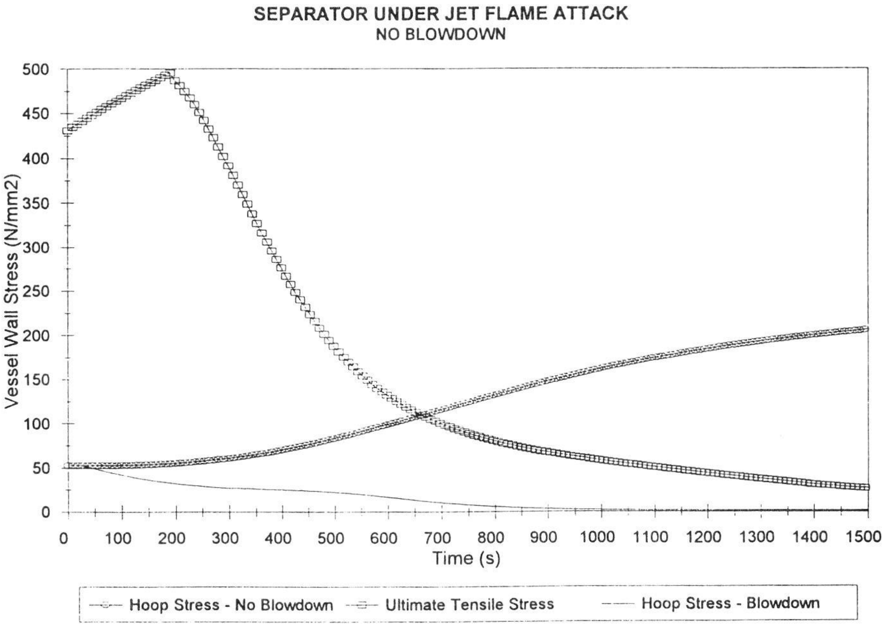

FIGURE 2

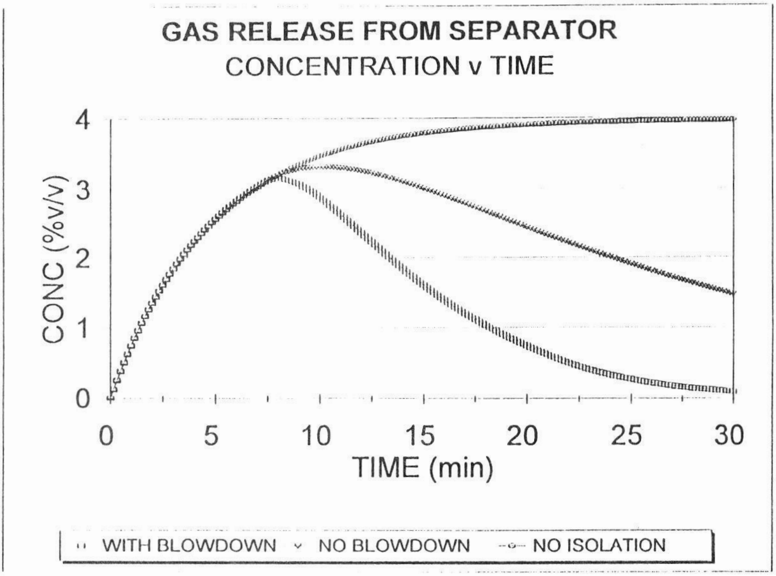
GAS RELEASE FROM SEPARATOR
CONCENTRATION v TIME
CONC (%v/v)
0
1
2
3
4
TIME (min)
0
5
10
15
20
25
30
WITH BLOWDOWN
NO BLOWDOWN
NO ISOLATION

FIGURE 3