A METHOD FOR PRELIMINARY DESIGN OF FIRE PROTECTION REQUIREMENTS ON AN OFFSHORE OIL PRODUCTION PLATFORM

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The Paper presents a method to allow designers of offshore installations who do not have in-depth knowledge of fire science, to perform a preliminary assessment of active and passive fire protection requirements. For a specified inventory of hydrocarbon in a vessel or pipeline, within a module, and for a defined release situation the method allows the designer to predict the longest duration (small) fire which cannot be extinguished plus the largest short duration (e.g. ten minute) fire which would be capable of causing structural damage. The former dictates the duration for which passive fire protection must be specified while the latter dictates the maximum extent of potential damage from a fire in that module i.e. the extent over which protection is needed. The intention is to use the method to help produce a preliminary design of fire protection systems which will subsequently be reviewed by an experienced fire engineer.

INTRODUCTION

The aftermath of the Piper Alpha Disaster in 1988 prompted many operators of offshore production platforms to review their facilities for fire and explosion protection. Evidence given by fire protection engineers, safety and combustion specialists to the Inquiry into the Piper Alpha Disaster identified potential deficiencies in the 'prescriptive' legislation relating to fire protection on offshore structures, notably that the "fire reference area" approach advocated by SI611 could lead designers to specify fire protection without fully appreciating the nature of the fire and explosion hazards and the risk and consequences of escalation. As a result the fire reference area approach could lead to inappropriate fire protection specification, which in some cases may represent "too little" protection to control a potential hazard and in other cases lead to protection being installed where no significant hazards warranting protection existed.

The Cullen Report [1] formally advocated a move away from prescriptive legislation and towards a goal setting approach to platform safety (including fire protection). A scenario based approach was proposed whereby it would be the duty of every offshore operator to formally identify and understand potential hazards on each platform they operate and to satisfy themselves (and the regulating authority) that adequate facilities to prevent or control the identified hazards exist on the platform. This theme has been carried through into the Proposed Offshore Safety Case Regulations.

In relation to fire protection, this approach should ensure that protection facilities are adequate to control any foreseeable fire scenario and prevent or restrict escalation of a fire for at least sufficient time to ensure that all personnel can safely be evacuated from the platform.

The approach obviously requires a great deal of detailed analysis, involving fire protection and combustion specialists to provide expert advice in relation to fire development, fire spread, effects of explosions etc. In this respect therefore the approach will increase the time involved, and cost, in designing fire protection for an installation. This prompted the Fire Protection Department of B.P. Exploration to consider whether it would be feasible to develop a methodology which could be used as guidance for a preliminary design of fire protection requirements (especially for new platforms) and which could be used by design engineers who did not necessarily have a detailed knowledge of combustion technology. The idea was not to develop a comprehensive design 'code', but to provide a tool which could be used in a screening study to at least get ideas for fire protection on drawings, which could then be passed on to fire protection and combustion specialists for detailed consideration. In this way it was hoped that it would be possible to quickly identify the key fire scenarios on which protection systems would ultimately need to be based so as to allow the specialists to devote more attention to these.

During the winter 1990/91 fire protection engineers from BP Exploration in conjunction with consultants from Burgoyne Consultants Ltd. (Combustion Engineers) and Altra Consultants Ltd. (Process Engineers) worked together to develop the methodology described in this paper.

UNDERLYING PRINCIPLES

The methodology is based on the following pragmatic principles:

The main parameters of interest in defining fire exposure caused by a fire scenario, which must be used as a basis for selection of fire protection requirements are:

1. The type of fire and its heat flux (i.e. jet or pool)
2. The duration of the fire
3. The size of the fire (fire spread).

The type of fire and heat flux will depend on the fuel being released, its initial state (i.e. gas or liquid) and, in the case of liquids, release conditions such as upstream pressure and release velocity (in order to determine amount of flash/spray/aerosol etc.)

The duration of the fire will mostly depend on the amount of fuel which will be released in a scenario, its release rate and possibly its burning rate (which may in turn depend on ventilation conditions).

The size of the fire will depend mostly on the release rate and ventilation conditions but will also depend on the inventory which may be released and the surroundings (topography) into which the release occurs.

A number of simplifying factors based on an understanding of the fundamentals of combustion phenomenon and engineering judgement are incorporated into the methodology to make the variables outlined above manageable.

The methodology starts from the principle that in order for a fire to pose a threat sufficient to warrant fire protection it must be of sufficient duration to be capable of causing damage to structure or equipment and it must be sufficiently large that it cannot be controlled by manual fire fighting alone.

Criteria are therefore introduced into the methodology to broadly identify those scenarios for which fire protection is required i.e. those which are big enough for long enough to threaten structure or equipment.

The methodology then recognises that a wide range of scenarios will exist for which fire protection is warranted and attempts to home in on the worst cases, that is to say the largest fires which can exist for long enough to cause damage and the longest duration fires which remain sufficiently large throughout such that manual firefighting alone is insufficient.

STAGES IN ASSESSMENT

From the above discussion it can be deduced that there are four main stages of interest in the methodology.

(1) Assessment of Inventory which may be released.
(2) Assessment of plant areas into which an inventory may be released.
(3) Assessment of release rates/release duration.
(4) Assessment of fire characteristics/fire duration.

Inventory

When assessing the inventory which may be released in a given scenario it must be recognised that most of a platform's processes are continuous. That is to say that while certain obvious static inventories exist (e.g. separators) there is normally a flo in and out of such inventories. The methodology therefore makes a basic, simplifying assumption that emergency isolation facilities operate reliably in accordance with their design intent, such that following the start of a fire scenario t inventory of interest becomes the "isolatable inventory" between consecutive emergency isolation valves in the process train.

This is obviously an assumption which must be scrutinized by experts, for various scenarios, in the final detailed design, as there may be influences such as explosion effects (notably explosion induced missiles) which may be a significant feature in the scenario and which may therefore reduce confidence in isolation valves operating on demand.

For this methodology however it is assumed that once a scenario is initiated it is identified by gas or fire detection, which then takes executive action to close emergency isolation valves. Thereafter the inventory for release in the scenario is defined.

Plant Areas

The first stage in the methodology is therefore to identify isolatable inventories and the second is to identify the platform areas or modules in which the isolatable inventories exist. In this respect it may be possible for an isolation valve downstrea of a significant inventory to be physically located in a different module to the major part of the inventory. In this way consideration of the same inventory into two plan areas (or modules) must be made.

At this stage it is important to evaluate the overall dimensions of the module, the type of walls and floors, identify any openings in walls, floors or roofs, identify any bunding and assess drainage as all of these will influence the fire analysis. Position of the plant area or module relative to other areas must be ascertained for consideration of potential fire spread.

This consideration should logically sub-divide the process plant into fire areas. For an open plan concept platform, where logical subdivision by firewalls, boundaries, drainage areas or solid floors is not apparent the plant will have to be broken down into manageable areas. The following maximum dimensions are suggested -

Height: 15m
Length: 60m
Floor area: 800m^2
Volume 8000m^3

These correspond to the dimensions of one level of a large module in a large northern North Sea oil production platform. With larger dimensions, the analysis would lose value and a more uniform value of protection is likely to be specified throughout the process and adjacent areas. If an artificial split is required it should be undertaken between process sections such as separation areas or oil pumping.

Given inventory, process data and fire area details, the worst incidents in each area may be assessed. Where both pool and jet fires are credible, separate analyses are necessary because a jet fire may cause failure in less time than a pool fire. Use of the analysis method has shown that the duration of jet fires can be reduced by altering the process design, and that in most cases the dominant, long-duration fires come from liquid releases forming pool fires. This may not be the case with the volatile liquids such as condensate.

Each process section should be analysed to determine the short, and longest significant fire cases. Where the inventory has both a gas and a liquid section (such as a separator), releases from both gas and liquid sections should be examined. Separate calculations may be required in pool fire cases if the inventory could be released in more than one area and into different sized drainage areas/bunds. In theory there could be a significant amount of work with typically up to 30 process sections on a platform and typically up to 10 fire areas. In practice, it is relatively simple to identify the dominant inventories and calculate the design requirements.

As already noted if a risk of explosion preceding the fire exists the scenario should definitely be re-assessed by an expert prior to finalising design as such events may lead to failures of emergency valves, secondary plant damage and walls being breached (either intentionally (explosion relief) or otherwise). These aspects will significantly influence the ultimate fire extent and duration, plus potentially change ventilation conditions.

Release Characterisation

There are specific methodologies for liquid, gas and liquid and gas inventories (e.g. separators). In the last case, there is a separate methodology for gas releases, to take into account boil-off during the fire and the flash fraction of the liquid. Each method examines different sized fire cases and can take into account multiple inventories fuelling the fire and inventory disposal to flare via the relief valves.

Another method examines release from a depressurisation or flare system.

Potential release conditions alter as an incident progresses. Usually, they start at the operating pressure and decay with time either to zero or to vapour pressure. Pressure may also increase as liquid inventory becomes vaporised and then stabilise at the relief valve pressure. Where depressurisation occurs, the pressure may stabilise at a value determined by the relationship between the boil-off rate and the depressurisation valve/flare system flow characteristics. Figures 1 and 2 show the types of pressure vs time curve which might be experienced for liquid and gas release respectively. In the liquid case, the pressure will determine the fire type (jet, spray or pool) and, in turn, the fire characteristics, the type of protection and the smallest significant fire. Clearly all gas releases and Liquified Petroleum Gas (LPG) releases at low pressures will create intense jet fires, as demonstrated by Shell at the British Gas Spadeadam site [2]. However, heavier crude oils will require higher pressures to create intense jets and may not be stable. This is an area of limited information requiring further research, so the method assumes that jet fires will occur above 7, 4 and 2 bar respectively for heavy crude oils, light crude oils, and condensate LPG liquids. To arrive at a practical method, certain assumptions have had to be made about the shape of the curves in figures 1 and 2 and about the transient and stable characteristics. In some cases, an initial transient pressure might have been ignored or an exponential pressure decay treated as a linear function, but as far as has been possible, all significant contributions to the size or duration of the fire have been taken into account and it is considered that the analysis is of sufficient accuracy for protection design specification.

Oil Releases

In cases of oil releases, i.e. in process sections such as oil pumps, well fluids which may be two phase, and liquid released from liquid/gas inventories, large (10 minute) and 60 minute fires are assumed to burn as pool fires, with depressurisation. The worst case assumes total liquid release plus that released before and during shutdown. From this, it is relatively simple to determine the pool area which could sustain a fire for a given time e.g. 10 minutes, based on known fuel burn rates per sq. m. Where the calculated pool area is greater than the module, the required overflow area into adjacent areas may be calculated. This would only occur if there was no bunding or the drains were unable to dispose of the oil and firewater. Where there is effective bunding, the fuel can be consumed only at a definable rate, indicating that maximum fire size is governed by pool area rather than by inventory and time. Control of pool fire size and efficient drainage is a most effective tool in reducing the scale of process fire hazards on a platform. Long duration fires will be governed by the stable pressure, Fig. 2. Where depressurisation occurs, the fire may be either pool or jet; without depressurisation, the inventory may reheat to give prolonged high pressure fires.

Condensate Releases

Condensate fires may be either jet or pool, depending upon the release pressures. These in turn will depend on the ability of the depressurisation system, if any, to relieve pressure and keep it below the critical 2 bar value during the fire. It has been assumed that in the 10 minute case fires would be jets and that fires of longer duration could decay into pools if pressures can be reduced. Without depressurisation, the constant pressures are assumed to be the vapour pressure in short fires and relief pressure in longer fires. In the latter case, the relief valve would operate and boil-off would pass to flare. With depressurisation, pressure would be determined initially by the flare rate and in the latter stages by the boil-off rate.

Designs to counteract the largest fire case should be based on the largest release rate at the critical point of 10 minutes; although larger fires will precede it, they will not be of sufficient duration to cause damage. This release rate will depend on the inventory, less the amount flared, or the maximum release orifice size (defined for the study). Longer duration fires with depressurisation will reach a stable pressure governed by boil-off and depressurisation systems characteristics. The longest duration fire case is determined by the significant fire size and whether it is jet or pool (1 or 2 kg/sec respectively). From the inventory, the initial high release rates and the flared portion, the duration of a fire can be calculated.

Gas Releases

The inventory available for a gas release is determined by the initial gas inventory and, where there is a liquid inventory, the flash fraction caused by reducing pressures and the inventory boiled-off. The actual quantities released and the release rates will be governed by flare rate, boil off rates and discharge through relief valves. The 10 minute case is easily calculated. The gas inventory, plus flash fraction as appropriate, determine the largest fire which can occur at 10 minutes. This is usually inventory-constrained but may be limited by hole size for very large inventories without depressurisation.

The gas and liquid cases are affected by the boil off rate. If this is less than 1 kg/s. it alone cannot sustain a significant fire. The analysis would be dominated by the gas fraction with the quantity boiled off by the fire being added to the initial gas inventory. If greater than 1kg/s, boil-off will sustain the fire until all the liquids have been vaporised and the residual gas release rate drops below 1kg/sec.

Flare Releases

One, worst case, flare release fire is examined: a 25mm hole with automatic shutdown and depressurisation initiated on release detection. (The examination does not apply to lines and systems leading from relief valves as these should have a minimal flow rate even after depressurisation has been initiated). It is assumed that the flare header would, initially follow the calculated pressure curve for normal depressurisation. The largest release would be calculated either from the pressure during sustained boil-off of all vessels in the fire or from the pressure at 10 minutes from emergency depressurisation - whichever is greater. The longest duration fire case would be where the flare pressure caused by boil-off could maintain a release of 1kg/sec through a 25mm hole. Figure 3 shows a typical simplified flare pressure profile.

Fire Assessment

The current state of the art understanding of large hydrocarbon fires is somewhat limited. The following sections address some of the problems in assessing fire behaviour in large congested enclosures, such as process modules on offshore production platforms. Recent research initiatives will hopefully in time improve knowledge in this area and allow better models to be developed and validated.

The methodology makes use of information from relevant testwork which existed at the time of development. It is hoped that an understanding of the fundamentals of combustion phenomenon has meant that assumptions in the fire assessment method reflect conservatism and this will, if anything, tend to overstate the hazards. In this way as the understanding of the hazards develops it will suggest less rather than more in the way of fire protection.

The methodology required a means of translating release rate data into fire characteristics assuming ignition arises. The variables of particular interest for a given fire are the size of the flame envelope (both within and outside a module) the emissive power of the flames (both within and outside a module) and the potential convective heat flux from the flames.

For combustion of any fuel the flame size will be a function of the burning rate although, as will be seen later, the environment in which the fuel is burning can influence flame extension.

For gas releases essentially all the released gas will burn (whether it be inside or outside the module) and thus the gas burning rate can be taken as the release rate. For liquid fuels however, the situation is more complicated. In the combustion of a liquid pool, back radiation from the flames causes liquid in the pool to evaporate to form gas which burns. A feedback equilibrium system is generated wherein the flame size depends on the burning rate which equates to the evaporation rate from the pool. For large pools the fuel can be treated as burning evenly over the entire pool area and thus the pool can be modelled as having a uniform regression rate over the entire pool area, the product of this regression rate and the pool area being the burning (or

evaporation) rate. A maximum pool area can be defined where the product of regression rate and pool area matches the liquid release rate and thus a basis for calculating the fire characteristics is defined.

If, however, the liquid is spilled into a confined area (e.g. a bund around a tank, or into an enclosure such as a module on an offshore platform), the maximum pool size may be determined by the confined area rather than the release rate. For a liquid release in a module the release rate may be sufficiently large to generate a pool fire occupying the entire floor area of the module. Larger release rates may cause fuel to spill into a neighbouring area or overboard to sea. It may well be the case that once the topography has been taken into account, the largest pool fire for a module in terms of its sphere of influence will be that where the pool fills the floor area. A critical average release rate just sufficient to satisfy a pool fire of this area may be defined and if this is achieved in a fire scenario it will represent a worst case in terms of extent of influence and duration of exposure. Large release rates would not give rise to a 'bigger' fire but would cause more fuel to spill out of an area with the net result of the fire being of shorter duration. Attention must however be paid to where the excess fuel will be spilled.

One of the main aims in considering liquid fires, therefore, is to determine whether the maximum pool area (and thus the burning rate) will be defined by the release rate or the confines of the area in which the spill occurs.

Even when the pool area has been defined, the regression rate can be difficult to predict, although published data for a wide variety of liquid fuels burning as large pools in the open air exist. These data typically indicate a regression rate of around 4 mm/min for a large pool of relatively heavy fuel. For this study an open pool regression rate of 0.05 $kg/m^2/s$ was assumed for crude oil.

Where liquid is released at high velocity from a source at high pressure, the liquid may break up to form a spray or mist. This spray will be combustible but with some fall out of liquid. As a pessimistic worst case for such spray fires it was assumed that all the fuel burned in the spray regime (i.e. burning rate = release rate). In the case of condensate this spray effect would be augmented by flashing of the liquid on release to atmospheric pressure. In this case (and more particularly following ignition) minimal liquid fall out is likely and thus condensate releases can be fairly accurately modelled as spray or jet fires with no reference to pool fires.

The characteristics of a fire can be heavily dependent on the surroundings, particularly when combustion occurs in an enclosure or compartment. In such situations the ventilation of the compartment becomes important as there may be insufficient air to support ideal combustion.

Fire in the Open

Gas / Condensate Fires

When a high pressure gas or condensate release occurs the turbulent nature of the release promotes goods entrainment of air into the released stream such that during combustion of such releases a degree of premixing of fuel and air occurs. This results in efficient combustion resulting in relatively short, soot free, flames with very high flame temperatures (approaching the adiabatic flame temperature). However, such flames tend to be relatively 'thin' and while their emissive power is potentially extremely high (note emissive power is proportional to the fourth power of the flame temperature) they do not behave as black bodies and thus have emissivity much lower than unity.

Experimental work on large scale jet flames indicates that the maximum radiant heat flux (emissive power x emissivity) is typically 120 kW/m^2 [2]. As the absolute temperature of such flames is very high and also as their turbulence creates efficient boundary effects, the convective heat output from such flames can also be very high (e.g. up to 160 kW/m^2) to a body at ambient temperature (from testwork [2]). The convective component is however dependent on the temperature difference between the flame and the body onto which it impinges. Thus as the body heats up the convective element reduces and when the body becomes very hot the convective element becomes relatively unimportant.

The momentum of jet flames means that they may be capable of eroding passive fire protection coatings, or displacing a water film on equipment or members protected by water deluge. Water deluge in particular may be ineffective against direct jet flame impingement. However, in a congested module any gas or condensate release will be likely to impinge on several items of equipment in its path. In this way the flame may rapidly become diffuse in nature, losing its erosive, momentum effects and reducing its efficiency in convective heat transfer.

The size and shape of jet flames in the open have been empirically characterised by a number of workers based on experimental results. For example empirical relationships derived by Hawthorne [3], Putnam and Speich [4] or Brztowski [5]. All give very similar predictions generally within 20% agreement. Using the Putnam and Speich approach it can be shown that the flame length for a given fuel will be a function of the mass release rate to the power 0.4. Thus for this work the following empirical relationship has been used:-

$$\frac{L}{d_j} = 29\left(\frac{Q_j^2}{g d_j^5}\right)^{1/5}$$

Where L = length of flame (m)
d_j = diameter of jet at base (ambient pressure) (m)
g = acceleration due to gravity (m/s^2)
Q_j = volumetric flowrate (ambient pressure) m^3/s

Which for the typical physical properties of the fuels of interest reduces to:-

$$L = 16.8\ W^{0.4} \text{ for gas}$$
$$L = 11.5\ W^{0.4} \text{ for condensate}$$

Where W = mass flow rate (Kg/s)

Liquid Fires

As already discussed, the size of flames from a liquid pool burning in the open depends on the evaporation rate resulting from back radiation to the pool. For large pools burning in the open the pool regression rate is constant and characteristic of the fuel.

The evolution of gases from the pool involves a fairly quiescent regime in comparison to the turbulent nature of gas releases discussed previously. Thus air ingress occurs largely through molecular diffusion which is much less rapid and results in less efficient, fuel rich combustion. Such fires are termed diffusion controlled and are characterised by large, thick luminous flames at the base and very sooty, smoke obscured flames higher up. In general, the higher the molecular weight of the fuel, the smaller is the luminous base and the greater is the smoke obscured top section of flame (displaying occasional 'blooms' of luminous flame). Crude oil fires generate copious volumes of thick black smoke with the luminous base representing only 5 or 10 percent of the total flame height. The luminous flames have much lower emissive power than jet flames as a result of the diffusion controlled burning but as they are thicker they have higher emissivity, approaching black body equivalence (emissivity unity). Experimental work has shown that the luminous flames of heavy fuel may have radiant heat flux of around 170 kW/m^2[6] while the average radiative heat flux over the whole of the flame may only be around 90 kW/m^2[7]. The smoky top section of the flame will have radiant heat flux slightly below 90 kW/m^2. the lower flame temperature and lower turbulence of pool fire flames mean that they exhibit much lower convective heat transfer properties than jet flames with maxima of around 40 kW/m^2[8] from the luminous section to a body at ambient temperature.

As with jet flames empirical relationships have been derived from experimental work. There are two such relationships which are frequently used and which show reasonable agreement. These are due to Thomas [9] and Moorhouse [10]. The Moorhouse correlation was derived more specifically for liquified natural gas fires and thus for this work the Thomas correlation was used, viz:-

$$\frac{H}{D} = 42\left(\frac{m}{\rho_a\sqrt{gD}}\right)^{0.61}$$

Where H = flame height (m)
D = pool diameter (m)
m = mass regression rate (Kg/m^{2}s)
ρa = ambient air density (Kg/m^3)

In this equation D is the equivalent pool diameter Deq.

Deq will represent either the floor area of the compartment given by Deq = 1.128A$^{0.5}$ where A is the floor area of the module or a maximum, equilibrium pool diameter, where

$$Deq = 2\left(\frac{V_L}{\pi y'}\right)^{1/2}$$

if the release rate is not high enough to give a pool fire covering the floor area. In this equation V_L is the volumetric release rate (m/s) and y' is the regression rate (m/s).

Effect of Wind

A crosswind will deflect the flames of a jet or pool fire burning in the open and also tend to increase the flame length. The increase is generally not substantial and has been ignored in this work. Deflection can however be very substantial, especially in respect of pool fires. For such fires the deflection from the vertical (ϴ) can be calculated from:-

$$\cos\Theta = 1 \; for \; u* < 1$$

$$\cos\Theta = \frac{1}{\sqrt{u}*} \; for \; u* > l$$

$$u* = u_w \,/ \left(\frac{gm\ D}{\rho_v}\right)^{1/3} \qquad [11]$$

Where u_2 = wind velocity (m/s)
ρv = density of fuel vapours (Kg/m^3)

For this work the main concern regarding flame deflection in a crosswind is in the case of flames venting out of a module. While these could be generated by either a pool or a jet fire, in the latter case impact with obstructions would cause the release to lose momentum and thus generate a more diffuse flame than would normally be the case. Thus it was felt that the above equation would be adequate for either jet or pool fires. By substituting typical values and high windspeeds (10 to 15 m/s) it can be shown that maximum deflection from the vertical of about 70° is possible, thus it was assumed that venting flames could be anywhere within a vertical segment of half angle 70^0 outside the module of interest.

Compartment Fires

For a fire in a complete or partial enclosure the supply of air may be restricted. In the early stages of development, or in the case of a low fuel release rate, there will be sufficient air within the compartment and entering the compartment through natural or forced ventilation, to satisfy the requirements of the fuel. The size and thermal characteristics of the fire at this stage will be similar to the equivalent fuel controlled fire in the open.

As the fire grows however (and assuming a sufficient release rate of fuel is sustained) it begins to interact with its surroundings i.e. the compartment. Hot gases and smoke generated by the combustion process will accumulate in the compartment and heat transfer from these back to areas of hydrocarbon liquid pool which are not burning, or other combustible material in the compartment, can cause them to rapidly become involved in the fire. This process, loosely termed 'flashover' can alter the fire very quickly from a small, localised one into a fully developed fire in which the compartment itself plays a leading role in determining the fire parameters. The term "fully developed" refers to the involvement of all exposed fuel surfaces in the fire, and the upper part of the volume of the compartment being filled with flame.

The fully developed period of the fire may continue for a prolonged period in a similar state with transience present only due to the thermal inertia of the fuel and boundary surface. Many analyses therefore address this period as one of steady-state burning. This period is principally responsible for the thermal exposure of the structure. Its duration, and the heat transfer rate during that duration, largely determine the fire resistance required of the structure. Finally, when the fuel is exhausted, there is a decay period which for hydrocarbon fuels may be negligibly short.

Thus the period of particular interest for structural fire protection of the compartment boundaries is the fully-developed burning period. They key features of it are its duration, representative temperature, and corresponding heat transfer rate to exposed surfaces.

During the fully developed stage, the fire may be fuel controlled or, more likely, there will be insufficient air ingress to satisfy the fuel's requirements and the fire is termed ventilation controlled. It is possible to predict the rate of air ingress through natural ventilation into a compartment fire using simple fluid mechanics and buoyancy effects and in theory it is possible to determine if this satisfies the combustion rate of the fuel. In the case of a gas release this is relatively straight-forward as all that is required is a comparison between the gas release rate and the air rate required for this to burn. Any residual, unburned gas can be considered to burn outside the compartment. However, for a liquid pool fire it is the evaporation rate of the fuel which determines the burning rate and air requirements.

For a pool fire in the open, or before interaction with the compartment is achieved, the evaporation rate is dependent on back radiation from the flames (hence constant over the pool area). In a compartment fire there may be competing influences determining the evaporation rate. For example the walls of the enclosure will heat up and radiate back to the pool (as in an oven or furnace) and particularly where these walls are coated with passive fire protection (whose role is to efficiently reflect radiation and thus prevent heat flux to the wall) the back radiation from the walls can be significant and will tend to increase the evaporation rate. In conflict with this however, the restricted air flow will make for less efficient combustion thus lower flame temperature and less back radiation from the flames, also the 'fuel rich' combustion will generate copious volumes of smoke in the compartment which will absorb radiation from the flames and the enclosure.

The state of the art does not represent a good understanding of these effects and the experimental work on compartment fires which has been done represents mainly cellulosic (and some plastics) fires in relatively small compartments. Computer models exist to simulate such compartment fires in small volumes but it would be futile to apply these models to large scale offshore modules with hydrocarbon fuels.

Without a good understanding of the influence of the enclosure it is not possible to accurately determine the burning (or evaporation) rate which is a key to characterising the fire. The best that can be done is to make some pragmatic, and hopefully conservative, assumptions.

Therefore, in the analyses where ventilation controlled pool fires were identified, it was assumed that the maximum evaporation rate of a pool fire would be the same as that observed for the same size of fire burning in the open. This is likely to be an upper limit for a real case given the inefficient combustion and absorption of radiation by smoke (also, it could be argued, as a consequence of deluge in the module). This assumption should, if anything, given an over-estimation of the flame height outside a module, but would predict a shorter duration fire than would probably be the case. In some cases the ventilation may be so poor that the fire would be in danger of self extinguishing and would represent more of a hazard of eruptive or even explosive burning (e.g. through sudden short duration increases in air flow) and of hazard to fire-fighters attempting to deal with it rather than attack on the structure.

Where such highly ventilation controlled fires arise it is improbable that sufficient air will be drawn into the module to support combustion over the whole of the pool area. Areas of the pool remote from the ventilation area will not therefore be involved in the fire.

For any compartment fire there will inevitably be a period of fuel controlled burning immediately after ignition until such time as the air initially within the module becomes depleted. Knowing the hydrocarbon burning rate in 'open' conditions and the volume of the module, plus forced ventilation air rate, it is possible to estimate the time taken for air depletion to occur and ventilation control to be established. (This is typically less than a minute for modules of 2,000 to 3,000 cubic metres and thus only becomes important for ventilation controlled fires in very large modules).

Ventilation Factor

The ventilation of an enclosure depends on the size, shape and disposition of the ventilation openings. For a simple rectangular opening it can be shown from simple fluid mechanics and buoyancy that the air ingress rate will be given by:-

$$M_a = 0.5\, A\sqrt{H}$$

kg/s where A is the area of the opening and H is its height.

This assumes an orifice flow coefficient of 0.65.

Where there are multiple openings however the overall ventilation factor (A √H) is not a sum of the individual ventilation factors and such an assumption can result in significant errors. Only when the individual openings are the same level, have the same height and similar shape will simple addition be acceptable. For other situations it is really necessary to perform a rigorous analysis to define a neutral plane (i.e. above which gases vent and below which air ingresses) and then calculate an overall A √H . It is necessary to use a computer program to achieve this.

Flame Extension

Unfortunately relationships for flame extension from large compartment fires involving hydrocarbon fuels do not currently exist. Data from such fires involving cellulosics are however available and relationships derived from these are the best that are currently available. The most widely accepted relationship is that due to Thomas and Law [12] viz:

$$Z + H = 18.6 \left(\frac{R}{W}\right)^{2/3}$$

Where Z is the extension above the upper level of ventilation openings (m).
H is the height of ventilation opening (m).
R is the mass burning rate (kg/s).
W is the width of the opening (m).

For louvred and wind walls care must be taken in specifying H and W for the above equation. For a louvred wall an effective width of 0.7 W should be assumed while for a wind wall it is necessary to calculate and 'effective H' from the estimated ventilation factor and known width W.

METHODOLOGY

Examples of the assessment methodologies for gas and oil release fire scenarios are presented in the following flowcharts (1 to 4) which in turn refer to figures 4 to 9 in respect of flame size predictions.

CONCLUSION

A simple, first pass method, of predicting the maximum potential fire consequences (in terms of maximum short duration fire size and maximum uncontrollable fire duration), based on identified isolatable inventories of hydrocarbon offshore platforms, have been developed and are presented. The method will allow designers of offshore installations to prepare preliminary recommendations for passive fire protection requirements prior to detailed design of fire protection requirements by specialist engineers.

The methodology should invoke standard fluid mechanics techniques for assessing release rates which are then used for assessment of fire dimensions using recognised techniques, published in the technical literature.

The methodology provides techniques to identify for each isolatable inventory the largest release / fire which can be sustained for at least 10 minutes and the longest duration fire which cannot be controlled by manual firefighting techniques. These will define the maximum extent and rating of passive protection requirements.

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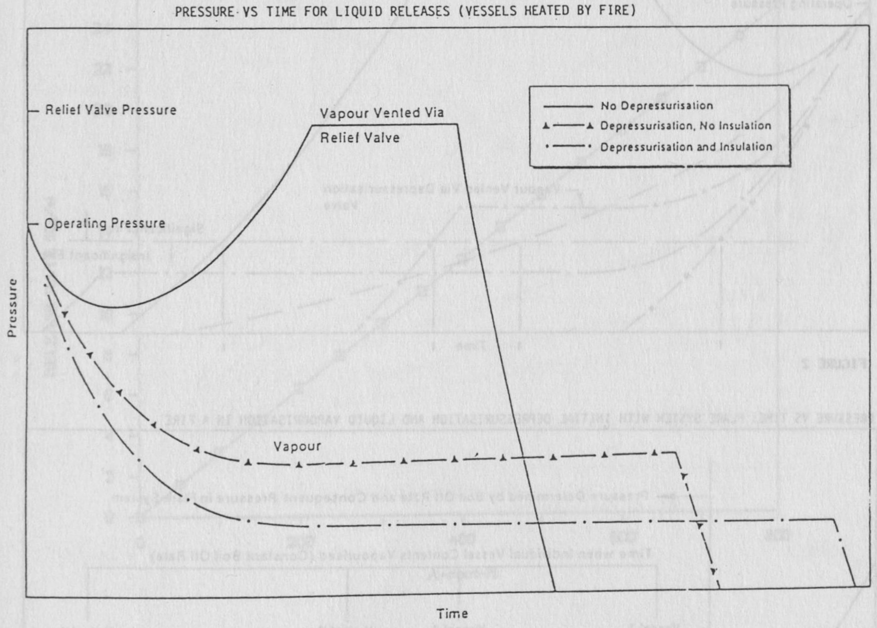


FIGURE 1

PRESSURE VS TIME FOR GAS RELEASES (VESSELS HEATED BY FIRE)

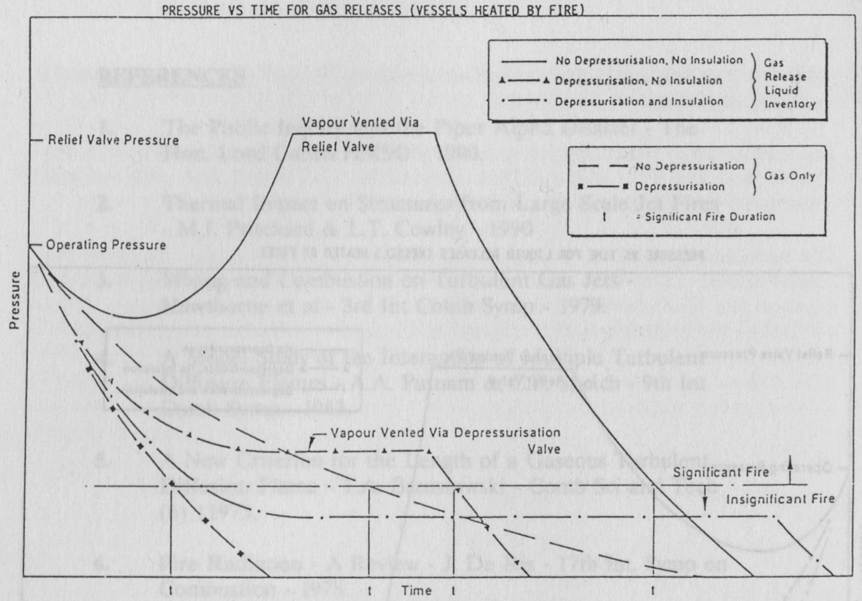


FIGURE 2

PRESSURE VS TIME: FLARE SYSTEM WITH INITIAL DEPRESSURISATION AND LIQUID VAPOURISATION IN A FIRE

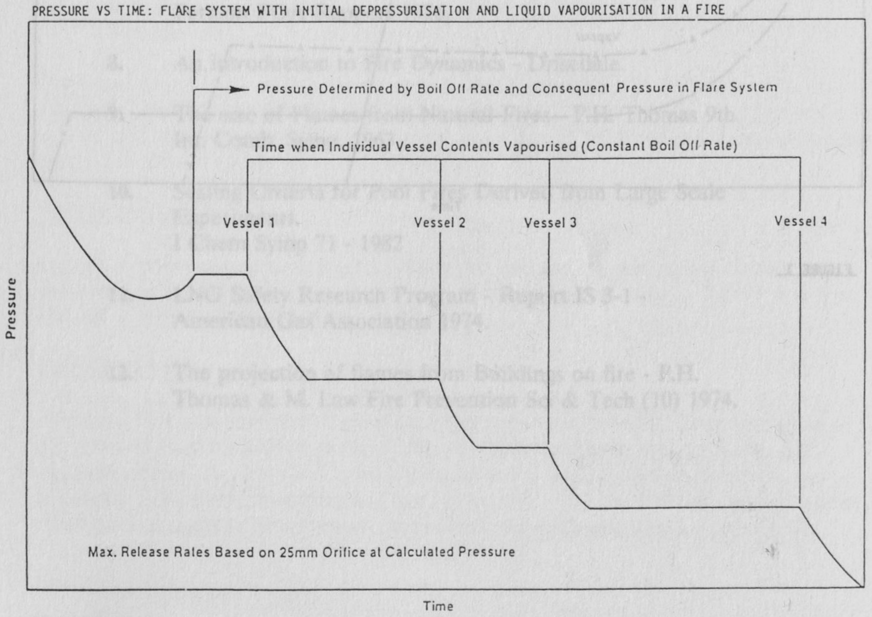


FIGURE 3

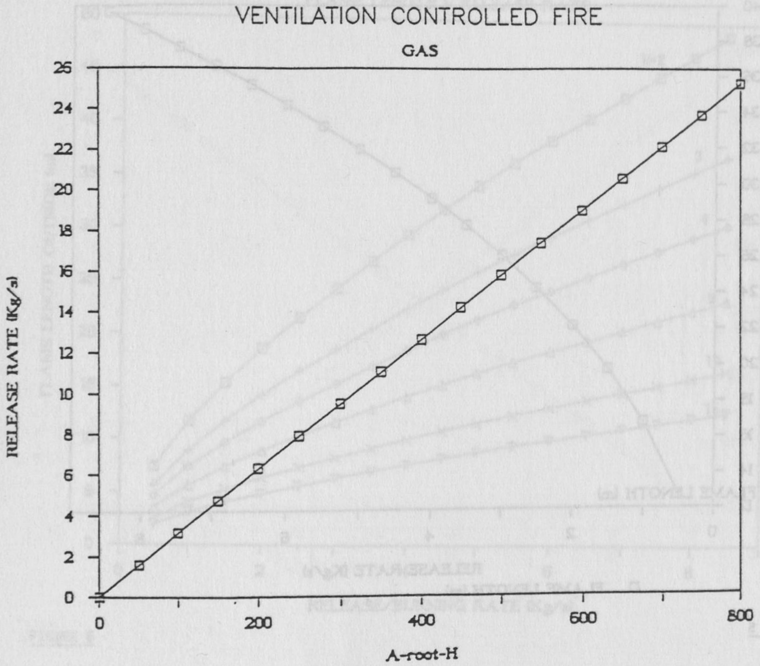


FIGURE 4

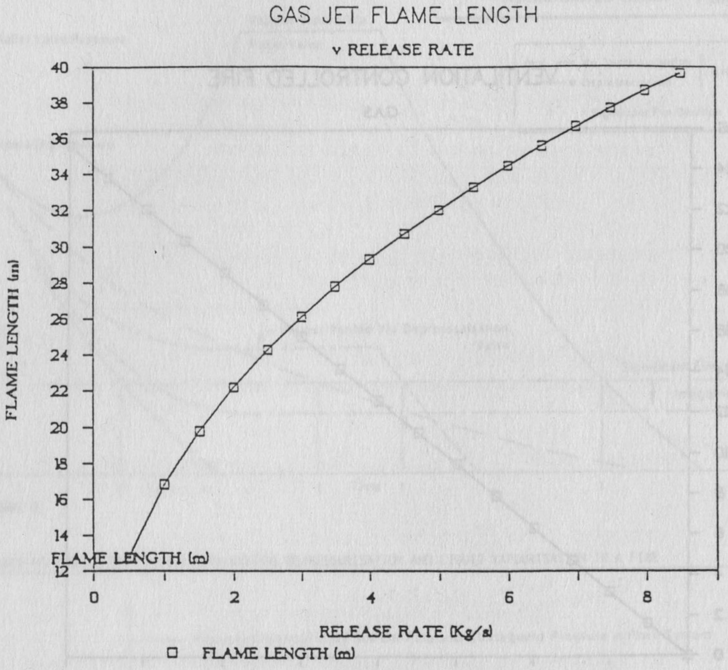


FIGURE 5

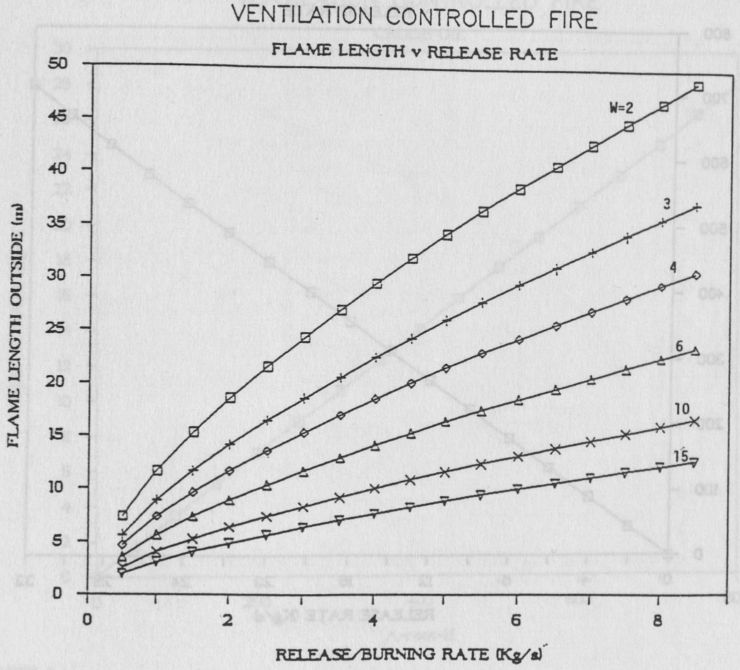


FIGURE 6

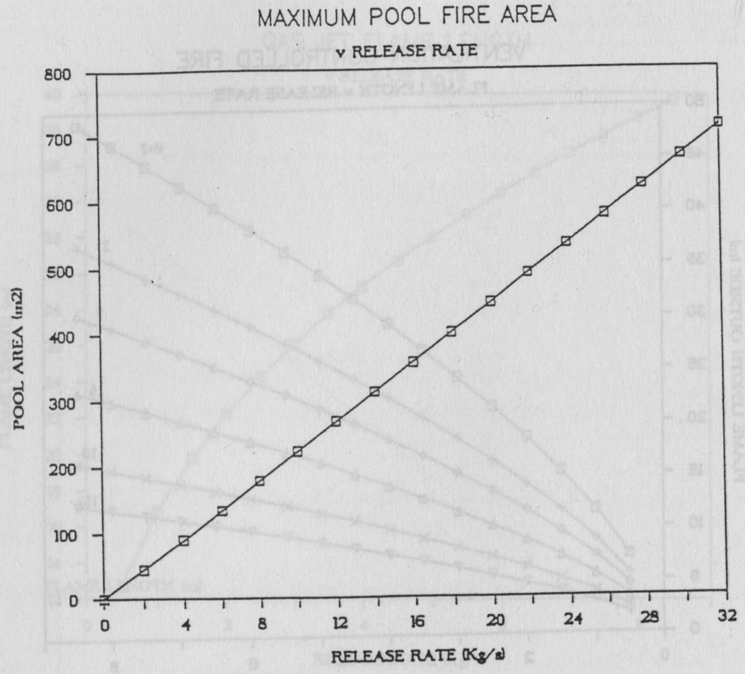


FIGURE 7

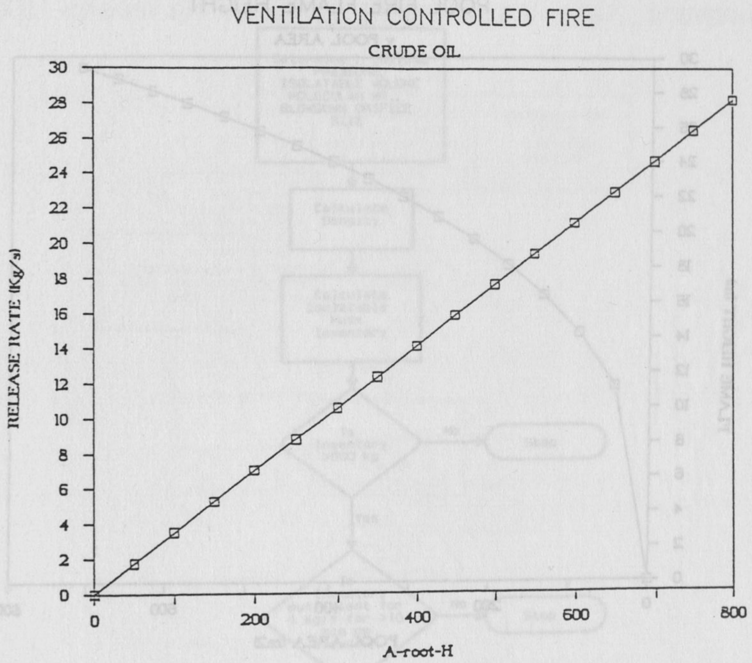


FIGURE 8

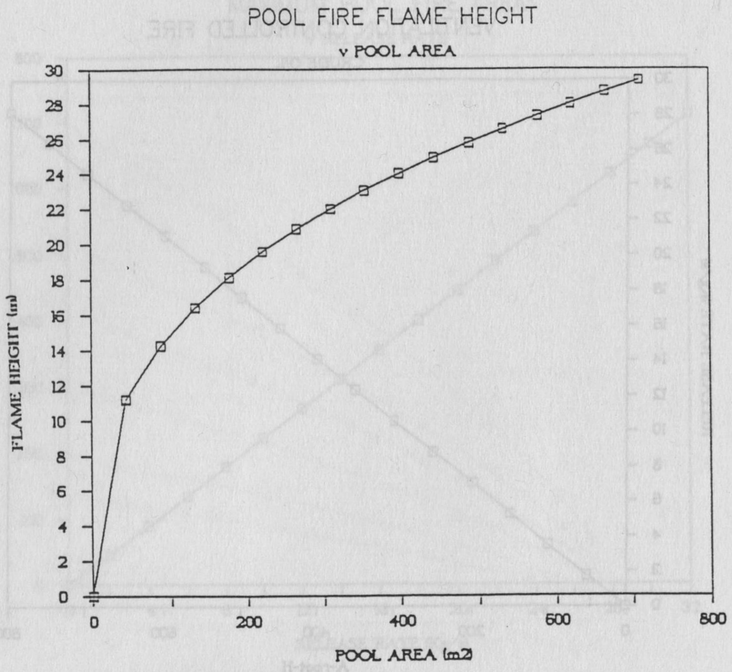
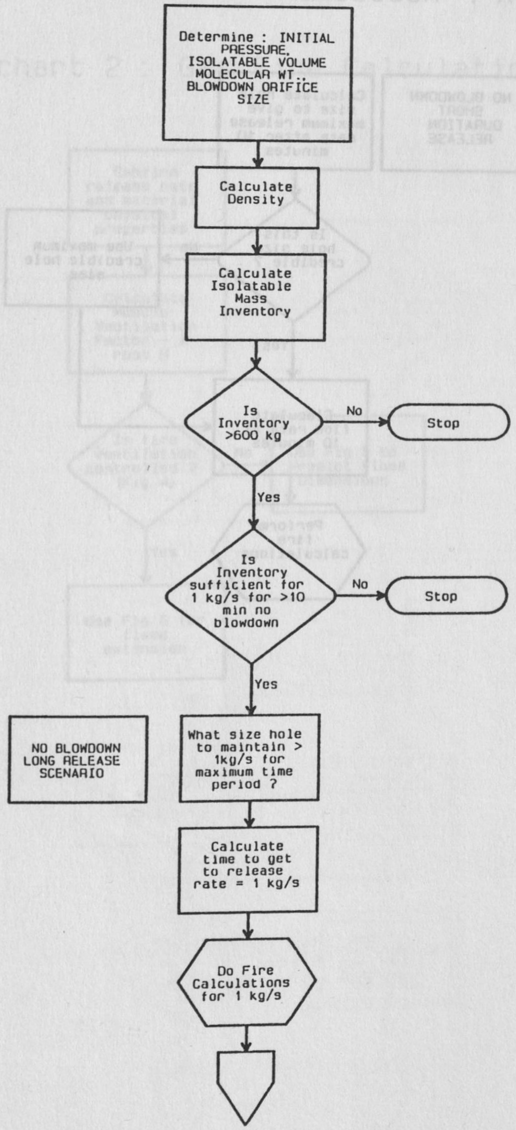
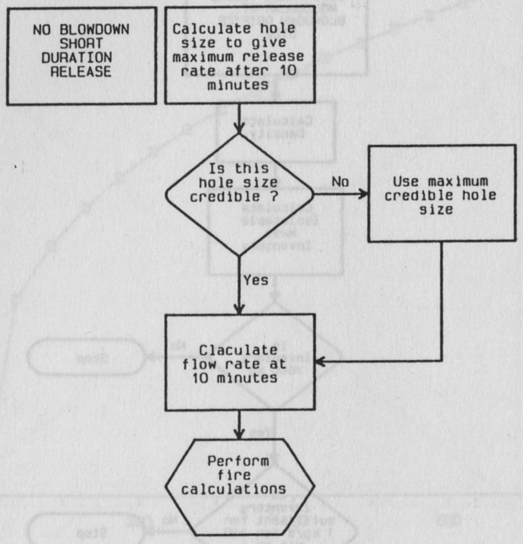


FIGURE 9

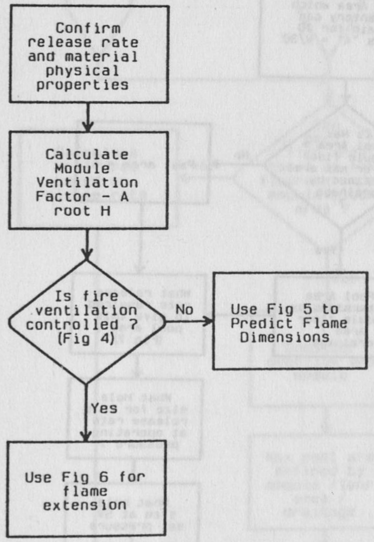
Flowchart 1 : Assessment of Gas Releases



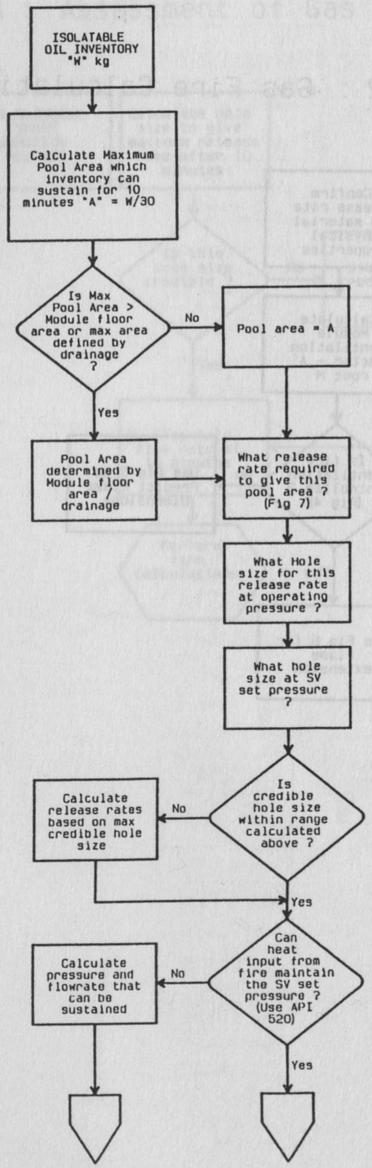
Flowchart 1A : Assessment of Gas Releases (Cont)



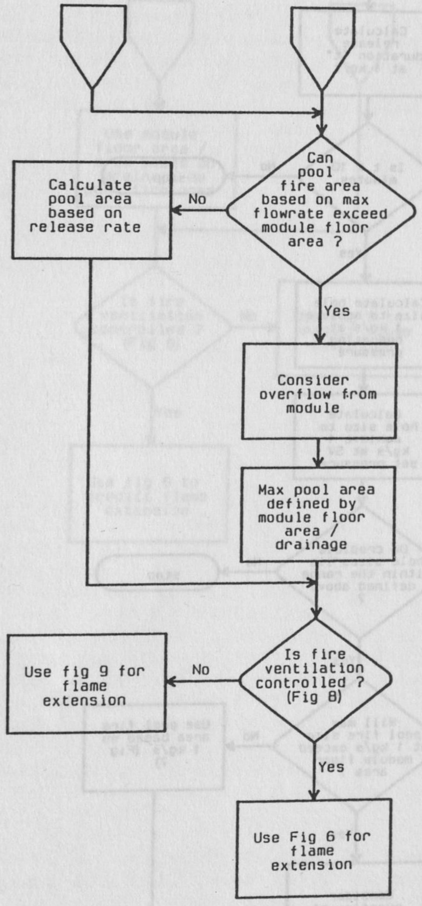
Flowchart 2 : Gas Fire Calculations



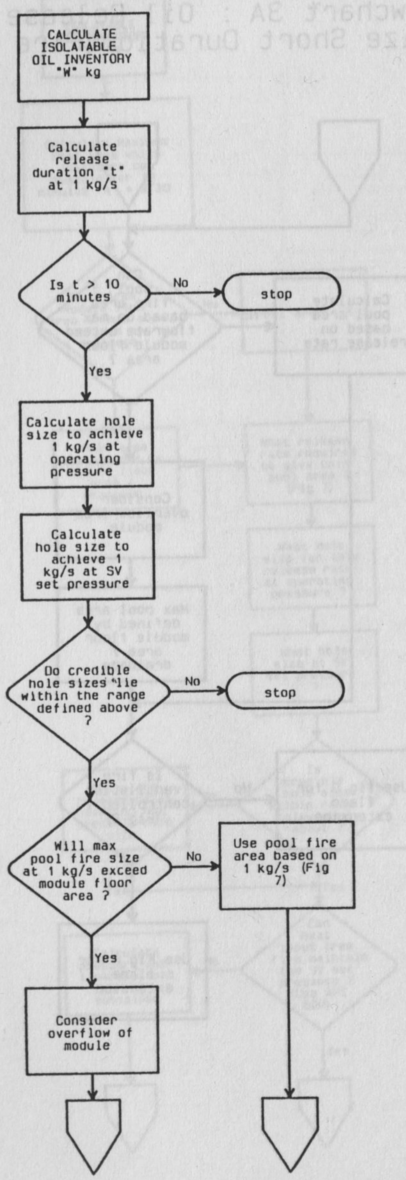
Flowchart 3 : Oil Release
Maximum Size Short Duration Fire



Flowchart 3A : Oil Release
Maximum Size Short Duration Fire (Cont)



Flowchart 4 : Oil Release
Long Duration Small Fire



Flowchart 4A : Oil Release
Long Duration Small Fire (Cont)