ASSESSING RISKS TO OCCUPANTS OF EXISTING BUILDINGS ON CHEMICAL PLANTS DUE TO HAZARDS OF FIRE AND EXPLOSION

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Following publication of the 1998 CIA guidance[1] on the design and location of occupied buildings, operators are now required to assess the risks to occupants of new, existing and temporary buildings. Eutech have been actively involved in carrying out occupied building assessments for a number of years now and have found that in the vast majority of cases, operators are faced with the problem of assessing existing buildings. Assessing existing buildings poses a particular problem in that the cost of modification can be very high. This paper describes a methodology using a mainly hazard based approach, which is used by Eutech for assessing risks to existing building occupants to enable a practical basis of safety to be developed. Practical use of the latest TNO 'GAMES' method for vapour cloud explosion modelling is also described.

Keywords: occupied building, fire, explosion, overpressure

INTRODUCTION – Why consider risks to building occupants on chemical plants?

Many chemical plants handle flammable or toxic materials, often in large quantities. The unplanned release of these chemicals can result in fire, explosion or toxic hazards. People who work on these plants do not expect to be at more risk whilst at work than if they stayed at home. It is natural to feel safe and protected when in a building, humans feel less vulnerable when surrounded by four solid walls and a roof. However, on chemical plants it is often people inside buildings who are actually more at risk, particularly in the event of an explosion, than those outside. The human body can withstand blast over pressure levels of 350 mbar (5 psi) or more before it is likely to sustain lung or other organ damage (although a person may be blown over or struck by flying debris at such overpressure levels). However, most people are expected to work inside buildings and not outside. Many buildings such as offices on chemical plants can fail catastrophically at over pressures of 140 mbar (2 psi) or less, resulting in serious injury or death to the occupants. Many chemical sites have been developed over the years and as a result, are becoming very congested, particularly specialty chemical sites. More and more sites are using contractors rather than in-house engineering resource, resulting in an increase in temporary accommodation such as portacabins. New plant is being installed with little thought as to its position relative to occupied buildings such as offices, and as a result, people are (often unknowingly) working closer and closer to the hazard. Unless directly involved in the operation of the processes, is it really necessary to have people working so close? Control rooms are an exception, where close proximity to the plant can be beneficial, and in these cases it is essential to ensure that following an incident, the control room and its occupants can still function to safely shut down other parts of the plant. Apart from all these reasons, in the UK at least, carrying out a risk assessment for any potentially hazardous activity, is a legal requirement.

BACKGROUND

The vulnerability of control rooms on chemical plants was strongly highlighted in England by the Flixborough disaster on 1 June 1974 when 28 people were killed in the control room as a result of the Nypro Chemical Works explosion. This was essentially a vapour cloud explosion involving cyclohexane. This incident caused companies such as ICI at its Teeside sites to re-examine their control rooms[2] and make some improvements to reduce the vulnerability of the occupants in the event of serious plant explosions. These included simple measures such as covering glass with plastic film and replacing heavy light fittings. The UK Chemical Industries Association (CIA) published a design guide in 1980, which specified the degree of protection required for new buildings in vulnerable areas. This guide did not apply retrospectively to existing buildings at that time.

Despite these developments, many older buildings continued to be used in locations where modern standards would only allow blast resistant buildings to be occupied. Arguments for not taking action were mainly based around the high cost involved in strengthening existing buildings. Operating companies preferred to spend money on reducing explosion probability. Memories of Flixborough faded during the 1980s and the urgency to update standards of older buildings became less of a priority.

The Piper Alpha disaster in the North Sea on 6th July 1988, caused 167 fatalities, most of who were in the accommodation module on the rig. This event had substantial impact on the layout and protection required for offshore oil platforms, including retrospective improvements to existing layouts to protect people working and living on them.

Then on 21st September 1992 a jet flame caused by decomposition of nitrotoluene distillation residue occurred at the Hickson & Welch chemical factory in Castleford[3], England. The force of the flame 'cut through' a lightly constructed control building, killing four people. It then struck and set fire to the main office building, 55 metres away, resulting in the death of a fifth person due to smoke inhalation. The effect of this incident was to reawaken the Chemical Industry and Regulators in the UK to the risks of locating occupied buildings near to hazardous plants. One of the lessons from this incident from the UK health and Safety Executive Inquiry report was

"The design and location of control and other buildings near chemical plant which processes significant quantities of flammable and/or toxic substances should be based on the assessment of the potential for fire and explosion and/or toxic releases at these plants. Companies should assess the suitability of existing buildings and if they are found to be vulnerable, reasonably practicable mitigating action should be taken."

The UK CIA Guidance was updated in 1998. The new guidance covers both new and existing buildings and includes details of risk criteria and tolerability and methods for assessing vulnerability of occupants. Such a quantification technique could be used in cases where major modification might prove prohibitive from a cost viewpoint. The HSE then sent letters to sites covered by the Control of Industrial Major Accident hazards regulations (CIMAH or Seveso I directive), asking them to assess the risks to building occupants in accordance with the new guidelines. With the introduction of The Control of Major Accident hazard Regulations (COMAH or Seveso II directive) in 1999, the need to assess risks to occupants has been extended to smaller sites such as fine chemical and pharmaceutical manufacturers.

EUTECH METHODOLOGY

Through experience within ICI and external clients, Eutech have developed a methodology for assessing risks to occupants of existing buildings. Generally a hazard-based approach would be used initially as this normally requires less work than a risk-based approach. This is summarised in the flowchart in Figure 1.

IDENTIFYING OCCUPIED BUILDINGS

In order to identify potentially occupied buildings, the first thing that is required is an up to date site plan showing location of all buildings and plant. It is a good idea at this stage to highlight all buildings, which are potentially occupied. Typical examples on chemical plants include workshops, control rooms, offices, canteens, warehouses, store rooms and amenities blocks. In some cases, particularly with fine chemical plants, production areas are often heavily occupied with control panels and small control rooms next to reactors and dryers etc. These should be included at this stage. To then fully assess the degree of occupancy, it is necessary to understand the building use, i.e. how many people use it, how often they use it etc. From this the likely occupancy can be determined and compared to the occupancy criteria set for the site. There is nothing written in the new CIA guidelines on occupancy criteria and what constitutes a 'building'. However, some guidance on this is expected and may be available at the time of this paper being published for the conference. ICI and other Teeside sites have an agreement with the HSE that if a building is occupied by anybody for more than 2 hours in a 24-hour period, then it needs to be classified as an occupied building. What actually constitutes a building is generally clear and obvious. Buildings with lower occupancy levels than this would normally not be assessed, although clearly if there are any changes to the building use, then reassessment would be required. Whatever criteria are used to determine occupancy and what constitutes a building, should be clearly recorded.

Another important point is to consider if an explosion in one plant can have an effect on adjacent company sites. An example of this is at Wilton in the UK. This is a very large site originally owned by ICI who maintained the overpressure circles for the whole site. Following significant divestment, only a small part of the site is now ICI owned, the remainder being owned by a large number of independent companies. Companies need to know how a fire or explosion in an adjacent site might affect their occupied buildings.

IDENTIFYING HAZARDOUS PLANT

Plants on any site, which are potentially hazardous, are usually well known to the site personnel. People are aware that gases such as hydrogen and ethylene are potentially explosive and that substances such as chlorine are highly toxic. Sometimes, the hazardous plant is not obvious to everyone and by focusing on obvious major hazards such as large confined plant structures full of high-pressure hydrocarbons, less obvious but nevertheless potentially serious hazards can be overlooked. An example of a hazardous plant not obvious at first site is given in Figure 2.

This building looks like an ordinary brick building presenting no apparent hazard. However, inside is a natural gas letdown unit handling natural gas at 7 barg. Although the likelihood of an incident here is low, the building is located only about 40 metres from the main site offices, which are heavily occupied. An explosion could project bricks and other debris as far as the building, penetrating glazing etc. The key thing is to also look for the less obvious hazards.

Typical common hazards on heavy chemicals plants such as petrochemical plants include all areas where flammable materials are being stored, handled or processed. Processes operating at high pressure or those containing boiling volatile materials are particularly hazardous as any leak could result in rapid loss of containment and formation of flammable clouds. Also look for areas of plant which are confined such as complex structures containing process vessels and pipework. Without some degree of confinement, a vapour cloud explosion is unlikely to create damaging blast pressure, although if very close to the hazard, a building may be vulnerable to thermal radiation from a flash fire. Liquids stored at a temperature above their atmospheric boiling point such as liquefied petroleum gases (LPG), can rapidly form very large flammable clouds if released. The storage area itself may have sufficient confinement to give rise to a weak vapour cloud explosion or the cloud could drift into a more confined zone. If the tanks are raised off the ground, there may be confined spaces and obstacles below the tanks, and if the tanks are close together, confinement sufficient for flame acceleration may exist between tanks.

On heavy chemical plants in particular, accidents involving atmospheric storage tanks are unlikely to represent a worse case scenario (except in the case of toxic release) as they are often located on tank farms a long distance from any occupied buildings. Tanks are often bunded and pool fires which result can often be contained. Pool fires also take some time to develop fully and in many cases, evacuation to a safe location may be possible well within this time. However, this is not always the case and consideration of the potential for running pool fires should be given. Also, loss of containment, particularly if refrigerated storage is used due to high volatility at atmospheric pressure, could result in the formation of a vapour cloud, which could drift into areas of confinement. On fine chemical plants or smaller heavy chemicals plants, occupied buildings might be located very close to atmospheric storage tanks and points where tankers offload, so the potential for loss of containment and fire/explosion must be considered. It also needs to be pointed out that it is not just flammable materials, which can present a hazard. Gases such as CO2 stored at high pressure have been known to fail resulting in overpressure due to ‘pressure burst’. In addition, fragments of the vessel can be projected long distances in the event of catastrophic failure.

On smaller plants such as fine chemical and pharmaceutical plants, large complex structures containing highly flammable materials are seldom present. However, the key difference is that the hazards on such plants are often much closer to the occupied buildings. Also, processes are mostly batch and often controlled locally and the high dependence on manual control, means that operators need to be present for a large proportion of the batch cycle. Production areas might therefore be considered as occupied buildings in certain circumstances. Many batch processes also rely on intermediate ‘buffer’ capacity and often have a large number of intermediate storage tanks to provide this capacity. and it is not unusual to find say 100 tonnes of flammable solvent contained in a plant within metres of a heavily occupied office building. Hazardous unit operations include batch reactors, dryers, mills, centrifuges to name a few. Such plants often also handle flammable dusts and dust/ solvent hybrid mixtures. Dust explosion hazards can therefore present a worst case in some situations. Explosion relief is one of the most common protection measures against dust explosions. On crowded, congested sites, it is rare to find a vent, which is truly directed, to a safe area. Explosion vents pointing directly towards office windows is not uncommon and on more than one occasion, Eutech's clients have requested evaluation of the likely effect on their own situation of a relief panel 'going off'.

EVENT IDENTIFICATION

Once the hazardous plant has been identified, it is then necessary to identify possible events, which could lead to a certain level of hazard being produced. An event at this stage is defined as something that will lead to the potential for fire or explosion, such as a leak or rupture. A thorough examination of the plant is required. In addition, a good knowledge of the plant, its maintenance history and any previous incidents is very useful. Clearly complex chemical plants often have a large number of possible events such as flange gasket blow out, guillotine failure of pipework, valve leakage etc. Often hundreds of possible events can be identified. Catastrophic vessel failure should be included, particularly where vessels operate above atmospheric pressure or at high temperature.

In the case of a VCE, for screening purposes (see section on consequence modelling) it is often sufficient to assume that the whole structure will fill with a flammable gas cloud to give a worst case. In this situation, identification of all events is not really necessary. However, identification of all events is required for determining the appropriate hazard level for buildings, which cannot be adequately screened out.

In the case of fires such as jet fires, flash fires and pool fires, the hazard level (i.e. thermal radiation) is dependent upon the nature of the leak event. A jet fire due to a guillotine failure of a 51mm (2") pipe for example, would give rise to a longer flame and higher thermal radiation level than say a gasket blow out between flanges. However, with software such as PHAST[4], is it possible to rapidly model different scenarios and screen out those where flame length would be negligible compared to the distance away of the nearest occupied building.

In the case of storage of materials above their atmospheric boiling point such as LPG, there is potential for Boiling Liquid Expanding Vapour Cloud Explosion (BLEVE). This could occur if say a pool fire occurred beneath a tank, or if a jet fire impinged on a tank. Another possibility is that a tank could be ruptured by direct impact from say flying debris following a VCE. With large inventories of LPG, fireballs, pressure effects and fragmentation missiles due to BLEVEs, can give rise to a larger hazard level than VCEs or fires. However, a BLEVE usually takes time to develop and evacuation of building occupants, particularly from small buildings, may be possible. Storage of liquids above their atmospheric boiling point is also common on smaller plants such as fine chemical plants, so BLEVE potential needs consideration here also. In fact, BLEVE could well represent the worst case hazard on many small plants.

CONSEQUENCE MODELLING

The objective of consequence modelling is to determine the hazard level against which the building's withstand capability will be assessed.

Initially, some form of screening can be performed. This is usually of benefit if there are a lot of buildings, which might be affected by the hazards. For screening purposes, one approach is to determine a 'worst case event'. In the case of a VCE, this is usually an event, which will fill most or all of the plant structure with a flammable mixture. In most situations, this makes identification of the actual event unnecessary as a VCE from a fully filled structure should give rise to the highest overpressure level.

Buildings can then be assessed against the 'worst case' hazard level by a competent structural engineer. Generally, if the building is capable of protecting its occupants against this worst case hazard level, then that building needs no further consideration. This screening method obviously assumes that any event results in exposure of the building to the worst case hazard level. This is clearly conservative, but such conservatism is justifiable bearing in mind the purpose is to eliminate buildings from further consideration.

The buildings, which cannot be screened out on this basis, need further consideration. In the CIA guidance, it states that 'buildings should be designed to protect their occupants against the hazards which might be expected to occur with a maximum return period of 10,000 years'

This provides a framework from which to determine the appropriate hazard level to use for each building. One recommended procedure[5] involves the following steps:-

- List all events for each hazard location (if more than one)
- Assign a frequency to each event (frequency data will be required)
- Determine hazard level (overpressure or thermal radiation) for each event at the building
- Plot cumulative frequency vs. hazard level
- Select hazard level where cumulative frequency equals $1x10^{-4}$

The remaining buildings are then assessed against the corresponding hazard level.

In order to calculate overpressure from vapour cloud explosions in external open structures, there are a number of methods available[6,7,8]. Examples include the TNT Method, The point source TNT method, The TNO Multi-Energy method, The Baker Strehlow Method in addition to a number of in-company developed methods such as The British Gas Method, and Shell method. Having reviewed many of these methods, Eutech have adopted the latest methodology from TNO on Guidance on the Application of The Multi Energy Method – Second part (GAMES)[9] which is an extension of the original TNO method. ICI co-sponsored part of the research to develop the guidance and ICI and Eutech will be co-sponsoring future research in this area. More rigorous methods such as use of CFD code would provide more accurate solutions and would be the ultimate approach. However, use of code such as FLACS and AUTOREAGAS, is generally considered too expensive by most clients for on-shore applications. For complex offshore structures, particularly where the structure is not fully open, use of CFD code would be required in many situations. Eutech use PHAST software for dispersion and fire modelling. PHAST generally provides adequate results for jet fire, flash fire, pool fire and BLEVE thermal radiation although results do need careful interpretation.

In addition, there are methods available[6,7,8] for estimating energy, pressure effects and missile sizes, velocities and travel distance from pressure vessel bursts and BLEVEs, and internal explosions in buildings. These methods could for example also be applied to predict damage due to bursting batch reactors during a runaway without adequate protection or for deflagration within plant. Caution should be exercised when using such methods as they are at best only rough estimates and require a number of assumptions to be made. There has also been research recently completed to better quantify the magnitude of thermal radiation from vented dust explosions[10]. Also a method is available in VDI3673[11] for estimating overpressure from vented dust explosions. This enables a better judgement to be made on what constitutes a safe vent discharge area.

TNO GAMES OVERPRESSURE CALCULATION

Overpressure affects due to explosions are usually dominant when considering risk to building occupants, so the methodology used by Eutech for VCE modelling, is described in more detail.

The TNO method is based on experimental work which showed that explosions develop in semi-confined structures as turbulence causes flame to accelerate through the structure. What matters is the volume of the semi-confined structure, the degree of confinement within the structure, and the initial flame speed of the gas/air mixture.

The standard TNO methodology needed only the volume of the semi-confined structure to assess the explosion effects. By calculating the volume of the plant structure, the method gives the blast wave overpressure at any required distance from the structure for a range of initial explosion strengths. The only judgement necessary, if need be, was to assess how much of the structure might fill with a flammable gas-air mixture, although the pessimistic answer was to simply assume that the whole structure filled. There was little guidance available on how to select the initial explosion pressure and use of a strength 7 line (500 mbar initial overpressure), was recommended for most reasonably congested structures.

However, as with the older TNT equivalence method, this simple application of the multi-energy method defaulted to the most pessimistic answer. It did not take into account the degree of semi-confinement within the structure, or the flame speed of the specific gas air mixture.

What was needed was better guidance on how to select the initial explosion overpressure. This resulted in a method, which correlated four parameters, the volume blockage ratio in the structure (VBR), the characteristic obstacle diameter (D), the flame path length (Lp) and the laminar burning velocity (S) of the stoichiometric gas-air mixture. The equation for 3D open volumes is given below:-

$$\mathbf{Po = 0.84 * (VBR*Lp/D)^{2.75}\ S^{2.7}\ D^{0.7}} \qquad \textbf{(1)}$$

Po = Initial overpressure (bar)

Equation 1 is used to calculate Po, the initial explosion pressure in the structure. The pressure vs. distance away from the structure (i.e. die off) is determined by use of the standard TNO curves, interpolating between curves if necessary. The majority of external plant structures can be considered as 3D open volumes which means that there are natural vent openings on all faces or at least most faces. There is also a correlation developed for 2D open volumes. The method should not be used inside buildings or in very confined areas, as it is likely to considerably under predict the pressure within the exploding cloud.

PRACTICAL APPLICATION OF TNO GAMES METHODOLOGY

To apply the methodology in practice, a detailed survey of the plant structure is required. There are essentially three stages to it

- Define Semi-confined Volume to analyse
- Obstacle Analysis
- Calculation

The determination of the semi-confined volume to analyse still requires a degree of judgement. The conservative approach for ‘worst case’ screening purposes is normally to assume that all of the structure volume will fill with a flammable gas or vapour mixture. However, experience has shown that most structures have a variable degree of confinement, and that parts with a low degree of confinement, make negligible contribution to overpressure. By splitting a structure into a few discrete portions and analysing each separately, it is often possible to show that certain portions contribute only slightly to overpressure and can therefore justifiable be excluded from the overall volume. This is one potential advantage of this more detailed method. When assessing different events, the semi-confined volume might be constrained by the volume of flammable gas, which can be released in the event.

Other factors to consider in volume determination are separation distance between adjacent structures (i.e. does more than one structure need to be included in the volume) and structure aspect ratio. For example, it is known that deflagrations need obstructions to maintain turbulence and hence flame speed, and therefore rapidly diminish in the open air (this does not apply to detonations where shock compression allows propagation in the open air, although detonations are rare in VCEs). Also, as the aspect ratio increases for a given volume, more side venting occurs which limits pressure build up. Some guidance was developed on this during the GAMES work and more research is planned to further refine this guidance.

The type of obstacle also has an influence. For example, although one part of a structure might be relatively open compared to other parts, it might contain obstacles with a higher potential for flame acceleration.

Once the confined volume is defined, it needs to be accurately measured.

To carry out the obstacle analysis, all obstacles within the plant structure need to be identified, recorded and dimensionally measured. This is a fairly time consuming process, but with experience, it becomes possible to know the types of obstacle which need accurate measurement and those where rough estimation is sufficient. This can save significant amounts of time. The dimensions are then used to determine the various parameters in equation 1. A typical open 3D structure for which this analysis would be applied is given in figure 3, with close up detail in Figure 4.

The calculation is then straightforward using equation 1 and the standard TNO overpressure die-off curves.. When calculating the distance from the structure to a building, generally the distance from the central point on the nearest face of the structure can be taken, rather than a corner of the structure. This is because side venting is likely to occur at corners, so the maximum overpressure at the extents of the structure is not likely to be developed near the corners. This actually makes little difference in most cases.

The methodology has shown that structures for which the standard TNO method would have required use of a line 7 strength line (500mbar overpressure), are in fact closer to line 5 (200 mbar overpressure) structures. This makes a lot of difference to the overpressure values at any given distance. The plant structure in Figs 3 and 4 is an example of this. The benefit can be a significant cost saving by having justification not to have to strengthen or move certain buildings. The method is approved by the UK HSE who also co-sponsored much of the TNO research. The main difficulty with application of the method, is that it requires the value of the laminar burning velocity (S) of the flammable gas or vapour. This is no problem with common pure gases such as methane and propane, where the value of S is well understood and documented. However, if for example, the gas is a complex mixture of hydrocarbons, it is difficult to obtain the mixture laminar burning velocity other than by experiment. Also for reactive gases such as hydrogen and acetylene, the high value of S, gives unrealistically high overpressures. The example below illustrates this.

Take a structure with the following parameter values for use in equation 1.

VBR = 0.1
D = 0.6 m
Lp = 10 m

The overpressure values for within this structure were calculated using equation 1 for propane and hydrogen and are given in table 1.

Table 1 :- Comparison of overpressure calculated for hydrogen and propane in a typical plant structure

Gas	**Laminar Burning Velocity (S) m/s**	**Overpressure in structure (mbar)**
Propane	0.46	280
Hydrogen	3.2	55000

An overpressure of 55000 mbar would not be reached in practice even in the event of a full detonation. Most of the experiments performed to develop the correlations, were performed with low to medium reactivity gases such as methane and propane. The method is therefore considered satisfactory for gases with values of S similar to or less than propane.

When considering common highly reactive gases such as hydrogen and acetylene, use of the method will not give realistic results. With more reactive gases it is best to resort back to the standard TNO method and use a high strength line, or use an alternative methodology. If this gave very large hazard zones, then with hydrogen in particular, an approach would be to look more carefully at dispersion of hydrogen and whether large flammable clouds are likely to form. This is because hydrogen is very buoyant and diffuses very quickly in air and large flammable clouds in external open structures are unlikely to form. Also, owing to the very low minimum ignition energy of hydrogen, releases tend to ignite very quickly resulting in jet fires. Typically, hydrogen releases tend to ignite within about 10 seconds on average.

Graphs to illustrate the effect of the parameters D, VBR and Lp on the overpressure within the exploding cloud are given in figures 5,6 and 7. A value of S of 0.45 m/s was selected (similar to propane), for all graphs.

BUILDING ASSESSMENT (EXISTING BUILDINGS)

Once the magnitude of pressure and/or thermal radiation has been determined for a particular building, an experienced structural engineer can then assess the likely affect on the building. This would typically involve a detailed survey of the building and examination of the building structural records. Further calculations would be performed where necessary to determine the likely deflection on walls and the roof etc. The assessment would also consider where within the building people sit and whether or not they would be likely to be vulnerable to say glazing failure or cladding failure. The objective of the assessment is to get a good judgement on what would be the likely failure mode of the building and therefore the probability of fatality at the assumed hazard level. The building would be considered to protect the occupants if the probability of fatality at the 1×10^{-4} hazard level was less than 0.01.

It is often possible to judge immediately that the building occupants would be highly vulnerable, for example in a wooden portacabin subject to 210 mbar (3 psi). Glazing area is also a good immediate indicator of vulnerability particularly if people sit close to the glazing. Large areas of glazing are likely to fail at very low overpressure unless designed to withstand a blast. Buildings with complex shaped footprints and elevations are usually less likely to withstand pressure than those with simple square or rectangular shapes. Multi storey buildings, unless specifically designed for pressure are likely to be more vulnerable as they have more area over which the blast wave will interact. There is also scope for internal floor collapse. Blast resistant buildings, particularly control rooms are normally designed with a single floor and simple in shape. Buildings with heavy objects on the roof such as HVAC equipment are likely to fail more easily and the inlets into the building provide a route for the blast to enter the building. This could cause failure of internal walls and objects can become missiles inside the building. To prevent this, installation of blast dampers is recommended for vents on any building likely to be subject to more than 70 mbar (1 psi) overpressure. Overhanging roofs are another indicator of vulnerability as the overhang is clearly likely to be subject to an extensive lifting force. Unless well tied down, the roof can easily fail.

However, if it is judged that the building can withstand the required level of hazard and protect the occupants (i.e. fatality probability <0.01), then no further work is required other than to document the basis of safety (see later).

WHAT IF BUILDING CANNOT WITHSTAND THE HAZARD LEVEL?

The building assessment would indicate how vulnerable the occupants would be if the building was subject to the predicted hazard level. If it was clear that the occupants would not be sufficiently protected, then action needs to be taken. The objectives here are to either improve protection to achieve a fatality probability of less than 0.01, to find a way of reducing the level of hazard, or to reduce or eliminate the occupancy.

There are many options, which can be considered. Can the hazard be eliminated or reduced by design?, i.e. Inherent safety. Can the hazard be moved? Focusing on the hazard at source rather than the buildings may be more cost effective when there is one hazard, which affects many buildings. Always look at the option of reducing occupancy duration, or even relocating all occupants and using the building for a non-occupancy role. Simple low cost measures should then be considered to try and improve protection to acceptable levels. This might include reducing or eliminating glazing area and replacing weak glazing with toughened glass. Consider moving people as far away from windows as possible, which is not always practical, as people, particularly in offices, like to sit close to windows. There is some debate as to the ability of protective film on weak glass to reduce the likelihood of injury following failure. Care should be taken when using film and it is recommended to replace weak glass whenever possible with toughened glass rather than use film. Other possible measures include fixing of cladding, use of double entry doors and replacement of heavy light fittings. These simple mitigation measures described are by no means exhaustive, but give an indication of what can be done.

If it is clear that these simple measures would not be sufficient to improve protection to acceptable levels, then strengthening of the building structure might be required. Retro-strengthening of buildings can be very expensive, and it may be more cost effective to completely re-build, relocate the building or even relocate the hazard, although there are likely to be few instances where moving the hazard will be feasible.

In cases where retro-strengthening is considered necessary, look at how to minimise the amount of the building needing strengthening. For example, it may be more cost effective to strengthen only those areas within a building which people would normally occupy. The remaining unstrengthened parts of the building might then be used for low occupancy tasks. It may be possible to create a blast haven within a building, although the plant would need very reliable warning systems and people would need to be able to get into the haven well within the predicted time for the event to develop. Which measures are justified will normally be decided on grounds of reasonable practicability.

If major retro-strengthening is required, then use of Quantified Risk Assessment (QRA) could be considered. QRA has the advantage at this stage in that it may allow a justifiable reduction in the hazard level against which the building needs assessing. This is mainly due to the fact that in a QRA, consideration is not only given to event frequency, but also to ignition probability. In the hazard based approach, ignition is always assumed to occur following an event. A risk quantification approach could be used at the outset. However, the amount of work involved and cost of undertaking a full QRA approach shouldn't be underestimated. Use of a hazard based approach in conjunction with appropriate screening techniques to minimise the amount of QRA required, can be more cost effective. There are a number of ways of carrying out QRA, which won't be described in this paper.

BASIS OF SAFETY

Once the assessments have been completed and any mitigation measures implemented, it is very important to document the basis of safety for the building. The basis of safety should be a written document clearly detailing the measures in place to safeguard occupants. For example a small office might have been vacated because it was considered vulnerable and used as a storage area instead. Removal of heavy objects such as filing cabinets from the room might have been one of the mitigating measures, or moving people away from windows. Unless the reason for these measures is clearly recorded, future occupants might not appreciate the importance and put themselves at risk again. Future changes to the building use or changes to the process may well affect the risk and this effect must be considered whenever a change is made. The basis of safety document for the building should therefore be a live document and updated as and when required. In addition, consideration of the effect on occupied buildings of any changes needs to be included within the site safety management procedures.

REFERENCES

1. UK Chemical Industries Association, 1998 Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites'

2. R.A.McConnell (ICI Chemicals and Polymers), 1998 Risk Management Plans for Existing Control Rooms, prepared for AIChemE Ammonia Safety Symposium, South Carolina, USA, 1998.

3. HSE Books, 1994 "The Fire at Hickson & Welch Ltd A Report of the Investigation by The Health and Safety Executive into the Fatal Fire on 21 September 1992"

4. PHAST, 'Process Hazard Analysis Software Tools'. DNV Ltd., London

5. Goose M., 1999 'Applying the CIA Occupied Buildings Guidance at Existing Hazardous Installations' Ref. PT/329 (Working Draft 4c).

6. CCPS, 1994, 'Guidelines for Evaluating the Characteristics of Vapour Cloud Explosions, Flash fires and BLEVEs', AIChemE.

7. Baker W.E., Cox P.A., Westine P.S., Kulesz J.J., and Strehlow R.A., 1983 'Explosion Hazards and Evaluation' Elsevier, Amsterdam.

8. IChemE, 1994, 'Explosions in The Process Industries' (second edition). Major Hazards Monograph.

9. J.B.M.M.Eggen, 1998 ‘GAME: Development of Guidance for the Application of The Multi-Energy Method’ TNO Prins Maurits Laboratory.

10. Holbrow P., Hawksworth S.J., 1998 “Thermal Radiation from Vented Dust Explosions” HSE research report number EC/98/30.

11. VDI, 1995, ‘Pressure Release of Dust Explosions’ VDI 3673

Figure 1: Methodology for assessing risk to existing building occupants

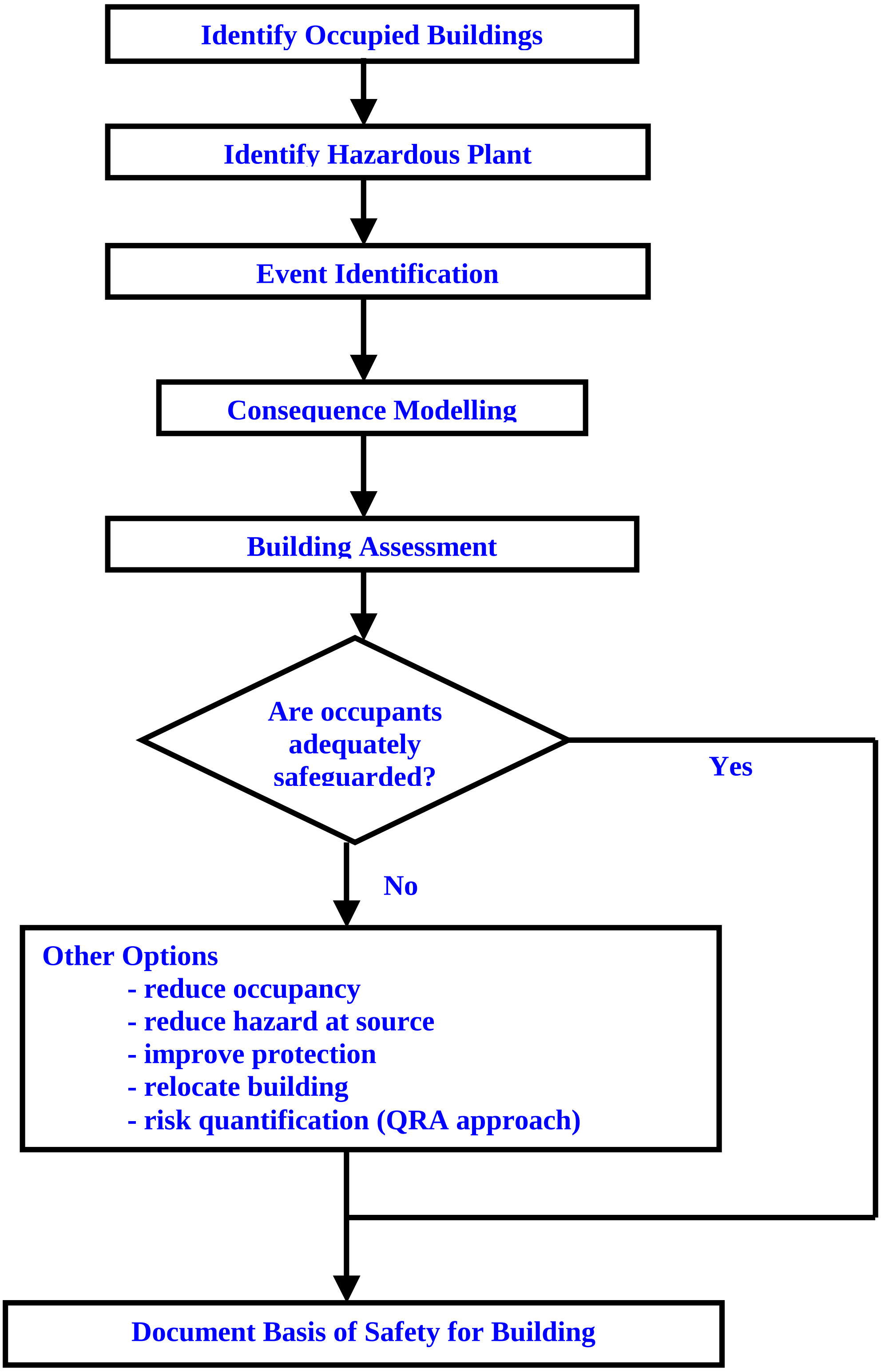

Figure 2: An enclosed Natural Gas Letdown Station

Figure 3: Typical plant structure suitable for TNO GAMES application

Figure 4: Close up detail of plant structure in Figure 3

Figure 5: Effect of flame path length on initial pressure

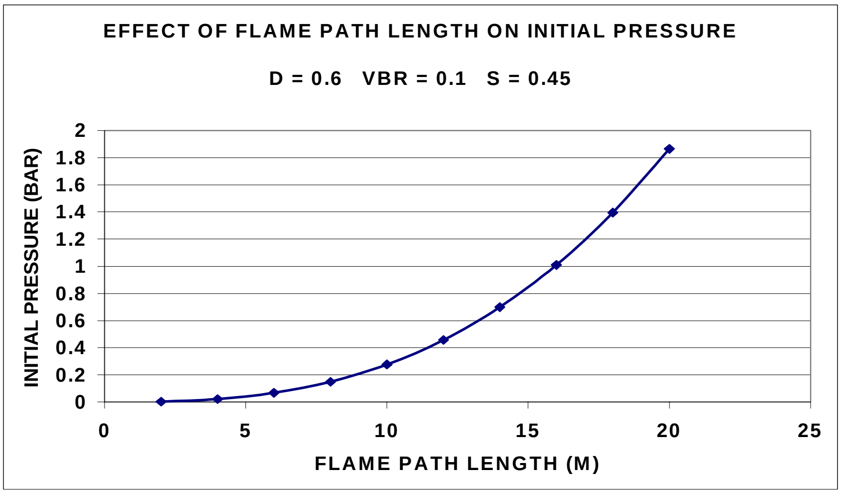

Figure 6: Effect of obstacle size on initial pressure

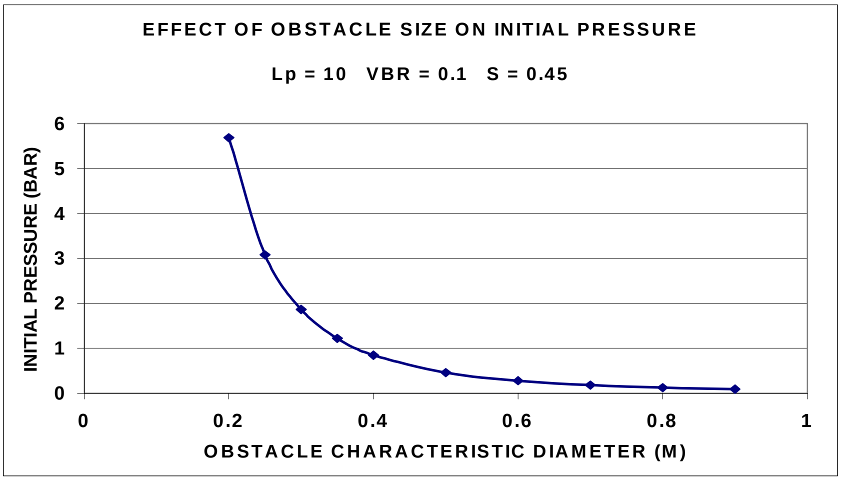

Figure 7: Effect of volume blockage on initial pressure