Location and design of occupied buildings – assessment step by step

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1. INTRODUCTION

The location and design of occupied buildings has been a recurring theme since the Flixborough incident in 1974. There have been many incidents since then that have killed or injured people who were in buildings at chemical plants. After the Flixborough incident the CIA produced guidance on the location and design of chemical plant control rooms. This was prescriptive and did not allow for many important factors that would be considered in a modern risk assessment. The new CIA guidance[1] covers all occupied buildings at an installation and is less prescriptive and more 'goal setting'. It is, therefore, adaptable to technical progress in the assessment of hazardous installations. Although written by the CIA for their membership, the approach adopted is applicable to chemical hazards generally.

The goal setting nature of the CIA guidance is, at the same time, a weakness in the sense that it does not provide a clear series of steps to follow when performing an assessment. This is an inevitable outcome of goal setting guidance or regulation such as the Health and Safety at Work etc. Act 1974. In both cases further information is needed outlining the practical steps to take to achieve the goal. This paper aims to provide that further information where the goals of the CIA guidance are to be met by adopting quantitative techniques.

2. WHAT IS RISK ASSESSMENT?

The foundation of the judgement making process in the CIA guidance is the production, and use, of an adequate risk assessment. It is used both for the design and location of new buildings and, to make judgements about the suitability of existing buildings and the necessity for any improvements. The validity of any judgements made using the guidance are crucially dependant on the quality of the risk assessment.

A risk assessment considers the likelihood and magnitude of a range of possible adverse effects, and then makes a judgement about these outcomes by comparison with criteria. Where the magnitudes and frequencies of the outcomes are combined into a single value or relationship, then the assessment is called a quantified risk assessment (QRA). There is ample scope for debate about the adequacy of the elements of a risk assessment, as they are each subject to varying degrees of uncertainty.

The separate steps in a risk assessment have been described more memorably as What If, What Then, Then What, and So What.

2.1. Step 1 "What if"

The first step of a risk assessment involves producing a list of all the possible initiating events that might lead, in due course, to adverse effects. For a Major Hazard Installation (MHI) these can be conveniently split into natural events such as flooding or seismic activity, and 'man made' events that are under the control of the MHI occupier, such as corrosion, maloperation, or impact by vehicular traffic.

The foundation of a good risk assessment is producing a comprehensive list of initiating events. It is also necessary to estimate the frequency (likelihood) of each initiating event if this is to be fed forward directly into the later parts of the risk assessment. It is also possible to adopt generic frequencies in the next step. In this case, frequencies of initiating events are less important and required only to give insight into the greatest contributors to risk. For example, if vehicular impact is being considered and the event frequency is predicted to be high when compared with other initiators then attention to impact protection is indicated.

2.2. Step 2 "What then"

The second step of a risk assessment involves setting out how each of the initiating events might lead to adverse effects. In the case of MHIs, the adverse effects derive from lost of containment incidents. These may be due to the failure of a vessel or pipework, or, in the case of packaged goods, their involvement in fire.

How each initiating event might lead to a hazardous event is considered for each event in turn. Each initiating event might lead to several hazardous events. For example, corrosion might lead to a vessel failure or a pipework failure. Similarly, hazardous events might have several causes. For example, pipework failure might be due to corrosion or vehicular impact. The procedure for tracing initiating events through to hazardous events can be made easier by the use of logic trees.

Logic trees can be used to calculate the frequency of the hazardous event from the initiating events that lead to it. It is comparatively easy to overlook initiating events and hence miscalculate the hazardous event frequency. It is, therefore, common to introduce generic failure frequencies derived from an analysis of historical data, at this stage, rather than calculate them from initiating event frequencies.

The result of this step is a list of failure 'scenarios' together with the predicted frequencies at which they might occur.

2.3. Step 3 "Then what"

The third step of a risk assessment involves working through the list of 'scenarios' and evaluating the effects on the surrounding areas, both in terms of consequences and frequency.

This might involve harm to people, structures, or the environment, according to the type of risk assessment being carried out. The degree of harm chosen for people, might be death or 'dangerous dose or worse'(2), according to the context of the assessment. Where a hazardous event does not produce equal consequences in all directions then the risk varies with both distance and direction.

There are a range of types of risk that might be calculated. The risk to individuals is commonly used when considering the establishment of new populations near existing hazardous installations. 'Societal' or 'group risk' is commonly used when considering the establishment of new hazardous installations.

2.4. Step 4 "So what?"

The final step of a risk assessment involves comparison of the calculated risks with some standard or policy. When considering health and safety matters, the HSE discussion document, 'Reducing Risks, Protecting People'(3) might be used. Different comparisons would be performed in different situations.

The outcome of the comparison might be that the risk is tolerable with or without safety improvements. If safety improvements are to be considered then an additional technique is required to put a 'value' on the risk reduction from any proposed improvement. The most common technique used, explicitly or implicitly, is to calculate the societal risk before and after the improvement, and use this to predict the number of 'statistical fatalities' averted over a relevant period of time. This can be used with financial criteria to help make judgements about which improvements, individually or in combination, are justified.

3. APPROACH FOR NEW BUILDINGS

For new buildings, the objective of the guidance is 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'. In order to meet this objective a method is given to derive a design load on the proposed building which, if it protects the occupants at this design load, will meet the overall objective. Because the method produces a design load in terms of an explosion overpressure, thermal radiation level, or toxic gas concentration, this has led to the method being called the 'hazard based approach'. As the method includes explicit consideration of hazard effects and the frequencies at which they might occur, it may justifiably called a risk based method, although some elements of a fully quantified risk assessment are absent.

The application of the method to new buildings should be straightforward, especially for occupiers of top tier CIMAH/COMAH sites because they should have carried out much of the assessment work already for their safety reports.

The procedure involves carrying out steps 1, 2 and 3 of a risk assessment as described above. Only the hazard level at the proposed location need be calculated. The result of this assessment is a set of scenarios each leading to a calculated hazard level at the proposed location at a stated predicted frequency. These are combined in a cumulative frequency/hazard relationship from which the hazard level corresponding to 1 in 10,000 years can be extracted. A scenario list for two plants, which might be the location of a vapour cloud explosion, describing the hazard level at the proposed location, is given in table 1.

Table 1 - Example Scenario List Giving Hazard Level at the Proposed Location

ID	Scenario	Hazard Level	Frequency
		(mbar)	(per year)
1	Plant A Vessel 1 Catastrophic Failure 100% full	500	4.0×10^{-5}
2	Plant A Vessel 1 Catastrophic Failure 50% full	400	3.0×10^{-5}
3	Plant A Vessel 1 Catastrophic Failure 25% full	300	3.0×10^{-5}
4	Plant A Vessel 2 Catastrophic Failure 100% full	450	4.0×10^{-5}
5	Plant A Vessel 2 Catastrophic Failure 50% full	400	3.0×10^{-5}
6	Plant A Vessel 2 Catastrophic Failure 25% full	350	3.0×10^{-5}
7	Plant A 100 mm Pipe-work Holes	150	3.0×10^{-4}
8	Plant A 100 mm Pipe-work Guillotine	250	1.0×10^{-4}
9	Plant A 75 mm Pipe-work Holes	100	1.0×10^{-3}
10	Plant A 75 mm Pipe-work Guillotine	150	3.0×10^{-4}
11	Plant A 50 mm Pipe-work Holes	75	3.0×10^{-3}
12	Plant A 50 mm Pipe-work Guillotine	100	1.0×10^{-3}
13	Plant B Vessel 1 Catastrophic Failure 100% full	375	4.0×10^{-5}

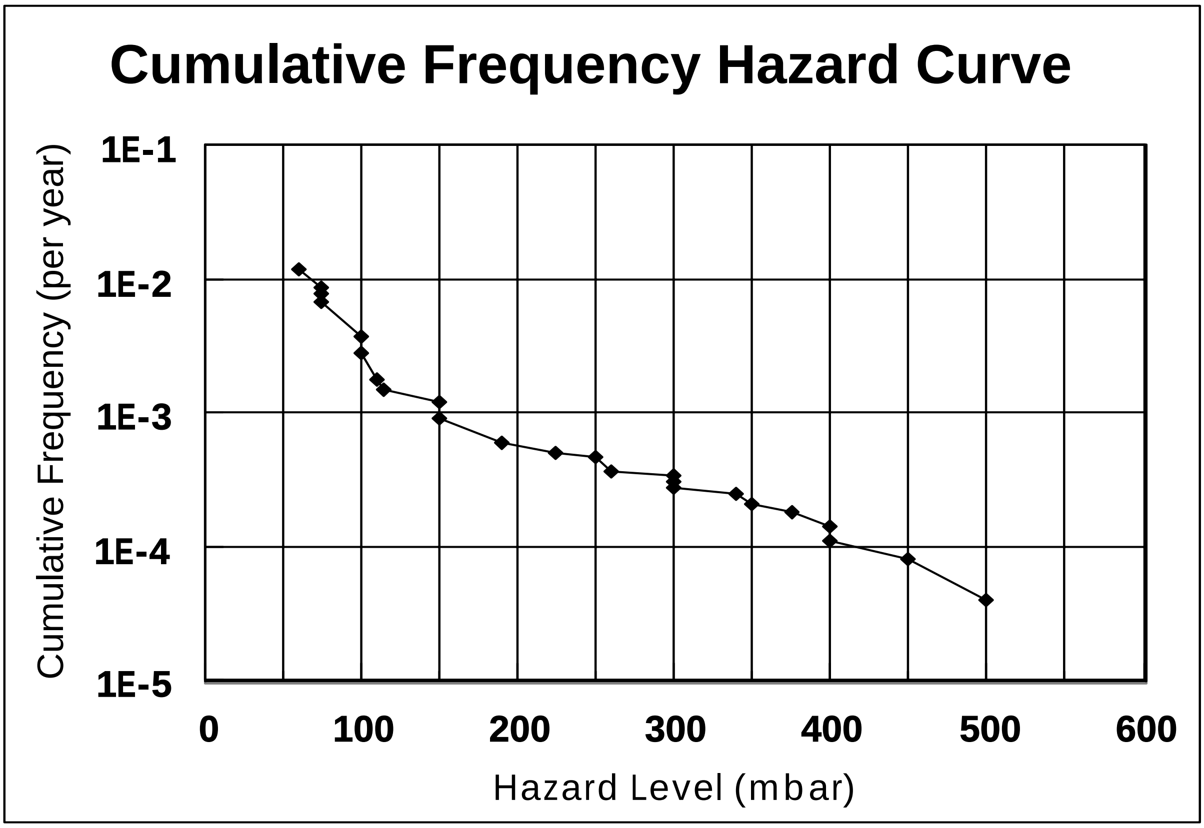
ID	Scenario	Hazard Level	Frequency
		(mbar)	(per year)
14	Plant B Vessel 1 Catastrophic Failure 50% full	300	3.0×10^{-5}
15	Plant B Vessel 1 Catastrophic Failure 25% full	225	3.0×10^{-5}
16	Plant B Vessel 2 Catastrophic Failure 100% full	340	4.0×10^{-5}
17	Plant B Vessel 2 Catastrophic Failure 50% full	300	3.0×10^{-5}
18	Plant B Vessel 2 Catastrophic Failure 25% full	260	3.0×10^{-5}
19	Plant B 100 mm Pipe-work Holes	115	3.0×10^{-4}
20	Plant B 100 mm Pipe-work Guillotine	190	1.0×10^{-4}
21	Plant B 75 mm Pipe-work Holes	75	1.0×10^{-3}
22	Plant B 75 mm Pipe-work Guillotine	110	3.0×10^{-4}
23	Plant B 50 mm Pipe-work Holes	60	3.0×10^{-3}
24	Plant B 50 mm Pipe-work Guillotine	75	1.0×10^{-3}

The treatment of this data to give a cumulative hazard curve from which the design hazard level can be extracted is illustrated in table 2. This second table is obtained by sorting the rows of the first table so that the largest values of hazard level are at the top. The cumulative frequency for each row is the sum of the frequency for that row and the cumulative frequency for the row above. The cumulative frequency for the first row being the frequency for that row alone.

Table 2 - Cumulative Frequency/Hazard Level Relationship at the Proposed Location

ID	Scenario	Hazard Level	Frequency	Cumulative Frequency
		(mbar)	(per year)	(per year)
1	Plant A Vessel 1 Catastrophic Failure 100% full	500	4.0×10^{-5}	4.0×10^{-5}
4	Plant A Vessel 2 Catastrophic Failure 100% full	450	4.0×10^{-5}	8.0×10^{-5}
2	Plant A Vessel 1 Catastrophic Failure 50% full	400	3.0×10^{-5}	1.1×10^{-4}
5	Plant A Vessel 2 Catastrophic Failure 50% full	400	3.0×10^{-5}	1.4×10^{-4}
13	Plant B Vessel 1 Catastrophic Failure 100% full	375	4.0×10^{-5}	1.8×10^{-4}
6	Plant A Vessel 2 Catastrophic Failure 25% full	350	3.0×10^{-5}	2.1×10^{-4}
16	Plant B Vessel 2 Catastrophic Failure 100% full	340	4.0×10^{-5}	2.5×10^{-4}
3	Plant A Vessel 1 Catastrophic Failure 25% full	300	3.0×10^{-5}	2.8×10^{-4}
17	Plant B Vessel 2 Catastrophic Failure 50% full	300	3.0×10^{-5}	3.1×10^{-4}
14	Plant B Vessel 1 Catastrophic Failure 50% full	300	3.0×10^{-5}	3.4×10^{-4}

ID	Scenario	Hazard Level	Frequency	Cumulative Frequency
		(mbar)	(per year)	(per year)
18	Plant B Vessel 2 Catastrophic Failure 25% full	260	3.0×10^{-5}	3.7×10^{-4}
8	Plant A 100 mm Pipe-work Guillotine	250	1.0×10^{-4}	4.7×10^{-4}
15	Plant B Vessel 1 Catastrophic Failure 25% full	225	3.0×10^{-5}	5.0×10^{-4}
20	Plant B 100 mm Pipe-work Guillotine	190	1.0×10^{-4}	6.0×10^{-4}
10	Plant A 75 mm Pipe-work Guillotine	150	3.0×10^{-4}	9.0×10^{-4}
7	Plant A 100 mm Pipe-work Holes	150	3.0×10^{-4}	1.2×10^{-3}
19	Plant B 100 mm Pipe-work Holes	115	3.0×10^{-4}	1.5×10^{-3}
22	Plant B 75 mm Pipe-work Guillotine	110	3.0×10^{-4}	1.8×10^{-3}
12	Plant A 50 mm Pipe-work Guillotine	100	1.0×10^{-3}	2.8×10^{-3}
9	Plant A 75 mm Pipe-work Holes	100	1.0×10^{-3}	3.8×10^{-3}
11	Plant A 50 mm Pipe-work Holes	75	3.0×10^{-3}	6.8×10^{-3}
21	Plant B 75 mm Pipe-work Holes	75	1.0×10^{-3}	7.8×10^{-3}
24	Plant B 50 mm Pipe-work Guillotine	75	1.0×10^{-3}	8.8×10^{-3}
23	Plant B 50 mm Pipe-work Holes	60	3.0×10^{-3}	1.2×10^{-2}



From this curve it can be seen that the design hazard level is just over 400 mbar. This is a significantly different result to that obtained if all events less frequent than 1 in 10,000 years are ignored and the worst event not less frequent than 1 in 10,000 years taken as the design hazard level. This would lead to a figure of 250 mbar (event ID 8).

This design hazard level becomes part of the civil engineering basis for the building which must protect its occupants against that external hazard level. In this context ‘protect’ can be taken to mean that their probability of death given the incident occurs is less than 1 in 100. Overall this should achieve an individual risk of death to building occupants of around 1 in 1,000,000. This broadly equates to the negligible risk criterion in the HSE discussion document, ‘Reducing Risks, Protecting People’.

4. ASSESSMENT OF EXISTING BUILDINGS

The steps that need to be taken at existing sites are initially similar for the different hazards. An alternative approach is advocated in the CIA guidance for toxic gas hazards due to the nature of the remedial measures that are appropriate for toxic gas hazards. This is described later in this paper. The existence of the alternative method does not preclude the use of the generic method given in the main body of the guidance. In the case of existing buildings, both the ‘hazard based’ and ‘risk based’ methods may be used. The data that is required is similar for both methods. The difference lies in how it is used.

4.5. The hazard based approach to existing buildings

This starts with deriving the ‘performance’ in terms of hazard level that would be required of a new building at that location. This is then compared with the anticipated performance of the actual building, assessed by a competent person. If there is a shortfall in ‘performance’, then a list of remedial measures is drawn up to improve the building performance or reduce the hazards/failure rates of the plant. The latter option may be preferred if several buildings are at risk from a one or more hazardous plants.

Which remedial measure(s) are justified is decided on the basis of reasonable practicability, without recourse to full quantification of costs and benefits. This approach may not always give sufficient information to enable a judgement to be made and it may be necessary to use the alternative risk based approach.

4.6. The risk based approach to existing buildings

Again, this starts with deriving the ‘performance’ in terms of hazard level that would be required of a new building at that location.

If this option is used, then the data gathered in the initial phase of the assessment will be supplemented by information on human vulnerability to the hazards. The data is then presented in the form of a predicted risk of death for a person in the building. This prediction is likely to be compared with the 'Reducing Risks, Protecting People' criteria. If the prediction is less than 1 chance in 1,000,000 per year, 'Reducing Risks, Protecting People' regards this as negligible. Values above this must be considered for reasonably practicable risk reduction. This may be carried out by the same methods given above for the hazard based approach. If an occupier uses QRA for the assessment of the building 'as is', a fully quantitative approach to assessing reasonable practicability may be adopted.

One such approach is to consider one or more improvements, alone or in combination, and revise the QRA to quantify the reduced predicted risk. This reduction cannot be used directly in any reasonable practicability judgement. It must be used to derive a 'value' in monetary terms which can be set against the costs. This is done by combining the risk value with the numbers exposed and an appropriate lifetime for the exposure, to give numbers of 'statistical' lives saved and subsequently their monetary 'value'. This is balanced against the costs of the improvements. Drawing such a balance is usually called a cost benefit analysis (CBA). CBA is discussed later in this paper.

Although considerable attention has been given to chemical plant QRA over the years, there remains a large amount of uncertainty in some areas. One area of uncertainty relevant here, is estimating the vulnerability of persons in buildings subject to external explosion. The uncertainty is in at least two parts. Firstly, how will a building collapse, given exposure to a certain overpressure, and what injuries will this cause to the persons within. Secondly, there is the question of the likelihood of recovery given increasingly sophisticated medical facilities. There are few sources of data, and those that do exist are the subject of much debate.

4.7. Risk screening

The amount of work involved in performing a quantitative risk analysis for existing buildings, possibly followed by a cost benefit analysis of one or more remedial measures, is substantial. For this reason, paragraphs 5.6 to 5.13 of the CIA guidance introduce the concept of risk screening to establish situations where risks are clearly sufficiently low that no further action need be taken. The CIA guidance does not explicitly state what this screening risk figure should be. However, paragraph 6.4 of the guidance reproduces the HSE tolerability framework, recently republished in 'Reducing Risks, Protecting People'. The only risk figure in that framework, which is compatible with a screening approach is the 10^{-6} per year, risk of death, which corresponds to a 'level at which further risk reduction need not be considered'.

Risk screening in the context of overpressure hazard is further developed in section A1.2 of the CIA guidance. Paragraph A1.2.5 states that individual risk can be calculated from the relationship:-

$$IR = f \times v \times o$$

where:-

IR is the individual risk, per year, of a particular level of harm

f is the frequency of the screening event in events per year

v is the vulnerability. This is the conditional probability, in the range 0-1, of sustaining the level of harm given that the screening event occurs

o is the occupancy. This is the conditional probability, in the range 0-1, of the most exposed individual being present in the occupied building

Paragraph A1.2.4 suggests that 10^{-4} events per year is a suitable frequency to use in conjunction with a screening vapour cloud explosion (VCE) event at chemical plant. There is no explicit statement as to what this screening VCE event should be. Anything less than a VCE resulting from ignition of a flammable cloud filling the whole volume of the hazardous plant is unlikely to be compatible with a screening approach. Paragraph 5.5 of the guidance makes it clear that an equivalent screening frequency for refinery plant should be 10^{-3} events per year.

In respect of occupancy probability, a screening approach should make a conservative assumption about the proportion of time the most exposed individual might be present in the building. Adoption of a low figure based on current occupancy could be overly optimistic and future changes to occupancy patterns might not trigger a re-evaluation. Conditional probabilities in the range 0.33 to 0.25 would be expected on this basis.

The most contentious component of the individual risk calculation is the vulnerability of persons in a building subject to blast load. These data are usually expressed in the form of a overpressure/vulnerability relationship. These relationships are subject to a high degree of uncertainty and must be used with great care as they can be very specific, not just to types of building (such as offices), but to actual designs of any particular type. The greatest uncertainty lies where the vulnerability is neither near zero nor near one.

The vulnerability relationships given on page 24 of the CIA guidance were derived from HSE published research. They are based on specific examples of the four types of building and are not intended to be conservative for that type of building as a class.

Overall, the sensitivity of the calculated value of individual risk to the uncertainties in the factors from which is derived, is most affected by the vulnerability assumption made, particularly if the assessed vulnerability is not near zero or one. Fortunately, for likely values of frequency and occupancy, the vulnerability will have to be low in order to meet the screening risk criterion. In this case the risk screening method can be simplified into a consequence screening method. Issues of event frequency and occupancy are avoided and all that remains relevant is assessing the consequences of the screening event at the building and comparing it with a criterion overpressure which leads to a low fatality probability in that building. Choosing a consequence screening overpressure for buildings is less problematical except where a building has been specially designed to protect its occupants from high overpressure. In the latter case the original design specification would be used to derive the screening overpressure value.

Screening overpressures used should be justified, as for any other assumption. Unless specific data exists for the particular building design, this will be done by reference to a range of published data and/or specialist structural engineering advice followed by adoption of a cautious value. For buildings having no special protection, but not being especially easily damaged, overpressures of 50 mbar and below might result from such a procedure.

5. ASSESSMENT STEP BY STEP

When HSE inspectors are considering the adequacy of these assessments they will not be exhaustively checking the data provided. They will be looking for a clearly demonstrated structured approach where the steps in table 3 are apparent.

Table 3 - Key Steps in an Assessment for Existing Buildings

Step	Action
1	Set out the criteria for selecting occupied buildings
2	Produce a list of occupied buildings resulting from the application of the criteria, including their occupancy details
3	Set out the criteria for selecting the hazardous plants (fire, explosion and toxic hazards) that will be assessed
4	Produce a list of hazardous plants for each hazard type, giving basic details of hazardous substance inventories and conditions (e.g. temperature and pressure) under which the hazardous substances are present
5	Produce a brief description of the predictive model(s) to be used and the source(s) of the frequency data. The term ‘predictive model(s)’ includes both prediction of hazardous effects and prediction of consequences for people. An example of the second type would be an overpressure/vulnerability relationship for people in a particular occupied building

Step	Action
6	Optionally, describe and apply any risk or consequence screening techniques used to eliminate any occupied buildings where it can be established that risks or consequences are clearly sufficiently low that no further action need be taken
7	For each hazard, for each plant, produce a scenario list that gives the magnitude of the hazard (e.g. overpressure) at source and the frequencies at which it is predicted that they might occur
8	For each hazard, for each occupied building, produce a scenario list that gives the magnitude of the hazard (e.g. overpressure) at the building location and the frequencies at which it is predicted that they might occur
9	For each hazard, for each occupied building, produce a cumulative frequency/hazard plot from the scenario list, and state the derived hazard level that corresponds to the 10^{-4} event frequency
10	For each hazard, for each occupied building, produce an assessment by a competent person of the maximum hazard level at which the building will protect its occupants
11	Produce a table listing all the occupied buildings, their required performance as derived from the frequency hazard plots, their actual performance as assessed by a competent person, and whether the assessed actual performance exceeds the derived value from the frequency hazard plot

6. COST BENEFIT ANALYSIS

Where an operator has assessed an existing building and found that it falls short of the standards that would be required of a new building, he must consider possible risk reduction measures and test them against the requirement to adopt reasonably practicable improvements. At this stage he may, if he has used a QRA for his analysis of the existing situation, decide to extend his use of QRA to test the cost-benefit balance for the prospective remedial measures. Use of a CBA for this purpose is a suitable approach, provided that it takes proper account of the factors identified below. However, the operator must be aware that a CBA is not, in HSE's eyes, the primary test of reasonable practicability.

In 'Reducing Risks, Protecting People', HSE discusses some issues relevant to assessing risk reduction options, including the matter of reasonable practicability. The document sets down HSE's expectation that risk reduction action will normally be taken using, in the first instance, established good practice as the baseline, it being taken that the balance between costs and benefits was accepted as reasonable when the good practice was formally adopted, and that the good practice then adopted is not now out of date. Authoritative sources of good practice could include prescriptive legislation, Approved Codes of Practice, guidance produced by Government, standards produced by standards-making organisations, and guidance agreed by a body representing an industrial or occupational sector such as a trade federation or a professional institution, provided the guidance has gained general acceptance in the safety movement that it does represent good practice. Submission of a cost-benefit argument for not following an established good practice is unlikely to be successful (see ‘Reducing Risks, Protecting People’ paragraph 128).

In the event that the operator finds that the adoption of established good practice precautions is an insufficient response to the hazards or risks (or where established good practice does not exist), he may then rightly turn to CBA to examine additional measures.

CBA is often a useful tool for judging the balance between the benefits of a risk-reduction option and the costs incurred in implementing it. It aims to express all relevant costs and benefits in a common currency, usually money, so that a comparison can be made. Guidance on the technical conventions used by Government when performing a CBA has been published by HM Treasury [4], and in its discussion document HSE examines those policy rules which it considers particularly relevant for assessing the balance between the costs and benefits of occupational health and safety measures.

The following components should be addressed in a CBA submitted within the occupied buildings project.

6.8. Identifying options for reducing risks

Consideration should be given at an early stage to the scope for eliminating the hazard by using alternative nonhazardous substances, or for reducing the scale of the hazard by operating with smaller quantities of the hazardous substance in process and/or in storage. Improvements in containment engineering and in process control follow at a lower level.

Options for reducing risk should continue to be considered, and implemented where appropriate, until such time that the risk has been made negligible or no identifiable reasonably practicable improvements remain to be made.

6.9. Costs to be taken into account

When considering each risk reduction measure the costs to be taken into account should be only those which are necessary and sufficient to implement the measure. Where the operator incurs additional costs for other reasons which lead him to adopt a ‘Rolls-Royce’ measure where a ‘standard’ measure would suffice, then the additional costs should not be counted.

It would be proper to include the costs of installation, operation, and maintenance, and the business losses which would follow from any shutdown of the plant undertaken solely for the purpose of putting the measure into place. However, if the costs of such shutdown are high, the operator would be expected to consider sensible scheduling of the installation to coincide with shutdown for another purpose, such as plant maintenance.

6.10. Benefits to be taken into account

The benefits to be considered include prevented fatalities, prevented injuries of varying severity, and avoided costs of environmental recovery (see 'Reducing Risks, Protecting People', annex 3, paragraph 12), plant reinstatement and business interruption. A study of the costs resulting from major accidents in the chemicals and petrochemicals sectors has shown that the costs of business interruption exceeded the costs of plant repair by a factor of two to three on average, but with wide variation, from zero to a factor of fourteen, between different cases.

6.11. Valuation of benefits

The CBA needs to express in monetary terms, among other things, the value of preventing a fatality. For the appraisal of road safety measures the Department of the Environment, Transport and the Regions (DETR) uses a "value of statistical life" of about £1,060,000 (at June 2000 prices). This is not intended to represent the value of a particular life, but is to be seen as the amount of money that individuals are willing to pay to secure small reductions in the risk of death in a road traffic accident. The stated value is broadly supported by research procured by HSE, and values of this magnitude are frequently used in CBAs.

However, there is evidence that individuals are willing to pay greater sums (perhaps two to three times greater) to reduce the risk of death from other forms of transport, in which it may be felt that those travelling have lesser control over the risks which face them. This is one example of how the 'context' of death can affect the value which society places on preventing it. Many such factors have been identified: they are generally considered as falling into three broad categories: 'dread', 'familiarity' and 'scale'. The latter category may be particularly important when considering the potential consequences of a major accident at a chemical plant.

It is widely held that within a CBA higher than pro-rata values are appropriate where there is a potential for many fatalities in a single accident, such as would provoke a socio-political response. A company might see such an enhancement as a premium which it would willingly pay to protect its public image and reputation. In some CBAs the valuation of benefits has been increased by as much as a factor of ten to accommodate scale and other context factors.

DETR's valuations of averting a serious injury and a slight injury (in road traffic accidents) are roughly 10% and 1% respectively of the value of averting a fatality.

6.12. Discounting of costs and benefits

In general the costs of implementing a risk reduction measure will comprise an initial capital outlay and occasional later payments for maintenance and replacement. The benefit will recur year upon year. It is a conventional practice in an investment appraisal to discount the values of all costs and benefits to a common single date, often the "present day", before comparing them. For most public policy applications the discount rate for both costs and benefits is currently 6% per year. In addition, the value that individuals place on safety benefits is expected to increase as their living standards increase; on the basis of past trends and Treasury guidance HSE regards an uprating by 4% per year as appropriate on the benefits side of the comparison. The net result is that costs and loss control benefits should be discounted at 6% per year, and safety benefits at 2% per year.

It is necessary to assume a future remaining lifetime for the plant in question. For fairly new plants, future lifetimes of thirty or forty years would be expected. For older plants shorter spans would be appropriate, but it is unlikely that estimates shorter than ten years would be acceptable as past experience has shown such prognoses to be generally unreliable.

6.13. Comparison of costs and benefits – gross disproportion

Of particular importance to the use of CBA in relation to "reasonable practicability" is the interpretation of the courts in the case of Edwards vs the National Coal Board, which established the notion of 'gross disproportionality'. From that judgement it is now taken that if a CBA shows the costs and benefits of a safety improvement to be roughly in balance then the improvement must be made; and that only if the costs are higher than, and grossly disproportionate to, the benefits is the improvement not justified. A CBA needs to recognise the notion of gross disproportionality, and to make clear the basis on which an allowance has been made. A higher allowance would be expected the closer the level of risk is to the maximum tolerable.

6.14. Uncertainties

The sensitivity of conclusions to plausible variations in key input parameters should be examined, to show that suitably cautious assumptions have been made and that the conclusions are robust.

7. COST BENEFIT ANALYSIS STEP BY STEP

When HSE inspectors are considering the adequacy of a cost benefit analysis they will not be exhaustively checking the data provided. They will be looking for a clearly demonstrated structured approach where the steps in table 4 are apparent.

Table 4 - Key Steps in a Cost Benefit Analysis for Existing Buildings

Step	Action
1	State the means of identifying options for reducing the risks
2	State the means of screening the options, to identify those for detailed consideration
3	State the rationale for multiplier applied to total lifetime benefit to recognise "contextual" and "scale of major accident" factors
4	State the rationale for applying gross disproportion
5	Generate a list of options and take the first option for detailed assessment.
6	Estimate the costs of adoption - design, procurement, installation, operation, maintenance
7	Determine the total lifetime cost, each item discounted to present-day worth
8	Estimate the benefits of adoption - reductions in Fatal Accident Rate (or similar) and Injury Rate, averted environmental recovery costs, averted plant reinstatement costs, averted business losses
9	Determine the total lifetime benefit, each item discounted to present-day worth
10	Apply the appropriate multiplier to total lifetime benefit to recognise “contextual” and “scale of major accident” factors
11	Compare the cost (item 7) with the benefit (item 10)
12	State the conclusion for this option (taking account of item 4)
13	Repeat the procedure from step 6 until no reasonably practicable options remain

8. ALTERNATIVE APPROACH FOR TOXIC GAS

Where the hazardous substance is chlorine, or a similar compressed liquefied toxic gas, the CIA guidance, at appendix 4, permits an alternative assessment method which takes no explicit account of the likelihood of the various possible hazardous events. This is stated to be justified because ‘the cost of most mitigation measures is relatively low’. If this alternative method is used then the key steps are as given in table 5.

Table 5 - Key Steps in an Assessment for Existing Buildings near a Toxic Gas Hazard

Step	Action
1	Set out the criteria for selecting occupied buildings.
2	Produce a list of occupied buildings resulting from the application of the criteria, including their occupancy details.
3	Set out the criteria for selecting the hazardous plants (compressed liquefied toxic gas hazards only) that will be assessed.

Step	Action
4	Produce a list of hazardous plants, giving basic details of hazardous substance inventories and conditions (e.g. temperature and pressure) under which the hazardous substances are present. Give details of the 'passive mitigation measures' (paragraph A4.1.2 of the CIA guidance) for which credit is being claimed.
5	Produce a brief description of the predictive model(s) to be used. The term 'predictive model(s)' includes both prediction of hazardous effects and prediction of consequences for people. The first type of model would include how the effect of passive mitigation measures is to be modelled. The second type of model would include the value of 'toxic gas concentration which could limit escape' (paragraph A4.1.3 of the CIA guidance) and its derivation.
6	For each hazardous plant, predict the hazard range to the 'toxic gas concentration which could limit escape' in representative weather conditions.
7	Produce a table listing all the occupied buildings, that are within the hazard ranges derived above and details of their compliance with the mitigation measures in paragraphs A4.2.1 to A4.2.7 of the CIA guidance.

In view of the statement in paragraph A4.1.1 of the CIA guidance about low cost, and the application of mitigation measures being based on an assessment of consequences alone, it was initially anticipated that non-compliant buildings would have the specific mitigation measures described in paragraphs A4.2.1 to A4.2.7 of the CIA guidance applied without resort to cost benefit analysis. However recent information from the CIA indicates that this was not their intention and that not all non-compliant buildings would be provided with the specific mitigation measures. Work is in hand to revise the text of the document accordingly.

Another option is to provide additional 'passive mitigation measures' for the hazardous plant to reduce the hazard ranges so that non-compliant buildings are no longer within the hazard range. These options may be used in combination.

9. ACKNOWLEDGEMENTS & AUTHORS NOTE

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