

Risk Criteria – When is low enough good enough?

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ABSTRACT

Criteria are used to help decide whether the risk associated with a project or activity is low enough to proceed. The key question then, is when is low enough good enough?

This paper describes the flexible framework in use in the oil, gas and petrochemical industries for deciding on the tolerability of risk. The levels of individual risk that are generally accepted world-wide as intolerable are presented. The situation is not so straightforward for societal risk, where there is a wide variation in both regulatory and operator criteria.

In reality, the risks associated with most facilities lie in the middle band of the risk tolerability framework – the ALARP region. This paper describes the process used to demonstrate that risk levels have been reduced to ALARP. Insights are provided on the appropriate tools to apply during the life of a facility. It is concluded that, in practice, this amounts to taking a balanced view and reaching a defensible consensus amongst stakeholders.

INTRODUCTION

No industrial activity is entirely free from risk and so many companies and regulators around the world require that safety risks are reduced to acceptable levels. The key question then is what level of risk is considered to be low enough? A subsidiary question is also what risk are we talking about, individual risk or societal risk? This paper attempts to answer these questions.

Why have Risk Criteria?

Risk criteria are standards used to translate numerical risk estimates, e.g. 10^{-7} per year, as produced by a quantitative risk assessment (QRA), into value judgements such as 'negligible risk' that can then be set against other value judgements such as 'high economic benefit' in the decision-making process (CMPT 1999).

Put more simply, criteria are used to help decide whether the risk associated with a project or activity is low enough to proceed.

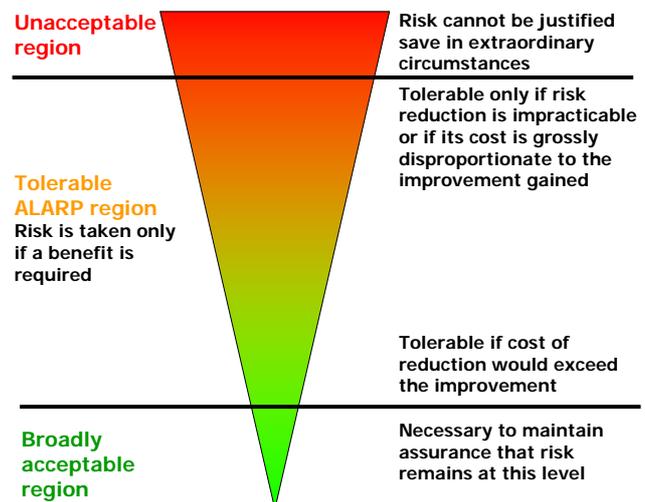
A Framework for Risk Criteria

The most common and flexible framework used for risk criteria divides risks into three bands (HSE 2001):

- An **unacceptable region**, where risks are intolerable except in extraordinary circumstances, and risk reduction measures are essential.
- A middle band, or **ALARP region**, where risk reduction measures are desirable, but may not be implemented if their cost is disproportionate to the benefit achieved.
- A **broadly acceptable region**, where no further risk reduction measures are needed.

This framework is shown in Figure 1.

Figure 1 – Framework for Tolerability of Risk



To define these bands, two levels of risk criteria are required; a maximum tolerable criterion above which the risk is intolerable and a broadly acceptable criterion below which the risk is insignificant.

Risk Measures for Loss of Life

Risks to people may be expressed in two main forms:

1. Individual risk – the risk experienced by an individual person
2. Societal (or group) risk – the risk experienced by the whole group of people exposed to the hazard. Where the people exposed are members of the public, the term societal risk is often used. Where workers are isolated and members of the public are unlikely to be affected, the term group risk is often used. Here, the term societal risk is used to encompass both public and worker risk.

The maximum tolerable (upper) criterion and the broadly acceptable (lower) criterion in use in the oil, gas and petrochemical industries are described in this paper, firstly for individual risk and then for societal risk.

INDIVIDUAL RISK

Individual risk criteria are intended to show that workers or members of the public are not exposed to excessive risk. They are largely independent of the number of people exposed and hence may be applied to a broad range of activities.

Individual risk is calculated by identifying all sources of fatality risk to a given individual, deriving the contribution from each source and then summing these to give the overall risk. For typical oil, gas and petrochemical workers the primary sources of risk are:

- Occupational, e.g. slips and falls, drowning
- Transport, e.g. road traffic accidents, air transport accidents
- Hydrocarbon related, e.g. loss of containment leading to toxic releases, fires or explosions

What are the levels of the Upper and Lower Criteria for Individual Risk?

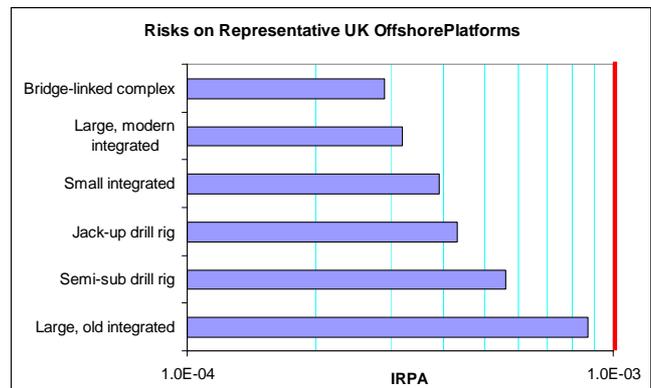
Individual risk criteria are most commonly expressed in the form of individual risk per annum (IRPA). Today, the following IRPA values for these criteria are generally regarded internationally as applicable for hazardous industries:

Table 1 – Individual Risk Criteria

	Workers	Members of Public
Maximum tolerable criterion	10^{-3} per yr	10^{-4} per yr
Broadly acceptable criterion	10^{-6} per yr	10^{-6} per yr

An IPRA of 10^{-3} per year was first used by the UK HSE as the maximum tolerable criterion because it approximated to the risk experienced by high risk groups in mining, quarrying, demolition and deep sea fishing (HSE 1992). As such, it would appear quite lenient for offshore and onshore oil, gas and petrochemical facilities. This is borne out by typical risk levels on offshore installations (which generally have higher risk levels than onshore facilities) shown in Figure 2 (HSE 1995).

Figure 2 – Risks on Representative Offshore Installations



Comparing risks is not a straight-forward task, but nevertheless Table 2 shows how many risky activities an individual would need to undertake in one year to reach an IRPA of 10^{-3} per year (derived from HSE 2001).

Table 2 – Risky Activities

Activity	Number of activities in one year that equals and IRPA of 10^{-3} per year
Hang-gliding	116 flights
Surgical anaesthesia	185 operations
Scuba diving	200 dives
Rock climbing	320 climbs

This further illustrates that 10^{-3} per year is actually quite high. However, in practice, few modern facilities with proactive risk reduction strategies have risk levels approaching 10^{-3} per year. This tends to be recognised in company risk tolerability standards, where benchmark design targets are often set for new facilities in the region of 3×10^{-4} to 1×10^{-4} per year. Risk levels are rarely ever insignificant, i.e. less than 10^{-6} per year and therefore tend to lie in the middle band of the risk tolerability framework – the ALARP region.

Summary – Individual Risk Criteria

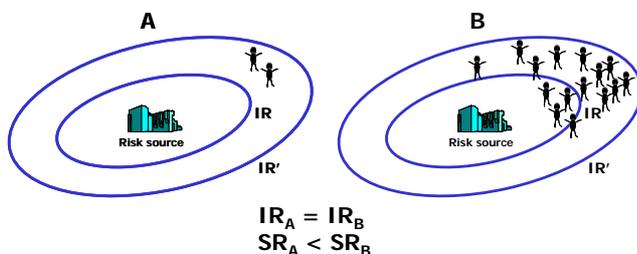
The maximum tolerable IRPA criteria of 10^{-3} per year for site workers and 10^{-4} per year for members of the public are generally accepted internationally. However, these levels are rather lenient for most facilities and companies often set more stringent criteria as much as 10 times lower for new designs.

SOCIETAL RISK

All fatal accidents are a cause for regret, but society generally tends to be more concerned about multiple fatalities in a single event. While such low-frequency high-consequence events might represent a very small risk to an individual, they may be seen as unacceptable when a large number of people are exposed. Such incidents can significantly impact shareholder value and, in some cases, the company never recovers (Sedgwick 2002).

The concept of societal risk is illustrated in Figure 3. Situations A and B have equal individual risk levels (IR and IR') but B has a larger societal risk (SR) because more people are exposed (Jonkman 2003). If the individual risk levels are acceptable, when is the societal risk not acceptable?

Figure 3 – Societal Risk



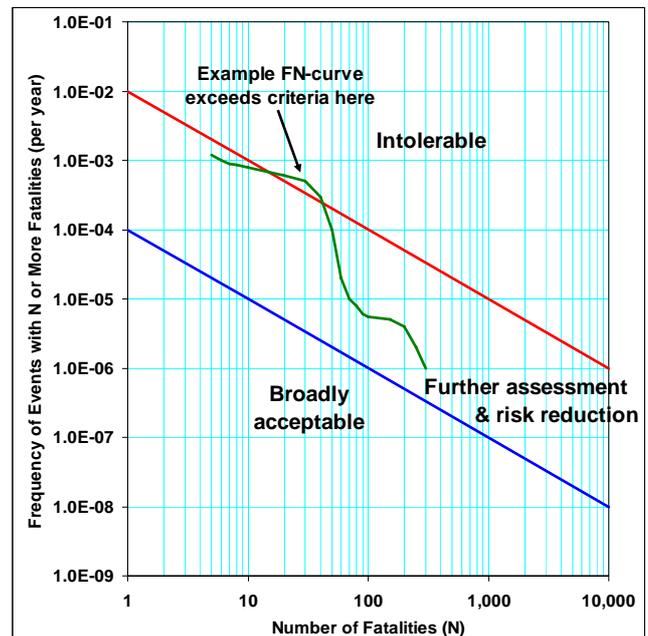
Criteria may be defined to limit the risk of major accidents and help target societal risk reduction measures such as restrictions on concurrent activities or land use, enhanced engineered safeguards, and improved building siting or protection.

“Multiple-fatality accidents can significantly impact shareholder value and, in some cases, the company never recovers”

FN-Diagram

A common form of presenting risk tolerability criteria for societal risk is on an FN-diagram, where two criteria lines divide the space into three regions – where risk is intolerable, where it is broadly acceptable and where it requires further assessment and risk reduction as far as is reasonably practicable, as shown in Figure 4. This is the same framework for risk tolerability as shown in Figure 1 above.

Figure 4 – Illustrative FN-Criteria



FN-criteria are not without their drawbacks but they are undoubtedly helpful when used in context. They clearly show the relationship between frequency and size of accident. A steep criterion slope also builds in multiple fatality aversion and favours design concepts with lower potential for large fatality events. The pros and cons of FN-criteria are summarised in Table 3.

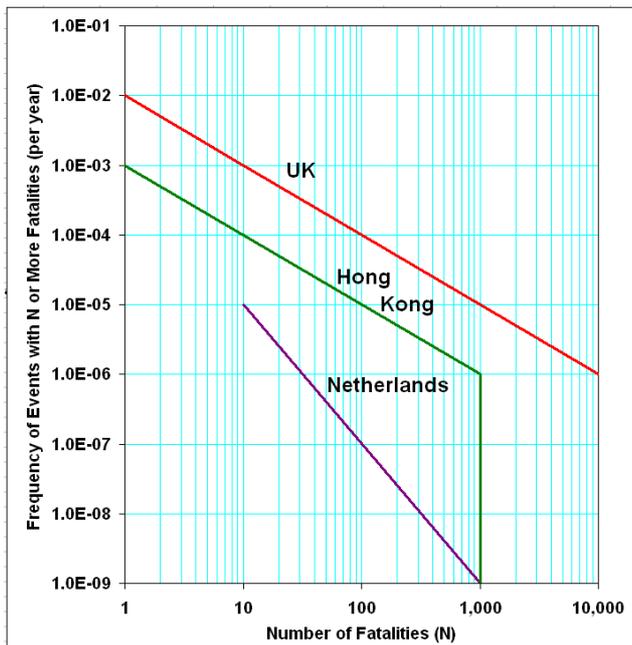
Table 3 – Pros and Cons of FN-Criteria

Pros	Cons
<ul style="list-style-type: none"> Clearly shows relationship between frequency & size of accident Allows judgement on relative importance of different sizes of accident Slope steeper than -1 provides explicit consideration of multiple fatality aversion & favours concepts with lower potential for large fatality events Allows company to manage overall risk exposure from portfolio of all existing and future facilities 	<ul style="list-style-type: none"> Cumulative expression makes it difficult to interpret, especially by non-risk specialists Can be awkward to derive May be difficult to use if criterion is exceeded in one area but otherwise is well below Much debate about criterion lines

What are the levels of the Upper and Lower Criteria for Societal Risk?

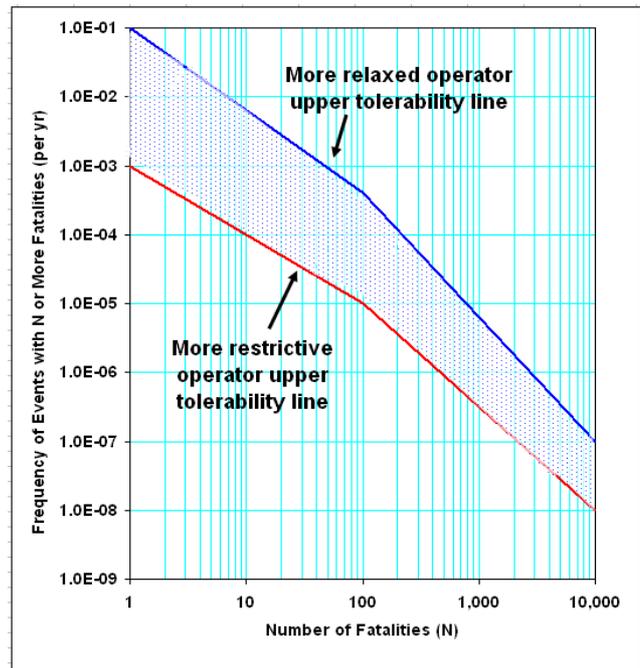
Unfortunately, unlike individual risk criteria, there are no single 'one-size-fits-all' criteria for societal risks in use by operators and regulators in the major hazard industries world-wide. Indeed, the variation in regulatory criteria is very wide, as shown by the upper tolerability criterion lines in Figure 5, which span a factor of over 100. The Dutch criterion is so restrictive that it raises a question about its merits.

Figure 5 – Regulatory Upper Tolerability FN-Criteria



A number of operators, including US corporations, do have their own FN-criteria or guidelines for their facilities but many others, including European corporations, do not. A review of a relatively small sample of international operators' FN-criteria shows a similarly wide variation to that seen in regulatory criteria, Figure 6.

Figure 6 – Operator Upper Tolerability FN-Criteria



For a company operating in regions where there are no regulatory criteria to meet, the choice of criteria to help decision-making therefore largely comes down to one of company values, i.e. the perceptions of the stakeholders directly affected by the decision and the values of the company in terms of its safety commitment and reputation.

When is too big too often?

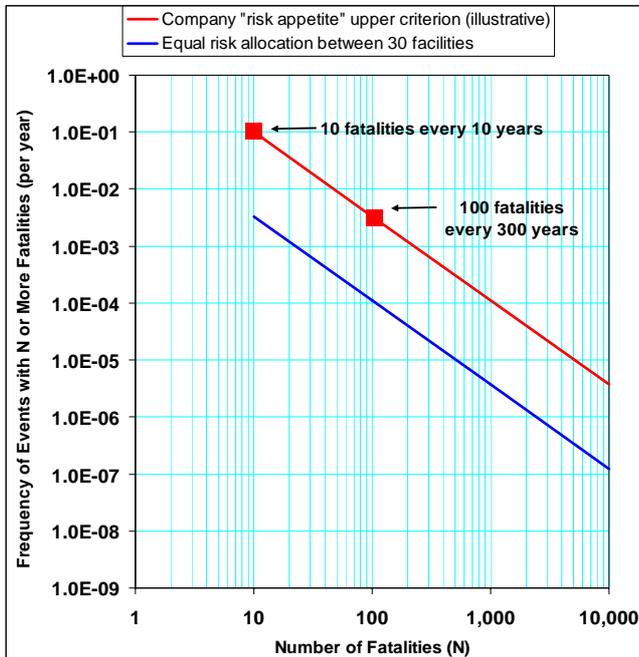
Expressed from a dispassionate business perspective, the company must decide how frequently large-fatality accidents would need to occur before the company's survival is put severely at risk due to the adverse reaction of shareholders, the regulator, media and public.

To illustrate this point, assume for example that a company believes that its future survival would be severely threatened if an accident causing 10 or more fatalities occurred more regularly than once every 10 years across all of its facilities, and if an accident causing 100 or more fatalities occurred more regularly than once every 300 years. A straight line can then be drawn between these two points and extrapolated to higher values of N. The slope of the line will determine whether large fatality aversion is included or not; in this example the slope is -1.5, implying a relatively high aversion.

Furthermore, if the company operated 30 facilities, it might decide to allocate its risk evenly between each facility. The resulting company upper criterion is shown in Figure 7 below, together with the single

facility criterion line if the company operated 30 facilities.

Figure 7 – Illustrative Company-wide FN-Criteria



An FN-curve for a single facility that lies on the 'wrong side' of the facility criterion line would use up an excessive proportion of the company risk appetite. In practice, the criterion line may be a reporting line, above which a higher level of corporate scrutiny would be applied. Only then can the decision be made by senior corporate management to proceed with the project or continue existing operations.

This example assumes the company allocates the total risk evenly between each of its 30 facilities. A variation on this is to allocate the total risk in proportion to the size of facility. While the approach has some merit (it recognises larger facilities generate greater economic value), it has one major disadvantage in that it may be misused to keep facilities on the 'right side' of the criteria.

PLL Criteria as an Alternative to FN-Criteria

The other main measure for societal risk is the annual fatality rate, where the frequency and number of fatalities are combined into a potential loss of life (PLL), which is a convenient one-dimensional measure of the total number of expected fatalities.

PLL is well suited for comparing alternative solutions for the same facility, is relatively easy to understand for non-risk specialists and must be calculated to be able to derive the cost-effectiveness of risk reduction options. However, no information is provided on the relationship between frequency and size of the accident, it is difficult to draw meaningful conclusions

from completely different facilities, and it often favours the concept that has the lowest manning level.

As such, there is little benefit to be gained in limiting PLL by explicit criteria. It is extremely rare (unknown) for organisations to have such limits.

Risk Contour Criteria as an Alternative

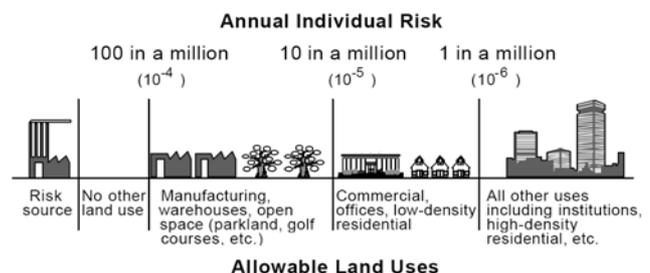
There are some other 'surrogate' measures of risk which do not explicitly show the relationship between frequency and consequence, but nevertheless provide a proxy for group risk in that useful inferences can be drawn to protect against large fatality events.

Risk contours are amongst the most common, where iso-risk contour plots represent the geographical variation of the risk for a hypothetical individual who is positioned at a particular location for 24 hours per day, 365 days per year. This is also known as location-specific individual risk (LSIR).

Although there is no consideration of the total number of expected fatalities or of any explicit aversion to low-frequency high-consequence events, an approach of lowering the risk contour criteria with distance away from a facility reflects an attempt to do this. Risk contour criteria tend to be used for land use planning purposes, with the local planning authority left to enforce land use controls.

For example, the Major Industrial Accidents Council of Canada (MIACC) recommends individual risk levels for use in respect to hazardous substances including the risk contributions from all sources, with the inner zone criteria of LSIR from 10^{-4} to 10^{-5} , middle zone 10^{-5} to 10^{-6} and outer zone beyond 10^{-6} per year. Restrictions are placed on activities or structures within the various zones, as shown in Figure 8.

Figure 8 – Canadian Risk Contour Criteria



The guidelines are thought to be realistic in terms of existing practices of risk management and levels of risk. They are also compatible with criteria that have been selected and implemented in other industries and other countries.

FN, PLL or Risk Contour Criteria?

In the absence of regulatory FN-criteria, some international operators have set their own FN-criteria but other operators believe there are simply too many issues associated with defining the upper and lower criterion lines. The preferred, quantitative, way for such operators of comparing risk reduction options in design and layout is through determining the change in PLL and the change in risk contour profiles.

Summary – Societal Risk Criteria

In the absence of regulatory criteria, the choice of societal risk criteria largely comes down to one of the company's values. But whatever criteria are selected, they need to be workable in practice – if they are too severe or too relaxed they will lose their usefulness – and should be based on a sound assessment of current good practice in industry.

ALARP

Whether considering individual risk or societal risk, safety risks need to be reduced to levels that are As Low As Reasonably Practicable, or 'ALARP'. The 'ALARP region' lies between unacceptably high and negligible risk levels.

If Risk is in the ALARP Region is it ALARP?

No, this is a common misconception. Even if a level of risk for a 'baseline case' has been judged to be in this ALARP region it is still necessary to consider introducing further risk reduction measures to drive the remaining, or 'residual', risk downwards.

The ALARP level is reached when the time, trouble and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained.

When does the ALARP Principle Apply?

Risk can be reduced by avoidance, adopting an alternative approach, or increasing the number and effectiveness of controls.

At the concept stage of a new project there is the greatest opportunity to achieve the lowest residual risk by considering alternative options, e.g. for an offshore oilfield development, options may range from fixed legged platforms to floating production vessels to subsea facilities.

Once the concept is selected and the early design progresses, the attention shifts to considering alternative layout and system options to optimise inherent safety. In the detailed design phase, the focus moves on to examining alternative options for improving safety systems.

During operations, the attention is on collecting feedback, improving procedures and personnel competence, and managing change to maintain the residual risk at an ALARP level. However, with advances in technology, what is ALARP today may not be ALARP tomorrow, so periodic reviews will be necessary.

"The concept stage provides the greatest opportunity to achieve the lowest residual risk by considering alternative options"

How is ALARP Demonstrated?

The definition of ALARP implies there is a mathematical formula to wield at the problem, and it is true that there is one. Having selected a range of possible risk reduction options, a QRA can be re-run for each option to identify the associated reduction in risk. Combining this improvement with the total cost of each option enables the options to be ranked in order of cost-effectiveness. The Implied Cost of Averting a Fatality (ICAF) is expressed in terms of \$ per statistical fatality averted and comprises the following generally annualised elements:

$$ICAF = \frac{\text{Net cost of option}}{\text{Potential saving of life}}$$

where *Net cost of option* =

Cost of option - *Reduction in loss of assets & production*

This calculation takes account of the fact that measures to reduce risk to people are also likely to reduce the potential damage to assets and loss of production.

The derived ICAF values for the proposed options may then be ranked and compared against company standards for ICAF. The typical ICAF value used by the UK offshore industry is around £6,000,000, i.e. in simplistic terms a measure that costs less than £6,000,000 and saves a life over the lifetime of an installation is reasonably practicable, while one that costs significantly more than £6,000,000 is grossly disproportionate and therefore is not justified. The UK HSE considers this to be the minimum level for the application of CBA in the offshore industry (HSE 2006).

In reality there is no simple cut-off and often a band of ICAF values is applied, as illustrated in Table 4.

Table 4 – ICAF Guidelines

ICAF (US\$)	Guidance
<\$10,000	Highly effective Always implement
\$10,000 - \$100,000	Effective Always implement
\$100,000 - \$1,000,000	Effective Implement unless risk is negligible
\$1,000,000 - \$10,000,000	Consider Effective if individual risk levels are high
\$10,000,000 - \$100,000,000	Consider At high risk levels or when there are other benefits
>\$100,000,000	Ineffective Cost grossly disproportionate

Discussion on this subject can be emotive and care must be taken to provide an explanation as to why it is necessary to venture into this seemingly sensitive area of option evaluation. However, experience is that derivation of ICAF achieves not only a ranking of improvement options but also provides a spur to the creative development of yet safer and more economic options.

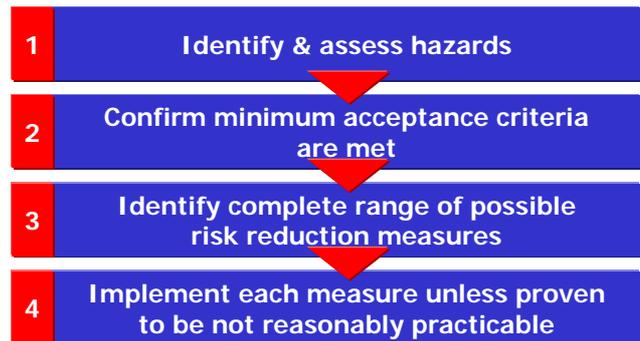
So is ALARP Demonstrated by QRA and CBA?

This is another common misconception. QRA and CBA are inexact and a high variability in results is often seen. This variability can arise from poor standards in performing the study, e.g. omitting hazards or making calculation errors, as well as genuine uncertainty in data and modelling methods. The use of numerical estimates of risk, by themselves, can be misleading and can result in decisions that either do not meet adequate levels of safety, or overestimate the real risks.

The 'formula approach' therefore should be used very cautiously and only in support of qualitative or engineering arguments. In general an approach that uses information from engineering and operational analysis, supplemented where appropriate by QRA, will lead to more robust decisions.

Demonstrating ALARP is a process rather than simply a calculation. The steps to follow are shown in Figure 9.

Figure 9 – ALARP Process



The critical step of this process is step 3, the need to identify a complete range of possible risk reduction measures. They should be based on modern good practice and be targeted at the largest risk contributors. This is best achieved through 'brainstorming' workshops to identify technically feasible improvements that may:

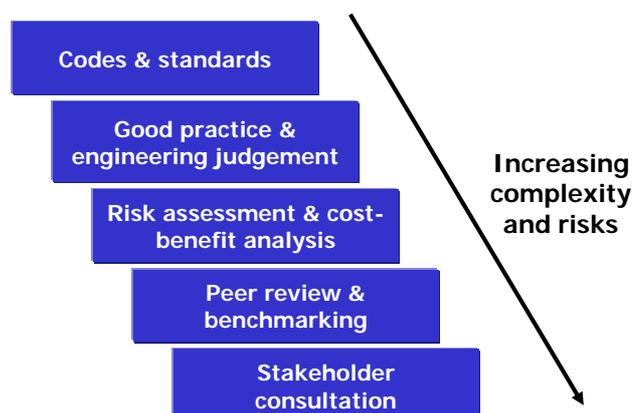
- Eliminate the hazard
- Reduce the exposure of personnel to the hazard
- Reduce the frequency of occurrence
- Mitigate the consequences if the event does occur
- Improve evacuation if control is lost

Risk levels are only ALARP once every measure identified during step 3 has either been implemented or proven to be not reasonably practicable. It is surprising how many people need reminding that risk levels will remain the same, or even increase, until real improvements are fully implemented. A formal risk assessment can generate a large number of recommendations and they need to be properly managed.

What Tools are Available to Help Demonstrate ALARP?

The tools available for demonstrating risks are reduced to levels that are ALARP are illustrated in Figure 10 (UKOOA 1999):

Figure 10 – ALARP Tools



In general, the more complex the project, the more complex the decisions and the more sophisticated the tools required. Also, the higher the risk, the more comprehensive and robust the ALARP assessment needs to be.

For example, in many common engineering situations, what is reasonably practicable may be determined simply by reference to the relevant code or current practice. The majority of decision making will usually fall into this category. The codes and standards capture the lessons from past experience and try to reflect best use of current technology and understanding.

In other cases, outside established codes and standards, the use of risk assessment and cost benefit analysis may be appropriate. A risk based approach can go some way towards addressing situations where, for example, there is high complexity, high costs, conflicting risks and uncertainty. It can provide a clearer picture of the decision implications and the pros and cons of the various decision options.

There may also be the need to take into account the views and concerns of those stakeholders affected by the decision. Their perception of the risks and benefits may be different from that analysed, affecting what they believe to be reasonably practicable as a solution. What one organisation may deem as the appropriate solution to manage the risks may be different from another organisation and in excess of that required by regulation.

Summary - ALARP Assessment

In practice ALARP decision making amounts to taking a balanced view and reaching a defensible consensus on prioritised improvements. A convincing ALARP demonstration lies in the documented consideration of improvement options, both implemented and discounted, at a level of resolution of detail appropriate to the facility life-cycle and magnitude of risk.

Current Industry Initiatives

Risk criteria are currently very topical. The Centre for Chemical Process Safety (CCPS) in the USA will, this year, develop a guideline book providing a framework for establishing quantitative safety risk tolerance criteria. The book will show how to develop criteria reflecting company-specific operating needs, while maintaining consistency with industry wide practices.

CONCLUSION

There is a high degree of commonality in individual risk criteria internationally, but societal risk criteria show a large variation. QRA is inexact and any quantitative criteria should be seen as guidelines. The risks associated with most facilities lie in the middle band of the risk tolerability framework – the ALARP zone - and require qualitative and sometimes quantitative demonstration of risk reduction to ALARP levels. In practice, this amounts to taking a balanced view and reaching a defensible consensus amongst stakeholders.

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