Examining the ALARP Principle

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ABSTRACT

The ALARP (***A***s ***L***ow ***A***s ***R***easonably ***P***racticable) principle assumes that there is a level of risk which is tolerable and requires that the risk be at least below that level. The qualifying term "reasonably practicable" determines how low risks should be pushed towards the region of negligible risks. An infinite amount of effort could reduce the risk to an infinitely low level, but an infinite amount of effort will be infinitely expensive to implement. So ALARP assumes that there is a risk level which is so low that "it is not worth the cost" to reduce it further. In essence this means that risk reduction measures should be implemented until no further risk reduction is possible without very significant capital investment or other resources expenditure that would be grossly dis-proportionate to the amount of risk reduction achieved. This paper examines the ALARP principle in the context of cost effectiveness using a case study.

1. Introduction

The UK's 1974 Health and Safety at Work Act (HSWA) requires those who conduct undertakings (generally employers) to ensure, so far as is reasonably practicable, (SFAIRP), the health, safety and welfare of their employees, of self-employed persons under their control, and of third persons (generally, the public). The HSWA system implies a dialogue between duty holders and an informed regulator. The burden of proof on the duty holder is defined by a "demonstration on balance of probabilities", rather than by "proof beyond reasonable doubt" (the condition used in the criminal law). The term "reasonable practicability" implies that cost can be taken into account in relation to risk reduction. However, SFAIRP cannot be pleaded as a defence in a failure to observe good practice, since accepted good practice is, almost by definition, always "reasonably practicable". The SFAIRP defence can only arise where good practice is unclear, or does not fully cover a given situation, or where an inspector is seeking to persuade a duty-holder to move forward from "good" to "best" practice as technology changes. The term "as low as reasonably practicable" – ALARP - is identical in meaning to SFAIRP, but is applied particularly where risk in principle can be quantified. The ALARP can only be demonstrated if the risk is properly assessed, understood and the results used to determine controls. If a risk had not been identified, assessed and controlled, it would not be deemed as being managed, even though the risk evaluation might put it in the tolerable area. Another issue associated with ALARP is the requirements of the set of all risk reduction measure must be complete before it can be claimed that the risk is ALARP.

Though improvements in management of risk are always very important; an equally important engine for continuous risk reduction is technological advance, which produces greater plant reliability together with the opportunity to provide better protection at lower cost. In all countries the aim has been to identify good practice and then standardise it, using legal or other instruments to secure conformity, and acting on the principle that new methods should at least maintain the existing risk position and if possible improve on it. In the UK, this approach is represented by the doctrine of tolerability, supported by the SFAIRP/ALARP principle. Existing good practice is taken as the minimum acceptable position, and the aim, implicit in the doctrine and in UK law is continuously to identify best practice as it emerges, and then seek to ensure that it becomes the general "good practice" of tomorrow.

Figure 1 demonstrates the decrease of risk against increasing costs of mitigation. When risks are very high, a relatively small investment generally allows reducing risks quickly whereas investments increase asymptotically when risks are reduced beyond a certain level. The graph shows the point at which an acceptable threshold of risk mitigation might be settled – stating explicitly that the costs of mitigation will realistically be too high to achieve a theoretical total abatement of risk. The blue vertical line is set in the ALARP/ALARP/BACT zone, i.e. a zone where risks are As Low as Reasonably Achievable (ALARA), As

Low as Reasonably Practical (ALARP), or obey to the Best Available Control Technology (BACT) concept. Needless to say that the definition of these risk abatement levels is not common in many industries.

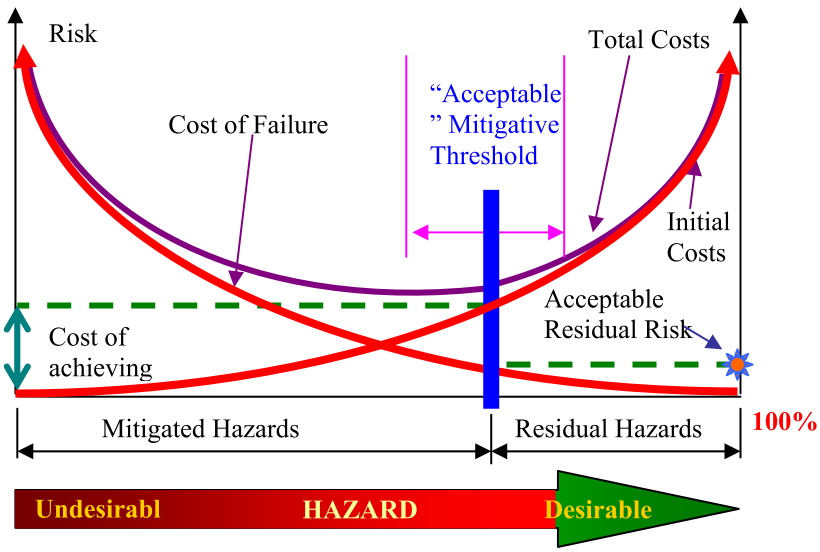

Figure1: Risk and its mitigation costs

2. Risk Based Approach

The purpose of risk management is to ensure that adequate measures are taken to protect people, the environment, and assets from harmful consequences of the activities being undertaken, while assuring the activities are economically viable and socially desirable. Risk management includes measures both to avoid the occurrence of hazards and to reduce their potential harms. Traditionally, risk management was based on a prescriptive regulating regime, in which detailed requirements were set to the design and operation of the arrangements. This regime has gradually been replaced by a more goal oriented regime, putting emphasis on what to achieve rather than how to achieve them. Risk management is an integral aspect of a goal oriented regime and it is acknowledged that risk cannot be eliminated but must be managed.

By far the codified methods are the most common approach in controlling major hazards. Such methods are based on"deemed to satisfy" solutions laid out in the general guidelines of the codes of practice. These guidelines (SOLAS, ISO, API, etc.) become mandatory if the prescriptive design method is used. They are formulated as detailed demands, and affect both the appearance and the activities performed therein by the application of certain limitations. In the prescriptive design method, fire and explosion protection is often dealt with in isolation from the other technical areas, and requiring to install of some specified passive and active measures, such as classification areas, fire fighting systems, type of equipment that can be used, strengthening and fire proofing. Generally, trade off are not allowed as each of these constitute a layer of protection (defence) and hence in their entirety satisfying the concept of defence in depth.

One compelling reason against prescriptive methods is their usefulness is based on a certain vision of how a system work and need protection, and such vision may be generally in gross error for new concept and thus could not be very effective for their costs. Structures constructed in today are of a widely varying nature, and the conditions envisioned in codes are far from generally valid. Adapting the risk reduction strategy for an individual installation makes way for more cost-effective fire protection measures, while retaining the same level of safety, compared with the application of a prescriptive design.

Risk-based design follows the well-established path of quantitative risk assessment. The following steps are needed to identify the optimal design solution (Figure 2). The common definition of risk (associated with a hazard) is a combination of the probability that hazard will occur and the (usually negative) consequences of that hazard. The following definition is used in risk analysis:

$$R = \sum_{i=1}^{n} P_{fi} \times C_{fi}$$

where:
R = risk [fatalities/year];
P_f = probability of failure per year;
C_f = consequence of the unwanted event.
Risk is therefore a summation over all possible hazards (scenarios) with their consequences.

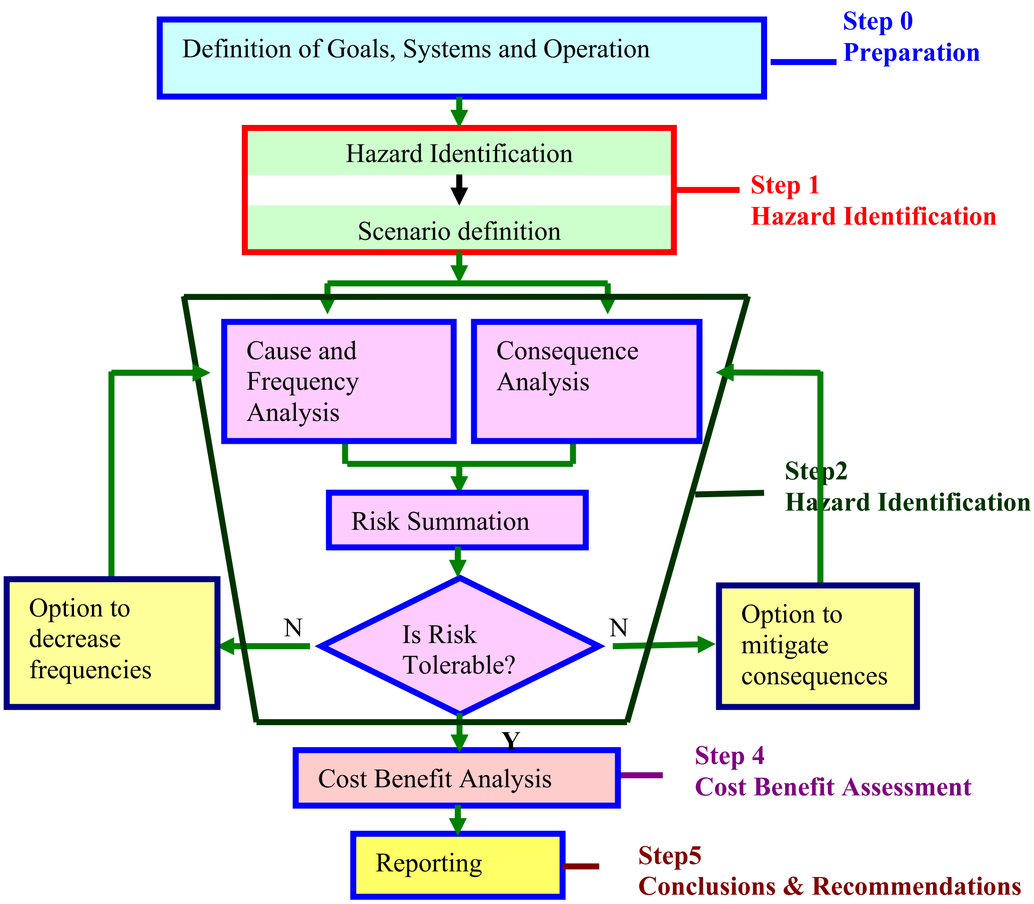

Figure2: Risk-based Safety Management

2. Accident Statistics

Accident statistics provide one of the most "hard" and reliable data sets available for scrutiny. Available statistics cover events of differing levels of severity, which include:

- Accidents, defined as events which involve injury and fatality;
- Accidents, defined as events which involve injury;
- Damage incidents, or non- fatal accidents which caused a worker to stay away for more than three days;
- Incidents, judged as such by workers as serious;
- Incidents, defined, essentially, as near-misses;

While the above are listed in descending order of severity, this severity (except the first one) is a subjective judgment. There is no universally accepted measure of the severity of these events. It may be judged that the event just experienced could very well have resulted in a fatal accident or injury but if, by chance, it did not there may be no cost, no damage and possibly even no report. An overall picture of the accident rate in an industry may be displayed by the Frequency-Consequence diagram as shown in Figure 3. The horizontal axis is the consequence, in this case in terms of fatalities, N. The vertical axis is shown the frequency of N or more fatalities per accident. Figures 3 & 4 show the facilities frequency in log-log scale. As it can be seen, there is an indication of power law (straight line).

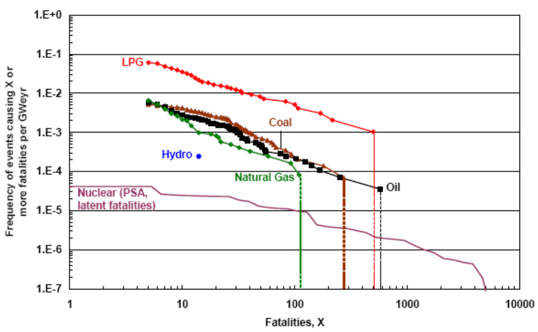

Figure 3: Comparison of frequency-consequence curves for full energy chains in OECD countries for the period 1969- 2000. The curves for coal, oil, natural gas, LPG and hydro are based on historical accidents and show immediate fatalities. For the nuclear chain, the results originate from the plant-specific Probabilistic Safety Assessment (PSA) for the Swiss nuclear power (1)

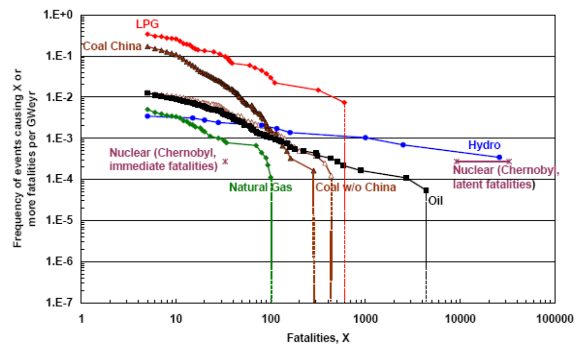

Figure 4: Comparison of frequency-consequence curves for full energy chains in non-OECD countries for the period 1969-2000. The curves for coal w/o China, coal China, oil, natural gas, LPG and Hydro are based on historical accidents and show immediate fatalities. For the nuclear chain, the immediate fatalities are represented by one point (Chernobyl); for the estimated Chernobyl-specific latent fatalities lower and upper bound are given. Dashed vertical lines represent maximum numbers of fatalities in fossil energy chains (1)

3. Power Law and F-N curve

The power law Distribution for a random variable X is defined as:

$$\Pr(X \geq x) = \left(\frac{k}{x}\right)^{\alpha} \qquad (1)$$

Where x is a value in the range defined for X, $k > 0$ is the <u>location parameter</u> and $\alpha > 0$ is the <u>slope parameter.</u>

For instance, if X is a random variable representing accidents, and that this variable follows a power law distribution with parameters $k = 0.1(\text{fatality})$ and $\alpha = 2$. Then the probability of having more than one fatality is 1/100, probability of having 10 or more fatality is1/10000 and probability of having 100 fatality is 1/1000000.

The Probability Density Function (PDF) may be easily obtained through derivation of Equation 1 to be

$$f(x) = \alpha k^{\alpha} x^{-\alpha-1} \qquad (2)$$

The above has infinite mean for $\alpha \leq 1$ and infinite variance for $\alpha \leq 2$ (these are not rare values for α in real-world scenarios. For instance, α was found to be approximately 2.1 for earthquake).

When X is discrete the distribution is inverse polynomial,

$$\Pr(X = x) = C\left(\frac{1}{x^{\alpha+1}}\right) \qquad (3)$$

and therefore:

$$\ln(\Pr(X = x)) = (-\alpha - 1)\ln x + \ln C \qquad (4)$$

Equation 4 is useful for visualizing the PDF and for determining α using linear regression of the sampled data.

Power law distributions are also called *scale free distributions* since they are invariant to scale. For example, if k is arbitrary and $\alpha = 2$ then as before, 1/100 events leads to than one fatality, 1/10000 event would lead to more than 10 fatalities and 1/1000000 of events would cause more than 100 fatalities, regardless of scale. Only power law distributions have this property.

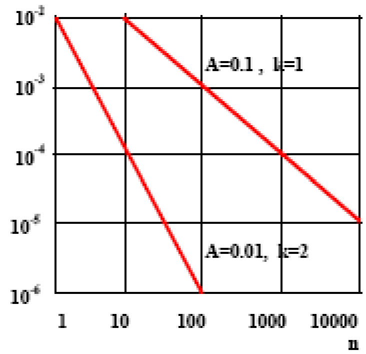

Figure 5: $F(n) = P(N_d \geq n) < An^{-k}$ requirement for one year (from ISO 2304).

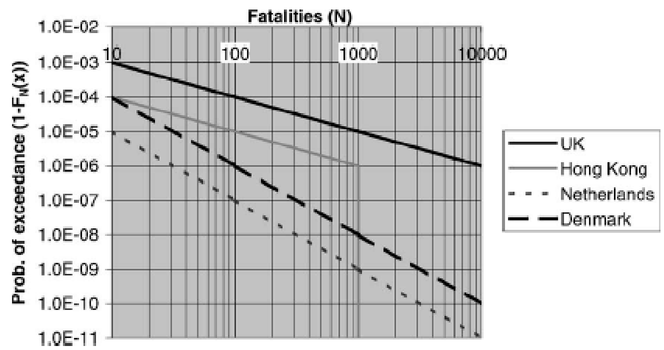

Fig. 6. Some international standards in FN format

The societal risk to human life is often expressed as power law (see for instance ISO 2394).

$$F(n) = P(N_d \geq n) < An^{-k} \qquad (5)$$

Here N_d is the number of fatality in a year in one accident. The value of A may range from 0.001 /year to 1/year and the value of k from 1 to 2. A is the tolerable risk for one fatality, $n = 1$. Two examples of $F - n$ curves are shown in Figure 1.

Curves with a slope of $k = 1$ are called risk neutral. If the steepness $k = 2$, the standard is called risk averse. In this case larger accidents are weighted more heavily and are thus only accepted with a relatively lower probability. Figure6 shows some national standards. Note that curve for Hong Kong and UK has a slope of 1 while Denmark and Netherland chose a curve with slope of 2.

In F-N, F_N is the frequency of N or more fatalities while f_N is the frequency of exactly N fatalities. Equation (5) is re-written as:

$$F_N = F_1 N^b \qquad (6)$$

4. Construction of societal risk criteria on F-N curves

Societal risk criteria were introduced as a measure of how much risk society, rather than the individual can tolerate, as a result of a specific activity. For example, an individual risk of 10^{-4} for a population of 10 will result in one death in the next thousand years. The same risk for a population of one million will result in 100 fatalities during the next year. Is society willing to accept such a death toll? What if those 100 fatalities were caused due to one single event? Would that make any difference in society's decision? This is the kind of questions that societal criteria try to answer.

Societal risk criteria are closely associated with F-N curves. Such curves plot the cumulative frequency of N or more fatalities against the number of fatalities, N, in a log-log diagram. The criterion lines are applied as straight lines on the log-log plot. There is an upper and a lower bound. Between the two, the ALARP principle applies. Risks above the upper bound are considered intolerable and should be reduced at all costs. Risks below the lower bound are considered very small for any risk Reduction Measures to be applied. Inside the ALARP area risks are reduced to the extent that it is practically possible. What is practically possible is currently determined through cost-benefit analysis.

Literature offers basically two ways of drawing the upper bound line. Both consist of determining one point and then drawing the line that passes from this point with a slope that has been pre-decided. In both cases the limit line is of the form of Equation (6). One approach makes use of the so called 'anchor- points'. Those are points on the *F-N* curves that represent experts' judgments on what risks can be tolerated by society and often reflect the amount of risk that has been tolerated in various circumstances. There have been used quite a few anchor points over the years, such as the Canvey point and the ACMH point. One of the most recent and important *anchor points* is the R2P2 *criterion* that states that '*accidents resulting in 50 or more fatalities should happen no more often than once in 5000 years*' [2]. On an *F-N* diagram this translates to the point (50, 1/5000).

The second method relies on mathematical formulation in order to calculate the upper bound of acceptance for fatal accidents for a specific activity, hence the definition of F_1. Vrijling [9] proposed an upper bound F_1 as,

$$F_1 = \left[\frac{\beta_i \times 100}{k \times N_A} \right]^2 \qquad (4)$$

where, $\beta_i \in (0.01, 100)$ is an indicator of the degree to which the individual takes part in an activity voluntarily. Activities with a big degree of voluntariness such as mountaineering suggest large β_i. Hence activities with little or no voluntariness suggest respectively smaller β_i; k is an index of the law- makers risk aversion (the proposed value is 3); N_A is the number of independent installations

5. Cost of Averting Fatality (ICAF)

Allowing some level of risk to persist in return for economic benefits implies putting a finite value on human life (or at least health) and some consider this to be inappropriate because a human life is invaluable. Indeed, these processes sometimes do implicitly put a finite, if un-stated, value on human life, environmental and cultural losses (12). The ALARP principle is under increased pressure as it requires all costs and benefits to be expressed in monetary terms. In the context of a market economy it makes safety from a vague ethical concept, into a good with a price worth paying. In practice the majority of risks fall in the ALARP region, in which case they should be managed so that they are *as low as reasonably practicable*. The cost benefit analysis focuses on the market price, but prices are influenced by the geographical region of the world, even in a single country.

The cost, or investment made to save an expected extra life (the investment divided by the decrease in expected number of fatality due to the operation) is known as Cost of Statistical Life saved, or CSL. This is also known as the implied cost of averting one fatality (ICAF). The ICAF value seems to be able to serve as a valuation of human life, as it indicates the willingness to pay for the saving of a life. The problem with this approach is that the resulting ICAF values differ widely across the globe. ICAF is not a value placed on a human life and neither is the amount of compensation for an accidental loss of life paid by insurance or as the result of legal proceedings. Rather, ICAF is the cost of achieving an increment of life safety risk reduction. For example, the ICAF for reducing the risk to an individual by 1 in 10 000 per year at an annualised cost of \$1 000 per year is \$10M = \$1000/ (1/10 000).

Some researchers suggested that an objective method is using the present value of the Net National Product (NNP) per capita of the country of operation (Net National Product = Gross National Product (GNP) minus depreciation). For the UK the NNP per head equals approximately \$ 27,000 per year. Thus, the value of a human life, being the present value of this amount over an average lifetime of, say, 75 years, is estimated in the range from \$ 750,000 to \$ 1,500,000, depending on the real rate of interest - this is similar to what is used in the UK for ICAF. The consequence of this approach is that the value of human life in a developing country is considerably lower.

To put a monetary value to human life, there are two main methods in use: the human capital method and the willingness-to-pay method. In the human capital approach, the major component of the cost of a fatality or injury is the lost economic output of the victim. The principle objection to this approach, is that most people do not value their life for its contribution to economic output, but rather because it has intrinsic value to them and to their relatives. In that case, the value of safety, or of reductions in risk to life, should be taken to be the amount that people are willing to pay for it, i.e. the willingness-today approach.

Recently an important concept, which helps to quantify the necessary investments into safety, i.e. the investments to save human life's (Nathwani,9), has found increased interest. The concept is based on a social indicator that reflects the quality of life in a society or group of individuals in terms of an individuals contribution to GNP, life expectancy, time for enjoyment of life, etc., such as the Human Development Index or **Life Quality Index** L, (10). The Life Quality Index L is a compound societal indicator, which is defined as a monotonously increasing function of two aggregated societal indicators, namely the gross domestic product per person per year, *g*, and the life expectancy at birth, *e*,

$$L = g^{w} e^{1-w} \tag{1}$$

The exponent w is the proportion of life spent in economic activity. In developed countries is assumed that $w = 1/8$. The Life Quality Index Criterion for acceptable risk implies that an option is preferred or accepted as long as the change in the Life Quality Index owing to the implementation of the option is positive. As an example, consider the safety of a railway tunnel and the marginal cost of improving this safety by the implementation of a particular measure (such as a service tunnel). The improved safety by implementation of this measure is expressed through a positive change, Δe, in the life expectancy, *e*. The cost of implementing the measure is expressed through a change, Δg, in the gross domestic product, *g*. The Life Quality Index Criterion implies that the measure is implemented when

$$\frac{\Delta e}{e} > -\frac{\Delta g}{g} \times \frac{w}{1-w} \tag{2}$$

which comes about by differentiation of the expression that defines the Life Quality Index L and requiring $\Delta L > 0$. Optimality is achieved when the inequality of the Life Quality Index Criterion is turned into an equality, as then the implementation of the considered option implies that status quo is just maintained by the fact that if a less cost-effective safety measure is implemented than the optimum, then the implementation would lead to reduction of the Life Quality Index. Implementation of a safety measure has several consequences, including one or more averted fatalities, which imply a number of life years saved, i.e., an increased life expectancy Δe. It also implies a cost owing to the investment in the safety measure. This cost is expressed as a change Δg in the gross domestic product. Consider now the prevention of one fatality. Under the assumption that the remaining life of an arbitrary individual in a population at a given point in time on average equals half the life expectancy *e* at birth, the number of years saved by averting one fatality is given by $\Delta e = e/2$. According to the Life Quality Index Criterion, the upper limiting value on the reduction in the gross domestic product then becomes

$$\left|\Delta g\right|_{\max} = \frac{g}{e} \times \frac{w}{1-w} \Delta e = \frac{g}{2} \frac{w}{1-w} \tag{3}$$

With reference to the definition of g as the annual gross domestic product per person, this can be interpreted as the optimum acceptable cost per life year saved, and the optimum acceptable implied cost of averting a fatality, ICAF, can then be calculated as

$$ICAF = \left|\Delta g\right|_{\max} \cdot \Delta e = \frac{ge}{4} \frac{w}{1-w} \tag{4}$$

Table 2 shows gross domestic products *g* and life expectancies *e* together with derived optimum acceptable implied costs of averting a fatality ICAF for a few developed countries in 1998 for *w*=0.125. As a consequence hereof the acceptable risk associated with a long railway tunnel project depends on the specific characteristics of the project. Major safety measures such as service tunnel, rescue stations etc. can be selected on the basis of the ICAF criterion.

Country	GDP ($/capita)	Life Exp. at Birth (years)	ICAF ($M/year)
UK	27,700	78.27	3.794
USA	37,800	77.43	5.122
Germany	27,600	78.54	3.793
Norway	37,700	79.25	5.229
China	5,000	71.96	0.630
Japan	28,000	81.04	3.971
Luxemburg	55,100	78.58	7.577
Tanzania	600	44.39	0.047
World	8,200	64.05	0.919

Table 2 GDP, Life Expectancy and ICAF (CIA Fact book 2003- estimated)

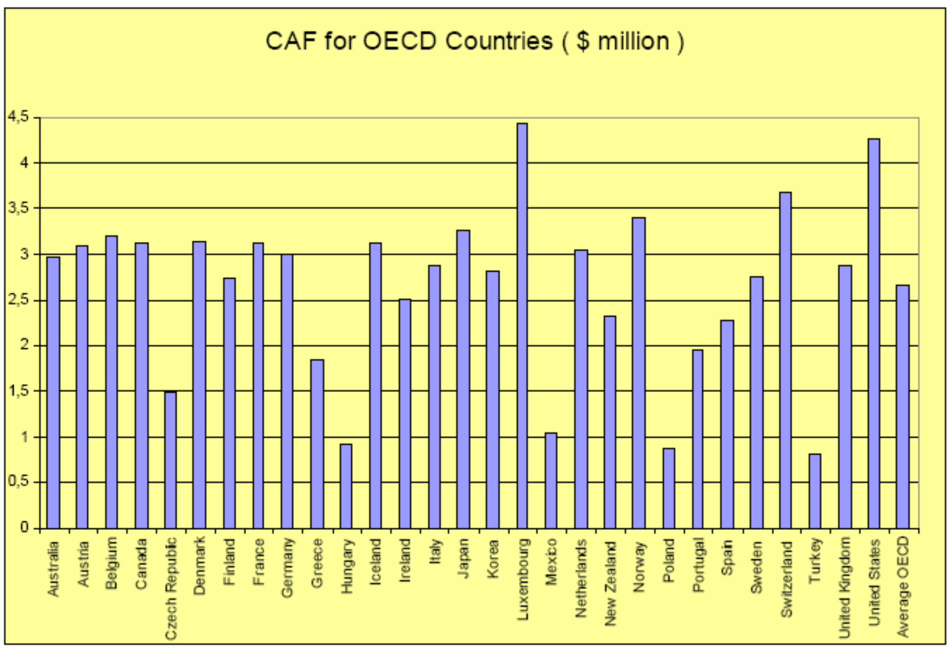

Figure 3: Comparison of values of implied cost of averting a fatality between the years 1984 and 1994 and between various countries (8).

The Life Quality Index Criterion for acceptable risk implies that an option is preferred or accepted as long as the change in the Life Quality Index owing to the implementation of the option is positive. The Life Quality Index contains such indicators as GDP/capita and life expectancy at birth. As a risk control option change these two, an optimum acceptable NCAF by be derived, and as GDP and life expectancy varies between countries there are variations in the evaluation criteria. Within OECD member countries with sustained memberships (representing some 95% of the global GDP), the variation is not very large, see Figure 3.

It has to be noticed that the CAF acceptance criterion of $3m can be used according to Figure 3 which is based on the average value for years 1984-1994. In Fig. 3 the average ICAF (for all OECD countries) for the above mentioned period is at about $2.7M.

Based on the above, a NCAF criterion of \$3M or £2M may be proposed for use for international regulations, in cases where fatalities in addition to representing fatality risk also represent an indicator of risk of injuries and ill health. The NCAF criterion is updated every year according to the average risk free rate of return (some 5%).

6. Cost-Benefit Analysis Method

Since CBA determines a monetary equivalent of each benefit and dis-benefit in a decision problem it is also capable of making comparisons of these benefits through time. The mechanism of discounting with a yearly discount rate to take into account the notional loss (or gain) of interest accrued through time enables the analyst to determine the net present value (NPV) of each benefit and dis-benefit. The preferences of the decision maker -in this case, society- are determined substantially by the choice of discount rate. Discount rates have the property of reducing large future differences to almost negligible present value differences. For long periods, the discounting rules of CBA give outcomes that often seem unreasonable, and in contradiction with other legal requirements. It should be noted also that actual discount rates are non-constant and highly uncertain.

Although most safety risk treatments reflect the implementation of good practice or contemporary technology, there are often numerous options available for controlling a particular risk. For example, a state of the gas detection system may represent both good practice and current technology. There are always numerous risk reduction measurers with varying degree of effectiveness in reducing risk and their cost In other words, the costs of some option may be grossly disproportionate to the benefits.

Benefits (in monetary terms) and costs at various times during the economic lifetime of an installation are not directly comparable. One method of comparing investments where payments are made at different times is the net present value method. The net present value method is based on the assumption that there is a yield requirement on the capital. If the capital is not tied up in the installation from the beginning, it can be used for other investments. This transformation is done with the aid of an interest rate calculated for costing purposes. The *real rate of interest* for calculating purposes reflects the yield requirement, and also takes inflation into account, see Equation(1). This is a variable that determines how advantageous it is to postpone payments to a later date.

$$r = \left(\frac{1 + r_c}{1 + r_{\inf}} \right) - 1 \qquad (1)$$

r =real or effective interest rate

r_c = Interest rate for costing

$r_{\inf}$ =Rate of inflation

Despite the fact that a relationship can be defined between the two rates of interest, it is difficult to find a rate of interest suitable for use in investment calculations, as both the future interest rate calculated for costing purposes and inflation are uncertain. In cost-benefit analyses performed, a real interest rate calculated for costing purposes of 5 to 7% are used. In the UK a value of 6% is adopted for r_c and $r_{\inf}$ is assume to be 4%.

7. Dis-proportionality factor

The consideration of costs relative to benefits requires a value judgement to be made. Case law indicates that duty holders should err in favour of making the expenditure on risk controls. The decision to not act should only be made where the likelihood of injury is remote or the cost is so disproportionate to the potential benefit that it would clearly be unreasonable to require the expenditure. It is not required every possible measure to be implemented to eliminate or reduce risk, but it places the onus on the person holding the duty to demonstrate (or be in a position to demonstrate) that the cost of additional measures to control the risk (over and above those risk controls already in place) would be grossly disproportionate to the benefit of the risk reduction associated with the implementation of the additional risk control.

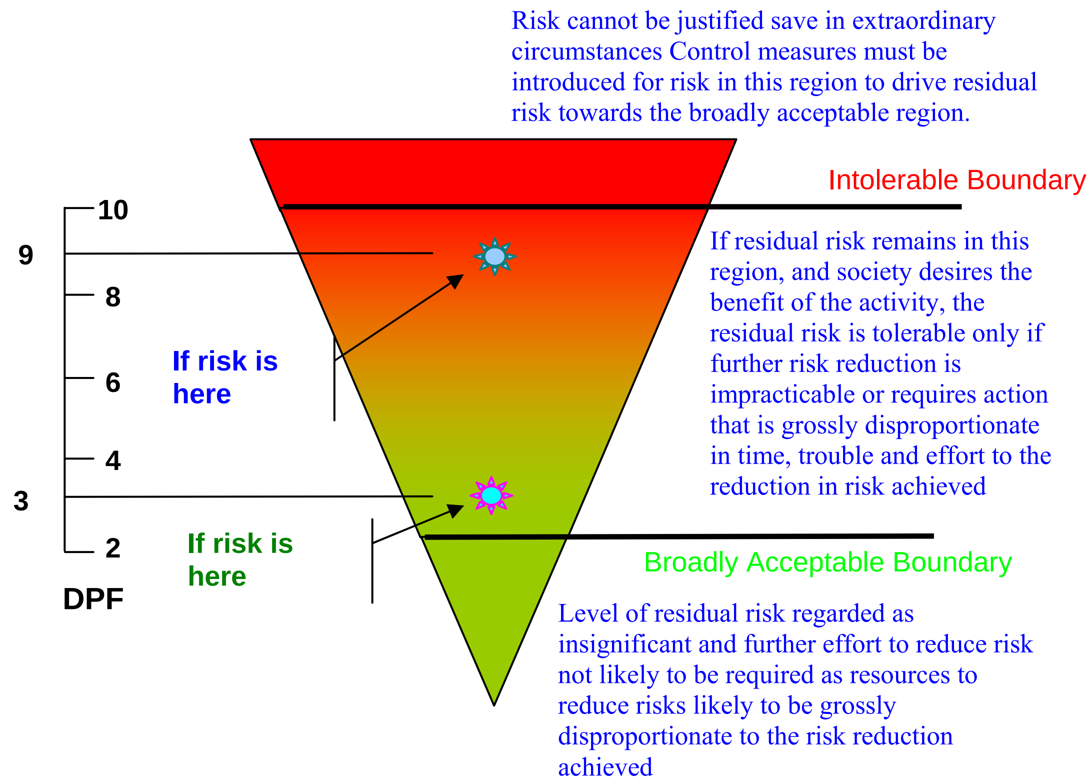

Figure 3: Dis-proportionality factor

Example1

Consider a hypothetical case where Five Risk Reduction Measure (RRM) were identified (Table 3) and the risk assessment performed assuming each one is in place (Figure 4).

RRM1 will reduce risk to below tolerable level for 10 fatalities. However, the combined RRM2 to RRM5 (assuming no overlap) would not reduce risk below the tolerable level. Generally there are overlaps between measures.

	PLL	ΔPLL	Cost	ICAF($M)
Base Case	2.76E-02			
RRM 1	2.60E-03	2.50E-02	300000	12
RRM 2	1.76E-02	1.00E-02	30000	3
RRM 3	2.56E-02	2.00E-03	7200	3.6
RRM 4	2.56E-02	2.00E-03	8400	4.2
RRM 5	2.66E-02	1.00E-03	80000	80

Table 3: Five risk reduction measures of example 1.

Now consider that RRM1 is implemented and it is required to demonstrate that risk is ALARP. Another round of QRA yields the **ΔPLL** for RRM2 to RRM4 (assuming each is implemented at a time). There is no point to pursue RRM5, as the ICAF for this is already 80. The following Table gives the results for the second round.

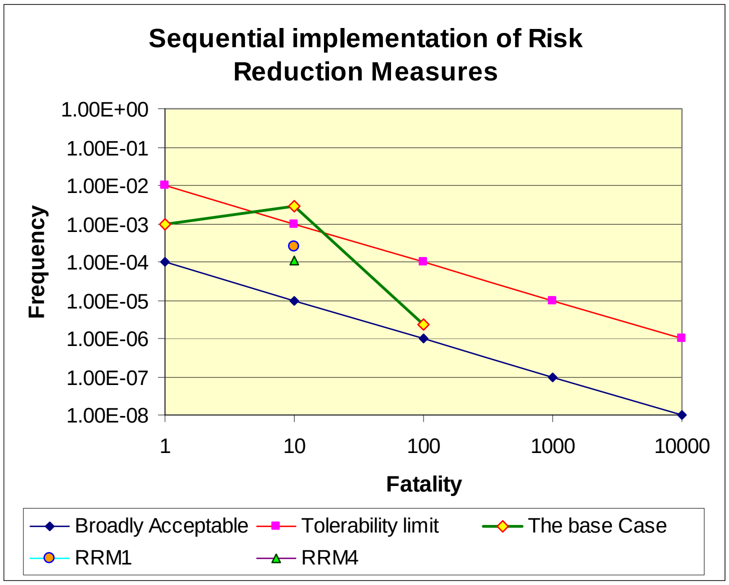

Figure 4: F-N diagram for Example 1.

	PLL	ΔPLL	Cost	ICAF($M)
New base case	2.60E-03			
RRM 2	1.10E-03	1.50E-03	30000	20.0
RRM 3	1.29E-03	1.31E-03	7200	5.5
RRM 4	1.07E-03	1.53E-03	8400	5.5

Table 4: Risk analysis results for Example 1 after implementing RRM1

Both RRM3 and RRM4 give ICAF equal to 5.5, but RRM4 reduces risk more than RRM3 and hence it will be chosen for implementation.

RRM2 should be dropped as its ICAF will increase. The only remaining option is RRM3. The following Table shows the effect of its implementation (after RRM1 and RRM4 are implemented).

It can be seen that implementation of RRM1 and RRM4 has reduced the effectiveness of RRM3 to the extent that the ICAF is 60. It is concluded that the risk is ALARP for this design.

	PLL	ΔPLL	Cost	ICAF($M)
New base case	1.07E-03			
RRM 3	9.53E-04	1.20E-04	7200	60.0

Table 5: ICAF for RRM3 of Example 1

8. Case Study

An existing production platform which is bridge linked to another platform is undergoing major modification for addition of new equipments. This platform will act as a hub for new developments which will be tied back to it. Consequently more potential leak sources will be added which could lead to enhanced risk of fire and explosion and hence requires risk reduction measures to mitigate risks.

The relevant regulations set a maximum limit on the frequency of annual impairment either for Temporary Refuge (and means of escape) or individually for each type of hazard. The aim is to make rescue possible in the case of extreme event. In general, existing platforms undergoing refurbishment triggers re-certification but it is not generally required to comply with the current regulations. The ALARP approach to risk is a very useful tool to generate all possible options and determine their effectiveness. The ALARP principle, with its flexibility, can assure that all risk reduction measures are indentified and would be implemented so far they are reasonably tractable.

8.2 Basic Assumptions and data

This ALARP evaluation only addresses this aspect of adding new equipment and ancillary piping. The platform has been in operation since 1992 and no major incident reported since then. The following assumptions are made

- Interest rate 6% (inflation adjusted)
- Remaining service life 30 yeas
- Persons on Board (POB) 45
- 100,000 bbl
- Cost of averting one fatality is $2M and increases by 4% annually
- Taxes and insurance not considered

The intention of risk assessment is to identify all risks and ways of dealing with them and finally to determine the residual risks. Dealing with risk requires addressing the following questions:

- Have all authority's requirements been satisfied?
- Have all company's requirements been satisfied?
- Are all project requirements met?
- Are risks comparable with other company's installations worldwide or in the region?
- Are all current good practices met?
- Is the concept robust and has adequate redundancies?
- Are recommendations of current codes and standard satisfied?
- Have the principals of sound engineering judgment been followed?
- Is the chosen solution inherently safe?
- Have the Best Available technologies been used?
- Has cost-benefit analysis proved that the "best" solution has been adopted?
- Is there a programme for continuous improvement in place?
- Is there a credible plan to deal with emergencies?

	Base case		After Implementation of Option 2	
Fatality, N and more	f- Likelihood (Base Case)	F- Likelihood of N, or more, fatality (Base case)	Likelihood N fatalities (after implementation of Option 2)	N- Likelihood of N, or more, fatalities (after implementation of Option2)
1	1.25E-03	2.83E-03	1.25E-03	2.05E-03
3	2.45E-04	1.58E-03	2.45E-04	7.98E-04
4	1.95E-04	1.34E-03	1.95E-04	5.53E-04
6	1.20E-04	1.14E-03	1.20E-04	3.58E-04
8	7.50E-05	1.02E-03	7.50E-05	2.38E-04
10	8.50E-04	9.48E-04	6.50E-05	1.63E-04
12	6.00E-05	9.78E-05	6.00E-05	9.78E-05
18	2.50E-05	3.78E-05	2.50E-05	3.78E-05
24	4.00E-06	1.28E-05	4.00E-06	1.28E-05
27	3.50E-06	8.75E-06	3.50E-06	8.75E-06
30	2.00E-06	5.25E-06	2.00E-06	5.25E-06
34	1.50E-06	3.25E-06	1.50E-06	3.25E-06
38	1.00E-06	1.75E-06	1.00E-06	1.75E-06
45	7.50E-07	7.50E-07	7.50E-07	7.50E-07

Table 6: Results of quantitative risk assessment of the case study installation

The first two columns of Table 6 gives the results of QRA organised in ascending order of fatalities. The third column gives the likelihood of N and or more fatalities. A plot of first column against the third column (the F-N curve) is given in Figure 5 using log-log scale (shown as dots). Lines of broadly acceptable and tolerability limit are also shown on this figure.

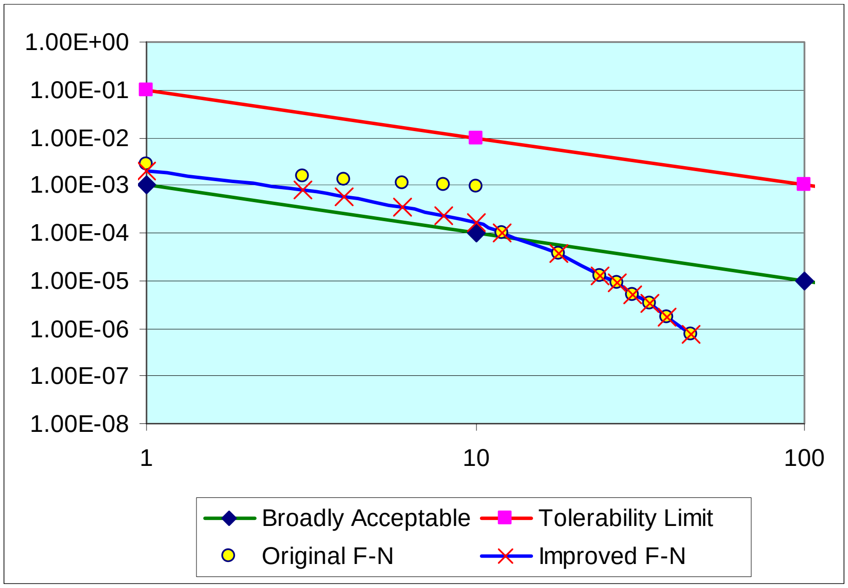

Figure 5: F-N diagram of the case study. The base case is shown as dots.

It can be seen that F-N for this installation falls within the ALARP region. Adding new equipment would aggravate the problem, but the new F-N curve (not shown on Figure 5) still remains in ALARP zone. The question is to show that risks are ALARP. We decide to use the existing condition as the base case, which gives a slightly higher estimate of ΔPPL compared with using the situation where new leak sources are introduced as the base case.

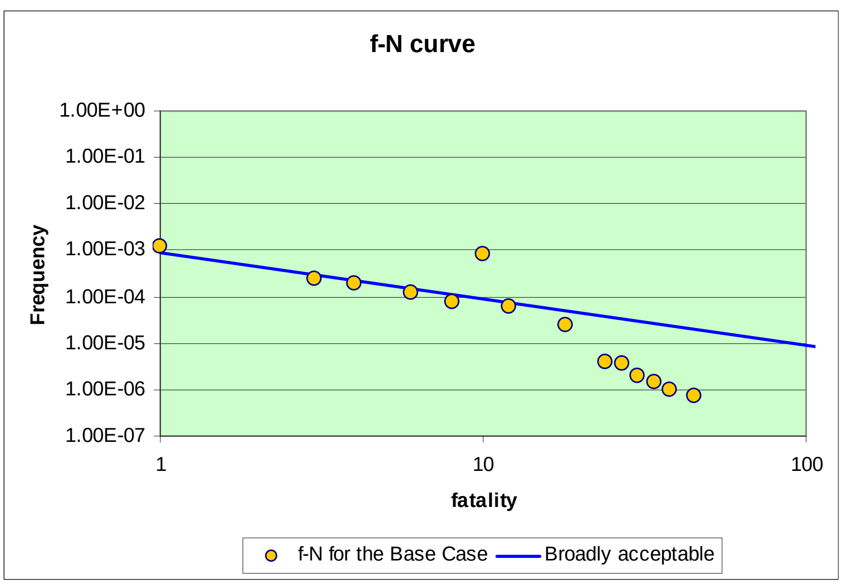

Figure 6: f-N diagram for the base case

Inspection of Figure 5 shows that having 10 and more fatality is closer to the tolerability limit compared with other points. This situation can be seen more clearly using f-N curve as shown in Figure 6. Further investigation reveals that this anomaly is due to 10 workers becomes causalities as a result of unavailability of the escape route due to heat and smoke.

The HAZID process indentified that the availability escape routes is a major contributor to risk as they may be impaired in several ways; e.g. severe structural distortion due to explosion would make them inaccessible, or extreme heat and/or dense poisonous smoke render them unusable. It is also possible that fire to cut off access to or from TR. Figures 7 and 8 put this higher than usual contribution to the accident in their proper context. These figures show that the main sources of risks are on the lower deck. The contribution of fatalities during escape, evaluation and rescue (EER) is quite high and it is dominated from the unavailability of escape route.

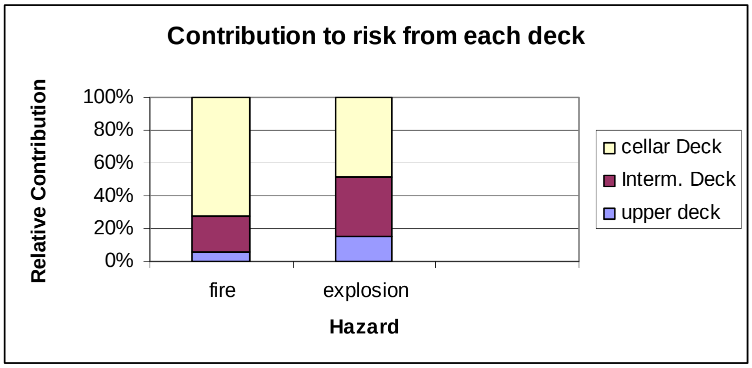

Figure 7: Fire and explosion contributions to risk

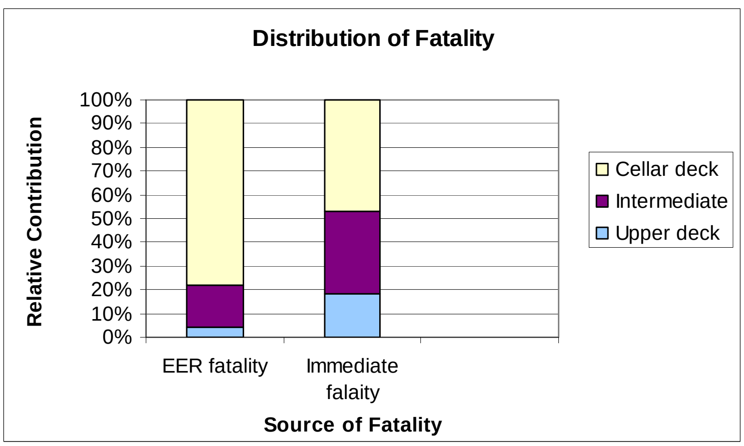

Figure 8: Immediate and EER fatalities distribution

A number of risk reducing measures were identified, and the following RRM showed the most promise.

- Reduction of leak sources by replacing bolted flanges with welded ones
- Opening of the Cellar deck area- only limited opportunity exists
- Protective cladding of the escape routes
- Addition of free fall lifeboat
- Change the blow down and deluge policy
- Change the rescue and evacuation policy, e.g. create additional escape route and TR.

All attempts should be made to identify possible technical and/or operational improvements of the installation that may contribute to risk reduction without substantial capital or operational costs, or other operational drawbacks while improves operation or maintenance, so that any increase in capital costs is offset by savings in operational costs.

When all measures that may fulfil the above criteria have been exhausted, the following assessments should be made for these alternatives:

- Overall expected net present value of all costs and income per statistical fatality averted;
- Cost distribution (material damage and delayed/deferred production income) for relevant years, given the occurrence of a major accident, with respect to scenarios which are influenced by the measures being considered;
- Overall expected net present value of all costs and income per statistically expected reduced clean up costs,
- Cost distribution (clean up costs, compensation claims, *etc.*) for relevant years, given the occurrence of a major accident, with respect to scenarios which are influenced by the measures being considered;
- Loss of reputation given the occurrence of a major accident or major oil spill, with respect to scenarios that are influenced by the measures being considered.

The values that are computed above may be compared to reference values, if stated, for:

- Cost per statistical fatality averted;
- Cost per statistically expected 1000 tons of reduced oil spill;
- Maximum loss that the company is able to survive in one single year.

Finally, it should be considered if higher limits may be accepted under special circumstances:

- Higher costs per averted statistical life lost, if the initial risk level is high
- Higher costs per statistically expected 1000 tons of oil spill, if the initial environmental risk is high
- Higher costs per statistically expected 1000 tons of oil spill, if the areas that may be exposed to spills are particularly sensitive.

The present ALARP evaluation is limited to protection of escape ways in case of fire, and is thus limited to personnel safety. Environmental risk is therefore not addressed at all.

8.3 Reduction of leak sources

This would require removing the majority of flanged connections in the process area and replacing them with welded connections. This would be particularly important in the crude oil export pumping area, which is the main source of fire risk with effect on the escape ways.

Removal of leak sources is in accordance with good practice, as well as codes and standards. But an evaluation of this proposal will focus on the side effects due to the fact that this will involve very extensive modification of the process systems. There will be a lot of hot work in the process area, not all of which will be conducted in a shut down and depressurised condition. It is therefore considered that the increase of risk during modifications is substantial, and will probably be considerably higher than the risk reduction per year.

It is further noted that a reduction of the impairment risk by 95% is needed in order to come below the limit of 10^{-4} per year; this means that leak frequencies will also need to be reduced by 95%. It is further noted that export pumps are important as leak sources, and that the relevant leak scenarios are almost impossible to eliminate.

The conclusion from the engineering judgement of this proposal is that it is unlikely to provide the necessary risk reduction and will increase risk substantially during implementation of modifications. This proposal is therefore not recommended for further consideration.

8.3.1 Relief Panels in the Cellar Deck Area Plus application of deluge on high gas detection

The platform is in a cold region and openings would unfavourably aggravate the working environment. It is also possible to add blast relief panels which reduce the blast severity. Although this is in accordance with good practice, the effect on fire likelihood is marginal. Activating deluge system immediately after gas detection inevitably would lead to some unnecessary use with consequent clean up and shutdown of production.

8.3.2 Protective cladding of the escape routes and Improvement of blow-down system

Installation of protective shielding on existing escape route which can withstand blast overpressure would prevent smoke ingress into the enclosed escape routes. This option certainly fulfils relevant requirements: shielding and overpressure protection of exposed escape ways is a common solution. The protective shielding may be a good solution to high heat loads, but it needs to be combined with overpressure protection in order to ensure that the escape route are not rendered unusable due to smoke ingress.

The effect on risk results has been calculated, and the results are as shown in Table B.2. It is shown by the results that a substantial reduction in the frequency of impairment of escape ways is due to this improvement, and also a clear reduction in PLL.

8.3.3 Addition of free fall lifeboat

Installation of freefall lifeboats (two boats for redundancy purposes) may reduce the need to use escape ways in case of fire. This is not usually a preferred solution, but may act as a compensatory measure if no other solution can be found. Obviously, the protection of escape ways is unchanged, but the need for escape to the shelter area will be formalistically reduced. On the other hand, this is more a formal solution than a practical, operational one. For escape purposes, escape over bridges to a shelter area on a separate installation is distinctly preferable to using lifeboats, including freefall lifeboats.

8.3.4 Addition another escape route

Provision of an additional escape route with sufficient shielding is the ultimate solution. This is the best solution for a new installation, but may not be practical to alter an existing installation. Another advantage of the additional escape route is building redundancy into the design, as it would be unlikely for both escape routes to be impaired at the same time, especially when one of these is thoroughly protected.

The effect on risk has been calculated, and the results are as presented in Table B.3. It is shown by the results that a substantial reduction of the frequency of impairment of escape ways is due to this improvement, and also a substantial reduction in PLL value.

The Gross Dis-proportionality factor for level of risk for 10 and more casualty at the calculated risk level is about 5.9 (Figure XX) and hence ratio of cost to benefit should be les than this to be cost effective. Table 2 shows that only Option 3 comes close to this requirement i.e. 6.86 which is just outside what is considered to be cost effective. As the choice is not clear cut one needs to examine parameters uncertainties.

Options	Description	Likelihood of being a fatality for the group ten	Initial Cost ($M)	Maintenance & Running /Year	PLL
Base Case		9.50E-04			9.50E-03
Option1	Do nothing	9.95E-04			9.95E-03
Option2	Add Relief panels & Activation of Deluge system	7.93E-04	$ 1.385	0.0045	7.93E-03
Option3	Protection around escape routs & Blow-down	3.90E-05	$ 1.835	0.0035	3.90E-04
Option4	Additional escape route	9.45E-06	$14.750	0.004	9.45E-05

Table 7: Incremental reduction of fatalities if an option is implemented

If the number of people at risk is 12 rather than 10 (20% error) the cost benefit ration drops down to 5.7. The same statement is true if the cost of averting one fatality goes up by 20% or the cost of implementing RRM reduces by 20%. One also should examine rules used in QRA to determine the likelihood and consequence. It is seen that the margin for rejecting Option 3 is very narrow and accounting for usual uncertainties will make this option acceptable. Accounting for parameter uncertainties for other option would not make them cost effective.

Options	ΔPLL	PV of cost ($M)	PV benefit ($M)	CB ratio
Base Case	0	0		
Option1	0	0		
Option2	1.57E-03	1.45E+00	4.75E-02	30.57
Option3	9.11E-03	1.89E+00	2.76E-01	6.86
Option4	9.41E-03	1.48E+01	2.85E-01	52.01

Table 8: Cost benefit analysis all options

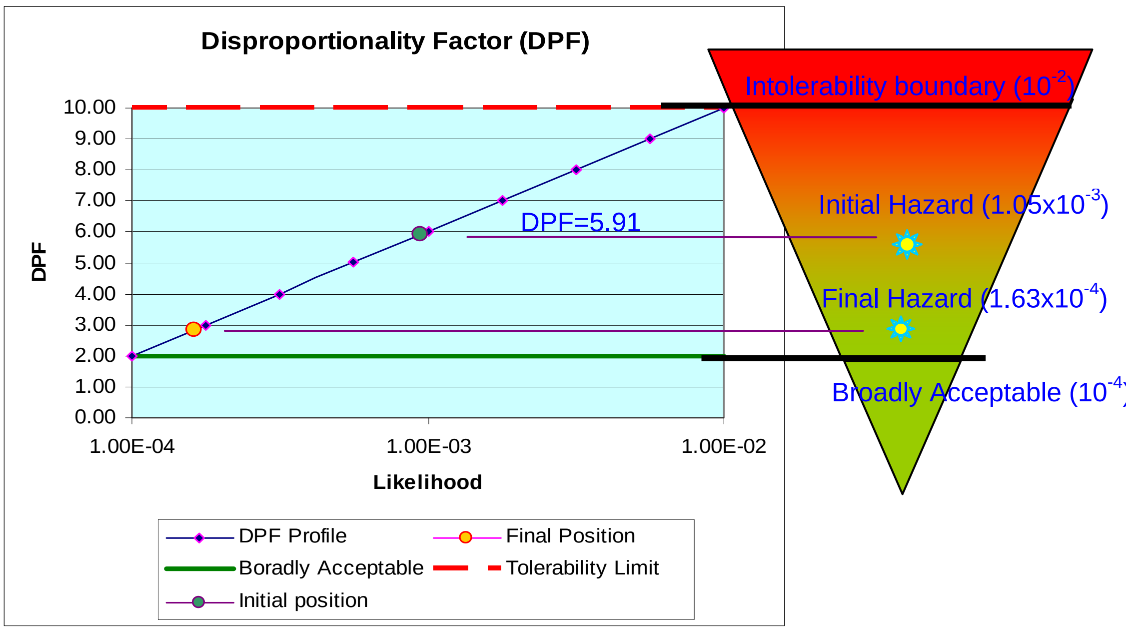

Figure 8: Determining the Dis-proportionality Factor (DPF)

Implementing this RRM would reduce the likelihood of 10 fatalities to 1.63E-03. The last two columns of Table 6 show the likelihood having N fatality and N and more fatalities, which is shown on Figure 5 as the solid line. It can be seen that the new F-N curve is no much closer to the broadly acceptable curve that other solutions indentified become even costlier than given in Table 7 and hence too costly for the benefit they provide. Options listed in Table 8 would not be cost effective.

10. Discussion and Conclusions

In order to demonstrate that a risk is ALARP, it is necessary to demonstrate that all credible risk reduction methods are impracticable. To do this, it is clearly necessary to first identify all credible risk reduction methods. Hence, the identification of risk reduction methods is considered a group activity (analogous to HAZOPS). The second significant problem is that applying the ALARP principle fully and accurately can be expensive (this is just to determine the ALARP status of risks, not to actually reduce risks, e.g. by system redesign). This is because accurately determining the cost and benefit of risk reduction can be difficult and time-consuming. To counteract this, the process is designed in two stages. The first stage is intended to be a relatively inexpensive and quick assessment, designed to identify risks that can quickly and clearly be shown to be ALARP. Those risks that can not quickly be shown to be ALARP, either because they probably aren't or because they are marginal, are then subject to the second stage of the process, which involves detailed costing and risk analyses.

The following aspects of ALARP give needs some attention:

1. The doctrine of tolerability can only fully address risk conditions where some quantitative estimate of existing or future risks can be made, either by applying QRA, or on the basis of historical accident frequencies; and that QRA involves a considerable margin of uncertainty (Yasseri 10).

2. Judgement using ALARP principles must not be allowed to override considerations of "good" or "best" engineering practice.
3. Regulatory framework - An ALARP regulator needs to be technically competent to conduct the necessary dialogue, and the regulatory framework, including the applicable laws must encourage discretionary and judgmental decision-making.
4. Indeterminacy of ALARP - ALARP decisions are often judgmental rather than determined by some precise rule or criterion, and ALARP can be open to difficulties and problems less apparent in more dogmatic approaches.
5. Cost escalation - Because ALARP insists on the possibility that more can be done to achieve safety, it has sometimes been accused in the UK of driving up industrial costs. In fact it is not clear that properly administered ALARP system imposes higher costs than more "directive" systems, and it provides greater scope for discussion before costly action is required.
6. ALARP was criticised as less suitable for smaller firms who are said to need more "directive" approach. HSE's view is that guidance to small firms can be simplified and made explicit, and many such guidance documents now exist. Beyond this, however, HSE argues that no company however small can be excused from the duty of taking its own common sense view of the hazards in its establishment and considering necessary precautions; and that no guidance can deal with all situations.

Part of the test for what is reasonable includes a comparison of how much more it would cost (in terms of time, money and effort) to reduce risks to a demonstrably lower level. This is a complex but well established safety process. Some operators have put forward proposals for acceptance of moving to a less protected situation, or a higher level risk within their safety case, due to an escalation of cost factors. This process is known as "*reverse ALARP*". The legal requirement to reduce risks to ALARP would prevent the regulator from accepting a less-protected approach to the control of risks on cheaper cost grounds. The ALARP process cannot be used to justify an increase in risk by diluting the effectiveness of existing safety measures.

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