Societal Risks

Final Report

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This project has focused on societal risks associated with hazardous installations (on and off-shore), nuclear power stations and the transport of dangerous goods. It is primarily this type of societal risk for which criteria have been developed over the last 30 years. Given that population density is a key factor, it is not surprising that three highly industrialised and densely populated countries - the UK, the Netherlands and Hong Kong - have led the development of criteria. These developments are reviewed chronologically against a backdrop of disasters and other events (major risk studies, key policy documents, public inquiries, etc). The debate on societal risk criteria is also reviewed with particular regard to the tolerability/acceptability of particular levels of risk, the degree of risk aversion to major disasters incorporated into criteria as well as consideration of some 'practical' problems associated with their implementation. For completeness, the mathematics underlying the presentation of societal risk results and criteria on FN plots is reviewed.

A key finding is that there is a surprising degree of consistency amongst FN-based societal risk criteria developed at different times, in different places, for different purposes and by different routes. Most criteria adopt a 'risk-neutral' degree of aversion although the Dutch authorities remain 'risk averse'. Although the setting of appropriate criteria requires the careful consideration of a range of parameters, it would appear that FN-based societal risk criteria have a role to play in decisions affecting public safety. Furthermore, the complexity and uncertainties surrounding the necessary quantitative risk assessments (QRAs) can lead to difficulties in implementation. With these points in mind, it is recommended that FN criterion lines should be seen more as guidelines rather than as strict criteria.

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the author(s) alone and do not necessarily reflect HSE policy.

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Since the 1960s, the sheer scale of some technological projects has led to concerns that new criteria may be necessary for judging the tolerability/acceptability of these activities. As a consequence, various ad hoc ideas have been put forward over the past three decades, the primary evolutionary trend having been towards the use of FN[1] diagrams on which likelihood - consequence curves for some specified activity are compared with criterion lines as a means of assessing tolerability.

The use of FN diagrams in this way has raised many questions, however. Some are matters of detail, but others are more fundamental, questioning either the validity or the utility of the methodology. These issues are important because the way in which societal risk is handled can have a major impact upon resource allocation, and on the types of technologies which are permitted to develop, some of which may be highly beneficial to public health or the economy, as well as affecting the magnitude of losses which society is prepared to contemplate.

In 1997, the Risk Assessment Policy Unit (RAPU) of the Health & Safety Executive (HSE) commissioned the Centre of Environmental Risk Management and Risk & Policy Analysts Ltd. to review the historical evolution of the societal risk concept and comment critically on the present position, offering advice where feasible and appropriate. This report is the outcome of that study.

MEANING OF SOCIETAL RISK

One of the problems with *societal risk* has been the term itself, which, as with the word *risk*, means different things to different people at different times, leading to some misunderstanding and confusion. For instance, from an engineering perspective societal risk is often regarded as no more than the relationship between the frequency and number of people suffering a specified level of harm from a particular hazard. Alternatively, others see societal risk as a much broader concept incorporating many other dimensions of harm, in some cases even the socio-political response in the aftermath of major accidents, or even lesser accidents where these might give rise to a significant expression of public concern.

While this problem will not quickly be solved, it is felt that there is actually some advantage in having a not overly prescriptive definition, since this at least permits flexibility in dealing with what is undoubtedly a complex issue. However, as an aid to clarification it is proposed that societal risks might be sub-classified into one of four kinds: collective risks, ‘simple’ or ‘diverse’ societal risks, and societal concerns. Collective risks would include risks from such hazards as incinerator emissions or radon exposure; ‘simple’ societal risks would relate to hazardous installations where the predominant issue is human safety; ‘diverse’ societal risks would apply to more complex situations where other dimensions of harm need to be considered, such as oil spills from tankers;

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[1] *FN curves are usually presented on log-log plots with the abscissa (x-axis) representing the scale of the consequences in terms of the number, N, of fatalities (or, less commonly, some other type of harm) and the ordinate (y-axis) representing the likelihood (expected frequency), F, of* $\geq N$ *fatalities (i.e. N or more fatalities).*

and societal concerns would relate to strategic level decision making where political and other factors come into play. The main focus of this report, according to this schema, is 'simple' societal risks.

EVOLUTION OF SOCIETAL RISK CRITERIA

The need for societal risk criteria can be traced in part at least to the development of techniques such as quantitative risk assessment (QRA) and consequence analysis in the 1960s and 1970s which permitted for the first time probabilistic analysis of major hazards. The outputs of these techniques were in the form of consequence versus probability scenarios which, by their very nature, demanded some sort of criteria against which they might be assessed. In the UK, the first industry to take up this challenge was the nuclear industry, and in the 1960s a relationship between the size and acceptable frequency of releases of radioactive iodine from accidents at nuclear power plants was proposed (the so-called Farmer curve).

ANCHOR POINTS

A second early and major influence in the evolution of societal risk criteria has been the work of the Advisory Committee on Major Hazards (ACMH) which, in 1976 made the tentative suggestion that for any particular plant a serious accident frequency of 10^{-4} per year might be regarded as "just on the borderline of acceptability". The term 'serious accident' was never defined by the ACMH, but it has been a fairly widespread practice amongst QRA practitioners to presume that this might be taken as 10 or more fatalities. This anchor point ($10, 10^{-4}$), as this report shows, can be observed in many FN criterion lines which are used to this day.

The approaches by Farmer and ACMH were based largely upon professional judgement. An alternative approach which has been used in the UK to derive anchor points for societal risk criteria has been to study historical decisions about major hazards, particularly those exposed to major public inquiry or discussion, and to use these as a means of determining a yardstick. This approach, originally proposed in the HSE landmark 'Tolerability of Risk' paper, and sometimes referred to as 'bootstrapping', has given rise to an alternative anchor point of ($500, 2x10^{-4}$) based upon the calculated post-remedial, tolerated risks of Canvey Island. This anchor point has been used by the Advisory Committee on Dangerous Substances (ACDS) in proposing FN criteria for communities living near to dangerous goods transport routes including sea ports.

A further anchor point ($100, 10^{-4}$)[2] has been proposed by the HSE in the nuclear context. This anchor point is also based upon consideration of the Canvey Island precedent and the Thames Barrier, but contains a further judgmental element based on the aversion which the public is considered to have for nuclear accidents in comparison with more conventional accidents. This is introduced via the co-ordinates of the anchor point itself, which are more restrictive than Canvey, and the requirement that the FN curve should apply, not to one site, but to the national inventory of nuclear reactors. This anchor point is therefore based upon both precedent (bootstrapping) and professional judgement.

In other countries where societal risk criteria have been promulgated, notably Hong Kong and the Netherlands, it can be seen that whereas the Hong Kong government adopted a position consistent with the ACMH point ($10, 10^{-4}$), the Dutch, apart from the Province of Groningen in

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[2] *The N = 100 co-ordinate relates in this case to deaths from cancer which would occur after some considerable delay.*

the 1970's, have chosen a different route. This is based upon, firstly, consideration of an acceptable level of individual risk, which was set at 1% of 'everyday' individual risk, leading to a value of 10^{-6} per annum, and then translating this into a societal risk anchor point of ($10, 10^{-5}$)[3]. It could be said that such an approach is based upon a combination of technical analysis and expert judgement.

In summary, anchor points which have been proposed for 'simple' societal risk criteria can be seen to have been based upon several different approaches which range from the analytic, which pays little or no regard to the cost-benefit implications, and the pragmatic which clearly does, whether based upon expert judgement or historical precedent. These anchor points apply to upper limits of tolerability. In those cases where 'broadly acceptable' limits have been defined as well, to provide a three tier structure akin to the 'tolerability of risk' (TOR) individual risk hierarchy, these are generally set two or three orders of magnitude lower on the 'F-axis'.

GRADIENTS OF FN LINES

The second parameter fixing an FN line is the slope. Most FN criteria are drawn with slopes of between -1 and -2 on log-log diagrams. A slope of -1 is commonly regarded as 'risk neutral' in that the weighting in preference of preventing large accidents is proportional to N, and not some higher power of N as in what is commonly referred to as 'risk averse' or 'multiple fatality averse' formulations[4]. Most of the criteria which have been published in the UK and Hong Kong have gradients of -1, whereas Dutch criteria are generally set at -2, applying what some would regard as a high degree of (multiple fatality) risk aversion.

These differences appear to originate from disparate regimes of control. The UK system, whether applied to individual risk as in the 'Tolerability of Risk' criteria, or societal risk, is founded more in past experience of what is practicable and has been accepted by society, whereas the Dutch criteria tend to more akin to new horizon 'technology-forcing' criteria. However, while, on the face of it, the Dutch criteria may appear to promote greater safety, this is not necessarily the case. The UK approach has always been to seek further reductions in risk below any specified tolerability limits according to the dictum of 'as low as reasonably practicable' (ALARP). This approach requires a high discretion and ability in the regulator's inspectors and a willingness to enforce. On the other hand, the stricter criteria of the Dutch have run into some local difficulties of implementation which have necessitated permission for derogations. The practical implications of the two systems are thus not easily compared without detailed study.

In addition, however, is the issue of whether society actually has a preference for a risk-neutral or risk-averse approach to multiple fatalities. While there is anecdotal evidence of ex-post risk aversion, the evidence gathered here, while limited, tends to support an ex-ante view of risk neutrality when considered purely in terms of multiple fatalities. The main exception to this is from one study of local politicians and risk managers in France who expressed aversion to major

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[3] *Although the precise relationship between individual and societal risk levels varies with the specific circumstances, a commonly-used guide amongst professionals is that if the societal risk of ≥ 10 fatalities is X, then the maximum individual risk will be of the order of 10X.*

[4] *As a result of the mathematics of FN curves, even a slope of -1 contains a degree of multiple fatality risk aversion.*

accidents, but this may have been because of managerial or similar responsibilities which might be deemed private rather than public interests.

On the other hand, it is sometimes argued that incorporation of aversion into FN criteria is a means of allowing for other factors besides fatalities which should weigh in risk decisions. Our view is that such factors should be dealt with separately and specifically, using whatever techniques are best suited for the purpose. Hidden weighting factors are opaque, unlikely to be proportionate to other consequences of societal hazards, and no more guarantee the occupation of the high moral ground than the option of risk neutrality.

RISK PERCEPTION, DREAD AND DECISION CRITERIA

There is a spectrum of opinion on the merits of incorporating public perceptions into decision making. An awareness of perceptions is of course helpful if not essential for decision makers, but the difficulty remains as to how this can be used in policy. Concepts such as ‘dread,’ for instance, appear to have outlived their usefulness, providing little constructive input to the decision process. And other measures, such as willingness-to-pay, also present difficulties for the unwary.

This is partly because societal risk issues are highly complex and are hard to tackle meaningfully in the kinds of encounters permitted by questionnaire-based interviews or even conventional focus groups which are the normal stock-in-trade of this kind of research. But, besides that, what matters most in dealing with issues such as this are the more deeply-held societal values rather than the more superficially-gauged perceptions, and these take much time and effort to elicit and reach agreement upon. However, once identified, alternative strategies for achieving fundamental goals can then be postulated and their relative merits compared against useful end points.

ALTERNATIVE CRITERIA

We are aware that questions have been raised about the usefulness of FN-based societal risk criteria and their form. Preferences have, for instance, been expressed for the use of disutility functions, or for the use of individual risk as a surrogate. Within the HSE itself, the Major Hazards Assessment Unit (MHAU) has derived its own ‘scaled risk integral’ (SRI).

Our conclusion is that FN diagrams remain a useful tool for the presentation of QRA data for major hazards, and should continue to be used for this purpose. The drawing of criterion lines on an FN diagram is in some way analogous to the equity constraints of the TOR framework. Although the usefulness of the latter has at times been questioned, we are of the opinion that FN criterion lines, even those of slope -1 which is the evidential position, provide useful information over and above that of individual risk contours, though still often requiring considered interpretation.

The fixing of criterion lines can be arrived at by various approaches which have been described. It is likely that for the time being at least the right choice or combination will depend on circumstances since there is no extant absolute criterion, and in many cases a direct transfer from one sector to another is unlikely to be satisfactory where the trade-offs between risks and benefits are different. In the longer term, however, it may be possible to move towards a unified criterion or set of criteria covering local and national requirements analogous to TOR.

The use of FN criteria as guidance on tolerability in no way militates against the use of disutility criteria or cost-benefit techniques in general. Indeed, it is fully to be expected that these measures be applied in reaching ALARP decisions for major hazards.

We have paid considerable attention to the MHAU's Scaled Risk Integral. A practical tool is clearly necessary for consistent treatment of the numerous planning applications involving major hazard sites. The SRI contains all the reasonable primary elements for these decisions, namely, risk level, number exposed, population density, and duration of exposure. Its mathematical derivation is, however, quite complex and its implementation requires further approximations. Consequently we have been unable to fully assess its implications as a societal risk decision aid, although a more detailed examination of case studies might shed light on this.

CONCLUDING COMMENTS

It should not be overlooked that societal risk decisions are, in a sense, of crucial importance since they shape significant features of the world in which we live and the direction in which it develops. Such decisions are necessarily highly complex since they should entail wide-ranging consideration of benefits, consequences and societal goals. This is a challenging task and, in our view, is unlikely to be one which well ever be resolvable by a simple algorithm.

Thus, while we see a continuing useful role for the expression of 'simple' societal risks as curves on FN diagrams, and for the application of societal risk criteria as guidelines, we stress that these techniques should not be seen as over-endowed with either scientific provenance or moral justification. As this report demonstrates, the history of the development of societal risk criteria remains in its infancy and there remain unresolved and fundamental philosophical and methodological issues. We consider that more attention should be given to these fundamental issues prior to any attempts to build further upon the existing mathematical foundations.

1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The Risk Assessment Policy Unit (RAPU) of the Health & Safety Executive (HSE) is involved with the development of risk assessment methodologies for application to the work of HSE.

Currently, there is some concern within RAPU, and HSE more generally, over the concept of societal risk and the use of societal risk criteria in decision-making. One definition of societal risk which is widely used by HSE (see, for example, Cassidy, 1997) and others is:

> *Societal Risk is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.* (IChemE, 1992).

In the UK, the origin of formal societal risk criteria can be traced back to the work of the Safety & Reliability Directorate of the UK Atomic Energy Authority (UKAEA) and in particular the work of Farmer (1967). The original Farmer curve, suggesting a relationship between the size and acceptable frequency of releases of radioactive iodine from accidents at nuclear power stations was later developed into the more familiar 'FN' curve[5] in the late 1970s. The concept was later developed both in the nuclear industry and in the non-nuclear industry as growth in the scale of technology led to the possibility of accidents resulting in impacts affecting hundreds, or even thousands, of people across a range of activities. In broad terms, historical data on the frequency of major accidents showed that for any particular activity, the chances of a large scale accident varied inversely with its consequences (ie the larger the accident the less likely it was to occur). In addition, the scale of the consequences (in terms of human injuries and/or fatalities) depends on the density of the nearby population. With these points in mind, it is perhaps not surprising that three highly developed countries with high population densities have been at the forefront of the development and use of societal risks - viz the UK, the Netherlands and Hong Kong.

In parallel with the emergence of societal risk as an issue in relation to major accidents, there has also been interest in the determination of the risks for cases where the individual doses (and, hence, individual risk levels) are very small but the exposed population is very large. Examples of such hazards would include radon and other sources of radioactivity, air pollution and food contaminants/additives.

1.2 AIMS OF THE STUDY

In the Netherlands and Hong Kong, societal risk criteria are clearly described. In the UK, although societal risk criteria have been developed for certain specific cases, such criteria appear to have been used more cautiously.

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[5] *FN curves are usually presented on log-log plots with the x-axis representing the scale of the consequences in terms of N fatalities and the y-axis representing F, the likelihood or expected frequency of N or more fatalities. A review of the associated mathematics is presented in Annex 1.*

This project has been commissioned to examine the development of societal risk criteria, to identify the underlying issues and the key arguments for and against the use of the societal risk concept and, where possible, to draw out conclusions on possible ways ahead.

1.3 APPROACH TO THE STUDY

The usefulness of societal risk as a concept is not universally accepted. When it is used, there are often difficulties in generating the necessary data via risk assessment and in defining associated criteria which results in debate over more ‘philosophical’ issues such as the setting of tolerable/acceptable levels and the degree of aversion to multi-fatality accidents.

The approach devised for this study is to chart the development of societal risk criteria in terms of their structure, function and the practical constraints at each stage of development. At intervals along this path have been a number of significant incidents, government publications and public debates (including public inquiries) that have also influenced the development and application of societal risk in the UK and elsewhere.

As mentioned above, there are a number of philosophical arguments relating to the determination of ‘how safe is safe enough’? These concerns are expressed in a number of key papers dating from the outset of the development of societal risk to the present day. In order to maintain a balanced approach, these have been related to their corresponding points in the development of societal risk.

1.4 STRUCTURE OF THE REPORT

Section 2 provides an introduction to the concept of societal risk and attempts to define those types of societal risk for which the development and application of societal risk criteria is a practicable proposition.

Section 3 provides an overview of the development of societal risk criteria over the last 30 years with particular reference to the UK, Hong Kong and the Netherlands. This overview is based on the more detailed (and broadly factual) account presented in Annex 2 which attempts to place the development of societal risk criteria within the context of the occurrence of major incidents and other significant events.

Section 4 provides a critical review of key issues associated with the ‘successful’ development and application of societal risk criteria.

Section 5 provides a view of the possible way forward with respect to the development and application of societal risk criteria within the UK context.

2. SOCIETAL RISK - AN OVERVIEW

2.1 TYPES OF RISK

Risk may be defined in terms of the likelihood (ie expected frequency) or probability of particular outcomes. A generic definition which is often used is: *the likelihood of a specified adverse consequence*.

When considering risks to people, however, there is often a distinction drawn between the risk to an individual (*individual risk*) and the risk to groups of people (*societal risk*). More formal definitions (from IChemE, 1992) of these are:

> *Individual Risk is the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards.*
>
> *Societal Risk is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards.*

From such definitions, it can be seen that risk is, at times, expressed as a function of two components - a measure of the frequency or probability and a measure of the associated consequences[6]. In some cases, it is also useful to consider a third measure of risk based on the product *frequency x consequence*. Such expressions represent the statistical loss over time (sometimes referred to as expected value or the probable loss).

By way of example, the risks to residents close to a hazardous facility may be presented as follows:

- the *individual risk* to the person at most risk amongst the residents is 1 chance in 100,000 per year of becoming a fatality due to an incident at the facility;
- the *societal risk* to the residents may be characterised as follows: the chances of 1 fatality or more, 10 fatalities or more and 100 fatalities or more are 1 in 100,000 per year, 1 in 300,000 per year and 1 in 1 million per year respectively; and
- the *probable loss of life* (PLL which is a measure of 'disutility') amongst the residents is (on average) one life per thousand years.

2.2 SOCIETAL RISK AS A CONCEPT

The concept of societal risk is complex and it is important to clarify what is under discussion. This is due to a wider problem in dealing with risk issues, since the precise meaning of risk terminology in general appears still to be substantially rooted in an individual's professional background, despite frequent exhortations that risk assessment and management are multi-disciplinary endeavours (Ball & Golob, 1997).

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[6] *More generally, risk is sometimes described as a multi-dimensional concept, depending upon the perspective taken - as discussed further in Section 2.2.*

Historically, the term societal risk has been related to the impacts, usually upon people, associated with accidents. However, in recent years, there has been a tendency to consider the 'broader' picture. By way of example, the Health & Safety Executive has defined societal risk simply as the "total harm to a population" (HSE, 1989a) and, more recently, in *Generic terms and concepts in assessment and regulation of industrial risks* (HSE, 1995) as:

> *The risk of widespread or large scale detriment from the realisation of a defined hazard, the implication being that the consequence would be on such a scale as to provoke a socio/political response, and/or that the risk (ie the chance combined with the consequence) provokes public discussion and is effectively regulated by society as a whole through political processes and regulatory mechanisms.*

In short, it is important to characterise the nature of 'risk' under discussion at the outset as this has a direct bearing on not only the complexity of the analysis but also whether associated criteria would be meaningful. For the purposes of this report, different types of risk have been characterised as shown in Table 1 and these are discussed in turn below.

Table 1
Characterisation of Societal Risks

Subject	**Risks associated with:**		**Suggested Term**	**Type of Criteria**
	'Normal' Activities?	**Accidents?**		
'Diffuse' risks associated with exposure to hazardous materials	Yes	No	Collective Risks	Individual Risk + cost benefit analysis
'Simple' risks associated with hazardous installations/ activities which can be readily compared	No	Yes	Societal Risks	FN criteria based on fatalities
Diverse risks associated with hazardous installations/ activities which require a broader basis for meaningful comparisons	No	Yes	Societal Risks	FN criteria based on fatalities and other dimensions of harm
Comparison of overall impacts/risks of technologies/strategies	Yes	Yes	Societal Concerns	Political judgement - possibly aided by multi-criteria techniques

In Table 1, it has been assumed that these types of risk represent those which are amenable to discussion and for which it is possible to reach a considered view on the nature and applicability of appropriate criteria. In practice, there are other multi-fatality events which result in the development of additional regulations or other control measures which are not necessarily formulated from a 'risk perspective'. By way of example, the death of four teenage canoeists in Lyme Bay in 1993 prompted an immediate tightening of safety regulations for outdoor activity centres. In some cases, it would appear that the authorities are forced to respond quickly to public and/or media pressure. Of course, it may be the case that the level of risk warrants rapid action but, as the recent banning of 'beef on the bone' demonstrates, it is not always possible to accommodate such actions within the type of framework which is considered in this report.

2.3 COLLECTIVE RISKS

Within the context of this study, societal risks are associated with accidents. With this in mind, it can be seen that risks associated with 'diffuse' effects as a result of 'normal' activities are different in nature. Typical examples would include the risks to society or vulnerable groups (young children, pregnant mothers, senior citizens, etc) associated with dioxins emitted from incinerators under 'normal' conditions, risks associated with 'normal' radioactive discharges from nuclear facilities, and the 'normal' (and, even 'abnormal') exposure to hazardous materials in everyday life (pesticides, solvents, etc). As indicated in Table 1, we suggest that such risks should be termed 'collective risks'.

From a technical 'risk' perspective, the associated risk to society (expressed in terms of PLL values) can be determined from the expression:

level of individual risk x number of people exposed

Using this approach, and invoking a 'value for a life', it is then possible to compare the costs and benefits (in human health terms at least) associated with different risk management strategies. Of course, this methodology is often used to test whether a particular measure meets the principles of ALARP, ALARA[7], etc (HM Treasury, 1996) and, indeed, is recommended for use in Regulatory Appraisal (Cabinet Office, 1996).

2.4 SOCIETAL RISKS

2.4.1 Simple Risks

The most widely used form of societal risk is based on the likelihood, F, of N or more fatalities. Where the use of fatalities provides a reliable 'shorthand' measure of consequences, the associated FN criteria (based on fatalities alone) can provide a valid basis for the evaluation of societal risks. This is not to suggest that other consequences (damage to the environment, financial loss, etc) are not relevant, but rather the use of 'fatalities' provides a simplified method of risk evaluation. By way of example, the societal risks associated with a particular hazardous installation could be determined for two alternative locations. The results could then be compared with each other and with the appropriate criteria (if available) to determine which location offered the lowest societal risk and whether the risks would be considered tolerable.

Clearly one of the advantages of using 'fatalities' for the engineers and natural scientists who by and large carry out these calculations is that the results can be readily expressed in mathematical form. Further, the types of techniques which have been developed for the quantification of risk from major engineered hazards, such as event trees and fault trees, and the numerous consequence models, produce outputs which can be expressed in an FN format.

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[7] *ALARP and ALARA are the acronyms for "as low as reasonably practicable" and "as low as reasonably achievable" respectively.*

However, broader comparisons are less meaningful. By way of example, suppose the societal risk curve for a particular airline was 100 times higher (in frequency terms) than that derived for a particular chemical plant. Although this might be regarded as interesting, does it tell us anything about the relative acceptability of the risks?

With this in mind, it is perhaps not surprising that societal risk criteria (based on fatalities alone) have been developed for particular groups of activities - notably hazardous installations and the transport of dangerous goods - as discussed further in Section 3.

2.4.2 Diverse Risks

In more complex situations, sole reliance upon FN criteria based on fatalities alone is likely to be insufficient. By way of example, for accidents involving the marine transport of oil and chemical products, the 'total harm' will depend not only human casualties but also upon the environmental fate of the product being transported (which will vary significantly from product to product). In such cases, any 'societal risk' criteria would need to account for the environmental damage to enable meaningful comparisons.

Such views are in accordance with those expressed over a decade ago by Slovic *et al* (1984) who state that, in attempting to model the impact of major accidents, they saw no alternative but to elaborate all the events and consequences which may result, including second order effects (consequences of consequences), their probabilities and some measures of their costs.

It is of note that in Switzerland (see Section A2.5.5, Annex 2), an attempt has been made to translate such an approach into criteria.

2.5 SOCIETAL CONCERNS

At the policy or decision-making level, the crude use of FN curves based on fatalities is meaningless. By way of example, assessing and contrasting the high consequence risks of alternative electricity generation systems may obscure as much as it reveals. Nuclear FN curves tend to have a long tail at low probabilities, but it is seldom made clear that this is predicated on fundamental assumptions about the shape of the dose-response curve for ionising radiation at very low doses, itself an increasingly hotly-debated topic (Anon, 1997). FN curves for fossil power plants and renewables, on the other hand, may not include potentially important considerations like the risks posed to society by the mobilisation and discharge of respiratory irritants and carcinogens, the associated discharge of greenhouse gases, or the social upheaval associated with the relocation of communities in the case of some hydroelectric schemes.

Clearly, at this strategic level, decision makers have to consider the full range of potential impacts (associated with both 'normal' activities and accidents) including fatalities, non-fatal injuries, property damage, environmental impacts, psycho-social harm, economic loss, business interruption costs and even the political consequences of major accidents. Open-ended definitions of this kind tend to be anathema to those whose focus is numerical analysis since many of the components are difficult to handle if not beyond quantification and, even if quantifiable, could not easily be assimilated into a decision model. In practice, however, optimum decisions can ultimately only be made by considering all of the goals and all of the consequences of various decision options, and in the final stages of policy formulation it is imperative that this be done.

These much broader considerations have been termed ‘societal concerns’ which is in accordance with the reported preference of some members of HSE (HM Treasury, 1996).

2.6 FOCUS OF ANALYSIS

The remainder of this report focuses on ‘societal risks’ as described above. In other words, the prime concern is the development and application of societal risk criteria which are applied to those hazardous installations and activities with the potential for large scale accidents.

3. DEVELOPMENT AND APPLICATION OF SOCIETAL RISK CRITERIA

3.1 INTRODUCTION

This section presents an overview of the development and application of societal risk criteria over the past thirty years with particular reference to the UK, Hong Kong and the Netherlands. The key 'milestones' are illustrated in Figure 1.

A more detailed and chronological account is provided in Annex 2 which is supplemented by a listing of major incidents in the UK and elsewhere together with a listing of other key events and publications.

3.2 DEVELOPMENTS IN THE UK

The origins of societal risk criteria can be traced back to the work of the UK Atomic Energy Authority (UKAEA) in the 1960s. In broad terms, there was recognition that a major event at a nuclear power plant could lead to severe consequences in the local area. There was therefore a need to ensure that the chances of a major accident were minimised and that nuclear power plants were located away from centres of population. This led to the formulation of the so called 'Farmer curve' which proposed risk criteria based on the 'acceptable' frequency of Iodine-131 releases.

Another early and major influence in the development of societal risk criteria within the UK was the work of the Advisory Committee on Major Hazards, established after the Flixborough disaster of 1974, which made an early tentative suggestion for a societal risk criterion:

> *... that in a particular plant a serious accident was unlikely to occur more often than once in 10,000 years (i.e.* 10^{-4} yr^{-1}*) ... this might perhaps be regarded as just on the borderline of acceptability* (ACMH, 1976).

This has often been taken (by practitioners) as a proposed criterion of 1 chance in 10,000 per year for 10 or more fatalities.

During the late 1970s, considerable progress was being made with the development of quantitative risk assessment (QRA) techniques which were being applied to both the nuclear and non-nuclear industry (with particular reference to the publication of the two Canvey Reports - HSE, 1978 & 1981). At this time, there was also considerable internal debate on the form of societal risk criteria within the nuclear industry (and UKAEA in particular) which eventually led to FN-based societal risk criteria being proposed for nuclear power plants (Kinchin, 1982).

Following the Sizewell B Inquiry in the mid-1980s, research into the 'tolerability of risk' from nuclear power stations was commissioned by HSE. The resultant report (HSE, 1988) is often identified as milestone in setting out the framework for risk control, not just in the nuclear industry, but in the UK generally. However, the report focuses very much on individual risk and no attempt is made to further develop the FN criteria proposed by Kinchin and others. Nevertheless, some discussion is presented on the 'tolerability' of major accidents with particular reference to the risks associated with the Canvey Island complex and the Thames Barrier.

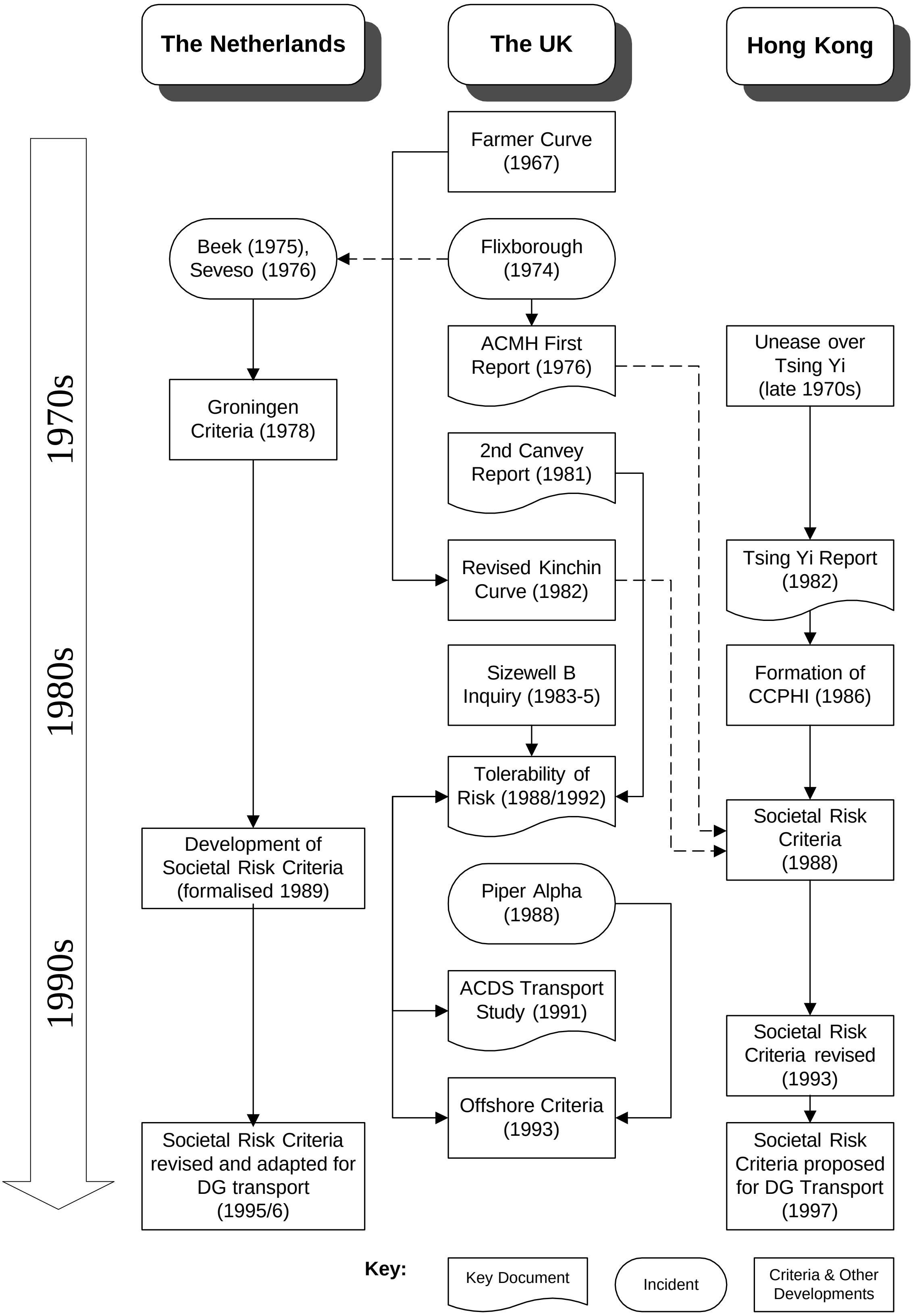

Figure 1. Milestones in the Development of Societal Risk Criteria

The Canvey Island study also provided the basis for setting the FN-based societal risk criteria presented in the transport risk study published by the Advisory Committee on Dangerous Substances (ACDS, 1991). This report extended previous thinking on societal risk in the UK, but observed that while the general *Tolerability of Risk* framework for individual risk also applied to societal risk, there were real conceptual difficulties in determining universally relevant levels for tolerable and negligible societal risk because of the complexity and diversity of the issues encompassed. In the end, the ad hoc Working Group (see Appendix 6, ACDS, 1991) proposed societal criteria for ports and rail and road risks by 'reading across' from the Canvey Island criteria, on the basis that the hazards were similar in nature and, in the case of Canvey, had been exposed to exhaustive analysis and public scrutiny. It should be noted that the criteria proposed related to a ‘certain complex of plants’ so differentiating ‘local societal risk criteria’ from those which might apply to a national inventory of hazardous plants, or from those applying to individual plant or cases.

The Working Group was not able to suggest criteria for intolerable national societal risk as might arise from, for example, all UK ports. However, a ‘national scrutiny level’ was proposed by scaling the Canvey criteria by the ratio of the national volume, in tonnes, of such trade and the trade at Canvey. The idea was that if national risk approached this level it would not necessarily be intolerable, but should be subjected to scrutiny. Further, the Working Group proposed that the ‘national scrutiny level’ could also be used to provide a yardstick, that is, ‘local intolerability criteria’ for ports, against which other ports could be compared simply by scaling the national criteria by the volume of trade at the port in question.

As a result of the Cullen Report (DEn, 1990) into the Piper Alpha disaster, the Offshore Safety Division was established within HSE and proposed societal risk criteria for application to the offshore situation (Schofield, 1993) which have subsequently been adopted. The criteria are derived directly from consideration of individual risk criteria (based on the ‘tolerability’ limit of 1 in 1,000 per year set in the *Tolerability of Risk* report).

One area where societal risk is considered, to some degree, on a routine basis is in relation to planning applications close to hazardous installations. Within HSE, expert advice on this issue is provided by the Major Hazard Assessments Unit (MHAU). In practice, risk judgements are generally made at the ‘local’ level by HSE Inspectors based on guidelines incorporating individual risk levels and the nature/size of the development (as originally set out in the document: HSE, 1989). However, in some cases (perhaps 15%), the planning applications will be referred to MHAU for further guidance. To assist in the formulation of their advice, MHAU utilises the Scaled Risk Integral (SRI) which explicitly accounts, *inter alia*, for individual risk level, the size of the development and the associated population density.

The *Tolerability of Risk* report was revised and reissued in 1992 (HSE, 1992). The revised report accounted for developments since its initial publication in 1988 with commentaries on the application of risk criteria to land-use planning, the approaches to societal risk adopted in the ACDS study and proposed for off-shore installations.

3.3 DEVELOPMENTS IN HONG KONG

In 1981, the Hong Kong Government commissioned a major study into the risks associated with the hazardous installations on Tsing Yi Island following concern over the proximity of high density residential apartment blocks. The study report recommended, *inter alia*, that there was a need to oversee the risk management of such facilities with particular regard to land-use planning.

Further studies of other hazardous facilities (notably water treatment works handling liquid chlorine) during the 1980s reinforced this view. By 1987, tentative societal risk criteria (based on the ACMH criterion and the Kinchin curve) were being used to judge the acceptability of societal risk results and these were formalised as part of the Interim Risk Guidelines in 1988 by a Government Committee (CCPHI).

The Societal Risk Guideline was revised in 1993 and, following the UK's lead, the HK Government commissioned two transport risk studies which were finalised in 1997. These studies led to proposed transport risk criteria based on both the existing criteria for fixed installations and the number of installations involved.

3.4 DEVELOPMENTS IN THE NETHERLANDS

In response to accidents involving hazardous materials in Europe (with particular reference to Flixborough in 1974, Beek in 1975, and Seveso in 1976), the Province of Groningen issued risk criteria in the form of individual and societal (referred to as 'group') risk criteria (Groningen, 1978). Around the same time, the landmark COVO study was being undertaken which involved a detailed risk assessment of a range of hazardous installations in the Rotterdam area (Blokker *et al*, 1980).

During the 1980s, the Dutch Government was involved with numerous further risk studies which led to the formulation of societal risk criteria which were formally adopted in 1989 (VROM, 1989). In parallel with developments in Hong Kong, these were revised in 1995/96 and societal risk criteria were introduced for DG transport.

3.5 SUMMARY

A number of different societal risk criteria are discussed in Annex 2. At first sight, these appear disparate and confusing but, in fact, there are many points of similarity as illustrated in Table 2. To facilitate comparison, some terms have been changed from the originals (which are presented in Annex 2). In particular, the 'limit of tolerability' has been used to represent the 'lower limit of unacceptability' and 'acceptable' has been used to represent 'negligible'.

3.6 COMMENTARY

3.6.1 Overview

As might be expected, societal risk criteria have been developed for a number of 'simple' risks (as discussed in Section 2.4) relating to the numbers of fatalities associated with large-scale accidents for a range of well defined activities.

Furthermore, the various criteria developed for hazardous installations (including nuclear and off-shore facilities) and the transport of dangerous goods are interlinked with particular reference to the gradient of FN criterion lines and their 'anchor points'.

Table 2 Summary of Societal Risk Criteria based on the Likelihood (F per year) of N or more Fatalities

Year	Country	Anchor Point		Slope	Criteria, Applicability[1] and Comment[2]
		N	F ($N)		
1976	UK	10	10^{-4}	n/a	ACMH - HI: *Single point criterion (frequency) with presumed consequences.*
1978	NL	10	10^{-4}	-2	Groningen[3] - HI: *Limit of tolerability - based on various factors and, perhaps, the ACMH criterion. 'Acceptable' line set 100 times lower.*
1982	UK	10	10^{-4}	-1	Revised Kinchin[4] - nuclear reactor: *Based on earlier Kinchin curve which suggested that risks from nuclear reactor programme should be similar to those from meteorites.*
1988	HK	10	10^{-4}	-1	SRG - HI: *Limit of tolerability based on ACMH criterion and revised Kinchin curve.*
1989	NL	10	10^{-5}	-2	SRG - HI: *Anchor point based on consideration of individual risks. 'Acceptable' line set 100 times lower.*
1991	UK	500	$2x10^{-4}$	-1	ACDS - community close to DG transport route: *Limit of tolerability based on Canvey Island risks. 'Acceptable' line set 1,000 times lower.*
1993	UK			-1 and -1.3	Offshore oil/gas platforms: *Limit of tolerability based on 'tolerable' individual risk. 'Acceptable' line set about 1,000 times lower.*
1993	HK	10	10^{-4}	-1	SRG - HI: *As 1988 criteria but ALARP region introduced. 'Acceptable' line set 100 times below limit of tolerability.*
1995/6	NL	10	10^{-5}	-2	SRG - HI: *As 1989 criteria but 'acceptable' region removed.*
1995/6	NL			-2	DG Transport: *Similar to above but based on fatalities per km.*
1997	HK			-1	DG Transport: *Limit of tolerability as 1993 criteria but accounts for numbers of installations involved.*

Notes:

1. *HI = hazardous installation; SRG = societal risk guideline; DG = dangerous goods.*
2. *Reference to, say, 100 times lower means that the line is drawn parallel but with a likelihood (F) two orders of magnitude lower than the 'upper' line.*
3. *Value of 10^{-4} for 10 or more fatalities taken from Groningen curve as opposed to being stated as an explicit 'anchor point'*
4. *Similarly, the value 10^{-4} for 10 or more 'delayed deaths' taken from revised Kinchin curve. Note also that the line for 'early' deaths is 30 times lower.*

3.6.2 Aversion

Although the UK and Hong Kong have adopted a gradient of -1 for FN criteria, the Netherlands has consistently used a 'risk averse' gradient of -2. As discussed in Annex 1, even a gradient of -1 carries an implicit degree of aversion and whether the Dutch position can be 'justified' on technical, ethical or economic grounds is open to debate[8].

Although the issue of aversion is discussed further in Section 4, it should be noted that FN criteria based on a gradient of -1 appear to offer the least complex solution in that:

- straight lines are the least difficult to draw; and

- there are no discontinuities nor inconsistencies - as might be associated with varying the gradient over ranges of N values and with the use of 'cut-offs'.

3.6.3 Anchor Points

As regards 'anchor points', there appear to have been three major routes to establishing them over the years:

- ensuring consistency with corresponding individual risk criteria (which are usually based directly on consideration of 'everyday' risks) as used by the Dutch authorities and for UK offshore facilities;

- comparison with an 'external standard' such as meteorites (for the Kinchin curves), Canvey Island risks (for the ACDS transport risk criteria) and expert view (for the ACMH criterion); and

- adoption and refinement of existing criteria such as the early Hong Kong criteria based on the ACMH criterion and revised Kinchin curve.

It is of note that the general approaches by the UK and Hong Kong regulators are characterised by Stallen *et al* (1994) as 'bootstrapping' in that:

> *The safety levels achieved with old risks provide him with a handy strap to use today's boots (the new risks), for they are the concrete demonstration of society's struggle to trade off optimally potential costs or risks and benefits.*

And, by contrast:

> *The official Dutch approach to SR comes close to the professionalist archetype. The fact that the regulator did not pay attention ... to costs incurred by industry or society as a whole suggests a diagnostic process by which what is best for society is decided on the basis of professional competence.*

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[8] *Strictly speaking, whether or not a criterion line of gradient -2 is less tolerant of large scale accidents than one of gradient -1 depends on the location of the line on the FN plot (ie the anchor points as discussed in Section 3.6.3).*

3.6.4 Categories of Societal Risk

As noted, the ACDS (1991) report proposed, in addition to local criteria, the use of national scrutiny criteria for flagging the need for further scrutiny of societal risks generated by a suite of comparable activities. This is consistent with the approach proposed some years before for nuclear power plants, in which national criteria were set for the entire industry in the UK (see Section A2.3.2). The ACDS report also proposes that national scrutiny criteria may be used to derive local criteria, for one such plant or complex, by scaling with an appropriate parameter such as plant throughput or productivity. These procedures appear to the authors of this report to provide helpful guidance, providing, as the ACDS report states, recognition is given to the following:

- estimates of risk are technical, but judgements of what is tolerable, justifiable, or acceptable are essentially political though they should be informed technically; and

- estimates of risk are uncertain, often to a substantial degree, and decision makers need to be aware of this.

The implication is that over-sophistication in designing criteria such as these is not warranted and could generate misunderstanding. Societal risk criteria should not, in other words, be viewed as more than broad indicators of a desirable objective, with many other, non-technical factors needing to be weighed in any final decision. As a starting point, the HSE (1989a) has identified forty-one additional criteria.

3.7 IMPACT OF SOCIETAL RISK CRITERIA

In reviewing the development of societal risk criteria, it must be remembered that until the detailed studies undertaken in the late 1970s and early 1980s, nobody knew the level of societal risk associated with hazardous installations (with particular reference to chemical and nuclear facilities).

During the 1980s, within a fairly small world of specialists at least, there was an increased understanding of the types of accidents that could occur, their likelihoods and their associated consequences. This led to criteria being adopted in both the Netherlands and Hong Kong.

In broad terms, the adoption of criteria has led to material changes including greater separation distances between hazardous installations and nearby areas of population in Hong Kong and policy measures in the Netherlands designed to reduce societal risks.

Within the UK, the situation has been more complex. It would appear that during the 1980s there was a move away from the further development of societal risk criteria based on FN lines - with particular regard to the lack of both debate at the Sizewell B Inquiry and input from ACMH (during its later years). It is perhaps therefore ironic that the UK should suffer a spate of severe disasters in the mid/late 1980s for which the subsequent Inquiries blamed a lack of safety structures and management.

In recent years, there has been a resurgence of interest in societal risk criteria based on FN lines and criteria have been adopted for off-shore platforms and proposed for the transport of dangerous goods. In addition, MHAU have developed the Scaled Risk Integral to provide a quantitative measure of societal risk (albeit without recourse to FN curves) to assist in the provision of advice on planning applications in the vicinity of hazardous installations.

4. CRITICAL REVIEW

4.1 OVERVIEW

This section provides a commentary on some of the underlying issues and their implications relating to societal risk and associated criteria.

4.2 ACCEPTABILITY OF SOCIETAL RISKS

Most people (as discussed in many of the referenced publications) would accept the proposition that there are three broad categories of risk:

- those that are so high as to be unacceptable/intolerable;
- those that are so low as to be acceptable/negligible; and
- those in between where consideration needs to be given to the various trade-offs between the risks and the benefits.

From Section 3, it can be seen that most criteria are based on such a proposition. The setting of the levels of risk which correspond to these categories depends on numerous factors. However, the societal risk criteria for installations are often ‘anchored’ about limits of 10^{-4} (or 10^{-5} in the Netherlands) per year for 10 or more fatalities where this anchor represents the limit of tolerability.

Furthermore, in general terms, the upper limit of those risks regarded as acceptable/negligible tends to be set two or three orders of magnitude (ie 100 or 1,000 times) lower on the likelihood (F) scale.

At first sight, this might appear to indicate a very broad band of risks which lie between these two limits. Indeed, as indicated in Annex 2, this was one of the reasons given for ACMH not pursuing societal risk criteria further since:

> *Most major hazard risks fall in a band between the clearly unacceptable and the clearly negligible* (para 20, ACMH, 1984)

However, it must be borne in mind that the quantification of risks can be very uncertain. A good number of risk issues get bogged down in over-elaborate quests for numerical precision even, in some cases, where none exists as in, for example, the valuation of safety. This presents a real danger because it diverts attention from more important factors, some of which may even be overlooked in their entirety. The Royal Society (1992) minces no words on this:

> *the lack of mathematical culture is revealed nowhere so conspicuously as in meaningless precision in numerical computations*

In short, the estimation of societal risks, in all their dimensions, is fraught with numerous uncertainties. For this reason, it is eminently sensible to regard societal risk criteria as no more than indicators.

4.3 SOCIETAL RISK CRITERIA AND AVERSION

4.3.1 Overview

FN diagrams may be used for at least three different purposes (ACDS, 1991):

- to show the historical record of accidents;
- to depict the results of quantitative risk assessments (QRAs); or
- to display criteria for judging the tolerability or acceptability of QRA outputs.

As described in the previous section, considerable effort has been expended by various agencies in trying to define societal risk criteria in terms of lines on FN diagrams. HSE has been rather circumspect about this, whereas in other countries, notably the Netherlands and Hong Kong, there has been less hesitation to draw formal lines. In the US there has been much controversy about decision criteria of this kind, occasionally referred to as ‘bright lines’. Congress has sometimes sought to include bright lines in legislation, but the 1997 report of the Presidential/Congressional Commission on Risk Assessment and Risk Management (P/C Commission, 1997) observes that a strict bright-line approach to decision making is vulnerable to misapplication since it cannot explicitly reflect uncertainty about risks, population variation in susceptibility, community preferences and values, or economic considerations - all of which are legitimate components of any credible risk management process.

As can be seen from Section 3 and Annex 2, most societal risk criteria are based on the expression:

$$F \text{ x } N^{á} = k$$

where, F = the likelihood of N or more fatalities (or other measure)
N = the number of fatalities (or other measure)
$á$ = ‘aversion’ factor (normally 1 or 2)
k = constant

In some cases, the values of ‘á’ and ‘k’ may change over the range of potential consequences (such as for the Groningen curve discussed in Section A2.3.4).

The gradient of the societal risk criteria (as plotted on a log-log basis) is simply ‘-á’. For the UK and Hong Kong, the value of ‘á’ is one which is often termed ‘risk neutral’. In other words, the criteria are based on the assumption that the permitted likelihood of an accident which kills 100 people (or more) should be 10 times lower than one which kills 10 people (or more)[9]. Similarly, the permitted likelihood of an accident which kills 10,000 people (or more) should be 1,000 times lower than one which kills 10 people (or more).

In the Netherlands, the value of ‘á’ has been taken as 2. This is usually interpreted to mean that the Dutch authorities have built in a degree of ‘risk aversion’ to larger accidents. By way of example, the permitted likelihood of an accident which kills 100 people (or more) is 100 times lower than one kills which 10 people (or more).

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[9] *However, as explored in Annex 1, this is not quite the same as saying that an accident which kills 100 people should be 10 times lower than one which kills 10 people since the use of the cumulative FN data introduces a degree of aversion.*

4.3.2 Basis for Aversion Factors

The apparent raison d'être for incorporation of a multiple fatality aversion factor into societal risk criteria is that many of those charged with policy formulation believe there is an additional public repugnance to an event which kills a large number of people which is over and above that felt for a series of smaller events which collectively kill the same number of people (see, for example, *Quantified risk assessment: its input to decision making* (HSE, 1989a - para 63) and Royal Society Study Group report on risk (Royal Society, 1992 - page 26). Seldom, however, has any clear indication been given of the provenance of this view, although it is noted in the UK context that both Sir Frank Layfield at the Sizewell Inquiry (DEn, 1987) and Lord Cullen at the Piper Alpha Inquiry (DEn, 1990) had earlier referred to the need for incorporation of public perceptions and aversion into societal risk decisions.

Yet the issue is of major importance in a society which is increasingly involved in the construction and operation of large scale technologies, a number of which have the capability to cause either local catastrophic harm or widespread dispersed harm. This is not just because such technologies need to be regulated from the societal perspective, but also because if they are over-regulated the associated benefits may be lost, possibly even to be replaced by a host of collectively less beneficial smaller scale activities with even higher risks (Hubert, 1984).

It is therefore worthwhile to consider the concept of risk perception and aversion and its relationship to policy with some care. As noted earlier, it is not within the scope of this project to carry this out in great detail, but a number of central issues can be addressed, and several of these are now listed prior to their further consideration:

- What evidence can be found in support of (or against) the concept of multiple fatality aversion?
- Are there other forms of aversion?
- How should public perceptions and aversions affect policy?

4.3.3 Multiple Fatality Aversion

The widely-held view that the public are more than proportionately affected by the number of fatalities in an accident stems, apparently, from several sources including the known public response in the aftermath of major accidents, and the large body of psycho-social research, particularly that by Slovic *et al* in the US, on the public perception of hazards.

The degree of public response following major accidents is, however, determined by an exceedingly complex set of interactions between sources of information, transmitters of information, and recipients (see, for example, Renn, 1992) as well as many other factors peculiar to each event including the identity of the victims and their circumstances, the respect for the agency responsible for the hazard, and the way in which the information is portrayed by the media. It has been said, for instance, that a single photograph of a child fleeing a napalmed village had as much impact on attitudes to the Vietnam war as countless more devastating events. Factors such as these make it difficult, if not impossible, to draw any reliable conclusions on the proportionality of public views about major versus minor accidents from casual post-event observations. It is also questionable whether ex-post reaction should have a major influence on ex-ante decision making anyway. As remarked by HSE's former Director General "(one can be) over-impressed with the event and too little impressed by any precedent risk and benefit equation" (Rimington, 1993). There is, as this implies, always a tendency to be regretful after an accident, but in a real world characterised by uncertainty, trade-offs between risks and benefits have always to be made. Societal decision makers will also be well aware that accumulated individual losses generally outnumber those occurring through major events[10], even though the former attract far less news coverage.

Turning then, to the psycho-social research evidence on multiple fatality aversion, an appropriate starting point is the work of Slovic on public perception of hazards. He found (see, for example, Slovic *et al*, 1980) that a number of factors were influential in determining attitudes to hazards besides the probability of harm, and these included involuntariness, catastrophic potential, degree of personal control, equity, familiarity and complexity, some of which characteristics became collectively, and perhaps unfortunately, known as ‘dread’. Many of the hazards associated with so-called dread were associated with modern, large-scale technologies, lending credence to a view that there might be a simple connection between scale of consequences and public desire for control.

However, in another early and formative paper (Slovic *et al*, 1984), the question of public preferences regarding the weighting of multiple fatality accidents was itself directly addressed. There, the authors noted that most of the earlier proposals for modelling the impacts of multiple-fatality accidents had been based on some form of utility function asserting that the societal cost of N lives lost in a simple accident was a function of $N^{á}$, and that these models could be classified as risk neutral ($á = 1$), risk averse ($á > 1$), or risk prone ($á < 1$). As already indicated, when applied to FN curves, the value of á determines the gradient. In relation to the criteria and associated FN curves presented in Section 3 and Annex 2, most are based on an á value of one although the Dutch authorities have adopted a ‘risk averse’ á value of two.

Wilson (1975) proposed that risk aversion was best represented by an á value of two, whereas Ferreira and Slesin (1976) suggested an á value of three, the latter being based on a study of the actual gradients of FN curves constructed from historical data, and resting on the assumption that past actuality represented some kind of revelation of public or societal acquiescence. This was disputed on several grounds, including the one of whether history could be said to provide a guide for future decisions, and also on the practical point that few existing high consequence technological hazards would satisfy an N^3 criterion (Griesmeyer *et al*, 1979). Notwithstanding this, Griesmeyer & Okrent (1981) and others (Spangler, 1982) have argued for a modest degree of risk aversion in safety criteria for nuclear reactors by proposing an á value of 1.2 for early deaths.

Alternatively, Keeney (1980) has presented several pieces of evidence which suggest a public preference for risk proneness. One, carrying a measure of intuitive support, is that the public would regard the societal impacts of two major accidents involving, say, 50,000 and 100,000 fatalities as fairly similar. It is questionable whether such a preference, no doubt stemming from the well-known inability of individuals to discriminate between very large (or very small) numbers even when significantly different, is tenable on ethical grounds.

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[10] *The common examples are road transport and industrial accidents. However, there are counter examples such as air transport where the total number of fatalities is dominated by those associated with major accidents. For incidents involving hazardous materials, there is evidence to suggest that the scale of the incident (in terms of fatalities) is inversely proportional to its likelihood - in other words, incidents which kill 10 people or more are ten times more likely to occur than those which kill 100 or more (Haastrup & Rasmussen, 1994).*

Thirdly, the risk-neutral function also has its many advocates who would ascribe to the notion that ‘a life is a life’ and consequently that resources should be distributed so as to maximise life saving (see, for example, Zeckhauser & Viscusi, 1990). Slovic *et al* (1982) also came out very firmly against the view that social response to multiple fatality accidents reflects risk aversion, and conclude that the use of the á model for decision purposes is in most situations entirely inappropriate. To quote:

> *Research indicates that the societal costs of an accident cannot be modelled by any simple function of N. We have found that accidents are signals containing information about the probability of their recurrence in similar or more destructive forms. As a result, their seriousness is often determined more by the message they convey than by their actual toll of death and destruction. An accident that takes many lives may produce relatively little social disturbance if it occurs as part of a familiar and well-understood system (e.g. a train wreck). A small accident in an unfamiliar system whose risks are judged to be unknown and potentially catastrophic may have immense consequences if it portends further, possibly greater mishaps.*
>
> *The public perception of nuclear power risks as poorly understood and potentially catastrophic implies that nuclear accidents will be seen as extremely informative and ominous signals. Thus, another core-damaging accident similar to that at Three Mile Island would likely raise fears that the technology is out of control, even if few lives were lost and the physical damage was contained. The major costs of such an accident would not be those from immediate loss of life, latent cancers, and direct economic expenses (e.g. property damage, repairs, cleanup), important as these may be. Instead, the dominant costs will arise from secondary impacts such as public reaction leading to shutdown of the entire industry and the resulting higher order consequences (dependence on more costly and more dangerous energy sources, economic collapse), which could total tens or hundreds of billions of dollars.*

The conclusion from this is that the overall toll of major accidents cannot generally be predicted by $N^{á}$ models, though in some special circumstances the model may be useful, and that even where it can there is no hard evidence that á should differ from unity.

There is only a limited amount of more recent research on this topic, but what there is tends to support rather than contradict the above conclusion. For instance, Jones-Lee & Loomes (1995), in a study of transport safety, found that the risk of large-scale accidents on the London Underground contributed nothing whatsoever to public willingness-to-pay-based values of safety. Evans & Morrison (1997), in a study of underground and overground railway safety in Britain, concluded that a scale premium for major accidents may be warranted, but only because patronage might fall, at least temporarily, after an event. This type of premium, however, comes under the heading of business interruption costs and is a private (company) risk which would not necessarily figure in public policy. Ad hoc studies of the attitudes of MSc students on CERM Risk Management courses have likewise failed to come up with any preference for non-proportionate investment in the safety of multiple fatality hazards. By a substantial majority the preference expressed has been for risk neutrality, with a requirement that any additional consequences of major hazards be treated as discrete items (see Box 1 for details).

Box 1. MSc Students and Societal Risk Decisions

During each year from 1994/5 to 1996/7 a sample of undergraduates and postgraduates at the University of East Anglia was asked to discuss amongst themselves and then rate a series of hypothetical safety programmes involving a range of hazards with different characteristics. Most of these hazards entailed individual risks but some posed societal risks. The students were asked to rate the programmes from the perspective of a decision maker allocating resources (the methodology is similar to that given in Mendeloff and Kaplan, Risk Analysis, 9, 3, pp 349-363, 1989). The societal risk issues considered are listed below and were compared in pairs, R with S, and T with U (only the first pair was used in 1994/5).

Programme R: prevents 750 fatalities in a single major accident on a car ferry.
Programme S: prevents 750 fatalities in numerous small accidents on car ferries.
Programme T: reduces the risk of a Bhopal-type chemical incident in your home country. The expected number of fatalities would have been 500. Those affected would have died quickly.
Programme U: reduces the risk of a major radiation leakage in your home country. The expected number of fatalities would have been 500 due to cancer.

Of the 1994/5 students (n = 44), thirty-two rated R and S of equal priority, ten preferred R to S, and two S to R. Of those who preferred R, the main reasons given were public and media attention, lack of personal control in the case of R, and possible contributory negligence in the case of S.

The roughly forty students in 1995/6 and 1996/7 were split into four discussion groups prior to forming group views on preferences. In 1995/6 three of the four groups rated R equal to S, and T equal to U. One group preferred R to S, and one preferred T to U (because deaths from U were unattributable). In 1996/7 the results were almost identical, with R and S and T and U being regarded as of essentially equal priority.

However, contrary to the above, Hubert (1991) did find evidence for a desire to assign extra weight to potential accidents with high numbers of casualties, in a study which was carried out in the industrial area of Lyon (France). The main difference here was that the sample survey included not the public, but representatives of the petroleum, chemical and transport industries, plus national and local administrators and elected officials. The primary objective was to obtain by questionnaire and interview a quantitative measure of aversion to catastrophic accidents amongst these professionals. The results indicate that, for this group of respondents, aversion was important and could be represented by an FN curve with an á value close to two (ie very similar to the Dutch criteria discussed in the Section 3).

A possible conclusion from this is that there is very little evidence for differential risk aversion by the public where this is based upon numbers of fatalities. However, there is a hint at least from the French study, and also the Dutch societal risk criteria which emanated from the Dutch political system (Vrijling *et al*, 1995) that elected officials, senior administrators and risk managers may be averse to major accidents. That this group should be averse to high consequence accidents is hardly surprising, but whether this is attributable to enlightened self interest or to a professional assessment of the wider consequences of such events for society, is less easy to discern.

4.3.4 Other Types of Aversion

Although many practitioners in risk are referring to multiple fatality aversion when speaking of aversion, this interpretation is not universal. Indeed, the meaning of aversion can be quite subtle (Ball, 1990) and, for instance, Linnerooth (1990) sees it is a multi-dimensional concept, as have other authors including Marshall (1988) and Clements (1989) though via different perspectives. Thus, Linnerooth identifies two dimensions (or types) as:

- aversion to multiple fatalities from a common cause; and
- aversion to collective fatalities where there is little control.

It can be argued that common-cause, though dispersed, fatalities can be just as harrowing and hence deserving of the decision-makers' attention as the more conventional collective-fatality societal risk, even though the former may receive comparatively diffuse media attention. Marshall and Clements, on the other hand, have approached the matter by defining additional dimensions of harm besides fatalities. Typically these include immediate and delayed deaths, birth defects, disabling injuries, non-disabling injuries, psychological harm (which has proved very significant for those living in the vicinity of Chernobyl[11]), disruption of people`s ways of life, permanent evacuation, environmental consequences, and property damage and other financial loss.

4.3.5 Perception, Aversion and Policy

There is a spectrum of opinion on the merits of incorporating public perceptions and aversions into decision making. As the picture has tended to be painted, one end apparently belongs to those who believe that the public is irrational concerning risk issues and that decisions should be based on 'facts' whereas the other end takes the opposite stance believing that 'facts' are largely based on not much more than the perceptions of scientists and engineers and, if that be so, then it is perfectly legitimate to include other people's perceptions. As McDaniels *et al* (1992) have put it:

> *If one adheres to the view that subjectively defined welfare changes, reflecting personal views of well-being, are conceptually appropriate for valuing risk changes, then this model suggests that perceived characteristics will directly enter into evaluation decisions. On the other hand, if one's view is that public policies towards hazards should be based on objective, statistical risk and not subjective assessments, then these results suggest the importance of risk communication efforts to alter the public's perceptions and their resulting values for safety from different hazards.*

Most of those with responsibilities for risk decisions occupy middle ground, rather than the extremes. Lord Cullen, Sir Frank Layfield, the HSE and others have all commented on the need to incorporate perceptions and aversion into risk management decisions but by no means eschew technical risk analysis. Despite years of social science research, however, there is still widespread confusion on how a fusion of technical and perceptual information could or should be achieved.

One of the reasons for this is that there has been a failure to build substantially upon the pioneering research of Slovic *et al* (1980) in a way which is helpful for policy formation. Much of what has been done, as pointed out by Covello (1983) and which is still true today, has taken the form of survey research which has been found to be subject to serious, even crippling, limitations. That these limitations should exist is none too surprising, for many policy issues are highly complex. Hence it could not reasonably be expected that members of the public would be

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[11] *See, for example, the numerous papers presented at the Society of Risk Analysis (Europe) Conference held in Stockholm in 1997.*

able to provide other than superficial responses to the kinds of questions posed in these surveys, questions which, though simplified, still carry diverse and complicated implications for thoughtful respondents whose beliefs may, in addition, be vague, ill-formed or even non-existent at the point of questioning (Lichtenstein *et al*, 1990). The consequences of this (Covello, 1983) are that:

- people typically respond to survey questions with the first thing that comes to mind and then become committed to their answer;

- people typically provide an answer to any question posed even though they may have no opinion, do not understand the question, or hold inconsistent beliefs; and

- survey responses are influenced by the order of questions, whether the question is open or closed, supplementary information, interviewer prompting, and how the question is posed.

Worse still is the now common knowledge that normal people do not cope well when confronted with risk problems and decisions. Human intellectual limitations require all of us to simplify problems, making use of inferential or judgmental rules known technically as heuristics. Two of the most important of these are *information availability*, or the tendency for people to judge an event more frequent if instances of it are easy to imagine or recall, and *representativeness*, or the tendency to assume that ‘roughly similar’ activities and events (such as nuclear power and nuclear weapons) have the same characteristics and risks. These judgmental operations enable people to reduce difficult probabilistic and assessment tasks to simpler tasks but they also lead to severe and systematic biases and errors (Covello, 1983 and Lichtenstein *et al*, 1990). This is particularly true in the case of low probability high consequence events which are difficult to imagine and of which individuals have little practical experience.

As described elsewhere (Ball *et al*, 1998), similar criticisms have been levelled at comparable techniques for eliciting views on public safety using contingent valuation (willingness to pay) surveys[12] (Diamond & Hausman, 1994; Ives *et al*, 1995; Swaney, 1997), hypothetical questions (Dorman, 1996) and expected utility theory (Camerer & Kunreuther, 1989). Furthermore, the very design and presentation of the questions used in surveys can influence the results (Wagenaar *et al*, 1988), although the introduction of such potential biases can be controlled.

The relevance of this for highly complex issues such as societal risk is that surveys of perceptions and individual willingness to pay, and concepts such as ‘dread’, are of limited usefulness to decision makers. This is partly because of the methodological problems and cognitive limitations described above. But it is also because the main point is largely missed, which is how to make reasonable decisions in a complex world of conflicting and changing values, where trade-offs have always to be made, often against a background of considerable uncertainty.

The continuing assignation of the term ‘dread’, for example, to comparatively new or emerging technologies such as nuclear power and biotechnology, is of little practical use to decision makers and may even be damaging to society, for dread implies ‘clamp down’ if not ‘ban outright’, whereas what should be done is to elaborate the risks and benefits of particular options and compare these with societal goals prior to making decisions. Dread, after all, does not necessarily imply a lack of acceptance. A visit to the dentist may be dreaded, but the alternative, most would agree, is worse. Certain aspects of nuclear power and biotechnology may, quite reasonably, be

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[12] *Indeed, HSE and NRPB, in a joint study of public willingness to pay for safety in 1988 (HSE, 1989b), decided to abandon the project after the pilot stage owing to the volatility of the survey responses.*

dreaded, but both may also provide huge opportunities. Nuclear power, the subject of countless opinion surveys which, by sheer repetition alone, may have increased the perceived probability of the hazard (Covello, 1983), is certainly not risk free but then, nor are any of the alternatives including the renewables (Ball & Roberts, 1995).

Thus, in our view, the central issue is really not about how dread and other perceptions should be incorporated into risk criteria, for they themselves are at best only indicators of broader underlying issues or, in some cases, misunderstandings. What do matter, however, are societal values and it may well be that this is what was implied by Lord Cullen and Sir Frank Layfield rather than perceptions *per se*. Identifying values, specifying goals and then assessing alternative strategies for achieving these goals in terms of the values would appear to be the optimum way, if not the only way, to proceed.

4.3.6 Summary

Though documented evidence is sparse, nowhere have we found any compelling support or arguments for an ex-ante stance of other than risk neutrality in societal decision making. Cogent philosophical and ethical arguments for risk neutrality have been put by Lichtenstein *et al* (1990), a position which has been endorsed by many other authors in both the public and private sectors at one time or another. On practical grounds too, the alternative of introducing weighting factors into FN criteria is questionable, for it does not hold out the promise of good decisions in most cases since these factors:

- are hidden from the decision makers which is generally considered to be undesirable, (ACDS, 1991 and HM Treasury, 1996);
- are unlikely to be proportionate to other consequences of societal hazards as is sometimes claimed; and
- no more guarantee the occupation of the moral high ground than could be achieved by the option of risk neutrality (Munthe, 1997).

Additional consequences and issues would better be dealt with by their inclusion as discrete supplementary factors in the decision process so that they may be considered on their own merits and by whatever tools are best suited for the purpose. Thus, for societal risk criteria based on FN lines, the clear implication is for a slope whose magnitude is unity (as consistently adopted in the UK and Hong Kong).

4.4 SOCIETAL RISK CRITERIA IN PRACTICE

4.4.1 Need for Criteria

As amply demonstrated by the historical record, multi-fatality disasters are a regular occurrence. Although disasters involving thousands of fatalities tend to be associated with ‘natural’ events (floods, droughts, etc) in Asia and Africa, lesser disasters involving tens of fatalities occur routinely in Europe. In the UK, there have been a number of such incidents in recent years: the Bradford City football stadium fire (1985), the fire at Manchester airport (1985), two helicopter crashes (1986 and 1994), the capsizing of the *Herald of Free Enterprise* (1987), the King’s Cross fire (1987), the loss of the Piper Alpha platform (1988), the Clapham train crash (1988) and the sinking of the *Marchioness* (1989).

In order to minimise the occurrence of future disasters and to assist those responsible for public safety, a range of techniques have been developed over the last 30 years or so to provide a means to predict the risks associated with a range of hazardous activities and operations. Collectively, these techniques form quantitative risk assessment (QRA).

Although it is generally accepted that QRA results are uncertain, they do provide a means to indicate, in quantitative terms, the risks associated with particular hazards. When the prime concern is the possibility of human fatalities, the results may be expressed in terms of the level of risk to the individual or in terms of the risk to society as a whole. The latter often takes the form of an ‘FN curve’ in which the likelihood (F) of N or more fatalities is plotted against N.

The presentation of an FN curve in isolation or, indeed, in comparison with FN curves derived for other hazards is unlikely to provide a readily accessible basis for taking robust decisions in which ‘risk’ is a significant factor. For this reason, it is desirable to provide appropriate criteria against which QRA results for particular hazards can be compared.

Of course, in reaching a particular conclusion, the decision maker must take into account numerous factors of which societal risk is just one - and, for this reason alone, it is considered that societal risk ‘criteria’ should be regarded as no more than ‘indicators’ or ‘guidelines’.

4.4.2 Development of Criteria

In relation to the setting of risk criteria, one view which is sometimes expressed is that the individual is primarily concerned about individual risk (ie risk to self) while the ‘state’ should be concerned about societal risk. To some extent, this view is borne out by the studies into risk perception - although perhaps this is simply a function of the complexity of the issue. Furthermore, it is noteworthy that the societal risk criteria discussed in Section 3 (and Annex 2) have all been developed by Government authorities or agencies without a direct input from the people that are exposed to the risks. Nevertheless, as noted above in relation to aversion factors, those responsible for setting criteria may well take into account their perceived view of what would be ‘socially’ and ‘politically’ acceptable.

4.4.3 Multiple Fatality Aversion

As discussed above, there appear to be few persuasive arguments for the aversion factor to be other than unity (ie risk neutral). In establishing criteria, consideration is often given to the historical record and it is of note that there are numerous studies of historical FN data showing an approximate slope of -1 over the range of, say, 1-100 fatalities (including: Fernandes-Russell (1988); Romer *et al* (1993); and Haastrup & Rasmussen (1994)).

However, perhaps of more weight is the practical implication of a steep (ie risk averse) societal risk FN line (such as adopted in the Netherlands). The prime difficulty is that at lower likelihoods, the greater the degree of uncertainty in risk analysis. Thus, at very low likelihoods of the order of 10^{-7} and 10^{-8} per year, it is very difficult to justify the robustness of the risk results. Similar difficulties can be encountered in Hong Kong, in which given the very high population density, it is sometimes difficult to ‘prove’ that events occurring at frequencies above 10^{-9} per year will not result in more than 1,000 fatalities.

At this point, it is important to emphasise that the events which make up the low likelihood:high consequence end of the societal risk spectrum are usually dominated by remote catastrophic events (as opposed to a combination of ‘smaller’ events). Thus, in assessing the risks associated with hazardous installations, remote events such as the ‘instantaneous’ failure of a large storage tank releasing hundreds (or even thousands) of tonnes of flammable or toxic materials will be the events which can lead to, say, 100 or more fatalities. In general terms, there is very little (if any) historical experience of such events and the assigned estimate of its predicted occurrence is as much an expression of belief as a statement of scientific fact. However the assignation of such values can determine whether the associated risks are judged to be ‘acceptable’ or not. This, of course, can lead to pressure being applied to those producing the numbers to ensure that the results fall on the ‘right’ side of the criteria.

4.4.4 Reliability of Results

It has been shown (Evans & Verlander, 1996) that the manner in which societal risk criteria are applied may influence the outcome. However, the proposal here is that societal risk criteria should not be used in a ‘prescriptive mode’. As already indicated, given the degree of uncertainty associated with the determination of societal risks, it is widely accepted that societal risk criteria (in the form of FN lines) should be regarded as no more than indicators or guidelines. Indeed, this view has been reflected in the most recent developments of criteria in the Netherlands and for some forms of dangerous goods transport in Hong Kong (see Sections A2.5.3 and A2.5.4). The notion of societal risk criteria as ‘guidance only’ has also been expressed in the UK (eg ACDS, 1991).

Furthermore, it is important to reiterate that even where societal risk criteria are rigorously applied (which is not a position advocated in this report), they do not provide the sole measure of risks. For example, for a development of, or near to, a Potentially Hazardous Installation (PHI) in Hong Kong, the following criteria must be satisfied:

- the individual risk (for the person at most risk) must be below the Individual Risk Guidelines (ie less than 1 in 100,000 per year of becoming a fatality); and

- the societal risks (as represented by FN curves) must lie totally below the ‘unacceptable’ region.

If both these criteria are not satisfied, the proposed development will not (normally) be permitted to proceed. If these two criteria are satisfied, then a third criterion is applied IF any part of the FN curve lies above the ‘acceptable’ region (ie within the ALARP region):

- the societal risks must be reduced in accordance with ALARP.

The application of the ALARP principle is based on the determination of Probable (or expected) Loss of Life Values ($PLL = \Sigma f_i N_i$) multiplied by a ‘value of a life’ (V) to give an overall ‘disutility’ function. The ‘cost-effectiveness’ of a risk reduction strategy is then evaluated as follows:

$$\text{IF } (PLL_{before} - PLL_{after}) \text{ x } V > \text{Cost of the Risk Reduction Strategy}$$

then the strategy is ‘cost-effective’ and should be implemented in accordance with the ALARP principle. It should be noted that, in practice, the value of V varies depending on where the (before) FN curve lies with respect to the Societal Risk Guidelines (the closer the curve to the unacceptable region, the higher the value of V).

4.4.5 Setting Criteria

For any particular hazard with the potential for large scale consequences, it should be clear that the setting of appropriate societal risk criteria requires careful consideration of numerous factors. As detailed in Annex 2, existing criteria may be characterised in terms of:

- ***applicability*** - in all cases, the ‘hazard’ covered by the criteria must be defined. For example, Annex 2 describes criteria applicable to any one of a group of hazardous installations while others are applicable to the overall risks associated with a set of nuclear reactors. Criteria for the transport of dangerous goods have been developed for the transport of particular substances as well as for communities exposed to a range of transport hazards;

- ***nature of harm*** - most criteria are based on consideration of ‘prompt’ human fatalities (as first discussed in Section 2.4) although, for the nuclear case at least, it may also be necessary to consider ‘delayed’ deaths. Although fatalities may be regarded as an indicator of other types of harm (environmental, material, financial, etc), the development of a comprehensive ‘harm index’ is complex - although attempts have been made to do this in Switzerland;

- ***those at risk*** - for installations, distinctions are sometimes made between workers on the site and the general public beyond the boundary fence (the off-site population). Although most criteria focus on off-site populations, some are directly associated with workers (such as the criteria for UK off-shore installations). In some cases, it may be necessary to further define the activities of the off-site population (workers at nearby installations, nearby residents, transient populations associated with road/rail traffic, etc). ACDS (1991), for instance, make the point that where “a small, isolated community” such as a village is exposed to a societal risk, then it would be reasonable to consider stricter criteria because of the impact which a major accident would have upon that community.

- ***aversion*** - as discussed above, the selection of a gradient of -1 for FN-based criteria appears reasonable; and

- ***anchor points*** - as summarised in Section 3.6, anchor points for particular criteria have been derived by different means. Clearly, in setting criteria, careful consideration will need to be given to the selection and justification of anchor point(s). This, in turn, will be influenced by existing criteria which may or may not be directly transferrable to the situation of interest as well as other factors such as public concern, political interest, etc.

As indicated above, the ‘risk regulators’ will normally be left to develop societal risk criteria. To undertake this task, the regulator will need to carefully define the parameters associated with the subject of interest. In an ideal world, there would be a close correlation between these parameters and those associated with existing criteria. By way of example, consider the hypothetical case of where the regulators wished to develop criteria for those living near to reservoir dams. This task would be facilitated if there were already FN-based criterion lines for those living near to a hazardous installation, since in both cases the prime focus would be the risk of residents within a well defined community being killed in the event of a major incident. Of course, in setting the anchor points, consideration would need to be given to not only whether particular standards could be achieved in practice but also, if there were to be significantly different standards for dams and hazardous installations, how could/would this be justified (different levels of public concern, different technologies, different risk/benefit relationships, national importance, etc).

In any event, the prime purpose of the resulting criteria or, preferably, ‘guidelines’ would be to provide assistance to those associated with both the generation of societal risks (‘industry’) and the protection of public safety (the ‘regulators’) - particularly in the ‘grey’ area between those risks which are neither so high as to be obviously intolerable nor those which are so low as to be obviously negligible. It is important to re-emphasise that the use of societal risk guidelines does not preclude the other means of assessing the tolerability of risks (such as consideration of individual risk levels or compliance with the ALARP principle).

Finally, the successful application of societal risk guidelines will depend on the robustness of the results from QRAs. Where considerable data on past incidents world-wide exist, it would seem likely that careful analysis could produce a reasonably robust site-specific QRA. This would be expected to be the case for all forms of conventional passenger transport. For hazardous installations (such as oil, chemical and nuclear facilities) and the transport of dangerous goods, although the incidence of major incidents is rare, there is usually sufficient data on smaller (or similar) incidents to synthesise an analysis - albeit with some uncertainty. However, for new or emerging technologies, such as the use of genetically modified organisms, or in extending the coverage of criteria to the ‘environment’ for example, there are much greater uncertainties. In these cases, the development and application of societal risk guidelines will require considerable caution.

5. THE WAY FORWARD?

5.1 OVERVIEW

This project has reviewed, albeit briefly, the evolution of societal risk criteria against the backdrop of major accident events. The project has also explored a selection of the more relevant psycho-socio-economic literature which sheds light on societal risk issues. From this we now attempt to provide suggestions, or comments at least, on a number of topical issues pertaining to societal risk. For the most part these should be taken as perhaps not much more than pointers for further discussion since there has been rather limited debate outside of certain select groups and the occasional Public Inquiry to date.

5.2 DEFINING SOCIETAL RISK

It is clear that, as with terms like ‘risk ranking’ and even ‘risk’ itself, there is not a universally agreed definition of ‘societal risk’, and different authors have tended to come up with definitions which are often linked to their own professional perspectives. Our view is that, even if a single agreed definition of societal risk could be achieved in, say, the major hazards sector in the UK, it is unlikely that other sectors would fall in line in the near future and even less likely that international consensus would be achieved because of semantic difficulties if nothing else. This, however, while problematical in some respects, does at least allow flexibility in addressing what is undoubtedly a complex, and as yet, modestly-researched topic. What would be worse, in our view, would be the premature adoption of a definition which impeded the evolution of thought on such an important topic. Having said this, it is important that when authors write about societal risk they make it clear what definition they have in mind.

5.3 TYPES OF SOCIETAL RISK

The types of societal risk expression which practitioners need to be aware of range from the narrowly-defined, multi-fatality criterion of the type commonly encountered in FN diagrams to the much more broadly-defined 'societal concerns' formulation apparently favoured *inter alia* by some members of the HSE which permits inclusion of all and any potential impacts of major accidents or, even, entire technologies or strategies. Some authorities (notably in Switzerland) have made a positive attempt to incorporate such considerations into setting criteria (for accidents at least).

With these points in mind, we have suggested three broad categories of ‘societal risks’:

- those associated with ‘normal’ exposure to harmful materials which produce, say, several cancer deaths across a wide population for which we suggest the term ‘collective risks’ is used;
- those associated with accidents which could result in multiple fatalities and/or other significant impacts for which we suggest the term ‘societal risks’ is retained; and
- those associated with the overall impacts of particular technologies or strategies for which we suggest the term ‘societal concerns’ continues to be used.

5.4 TYPES OF CRITERIA

For ‘collective risks’, we believe that the associated criteria of acceptability or tolerability will be largely based on individual risk criteria and cost-benefit analysis.

For ‘societal risks’, we believe that the now familiar FN-based criteria are appropriate. In some cases at least, the use of ‘fatalities’ as an indicator of the consequences appears appropriate. In other cases, it would be desirable to further develop a broader measure of potential consequences (including environmental damage and financial loss).

For ‘societal concerns’, we see little prospect of developing criteria which would be universally applicable. Complex issues of this kind will need to be dealt with by whatever techniques and criteria are best suited to the particular purpose.

5.5 PRESCRIBING CRITERIA

Focusing first on multi-fatality aversion, although it is a widely-held view in some circles that the public are ‘averse’ to major consequence hazards there is very little supporting ex-ante evidence to substantiate this. Indeed, we have found little evidence to suggest that a ‘risk neutral’ position is inappropriate. In relation to FN curves, this risk neutral position has been taken as gradient of -1 (although due to the underlying mathematics this, in fact, carries a degree of risk aversion) which is used in societal risk criteria in Hong Kong and the UK although in the Netherlands, steeper gradients are used (*ie* the Dutch authorities are ‘risk averse’).

Of course, in prescribing FN criteria, it is necessary to ‘anchor’ the curve. As has been described, anchor points have been arrived at by a variety of techniques ranging from the analytical, to the use of expert judgement, or by ‘bootstrapping’ to earlier societal risk decisions, or by any combination of these. At present, it is not possible to identify any simple approach as universally preferable - all have their strengths and limitations. The position taken in the UK has largely been to rely upon a hybrid of bootstrapping and professional judgement as a means of producing guidelines, but with continuing pressure to reduce societal risks in accordance with the ALARP principle. There is no evidence to suggest that this is not a reasonable approach to adopt.

Given an ‘anchor’ and a gradient, the resultant societal risk criteria can be prescribed. Given the inherent uncertainties of risk assessment techniques - particularly in relation to ‘low frequency/high consequence’ events - there is considerable merit in regarding FN criteria as ‘guidelines’ rather than rigid standards. Indeed, this view has been reflected in the most recent developments of criteria in the Netherlands and for some forms of dangerous goods transport in Hong Kong.

More generally, we believe that, for some applications, there is potential in further developing criteria (or guidelines) based on more than just fatalities.

5.6 PUBLIC POLICY AND PERCEPTIONS OF RISK

There has been considerable interest of late in how and the extent to which public perceptions might or should be incorporated into policy decisions. Our view is that the key point may have been missed, for it is not perceptions as such that count, but *values*. For instance, some things may be perceived as having undesirable features, but may still present the best option even in the eye of the beholder. What is needed therefore, is a proper evaluation of the full range of potential impacts, beneficial and prejudicial, of any project against publicly-supported criteria of assessment. This we might refer to as addressing ‘societal concerns’ in which consideration of both ‘collective risks’ (ie those associated with ‘normal’ operations) and ‘societal risks’ (ie those impacts associated with accidents) would play a part.

5.7 WHOSE RESPONSIBILITY TO DEVELOP CRITERIA?

Safety cases are generally the responsibility of the duty holder. It has also been said that criteria for assessment are the responsibility of the duty holder (DEn, 1990). Certainly, individual industries have to have a role in management decisions about societal risk because some factors which need to be considered will relate to non-public concerns such as business interruption costs, public confidence in an enterprise, and so on.

The importance of these issues has already been recognised by the more highly developed major industries including nuclear, off-shore, and air and rail transport - often as a result of a major disaster.

Not all duty holders will be so advanced in their thinking, however, and here, in particular, we believe there is an important role for the HSE in providing guidance if not ratification. Other agencies, too, will need to play a role, such as local planning authorities, but these too are likely to need support in dealing with some of the more complex policy issues.

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ANNEX 1. MATHEMATICS OF SOCIETAL RISK

A1.1 INTRODUCTION

The results of calculations of societal risk are often presented in graphical form. Such graphs are normally ‘log-log’ plots with the x-axis representing the consequences and the y-axis representing their likelihood of occurrence.

In assessing the risks associated with hazardous installations or activities, the consequences are often ‘measured’ by the number of fatalities (N). The associated likelihood (or expected frequency) is normally expressed in terms of events per year.

In many cases, the likelihood of multi-fatalities is very remote and, as a result, the likelihoods are usually expressed in the form 4.5 x 10^{-5} per year or 4.5E-05 per year. A value of 4.5 x 10^{-5} per year is equivalent to 4.5 chances in 100,000 per year or, more simply, one chance in 22,000 per year.

Societal risks may be plotted on a ‘non-cumulative’ basis and referred to as ‘fN curves’ or on a ‘cumulative’ basis and referred to as ‘FN curves’. The differences between these are discussed further below.

A1.2 fN vs FN CURVES

To illustrate how societal risks may be presented as fN or FN curves, consider the (hypothetical) results presented in Table 3 obtained from a quantitative risk analysis (QRA) covering ten events which could result in multi-fatalities.

Table 3
Sample QRA Results

Event	No. of Fatalities, N	Likelihood, f, per year
1	12.1	4.8E-03
2	123	6.2E-06
3	33.4	7.8E-03
4	33.2	9.1E-04
5	29.2	6.3E-03
6	15.6	7.0E-04
7	67.3	8.0E-05
8	9.5	4.0E-03
9	52.3	1.2E-06
10	2.7	3.4E-04

It will be immediately noted that, contrary to views expressed by some authors, the fatalities are not integers. This is because the fatalities have been generated on a probabilistic basis and it may be the case that the number of fatalities will depend on the probability of the wind blowing in a particular direction. Similarly, if the results were based on averaging the consequences of past incidents, then non-integers would be expected.

Rearranging the data in ascending order of the number of fatalities gives the data set presented in Table 4.

Table 4
QRA Results by Increasing N

No. of Fatalities, N	Likelihood, f, per year	Event
2.7	3.4E-04	10
9.5	4.0E-03	8
12.1	4.8E-03	1
15.6	7.0E-04	6
29.2	6.3E-03	5
33.2	9.1E-04	4
33.4	7.8E-03	3
52.3	1.2E-06	9
67.3	8.0E-05	7
123	6.2E-06	2

The results can now be plotted on a ‘fN curve’ as shown in Figure 2 - but as can be seen, this form of presentation does not provide information which can be readily interpreted. Another form of presentation is to present the variation of likelihoods with ranges of consequences. Such an approach is illustrated in Table 5 and Figure 3.

Table 5
QRA Results by Ranges of N

No. of Fatalities, N	Likelihood, f, per year	Events
1-10	4.3E-03	10, 8
10-30	1.2E-02	1, 6, 5
30-100	8.8E-03	4, 3, 9, 7
100-300	6.2E-06	2

However, the form of presentation which has now gained general acceptance is the cumulative

‘FN curve’ in which F is the likelihood of N *or more* fatalities. The associated societal risk data is presented in Table 6 and as an ‘FN’ curve in Figure 4.

Table 6
‘FN’ presentation of QRA Results

No. of Fatalities, N	Likelihood, F, per year	Events
1 or more	2.49E-02	1-10
3 or more	2.46E-02	1-9
10 or more	2.06E-02	1-7, 9
30 or more	8.80E-03	2-4, 7, 9
100 or more	6.20E-06	2
300 or more	not credible	none

A1.3 PRESENTATION OF SOCIETAL RISK CRITERIA

As discussed elsewhere in this report, societal risk criteria are generally presented as ‘lines’ on FN plots. Mathematically, such expressions may be presented as:

$$F \text{ x } N^{\alpha} = k$$

where, F = the likelihood of N or more fatalities
N = the number of fatalities
α = ‘aversion’ factor
k = constant

Care needs to be taken in interpolating between such criteria and fN (ie non-cumulative based) criteria. The underlying mathematics has been explored in a number of papers[13] from which a number of points emerge:

- as would be expected the greater the degree of aversion (as measured by α), the steeper the line slope (in fact, the gradient on a log-log plot is $-\alpha$);
- if fN data are translated to FN data (or vice-versa), the FN line lies above the fN line;
- derived mathematical expressions (such as $3FN = 3\frac{1}{2} f \{N^2 + N\}$) rely on consideration of f and F values (including zero values) for each and every integer value of N.

To illustrate these points, the following criteria were considered:

$$fN^2 = 1E\text{-}03 \quad \text{and} \quad FN^2 = 1E\text{-}03$$

For the fN-based criterion, values of f were computed for every integer value of N between 1 and 1000 (taken to be N_{max}). From this data set, the corresponding values of F (ie likelihood of N or

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[13] *See, for example, ACDS (1991), Schofield (1993) and Hirst (1998).*

more fatalities) were also computed. Similarly, starting with the FN-based criterion, values of F were computed for each and every integer value of N and, from these, the corresponding values of f were computed. The results are illustrated in Figure 5.

From Figure 5 the following observations can be made:

- if the criterion ‘line’ is taken as an FN line with a slope of -2, then the corresponding fN line is steeper with a slope of about -3. Similarly, the use of a so-called ‘risk neutral’ slope of -1 on an FN criterion line corresponds roughly to a ‘risk averse’ slope of -2 on the resulting fN plot; and

- if the criterion ‘line’ is taken as an fN line with a slope of -2, then the corresponding FN line is shallower with a slope of about -1.2 over the range of 1 to $N_{max}/2$.

Interestingly, if the exercise is repeated for a discrete set of N values rather than a continuous set, different results emerge. Using the data set presented in Table 7 produces the results shown in Figure 6.

Table 7
fN vs FN Criteria

Number of Fatalities, N	f values derived from FN-based criteria	Criteria based on f or F x N^2 = 1E-03	F values derived from fN-based criteria
1	7.5E-04	1.0E-03	1.4E-03
2	1.9E-04	2.5E-04	3.6E-04
4	3.5E-05	6.3E-05	1.1E-04
6	1.8E-05	2.8E-05	4.4E-05
10	6.1E-06	1.0E-05	1.6E-05
16	2.4E-06	3.9E-06	6.3E-06
26	9.1E-07	1.5E-06	2.4E-06
42	3.5E-07	5.7E-07	9.2E-07
68	1.3E-07	2.2E-07	3.5E-07
110	5.1E-08	8.3E-08	1.3E-07
178	2.0E-08	3.2E-08	5.1E-08
288	7.5E-09	1.2E-08	1.9E-08
466	2.8E-09	4.6E-09	7.0E-09
754	1.1E-09	1.8E-09	2.4E-09
1220	6.7E-10	6.7E-10	6.7E-10

As can be seen, the selection of a smaller data set results in a different picture in that both the FN and fN lines are essentially parallel to the criterion line although the relative positions of the FN, criterion and fN lines remain as before.

A1.4 INDIVIDUAL vs SOCIETAL RISK

A1.4.1 Introduction

Although the precise relationship between individual and societal risk will vary with the particular hazard under consideration, the two are linked.

A1.4.2 Fatality Probabilities

To illustrate the linkage, consider a hazardous installation for which three hazardous events have been identified, each of which has an associated 'hazard range' (ie the maximum distance at which fatalities could occur). Furthermore, it has been assumed that the relationship between fatality probability and distance (along the effects axis if appropriate) can be characterised using the expression below (with the implicit assumption that FP = 1 at R = 0):

$$FP = 0.5 \times \{1 + \cos(\pi R / R_{max})\}$$

where, FP = fatality probability (range 0-1)
R = distance from hazard (m)
R_{max} = hazard range (m)

Using this expression for each of three events generates the fatality probabilities in Table 8 which are illustrated in Figure 7.

Table 8
Fatality Probabilities by Event and Distance

Event	1	2	3
R_{max}	260m	360m	500m
Distance from hazard, R = 50m	0.911	0.953	0.976
100m	0.677	0.821	0.905
150m	0.38	0.629	0.794
200m	0.126	0.413	0.655
250m	0.004	0.213	0.5
300m	0	0.067	0.345
350m	0	0.002	0.206
400m	0	0	0.095

A1.4.3 Determination of Individual Risks

Now if the likelihoods of events 1, 2 and 3 were estimated to be 1.0×10^{-3}, 1.0×10^{-4} and 5.0×10^{-6} per year respectively, it is then possible to derive the variation of individual risk with distance. For the purposes of this example, it will be assumed that the wind is a factor (as would be the case for a toxic gas release) and the probability of the wind blowing in any particular direction will be taken as 0.1. At each point, the contribution to individual risk can then be calculated as follows:

$$IR_{i,j} = f_i \times FP_{i,j} \times P_{wd} \times P_{occ}$$

where, $IR_{i,j}$ = individual risk component for the *i*th event at the *j*th location
$FP_{i,j}$ = fatality probability for the *i*th event at the *j*th location (from above)
P_{wd} = wind direction probability (taken as 0.1)
P_{occ} = probability of occupancy, non-escape, etc. (taken as unity)

The resultant contributions to individual risk are shown in Table 9 and the overall variation in individual risk with distance is shown in Figure 8.

Table 9
Individual Risk Calculations

Distance from source, R (m)	**Individual Risk by Event**			
	1	**2**	**3**	**Overall**
50	9.1E-05	9.5E-06	4.9E-07	1.0E-04
100	6.8E-05	8.2E-06	4.5E-07	7.6E-05
150	3.8E-05	6.3E-06	4.0E-07	4.5E-05
200	1.3E-05	4.1E-06	3.3E-07	1.7E-05
250	3.6E-07	2.1E-06	2.5E-07	2.7E-06
300	0	6.7E-07	1.7E-07	8.4E-07
350	0	1.9E-08	1.0E-07	1.2E-07
400	0	0	4.8E-08	4.8E-08

It can be seen, for example, that at 200m the individual risk is about 1.7×10^{-5} per year reducing to 8.4×10^{-7} per year at 300m.

A1.4.4 Determination of Societal Risks

Now in order to compute societal risks, it is necessary to consider the population at risk. For the purposes of this example, it will be assumed that there are three areas of population at risk (A, B, C). These areas are located at distances of 200m, 300m and 350m from the hazard with populations of 20, 100 and 250 respectively. To calculate the overall societal risks, it is necessary to evaluate the numbers of fatalities within each area for each event (to give 9 'fN' pairs). For Area A and Event 1, the calculation would appear as:

Likelihood of Event 1= 1 x 10^{-3} *per year*
Probability of wind direction towards Area A= 0.1
Fatality Probability at Area A= 0.126 (from Table 8)
Number of people at risk (in Area A)= 20
Number of fatalities (in Area A)= 2.5 (from 0.126 x 20)
Associated likelihood= 1 x 10^{-4} *per year*

Repeating this exercise for the other combinations gives the results shown in Table 10.

Table 10
Generation of 'fN pairs'

Area	Event	Fat. Prob.	No. at risk	N_i	f_i
A	1	0.126	20	2.5	1.0E-04
A	2	0.413	20	8.3	1.0E-05
A	3	0.655	20	13.1	5.0E-07
B	1	0	100	0	1.0E-04
B	2	0.067	100	6.7	1.0E-05
B	3	0.345	100	34.5	5.0E-07
C	1	0	250	0	1.0E-04
C	2	0.002	250	0.5	1.0E-05
C	3	0.206	250	51.5	5.0E-07

The results can then be rearranged (by increasing N) to give the overall societal risks as shown in Table 11 and as plotted on Figure 9.

Table 11
Generation of FN Data

Number of Fatalities, N	Likelihood, f, of N Fatalities	Likelihood, F, of N or more Fatalities
0.5	1.0E-05	1.3E-04
2.5	1.0E-04	1.2E-04
6.7	1.0E-05	2.2E-05
8.3	1.0E-05	1.2E-05
13.1	5.0E-07	1.5E-06
34.5	5.0E-07	1.0E-06
51.5	5.0E-07	5.0E-07

A1.4.5 Summary

This example has been presented to illustrate how individual and societal risks are derived from data on incidents and the population at risk. In the example, consideration was given to events which were directional. However, since the associated wind direction probabilities were factored into both sets of calculations, the overall relationship between the individual and societal risk would be the same for an omni-directional event (such as the effects of an explosion or major fire).

From the results, those at greatest risk would be those closest to the hazard (ie those in Area A with an individual risk of 1.7 x 10^{-5} per year). For comparison, the calculated value for 10 or more fatalities is about 5 x 10^{-6} per year. Although the precise relationship between individual and societal risk values depends on numerous factors, this example provides an indication of the sort of relationship in numerical values that would be expected.

A1.5 OTHER MEASURES OF SOCIETAL RISK

A1.5.1 PLL or EV

Another form of risk measurement is the use of ‘probable loss of life’ (PLL) values (sometimes referred to as ‘expected values’ (EV)). Using the figures generated in the above example, the PLL values can be calculated for each Area as follows:

$$PLL_i = n_i \text{ x } IR_i$$

where, PLL_i = probable loss of life (‘statistical’ lives lost per year)
n_i = number of people at risk
IR_i = level of individual risk

For Area A, with an individual risk level of 1.7 x 10^{-5} per year and a population of 20, the associated PLL value would be: 3.4 x 10^{-4} per year (or 1 life would be lost, on average, every 3,000 years). Mathematically, this value is the same as derived from ' f_iN_i.

In comprehensive quantitative risk assessments (QRAs), the normal procedure is to identify numerous accident scenarios (by size of event, time of event, different weather/wind conditions, etc) and evaluate f_i, N_i and PLL_i for each and every case.

Although PLL values are very useful in comparing the benefits in risk terms from ‘before’ to ‘after’ safety improvements they do not provide a comprehensive measure of societal risks. This is primarily because PLL values do not differentiate between low likelihood/high consequence and high likelihood/low consequence events.

A1.5.2 Scaled Risk Integral

HSE provides advice to local planning authorities on land-use in the vicinity of hazardous installations. To assist in providing advice on the 6,000 planning applications received each year by HSE, the Major Hazards Assessment Unit (MHAU) has developed a simplified screening tool known as the Scaled Risk Integral (SRI).

Originally described by Carter (1995), the Risk Integral is defined as:

$$RI = 3F_i N_i \text{ (for } i = 1 \text{ to } N_{max})$$

where, RI = risk integral
F_i = likelihood of N_i or more people being exposed to a prescribed level of harm
N_i = number of people exposed to a prescribed level of harm

Furthermore, Hirst (1998) has shown that:

$$\Sigma F_i N_i = \Sigma \tfrac{1}{2} f_i N_i (N_i + 1)$$

where, f_i = likelihood of N_i people exposed to a prescribed level of harm

Now, for a group of people exposed to the same level of risk (as would be expected for a discrete development in the vicinity of a hazardous installation), it might be possible to postulate a single event which could result in N_{max} fatalities (say). Clearly such an event would also result in N_{max} - 1 or more fatalities, N_{max} - 2 or more fatalities, etc.

If there were no other hazardous events to consider, then the associated values of F for 1 or more fatalities, 2 or more fatalities, etc. would be the same so that the Risk Integral would become:

$$\begin{aligned} RI &= \Sigma F_i N_i \text{ (for } i = 1 \text{ to } N_{max}) \\ &= F\, \Sigma N_i \text{ (for } i = 1 \text{ to } N_{max}) \\ &= F N_{max} (N_{max} + 1) /2 \end{aligned}$$

Now Carter (1995), defines the Scaled Risk Integral as

$$SRI = IR \times n\,(n + 1)/2 \times P_{occ}/A$$

where, IR = individual risk level (in chances per million per year - cpm)
n = number of people in the development
P_{occ} = occupancy factor
A = development area (ha)

Clearly, there is a link between the two expressions outlined above although the precise basis for both is open to discussion. Nevertheless, for planning purposes, it would appear that the SRI contains relevant factors (risk levels, numbers of people potentially at risk, size of development and population density).

MHAU has advised[14] that values of less than 2,500 (4,000 for 'in-fill' developments) and 1,100 are deemed tolerable on societal risk grounds when considering the risk of exposure to a 'dangerous dose or worse' and the risk of becoming a fatality respectively. For Area B considered above, the SRI would be calculated using the following parameters:

IR = 0.84 cpm (of becoming a fatality); n = 100; P_{occ}= 1 (assumed); and
A= 1.6 ha (based on a typical population density of 62.5 /ha)

The resultant SRI would then be: = 0.84 x 100 x 101 x 0.5 x 1/1.6
= 2,651

In other words, for our hypothetical example, a proposal to construct 40 houses at Area B would be turned down on risk grounds. Interestingly, if the proposal involved a development site of four hectares, the resultant SRI would be reduced to 1,060 which might be deemed tolerable.

We conclude that the derivation of the SRI is actually complex and that the significance of the numbers generated is rather hard to assess other than by empiricism. This is not to deny the

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[14] *Letter from HSE to the Consultants dated 18 June 1998.*

merits of a ‘simple’ system of assessment, however, it would be of some interest to compare planning decisions arrived at via the use of the SRI with, say, those concluded on the basis of QRA calculations and more formal societal risk criteria.

A1.6 SUMMARY

Based on the above analysis, the following general observations can be made:

- the results of calculations of societal risk appear to be most readily accessible through the use of FN plots (on a log-log basis) - where F represents the likelihood of N or more fatalities;

- although societal risk results can be manipulated to generate relationships between FN and fN data (where f represents the likelihood of N fatalities), there are traps for the unwary (for example, some relationships only hold true if f and F values are determined for each and every value of N);

- other measures of societal risk include PLL (probable loss of life) values which is equivalent to $\sum f_i N_i$ or, in simple cases at least, the number of people exposed x individual risk level (for example, when considering ‘small’ geographical areas); and

- for discrete developments near to major hazard sites, the Major Hazards Assessment Unit (MHAU) of HSE uses the Scaled Risk Integral (SRI) which is stated to be a simplified form of $\sum F_i N_i$. The basis for the SRI is difficult to determine and it would be of interest to compare SRI-based decisions with those that would result from the use of QRAs and other forms of societal risk criteria.

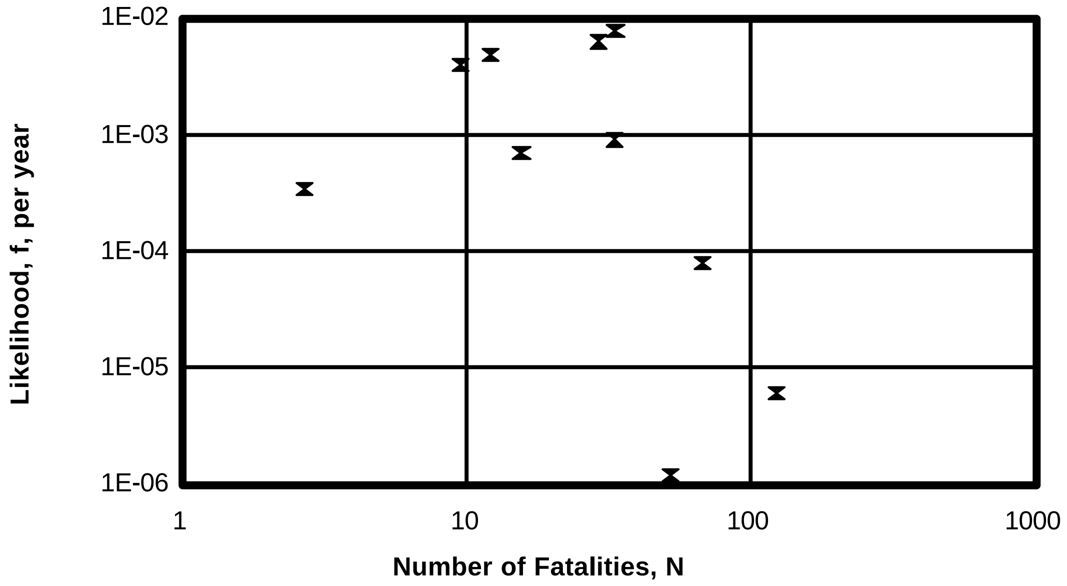

Figure 2. Societal Risks
(fN Plot)

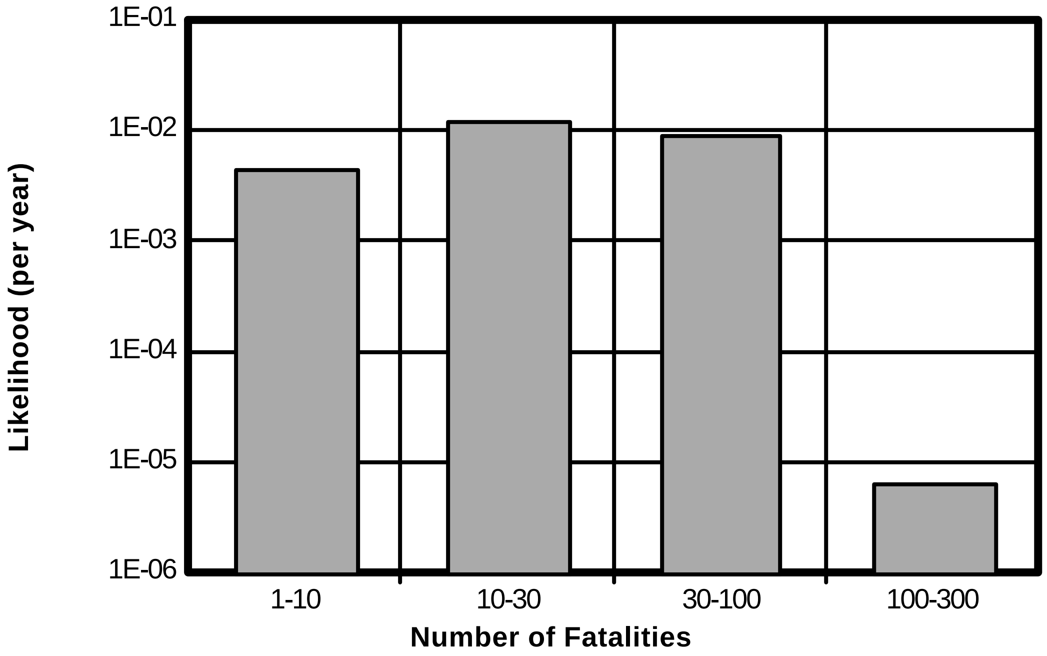

Figure 3. Societal Risks
Likelihoods vs Ranges of N

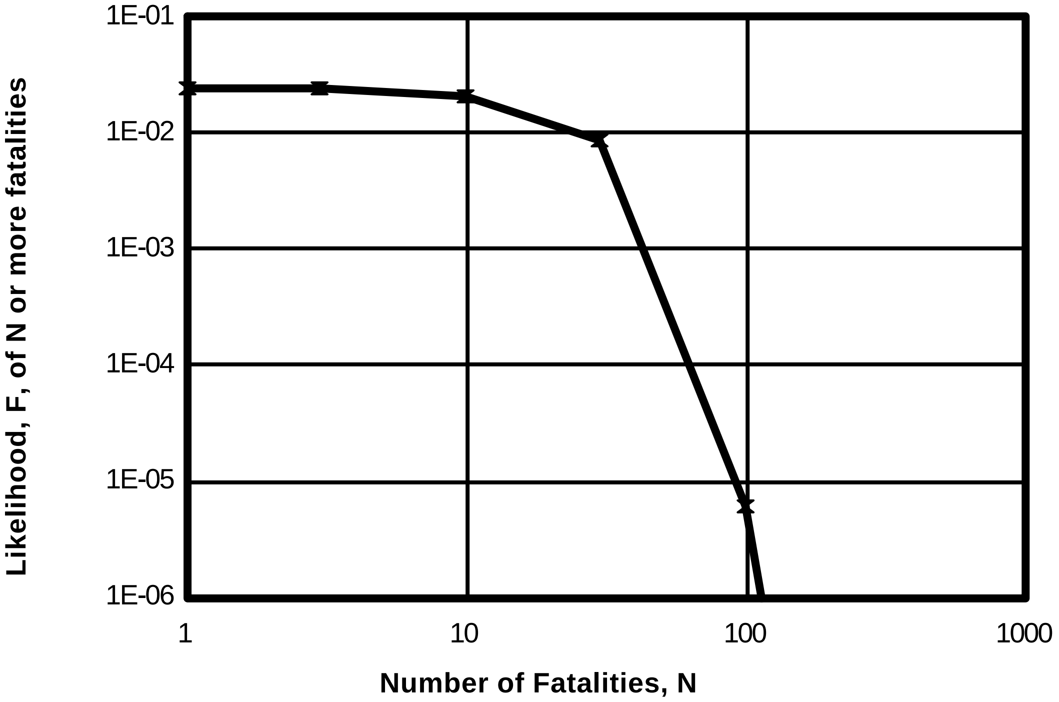

Figure 4. Societal Risks
(FN Plot)

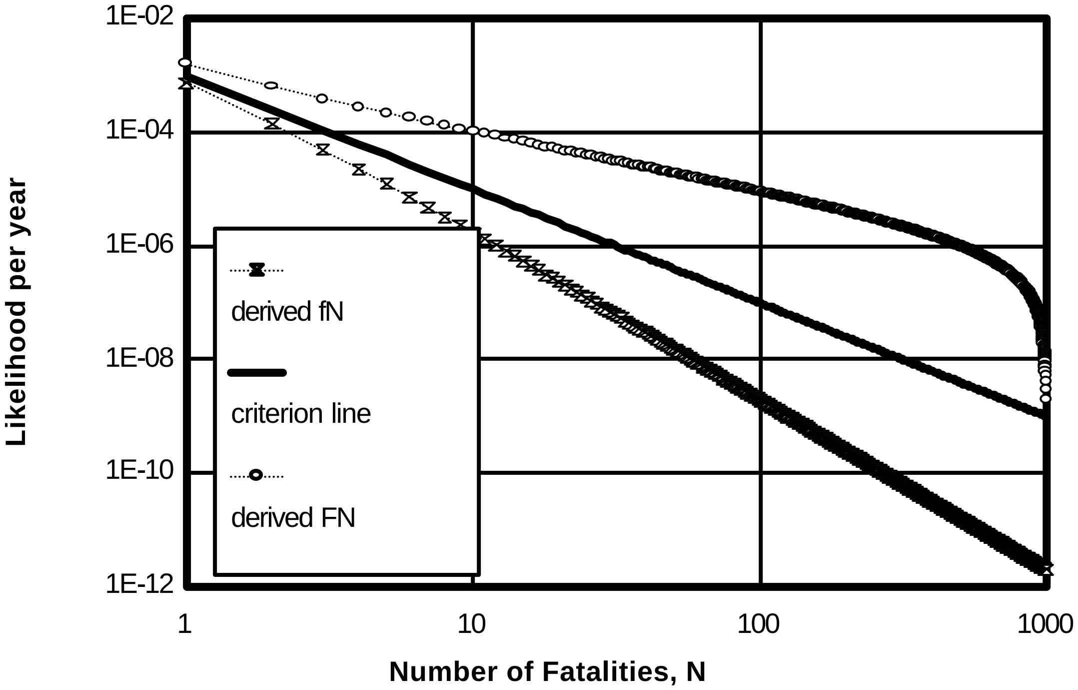

Figure 5. Societal Risk Criteria

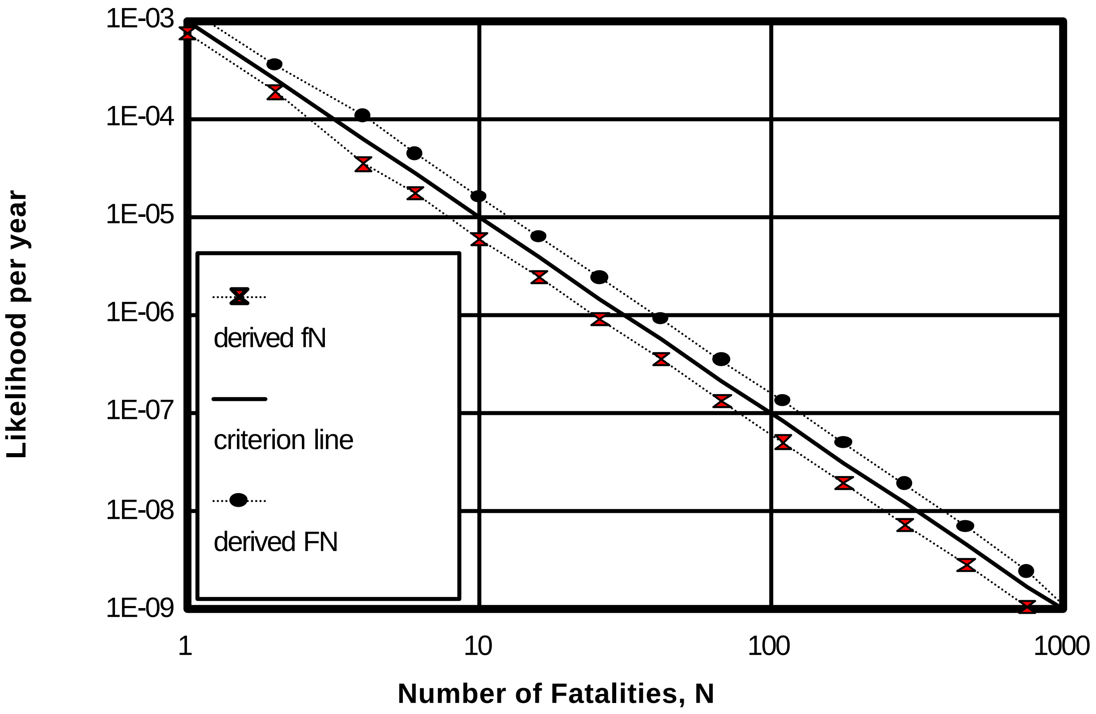

Figure 6. Societal Risk Criteria (Small Data Set)

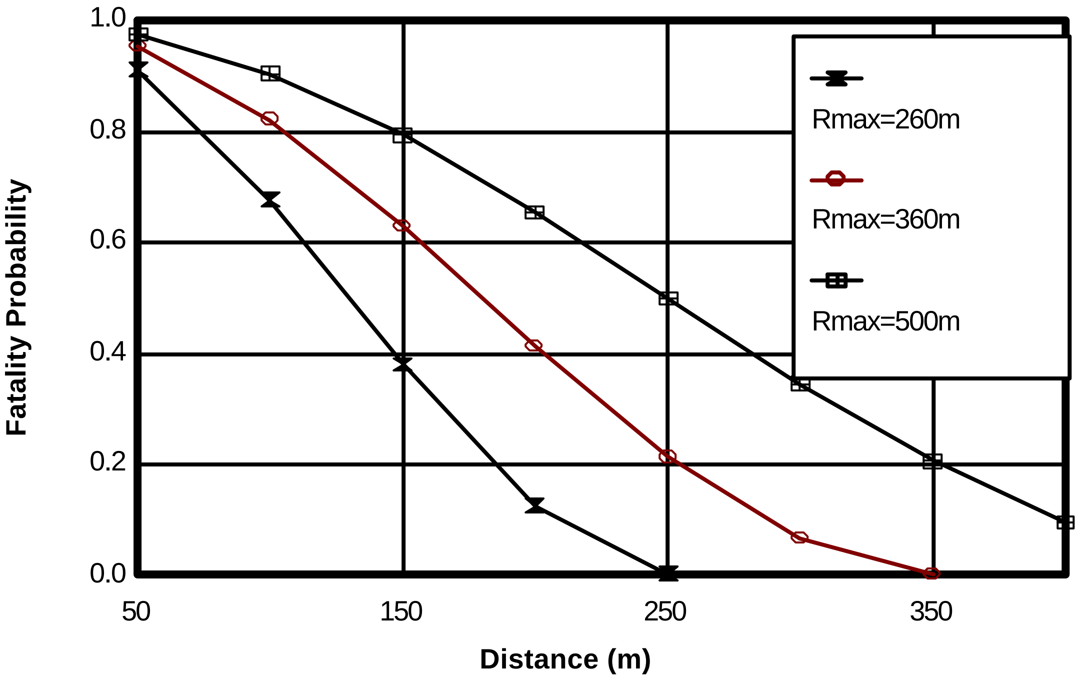

Figure 7. Fatality Probs. vs Distance vs Rmax

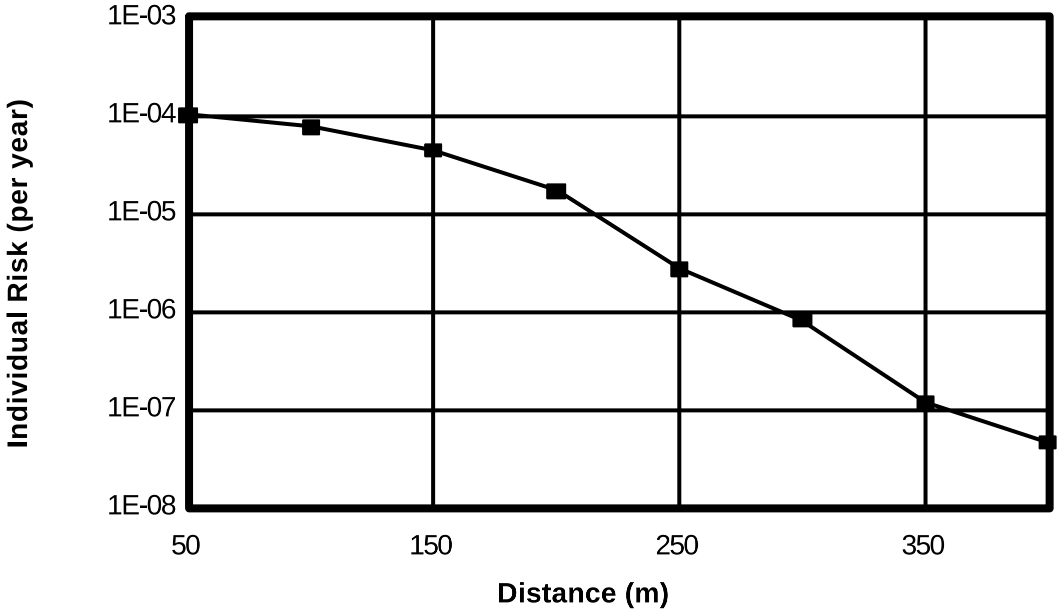

Figure 8. Individual Risk vs. Distance

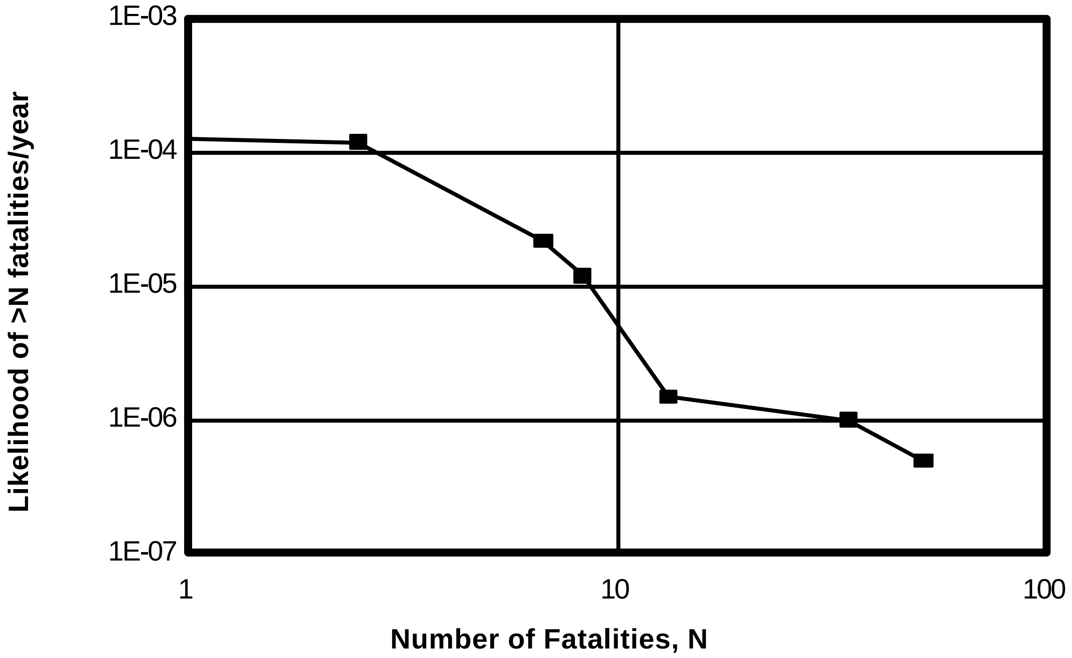

Figure 9. FN Plot

ANNEX 2. DEVELOPMENT OF SOCIETAL RISK CRITERIA

A2.1 INTRODUCTION

This Annex presents a chronological account of the development of societal risk criteria over the past thirty years with particular reference to developments in the UK, the Netherlands and Hong Kong. The commentary on each period is supplemented by a listing of major incidents in the UK and elsewhere together with a listing of other key events and publications.

The incident listings (presented at the end of this Annex) are not comprehensive but are intended to provide an overview of the type of incidents which result in numerous fatalities. For the UK, a selection of incidents which have resulted in three or more fatalities have been included. In broad terms, house fires and road accidents have largely been ignored.

Further afield, incidents in Europe (with an emphasis on Western Europe) have been included against the following criteria:

- air disasters >140 dead; and
- other events >40 dead.

In addition, some other incidents of particular significance (such as Bhopal) have been included. In all cases, acts of war and sabotage have been ignored.

A2.2 LATE 1950s AND 1960s

A2.2.1 Key Events

Some of the multi-fatality accidents in the UK and elsewhere are listed in Box 2. Key events relating to the development of societal risk criteria are listed in Table 12.

Table 12
Key Events pre-1970

Date	Description	Reference
1957	Fire at Windscale nuclear facility	
1966	Aberfan tip slide leaves over 140 dead.	Box 2
1967	Appearance of the ‘Farmer’ curve	Farmer (1967)

A2.2.2 Commentary

The origins of societal risk criteria can be traced back to the work of the UK Atomic Energy Authority (UKAEA) in the 1960s. In broad terms, there was recognition that a major event at a nuclear power plant could lead to severe consequences in the local area. There was therefore a need to ensure that the chances of a major accident were minimised and that nuclear power plants were located away from centres of population. This led to the formulation of the Farmer curve which proposed risk criteria based on the ‘acceptable’ frequency of Iodine-131 releases (as an indicator of the severity of nuclear reactor accidents). The Farmer curve was based on the following premises:

- accidents resulting in releases of around 1,000 Curies should not occur more than once in 1,000 years per reactor;

- for larger accidents, their likelihood of occurrence should be reduced more rapidly than their severity (ie a degree of aversion should be incorporated); and

- the likelihood ‘small’ accidents should not exceed 1.0 x 10^{-2} per reactor year.

The Farmer curve is presented in Figure 10 which has the following characteristics:

Application: *one nuclear reactor in the UK*
Zones: *2 - Unacceptable, Acceptable*
Anchor Point: 10^{-3} *per year for a release of 1000 Curies*
Line slope: *-1.5 for releases above 1000 Curies*
Consequence cut-off: *None*
Frequency cut-off: *1 x* 10^{-2} *per year (upper limit for ‘small’ releases)*

A2.3 1970s

A2.3.1 Key Events

Some of the multi-fatality accidents in the UK and elsewhere are listed in Box 3. Key events relating to the development of societal risk criteria are listed in Table 13.

Table 13
Key Events 1970s

Date	Description	Reference
1973	Summerland fire, Isle of Man leaves 50 dead.	Box 3
1974	Flixborough explosion, 28 dead.	Box 3
19751975	Advisory Committee on Major Hazards (ACMH) formed. US Reactor Safety Study (WASH-1400) published. Beek (the Netherlands) explosion, 14 dead.	 USNRC (1975) Box 3
1976	First ACMH Report published. Seveso accident in Italy, 400+ cases of chloracne.	ACMH (1976) Box 3
1978	Spanish campsite disaster (LPG fireball), 200 dead. Canvey Island (1st Report) published. ‘Kinchin’ curve published. ‘Groningen’ curve published in the Netherlands.	Box 3 HSE (1978) Kinchin (1978) Groningen (1978)
1979	COVO study completed in the Netherlands.	Ale (1992)

Against a background of a succession of disasters, progress is made with the development of quantitative risk assessment (QRA) techniques with a range of detailed studies being undertaken in the mid/late 1970s including WASH-1400 in the US (USNRC, 1975), the first Canvey Report in the UK (HSE, 1978) and the COVO study in the Netherlands (Blokker *et al*, 1980).

Concurrent with the development of QRA techniques, was the development of the concept of societal risk with particular regard to the use of FN curves (discussed in Annex 1) and the emergence of tentative criteria in the late 1970s in the UK and the Netherlands.

A2.3.2 The UK

The Advisory Committee on Major Hazards, established after Flixborough, made an early tentative suggestion for a societal risk criterion:

> *... that in a particular plant a serious accident was unlikely to occur more often than once in 10,000 years (ie 10^{-4} yr^{-1}) ... this might perhaps be regarded as just on the borderline of acceptability* (ACMH, 1976).

This has often been taken to be a proposed criterion of 1 in 10,000 per year for 10 or more fatalities. As discussed in Annex 1, there is linkage between societal risk and the risk to an individual (individual risk) although the precise relationship will depend on the nature of the hazard (fire, release of toxic material, etc.), local conditions (topography, meteorology, etc.) and the distribution of the people at risk. However, experience of numerous risk assessments indicates that, as a guide, it is often the case that: *if the societal risk of\$10 fatalities is X, the maximum individual risk will be of the order of 10X.*

The Canvey report (HSE, 1978) was the first openly published risk assessment in the UK. The risks associated with a range of hazardous installations were provided in the form of both individual and societal risks (it is worth noting that the cumulative FN curves are presented on a log-lin basis rather than the now familiar log-log plots). In succeeding years, it was broadly agreed that the risks (which were based on casualties rather than fatalities) were overestimated. Although societal risk criteria as such were not advanced, various risk reduction measures were proposed.

During the 1970s, considerable progress was made within the nuclear industry in developing computer models to predict the consequences of accidents involving nuclear power plants. In other words, for a given release, it was possible to determine the numbers of fatalities on a probabilistic basis taking account of meteorological conditions, population distribution, etc. The next step was to translate the Farmer curve into societal risk criteria. Within the nuclear industry (and UKAEA in particular), there was considerable internal debate on how this should be achieved. In 1978, the ‘Kinchin’ curve (see Kinchin, 1978) was presented[15] which included both ‘early’ and ‘delayed’ deaths. This was still presented in the form of frequency vs. consequence (as discussed by Griffiths, 1981). The underlying principles of the Kinchin curve were to adopt an aversion slope[16] of -1 and to ensure that the societal risks associated with a nationwide programme of 30 nuclear reactors would be similar to those associated with the impact of meteorites.

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[15] *At the time, GH Kinchin (like FR Farmer before him) was the Director of the Safety & Reliability Directorate, UKAEA.*

[16] *In part, this change from the slope of -1.5 on the Farmer curve was due to the results of the translation of release sizes into numbers of deaths.*

A2.3.3 Hong Kong

During the 1970s, the oil companies (Shell, Mobil, Caltex, etc.) located their oil/LPG terminals to Tsing Yi island. However, the proposals for high density residential development on the island at the end of the decade were beginning to cause unease.

A2.3.4 The Netherlands

In response to accidents involving hazardous materials in Europe (with particular reference to Flixborough in 1974, Beek in 1975 and Seveso in 1976), the Province of Groningen issued risk criteria in the form of individual and societal (referred to as ‘group’) risk criteria (Groningen, 1978). The societal risk criteria were presented on a cumulative FN basis and divided into three regions: “unacceptable”, “further assessment and evaluation”, and “acceptable”. It is important to note that the ‘consequences’ were based on equivalent fatalities (ie 1 fatality (or serious injury) was equivalent to 10 injuries, 100 slight injuries or 1,000 very slight injuries). The criteria were derived from consideration of historical risks (both on an individual and societal basis) as well as an aversion slope of -2 (which “was chosen on largely subjective grounds”) and inclusion of a 1,000 (equivalent) fatality ‘cut-off’ (ie no accident should result in more than 1,000 fatalities).

In parallel with the societal risk criteria, an individual risk of death of 1 chance in 100,000 per year was advanced (based on 1% of the total individual risk of accidental death). It is of note that the “unacceptable” limit of 10 fatalities or more is 1.0 x 10^{-4} per year which is numerically ten times higher than the corresponding individual risk criterion. As mentioned above, this degree of linkage between societal and individual risk values is to be expected.

The criteria, illustrated in Figure 11, may be characterised as follows:

Application: *a facility handling dangerous goods (in the Netherlands)*
Zones: *3 - Unacceptable, Further assessment and evaluation, Acceptable*
Anchor Point: *Perhaps 1 x 10^{-4} per year for 10 or more (equivalent) fatalities (lower limit of unacceptability)*
Line slope: *-1 for 0.01 to 1 fatality and -2 for >1 fatality*
Consequence cut-off: *1000 (lower limit of unacceptability)*
10 (upper limit of acceptability)
Frequency cut-off: *1 x 10^{-10} per year*

In the late 1970s, the landmark COVO study was undertaken where this involved a detailed full risk assessment of a range of hazardous installations in the Rotterdam area (Blokker *et al*, 1980).

A2.3.5 Elsewhere

In the US, various criteria were being advanced in relation to nuclear power plants. In 1973, staff of the Atomic Energy Commission proposed that the probability of a ‘serious reactor accident’ should be less than 1 chance in a million per year which was subsequently endorsed by the Advisory Committee on Reactor Safeguards (ACRS) in 1976 (Okrent & Wilson, 1982). In the wake of WASH-1400 and, perhaps more importantly, the events at Three Mile Island (in 1979), ACRS was asked to develop quantitative safety goals for nuclear plants (Okrent, 1987).

In parallel with developments in the nuclear industry, risk assessment techniques were being applied to other hazardous activities in the US - notably the marine transport of liquefied natural gas (LNG). However the results of these ‘early’ assessments were sometimes heavily criticised due to the uncertainties in the analysis (see, for example, Davis, 1979). Nevertheless, such studies were important to the ongoing development of mathematical models for the prediction of the consequences of major incidents and, hence, the associated risks (see, for example, Havens, 1982).

A2.4 1980s

A2.4.1 Key Events

Some of the multi-fatality accidents in the UK and elsewhere are listed in Box 4. Key events relating to the development of societal risk criteria are listed in Table 14.

Table 14
Key Events 1980s

Date	Description	Reference
1980	Alexander Kielland oil rig collapses, 186 dead.	Box 4
1981	Second Canvey Report published.	HSE (1981)
1982	Tsing Yi Report (Hong Kong) published.	ERL (1982)
	Kinchin curve re-presented.	Kinchin (1982)
1983	Sizewell B Inquiry commences	DEn (1987)
1984	LPG fire/explosions in Mexico, over 500 dead.	Box 4
	Bhopal, 3,000 dead.	Box 4
1985	Bradford football ground fire, 55 dead.	Box 4
	Heysel football stadium disaster, 39 dead.	Box 4
1986	Risk Guidelines in the Netherlands formulated.	Ale (1992)
1987	Herald of Free Enterprise capsizes, 193 dead.	Box 4
	King's Cross underground fire, 31 dead.	Box 4
1988	Tolerability of Risk report published.	HSE (1988)
	Interim Risk Guidelines adopted in Hong Kong.	
	Piper Alpha oil rig fire, 166 dead.	Box 4
	Clapham rail disaster, 35 dead.	Box 4
1989	HSE Risk Criteria and Land-use Planning document published.	HSE (1989)

Considerable progress is made with the development of quantitative risk assessment (QRA) techniques as applied to installations handling hazardous materials. This, in turn, provided a basis on which to establish national societal risk guidelines in the Netherlands and Hong Kong. In the UK, further discussion documents (HSE, 1988 & 1989a) were produced following the Sizewell Inquiry and against a background of a succession of disasters in the late 1980s.

A2.4.2 The UK

In the early 1980s, there appeared to be an emerging consensus that societal risk curves should be presented in the cumulative FN form. Thus, the Kinchin (and Farmer) curves were re-presented in this form (Kinchin, 1982). The revised Kinchin curve, illustrated in Figure 12, can be characterised as follows:

Application:	*one nuclear reactor in the UK*
Zones:	*2 - above and below suggested "permissible" criteria lines*
Anchor Points:	*None specified as based on further reworking and refinement of earlier Kinchin curve*
Line slope:	*-1*
Consequence cut-off:	*None*
Frequency cut-off:	*1 x 10^{-7} per year (effectively)*

Although 'anchor points' are not specified, it is interesting to note that the 'permissible' likelihood of 10 or more 'delayed' deaths is close to 10^{-4} per year (ie the same as the ACMH criterion) with the corresponding values for 'early' deaths a factor of 30 lower.

Although cumulative FN data are presented in the Second Canvey Report (HSE, 1981), no FN curves are presented nor is there any discussion of the acceptability of the societal risk results beyond the observation that they are considerably lower than those presented in the first Canvey Report.

The third and final report of the ACMH was published in 1984 (ACMH, 1984). It is noteworthy that ACMH appeared to conclude that there was little merit in pursuing the question of societal risk criteria on the grounds that:

> *Most major hazard risks fall in a band between the clearly unacceptable and the clearly negligible* (para 20).

One of the leading members of the ACMH, the late VC Marshall, was slightly more candid:

> *The question of "acceptable" risk is a thorny one from which the ACMH, perhaps wisely, drew away, certainly so far as putting forward any numerical criteria of "acceptability" was concerned.* (Marshall, 1984).

The long-running Sizewell B Inquiry (January 1983 - March 1985) presented an opportunity for societal risk criteria to be discussed in detail. In the event, it was left to the objectors to raise the issue of societal risk (referred to as 'social' risk in the Layfield Report (DEn, 1987)) since neither the Central Electricity Generating Board (CEGB) nor the Nuclear Installations Inspectorate (NII) relied on societal risk criteria in their respective cases. Although 'safety' was a major issue at the Inquiry, it is apparent that there was a lack of definition over what could constitute an acceptable level of risk for both individual and 'social' risks (Layfield's conclusions in para 36.95 refer).

Following the Sizewell B Inquiry, research into the 'tolerability of risk' from nuclear power stations was commissioned by HSE. The resultant report (HSE, 1988) is often identified as milestone in setting out the framework for risk control, not just in the nuclear industry, but in the UK generally. However, the report focuses very much on individual risk and no attempt is made to further develop the FN criteria proposed by Kinchin and others. Nevertheless, some generalised discussion is presented on the 'tolerability' of major accidents with particular reference to the risks associated with the Canvey Island complex and the Thames Barrier. This leads to the view, for nuclear power stations, that:

> *... taking all these factors into account a figure that might be accepted as tolerable for a considerable uncontrolled release anywhere in the UK might be about 1 in 10,000 per annum ...* (para 133).

The report goes on to explain that such an event could lead, pessimistically, to 100 delayed deaths[17]. For 10 reactors nationally, this would equate to a tolerability criterion of: 10^{-5} per year per reactor for 100 'delayed' deaths - which is consistent with the (revised) Kinchin curve.

HSE published two further documents which reiterated their long-held position that setting societal risk criteria was problematic. In the first document (HSE, 1989), a seemingly cumbersome set of individual risk criteria was proposed. This was also used to provide a basis for determining the 'risk' acceptability of multi-person developments by combining 'people equivalents' with particular levels of individual risk (for example, more than 25 people would not be permitted where the risk (of receiving a 'dangerous dose') exceeded 1 in 10 million per year). Although such an approach implies the use of societal risk, the use of formal societal risk criteria is rejected (although a review of the use of FN curves is presented).

In the second document (HSE, 1989a) various societal risk results for UK situations are reviewed, from which it is concluded that:

> *Comparison of the relevant FN curves suggests that there is no readily deducible and uniformly applicable upper level of acceptable societal risk.*

The document then suggests that there are 41 factors which need to be taken into account in determining whether particular societal risks are likely to be acceptable within a given situation. However, a suggested 'maximum tolerability line' is suggested for a national PWR nuclear reactor programme. This line is 'anchored' at 10^{-4} per year for 100 or more delayed deaths (based on the 'tolerability' criterion discussed above) with an aversion slope of -1 although it is noted that:

> *A line of this slope would seem to reflect the least that we judge the public might require for larger N; and they might want a steeper curve.* (para 73).

However, considerable 'aversion' was deemed to have already been incorporated by anchoring the line well below those for Canvey Island and the Thames Barrier (para 10 refers). Furthermore, this would apply to any "new family of nuclear reactors".

A2.4.3 Hong Kong

In 1981, the Public Works Department of the Hong Kong Government commissioned a major study into the risks associated with the hazardous installations on Tsing Yi Island following concern over the proximity of high density residential apartment blocks to some of these installations. The resultant report (ERL, 1982) presented the societal risk results (in tabular form

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[17] *In light of the consequences of the Chernobyl disaster (in 1987), it is debatable whether the estimates would still be considered 'pessimistic'.*

and with FN curves) associated with each of the hazardous installations. The 'consequences' were expressed in terms of casualties (rather than fatalities) - probably to enable comparisons with the Canvey Island study (Leddy, 1993). The study report recommended, *inter alia*, that certain hazardous installations be formally designated as such and that a Governmental committee be established to oversee the risk management of such facilities with particular regard to land-use planning.

Against this background as well as a growing number of LPG cylinder incidents in domestic premises (Ho & Wong, 1997), the Government took three steps:

- the establishment of the Gas Standards Office (GasSO) in September 1982 to be responsible for gas safety (specifically towngas and LPG) and naphtha safety (used as a feedstock for towngas production);

- the designation of the Environmental Protection Department to act as risk advisors in relation to other hazardous materials (notably chlorine, explosives and non-LPG petroleum products); and

- the establishment of an inter-departmental committee (CCPHI) in December 1986 to oversee issues relating to risk management and land-use planning.

During the mid-1980s, there were a number of studies into the risks associated with the use and storage of large quantities of liquefied chlorine at water treatment works - often at sites overlooking areas of high density residential population. By 1986, individual risk criteria were being proposed (see, for example, ERL (1986)) with associated discussions on the acceptability of societal risks. In 1987, tentative societal risk criteria (based on the ACMH criterion and the Kinchin curve) were being used to judge the acceptability of societal risk results and by 1988, societal risk criteria were under active consideration by the CCPHI.

In addition, the Government commissioned a study to identify future PHI sites[18] which led to the realisation that restrictions on nearby development would be required if the identified sites were to remain 'acceptable' from a risk perspective.

These events led to the adoption by the CCPHI of formalised risk criteria in February 1988. These Interim Risk Guidelines related to both individual and societal risks (PELB, 1991). The individual risk limit was set at 1 x 10^{-5} per year and the societal risk curve, illustrated in Figure 13, may be characterised as follows:

Application:	*development of, or near to, a Potentially Hazardous Installation*
Zones:	*2 - Unacceptable, Acceptable*
Anchor Point:	*1 x 10^{-4} per year for 10 or more fatalities*
Line slope:	*-1*
Consequence cut-off:	*1,000 fatalities*
Frequency cut-off:	*1 x 10^{-9} per year*

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[18] *In Hong Kong, Potentially Hazardous Installations (PHIs) are defined as those handling quantities of materials above the threshold values listed in Schedule 1 of the UK Notification of Installations Handling Hazardous Substances Regulations 1982. As of May 1991, there were 32 PHIs in Hong Kong.*

It should be noted that the introduction of the 1,000 fatality cut-off was essentially a ‘political’ decision (in a similar manner as that introduced for the Groningen criteria).

In the late 1980s, the risks on Tsing Yi were reassessed following safety improvements, refinements to the risk assessment techniques and the introduction of the Interim Risk Guidelines. The results indicated that although there had been considerable reductions in risk from those previously assessed, some sites did not comply with the risk guidelines (Technica, 1989). The assessors did note that perhaps it would be prudent to refine the societal risk guidelines to further separate the “unacceptable” and “acceptable” regions.

The Interim Risk Guidelines soon resulted in changes - mainly due to the assessed societal risks exceeding the criteria - including:

- the storage of bulk chlorine at water treatment works was phased out;
- a planned bulk chemical terminal did not proceed; and
- the need to relocate facilities on Tsing Yi was actively discussed.

A2.4.4 The Netherlands

During the 1980s, the Dutch Government commissioned a range of detailed risk studies into the use and transport of hazardous materials (for example TNO, 1983) as well as assisting in the development of computerised packages to facilitate the production of consistent risk reports (Ale, 1992).

This work led to the development of risk criteria (slightly ahead of Hong Kong). By 1987, policy decisions were being taken[19] on the basis of societal risk criteria - including the abandonment of the use of chlorine at water treatment works due to the associated transport risks and the relocation of LPG filling stations (for vehicles running on LPG rather than petrol/diesel) away from urban areas - which were formally adopted in 1989 (VROM, 1989).

The Dutch approach to the development of criteria may be summarised as follows (according to Ale, 1992):

- start from the premise (as earlier expressed by ACMH) that “*the risk from a hazardous activity to a member of the public should not be significant when compared with risk in everyday life*”;
- identify age group at lowest risk (10-14 year olds) and the ‘everyday’ risk level for this group (1 x 10^{-4} per year);
- base individual risk criterion on 1% of lowest everyday risk - ie 1 x 10^{-6} per year;
- translate this into a societal risk ‘anchor’ of 10^{-5} per year for 10 or more fatalities;
- apply an aversion slope of -2 as “*a heavier weight must be assigned to the larger consequences*”; and
- apply a factor of 100 to both individual and societal risk criteria to generate “negligible” risk values.

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[19] *These observations are based on personal recollection and will require further substantiation.*

The resultant FN curves are illustrated in Figure 14 and may be characterised as follows:

Application:	*Those close to existing hazardous facilities (in the Netherlands)*
Zones:	*3 - Unacceptable, Reduction desired, Acceptable*
Anchor Points:	*1.0 x* 10^{-5} *per year for 10 or more fatalities (lower limit of 'unacceptable')* *1.0 x* 10^{-7} *per year for 10 or more fatalities (upper limit of 'acceptable')*
Line slope:	*-2*
Consequence cut-off:	*1000 (effectively)*
Frequency cut-off:	*1 x* 10^{-9} *per year*

For new hazardous installations, the frequency components of the criteria were reduced by a factor of ten.

A2.4.5 Elsewhere

As a result of the accident at Three Mile Island (in 1979), various numerical safety goals for nuclear power plants were being advanced in the US in the early 1980s culminating, in February 1982, with the following proposed risk criteria (Okrent, 1987):

> *The risk to the population near the reactor of being killed in a reactor accident should not exceed 0.1 percent of the risk of being killed in any kind of accident;* and
>
> *The risk to the population living within fifty miles of the plant eventually dying from cancer as a result of a reactor accident should not exceed 0.1 percent of the risk of dying from any other causes.*

Such criteria carry societal risk implications. Morone & Woodhouse (1986) provide the example that if 200 people lived close to the reactor then the criterion for 'prompt' deaths would translate to societal risk criteria of 1 chance in 10,000 per reactor per year for an accident with 1 fatality, 1 chance in 100,000 for an accident with 10 fatalities, etc. The authors then continue to examine the difficulties associated with such criteria - notably, the 'proof of compliance' relies on a very uncertain analysis (ie do the assessed risks correspond to the 'real' risks?). In subsequent years, further numerical criteria were considered but eventually, the Nuclear Regulatory Commission opted to base their quantitative safety goal policy on the 1982 proposals (with minor modifications) together with qualitative goals including:

> *societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks* (as given in Okrent, 1987)

In Denmark, a national task force recommended similar societal risk criteria as adopted in the Netherlands for hazardous chemical plants (albeit with the frequency scale increased by a factor of ten) in 1989 (as discussed by Stallen *et al*, 1996).

A2.5 RECENT DEVELOPMENTS

A2.5.1 Key Events

Some of the multi-fatality accidents in the UK and elsewhere are listed in Box 5. Key events relating to the development of societal risk criteria are listed in Table 15.

Table 15
Key Events 1990s

Date	Description	Reference
1991	ACDS Transport Study published.	ACDS (1991)
1992	Tolerability of Risk report revised.	HSE (1992)
1993	Hong Kong Risk Guidelines revised. Proposed criteria for UK offshore installations.	Planning Dept. (1993) Schofield (1993)
1995/6	Criteria in the Netherlands revised and additional criteria for DG transport adopted.	Ale (1997)
1997	Societal Risk criteria proposed for DG transport in Hong Kong.	DNV Technica (1996) & Boult (1997)

The use of societal risk criteria was further refined and extended, notably to DG (dangerous goods) transport, in the UK, Hong Kong and the Netherlands. Elsewhere, further efforts were being made to incorporate risk assessment and associated criteria into decision making.

During the 1970s and 1980s, criteria were developed for particular installations (notably nuclear and chemical facilities). For each of these installations, those at risk were those in the vicinity. It was then possible to compare societal risks associated with different installations on a ‘like with like’ basis. Furthermore, as evidenced by the UK nuclear power station criteria discussed in A2.4.2, it was possible to simply ‘gross up’ the societal risks from individual facilities to the overall societal risks at a national level.

The situation for transport related activities is more complex. By way of example, consider the national distribution of a hazardous chemical by road and/or rail. At any particular point along the various routes, the chances of an accident resulting in fatalities amongst those nearby would be very low indeed - in other words, the individual risk would be very low. However, given the numbers of journeys and the distances involved, the chances of such an accident somewhere in the country may be significant. In other words, although the individual risk is negligible, the societal risk may be significant. This means that the ‘linkage’ between individual and societal risk for transport risks is quite different from that associated with installations. Furthermore, since the population at risk could include the majority of the population (for example in relation to the distribution of petrol to every petrol station in the land), care is required to develop appropriate (and meaningful) criteria.

A2.5.2 The UK

Following the recommendations of the 3rd ACMH report (ACMH, 1984), the Advisory Committee on Dangerous Substances published its transport risk study (ACDS, 1991) after six years study. The approach to the development of risk criteria is set out in Appendix 6 of the report. They key steps are as follows:

- for individual risk, start from the premise that a "*risk of death of one in a thousand per annum is about the most that is ordinarily accepted under modern conditions for workers in the UK*" (para 8). This was taken from the tolerability of risk paper (HSE, 1988) but is debatable[20];

- suggest that 1/10 of this should be tolerable for risks associated with 3rd party activities to members of the public (ie 1 x 10^{-4} per year - which is 10-100 times higher than values previously suggested in the UK and elsewhere) - although the report goes on to suggest that such a risk "*is in our view only barely tolerable*" (para 14);

- for societal risk, start from the assertion that the risks associated with the Canvey Island complex (after improvements as assessed in HSE, 1981) "*were regarded as just about tolerable*" (para 31);

- for "*an identifiable community near a port*" (para32), use the Canvey societal risk results to provide an 'anchor' for the lower limit of intolerability (at 2 x 10^{-4} per year for 500 or more fatalities[21];

- apply an aversion slope of -1 which although often considered to be 'risk neutral' implies a degree of risk aversion (as discussed in Appendix 6) to generate a 'local intolerability line'; and

- insert a corresponding 'negligible' line 1,000 times lower and, in addition, insert a 'local scrutiny line' to account for local factors - which for the port of Felixstowe is 10 times lower than the local intolerability line.

The resultant criteria (excluding the local scrutiny line), illustrated in Figure 15, can be characterised as follows:

Application:	*'identifiable community' close to a DG transport route in the UK*
Zones:	*3 - Intolerable, ALARP, Negligible*
Anchor Points:	*2.0 x 10^{-4} per year for 500 or more fatalities (lower limit of 'intolerable').* *Upper limit of 'negligible' 1,000 times lower*
Line slope:	*-1*
Consequence cut-off:	*None*
Frequency cut-off:	*1 x 10^{-8} per year (effectively)*

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[20] *According to the latest statistics (Health & Safety Commission, 1996) the group of workers with the highest individual risk in 1995/96 is Group CA - Mining and Quarrying of Energy Producing Materials - with an individual risk of 2.3 x 10^{-4} per year (and the corresponding figure for 1994/95 is 6.9 x 10^{-5}). Although there will be variation in the risk levels for particular sub-groups, it can be seen that to suggest that risks of 1 in 1,000 per year would be ordinarily accepted is potentially misleading.*

[21] *This was determined by comparing the FN data from the Second Canvey Report (with the number of casualties divided by three to generate fatalities) with an FN criterion line using an aversion slope of -1 and determining the point of contact between the two.*

In relation to the setting of the ‘intolerability line’, three observations can be made:

- the proximity of large numbers of people to the range of hazardous installations in the Canvey Island complex is perhaps ‘worse’ than anywhere else in the country (which is one of the reasons why it attracted detailed study in the first instance);

- although the Second Canvey Report represented a significant advance in the application of risk assessment techniques at the time, it is likely that a reassessment today would produce significantly lower overall risk figures - particularly in relation to determining the numbers of fatalities for extreme events; and

- as a result, it is hardly surprising that the risks derived in the ACDS study fall well below the ‘intolerability line’.

The apparent resurgence in interest in societal risk issues was reinforced when the then HSE Director General in the opening paper to a major international conference (Rimington, 1992) suggested that societal risk calculations should be taken much further. In particular, Rimmington expressed the view that if all the components of societal risk could be given a monetary value, it would be possible to:

> *.. compare and contrast different investments and different social burdens, either of risk or of continuous damage from known, existing sources of detriment.*

Although the timing of such comments coincided with the introduction of formalised risk-benefit techniques to the use of hazardous materials (see, for example, RPA (1992)) which are based on such approaches, it still appeared to be a significant policy shift from the 1980s, during which time societal risk was rarely mentioned.

As a result of the Cullen Report (DEn, 1990) into the Piper Alpha disaster, the Offshore Safety Division was established within HSE and proposed societal risk criteria for application to the offshore situation (Schofield, 1993) which have subsequently been adopted. The criteria are derived[22] directly from consideration of individual risk criteria (based on the ‘tolerability’ limit of 1 in 1,000 per year[23]) and the number of people on board (POB). For POB=150, the criteria, illustrated in Figure A2.5(b), can be characterised as follows:

Application: *offshore installations*
Zones: *3 - Intolerable, ALARP, Acceptable*
Anchor Points: *‘Tolerable’ individual risk of 1 x* 10^{-3} *per year*
‘Broadly acceptable’ individual risk of 1 x 10^{-6} *per year*
Line slope: *-1 and -1.3 for the tolerable and broadly acceptable lines respectively.*
Consequence cut-off: *1000 (effectively)*
Frequency cut-off: *1 x* 10^{-8} *per year*

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[22] *It should be noted that the mathematical derivation of the societal risk criteria is fairly complex and the results presented are not readily reproducible from the information provided.*

[23] *Interestingly, Schofield notes that the individual risk to off-shore rig workers is about 3 x* 10^{-4} *per year (which is increased to 9 x* 10^{-4} *per year with the inclusion of the deaths from the Piper Alpha disaster).*

The Tolerability of Risk report (as discussed in Section A2.4.2) was revised and reissued in 1992 (HSE, 1992). The revised report accounted for developments since its initial publication in 1988 with commentaries (see Appendix 4 of HSE, 1992) on the application of risk criteria to land-use planning (as outlined in Section A2.4.2), the approaches to societal risk adopted in the ACDS study and proposed for off-shore installations (as discussed above).

Although the use of risk assessment in Government Departments was studied by ILGRA (Interdepartmental Liaison Group on Risk Assessment), the resultant report (HSE, 1996) concentrates on 'individual' risk and the 'value of a life' with no specific reference to societal risk criteria. Concurrently, another 'expert' report (HM Treasury, 1996) noted that societal risk:

> *.. helps to establish where different qualities of risk might play a role. On the other hand as an analytical tool it has now come to be criticised as an oversimplification, and as a concept which needs to be replaced, or perhaps redefined more clearly. The HSE now prefers the clearer term "societal concerns".* (page 9).

Unfortunately, no further information is presented in support of these views. Elsewhere, the views of HSE are presented slightly differently (see, for example, Cassidy, 1997) in that societal risk criteria involve 'difficulties' which have led HSE to adopt societal risk judgements based on individual risk levels (as originally set out in the document: HSE, 1989). To some extent, this is a practical solution to provide a 'societal risk' consideration in the determination of the several thousand planning applications per year which involve the development of, or near to, hazardous installations covered by the CIMAH Regulations.

However, several hundred such applications are passed each year to HSE's Major Hazards Assessment Unit (MHAU) for further consideration. The preparation of detailed QRAs for each and every application with the results presented as FN curves would clearly involve considerable effort (particularly if the potential effects could extend for many kilometres). Nevertheless MHAU do give consideration to a weighted measure of societal risk - the Scaled Risk Integral (which is discussed further in Annex 1).

Increasingly, risk assessment techniques are being used to assess not only the risks to people but also to the environment. As might be expected, criteria for the acceptability of environmental risks are difficult to define. One proposal using the 'FN' approach has recently been put forward by the Environment Agency (Slater, 1997) which defines three regions (Intolerable, ALARP and Acceptable) using an 'environmental harm index' along the 'N' axis.

A2.5.3 Hong Kong

Following the second Tsing Yi study, further action was taken by the Government to further separate high density housing from the hazardous installations. This necessitated the relocation of three facilities (Leddy, 1993).

In 1993, and in line with the recommendations of the second Tsing Yi study, the CCPHI (and the Government) adopted revised societal risk criteria as well as (slightly) amending the definition of PHIs (Planning Dept., 1993). In essence, the 'original' unacceptable line was retained (see Section A2.4.3) while the 'acceptable' line was reduced by a factor of 100 to give an ALARP region. The revised Societal Risk Guidelines, illustrated in Figure 17, may be characterised as follows:

Application: *Those close to PHIs (in Hong Kong)*
Zones: *3 - Unacceptable, ALARP, Acceptable*
Anchor Points: *1 x 10^{-4} per year for 10 or more fatalities (lower limit of 'unacceptable' - as before). Acceptable limit 100 times lower.*
Line slope: *-1*
Consequence cut-off: *1,000 fatalities*
Frequency cut-off: *1 x 10^{-9} per year*

Following the UK's lead, the HK Government commissioned two transport risk studies which resulted in different societal risk criteria - perhaps all the more remarkable in that both studies were undertaken by the same Consultant.

The parallel DG Transport studies were finalised in 1997. For the transport of LPG throughout the Territory, societal risk criteria were proposed (as outlined in Boult, 1997) with two regions - an 'ALARP' region and an 'acceptable' region - based on consideration of the existing PHI societal risk criteria and the number of PHIs handling LPG. The limiting FN line, as illustrated in Figure 18, has the following characteristics:

Application: *Those close to LPG transport routes (in Hong Kong)*
Zones: *2 -ALARP, Acceptable*
Anchor Point: *Based on existing PHI criteria and number of LPG PHIs*
Line slope: *-1*
Consequence cut-off: *1,000 fatalities*
Frequency cut-off: *1 x 10^{-9} per year*

For the other study (DNV Technica, 1996), the proposed criteria were based on directly increasing the frequency scale of the PHI societal risk criteria (as shown in Figure 17) by the number of PHIs. So, for example, with 14 'chlorine' PHIs, the resultant societal risk criteria for chlorine transport (throughout the Territory) are shown in Figure 19.

A2.5.4 The Netherlands

In the Netherlands, the societal risk criteria were revised in 1995/96 with the removal of the 'acceptable' region (see Figure 14) as well as the differentiation between existing and new installations (Ale, 1997). It is understood that this was due to the view that the 'acceptable' line was of limited value for land-use planning purposes. The resultant criteria, as illustrated in Figure 20, may be characterised as follows:

Application: *Those close to hazardous facilities (in the Netherlands)*
Zones: *2 - Societal risk to be reduced, ALARA*
Anchor Point: *Earlier criteria (see Section 2.4.4)*
Line slope: *-2*
Consequence cut-off: *1000 (effectively)*
Frequency cut-off: *1 x 10^{-9} per year*

Concurrently, societal risk criteria were introduced for DG transport as shown in Figure 21. The numerical values are ten times higher than for the fixed installations and the frequency axis is expressed in terms of the likelihood of N or more fatalities **per kilometre year**.

A2.5.5 Elsewhere

In Switzerland, societal risk criteria were published (BUWAL, 1991 & 1992) covering a wide range of hazardous activities[24]. Interestingly, the 'N' axis was based on consideration of nine factors (numbers of people killed, injured and evacuated, an alarm factor, numbers of animals killed, damage areas of ecosystem, contaminated land and polluted surface waters as well as the associated overall damage costs) to derive an overall Accident Value (generally in the range 0 to 1). The precise basis for acceptability/unacceptability has not been determined but the resultant criteria for hazardous installations, as illustrated in Figure 22, may be characterised as follows:

Application:	*Hazardous facilities (in Switzerland)*
Zones:	*3 - Unacceptable, Transition, Acceptable.*
Anchor Points:	*Not determined*
Line slope:	*-1 (in appearance at least)*
Consequence cut-off:	*Accident Value =1*
Frequency cut-off:	*1 x 10^{-11} per year*

In various states in Australia, although detailed individual risk criteria have been introduced, specific societal risk criteria have not been adopted. In a New South Wales guidance note (NSW, 1992), two specific reasons for this have been identified:

- societal risk criteria are society specific and further research would be required to justify the application of criteria from elsewhere to NSW; and

- the use of the FN approach is complex.

Of note is that under a UN programme, the Dutch authorities 'exported' their criteria to Latvia albeit with a factor 10 increase in the frequency scale in 1990/91 (Blokker, 1991).

Finally, in the US, there were continuing debates on the development of numerical risk criteria for nuclear power stations. Helton & Breeding (1993) present the results of a very detailed and complex risk analysis in FN curves (which are referred to as 'frequency exceedance curves') which are plotted alongside the 1967 Farmer curve to demonstrate their 'acceptability'. In short, it would appear, that in some areas at least, very little progress has been made in the last 30 years.

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[24] *In Switzerland, there is a long established use of quantified risk assessment techniques dating back to the 1970s, particularly in relation to the storage of explosives and ammunition (see, for example, Schneider, 1978).*

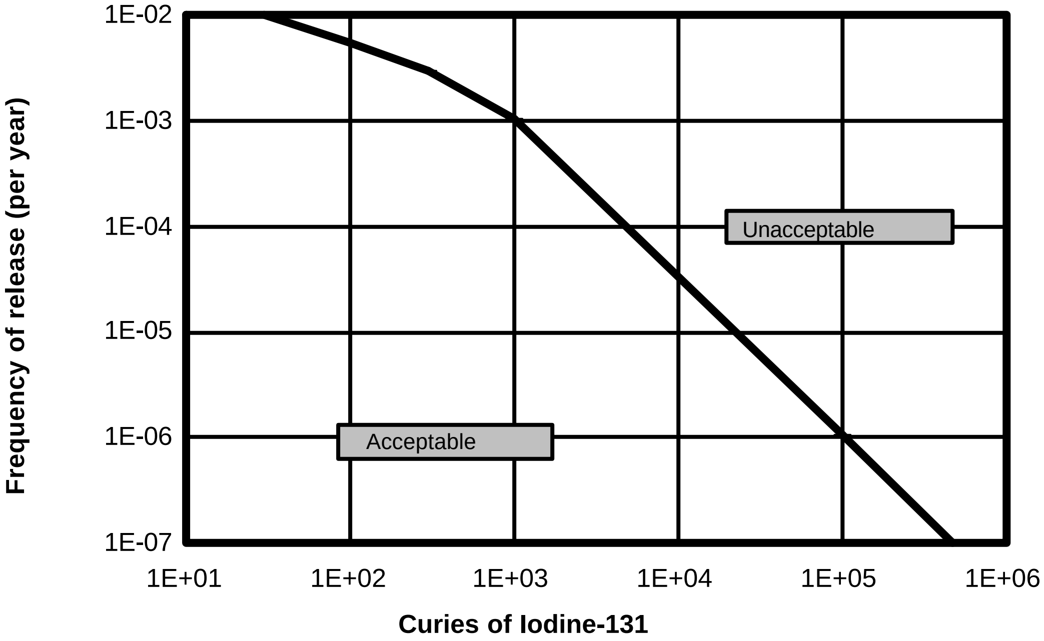

Figure 10. Farmer Curve (1967)

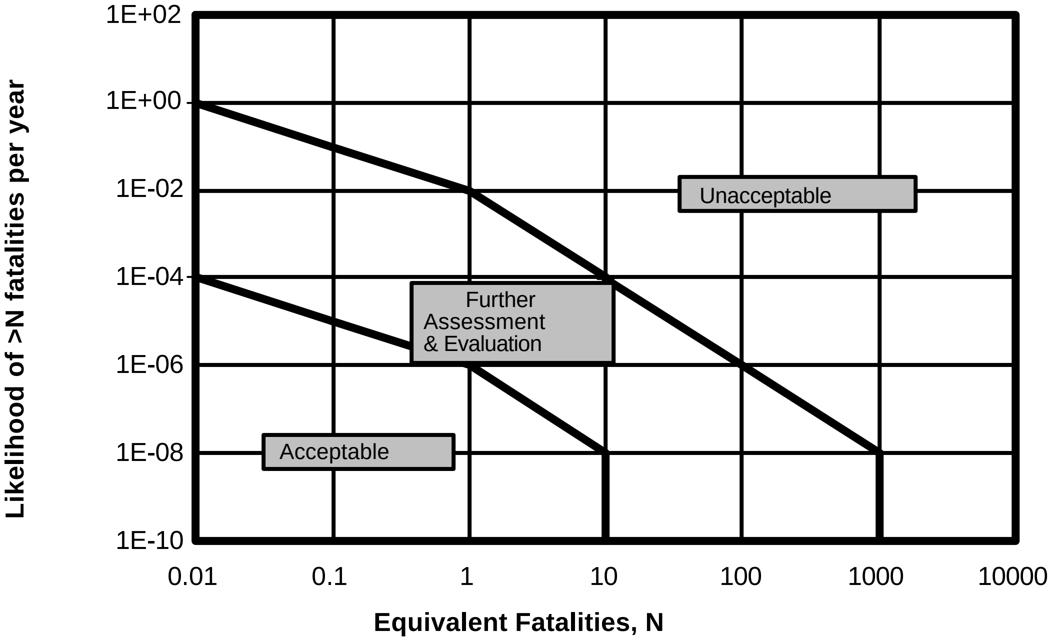

Figure 11. Groningen Curve (1978)

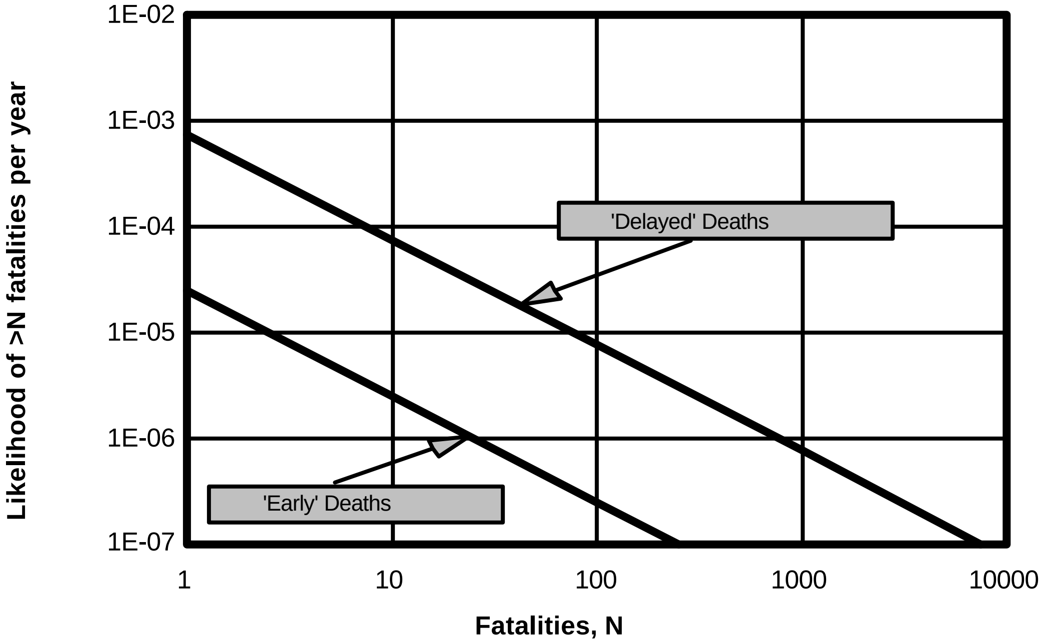

Figure 12. Revised Kinchin Curve (1982)

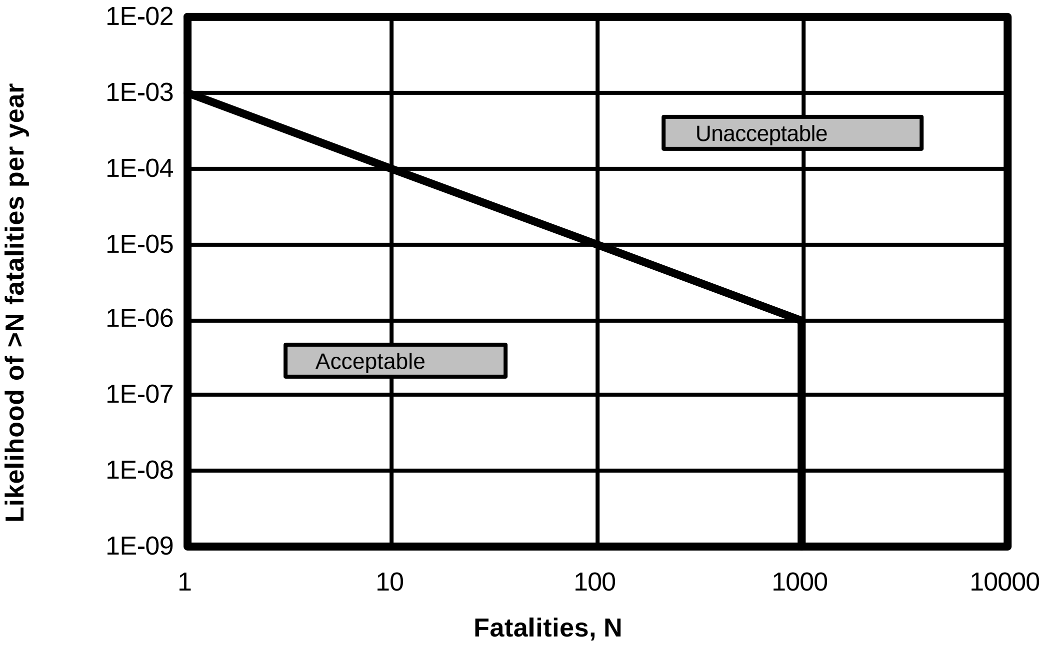

Figure 13. Hong Kong (1988)

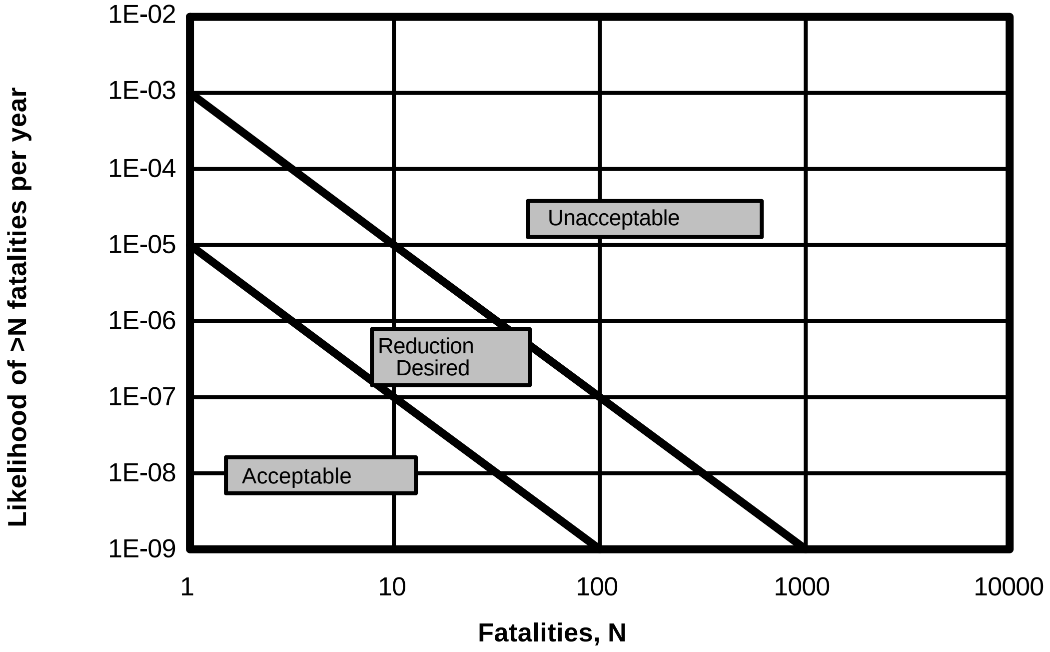

Figure 14. The Netherlands (1980s)

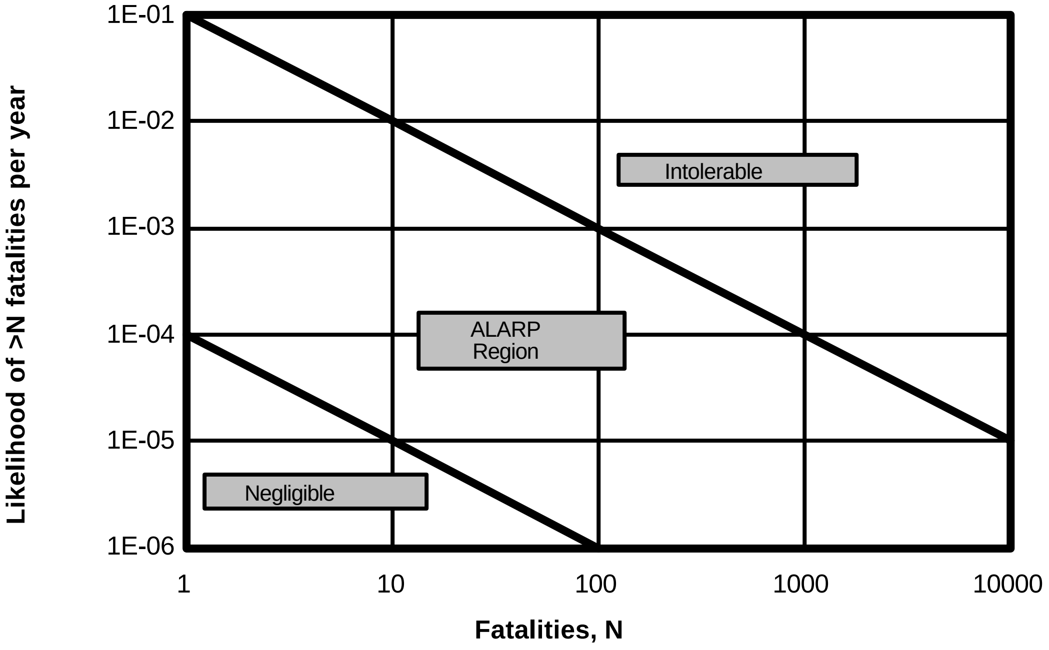

Figure 15. ACDS - UK (1991)

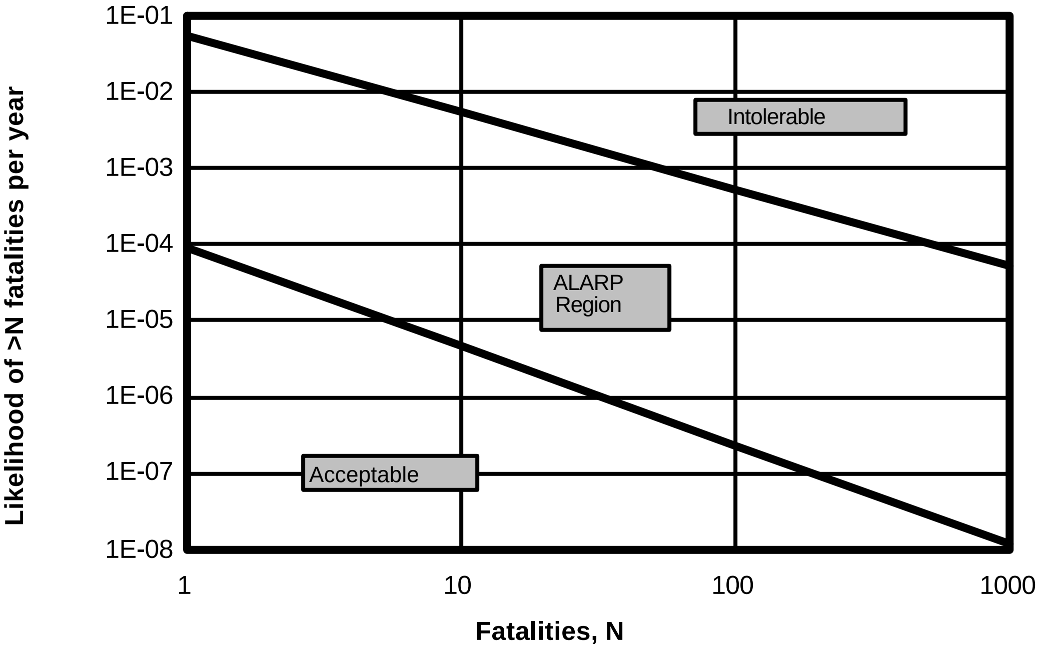

Figure 16. UK Offshore (1991)

Criteria for POB = 150

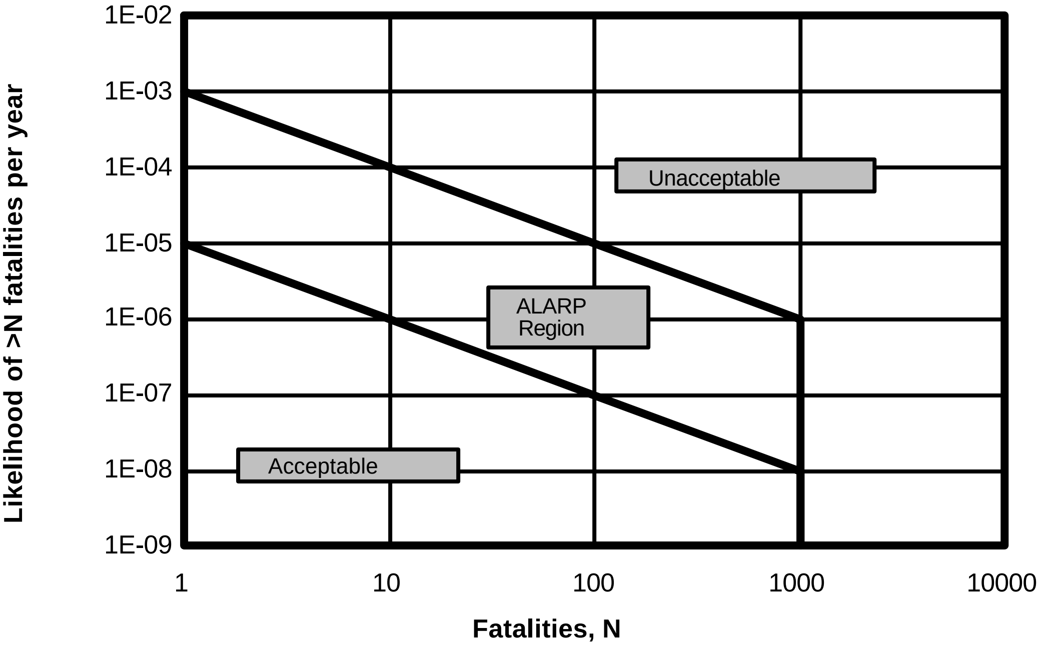

Figure 17. Hong Kong (1993)

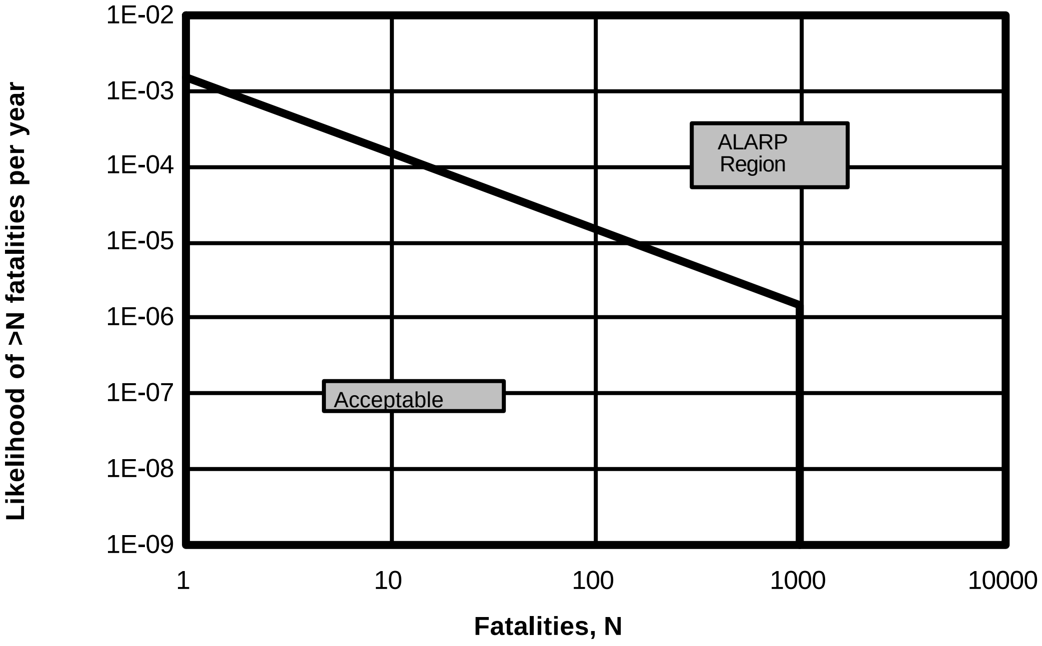

Figure 18. HK DG Transport (1997)
FN criteria presented for LPG

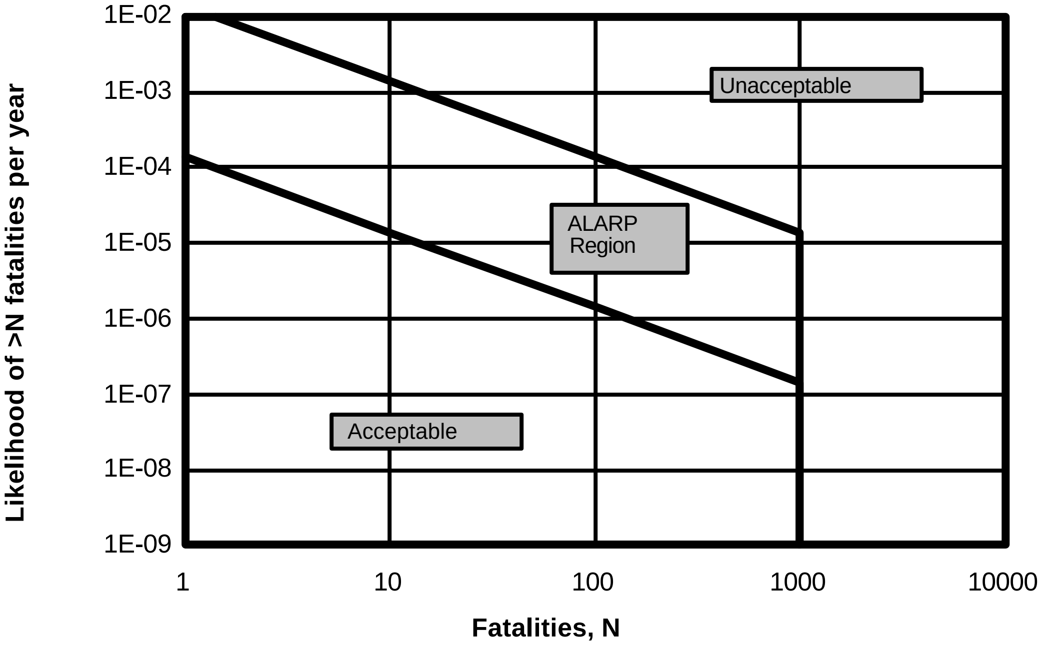

Figure 19. HK DG Transport (1997)
FN criteria presented for Chlorine

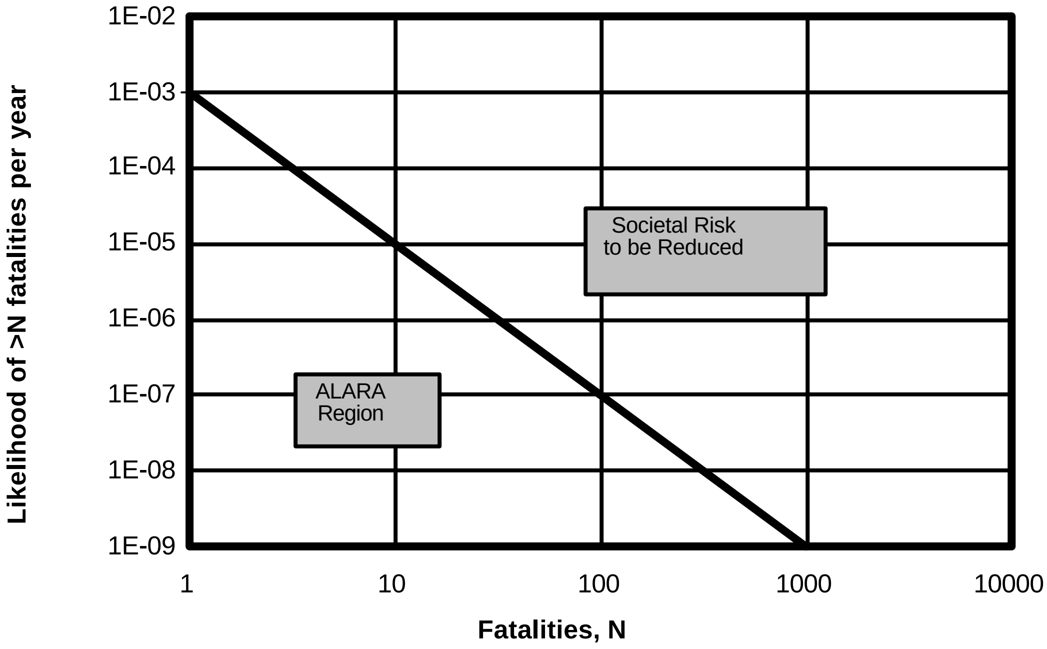

Figure 20. The Netherlands (1996)

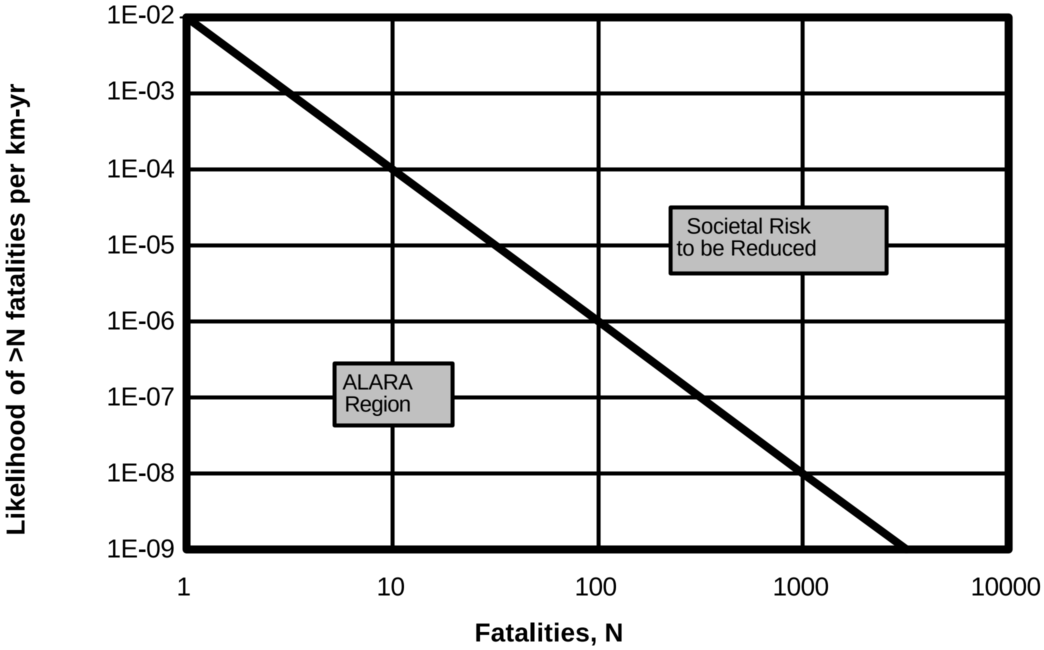

Figure 21. NL DG Transport (1996)

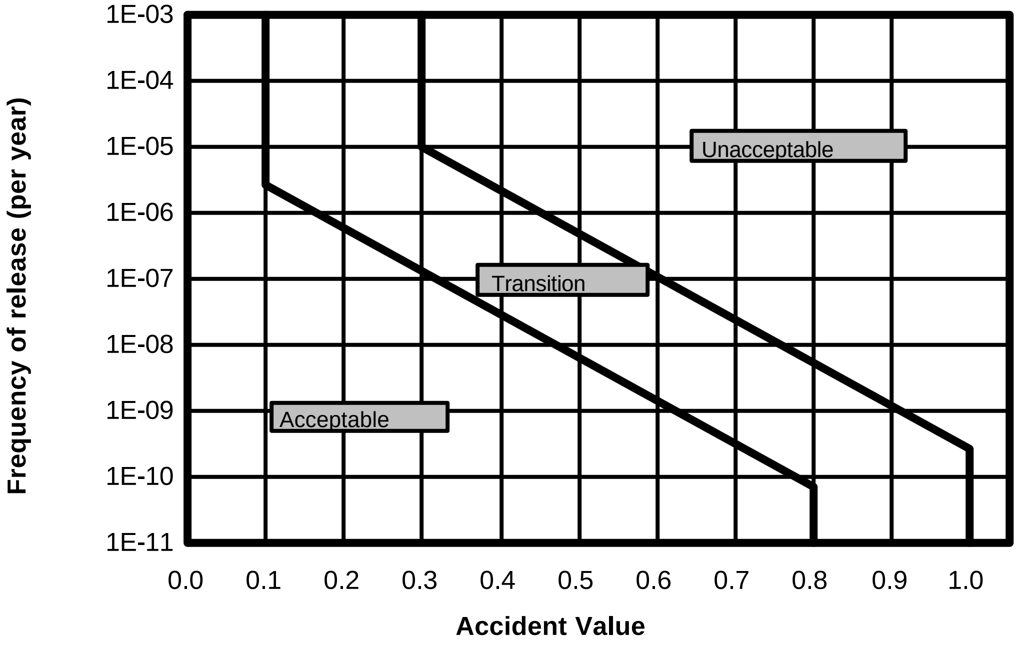

Figure 22. Switzerland (1991/2)

Criteria for Hazardous Installations

Box 2. Incidents in the UK, Europe and Elsewhere (1960s)

Date	Outline of Incident	Reference
08.01.62	Train crash, Woerden (Netherlands), 91 dead.	9
17.02.62	Floods in Germany (North Sea coast), 343 dead.	9
08.04.62	British liner *Dara* lost in Persian Gulf, 236 dead	9
03.06.62	Aircraft crashes on take-off from Orly (Paris), 130 dead.	8
27.09.62	Floods in Barcelona, 445 dead.	9
09.10.63	Vaiont dam (NE Italy) collapse. 1,189 dead.	1, 2, 6
19.12.63	Fire on passenger vessel *Lakonia* near Madeira, 128 dead.	10
26.07.64	Train crash, Oporto (Portugal), 94 dead.	9
05.09.64	Typhoon Rose hits Hong Kong & China, 735 dead.	9
21.10.66	Aberfan tip-slide leaves over 140 dead.	1, 2, 6
3/4.11.66	Floods in Florence & Venice, 113 dead.	9
08.12.66	Passenger ship *Heraklion* sinks in storm in Mediterranean, 217 dead.	10
1966	Landslip in Hong Kong, 64 dead	2, 6
28.02.68	Fish factory ship *Tukan* sinks in storm off Jutland, 57 dead.	10
22.05.67	Store fire in Brussels, 322 dead.	9
04.06.67	Aircraft crashes into Stockport on approach to Manchester Airport, 72 dead.	8
13.11.67	Fire in plastics factory in Somerset, several firemen die in subsequent years due to alleged inhalation of toluene di-isocyanate.	7
26.11.67	Floods in Lisbon area, 464 dead	9
26.02.68	Hospital fire in Shrewsbury, 22 dead.	9
May 68	US submarine *Scorpion* sinks near Azores, 99 dead.	10
18.11.68	Factory fire in Glasgow, 24 dead.	9
05.01.69	Aircraft crashes on approach into Gatwick, 50 dead.	8
Jan. 69	Israeli submarine *Dakar* sinks in Mediterranean, 69 lost.	10

Box 3. Incidents in the UK, Europe and Elsewhere (1970s)

Date	Outline of Incident	Reference
April 70	Avalanche near Mont Blanc engulfs sanatorium, 71 dead.	1
01.11.70	Night club fire in France leaves 146 dead.	1, 9
02.01.71	Crowd stampede at Ibrox stadium, 66 dead.	2
11.01.71	Ship-ship collision in English Channel leaves 8 dead. Wreckage is hit the next night leading to a further 21 dead. A month later, another ship hits wreckage leaving a further 21 dead.	1
01.08.71	Typhoon hits Hong Kong, 130 dead.	9
16.06.72	Train crash, Vierzy (France), 107 dead.	9
19.06.72	Aircraft crashes after take-off from Heathrow, 118 dead.	8
05.07.72	Fire in Sherborne (England) hospital, 30 dead.	9
14.08.72	Aircraft lost over Germany, 156 dead.	8
1972	Building collapse in landslip in Hong Kong, 70 dead.	2, 6
02.08.73	Summerland fire, Isle of Man leaves 50 dead.	1
03.03.74	DC10 crashes near Paris, 346 dead.	1, 8
2/3.04.74	Tornadoes in US leave 324 dead.	1, 2
01.06.74	Flixborough, cyclohexane explosion, 28 dead.	5, 7
30.08.74	Train crash, Zagreb (Yugoslavia), 153 dead.	9
07.11.75	Beek (Holland), propylene explosion, 14 dead.	5
09.03.76	Ski cable car falls at Cavalese (Italy), 42 dead.	1
10.07.76	Seveso (Italy) incident results in 400+ cases of chloracne	1, 2, 5, 7
10.09.76	Mid-air collision over Yugoslavia, 176 dead.	8
19.09.76	Aircraft collides with mountain in Turkey, 155 dead.	8
1976	Landslide, Hong Kong, 22 dead.	6
27.03.77	Teneriffe air plane disaster, 582 dead	1, 2, 8
11.07.78	Spanish campsite engulfed by LPG fireball following truck crash, 200 dead.	3, 4, 5, 7
11.12.78	LPG road tanker accident in Mexico, 100 dead.	4
08.01.79	Bantry Bay (Ireland) oil tanker explosion, 50 dead.	3, 5, 7
28.03.79	Major incident at Three Mile Island nuclear plant	2
14.07.79	Hotel fire in Saragossa (Spain), 80 dead.	9
10.11.79	Mississauga train crash, 250,000 people evacuated.	3, 5
14.08.79	Storm hits Fastnet yacht race, 15 dead.	1, 7

Box 4. Incidents in the UK, Europe and Elsewhere (1980s)

Date	Outline of Incident	Reference
27.03.80	Alexander Kielland oil rig collapses, 186 dead.	1
29.11.80	LPG incident in Spain, 51 dead.	4
14.02.81	Night club fire, Dublin leaves 46 dead.	1
01.12.81	Aircraft collides with mountain in Corsica, 180 dead.	8
13.02.83	Cinema fire, Turin, 64 dead.	9
27.11.83	Aircraft crashes into hills on approach to Madrid, 181 dead.	8
17.12.83	Discotheque fire, Madrid, 83 dead.	9
24/25.02.84	Pipeline fire in Brazil, maybe 500 dead.	3, 5, 7
23.05.84	Abbeystead methane explosion, 16 dead.	5, 7
19.11.84	LPG storage tank fire/explosion in Mexico, 503 dead.	4, 5, 7
2-9.12.84	Bhopal, 3,000 dead.	2, 5, 7
January 85	Gas explosion in Putney, 8 dead.	7
19.02.85	Aircraft crashes on approach to Bilbao (Spain), 148 dead.	8
11.05.85	Bradford City football stadium fire, 56 dead.	2, 7
29.05.85	Crowd stampede at Heysel stadium, 39 dead.	2, 7
19.07.85	Dam failure, northern Italy, 361 dead.	9
22.08.85	Fire on take-off leaves 55 dead at Manchester airport.	7, 8
29.11.85	Gas explosion in Glasgow, 5 dead.	7
26.04.86	Chernobyl nuclear disaster, 10,000+ delayed deaths.	2, 7
06.11.86	Helicopter carrying oil-rig workers crashes, 45 dead.	8
06.03.87	Herald of Free Enterprise ferry capsizes, 193 dead.	2, 7, 10
18.11.87	King’s Cross tube station fire, 31 dead.	7
June 88	Train crash in Lyons station in Paris, 56 dead.	7
06.07.88	Pipe Alpha oil rig disaster, 166 dead.	2, 5, 7
06.07.88	Aluminium sulphate contaminated water delivered to 20,000 people in Camelford. Numerous claims for adverse health effects,	7
12.12.88	Clapham rail disaster, 35 dead.	7
04.06.89	Two trains engulfed in gas pipeline explosion in Russia, 400 dead.	2, 3
20.08.89	*Marchioness* disaster, 51 dead.	7
10.09.89	Steamer *Mogosoaia* capsized after collision on R. Danube. 164 dead	10
23.10.89	Ethylene explosions at polyethylene plant in Texas, 23 dead.	7

Box 5. Incidents in the UK, Europe and Elsewhere (1990s)

Date	Outline of Incident	Reference
07.04.90	Ro-ro ferry *Scandinavian Star* caught fire off Danish coast, 158 dead.	10
1990	8ft tyre on Caterpillar digger explodes in Nottingham, 3 dead.	7
08.01.91	Train crashes into buffers at Cannon St. (London), 2 dead and 200 injured.	7
10.04.91	Ferry/oil tanker collide in Livorno harbour (Italy), 140 dead.	9, 10
22.04.92	Vapours explode in sewers in Guadalajara (Mexico), 200+ dead.	7
21.09.92	Chemical plant explosion/fire in Castleford, 5 dead.	7
14.01.93	Ro-ro vessel *Jan Heweliusz* capsized in Baltic storm, 55 dead.	10
March 93	4 young canoeists drowned in Lyme Bay, Dorset.	7
02.06.94	Helicopter crash in Scotland, 29 dead.	7
28.09.94	*Estonia* ferry disaster in the Baltic, 838 dead	7, 10
15.10.94	Trains collide in Kent, 5 dead.	7
23.05.95	Coach crash on M4 near Bristol, 10 dead.	7
24.05.95	Air-taxi crashes in Yorkshire, 12 dead.	7
15.04.97	Fire sweeps through 70,000 tents near Mecca, 343 dead.	7
19.09.97	Train crash near London, 7 dead.	7

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