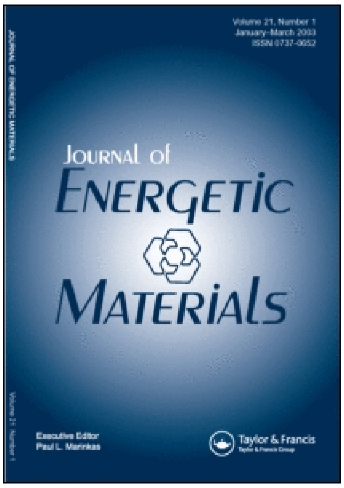

Journal of Energetic Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713770432

Development of risk assessment techniques for use in the field of explosives and ammunition

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To cite this Article Clifton, J. , Edmondson, J. N. , Hartley, F. R. and Moreton, P. A.(1989) 'Development of risk assessment techniques for use in the field of explosives and ammunition', Journal of Energetic Materials, 7: 1, 29 — 54
To link to this Article: DOI: 10.1080/07370658908012559
URL: http://dx.doi.org/10.1080/07370658908012559

DEVELOPMENT OF RISK ASSESSMENT TECHNIQUES FOR USE IN THE FIELD OF EXPLOSIVES AND AMMUNITION. PART II. RISK EVALUATION

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ABSTRACT

Criteria for estimating the risks involved with ammunition and explosives are presented against a background of the public's perception of risk. The criteria are presented in terms of a three band approach separated by two threshold risk levels. The upper and lower bands represent unacceptable and trivial risk situations respectively, whilst the middle band represents a region in which the risk levels must be reduced to as low a level as is reasonably practicable.

Individual Risk criteria are presented for three groups of people: the workforce necessarily exposed to risk in the course of their daily work, those members of the workforce who do not need to be exposed to risk in order to do their work and the general public. In the case of Societal Risk only one set of criteria are presented on the basis that when a major incident involving large numbers of casualties occurs the public reaction does not discriminate in its perception of horror between members of the general public and members of the workforce. In addition to preserving life it is suggested that criteria are required to preserve stocks in situations where life itself may not be at

risk. For this it is recommended that the propagation of initial initiation or explosion to other munitions nearby by sympathetic detonation should be prevented, as far as possible, by the maintenance of the current separation distances for magazines, updated where necessary as new knowledge becomes available and new explosives and munitions are developed.

The present tentative proposals are compared with quantitative risk evaluation criteria proposed in other countries and in other industries.

INTRODUCTION

The process of Risk Assessment can be divided into two phases, Risk Analysis and Risk Evaluation. In Part I a method was described for estimating the risk levels involved in the storage of explosives and ammunition[1]. The present paper attempts to develop criteria against which the significance of those risk levels may be considered. The views presented represent those of the authors alone and should not be taken as being in any way representative of the views of the British Government.

BACKGROUND

Many, many articles have been published in the technical literature, in semi-popular journals and in the popular press which attempt to evaluate risk criteria. These articles teach at least two things:

- i It is extremely difficult to develop criteria.
- ii It is impossible to develop criteria of what is an acceptable risk for a particular activity which command universal support; the only criterion that appears to fulfil this objective is that of "zero risk", but this is not an achievable goal in any field.

A wide variety of techniques have been used to analyse the public's perception of risk. These are well summarised by the Report of a Royal Society Study Group published in 1983[2]. This clearly shows that a major factor in the public's perception of the degree of risk they are prepared to accept concerns their perception of the benefit derived from the activity. The greater the benefit the greater the degree of risk they are prepared to accept. At one extreme people who enjoy mountaineering are prepared to accept very high levels of risk, whereas there are few who would wish to accept any but the lowest possible risk level of a nuclear accident, and many wish to accept no risk at all by proposing to ban both nuclear weapons and nuclear power plants. However although there is a link between the degree of risk that is tolerable and the perceived benefit, it is not a simple one. At the very least it is multi-dimensional.

In such a broad range of risk levels it is clearly difficult to determine the degree of risk that would be acceptable in the field of explosives and ammunition. That the acceptable level of risk is greater than the hypothetical "zero" is demonstrated by the fact that within the world today there exist only a minority of pacifists. The majority of people are prepared to support the concept of war in defence of what they see as the infringement of their rights and liberties. The consequence of this, coupled with the human race's seemingly infinite capacity to produce individuals or leaders who wish to promote their or their followers' well-being at the expense of others, has led to there being few years in which explosives have not been used in conflict since at least the beginning of the 15th century. Since explosives and ammunition are an "essential" feature of the world it is important to ensure that they are handled and stored in the safest practicable way.

Apart from the perceived benefit arising from an activity the other main perceptions that influence the British public's view of risk are well summarised in the conlusions of a "Sunningdale Seminar" held in 1979[3]:

i Concentrated, obvious risks (e.g. motorway pile-ups or major industrial explosions) are regarded as worse than diffuse risks like those from general road accidents or an equal number of deaths scattered around as a result of smaller scale industrial accidents.

ii Risk to non-beneficiaries (e.g. general public exposed to emissions from nuclear power stations, or people living alongside railways) are regarded as worse than risk to beneficiaries (e.g. recipients of radio-therapy or railway workers).

iii Involuntary risks (e.g. of receiving carcinogens in food) are regarded as worse than voluntary risks (e.g. rock climbing).

iv Risks that are isolated and are not compensated for by associated benefits (e.g. exposure to x-rays in fitting shoes) are regarded as less acceptable than risks obtained in a largely beneficial context (e.g. risks from radon emissions in buildings that otherwise provide warmth at low energy cost).

vi Immediate hazards (e.g. of new electrical equipment) are regarded as worse than deferred hazards (e.g. resulting from bad maintenance).

vii Unfamiliar, unnatural or "new hazards (e.g. from new food additives or radiation from nuclear industry) are regarded as worse than risks from familiar, natural and established causes (e.g. by traditional foods, cosmic radiation or emissions from Cornish granite).

viii Risks arising from secret activities (e.g. in the defence field) are regarded as worse than those derived from open activities.

ix Risks evaluated by groups who are suspected of partiality (e.g. statements by an industry about the safety of its own installations) are regarded as worse than risks evaluated by impartial groups.

x Risks that some other person pays to put right are regarded as worse than risks individuals have to pay themselves to remedy.

AIM

This paper shows how to estimate risk levels in the field of explosives and ammunition and attempts to propose criteria for their evaluation. It does so against a rich background literature which clearly demonstrates that the public's acceptance of risk is not well understood, but is clearly multi-dimensional with many apparently inconsistent and mutually contradictory components.

EVALUATION OF RISKS TO PEOPLE

The risks to people are generally expressed in terms of the Individual and Societal Risk associated with a particular activity. The Individual Risk represents the frequency with which a specific individual person may be expected to sustain a defined level of harm. The Societal Risk represents the frequency with which specified numbers of people in a given population, or the population as a whole, sustain a specified level of harm from the realisation of specified hazards. The specified level of harm is usually based on either fatality or serious casualty; in this paper we use the former.

The Individual Risk is determined by summing up each of the separate risks to which that individual is exposed. Those separate risks are estimated as follows:

i The frequency of occurrence of fire and explosion incidents from which the individual may suffer harm are estimated as described in Part I[1].

ii Given the occurrence of an incident the probability of the individual becoming a fatality is estimated using the consequence analysis based on blast overpressures, projection attack and thermal radiation described in

Part I[1].

iii The Individual Risk is then estimated as the sum of all the risks arising from each separate incident, where the risk arising from a specific incident is the product of its frequency of occurrence and the probability of an individual becoming a fatality.

The Societal Risk is evaluated by estimating the expected number of casualties from each incident on the basis of the consequence models described in Part I[1]. In this evaluation it is important to determine the average population present in each location, since people outdoors or behind large glass windows are more likely to become fatalities than those behind brick walls. A combination of the frequency estimates and all the total fatality predictions enable Societal Risks to be expressed in the form of a frequency in $years^{-1}$ of causing N fatalities. Accordingly it is possible to draw contours around explosives facilities showing zones within which up to a certain number of fatalities may be expected to occur with a particular frequency.

When estimating both Individual and Societal Risks with explosives facilities it is important to take account of the possibility of a "domino effect" whereby an initial explosion or fire in one part of the facility initiates second, third and fourth incidents. These secondary and tertiary incidents may be the cause of fatalities to people who were out of range of the primary incident.

Interested Parties

The entire population has an interest in the levels of risk associated with explosives and ammunition. However four groups have an especial interest because of their direct involvement. These are:

i Those who work in explosives and ammunition facilities and who, in order to undertake their daily work, must necessarily be exposed to risk.

ii Employees working within explosives and ammunition facilities who do not need to be exposed to risk in order to undertake their daily work (e.g. secretaries and telephonists).

iii Those who live or work or travel in the vicinity of explosives and ammunition facilities.

iv The owner of the facility, whether that be the Government or a private company.

The owner of the facility has an interest on three levels:

a As the owner of the stocks.

b As the employer of a workforce whose goodwill he wishes to retain.

c As an organisation which wishes to cultivate the goodwill of the population as a whole.

Clearly points b and c are subsumed by the interests of the workforce and the local population. This is also true of two other parties who have an interest in levels of risk involved, namely the organisations responsible for safety (in the UK this is the Health and Safety Executive) and for local planning (in the UK this is the Local Planning Authority). Thus consideration of the interests of the four groups set out in i to iv above includes the interests of the other relevant parties.

<u>Threshold Risk Levels</u>

Many events throughout the World have demonstrated that it is virtually impossible to gain universal acceptance of any particular level of risk for any potentially dangerous activity. Nevertheless decision-makers need some guidelines as to the levels of risk that should be accepted. Indeed the worst possible situation arises in the absence of any guidelines when the decision-makers are left free to do as they wish[4]. We suggest that a way out of this dilemma is to consider what is an unacceptable level of risk. An unacceptable level of risk would then be a threshold above which no operation should be permitted to continue. We also suggest that there is also a level of risk below which situations can be considered to pose a trivial risk. Below this threshold level activity should be allowed to continue, with the proviso that the situation be regularly monitored to ensure that the risk remains below the lower threshold level and is not allowed to rise due to neglect.

All activities that lie between the two threshold levels must then be analysed to determine whether or not the activities that give rise to them are essential. If they are essential, then they must be examined in detail to determine:

i whether it is inordinately expensive to reduce the level of risk posed; if it is, then the situation and its attendant risk level must be accepted; or

ii whether it is possible within a reasonable cost to reduce the level of risk; if such is possible then the situation must be improved, and expenditure must be incurred in effecting the necessary improvements.

The result is that all situations posing levels of risk that lie between the two threshold levels have been made as safe as is reasonably practicable. This concept of reasonable practicability is now enshrined in UK law[5], whilst the three band approach described here (Figure 1) has been adopted by the Dutch Government for the control of major hazards[6].

THRESHOLD INDIVIDUAL RISK LEVELS FOR THE WORKFORCE

Two conditions must be satisfied before a person can be deemed to have accepted a risk voluntarily[7,8]. These conditions are:

i full information about the nature and level of risk must be available to the person at risk, and

ii acceptable alternatives also must be available to that person, although these alternatives may be considered less desirable than accepting the risk (unemployment, for instance).

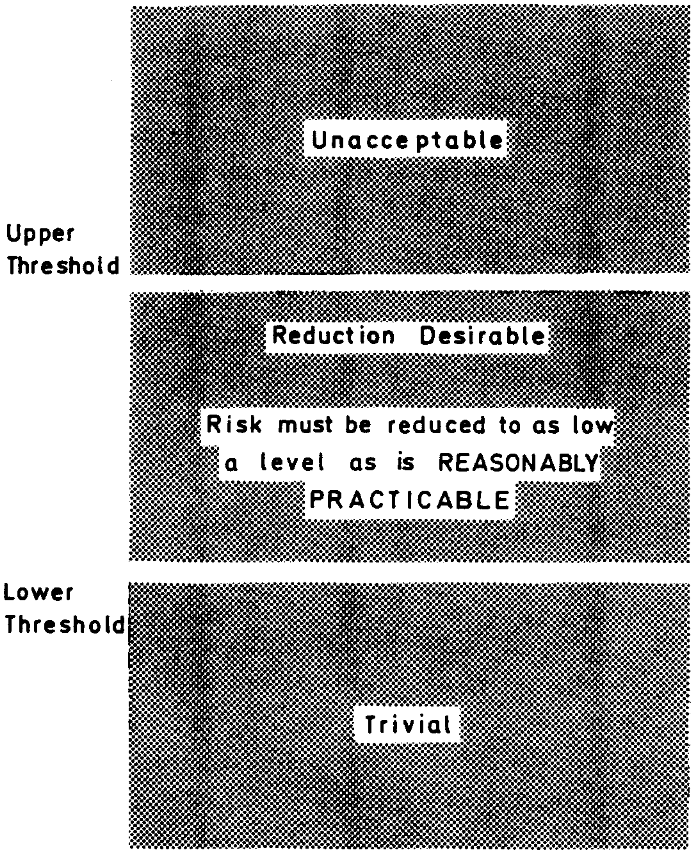


Figure 1 A THREE-BAND APPROACH FOR EVALUATING SITUATIONS INVOLVING RISK

Both of these conditions are satisfied in the case of those workers in explosives and ammunition facilities who are directly involved with the explosives and ammunition. First of all, such workers are necessarily informed of the hazards associated with handling ammunition and receive special training to reduce the risks; the need to observe strict safety procedures must also reinforce an awareness of the potential hazards. Secondly, it may be fairly claimed that those people who work in ammunition depots do so by their own choice. However, there is often a second group of employees within explosives and ammunition facilities to whom the first condition of full information does not apply. These are persons who are not directly involved with explosive items in the course of their daily work. This category includes, for example, secretaries and telephonists. We believe the two groups should be considered separately.

i <u>Workforce necessarily exposed to risk</u>

The workforce who have to be exposed to risk from explosive items in order to undertake their daily work can be said to have voluntarily accepted the risk involved. A voluntary risk has been said to be by definition an acceptable risk. However, the application of a simple risk comparison approach may demonstrate whether the acceptance by a workforce of a particular occupational risk can be considered reasonable. Of interest here is a comparison of the various levels of risk to which workers employed in different industries are exposed. There is a case for suggesting that the risks to ammunition workers should be no higher than the risks to workers employed in the chemical industry, on the basis that the potential hazards associated with such dangerous chemical substances as liquid petroleum gas and liquified natural gas are similar to explosives, that is mass explosion and fire. Ideally, perhaps, risk levels might be linked to the petrochemicals industry only. However information concerning the risk levels in this part of the chemical industry alone is not available. Accordingly the proposals made here are linked to the chemical industry as a whole.

The Fatal Accident Rate (FAR) for the chemical industry in the UK avergaged 2.6 fatalities per 100 million exposed hours during the period 1976-1980[9]. These figures are substantially lower than for metal manufacture (5) and construction (7) but above that for British manufacturing industry as a whole (1.6). If a working year is assumed to be 2000 hours, an FAR of 2.6 is equivalent to a risk of one fatality in every 20,000 years of work for the chemical industry. On this basis it is suggested that the upper threshold level of risk from explosives and ammunition should be set at 1 fatality per 20,000 exposure years. It should be noted that this is an improvement on the suggestion of the UK Advisory Committee on Major Hazards which recommended[10] in 1976 that an activity which led to a serious accident rate in excess of 1 in 10,000 years should be considered unacceptable. Their proposal has not been seriously challenged in the past 12 years, and indeed has been used in making a considerable number of decisions.

It is suggested that the lower threshold level of risk for the workforce, below which the risk can be considered trivial should be set at the same value as that for members of the general public. Thus all risks incurred by employees greater than those to which they are exposed as members of the general public should be reduced to as low as is reasonably practicable. The Royal Society Study Group 1983 recommended[2] that, where clear causal links exist between a material and its hazard a fatality rate of 1 in 10 million exposure years could be considered trivial. Accordingly we recommend this value as the lower threshold level.

ii <u>Workforce not necessarily exposed to risk</u>

Since the Flixborough disaster in 1974 it has become recognised that those members of the workforce who do not need to be exposed to risk in order to undertake their daily work should, as far as possible, be located away from areas of high risk. Accordingly we recommend that staff such as secretaries and telephonists, and facilities such as meeting rooms and workshops covering non-explosive stores should be located where the risk levels are no greater than those to which the general public may be exposed. It should, of course, be emphasised that the levels of Individual Risk depend on the duration of the exposure. It is normally assumed for the calculation of Individual Risk that the most exposed member of the general public is exposed to the risk 24 hours a day for 7 days a week. In contrast the workforce are usually assumed to be exposed for 8 hours a day, 5 days a week. Accordingly, greater separation distances are required for members of the general public than for members of the workforce.

THRESHOLD INDIVIDUAL RISK LEVELS FOR THE GENERAL PUBLIC

The risk to the general public posed by explosives and ammunition facilities applies principally to those who live and work in the vicinity of a facility as well as those who travel past it. For some this risk is voluntary in that they choose to live in houses close to a facility, perhaps because their house is a tied house provided for an employee and his family. For others this risk is involuntary and may to a large extent be described as inequitable, as they receive no direct benefit in compensation; furthermore, these people have no direct access to information about the hazard to which they are exposed, its probability of occurrence and its likely consequences. However, it must be admitted that even if such information became available, it is likely that those exposed to risk would have no alternative but to tolerate it; "fleeing" the source of risk could not be considered an acceptable alternative in view of the disruption this would entail. Such a situation is difficult to justify on ethical grounds, although this type of situation is not uncommon in society; one has only to think of the large numbers of people who live and work in the vicinity of chemical plants and areas where petroleum, gas and toxic chemicals are stored.

It might be thought that involuntary risks could be made more equitable, and perhaps even acceptable to the risk exposed person, by the payment of "danger money" or some other form of compensation. However, this raises the problem of deciding a level of compensation that may be considered fair. From the point of view of the individual, a risk can only be considered acceptable if he understands the risk, considers the benefits accruing from it to be worthwhile and chooses the risk in preference to acceptable alternatives. However, if this principle is followed through to its logical conclusion, then any individual exposed to risk as a *fait accompli* effectively would be allowed to set his own price for either tolerating the risk or for some remedial action to be taken. Such a policy could place intolerable burdens on society. Clearly there must be a trade-off between the interests of risk-exposed individuals on the one hand and the interests of society as a whole on the other. Society as represented by the Government does not have the resources to eliminate all involuntary risks to individuals, and those resources which are available for safety enhancement logically should be allocated so as to achieve the greatest overall reduction in risk levels. Payment of direct monetary compensation to risk-exposed individuals may in fact evoke negative reactions in other sections of the community. Of interest here is the case of direct payment of compensation by a utility company to a citizens' action group in the city of Bergkamen, Germany[11]. The citizens' action group had been formed to protest against the plans of the utility company to construct a 1400MW coal power plant in the Bergkamen area. In March 1977 the utility company paid the citizen's action group DM1.5 million in return for which the action group agreed to cease protesting against the project. This decision was greeted with negative reactions by West German public opinion, and concern voiced in the media that health and safety were citizens' inalienable rights that could not be bought off with money.

There is clearly a need to limit the risk to those people who live and work in the vicinity of ammunition and explosives facilities. Defining a threshold level of risk which might be considered fair for those people exposed involuntarily to risk is an exceptionally difficult problem. It would seem that a solution to the problem which might be considered fair by society as a whole would be to adopt the same safety goals for ammunition and explosives storage depots as those that have been proposed for chemical plants and other hazardous installations. An additional argument which may be advanced in support of this proposal concerns the perception of the public at large that direct personal benefits are not derived from chemical plants. Thus there is no justification for allowing the risks associated with chemical plants to be larger than the risks associated with ammunition and explosive facilities on the grounds that the public perceives greater benefit for the former. Kletz[12] has suggested that the maximum level of risk to the public from chemical plants should be limited to the range 10^{-5}-10^{-6} fatalities per person per year. O'Donnell[13], considering numerical acceptance criteria for hazardous installations, has also suggested an individual fatality risk of 10^{-5} per exposed person per year and has shown that this figure compares favourably with numerical acceptance criteria proposed by other authors.

Accordingly an upper limit to the individual risk of death of one fatality per 100,000 years of exposure is proposed for those members of the general public specifically exposed to risk. The Royal Society[2] figure of one fatality in 10 million years of exposure has already been proposed for the lower threshold risk level for the general public.

SOCIETAL RISK LEVELS

It has already been noted that it is well-established that public concern about multiple fatality accidents increases rapidly and non-linearly with the number of casualties. Accordingly there is a clear need to define upper limits of tolerable frequency for multiple fatality accidents. Societal Risk criteria are usually presented graphically in the form of plots of the frequencies of accidents giving rise to $\geq$ N fatalities against the number of fatalities(N); such plots are often known as F/N plots.

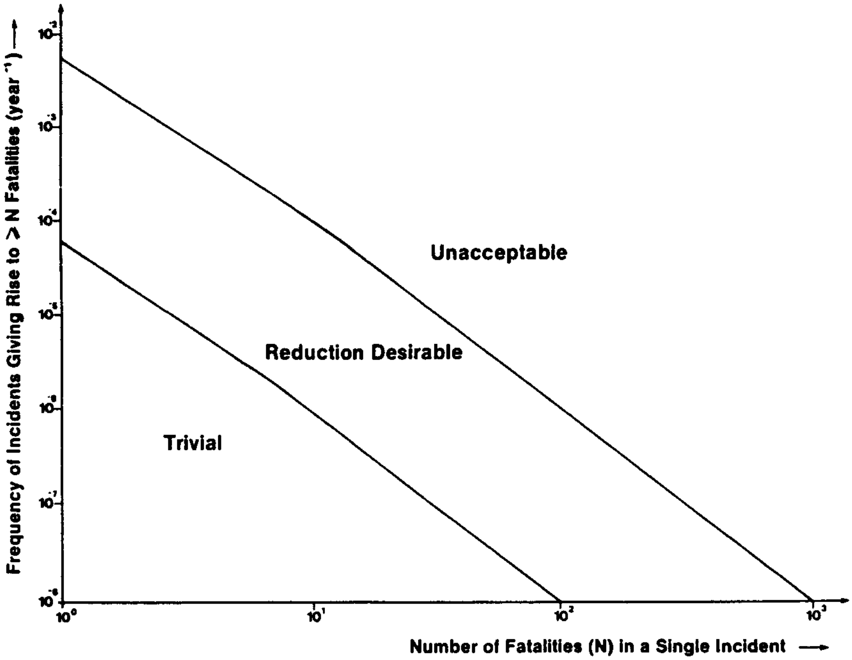
In the case of explosives facilities the number of people necessarily exposed to risk in order to accomplish their jobs is relatively small, in large measure because the facilities are well spread out over a large area. As a consequence when incidents have occurred in the past in which large numbers of people (i.e. greater than 20) have been killed, many of the fatalities have been amongst members of the general public and those members of the workforce who do not need to be exposed to risk in order to do their daily work. Accordingly we do not believe it is helpful to show separate F/N plots for societal risk for the workforce and the general public. A single plot will reflect society's aversion to multiple fatality accidents irrespective of whether those fatalities are amongst members of the workforce or members of the general public.

It has been calculated[14] that for the entire UK chemical industry the probability of having an accident involving 10 or more fatalities is about one in every 10 years. Thus the F/N plot would pass through the point 10^{-1}year^{-1} for $N \geq 10$. Since there are more than 100 times as many chemical plants as explosives and ammunition facilities the upper threshold level of acceptability from all explosives facilities should pass through the point 10^{-3}year^{-1} for $N \geq 10$. There are about 10 significant (in terms of the risk they pose) sites in the UK, so that for an individual site the upper threshold level of acceptability should pass through the point 10^{-4} $year^{-1}$ for N$\geqslant$10. Such a figure is consistent with the recommendation of the Advisory Committee on Major Hazards[10] that a limit of one major accident at any one plant every 10,000 years represents the upper limit of what might be deemed to be just on the borderline of acceptability. If a major accident is assumed to result in 10 or more fatalities then the upper threshold level of acceptability would pass through the point 10^{-4} $year^{-1}$ and N$\geqslant$10. It is further suggested that the threshold limit, below which the risks from a single site can be considered trivial, should be set 2 orders of magnitude below the upper threshold limit, as applied for the individual threshold level criteria for members of the general public. Thus the lower threshold level passes through the point 10^{-6} $year^{-1}$ for N$\geqslant$10.

It has already been noted that the public's perception of risk increases sharply and non-linearly as the number of fatalities increases. An analysis of the multiplicity of suggestions available in the literature[6,15,16] suggests that up to 10 fatalities public concern rises approximately with the 3/2 power of the number of fatalities, whereas above 10 fatalities it rises with the square of the number of fatalities.

When the threshold level criteria of the previous two paragraphs are put together, they yield the acceptance criteria shown in Figure 2. A cursory examination of the criteria in Figure 2 might suggest that the threshold level of unacceptability for killing one individual is 1 in 200 exposure years. This seems at first sight inconsistent with the criterion of an individual upper threshold level of 1 in 100,000 exposure years cited above. The apparent discrepancy arises because the figure of 1 in 200 years arising from the societal risk criterion refers to the possibility of killing any individual at all, whereas the figure of 1 in 100,000 years arising from the individual risk criterion refers to the possibility of killing a

Figure 2 **Proposed Societal Risk Acceptance Criteria for Explosives and Ammunition Facilities**



specific individual, not just any individual.

THRESHOLD RISK LEVELS FOR THE OWNER OF THE FACILITY

It has already been emphasised that the owner of the facility be it an industrial enterprise or the Government has an interest in ensuring that serious accidents which result in injury or death to its workforce or to the general public do not occur. This interest is safeguarded by the criteria just given. In addition both industrial enterprises and the Government have an interest in preserving both the stocks and the facilities. For an industrial enterprise these stocks and facilities have a commercial value and so, in situations where neither loss of life nor injury can occur, it is possible to determine how much should be spent on enhancing safety by balancing the reduced likelihood of loss of stocks or damage to facilities with the costs incurred in enhancing safety. A number of safety improvements can be considered; each will have a certain cost and will reduce the risk of losing a certain value of material. The optimum safety improvement is that where the two costs are equal (Figure 3).

Whilst the monetary criterion shown in Figure 3 may be very helpful for industry, it is a great deal less helpful to Government. The reason for this is that if an accident occurs during the run up to a major conflict, or during the conflict itself, the ammunition stocks cannot be replaced in time to be used. Being irreplaceable they really have no sensible financial value, and it is essential that they are not lost by accident. Accordingly it is proposed that the probability of an initial incident occurring should be set no higher than the current value, which although not formally known can be determined by the Risk Analysis procedure described in Part I[1]. Furthermore the propagation of an initiation by sympathetic detonation should be prevented. This should be achieved by adhering to the prescribed minimum separation distances for magazines;[17] the values used for these should be kept under continuous review as new knowledge

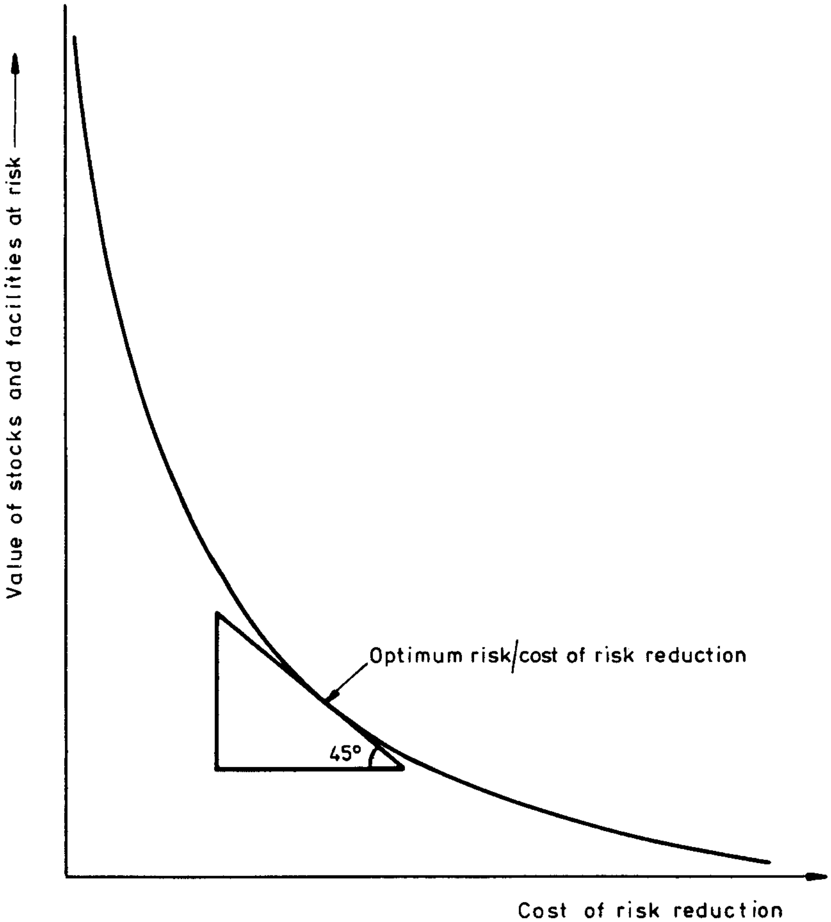


Figure 3 THE RELATIONSHIP BETWEEN RISK AND THE COST OF RISK REDUCTION SHOWING THE OPTIMUM POINT WHERE ONLY STOCKS AND FACILITIES (i.e. NOT LIVES) ARE AT RISK

becomes available and new explosives and munitions are developed.

DISCUSSION; COMPARISON OF THE PRESENT PROPOSALS WITH THOSE USED ELSEWHERE

It is instructive to compare the present proposals for threshold risk levels for individuals, groups and for the preservation of stocks with the criteria used by others. The NATO Quantity-Distance Rules[17] do not specify either the assumed frequencies of incidents or the acceptable level of damage. Direct comparison is not therefore possible.

Swiss Consulting Engineers have proposed risk criteria for both individuals and societal groups[18,19]. Most Swiss ammunition facilities employ very few workers; they therefore pose their major risk to the general public. Accordingly all persons, be they members of the workforce or the general public, are assessed by the same criteria. Furthermore the Swiss only use one threshold risk level, equivalent to the upper threshold level of the present paper, to distinguish what is unacceptable from what is acceptable. The Swiss Consulting Engineers proposed that a level of risk greater than one fatality in 100,000 exposure years was unacceptable[18,19]. This is the same as proposed in the present paper for the upper Individual Risk threshold for the general public and the members of the workforce who do not need to be exposed to risk in order to accomplish their daily task.

For Societal Risk the Swiss Consulting Engineers proposed a criterion based on risk/benefit analysis which depends on the concept of Society's willingness-to-pay to save a human life[18,19]. By analysis of a wide range of situations, they concluded that Swiss society would be prepared to spend 10 million Swiss Francs (~£4 million) to preserve a life from an explosive incident. The Societal Risk posed by a given facility is determined in units of lives. The cost of reducing that Societal Risk in a number of ways is then determined, and a plot is prepared of the lives at risk against the cost of achieving this (Figure 4). The point c where the tangent, which has a slope of 10 million Swiss Francs per life meets this curve is then determined. This point, c, then defines both the cost that must be met if the facility is to continue to be used (point b, Figure 4) and the resulting acceptable level of Societal Risk posed by that facility (point a, Figure 4). During the course of the present work careful consideration was given as to whether or not to develop Risk Acceptance criteria based on the value of human life. This approach was rejected for two main grounds which each cover a multitude of issues:

i There is no simple or widely agreed criterion for determining the value of a human life. The true breadth of the problem is well illustrated by the cost that UK society was willing to pay in 1980 to save a life, which varied from about £5000 for an agricultural worker to £20 million for a high rise flat dweller[20].

ii Even if a value could be determined at a given point in time, it would then be necessary to regularly modify this to allow for inflation. Such an exercise is far from simple; for example the rate of escalation of court settlements for serious injuries and fatalities over recent years has born little relation to the general rate of inflation.

The Dutch Government has debated and now published risk acceptance criteria for potential hazards in order to protect individuals against undue risk levels and to prevent catastrophic accidents[6]. Their criteria, which apply to both the chemical and the nuclear industries, are based on the three band approach advocated in this paper. No distinction is made between the workforce and the general public. For Individual Risk the upper and lower threshold levels are set at 1 in 1 million and 1 in 100 million exposure years respectively for the probability of being killed or injured. Between these two limits a reduction in the

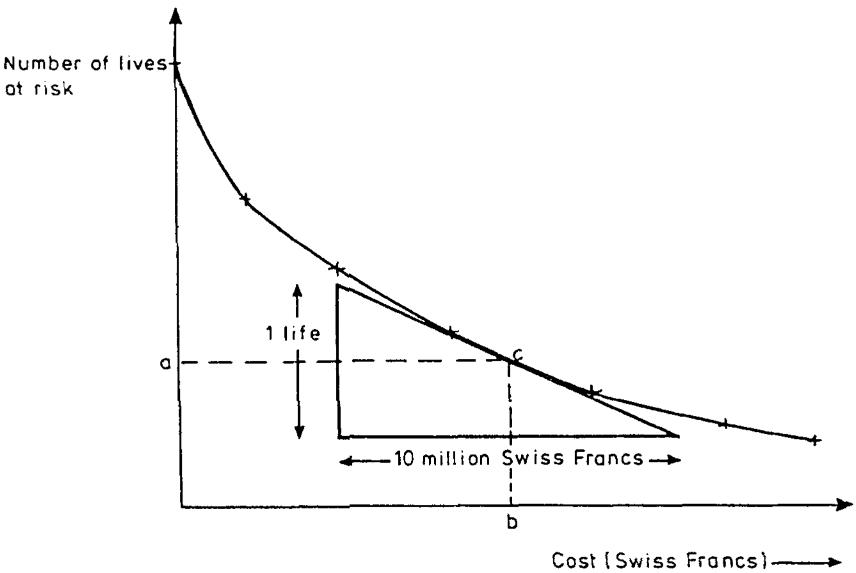


Figure 4 DETERMINATION OF THE ACCEPTABLE SOCIETAL RISK FOR A SWISS AMMUNITION DEPOT

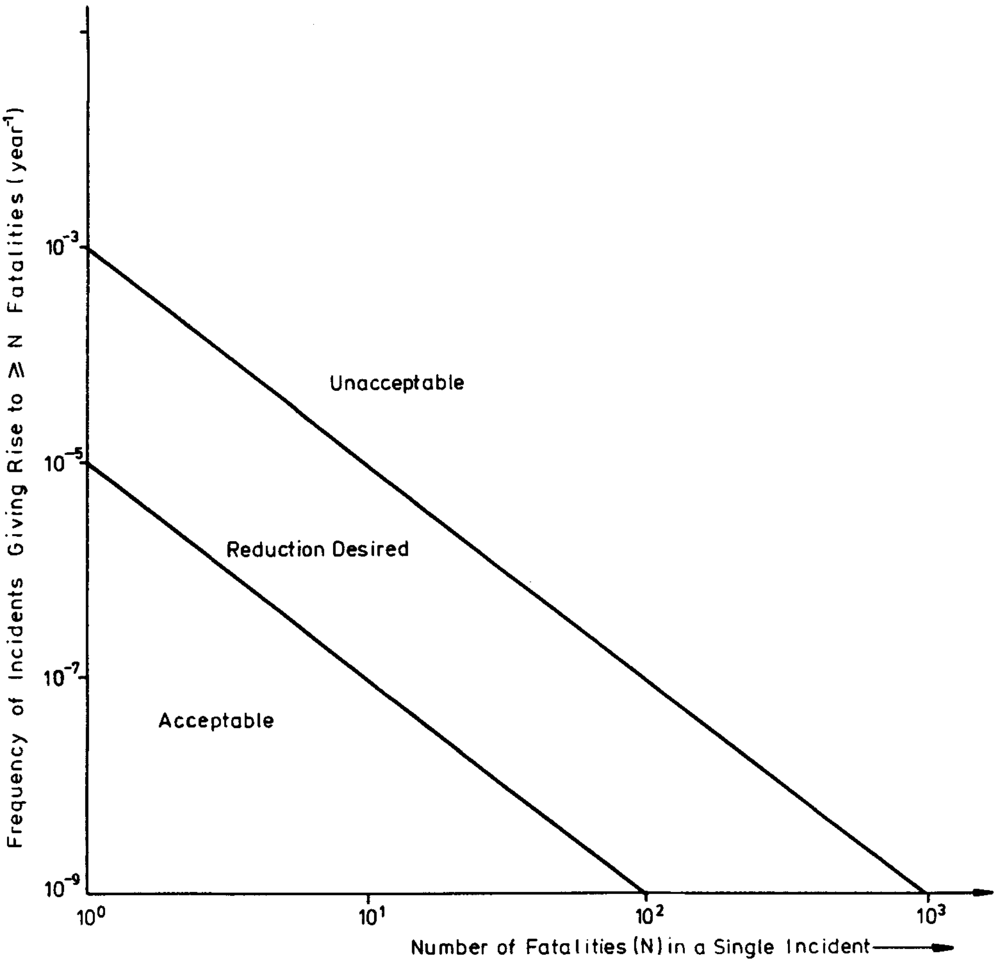


Figure 5 SOCIETAL RISK ACCEPTANCE CRITERIA FOR INDUSTRIAL MAJOR HAZARDS IN THE NETHERLANDS

risk level is "desirable". The upper threshold level was based on the idea that the lowest mortality rate in the Dutch population, which applies to children between the ages of 10 and 15, is 10^{-4} and an industrial activity should not enhance this rate by more than 1%. For Societal Risk the Dutch criteria are shown in Figure 5, where the upper and lower threshold levels both have slopes of 2 as proposed in the present paper for incidents in which more than 10 people are killed.

It is apparent that the criteria that are tentatively suggested in the present paper for evaluating the risks involved with explosives or ammunition are consistent with criteria used elsewhere and in other fields. It must be emphasised that setting criteria against which risk levels may be evaluated is an extremely difficult task. The purpose of this paper is to present some proposals which have been given careful thought as a means of initiating an informed discussion. Those interested in contributing to this discussion are strongly encouraged to write to the authors c/o The Principal's Office, The Royal Military College of Science.

ACKNOWLEDGEMENT

The advice and help of Mr B. H. Harvey CBE was invaluable throughout this work. We acknowledge also considerable help from members of the Health and Safety Executive.

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