AN APPROACH TO THE SAFE MANAGEMENT OF THE STORAGE OF MILITARY EXPLOSIVES BASED ON QUANTITATIVE RISK ASSESSMENT

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INTRODUCTION

1. The procedures currently used by the United Kingdom Ministry of Defence (MODUK) to control the hazards associated with the storage of explosives are based on criteria known as Quantity-Distance, or QD, Rules. These specify minimum distances between stored explosives and specified exposed sites to give an assurance that accidental explosion will not cause unacceptable damage at the exposed site. They are primarily concerned with damage to buildings rather than risks to individuals. QD Rules are based either on historical data, for instance WWII bomb damage data, or on more recent experimental evidence.

2. The rules apply to individual storehouses or stacks of explosives and lead to a method of control based on licences. Under the terms of a licence, the quantities of the various classes of explosive substances and/or articles which may be kept in a particular place or storehouse are restricted according to the separation distances from other buildings or areas with public access.

3. In Great Britain the keeping of explosives is controlled by the 1875 Explosives Act. MODUK is exempt from the requirements of this Act. However, MODUK is not exempt from the more general

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requirements of the Health and Safety at Work etc Act 1974. This Act places obligations on employers to ensure, so far as is reasonably practicable;

a) the health, safety and welfare at work of all their employees and

b) that persons not in their employment are not exposed to risks to their health and safety.

Implicit in these duties is the need to assess risks in order to demonstrate that all reasonably practicable measures to reduce them have been taken. More recent and explicit regulations about to come into force require employers to assess the risks to the health and safety of employees and others as a result of their activities. The complexity of these assessments depends on the nature of the activities being carried out at the workplace but for sites presenting a major hazard, a quantitative risk assessment (QRA) is likely to be required.

4. Statutory compliance is therefore an important driver of studies of QRA by MODUK. However, in addition to ensuring compliance QRA has other advantages. It helps managers to identify clearly the major contributors to risk at a site and provides a tool for investigating the effectiveness of measures to reduce risk. If a QRA establishes that risks at a site are intolerably high, then the method can be used to examine proposals for improvement, allowing the most cost effective remedies to be implemented. The use of QRA thus offers more flexible management of explosives safety than can be achieved

under prescriptive QD Rules, with the prospect of reducing costs and at the same time enhancing safety.

5. For all these reasons, MODUK, through the Explosives Storage and Transport Committee (ESTC) has investigated risk based approaches to the control of its explosives sites. This paper describes those investigations to date, outlining the methods which have been adopted and proposing how they might be applied to give a safe and cost-effective system for the management of the storage of military explosives.

AIM

6. To outline the development within MODUK of a QRA method applicable to the management of explosives storage and to discuss the notion of the tolerability of risk.

THE QRA METHOD

7. In outline, the approach adopted by MODUK permits estimation of the maximum annual risk of fatality for an individual at each site exposed to the hazard from handling and storing explosives. The risk in this instance is expressed as the product of the estimated maximum frequency of initiation and the probable lethality consequent on the worst credible accident.

8. To generate the frequency of initiation, details are required of the quantities and types of explosives stored. The subsequent calculation is based on either historic accident data (Level 1 Method), or on failure mode analyses and fault trees (Level 2 Method). Important factors to be considered in the case of military ammunition depots include any on-site processing, within site transport or the possibility of malicious damage

together with external hazards such as adverse weather, accidental aircraft strike or other nearby hazardous activities.

In both the Level 1 and Level 2 Methods the estimation of the frequency of initiation relies on the maintenance of consistent and controlled standards within the site. This has to be confirmed by evaluating both internal and independent audit reports.

9. Reliance on accident data suffers from major flaws. Firstly, there are few accidents on which to base any estimates; secondly building standards have changed substantially since WWII so that damage effects and hence the risks of harm to individuals have also changed; thirdly new explosives and articles may present substantially different hazards than those of earlier generations and finally every accident which has occurred should lead to changes in operating procedures which reduce the risk of recurrence. However, the data do allow an estimate to be made of the maximum credible initiation frequency for all types of explosives in MODUK storehouses.

10. A study of the available data has lead to the conclusion that major incidents of fire and explosion involving explosives materials stored by or for MODUK have occurred at a rate of 1.5×10^{-5} per storehouse-year over the period 1946 to 1990. It is not possible to derive initiation frequencies for individual explosive items from the data but these figures are essential to the QRA method. They have therefore been derived from a survey of expert opinion in which a group of experts in weapon and explosive safety individually ranked a series of substances and articles in order of expected accidental initiation frequency.

These experts agreed that the greatest initiation hazard was presented by gunpowder. The historical data, which may be incomplete, indicates that there have been some 3000 gunpowder storehouse operating years in the UK since 1945 with no major storage incident. This suggests an upper bound no greater than 1 in 10^{-3} per storehouse-year for accidental initiation of this, the most sensitive explosive in UK service.

11. The experts were then asked to estimate relative frequencies of initiation for the articles and substances they had ranked and on this basis it was concluded that, for the least sensitive explosives and articles, an initiation frequency of no greater than 1 in 10^{-6} per storehouse-year was appropriate, giving a scale broadly consistent with the overall UK incident frequency. This scale may well be overly pessimistic but it is difficult to justify lower figures on the basis of the limited data available. The end product is a means of estimating initiation frequency based on history and expert knowledge which, although far from being perfect, provides a reasonable and defensible figure. Quite deliberately, at every stage of the estimation conservative assumptions are made so that frequency estimates should err on the side of caution.

12. The Level 2 Method uses failure mode analysis to generate fault trees and, given a set of base event frequencies, an estimate of initiation frequency can be made and direct comparisons between different routes to initiation are possible. Here again the main problem is the lack of hard data on which to found base event frequencies. In a complex chemical or nuclear plant the routes to hazardous events are likely to involve component failures and techniques exist to estimate the

likelihood of such failures. The factors leading to accidental initiation of explosives in storage are difficult to identify in purely mechanical terms and are more difficult to quantify. Factors such as inadequate training, ambiguous instruction, human error or even malicious behaviour may play a significant role.

13. The lethality consequence models evaluate the effects of blast, weapon fragments, building debris and thermal radiation on people, both inside normal domestic housing and in the open. Normal procedures assume an explosion on the surface, but models are also available for underground explosions. The development of these models, and their incorporation into software, has formed a major part of the work.

14. Each model is derived in essentially two stages. In the first the physical output resulting from initiation of the explosives being stored is estimated. The complex effects of the shock, heat and fragments generated by an explosion on buildings make this a difficult task. There is some experimental data, including data generated to support QD Rules but in some cases models have to be derived from basic principles with little or no direct verification. In the second stage the effect of the physical output on exposed individuals must be estimated. Again, this is a difficult task, particularly for individuals at some distance from the source of the accidental event. Historical data can be helpful here and in another report to this Seminar, Dr Hewkin of the ESTC Risk Assessment Study Team will discuss detailed work relating to one of the consequence models which involves a survey of accident records.

15. The consequence models we have developed in this work may well be of value to other workers involved in the evaluation of explosion effects quite independently of their use in QRA.

16. Application of the QRA method requires a detailed understanding of all its components, and the way in which they interact together with a good knowledge of explosives properties. Unlike QD Rules, which can be applied by site managers locally based on straightforward training, QRA requires and will continue to require expert judgement and a dedicated team for its application.

17. To carry out an assessment, members of the expert team need to visit and to survey the site of interest to determine the inputs to the QRA and the initiation frequency and consequence models to be employed. The procedure then provides a method for estimating the maximum risk expected for an individual continuously exposed (indoors or out) at any point on or off the site. The output will normally be the risk of fatality at each exposed site for a single continuously exposed person, per year, but the major contributions to each risk can also be identified.

18. Once the risk to an individual has been estimated, its tolerability can be assessed in comparison with published criteria or the risks associated with other activities.

19. In addition to giving an estimate of individual risk, the method can also provide an estimate of societal risk, the relationship between frequency and the number of people suffering from a specified level of harm (death in the case of the MODUK QRA method) in a given population from the realisation of

specified hazards. Societal risk measures the risk to the population as a whole and is important for two reasons:

a) in many cases a particular individual may be exposed to the hazard for only a short time, for example while driving past an ammunition store on a public road, in which case the risk to the individual may be tolerable but the large numbers using the road may nevertheless render the total societal risk intolerable.

b) society tends to find accidents involving large numbers of fatalities proportionately less aceptable than accidents involving one only

Societal risk is usually expressed in terms of F/N plots of the frequency F of N or more deaths occurring as a result of an accident as a function of N.

20. The tolerability of societal risks can, as with individual risk, be assessed by comparison with published criteria or with risks associated with other industries. Here, however, any criterion will take the form of a line on an F/N plot with greater negative slope indicating a greater aversion to multiple fatalities.

TOLERABILTY OF RISK

21. Several times in this paper reference has been made to the notion of the tolerability of risk. This is a difficult concept inviting questions as to why one individual's activities should be allowed to put another individual at risk. However, everyone

take risks - we drive vehicles, we cross the road, we ski or hang-glide - and everyone benefits from activities which place themselves and/or others at risk, for example a thriving chemical industry. We would very quickly complain if hazardous substances such as gasoline were no longer available to us. Implicitly at least, some degree of risk is accepted so that a benefit may be enjoyed.

22. The question to be addressed therfore concerns the level of risk that it is reasonable to impose on exposed populations so that stores of military explosives and ammunition can be maintained. There is an almost universal agreement on the need for nations to maintain adequate defences and therefore a recognition of the benefit to society of the ammunition stockpile. However, as an MOD employee and from the comfort of my office many miles from the nearest explosives store, my concept of what is tolerable may be quite different from that of someone not employed by MOD who lives next-door to one of our depots.

23. In the UK, the Health and Safety Executive (HSE) has taken a lead in addressing such issues. The HSE is the body responsible for enforcing health and safety legislation, and it provides guidance on how compliance with the very generally framed law can be assured. As a part of this process, the HSE has produced a series of well written and useful documents on QRA and risk tolerability and has generated a conceptual framework within which the tolerabilty issue can be discussed. The framework is expressed in Figure 1.

24. This framework draws heavily on the statutory requirement in the UK to demonstrate that risks are as low as is reasonably practicable - the so-called ALARP principle. It is based on individual risk but the principles apply equally to societal risk. Risks above a certain level are intolerable and require immediate action to reduce them irrespective of cost. At a substantially lower level is a region where risks are broadly tolerable. This is a region where, provided there is a benefit to be gained and proper precautions are taken the risk does not cause us to alter our normal behaviour. Between these two levels is the important ALARP region.

25. In the ALARP region risks must be reduced, as the law demands, so far as is reasonably practicable. The test of reasonable practicability is that the costs of extra safety should not be grossly disproportionate to the benefits accrued. A cost-benefit analysis is essential.

26. The HSE framework derives from UK legislation but it has a broader applicabilty in that it provides a model within which managers can use QRA to assist them in decisions about the cost effectiveness of resource commitments.

27. Determining criteria against which the tolerability of risks can be assessed is difficult. However, the HSE has given some guidance on this. The levels are set not by some absolute scientific law but by what society will tolerate at any given time. Almost certainly this degree of tolerance has reduced over the years, people expect life to become safer and expect to die naturally rather than by accident. On the other hand, in time of war greater risks would be expected and accepted and at any time

we might expect those likely to benefit the most to tolerate the greater risk. In the UK no employment involving any significant number of people is estimated to present an individual with more than a 1 in 10^{-3} chance of death in one year. This level is often quoted as defining the limit of tolerability. At the other end of the scale, figures of the order of 1 in 10^{-6} are regarded as falling at or close to the limit where the risk might be regarded as being negligible.

28. It would be quite wrong to regard these values as set in tablets of stone. Society's expectations will undoubtedly increase, they may vary from place to place and, of course, they may well be influenced by the size of the tax bill! Different activities give different benefits and, in societal risk terms, those most exposed to risk may take a different view from those who benefit at little risk to themselves. Ultimately, decisions on the tolerability of risk are political rather than technical but we might reasonably expect the reduction in world tensions over the past few years to be reflected in reduced tolerability of risks associated with defence activity. Whether that means that the public would expect a lower risk from such activity than from, say, nuclear power plant or chemical plant is another matter.

29. For all these reasons MODUK has avoided setting any tolerability criteria and does not envisage using QRA as an absolute tool, determining what may or may not be done. The view taken is that such criteria could only be derived from informed political debate and that such debate still has a long way to run. However, that does not mean that QRA does not have immediate practical application.

THE APPLICATION OF QRA

30. QD Rules have a number of important attributes. They are prescriptive and can be applied by managers locally without the need for expert support. They provide unambiguous conclusions. Over many years they have been a key feature in achieving what is a very high standard of explosives safety within MODUK. It would be foolish to cast aside these advantages. On the other hand, QD Rules do not provide any explicit assessment of risk. We therefore intend to complement QD by QRA, not to replace it.

31. We see QRA as underpinning QD, demonstrating that the risks of operating under a QD regime are tolerable. Where QRA shows that risk levels are relatively high, the major factors contributing to the risk can be identified and risk reduction measures assessed and implemented in line with the ALARP principle. Given that the assumptions on which the QRA is based do not change, then the assessment and management of the site can continue under QD Rules in the knowledge that this provides a tolerable upper limit on the risk.

32. The combination of QD and QRA thus provides an assurance that risks are capped provided that the QRA remains valid. This limits the need for the expensive QRA process to be repeated to occasions where there are significant changes in site operation to be considered. Such changes would include changes in the site layout, including both explosive and non-explosive buildings, changes in staffing levels within the site and any changes in land use and population density outside the site but within the area potentially at risk. Perhaps most significantly, changes in management procedures must also be included. A system of explosives safety management involving licensing, inspection and

audit must be an integral part of a combined QD/QRA control system.

33. There is, of course, pressure in the regulatory system and from the general public to ensure that risks decrease with time. The standards acceptable to our parents are not acceptable to us and our children will expect better still. These pressures are recognised in the ALARP principle since what is not practicable today may well be practicable tomorrow. A QD based system alone cannot help here but QRA provides an effective mechanism by which to bring about such improvements.

34. One feature of present QD Rules is that it is far from clear that explosives of different hazard divisions are treated in a way that ensures that they present equal risks. In fact this is almost certainly not the case. QRA will allow the risks associated with the different classes to be compared and for them to move over a period of time towards comparability. This should not, of course, be taken as an argument for increasing risks to the lowest common denominator, that is unlikely to impress either the regulators or the public, but it will help to curb unnecessary expenditure and to target resources where they will have most effect.

35. One final point should be made, in the UK we see the study we are conducting on storage as being a pilot. If the outcome is successful we would expect to extend the method to cover other situations involving explosives risks, including transport, range control, testing of all up rounds and demilitarisation.

CONCLUSIONS

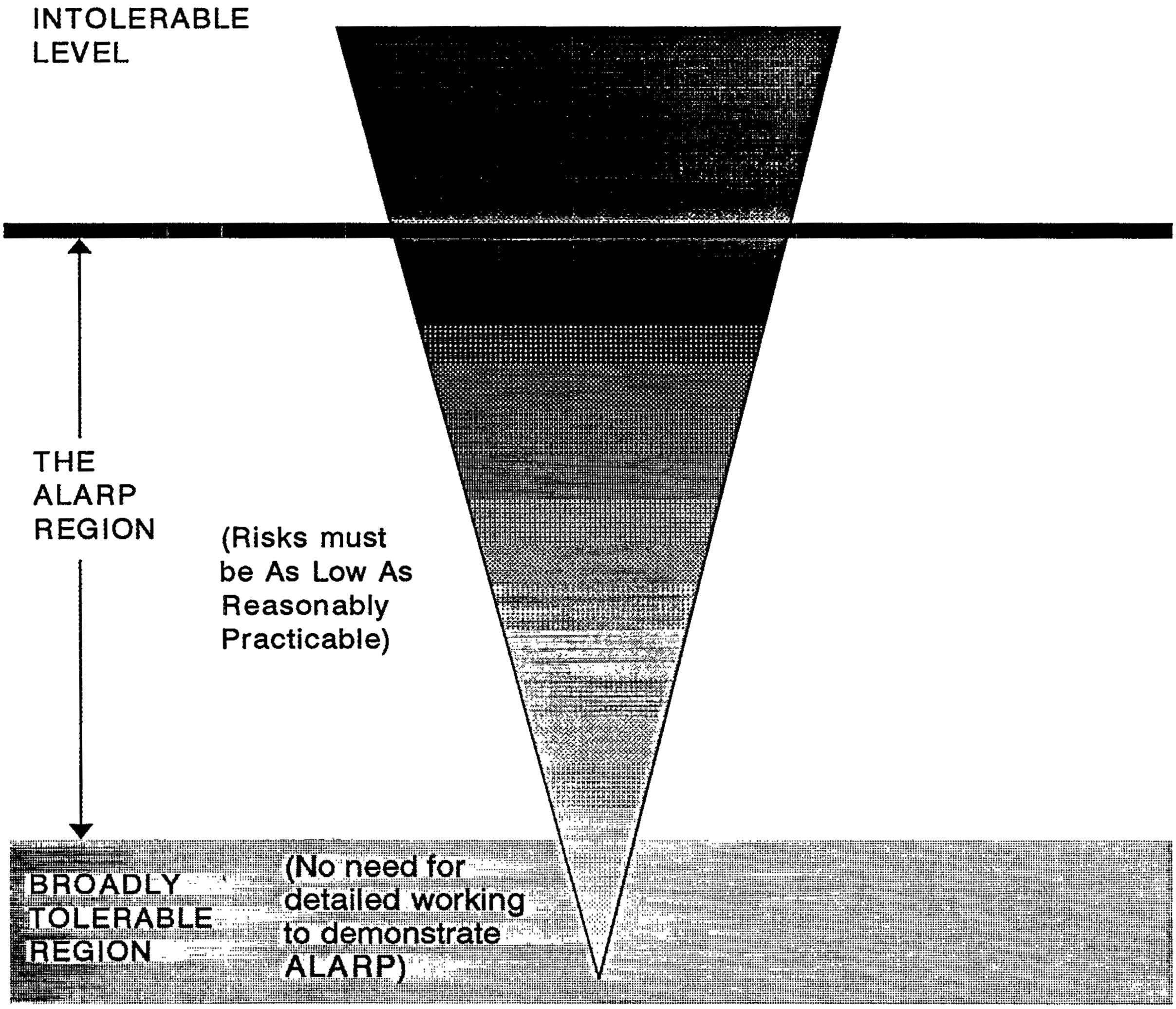
36. Within the UK Ministry of Defence we are developing methods which will allow us to determine the maximum credible risk associated with our explosive storage activities. The first generation of such methods is now close to being ready to be applied and is being assessed against our present storage regime.

37. We envisage these QRA methods being applied to complement existing QD Rules rather than to replace them. They will demonstrate where our operations present a tolerable level of risk to MOD personnel and to the public and, where risks are assessed as being relatively high, will identify the major contributors and the most effective means of risk reduction.

38. QRA will also provide a valuable management tool, allowing the effects of changes in site layouts, handling procedures and management policies on explosives safety to be assessed.

39. The techniques currently being developed for the assessment of initiation probabilities and their consequences are relatively primitive. There is scope for substantially more work to be done to improve the accuracy and precision of the models we use and we would welcome collaboration with others in this work.

Figure 1. LEVELS OF RISK AND ALARP



(Adapted from a diagram in "The tolerability of risk from nuclear power stations", HSE, 1988.)