RISK MANAGEMENT-BASED APPROACH TO RANGE SAFETY

BY

LIEUTENANT COLONEL G BARKLEY
SECRETARY, AUSTRALIAN ORDNANCE COUNCIL
DEPARTMENT OF DEFENCE
CANBERRA

ABSTRACT

Many aspects regarding range safety are based on empirical or historical factors. The ever increasing public awareness of and concern regarding Defence activities, the mounting pressure upon existing range space and a more professional attitude by the Services towards maximising the safety of all aspects of munitions has contributed to an evaluation of the existing empirical range safety guidelines. A new scientific procedure for the determination of range safety criteria was developed under the auspices of the Australian Ordnance Council. An overview of this procedure is presented in this paper. Some other areas are examined, such as storage and transportation of explosives and the use of lasers.

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INTRODUCTION

1. The use of a weapon of any type is always potentially dangerous, to different degrees, for those service and civilian personnel associated with the weapons use or in the vicinity of the weapons area of influence. As well as the uncertainties as to what the risks are involved, there is another factor which is the responsibility of all concerned (directly or indirectly), that is the legal 'duty of care' which mandates our involvement.

2. The current accepted and commonly used basis for determining range danger areas (two dimensions as in direct fire weapons) and danger zones (three dimensions as in air-to-ground and indirect fire weapons) is an anachronism in 1990. The current methodology implies that the range danger areas or zones are large enough to contain the potential danger from weapons use. There is no such situation however, as absolute safety on the 'safe' side of a weapons danger template or on the other side of the fence around a weapons range. What must be known is the acceptable risk a service person may be exposed to achieve the operational or training objectives as well as protecting other non-involved service and civilian persons in the vicinity. What should be remembered is that people are exposed to different risks and levels of risk every day and night, and that sometimes service persons are exposed to greater risks necessitated by the nature of their employment.

BACKGROUND

3. The current operation of the Australian Defence Force weapons ranges is based upon the implicit understanding that range boundaries are sufficiently large so as to ensure that:

a. persons outside designated boundaries are not subjected to risk of injury or death, and that property beyond those boundaries is not damaged when firings are undertaken; and

b. persons within designated boundaries and outside safety templates can operate and fire weapon systems, individually or in concert, with no risk of injury or death.

4. The concept thus implied is one of absolute safety based upon the use of an absolute danger area (or danger zone if danger to aircraft in the space above is also to be included).

5. In view of this situation, the Australian Ordnance Council (AOC), the Australian Department of Defence governing body charged with providing advice on Service safety matters, initiated a review of Australian range safety policies and procedures in 1984 to determine their applicability for service Defence and community needs for the present and the foreseeable future. This task was placed on the Ballistics Coordination Committee (BCC); the committee of the AOC responsible for the detailed consideration of ballistic related/range safety matters. The three sequential stages to this review were:

a. determine the basis for current range safety procedures,

b. assess their applicability to current and future needs; and

c. if found wanting, develop new scientific procedures which realistically take into account current and future Defence and community needs.

6. The AOC review identified problems with the use of this absolute safety concept, some of the more salient ones being that:

a. The assessment of many of the effects of weapon system operations, on which danger areas or zones depend, were based on ad hoc methods, personal experience and, in some instances, post accident investigation - scientific methodology has been conspicuous by its almost total absence! Many other safety doctrines were traced back to British War Office publications of circa 1900 - their relevance to present day range safety needs is questionable to say the least.

b. Measures taken to ensure safe training of Service personnel and/or operation of Service equipment had, to some extent, been over-emphasised such that the training became unrealistic and its value and effectiveness diminished.

c. Procedures used to determine danger areas or zones between Services had been inconsistent and non-uniform. It should be noted that similar situations have been acknowledged to exist in other countries' Defence Forces.

7. Clearly this was a most disturbing and unsatisfactory state of affairs in respect of range safety determination, it did not inspire confidence but rather raised the spectre of legal complications and difficulties.

8. The AOC review identified the need for a rigorous scientific basis for the determination of danger areas/zones which incorporated all significant inputs (whatever they should be), whilst acknowledging explicitly areas of uncertainty and gaps in knowledge, and which would allow range boundaries to be determined consistent with any specified level of accepted risk. In other words, replace the old 'black and white safe/unsafe, worst case' concept of absolute safety with a more realistic risk management approach based on allowing for intermediate levels of risk other than that perceived as safe/unsafe. The ability to determine levels of risk would allow more realistic training to be undertaken and/or allow the use of economically valuable land which would otherwise be contained within an existing range boundary.

NEW APPROACH TO RANGE SAFETY

Development of the New Approach

9. The Central Studies Branch of the Department of Defence was tasked by the AOC to develop a new scientific procedure for the determination of range safety criteria, deemed necessary by the AOC review. Certain of the assumptions underlying the theoretical development of a new procedure were that:

a. weapons systems perform in accordance with specifications (ie. no defects in the system),

b. normal range discipline applies, and

c. there will be no negligence on the part of any individual involved in the firing.

10. It should be noted that the research conducted and the resultant papers [1, 2 and 3] are working documents only, forming a basis for the AOC BCC to develop a Pillar Proceeding on Range Safety, which should be issued in October 1990.

11. In order to more easily understand the essentials of the theoretical model a simplified review is presented. The simplifying assumptions are:

a. the use of a flat range surface,

b. a maximum of one ricochet only, and

c. no fragmentation of the projectiles.

Methodology Overview

12. The basis of this new approach to range safety is to develop and use risk contours. To evaluate risk contours the distribution of the final impact point is required. An overview of the methodology leading to the determination of this distribution follows.

13. **Risk Contours.** A risk contour is a curve enclosing an area such that the probability (or risk) of a projectile landing outside this area (where it is assumed it could have a catastrophic effect on an individual) has a predetermined value. Hence to each level of risk that may be of interest there is a corresponding contour.

14. **Determination of Final Impact Distribution.** As it is assumed that only one ricochet is possible, we have two cases to consider:

a. the projectile flight terminates at first impact (ie. without ricochet), or

b. the projectile flight terminates at second impact (ie. after one ricochet).

15. **Impact Distribution (No Ricochet).** It is assumed that the launch distribution is known (ie. the variation in elevation angle, azimuth angle and muzzle velocity). Using this the impact distribution (ie. the variation in impact point and velocity at impact) can be determined using the projectile flight equations.

16. It can be seen that the impact distribution is completely determined by the launch distribution and flight equations.

17. **Impact Distribution (Ricochet).** The direction and speed of the projectile immediately after ricochet depends on the

direction and speed of the projectile immediately before impact. Since the distribution of the first impact (input to ricochet) has already been determined the distribution of the ricochet output (ie. the variation in direction and speed immediately after ricochet) can be found.

18. The remaining step is to determine the final impact distribution. This can be expressed in terms of the distribution of the ricochet output using the ricochet flight equations.

19. The distribution of the final impact is completely determined by the launch distribution, flight equations (for first flight and ricochet) and the conditional ricochet distribution.

20. **Final Impact.** The final impact distributions for the ricochet and no ricochet cases are now combined (using the probability of ricochet) to give the distribution of the final impact.

21. **Final Impact Point.** The distribution of the final impact point is derived from the distribution of the final impact by 'integrating out' the velocity components.

22. **Essential Inputs.** The essential inputs to the process of determining the distribution of the final impact point are:

a. Launch Distribution.

b. Flight Equations for Projectile (for first flight and ricochet flight).

c. Probability of Ricochet Given Input Vector.

d. Conditional Ricochet Distribution for the Ricochet Output Given the Ricochet Input.

23. **Issues not Included Above.** In keeping with this simple review, issues such as fragmentation, non flat ranges, non standard meteorological conditions and most importantly the risk to an individual were not discussed in this overview. However the theoretical model does provide the framework for dealing with these issues. For instance, in theory, risk contours can be determined where the risk relates not to the probability of finding a projectile or fragment in a given zone but to the risk of an individual being hit in that zone, however further work needs to be done to develop a usable methodology for the calculation of such risks. Fragmentation modelling is another area where further work needs to be done.

INTERNATIONAL REVIEW/INTEREST

24. Over the period 1987 to 1988, the AOC became aware that its concerns on range safety were shared by other non-NATO and NATO nations alike. Acquainting these nations with the AOC work elicited a favourable response and the possibility of its adoption and use. Accordingly, under the auspices of the United Kingdom Ordnance Board, the First International Conference on Range Safety was convened in London in May 1989. The objective of this conference was to subject the AOC work to international scrutiny and if acceptable, to propose its adoption as the basis for the first uniform and internationally accepted methodology for the determination of range safety.

25. At the Second International Conference on Range Safety in London in March 1990, the prevailing international views were expressed by the Vice President of the Ordnance Board in the following terms:

a. There is a need to move towards common danger area templates, particularly for the same weapon system when used in the same country; and

b. In regard to the future introduction of a probabilistic approach to range safety, there is a need to understand the risks involved and to be able to justify range areas. The risks need to be quantified and criteria for tolerable levels of risk established. This approach would enable range danger areas to be defined that take into account the nature of the environment and specified levels of protection for the public. It would also allow flexibility to make informed changes if necessary. The need for a common approach and way forward was emphasised, as was the need for the free exchange of information, collaboration and perhaps the sharing of costs on expensive trials. [4]

26. This viewpoint was endorsed by nations attending and attested to by the acknowledged legal consequences arising from failure to have such a methodology in place.

27. The tangible results arising from these two conferences were that:

a. the United States is in the process of adopting risk based management principles as standard range safety policy and practice;

b. a Memorandum of Understanding (MOU) is being negotiated between Australia, the United States and the United Kingdom for the collaborative development and implementation of the Australian methodology on risk management based range safety principles; and

c. the United States, using the Australian methodology, will be producing the first risk management based range safety criteria for 0.50 inch ammunition by September 1990.

CURRENT STATUS

28. Since the inception of the AOC work in 1984, progress has been increasingly rapid and is continuing to gain momentum. International acceptance is being progressed and further international collaboration in the development of the methodology is being negotiated by means of an MOU.

What Has Been Achieved

29. The following aspects of the scientific method have been achieved:

a. A theoretical model capable of handling many range circumstances has been developed.

b. A prototype computer program which calculates probabilities of hitting given areas on a range has been produced.

c. The theoretical model with the prototype computer program requires only short execution times.

30. At this stage, two essential aspects of the method are prohibiting it from being progressed further, namely the availability of:

a. adequate data inputs for the program, and

b. satisfactory models for ricochet behaviour and post-ricochet flight.

Future Development of the Method

31. For the future development of the method the following aspects will need to be considered [5]:

a. **Smoothing.** Investigate the theoretical and computational aspects of smoothing the raw output from the firing programs, specifically to provide a suitable method for smoothing and determine the different amounts of smoothing required.

b. **Confidence Limits and Error Analysis.** Development of appropriate techniques for conducting an error analysis and for assigning confidence limits to the probabilities or contours produced by smoothing the program outputs.

c. **Statistical Analysis of Ricochet.** Evaluation and comparison of existing statistical models of the output of ricochet with one another and available data, and possibly develop new models, in order to find a suitable representative of ricochet in the firing programs. No modelling of the mechanics of ricochet is intended: attention will be focused on statistical relationships between the outputs (such as impact speed, angles and nature of the surface) and the outputs.

d. **Sensitivity Analysis.** Extend the analyses already completed [3].

e. **Probable Longer Term Work.** The following are longer term goals:

(1) Risk definitions should be based on probability of an injury or damage.

(2) Ricochet models incorporating correct post-ricochet drag laws and the treatment of realistic range topography be developed.

RELATED AREAS FOR THE USE OF RISK-BASED MANAGEMENT

32. There is an increasing use of risk management in almost all fields where safety of personnel and materiel necessitate an informed judgement on the acceptance of potential risks offset against the benefits this method and the costs of the status quo. The knowledge and/or acceptance of risks associated with every day activities, both voluntary and involuntary and individual and societal risks, is preparing the way for the greater application of risk management methodology in the community, industry and the services. A key difficulty with a risk management method is the acceptance of

a level of risk for an activity by the appropriate authorities, with the knowledge that an incident can occur at any time, regardless of the risk level being accepted.

Explosives Activities

33. The application of risk-based management to explosives activities has been in operation in varying degrees for many years. The Swiss adopted a risk assessment method for explosive storage in the mid 1960s and other countries such as Germany, Norway and France have also adopted the method in varying degrees. The United Kingdom has been assessing for a number of years the application of risk assessment in the storage and handling of explosives as compared to the simple damage-related basis of the NATO storage rules (Q-D tables) [6].

34. It seems the largest problem in the application of this method to explosives activities is the scarcity of historical data on the levels of risk presented by explosives.[6] This and other difficulties however do not overshadow the significant potential advantages in adopting a risk-based method. The main advantages are:

a. **Cost Savings** - in the more efficient use of existing explosives facilities and avoidance of unnecessary expansion.

b. **Credibility** - in the Service, government and public arena as a tool for presenting a complex technical case and because it presents risk from explosives on the same basis as the risks from more familiar and generally better understood hazards in general industry.

c. **Management Tool** - for use by all involved in explosives activities as it is based on a quantifiable method, risks are accepted and the ramifications understood or at least acknowledged including the legal 'duty of care'.

Laser Equipment

35. The application of risk-based management to the use of lasers in fire control, ranging, guidance and training systems is becoming the recognised way ahead for a number of countries, despite the fact that all national laser safety standards are based on a deterministic approach. The United Kingdom Ordnance Board Military Laser Safety Committee has adopted a risk-based method since 1988 [7] which is also being

assessed for application in Australia. Much preparatory work has already been conducted by the Australian Ordnance Council Defence Laser Safety Committee and the Defence Science and Technology Organisation [8,9] as a basis for introducing laser safety risk-based management to the Department of Defence. It is also likely that the next generation of national laser safety standards will recognise the risk-based management method and allow for its use in certain situations.[9]

CONCLUSION

36. In 1984, a new approach to the construction and use of range safety danger areas using risk-based range safety management criteria was commenced to:

a. realistically address and reconcile the conflicting operational, commercial and community pressures arising from the acquisition and/or use by the Services of ranges to satisfy training needs;

b. lead to significant savings in new Service training land requirements and/or the more effective utilisation of existing ones, whilst providing a more realistic training environment for the Australian Defence Force; and

c. replace the extant range safety determination principles (the majority of which are of unknown origin and/or validity, non-uniform and contain inherent and unquantifiable errors and therefore are legally flawed in fulfilling the Services' 'duty of care' obligations), by one based on firm and documentary scientific principles with legal validity.

37. The theoretical model provides a basis for the development of risk contours for any weapon in any terrain subject to the availability of appropriate data. And therein lies the main obstacle to its practical use in the near future, the current dearth of relevant data; for example data on launch distributions, ammunition ricochet and fragmentation, essential in any range safety work. The collation of this and other data is not an insurmountable task, it is simply a matter of commitment of time and resources and is currently being progressed jointly by Australia, the United States of America and the United Kingdom.

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