RISK CRITERIA FOR THE RISK BASED SITING OF SINGAPORE ARMED FORCES (SAF) EXPLOSIVE FACILITIES

Audrey Lao Linmei
Armament Systems, Defence Science & Technology Agency
1 Depot Road #18-05 Singapore 109679
Phone: (65) 6373 3845
Fax: (65) 6273 1825
llinmei@dsta.gov.sg

Joseph Lum Yue Hao
josephlum@nus.edu.sg

Yen Chong Lian
Armament Systems, Defence Science & Technology Agency
1 Depot Road #18-05 Singapore 109679
Phone: (65) 6373 4287
Fax: (65) 6273 1825
ychongli@dsta.gov.sg

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ABSTRACT

Quantity Distance (QD) criteria has been used for the safe siting of military explosive facilities worldwide for decades; the SAF has also adopted QD. In land scarce Singapore, there are occasionally situations where QD cannot be met. The consequences of deviating from QD need to be understood to facilitate risk management. Many nations have developed a risk-based approach and Quantitative Risk Assessment (QRA) models to better appreciate the risks. In 2005, with the permission of the U.S. DoD Explosives Safety Board (DDESB), the Defence Science & Technology Agency (DSTA) of Singapore acquired the Safety Assessment for Explosives Risk (SAFER) v3 software and training package to provide us with a risk-based explosives siting capability. A pertinent question arose: What risk criteria is acceptable? With reference to the Risk-Based Explosives Safety Criteria Team (RBESCT)'s approach to develop DDESB risk criteria, DSTA researched into the various risk criteria for the siting of SAF explosive facilities. These include the industrial accident data and causes of fatalities in Singapore and regulatory standards adopted by various countries for explosive risk management. The data are displayed in a Risk Scale format for comparison between the various risk figures. This paper describes the work done and the proposed risk criteria for the risk-based siting of SAF explosive facilities.

INTRODUCTION

<u>Management of Explosives Siting Risks using Quantity Distance</u>. There are inherent risks in the activities involving military explosives. In the SAF, a robust safety management system for military explosives and explosive facilities is in place to

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14. ABSTRACT

Quantity Distance (QD) criteria has been used for the safe siting of military explosive facilities worldwide for decades; the SAF has also adopted QD. In land scarce Singapore, there are occasionally situations where QD cannot be met. The consequences of deviating from QD need to be understood to facilitate risk management. Many nations have developed a risk-based approach and Quantitative Risk Assessment (QRA) models to better appreciate the risks. In 2005, with the permission of the U.S. DoD Explosives Safety Board (DDESB), the Defence Science & Technology Agency (DSTA) of Singapore acquired the Safety Assessment for Explosives Risk (SAFER) v3 software and training package to provide us with a riskbased explosives siting capability. A pertinent question arose: What risk criteria is acceptable? With reference to the Risk-Based Explosives Safety Criteria Team (RBESCT)s approach to develop DDESB risk criteria, DSTA researched into the various risk criteria for the siting of SAF explosive facilities. These include the industrial accident data and causes of fatalities in Singapore and regulatory standards adopted by various countries for explosive risk management. The data are displayed in a Risk Scale format for comparison between the various risk figures. This paper describes the work done and the proposed risk criteria for the risk-based siting of SAF explosive facilities.

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reduce the chance of an accident occurring as well as to limit the damage should an accident occur. The latter is managed by imposing limits on the quantity of explosives, and the enforcement of safe separation distances – Quantity Distance (QD) between a Potential Explosion Site (PES) and an Exposed Site (ES) where personnel are present. The SAF has adopted the UK JSP 482 as the standard for QD.

Need for Deviation from Quantity Distance. Singapore's land area is 710 km^2 or 274 $miles^2$ (Statistics Singapore 2010). In land-scarce Singapore, there are occasionally situations where QD cannot be met. This is due to Singapore's high population density of 7022 persons/ km^2 (Statistics Singapore 2010) and proximity of inhabited buildings to military explosive facilities. The consequences of deviating from QD need to be understood, so that decision-makers are accurately informed of the risks. Accurate information on the risks facilitates risk management (Figure 1).

Figure 1. Risk management

Risk-based Approach: Apply Quantitative Risk Assessment when there is Deviation from Quantity Distance. The risk-based approach uses QRA software to quantify the risk to personnel. The results are compared to a set of criteria and a decision is made to accept, reject or modify the sources of risks. The US, UK, Australia, Netherlands and Switzerland have adopted the risk-based approach for the siting of explosive facilities when QD cannot be met (Figure 2).

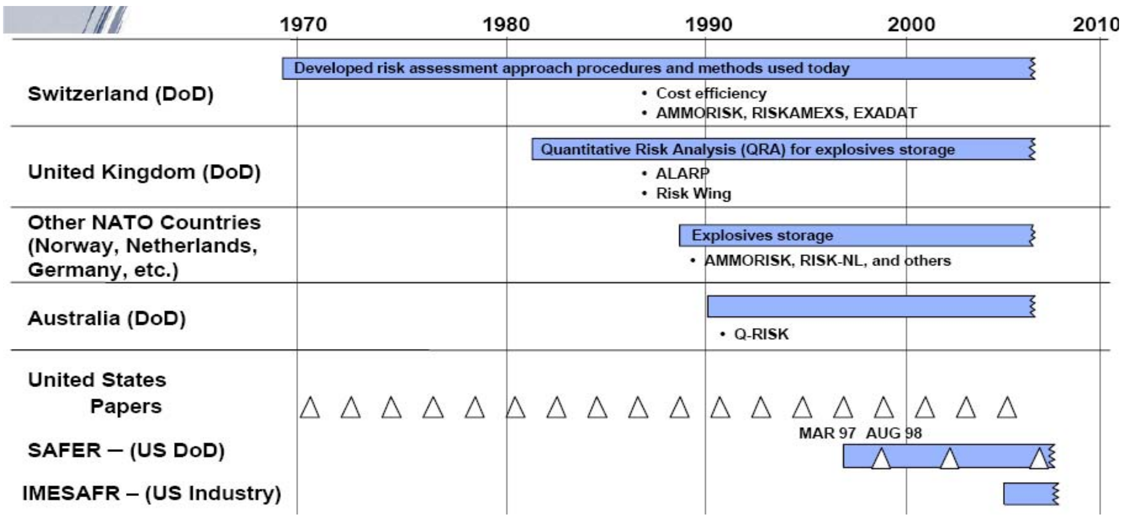

Figure 2. Countries that use QRA software for risk-based explosives siting (Young et al, 2007)

Potential Use of the Risk-based Approach. In line with the international community, DSTA recognised that the risk-based approach has the potential to complement the QD approach for the siting of military explosive facilities.

SAFER V3 QUANTITATIVE RISK ASSESSMENT SOFTWARE

SAFER. Safety Assessment for Explosives Risk (SAFER) is an internationally-recognised QRA software model sponsored, developed and approved by DDESB for DoD risk-based explosives safety siting and risk management analysis.

Development of SAFER. In 1997, DDESB formed the Risk-based Explosives Safety Criteria Team (RBESCT) to develop the risk-based approach for US DoD to manage the siting of explosive facilities. The RBESCT comprised members from DDESB, the US Army, Navy, Air Force, Marine Corps, international subject matter experts and risk analysis companies. APT Research Inc, a DoD contractor specialising in safety engineering, developed the SAFER software.

Acquisition of SAFER v3. In 2005, with the permission of DDESB, DSTA acquired the SAFER v3 software and training package to enhance the risk assessment capability of the Singapore Armed Forces Ammunition Command (SAFAC).

Use of SAFER v3 in Singapore. DSTA and SAF have since started to use SAFER for risk-based explosives siting and risk analysis, to provide quantified information of risk, facilitate the comparison of risk, facilitate the allocation of resources to mitigate risk, and decision-making given the knowledge of the predicted risk. Guidelines (work in progress) have been developed for the use of risk-based explosives siting in Singapore. These include draft guidelines for risk criteria, how and when to use risk-based explosives siting, risk-based siting approval, SAFER user requirements and SAFER report submission requirements.

SAFER V3 QUANTITATIVE RISK OUTPUTS AND ITS APPLICATIONS

Quantitative risk is expressed by SAFER in terms of probability of accident, probability of fatality given the accident, exposure of personnel, individual risk, group risk, number of fatalities and number of injuries. These risk figures are useful for explosive risk management for risk identification, assessment, mitigation and acceptance. The definition of the risk terms are described in the following sections.

Definitions

Individual risk P_f is the likelihood that a person in an ES will die from an unexpected explosion. It is computed by multiplying the probability of an event (probability of accident) P_e, the probability of a fatality given the accident has happened $P_{f|e}$, and personnel exposure E_p:

$$P_f = P_e \text{ x } P_{f|e} \text{ x } E_p$$

Group risk E_f is the risk experienced by a group of people exposed to the explosives hazard. It is the sum of all individual risks in an ES:

$$E_f = \sum(P_e \, x \; P_{f|e} \text{ x } E_p)$$

Risk Criteria are standards used to translate numerical risk estimates produced by a QRA into value judgements (e.g. negligible risk) that can then be set against other value judgements (e.g. high economic benefit) in the decision-making process. Simply put, risk criteria are used to help decide whether the risk associated with a project or activity is low enough to proceed (Risktec, 2007).

Risk Figures where the Accident is Possible (Probability of Accident <1)
Probability of Event. This is also known as the probability of accident. Through the RBESCT and historical US DoD accident records, SAFER provides the probability of an accident for a specified explosive activity. This could be benchmarked to the limits defined by the UK Health and Safety Executive (HSE): the maximum probability of an accident causing the death of 50 people or more in a single event should be less than 1 in 5,000 (i.e. 2×10^{-4}).

Individual Risk and Group Risk. Individual and group risks can be compared with the risk criteria established by other nations e.g. Switzerland, US, UK to benchmark safety. When there are many PESs generating risk to a single ES, the individual and group risk results can also be used to identify the PES that generates the greatest risk.

Consequence Figures when the Accident has Occurred (Probability of Accident = 1)

Number of Fatalities, Major Injuries and Minor Injuries. The fatality and injury predictions can be communicated to commanders to make a risk-informed decision whether or not to proceed with the operation.

Probability of Fatality Given that the Accident has Happened. SAFER gives the probabilities for 1) overpressure resulting in lung rupture, body displacement, skull fracture 2) structural failure such as broken glass or collapsed building; 3) debris comprising both vertical and horizontal debris; and 4) thermal effects. By comparing the results, the main cause of fatality and injury can be determined. The appropriate mitigation measures to reduce the likelihood of injury can also be implemented.

SAFER increases understanding of the dimensions of risk

Risk has multiple dimensions – probability of occurrence and consequence are some of them. SAFER v3 increases our understanding of risk by giving information on both dimensions. In comparison, the traditional methods (QD) focus on the consequence aspects of risk. Examples, explanations and the applications of Quantitative Risk figures generated by SAFER are summarised in Tables 1 and 2.

Type of Risk Output	Use of Risk Figure
Probability of Event P_e	Benchmark to UK limits for probability of event.
Individual Risk P_f	Compare to individual risk criteria to benchmark the safety.
Group Risk E_f	Compare to group risk criteria to benchmark the safety. Identify the PES that generates the greatest risk to that ES to focus mitigation efforts.

Table 1. Examples of SAFER output in the event of a possible accident (probability of event < 1)

Type of Risk Output	Use of Risk Figure
Number of fatalities N_f	Communicate to decision-makers the expected number of fatalities, major and minor injuries (if accident happens).
Number of major injuries	Compare to identify the main cause of fatality (blast, thermal, building collapse or debris) to focus mitigation efforts.
Number of minor injuries	
Probability of fatality from 1) overpressure or 2) thermal effects or 3) building collapse or 4) debris	

Table 2. Examples of SAFER outputs where the accident has happened (probability of event =1)

QUANTITATIVE RISK BENCHMARK DEVELOPMENT

Use of Risk Criteria. Risk criteria are used to help decide whether the risk associated with an activity is low enough to proceed. Although the risk criteria of the US and the UK can be used as a guide, different countries have different tolerability levels and attitudes on the amount of resources that should be devoted to mitigate risk.

Basis of the Proposed Risk Criteria. With reference to how DDESB and RBESCT developed the US risk criteria, we have considered the following factors to support our proposed risk criteria for Singapore:

a. Precedents in international and Singapore regulatory standards

b. Risk levels accepted by workers in other industries in Singapore

c. Experience in using QRA in the SAF

d. The Singapore Universal Risk Scale

INDIVIDUAL RISK CRITERIA

Precedents in International Regulatory Standards. According to the ammunition storage regulations of various countries (Table 3), an individual risk criterion of 1 x 10^{-6} is a widely accepted level of risk for members of the public i.e. one fatality in a million years, or 10 fatalities in 10 million years. This level of risk is also considered by the UK HSE to be very low (i.e. in the range of broadly acceptable) (JSP 482, 2006).

Ammunition Storage	Individual Risk	
	Worker	Public
US (DDESB)	1.00 x 10^{-4}	1.00 x 10^{-6}
Switzerland (TLM 75)	1.00 x 10^{-4}	1.00 x 10^{-5}
Norway (MOD)	4.00 x 10^{-5}	2.00 x 10^{-7}
Sweden (MOD)	Not Available	1.00 x 10^{-6}
UK (HSE)	1.00 x 10^{-3}	1.00 x 10^{-6}
The Netherlands (existing facilities)	Not Available	1.00 x 10^{-5}
The Netherlands (new facilities)	Not Available	1.00 x 10^{-6}
Australia	5.00 x 10^{-4}	1.00 x 10^{-6}
Canada (DND 2009, draft criteria)	1.00 x 10^{-4}	1.00 x 10^{-6}

Table 3. Precedent regulatory standards for individual risk (TP 14, 2007 and DND, 2009)

Precedents in Singapore Standards. The QRA approach is used not only for safety of explosives, but also potentially hazardous industries such as nuclear power, space systems and chemical plants. A comparison is done with other standards in Singapore, specifically the criteria set by the National Environment Agency (NEA) for installations which store, transport or use hazardous substances (Table 4). According to NEA, the first contour with an associated risk of 5 x 10^{-5} and above is the individual risk permissible to workers and the third contour with an associated risk of 1 x 10^{-6} is the maximum individual risk permissible for the public. The latter supports the statement that 1 x 10^{-6} is considered as low risk and may be a suitable limit for explosives risk to the public in Singapore.

Individual Fatality Risk (IR) Contours	Remarks
5 x 10^{-5}	Contour remains on-site
5 x 10^{-6}	Extends into industrial developments only
1 x 10^{-6}	Extends into commercial and industrial developments only

Table 4. NEA guidelines for Quantitative Risk Assessment (NEA, 2008)

Risk Levels Accepted by Workers in Other Industries in Singapore. The level of risk for the workers in the service sectors is 1.2 x 10^{-5} from 2006 to 2008. This is lower than all international standards for explosive risk management (Table 3) and is not comparable to typical risk levels for explosives. For reference, the total number of fatalities (67) over the total number of service workers (5,600,166), gives us 1.2 x 10^{-5}.

Risk Levels from the Construction and Manufacturing Industries in Singapore. We identified both the construction and manufacturing industries as suitable benchmarks to find the upper limit of the risk levels acceptable by workers in jobs with higher risk. Employment and fatality statistics (Ministry of Manpower, 1996 to 2009) are tabulated to obtain the average annual fatality risk for these two industries. Statistics are taken only from years 2001 to 2008 for a more conservative estimation of risk as earlier years reflect higher fatality rates. The risk figures derived are shown in Table 5.

Industry (2001 – 2008)	Average Annual Fatality Rate
Construction	1.10×10^{-4}
Manufacturing (including shipbuilding and repairs)	1.17×10^{-4}

Table 5. Average annual fatality rate for other industry workers in Singapore

Possible Risk Levels for Explosives Workers in Singapore. Considering the level of risk experienced by workers in the construction and manufacturing industries in Singapore, it seems appropriate for us to adopt 1×10^{-4} as the upper limit for explosives workers. This is to ensure that the level of explosive risk is not higher than the risk experienced by workers in high-risk industries in Singapore. 1×10^{-4} is also the individual risk limit for Swiss and US explosives workers.

UNIVERSAL RISK SCALE

Development and Use of Universal Risk Scale. The US RBESCT uses the Universal Risk Scale (URS) to assist in selecting the appropriate risk criteria (Rufe, Pfitzer, 2001). Decision-makers are able to compare explosives risk to other common risks in order to better understand the risk figures. The URS uses a log scale to display the wide spread of data. This is not only for the convenience of displaying many different risks in a single space, but also to allow for better comparisons of relative risk in orders of magnitude so that the concept of risk can be more properly understood.

There are two types of information shown in the URS. The first comprises various risk-related legal precedents and governmental standards, while the second comprises real-world statistical data derived from documented accident experience (TP 14, 2007). Voluntary and involuntary risks associated with different modes of fatalities are shown in the scales and compared against regulatory standards, where voluntary risks are used for workers and involuntary risks for the general public. All data are shown in terms of annual risk.

Singapore's Universal Risk Scale. To understand risks for Singapore, voluntary and involuntary Individual Risk and Group Risk URS were prepared (Figure 3). Data from explosive risk criteria established for use in foreign countries (TP 14, 2007) as well as Singapore death statistics (Registrar for Births and Deaths, 1980 to 2007) were used. The average annual risk from each cause of fatality e.g. cancer was calculated by summing the total deaths from cancer from 1980 to2007, then dividing it by the summed population from 1980 to 2007.

The right side of the Singapore URS for Individual Risk consists of all the data compiled from Singapore statistics and the left side consists of regulatory standards as well as the two proposed draft criteria for explosive risk. The items in blue refer to voluntary risks and are compared to risks undertaken by explosives workers.

Proposal for Explosives Workers and Public Individual Risk Criterion. As shown on the Individual Risk Singapore URS (Figure 3), the draft individual risk criterion of 1 x 10^{-4} for explosives workers, and 1 x 10^{-6} for the public are widely accepted by various other countries and compare reasonably with other common risks in Singapore.

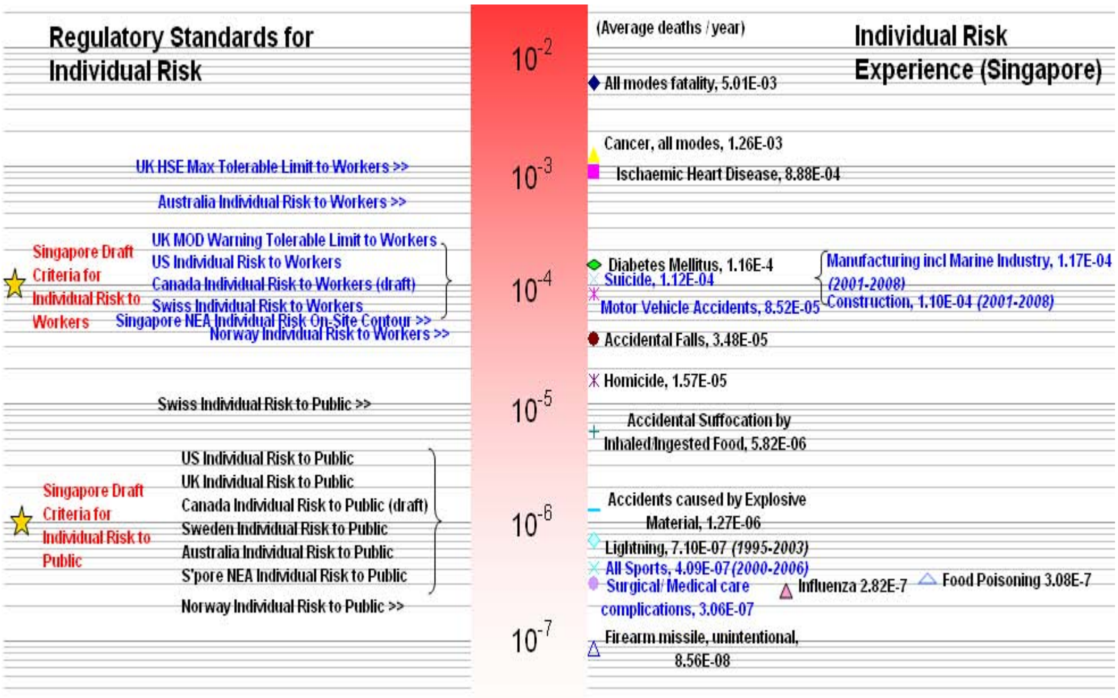

Figure 3. Singapore URS for individual risk (proposed worker and public individual risk criteria for explosives risk)

GROUP RISK CRITERIA

Individual risk does not take into account the total number of people at risk from a particular event. Hence, an individual risk criterion alone is insufficient in regulating explosives risk. Realised hazards that affect society can have adverse repercussions for institutions responsible for putting in place provisions and arrangements for protecting people e.g. Parliament, the Government of the day. This type of concern is associated with high-casualty or multiple-fatality events which are likely to provoke a socio-political response (HSE 2001). There is hence a need for regulation to control the explosives risk exposure to a group of people. Group risk criteria would be an overlay of protection to the individual risk criteria.

UK Approach to Group Risk – Societal Risk

Assessment on UK Approach to Group Risk. The SAF adopts the UK standard, JSP 482, for explosives siting. JSP 482 primarily contains guidance for QD siting. However, JSP 482 also advises to adopt a risk-based approach when QD cannot be met, along with UK-approved individual and group risk criteria. We should therefore assess the suitability of the UK risk criteria for application to the Singapore context. The UK individual risk criteria are shown in Figure 3 and the UK approach to group risk is explained as follows.

Development of f-N Graph. The UK approach to group risk (known as societal risk) for explosive hazards is an *f-N* graph. The frequency, *f*, of any individual event which may lead to *N* fatalities is plotted as a scattering of points. The rationale for multiple pairs of *f-N* data is that explosive accidents have wide ranges of frequencies and outcomes, depending on the individual circumstances e.g. weather.

UK Societal Risk Criteria. The UK Explosives Storage and Transport Committee (ESTC) has established criteria for societal risk in the form of a red line with slope of -1. This is shown in Figure 4. The maximum probability of an accident causing the death of 50 people or more in a single event should be less than 1 in 5,000 (2×10^{-4}), and any situation which could give rise to a societal risk of greater than 50 fatalities overall, or more than 10 fatalities of members of the general public, must be viewed with great concern. The *f-N* graph plotted for the situation under study must fall below the ESTC societal risk criteria.

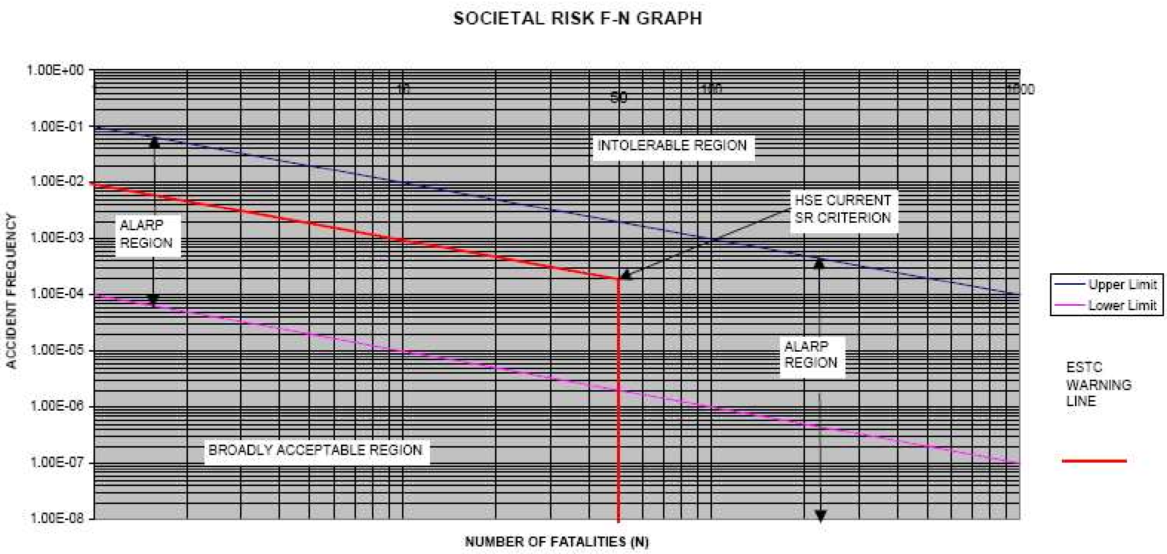

Figure 4 . UK ESTC societal risk criteria (JSP 482)

Applicability of UK Group Risk Approach to Singapore. The *f-N* curve is resource-intensive and the required software, country-specific empirical/field data and skills necessary for this approach are not available to us. Hence, the implementation of the *f-N* graph would not be feasible in our local context.

US Approach to Group Risk

Derivation of US Group Risk Criteria. The US has also derived their group risk criteria using a graph of the accident frequency versus the number of fatalities with lines of slope -1, which can be described by the risk measure of annual expected number of fatalities (Pfitzer, 2008). The US DDESB group risk acceptance criterion for all workers is $<1 \times 10^{-3}$, while the US DDESB group risk acceptance criterion for the public is $<1 \times 10^{-5}$ (Ward, Hardwick, 2009).

Proposed Group Risk Criteria Figures for Singapore

Proposed Approach for Deriving Group Risk Criteria. In evaluating the actual figures for group risk, we propose to use the URS for voluntary and involuntary risks. For the US RBESCT, the number of persons surrounding a post, camp or station may be 1,000 (Rufe, Pfitzer, 2001). Our population density is 7022 per square kilometre (Singapore Statistics 2010), we however believe that 1,000 is a not unreasonable figure since our ammunition depots are usually situated away from built up areas. Hence, we propose to use 1,000 as the normalisation for voluntary and involuntary group risks in our URS as well.

Proposal for Public Group Risk Criterion. From the URS (Figure 5), it seems reasonable to propose the preliminary risk criterion for the public as 1 x 10^{-5}. It is below most involuntary risks. The US has also set the public group risk criteria to <1 x 10^{-5}.

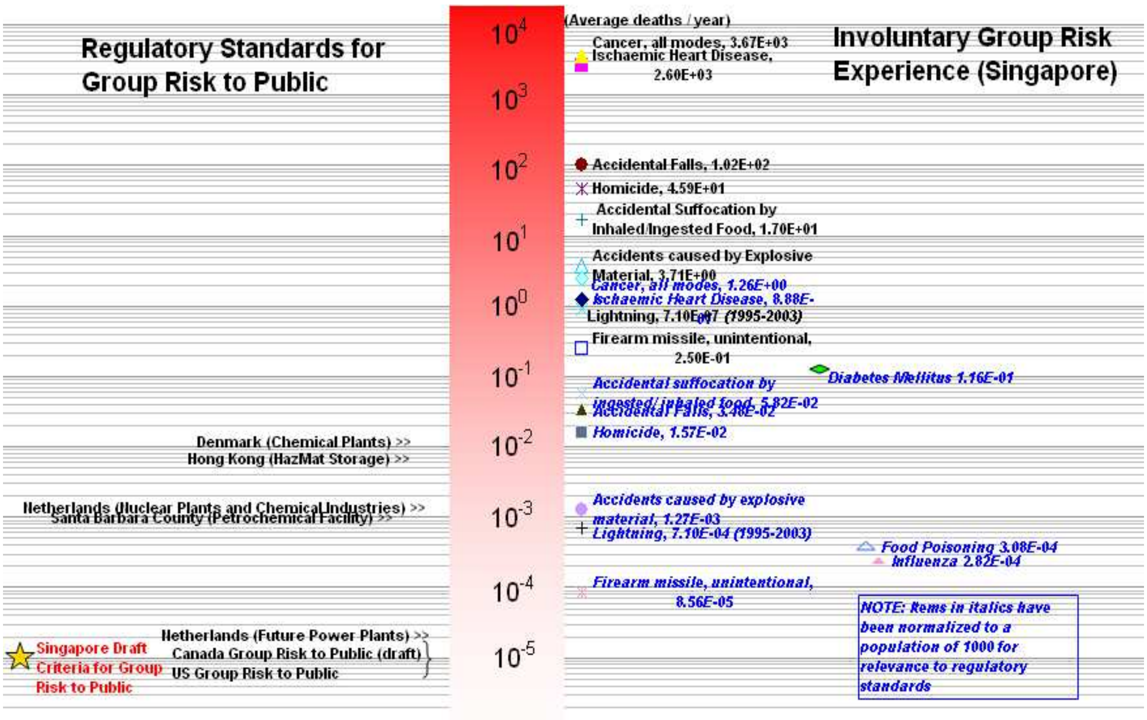

Figure 5. Singapore URS for involuntary group risk (proposed public group risk criteria for explosives risk)

Proposal for Explosives Workers Group Risk Criterion**.** For explosives workers, the recommended criterion is 1 x 10^{-3} (Figure 6). 1 x 10^{-3} is the UK maximum tolerable limit for workers, and is the same risk criterion for US. 1 x 10^{-3} is lower than the risk of fatality from sports, surgical or medical care complications in Singapore.

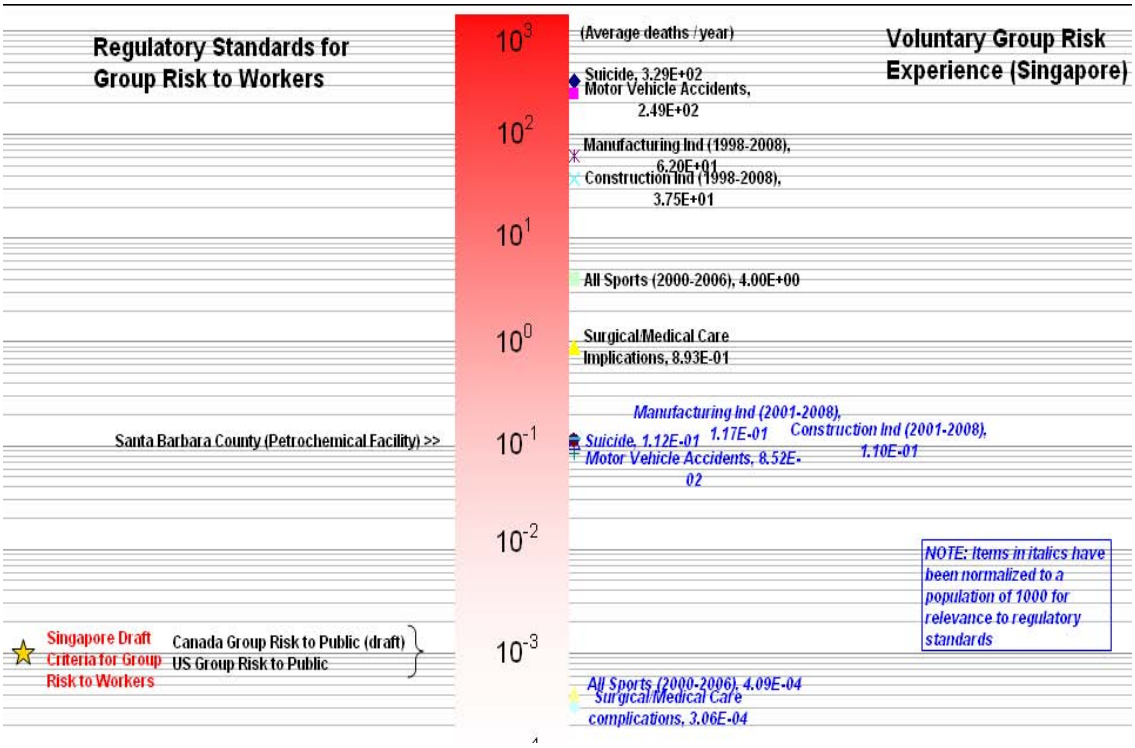

Figure 6. Singapore URS for voluntary group risk (proposed explosives worker group risk criteria)

COMPARISON OF PROPOSED RISK CRITERIA WITH PAST QRAS CONDUCTED FOR THE SINGAPORE MILITARY

It is sensible to compare the proposed individual and group risk criteria with past QRAs conducted for the Singapore Military. This serves as an indication of whether the proposed risk criteria are adequately robust and practicable for use in Singapore.

Underground Ammunition Facility (UAF) QRA. For the Underground Ammunition Facility (UAF) in Singapore, QRA was conducted for the engineering systems as well as other systems, sub-systems, as well as explosives storage and processes. The results of these analyses were integrated to form the overall safety case for the facility. During the integration and endorsement process, the question was asked – how many fatalities could be expected during the design life of the facility? The summation of risks was conducted to arrive at the total expected fatalities for the UAF. It was concluded that the summation of risks represents a good indication of the overall safety integrity of the facility and made it easier for the risk acceptance authority in decision-making. It also facilitated comparison of the risk of a single high-risk hazard to the cumulative risk of many low-risk hazards, thereby providing better resource allocation to tackle scenarios that warrant the highest attention (Zhou et al, 2008).

Comparison with UAF Data. The proposed criterion of 1 x 10^{-4} for the individual risk of personnel directly involved is comparable with the summed individual risks in the UAF. This indicates that the figure of 1 x 10^{-4} can be a reasonable and practicable individual risk criterion for explosives workers. The findings are similar for the proposed criterion of 1 x 10^{-3} for the group risk of personnel directly involved. It should be noted that the SAFER software was not used for this QRA.

Comparison with other QD-deviation cases. Since 2005, DSTA has started to use SAFER in a number of QD-deviation cases, to better understand the risk. The case situations vary broadly, in terms of degree of QD-deviation, number of persons exposed, time duration of exposure, explosive activity, building structures and complexity of the explosives siting.

From our case studies, the proposed individual risk criterion of 1 x 10^{-4} can be met. This is not surprising given the effort invested to decrease the risk, particularly by limiting the duration of the explosives operation (therefore decreasing percentage time where both people and explosives are present), and by designing hardened building structures for exposed sites. Moreover in some cases, the QD-deviation is minor.

From our brief experience, DSTA has observed that the 1 x 10^{-3} group risk criterion for workers is typically the limiting factor, rather than the individual risk criterion. This is due to our high population density and corresponding large number of personnel in buildings, which corresponds to a large group risk result. If the group risk exceeds criteria, the risk is mitigated to the extent possible until it drops within risk criteria and is As Low As Reasonably Practicable (ALARP).

PROPOSED RISK MANAGEMENT OF RISK BASED EXPLOSIVES SITING IN SINGAPORE

An explosives siting that meets QD is the norm in the SAF. All other factors being equal, an explosives siting that deviates from QD is likely higher risk than an explosives siting that meets QD. SAFER helps us in risk analysis to understand this increased risk quantitatively. However risk analysis is only one component of risk management.

Risk Management may in general terms be referred as “the architecture (principles, framework and process) for managing risks effectively” (ISO 31000, 2009). Figure 7 illustrates the relationship. The risk management of risk based explosives siting in Singapore is still in development, however it is generally in-line with the guidance from ISO 31000. An overview of the proposed risk management approach is provided.

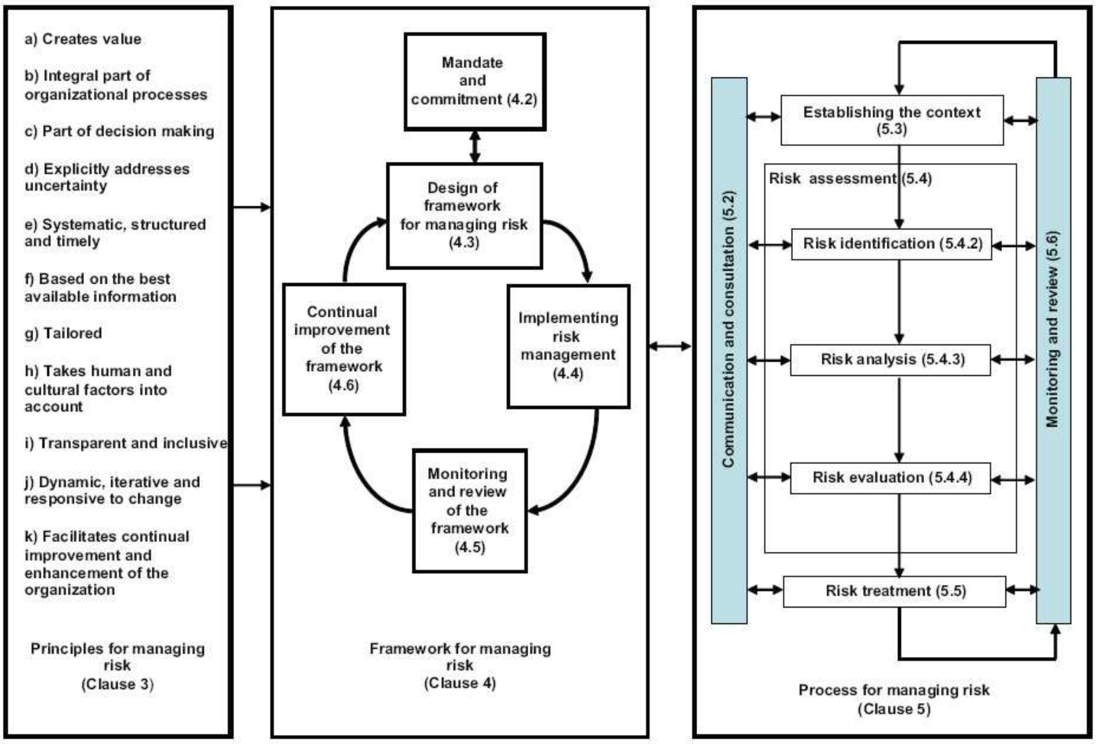

Figure 7. Relationships between the risk management principles, framework and process (ISO 31000, 2009)

Principles for managing risk based explosives siting

Proposed principles. Guiding principles are proposed to manage risk based explosives siting. They are adapted from DoD Policy Letters 2001, 2004 (APT, 2006) on the subject.

1) Risk Based Explosives Siting shall not be used to justify the reduction of current safeguarded zones.

2) Risk Based Explosives Siting may be used after a concession for a waiver or exemption from QD has been obtained.

3) The SAFER software is used, the risk is within the proposed SAF risk criteria and reduced to ALARP

4) The quantitative risk is tabled for endorsement and acceptance, in accordance to the risk based explosives siting risk management framework

5) An explosives licence issued via risk based explosives siting is subject to review every two years or when conditions change, whichever occurs earlier.

6) Trained SAFER users shall prepare the SAFER study; an independent team checks the results. The results are submitted according to the risk based explosives siting report requirements.

Proposed Framework and Process for managing risk based explosives siting

Overview of existing safety framework and process. DSTA and SAF have adopted System Safety and the Residual Mishap Risk Management Framework (Table 6, DSTA, 2010) to provide safety assurance to projects that acquire weapon systems for the SAF.

The residual mishap risk management framework requires technical authorities to assess if the mishap risks (categorised to Low/ Medium/ Serious/ High), have been reduced to ALARP. Technical risks are endorsed before the mishap risks are submitted to stakeholders for risk acceptance. If stakeholders do not accept the level of mishap risks involved, more resources may have to be committed to lower the risks (DSTA, 2010). For clarification, MINDEF refers to the Singapore Ministry of Defence.

Hazard Risk Index	Mishap Risk Category	Technical Risk Endorsement	Authority for Acceptance of Residual Mishap Risk
1 - 5	High	Technical committee at MINDEF level	Committee at joint or service level
6 - 9	Serious	MINDEF technical working group	Committee at joint or service level, or lower
10 - 17	Medium	MINDEF technical working group	Appropriate commanding officer or head of department
18 - 20	Low	Programme manager	Operations manager

Table 6, Residual Mishap Risk Management Framework (DSTA, 2010)

Leverage on existing framework. The SAF is familiar with the residual mishap risk management framework for managing explosives risk. It has been applied for the Underground Ammunition Facility (DSTA Horizons, 2005) and for warship explosives stowage safety (Lao, 2008). Leveraging on an established framework would promote the implementation and integration of risk-based explosives safety into the existing safety systems.

Proposed Framework and Process for risk based explosives siting. The proposed risk based explosives siting safety framework functions in a similar manner to the established residual mishap risk management framework. Quantitative risk results from SAFER are assigned into Low/ Medium/ Serious/ High risk categories; the technical risk endorsement and risk acceptance authorities follow the mishap risk endorsement and risk acceptance authorities.

The proposed risk criteria are tagged to the upper limit of Medium risk. The proposed risk criteria should not form the upper limit of Low risk, as Low risk is when QD is met. Studies have been conducted internally to validate this. The draft risk based explosives siting safety framework for individual and group risks to workers and the public is shown in Table 7.

Risk Based Explosives Siting Risk Level	Risk Categories for Workers	Risk Categories for the Public	Technical Risk Endorsement	Authority for Acceptance of residual mishap risk
High	IR>1E-3 GR>1E-2	IR>1E-5 GR>1E-4	Follow Mishap Risk Authorities (Table 6)	
Serious	1E-4<IR<1E-3 1E-3<GR<1E-2	1E-6<IR<1E-5 1E-5<GR<1E-4		
Medium	1E-6<IR<**1E-4** 1E-5<GR<**1E-3**	1E-8<IR<**1E-6** 1E-7<GR<**1E-5**		
Low	IR<1E-6 GR<1E-5	IR<1E-8 GR<1E-7		

Table 7, Proposed Risk Based Explosives Siting Risk Management Framework

RECOMMENDATIONS

Risk criteria are used to help decision-makers decide whether the risk associated with an explosive related activity is low enough to proceed. The upper limit is a measure of management's tolerability towards risk. Defining the risk benchmarks for individual and group risk to workers and to the public demonstrates transparency in the QRA process.

In the selection of the US criteria, RBESCT had first recommended a 'Strawman Criteria' (Pfitzer, Rhodes, 1998) for trial use. Upon further review and examination, this was amended to arrive at the risk criteria approved by the DDESB in Dec 1999 (TP 14, 2007), which has since evolved (Ward, Hardwick, 2009).

The proposed risk-based acceptance criteria for explosive safety in the Singapore context, summarised in Table 8, should similarly be reviewed after a trial period of a few years to ensure that it is robust for risk management and yet practical for use.

Type of Explosives Risk Benchmark	Proposed Quantitative Risk Criteria
Individual Risk to Workers	$< 1 \times 10^{-4}$
Individual Risk to the Public	$< 1 \times 10^{-6}$
Group Risk to Workers	$< 1 \times 10^{-3}$
Group Risk to the Public	$< 1 \times 10^{-5}$

Table 8. Summary of proposed quantitative risk criteria

To facilitate implementation and safety management of risk based explosives siting, quantitative risk results may be tagged to the risk categories Low/ Medium/ Serious/ High. This approach leverages on mishap risk categories, risk endorsement and risk acceptance authorities that are already established in the SAF mishap risk management framework. The proposed quantitative risk criteria may be assigned to the upper limit of the Medium risk category.

CONCLUSIONS

QRA is not a replacement for QD. Risk-based explosives siting using QRA should only be applied when QD requirements cannot be met. QRA may be used in conjunction with system safety as QRA enables a better understanding of the actual risk. The risk can then be effectively mitigated and reduced and also appropriately communicated to decision-makers. Risk criteria serve as a guideline in risk management by providing a benchmark on the level that is considered tolerable. However, risk should always be reduced to ALARP and risk mitigation has to remain as a key defence against accidents.

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Risk Criteria for the Risk-Based Siting (RBES) of Singapore Armed Forces Explosive Facilities

Audrey Lao Linmei

DDESB Seminar, 14 Jul 10

DSTA-Armament Systems

Background

- Risk from Singapore military explosive facilities is managed via Quantity Distance (QD)

- A risk-based approach is needed to complement QD, given Singapore's land area and population

Development of RBES in Singapore

DSTA
Defence Science & Technology Agency

1980's

- **QD approach adopted**
- **UK JSP 482 standard**
- *Observed international developments in RBES*

2005

- **Acquired SAFER v3 & training package**
- **Used SAFER for various risk analyses**
- *Recognised the need for a RBES framework*

2010

- **Proposed RBES framework for the Singapore Armed Forces (SAF)** - work in progress

Development of RBES in Singapore

Why RBES?

Principal Considerations

Propose Framework

Implement & Review

Why RBES?
- Need a risk management framework to enable fulfilment of ops, *safely*, when QD is not met

Principal Considerations
- International practice
- Applicability
- Balance safety and practicality
- Process transparency
- Integration with existing safety frameworks
- Response to changes

Propose Framework
- **Usage Guidelines**
- **Software**
- **Risk Criteria**
- **Approval Process**

Implement & Review
- Monitor & Review framework

Proposed Software

- Safety Assessment For Explosives Risk (SAFER)
  - Acquired SAFER v3 and training package in 2005
  - Positive user experience
- Other positive observations
  - SAFER is DDESB-approved and actively used
  - SAFER is well documented
  - SAFER is based on accident data and test data
  - SAFER is peer reviewed
  - SAFER compares reasonably with other risk models
  - SAFER can assess risk for various explosive activities, building structures and multiple PES-ES pairs

Proposed Risk Criteria (Workers)

Directly involved & indirectly involved

Risk to:	Criteria
Individual Risk – Worker	$< 1 \times 10^{-4}$
Group Risk – Workers	$< 1 \times 10^{-3}$
Individual Risk – Public	$< 1 \times 10^{-6}$
Group Risk – Public	$< 1 \times 10^{-5}$

- **Individual Risk – Worker**. < $\underline{1 \times 10^{-4}}$ is the US, UK, Swiss, draft Canadian risk criteria. *Comparable* to Singapore National Environment Agency's risk criteria
- **Group Risk – Worker**. Probability of fatality approach is preferable to setting a fatality limit (UK) or a dollar value to prevent a fatality (Swiss). Propose < $\underline{1 \times 10^{-3}}$ which is the US and draft Canadian group risk criteria

Proposed Risk Criteria (Public)

Risk to:	Criteria
Individual Risk – Worker	$< 1 \times 10^{-4}$
Group Risk – Workers	$< 1 \times 10^{-3}$
Individual Risk – Public	$< 1 \times 10^{-6}$
Group Risk – Public	$< 1 \times 10^{-5}$

Not involved (Individual Risk – Public; Group Risk – Public)

- **Individual Risk – Public**. < $\underline{1 \times 10^{-6}}$ is the US, UK, Swedish, draft Canadian, Australian and Singapore National Environment Agency risk criteria.

- **Group Risk – Public**. < $\underline{1 \times 10^{-5}}$ is the US and draft Canadian group risk criteria

Preceding Singapore Regulations

- Singapore National Environment Agency (NEA) risk criteria for installations which store, transport or use hazardous substances

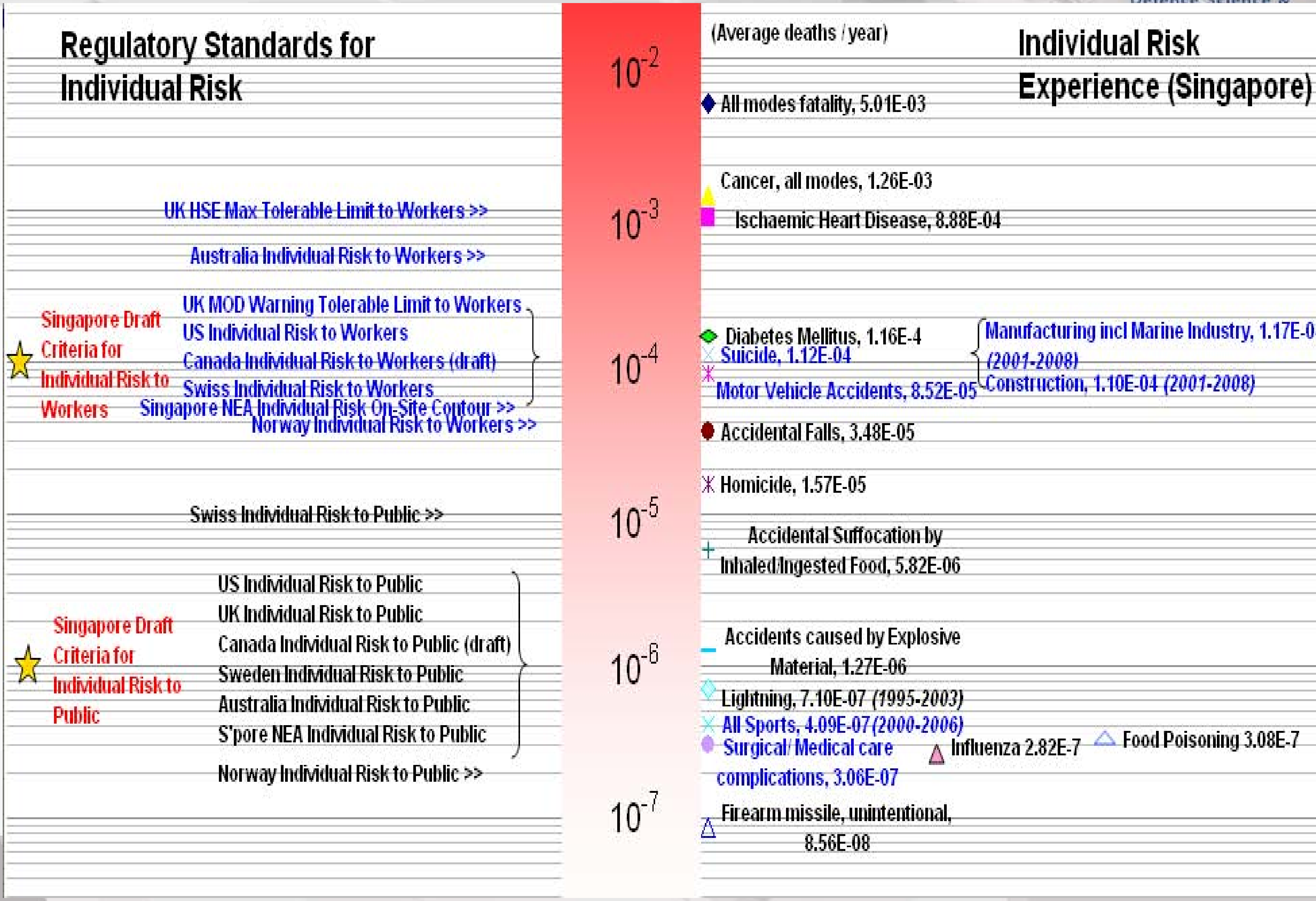
NEA Individual Fatality Risk Contours	Remarks
5 x 10-5	Contour remains on-site
5 x 10-6	Extends into industrial developments only
1 x 10-6	Extends into commercial and industrial developments only

Pollution Control Department (PCD) Guidelines for Quantitative Risk Assessment (QRA) Study

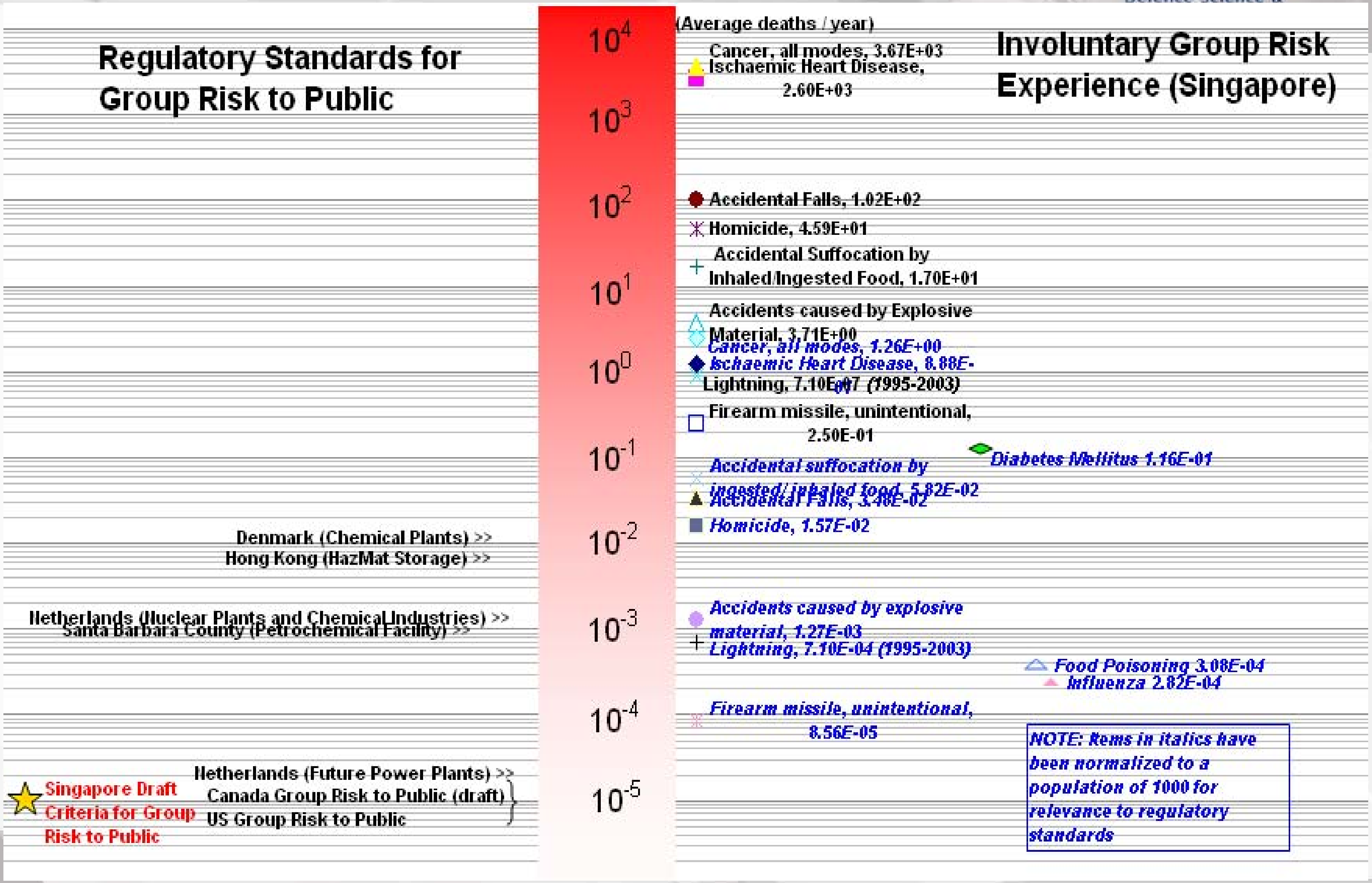
- NEA has not adopted group risk criteria for chemicals, however we propose to adopt group risk criteria for explosives

- We also propose to specify risk criteria for workers (directly and indirectly involved) within the premise

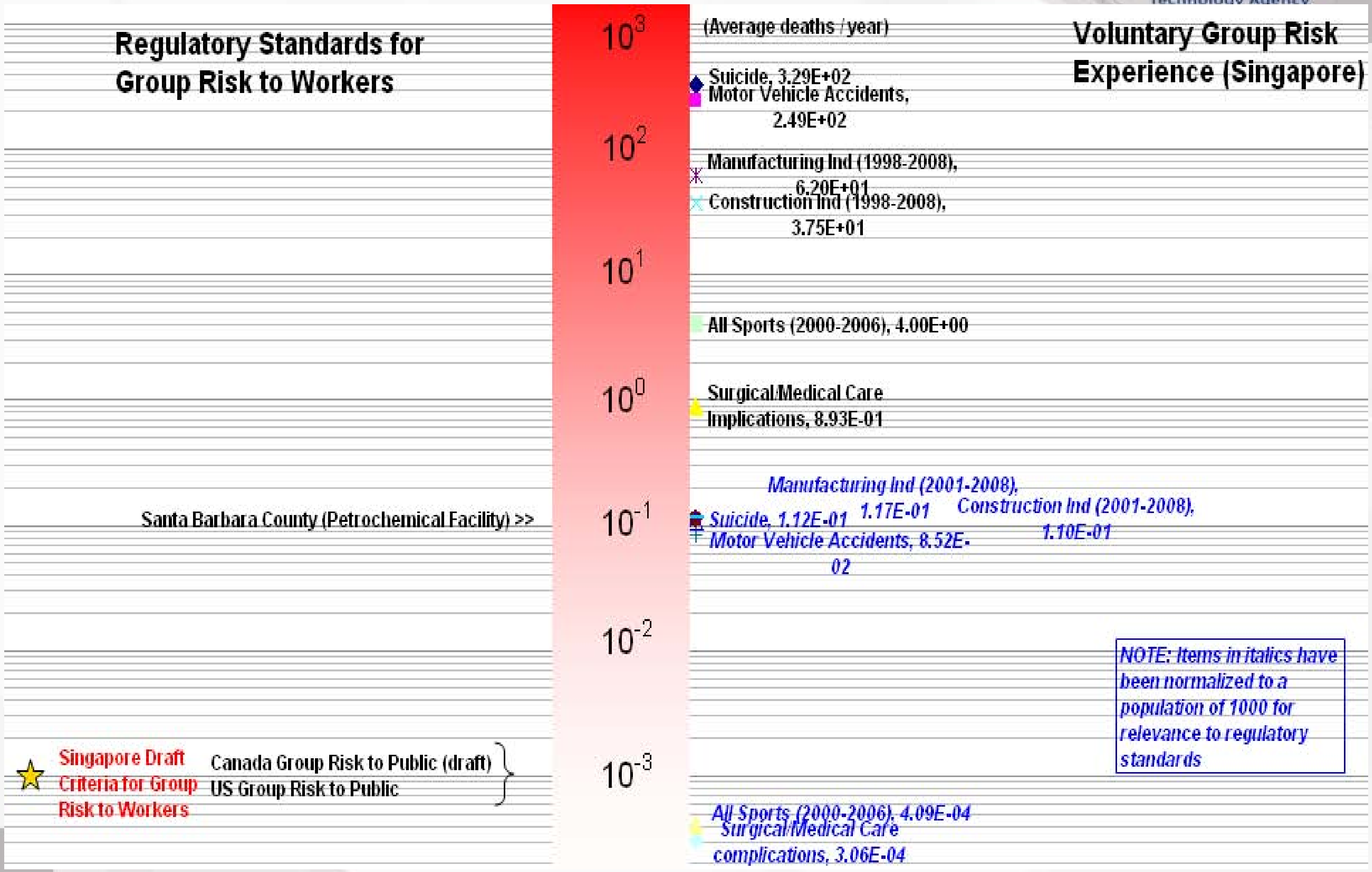
Risk Scale (Individual Risk)



Risk Scale (Group Risk - Worker)



Risk Scale (Group Risk - Public)



Proposed Risk Management Framework

DSTA
Defence Science & Technology Agency

(*Already Established*) Residual Mishap Risk Management Framework →

Hazard Risk Index	Mishap Risk Category	Technical Risk Endorsement	Authority for Acceptance of Residual Mishap Risk
1 - 5	High	Technical committee at MINDEF level	Committee at joint or service level
6 - 9	Serious	MINDEF technical working group	Committee at joint or service level, or lower
10 - 17	Medium	MINDEF technical working group	Appropriate commanding officer or head of department
18 - 20	Low	Programme manager	Operations manager

Proposed Risk Based Explosives Siting Risk Level	**Proposed Risk Categories for Workers**	**Proposed Risk Categories for the Public**	Technical Risk Endorsement	Authority for Acceptance of Residual Mishap Risk
High	IR>1E-3 GR>1E-2	IR>1E-5 GR>1E-4	Technical committee at MINDEF level	Committee at joint or service level
Serious	1E-4<IR<1E-3 1E-3<GR<1E-2	1E-6<IR<1E-5 1E-5<GR<1E-4	MINDEF technical working group	Committee at joint or service level, or lower
Medium	1E-6<IR<**1E-4** 1E-5<GR<**1E-3**	1E-8<IR<**1E-6** 1E-7<GR<**1E-5**	MINDEF technical working group	Appropriate commanding officer or head of department
Low	IR<1E-6 GR<1E-5	IR<1E-8 GR<1E-7	Programme Manager	Operations manager

Guidelines for Use of RBES

1) Risk Based Explosives Siting shall not be used to justify the reduction of current safeguarded zones.

2) Risk Based Explosives Siting may be used after a concession for a waiver or exemption from QD has been obtained.

3) The SAFER software is used, the risk is within the proposed SAF risk criteria and reduced to ALARP

4) The quantitative risk is tabled for endorsement and acceptance, in accordance to the risk based explosives siting risk management framework

5) An explosives licence issued via risk based explosives siting is subject to review every two years or when conditions change, whichever occurs earlier.

6) Trained SAFER users shall prepare the SAFER study; an independent team checks the results. Submit the results according to the risk based explosives siting report requirements.

Way Ahead and Future Work

- The proposed RBES risk criteria and risk management framework are work in progress

- Plan to develop a version of SAFER customised to Singapore's needs (with permission from DDESB)
  - Singapore-type building materials
  - Singapore-type building structures
  - Modifications and preferences gleaned from our experience with SAFER v3

Conclusions

- The Singapore RBES risk criteria and management framework is proposed
- It facilitates approval to site military explosive facilities and inhabited buildings that do not meet QD in Singapore
- In the face of intensive land use, RBES is a useful risk management tool to enable the fulfilment of operational missions safely