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Risk-Based Explosives Safety Analysis

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DISCLAIMER

The principles and techniques given in this document are in the opinion of the DDESB, the best available at the time of publication. Adherence to these principles should provide an acceptable level of safety of ammunition and explosive operations. It does not ensure or guarantee a risk-free situation, neither can the principles cater for every possible situation which could be encountered. Because of the inherent danger in handling ammunition and explosives, the DDESB cannot be held responsible for any mishap or accident resulting from the use of this document.

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Acronyms and Abbreviations

ALARP	As Low As Reasonably Practicable
CG	Compatibility Group
COEHD	Corps of Engineers Huntsville Division
DDESB	Department of Defense Explosives Safety Board
DoD	Department of Defense
ECM	Earth covered magazine
E_f	Expected Fatalities
Ep	Personnel Exposure
EPA	Environmental Protection Agency
ES	Exposed Site
ESTC	Explosives Storage and Transport Committee
FB	Fragment Blocking Value
HAS	Hardened Aircraft Shelter
HC/D	Hazard Class / Division
HD	Hazard Division
I	Impulse
IBD	Inhabited Building Distance
ICT	Integrated Combat Turn
IR	Individual Risk
LAP	Load-Assemble-Pack
MODUK	Ministry of Defense United Kingdom
NATO	North Atlantic Treaty Organization
NAVFAC	Naval Facilities Command
NEWQD	Net Explosives Weight for Quantity Distance
OCONUS	Outside Continental United States
P	Pressure
PC	Personal Computer
P_e	Probability of Event
PEMB	Pre-Engineered Metal Building
PES	Potential Explosion Site
P_f	Probability of Fatality
$P_{f/e}$	Probability of Fatality given and Event and a Person
P_i	Probability of Impact
PRA	Probabilistic Risk Analysis
PTR	Public Traffic Route
Q-D	Quantity-Distance
QRA	Quantitative Risk Assessment
R/C	Reinforced Concrete
RAC	Risk Assessment Code
RALCT	Risk and Lethality Commonality Team
RAWG	Risk Assessment Working Group
RBESCT	Risk-Based Explosives Safety Criteria Team
RCC	Range Commander's Council
RMP	Risk Management Programs
SAFER	Safety Assessment for Explosives Risk

SR	Societal Risk
TDY	Temporary Duty
URS	Universal Risk Scales
US	United States
W/V	Weight / Volume
Z	Scaled Distance

Definitions

Acceptable risk - A predetermined criterion or standard for a maximum risk ceiling.

Accident - That occurrence in a sequence of events which usually produces unintended injury, death or property damage.

Collective risk - The total risk to an exposed population; the expected total number of individuals who will be fatalities. Defined as expected fatalities.

Expected fatalities - The expected number of individuals who will be fatalities from an unexpected event. This risk is expressed with the following notation: 1E-7 = 10^{-7} = 1 in ten million.

Exposure - The time per year an individual is exposed to the potential explosives event.

Hazard - Any real or potential condition that can cause injury, illness, or death of personnel, or damage to or loss of equipment or property.
Hazardous event-Event which causes harm.

Individual risk - The risk to any particular individual, either a worker or a member of the public. A member of the public can be defined either as anybody living at a defined radius from an establishment, or somebody following a particular pattern of life.

Maximum individual risk - The highest level of risk to any one person for a given event.

Population at risk - A limited population that may be unique for a specific explosives risk.

Probability of fatality-The likelihood that a person or persons will die from an unexpected event.

Probit analysis - A statistical transformation which will make the cumulative normal distribution linear. In analysis of dose-response, when the data on response rate as a function of dose are given as probits, the linear regression line of these data yields the best estimate of the dose-response curve. The probit unit is $y = 5 + Z(p)$, where p = the prevalence of response at each dose level and $Z(p)$ = the corresponding value of the standard cumulative normal distribution.

Risk - A measure that takes into consideration both the probability of occurrence and the consequence of a hazard. Risk is measured in the same units as the consequence such as number of injuries, fatalities, or dollar loss.

Risk analysis - A detailed examination including risk assessment, risk evaluation, and risk management alternatives, performed to understand the nature of unwanted, negative consequences to human life, health, property, or the environment; an analytical process to provide information regarding undesirable events; the process of quantification of the probabilities and expected consequences for identified risks.

Risk assessment - The process of establishing information regarding acceptable levels of a risk and/or levels of risk for an individual, group, society, or the environment.

Risk evaluation - A component of risk assessment in which judgments are made about the significance and acceptability of risk.

Safety - Relative protection from adverse consequences.

Societal risk - The risk to society as a whole. For example, the chance of a large accident causing a defined number of deaths or injuries.

1.0 Use of Risk Analyses

1.1 Objectives

The objectives of this publication are to provide the technical background for the Department of Defense (DoD) Explosives Safety Board (DDESB) approved Safety Assessment for Explosives Risk (SAFER) model and the rationale for the selection of the acceptance risk criteria. SAFER was developed by the Risk-based Explosives Safety Criteria Team, a working group reporting to the DDESB.

1.2 Background

Quantity-Distance (Q-D) criteria have been used in making safety judgments for 70 years. For the last 30 of those years, it has been recognized that Q-D, which considers only the explosive quantity and hazard class to determine a safe separation distance, could be improved upon by including other considerations such as the type of activity, number of people, building construction, and environment to assess the overall risk of the operation. This section briefly describes selected background work in other countries and key United States (U.S.) papers supporting the risk-based model.

1.2.1 Switzerland

In the late 1960's, a number of challenges arose in Switzerland with regard to ammunition storage. The challenges could not be solved reasonably and economically using the existing safety regulations of Quantity-Distance criteria, so the individuals responsible for explosives safety began looking for alternative safety assessment models. A quantitative risk analysis approach was introduced and applied to the urgent issues. AMMORISK, a model to estimate risk, was developed. Since then the Swiss have continued to develop and improve a quantitative risk analysis approach and model, have adopted regulations, and have established an organization for implementing quantitative risk analysis.[i]

1.2.2 United Kingdom

"*A risk-based approach to safety requires more openness of the experts, it presents decision makers with choices and responsibility, it is available to public scrutiny. The goals of explosives safety will be unchanged, the ways of achieving those goals will be very different.*"
- Dr. John Connor, Chairman of the UK ESTC

The Ministry of Defense United Kingdom (MODUK) Explosives Storage and Transport Committee (ESTC) funded work to study the feasibility of quantitative risk assessment (QRA) for explosives storage in 1983. The method developed provides an estimate of an upper bound to the annual risk of fatality of an individual from the handling and storing of explosives as the product of two components: the maximum expected frequency of initiation and the expected lethality consequence of the worst credible accident.[ii] The ESTC method requires the user to define details of the potential explosion site (position coordinates, store size, shape and construction), store contents (net explosive quantity and weapon type), and other relevant information. The user must also specify population densities around the site for both workers and the general public. Outputs are calculated in terms of the risks to individuals at exposed sites from all potential explosion sites which pose a threat. The outputs are used to support Q-D regulations in accordance with ESTC Leaflet 22.

The Explosives Storage and Transport Committee currently uses the RISKWING model for their quantitative risk assessments.

1.2.3 Norway

The ammunition storage regulations used in Norway are similar to NATO recommendations. Risk assessment is used to complement the regulations for approval of some ammunition storage.

During the late 1970's, one third of the licenses that were issued had a concession included with them. Many of the waivers were issued because of minor infringements with the quantity-distance rules. In 1989, it was decided that the number of waivers needed to be reduced. This was accomplished by seeking approval to license storehouses on the basis of risk assessment, building new storage facilities, and accepting reduced availability.[iii]

The Norwegians use a quantitative risk assessment approach that is similar to the Swiss approach. The model used to estimate risk is a modification of the Swiss AMMORISK software program.

1.2.4 Australia

General licensing practices for storage and handling of explosive ordnance within the Australian Defence Force are based on criteria commonly referred to as Q-D rules. The principles are similar to those defined by NATO Manual AASTP-1.[iv] Current Defence policy is that risk assessment may be used to support applications for public and departmental risk waivers, and to assist in the licensing of ordnance handling and storage operations. Risk assessment is not used as an alternative to Q-D rules.

Risk assessment methodology is similar to that applied by the MODUK ESTC with only a minor variation in the techniques used to assess risk. The Individual Risk (IR) and Societal Risk (SR) are key outcomes and are considered separately, but not in isolation. IR is the risk related to the personal safety of an individual. SR deals with the frequency of incidents and the likely number of fatalities following an incident.

Australia has two software models available for QRA: AUSRISK for site risk assessments, and Q-RISK for "quick-scan" risk appraisals.

1.2.5 United States

Within the United States (U.S.), risk-based standards have been infrequently used in the explosives safety community. A risk-based approach, NOHARM, was first proposed by Keenan (1978[v], 1980[vi]) and the project was supported by Naval Facilities Command (NAVFAC). All of the essential ingredients in a risk analysis were defined in that project, but data were lacking for determining event probabilities and vulnerabilities of structures. Funding was stopped before the program was completed.

In the meantime, other technical areas in the United States did make progress with risk methods. The PRA (Probabilistic Risk Analysis) concept was developed under the oversight of the Nuclear Regulatory Commission (WASH 1400, 1975),[vii] and comprehensive PRA's were performed on every reactor in the U.S.; in addition, U.S. methods were applied to reactors all over the world. Although criticized in some areas after its release, the general methodology defined in WASH 1400 has become a standard for many industries.

In other areas of DoD, risk analyses have been performed to establish the risk of rocket launches. Vehicles are routinely held, or released for launch, based on the results of pre-launch risk analyses against a specified acceptable risk criteria (weather being the major consideration). This has been in place since the late 1960's.

The Environmental Protection Agency (EPA) has generally chosen to stay with hazard based criteria, but EPA sponsors many studies and analyses that look at the problem from a risk perspective.

Until more recently, the U.S. petrochemical industry relied on hazard analyses to identify factors that could have adverse onsite or offsite consequences. In the past few years, many U.S. refineries have specified acceptable risk criteria and have extended their hazard analyses to specification of the associated likelihood of events. They have realized that merely defining hazards, without the corresponding event probabilities, results in an inadequate means for determining the adequacy of, or need for, mitigations. In addition, legislation in California and New Jersey (risk management and prevention programs 1989/90) and the U.S. (40 CFR Part 68[viii]), regarding requirements for risk management programs (RMP) has shifted the emphasis to consideration of risk for all hazardous facilities that store or use hazardous materials above state and federal threshold quantities.

Recently the U. S. explosives safety community has become more aware of the need for risk-based approaches in explosives safety, and numerous papers have been written on the subject. Two notable papers are the Pacific Northwest Study[ix] and the 1996 Corps of Engineers Huntsville Division (COEHD) study.[x] A third study[xi] performed by the Risk and Lethality Commonality Team (RALCT) is also noted because of its work in standardizing risk acceptability for rocket launches. These studies are summarized below.

1.2.5.1 Pacific Northwest Study

In August 1996 at the 27th DDESB Explosives Safety Seminar, Pacific Northwest National Laboratory in conjunction with Bienz, Kummer, and Partner Ltd. of Switzerland presented a risk-based approach as a complement to the Q-D approach.[ix]

The risk analysis approach defined in the paper is currently used by the Swiss. The risk analysis consists of four steps: event analysis, effect analysis, exposure analysis, and risk calculation. Once the risks are calculated, a risk appraisal is performed to determine if they are acceptable.

The calculated risks are compared to criteria (from Swiss Department of Defense policy) to determine acceptability.

Risk is calculated using the following equation: $R=F*D$, where R is risk, F is frequency, and D is damage. When a risk appraisal is performed, the calculated risk is compared with the approved risk limits (criteria) for direct personnel, indirect personnel, and third persons. The perceived collective risk is evaluated to see if corrective measures need to be taken to reduce the risk.

To account for catastrophic events, an aversion factor is multiplied by the actual risk to give a perceived risk. In the Swiss approach there is not a criterion for perceived risk but there is a "willingness-to-pay" approach. The "willingness-to-pay" sets an upper limit on what is reasonable to pay for risk mitigations to save a person's life (not on the value of the life).

Swiss DoD policy states that explosives workers should not incur a higher risk than the average working public. They now use the computer model RISKAMEXS to perform explosives safety risk assessments.

1.2.5.2 RALCT

The Risk and Lethality Commonality Team (RALCT) was formed by the Range Commander's Council (RCC) Range Safety Group in February 1996. The purpose of the RALCT was to publish a common standard[xii] for debris protection criteria and analytical methods. Before this group was formed, each national range used its own set of criteria and analytical methods for calculating risks to personnel.

Risk-based criteria were developed to protect personnel from potentially lethal debris. Personnel protection criteria were defined for the general public and for mission essential personnel (individual and collective risk).

Once the criteria were defined, five areas were addressed to justify the RCC criteria: consistency with other safety criteria, legal considerations, similar regulatory experience, comparable accident statistics, and correlation to other criteria.[xi]

The RALCT defined many of the analytical and philosophical approaches used by the Risk-Based Explosives Safety Criteria Team (RBESCT) to develop the current risk-based approach for explosives safety.

1.2.5.3 Corps of Engineers, Huntsville Division

In 1994, the Corps of Engineers Huntsville Division (COEHD) proposed using the Risk Assessment Code (RAC) matrix defined in MIL-STD-882C[xiii] to determine inhabited building distance (IBD) separations.[x]

MIL-STD-882C establishes procedures for evaluating the risks associated with the operation of DoD facilities. These procedures can be used to qualitatively evaluate the severity of an event as well as the probability of occurrence. The combination of the two in the form of a risk matrix provides decision makers with a tool to evaluate the relative risk associated with a particular explosive source.

The proposed risk model is based on two components: hazard severity and hazard probability. Total quantity of explosives and the scaled range are identified as hazard severity. Type of construction, function of facility, and expected occupancy level are used to determine a hazard probability. Using the RAC matrix, the risk to the public beyond IBD can be determined. There are two assumptions in this approach: that only risks from overpressure are considered, and that an event will occur.

1.3 The Benefits of a Risk-Based Approach

Initially, the intended uses of the risk-based approach will be to evaluate the risk acceptability as well as the approval level for those site plans in violation of the deterministic part of the standard. Currently, waivers and exemptions are authorized without quantified knowledge of the risks taken. The criteria are inflexible (requiring waivers for non-compliance). Perhaps most importantly, the use of Q-D does not provide consistent risk or damage criteria.

The numerous benefits that are expected with a risk-based approach include:

- Providing decision makers with the knowledge of the actual risk that is being accepted;
- Decreasing the number of waivers required;
- Prioritizing non-compliance (since a level of risk can be associated with each);
- Comparing quantitative measures of risk to established criteria;
- Providing a means for identifying and prioritizing risk contributors as well as ways to mitigate those contributors, and
- Cost savings resulting from better use of real estate, less expensive building designs, standardized waiver review and processing, and increased mission capability.

As a minimum, the benefits include consistency in a risk analysis methodology, a basis for decision making, reducing potential liability, and quantifying the risks that are taken.

In contrast, there are at least two factors which may reduce the benefits. More training may be needed because of the change to a new siting approach (compared to Q-D), and more data are needed to calculate risk.

1.4 Analysis Methodology

A probabilistic approach for explosives safety risk analysis entails calculating the product of three components to estimate annual **expected fatalities** (i.e. the average number of fatalities expected per year) as the basic measure of risk. The probability of an explosives event (P_e), the probability of a fatality given an event ($P_{f/e}$), and the expected exposure of people (E_p) are multiplied as shown in the following equation:

$$E_f = P_e \times P_{f/e} \times E_p$$

The P_e is defined as the probability that an explosives event will occur per Potential Explosion

Site (PES) per year. The $P_{f/e}$ is defined as the probability of fatality given an explosives event. E_p is the exposure of people to a particular PES on an annual basis.

1.5 Criteria Considerations

The selection of applicable criteria involves first selecting the measure of risk and then determining the acceptable quantity of that measure.

Risk measures define (1) who or what is at risk, (2) the consequences of the risk, and (3) the time period of the risk. The four measures selected are expected fatalities (E_f) as the basic measure, maximum expected fatalities, individual probability of fatality, and peak individual probability of fatality per year. By using a combination of these measures, the decision-maker will have a broader understanding of the risks. These measures are applied to three categories of personnel: those whose jobs relate to the potential explosion site (related), persons who are exposed by virtue of employment (non-related), and all others not included in the previous definitions (public).

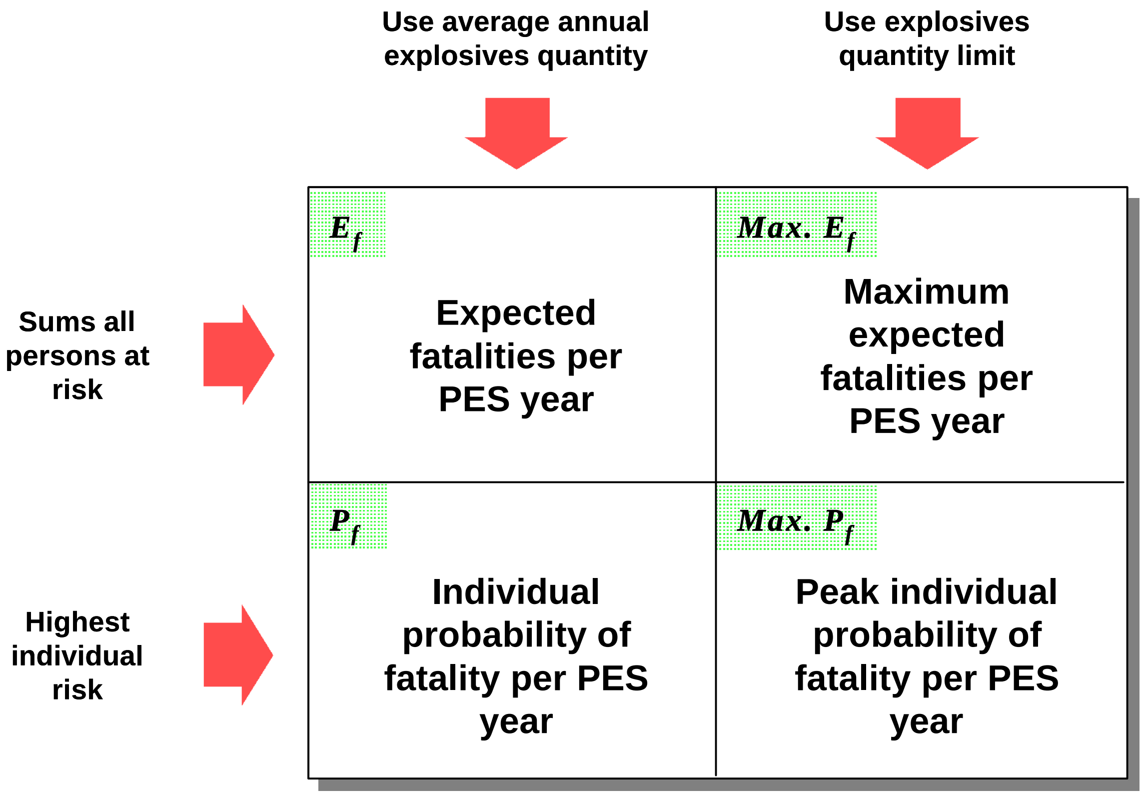
Measure Selection	Selected	Considered
Who or what is protected?	People (2 categories: related, non-related)	• High value facilities • Mission
From what consequence?	• E_f • Maximum E_f • Individual P_f • Peak Individual P_f	• Probability of injury • Expected number of injured • Expected damage to facilities • Change in risk
For what time period?	Per year	• Per day • Per operation

Figure 1: Measures Considered

How much risk is acceptable? The acceptability of various risk levels can be a controversial topic, which transcends logical and emotional considerations. Much of public policy sidesteps the obvious debate on the value of human life. For example, the Swiss state the amount of risk as not higher than that for "the average public worker." The British use a range of accepted values from 1×10^{-3} to 1×10^{-6} for maximum risk to a single person.

Three variations of the basic measure can be useful to decision-makers. As shown in Figure 2, minor variations in the probability formula are used to calculate the other measures:

1) Maximum expected fatalities could be determined by substituting the explosive limits for the PES in place of the expected value for the explosives quantity.
2) Individual P_f could be determined by using the highest individual risk from the E_f equation.
3) Peak individual P_f could be determined by using the highest individual risk from the maximum E_f equation.



	Use average annual explosives quantity	Use explosives quantity limit
Sums all persons at risk	E_f Expected fatalities per PES year	Max. E_f Maximum expected fatalities per PES year
Highest individual risk	P_f Individual probability of fatality per PES year	Max. P_f Peak individual probability of fatality per PES year

Figure 2: Risk Criteria Measures

2.0 Model Description

For ease of illustration, the model is being described in terms of a single Potential Explosion Site (PES), surrounded by various Exposed Sites (ES). We recognize that more complex situations exist, and that several PES's may present different threats to the same ES at different ranges.

2.1 Event Analysis

As shown in Section 1.3, the first component in the probabilistic approach is the P_e determination. Of the three components of the E_f formula, P_e offers the most uncertain analytical assessment. Recognizing this inherent uncertainty, the RBESCT determined that grouping the P_e factor into probability bins would offer the most appropriate analytical approach. Twelve probability bins were defined spanning a total probability from 1 in a million (1E-6) to 3 in 10 (3E-1). Each bin spans one half order of magnitude (a factor of 3.1). The determination of the appropriate probability bin for a given PES is found using the P_e matrix (shown in Figure 3) developed by the RBESCT.

Within the P_e matrix three factors can alter the probability of an explosives event: activity type at the PES, the explosives transportation and storage Compatibility Group, and "other factors." The activity type describes the primary operation being performed at the PES. Historical data show that this factor can vary the P_e by up to four orders of magnitude. The explosives transportation and storage Compatibility Groups (used in DoD 6055.9-STD[xiv]) are used to describe the types of explosives in the PES. This factor results in variations of P_e up to 1 1/2 orders of magnitude. To account for this variation, the Compatibility Groups are divided into three sets designated by the Roman numerals in the matrix. Set one (I) contains Compatibility Groups L, A, B, G, H, J, and F; set two (II) contains C; and set three (III) contains D and E. "Other factors" (scaling factors) consist of a variety of environmental circumstances which can increase the P_e by up to one order of magnitude. Each activity has a set of allowable scaling factors for that particular activity. The scaling factors are shown in the second column of the matrix in Figure 3.

To use the P_e matrix shown in Figure 3, select the row in the table that corresponds to the activity type at the PES, read over to the proper Compatibility Group, then read up to find the probability of event. This gives the basic P_e which may then be increased if any of the scaling factors apply. The scaling factors are reviewed for applicability and if one applies then an adjustment is made to the P_e. If more than one scaling factor applies, only one adjustment is made using the factor with the highest adjustment.

The P_e matrix was developed using a compilation of historical, explosives accident data from the U.S. Army, Navy, and Air Force. The data set is composed of 313,051 PES-years and 175 explosives events. These data provided numerous data points within the matrix which were “anchored” to actual accident experience. Similar activities were combined into activity groups, which provided a high statistical confidence in the anchor chosen. Explosives Compatibility Groups, combined with engineering judgment and the experience of the panel, were used to define the spread of probabilities between Compatibility Groups for each activity group within the matrix.

The RBESCT recognizes that this matrix has inherent uncertainties. However, it is considered to be the best available current assessment of future explosives events. As knowledge increases, the matrix can be modified.

		Probability of Event (per PES-year)											
PES used primarily for:	Allowable Scaling Factors	1E-6	3E-6	1E-5	3E-5	1E-4	3E-4	1E-3	3E-3	1E-2	3E-2	1E-1	3E-1
Burning Ground / Demilitarization / Demolition / Disposal	A1, A2, A8, B1, B2							III	II		I		
Assembly / Disassembly / LAP / Maintenance / Renovation	A1, A4, A5, A8, B1, B2					III	II		I				
Lab / Test / Training	A1, A3, A4, A5, B1, B2, B3, B4					III	II		I				
Manufacturing	A4, A5								All				
Inspection / Painting / Packing	A1, A2, B1, B2				III	II		I					
Loading / Unloading	A1, A2, B1, B2, B3, B4				III	II		I					
In-Transit Storage (hrs - few days)					III	II	I						
Temporary Storage (1 day - 1 month)				III	II	I							
Deep Storage (1 month - year)	A1, A2		III		I, II								

Notes: The elements in the matrix are made up of Compatibility Groups. Definitions of the Compatibility Groups can be found in DoD 6055.9-STD.[xiv]

Elements	Compatibility Group
I	L, A, B, G, H, J, F
II	C
III	D, E

Scaling Factors:

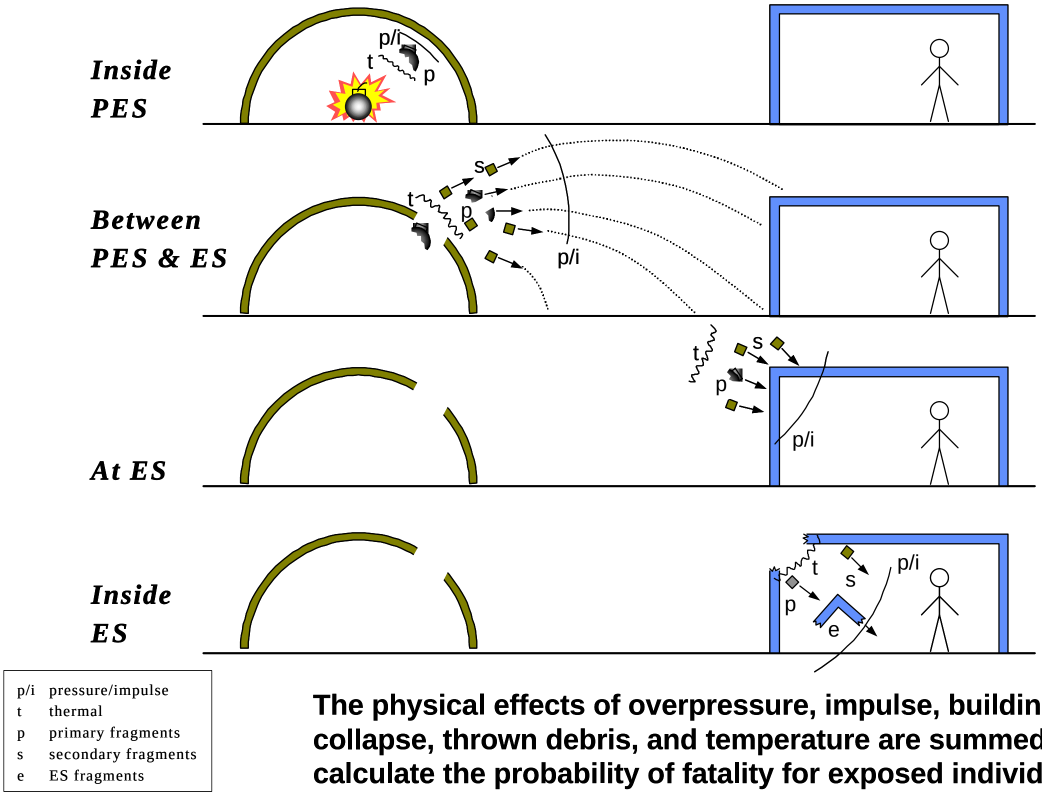
A. Increase P_e by a factor of 10 (two columns to the right) for:
   1. Outside Continental United States (OCONUS) operations in support of wartime actions
   2. Operations involving dangerously unserviceable items awaiting destruction
   3. Initial tests of new systems
   4. Operations occurring in hazardous environments with gases, fibers, etc.
   5. Required remote operations
   6. Temporary Duty (TDY) activities during exercises/contingencies/alerts
   7. Integrated Combat Turn (ICT) operations
   8. Operations involving exposed explosives

B. Increase P_e by a factor of 3 (one column to the right) for:
   1. Outdoor storage/operations normally done indoors
   2. Home station activities during exercises/contingencies/alert
   3. Flightline holding areas
   4. TDY operations during peacetime

Figure 3: P_e Matrix. *This matrix is used to estimate the probability of an explosives event per PES-year.*

2.2 Effects Analysis

The probability of fatality given an explosives event ($P_{f/e}$) is determined by aggregating the potentially fatal effects of impulse/overpressure, building collapse, debris (fragments from the explosives casing and building debris), and thermal effects. This was accomplished by defining an architecture that specifies all the fatality mechanisms, based on the set of inputs. Based on the fatality mechanisms depicted by Figure 4, a $P_{f/e}$ architecture was developed. This architecture is shown in Figure 5.



The physical effects of overpressure, impulse, building collapse, thrown debris, and temperature are summed to calculate the probability of fatality for exposed individuals.

Figure 4: Fatality Mechanisms

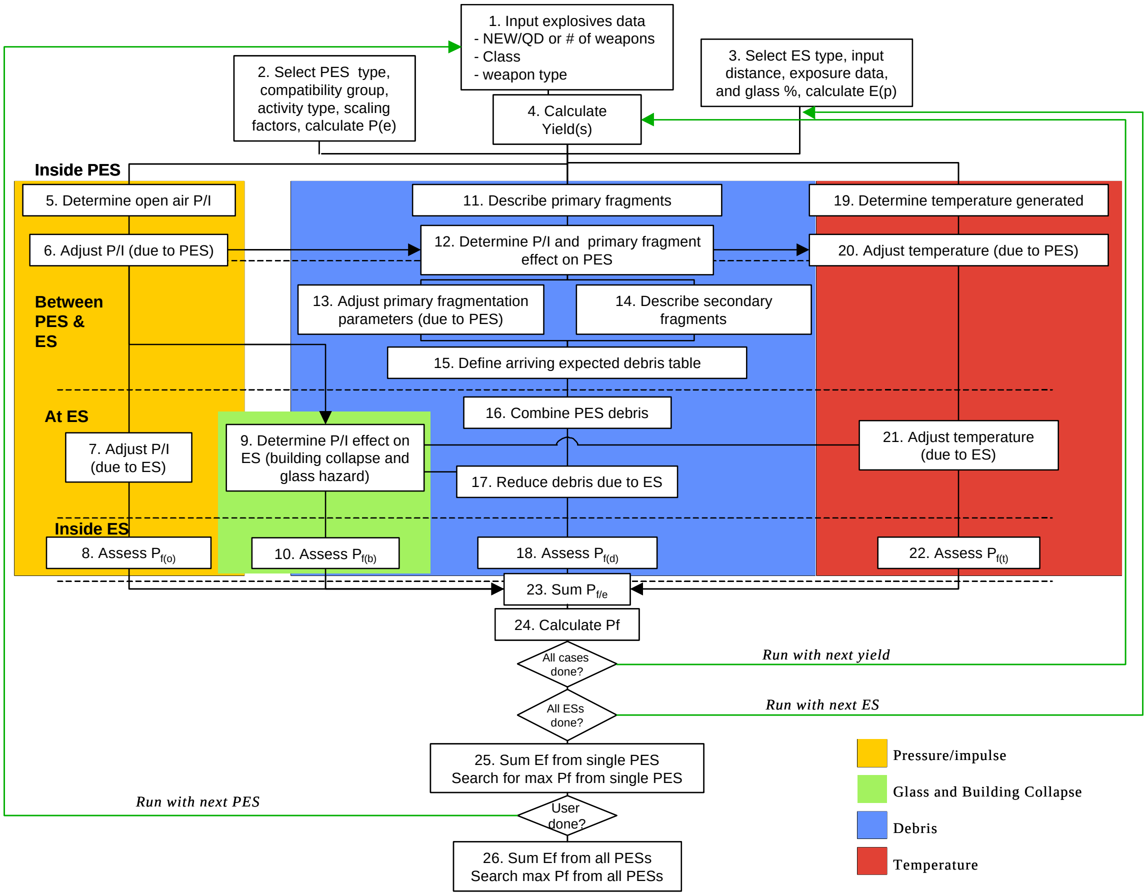


Figure 5: $P_{f/e}$ Architecture for SAFER

The inputs and explanation of the architecture for SAFER follow:

1. Input explosives data.

The user enters the average and maximum weights (Net Explosives Weight Q-D (NEWQD) and selects from a list of explosives classes, and available weapon types or a general description. If the user does not enter all data, default values have been defined. The user has the option of choosing different yields for different Hazard Divisions (a mixture of Hazard Division (HD) 1.1, HD 1.2, and HD 1.3).

Weight:
- Average NEWQD
- Maximum NEWQD

Hazard Division (HD):
- 1.1
- 1.2.1
- 1.2.2
- 1.3

Weapon Types:
- MK 82 (default for 1.1 items)
- M107 (default for 1.2 items)
- Bulk/light case (default for 1.3 items)

General Descriptions:
- Large and thick-skinned (explosive type - tritonal)
- Small and thick-skinned (explosive type - Comp B)
- Thin skinned (explosive type - TNT)

Outputs: weight information, explosive type

2. Select PES type, Compatibility Group, activity type, and scaling factors.

The user will select the PES type from a list of available building types. The options for the types of PES buildings are as follows:
- Open
- Earth-covered magazine
- Above-ground brick structure
- Pre-engineered butler building/hollow clay tile
- Ship
- Hardened aircraft shelter
- Operating building

The options for the type of activity at the PES are:
- Assembly
- Load-Assemble-Packout (LAP)
- Burning Ground
- Demolition
- Lab
- Disassembly
- Maintenance
- Demilitarization
- Disposal
- Test

- Training
- Inspection
- Painting / Packing
- Deep Storage
- In-Transit Storage.
- Loading / Unloading
- Manufacturing
- Renovation
- Temporary Storage

The user will select the compatibility group from a list of available Compatibility Groups. Initially, the list is: L, A, B, G, H, J, F, C, D, and E.

The user will select scaling factors from the list of factors shown below. The "A" factors will increase the P_e *by a factor of 10. The "B" factors will increase the* P_e *by a factor of 3.*

Scaling Factors:

A. Increase P_e by a factor of 10 (two columns to the right in Figure 3) for:
   1. Outside Continental United States (OCONUS) operations in support of wartime actions
   2. Operations involving dangerously unserviceable items awaiting destruction
   3. Initial tests of new systems
   4. Operations occurring in hazardous environments with gases, fibers, etc.
   5. Required remote operations
   6. Temporary Duty (TDY) activities during exercises/contingencies/alerts
   7. Integrated Combat Turn (ICT) operations
   8. Operations involving exposed explosives

B. Increase P_e by a factor of 3 (one column to the right in Figure 3) for:
   1. Outdoor storage/operations normally done indoors
   2. Home station activities during exercises/contingencies/alert
   3. Flightline holding areas
   4. TDY operations during peacetime

Using the activity type, compatibility group, and scaling factors, the probability of event (P_e) will be determined.

Outputs: PES number, P_e

3. Select the ES type, input distance, exposure data, and glass percentage.

The user will select the ES building type and ES roof type from a list of available types.

The options for the type of ES building are:

- Open
- Tilt-up reinforced concrete
- Steel and masonry
- Brick
- Pre-engineered metal building
- Timber
- Reinforced concrete
- Reinforced concrete and masonry
- Reinforced masonry
- Light steel frame
- Large/heavy timber
- Modular/trailers
- Multi-story reinforced concrete offices/apartments
- Multi-story reinforced concrete and masonry
- Multi-story steel frame offices/apartments

- Large pre-engineered metal building

The three ES roof types are:

- Built-up wood panel,
- Steel panel / corrugated metal, and
- 4" reinforced concrete.

Three roof types are available to select from: 4" reinforced concrete (heavy protection), steel panel/corrugated metal (medium protection), and built-up/wood panel (light protection). A default roof type has been defined for each building type. The default roof type for the reinforced concrete ES is a 4" reinforced concrete roof. A built-up / wood panel is the default roof type for the tilt-up reinforced concrete, reinforced concrete and reinforced masonry, steel and masonry, reinforced masonry, brick, large heavy timber, timber, reinforced concrete offices/apartments (multi-story), and reinforced concrete and masonry offices/apartments (multi-story) ES types. A steel panel / corrugated metal roof is the default roof type for the light steel frame, pre-engineered metal building, modular/trailers, steel frame offices/apartments (multi-story), and large pre-engineered metal building (industrial) ES types.

The user will enter the distance between PES and ES, the percentage and type of glass on the ES, and the floor area of the ES. For each ES entered, the user will assign the orientation of the PES to the ES (if distinct orientation information is available). The user will also enter the number of people and hours present at the ES for related, non-related and public persons.

The model will allow the user to select multiple ES types for each PES.

Outputs: ES type(s), distance between PES and ES, percentage of glass on ES, floor area of ES, orientation to PES, and annual exposure.

4. <u>Calculate yields</u>.

Given the explosives data entered in Step 1, the program will calculate NEW values to be used throughout the logic.

<u>For a single class of explosives:</u>

For a single class of explosives the NEW (or “unmodified yield”) will be determined based on the stored conversions of weapon/explosives information shown in Table 1.

Explosive Type	Conversion Factor*
TNT (default)	1.0
H-6	1.35
Tritonal	1.07
Composition B	1.11
ANFO	0.83

*assumes "TNT equivalence" does not vary with distance

Table 1: TNT Conversion Factors

Equivalent NEW = NEW ´ conversion factor
(1)

For mixed explosives:
Up to five cases are defined here, each with an associated equivalent NEW.

When 1.1 and 1.2 are present
- Best Credible Case Detonation
- Average Case Detonation
- Worst Case Detonation

And, if any 1.3 material is present
- Best Credible Case Burning
- Worst Credible Case Burning

The equivalent NEW for a detonation case is used in the overpressure, building collapse, and fragmentation branch of the code. It is assumed that there will be no significant contribution from the thermal branch in a detonation case. Conversely, the equivalent NEW for a burning case is only considered in the thermal branch, as any other effect will have already been considered in an earlier case.

The equivalent NEWs are determined as follows:
W1: Weight of HD 1.1 material
W2: Weight of HD 1.2 material
MCE2: HD 1.2 MCE (MCE2 = 44.7 lbs*)
W3: Weight of HD 1.3 material

* Assumes that a M107 (155mm projectile) is used to model the blast from the HD 1.2 event. The MCE for this item is 14.9 pounds (HE plus propellant). The MCE2 assumes three rounds detonate.

TNT equivalence should be calculated for each NEW before mixing rules are applied.

Equivalent NEW = NEW ´ conversion factor
(2)

Calculate hazard factor (Z), also know as K factor:

$$Z = D / W^{1/3} \qquad (3)$$

Calculate natural log of hazard factor (Z):

$$X = \ln(Z) \qquad (4)$$

For 1.1 material, adjust the weight using the following equations:

For a MK 82 bomb or large thick skinned weapon type, $Y_{1.1}$ is determined as follows:

$(Z > 86) \qquad Y_{1.1} = 275 \times (W / 192)$
$(Z \quad 2.9) \qquad Y_{1.1} = 235 \times (W / 192)$ (5)
$(2.9 < Z \quad 86)$
$Y_{1.1} = (W / 192) \times \exp(4.4477 + (1.2902 \times X) - (0.34374 \times X^2) + (0.025341 \times X^3))$

For a M107 projectile or small thick skinned weapon type, $Y_{1.2}$ is determined as follows:

$(Z > 86) \qquad Y_{1.2} = 12.8 \times (W / 15.1)$
$(Z \quad 2.9) \qquad Y_{1.2} = 42 \times (W / 15.1)$ (6)
$(2.9 < Z \quad 86)$
$Y_{1.2} = (W / 15.1) \times \exp(3.7993 + (0.35294 \times X) - (0.51476 \times X^2) + (0.11606 \times X^3) - (0.0073289 \times X^4))$

For a bulk/light cased weapon, no adjustment is made to the weight (bulk light case 1.1 weight = $Y_{1.3}$).

The adjusted yields for 1.1 materials are summed up as follows:

$Y_1 = Y_{1.1} + Y_{1.2} + Y_{1.3}$ (7)

For 1.2 materials, use the following mixing rules to determine the weights to be adjusted:

W_2 (best) = MCE2 = 44.7 lbs if 1.2.1 material is present, otherwise it is 0
W_2 (average) = $W_{1.2.1} + (0.5 \times W_{1.2.2})$ (8)
W_2 (worst) = $W_{1.2.1} + W_{1.2.2}$

Use the mixed weights above to calculate an adjusted yield for the best, average, and worst case using the following equations:

$(Z > 86) \qquad Y_2 = 12.8 \times (W_2 / 15.1)$
$(Z \quad 2.9) \qquad Y_2 = 42 \times (W_2 / 15.1)$ (9)
$(2.9 < Z \quad 86)$
$Y_2 = (W_2 / 15.1) \times \exp(3.7993 + (0.35294 \times X) - (0.51476 \times X^2) + (0.11606 \times X^3) - (0.0073289 \times X^4))$

For 1.3 materials, the yields are determined as follows:

Y_3 (best) = 0
Y_3 (average) = $0.5 \times W_{1.3}$ (10)
Y_3 (worst) = $W_{1.3}$

Case	Effective Yield
Best Average Worst	$Y_1 + Y_2$ (best) $Y_1 + Y_2$ (average) + Y_3 (average) $Y_1 + Y_2$ (worst) + Y_3 (worst)

Table 2: Detonation Cases

Case	Effective Yield	Treatment
Best Worst	Y_1 or Y_2 (best) or Y_3 (best) $Y_1 + Y_2 + Y_3$	Use the largest of the three

Table 3: Burning Cases

When a mixture of explosives is present Equations 11-18 are not used; the yields calculated in Tables 2 and 3 are used to calculate the pressure and impulse in Equations 19-20.

The model will loop from this Step through Step 23 and present results for each of the five cases for the average and maximum NEWQD.

Output: equivalent NEW (for each case)

5. Determine open air Pressure, Impulse (P, I).

Using a simplified Kingery-Bulmash hemispherical TNT equation[xv] (for a given unmodified yield), unmodified pressure and impulse values (P, I) are generated.

Given:
W = equivalent NEW [lbs] (from Step 4)
D = distance to ES [ft] (from Step 3)

The effective yield, Y, must be defined if the weapon type is not “bulk/light case”. The following definitions are used in the determination of Y:

Calculate hazard factor (Z), also known as K factor:

$$Z = D / W^{1/3} \qquad (11)$$

Calculate natural log of hazard factor (Z):

$$X = \ln(Z) \qquad (12)$$

Calculate effective yield (Y) for various explosives types:

For a MK 82 bomb weapon type or large and thick-skinned weapon, Y is determined as follows:

$$(Z > 86) \qquad Y = 275 \times (W / 192)$$

$(Z \quad 2.9)$ $\qquad Y = 235 \times (W / 192)$ (13)
$(2.9 < Z \quad 86)$
$Y = (W / 192) \times \exp(4.4477 + (1.2902 \times X) - (0.34374 \times X^2) + (0.025341 \times X^3))$

For a M107 projectile weapon type or small and thick-skinned weapon, Y is determined as follows:

$(Z > 86)$ $\qquad Y = 12.8 \times (W / 15.1)$
$(Z \quad 2.9)$ $\qquad Y = 42 \times (W / 15.1)$ (14)
$(2.9 < Z \quad 86)$
$Y = (W / 15.1) \times \exp(3.7993 + (0.35294 \times X) - (0.51476 \times X^2) + (0.11606 \times X^3) - (0.0073289 \times X^4))$

For a bulk/light case weapon type or thin-skinned weapon, Y is determined as follows:

$$Y = W \times 1 \tag{15}$$

Calculate the nominal weight (W_o).

The nominal (or open-air) weight, W_o, can be calculated using the following equations:

$W_o = Y \times (\text{fill factor})/1$ (bulk/light case fill factor = 1)
$W_o = Y \times (\text{fill factor})/1.07$ (MK 82 bomb fill factor = 1.07) (16)
$W_o = Y \times (\text{fill factor})/1.11$ (M107 projectile fill factor = 1.11)

Using this value of W_o, the following definitions are introduced:

Calculate adjusted hazard factor:

$$Z_o = D / W_o^{1/3} \tag{17}$$

Calculate adjusted natural log of hazard factor:

$$X_o = \ln(Z_o) \tag{18}$$

Calculate the open-air values of pressure (P) as follows:

$(0.5 < Z_o \quad 7.25)$
$P = \exp(6.9137 - (1.4398 \times X_o) - (0.2815 \times X_o^2) - (0.1416 \times X_o^3) + (0.0685 \times X_o^4))$
$(7.25 < Z_o \quad 60)$ (19)
$P = \exp(8.8035 - (3.7001 \times X_o) + (0.2709 \times X_o^2) + (0.0733 \times X_o^3) - (0.0127 \times X_o^4))$
$(60 < Z_o \quad 500)$
$P = \exp(5.4233 - (1.4066 \times X_o))$

Calculate the open-air values of impulse (I) as follows:

$$(0.5 < Z_o \quad 2.41)$$
$$I = [\exp(2.975 - (0.466 \times X_o) + (0.963 \times X_o^2) + (0.03 \times X_o^3) - (0.087 \times X_o^4))] \times W_o^{1/3}$$
$$(2.41 < Z_o \quad 6.0) \qquad (20)$$
$$I = [\exp(0.911 + (7.26 \times X_o) - (7.459 \times X_o^2) + (2.960 \times X_o^3) - (0.432 \times X_o^4))] \times W_o^{1/3}$$
$$(6.0 < Z_o \quad 85)$$
$$I = [\exp(3.2484 + (0.1633 \times X_o) - (0.4416 \times X_o^2) + (0.0793 \times X_o^3) - (0.00554 \times X_o^4))] \times W_o^{1/3}$$
$$(85 < Z_o \quad 400)$$
$$I = [\exp(4.7702 - (1.062 \times X_o))] \times W_o^{1/3}$$

The outputs of Step 5 are unmodified pressure and impulse (P, I).

6. <u>Determine adjusted P, I (due to PES)</u>.

Using the adjustment techniques found in the Blast Effects Computer,[xvi] an effective yield is determined. This modified yield will be used to determine the effective pressure and impulse outside of the PES (P’, I’). An adjustment is not made if there is not a PES or if the PES selected is a pre-engineered metal building. Inside structures, the equivalent hemispherical TNT yield (Y) is independent of type of explosives and type of ammunition.

As in Step 5, given:
W = equivalent NEW [lbs] (from Step 4)
D = distance to ES [ft] (from Step 3)
$Z = D / W^{1/3}$ (from Step 5)
$X = \ln(Z)$ (from Step 5)

The adjusted weight, W_a, is determined based on the PES structure type and orientation to the ES.

Earth-Covered Magazine—Front

$$(Z > 67) \qquad W_a = 0.36 \times W$$
$$(Z \quad 2) \qquad W_a = 1.82 \times W \qquad (21)$$
$$(2 < Z \quad 67)$$
$$W_a = W \times \exp[0.87439 - (0.55467 \times X) + (0.33222 \times X^2) - (0.12237 \times X^3) + (0.011663 \times X^4)]$$

Earth-Covered Magazine—Side

$$(Z > 67) \qquad W_a = 0.37 \times W$$
$$(Z \quad 1.5) \qquad W_a = 0.047 \times W \qquad (22)$$

$(1.5 < Z \quad 67)$ $W_a = W \times \exp[-3.4507 + (1.6641 \times X) - (0.13333 \times X^2) + (0.018242 \times X^3)$
$- (0.0121 \times X^4)]$

Earth-Covered Magazine—Rear

$(Z > 55)$ $W_a = 0.22 \times W$
$(Z \quad 1.5)$ $W_a = 0.06 \times W$ (23)
$(1.5 < Z \quad 55)$ $W_a = W \times \exp[-3.0987 + (0.97882 \times X) + (0.064568 \times X^2)$
$- (0.023882 \times X^3) - (0.0071616 \times X^4)]$

Hardened Aircraft Shelter—Front

$(Z > 69)$ $W_a = 0.\ 05 \times W$
$(Z \quad 3.5)$ $W_a = 0.05 \times W$ (24)
$(3.5 < Z \quad 69)$ $W_a = W \times \exp[-84.6398 + (221.07 \times X) - (242.113 \times X^2)$
$+ (137.184 \times X^3) - (42.2745 \times X^4) + (6.73641 \times X^5) - (0.435128 \times X^6)]$

Hardened Aircraft Shelter—Side (W > 1000 pounds)

$(Z > 99)$ $W_a = 0.8 \times W$
$(Z \quad 2.2)$ $W_a = 0.025 \times W$ (25)
$2.2 < Z \quad 99)$ $W_a = W \times \exp[-5.9334 + (3.4736 \times X) - (1.3812 \times X^2)$
$+ (0.70065 \times X^3) - (0.18461 \times X^4) + (0.01622 \times X^5)]$

Hardened Aircraft Shelter—Side (50 < W   1000 pounds)

$W_a = W \times (0.0000512 \times W^{0.90361})$ (26)

Hardened Aircraft Shelter—Rear

$(Z > 40)$ $W_a = 0.05 \times W$
$(Z \quad 2.9)$ $W_a = 0.02 \times W$ (27)
$(2.9 < Z \quad 40)$ $W_a = W \times \exp[-5.515 + (0.55214 \times X) + (1.9611 \times X^2) - (1.2165 \times X^3) +$
$(0.33987 \times X^4) - (0.040239 \times X^5)]$

Above ground brick structure[xvi]

$(Z \leq 2.5)$ $W_a = 0.10 \times W$
$(Z > 60)$ $W_a = 0.43 \times W$ (28)
$(2.5 < Z \quad 60)$ $W_a = W \times \exp[(-3.4004 + (1.00318 \times X) + (0.423786 \times X^2) - (0.12602 \times X^3)]$

Operating building (the operating building is considered to be the same as the above ground brick structure)

$(Z \leq 2.5)$ $W_a = 0.10 \times W$
$(Z > 60)$ $W_a = 0.43 \times W$ (29)
$(2.5 < Z \quad 60)$ $W_a = W \times \exp[(-3.4004 + (1.00318 \times X) + (0.423786 \times X^2) - (0.12602 \times X^3)]$

Ships[xvi]

$(Z \leq 9)$ $W_a = 0.52 \times W$
$(Z > 74)$ $W_a = 0.76 \times W$ (30)
$(9 < Z \quad 74)$ $W_a = W \times \exp[-13.7765 + (20.0853 \times X) - (11.8223 \times X^2) + (3.34422 \times X^3) - (0.458199 \times X^4) + (0.024806 \times X^5)]$

*Underground magazines (*unavailable in current version of SAFER)

Using the newly determined value of W_a the following equations are used as in Step 5:

$Z_a = D / W_a^{1/3}$ (31)

$X_a = \ln(Z_a)$ (32)

Calculate the adjusted pressure value as follows:

$(0.5 < Z_a \quad 7.25)$
$P' = \exp[6.9137 - (1.4398 \times X_a) - (0.2815 \times X_a^2) - (0.1416 \times X_a^3) + (0.0685 \times X_a^4)]$
$(7.25 < Z_a \quad 60)$ (33)
$P' = \exp[8.8035 - (3.7001 \times X_a) + (0.2709 \times X_a^2) + (0.0733 \times X_a^3) - (0.0127 \times X_a^4)]$
$(60 < Z_a \quad 500)$
$P' = \exp(5.4233 - (1.4066 \times X_a))$

Calculate the adjusted impulse value as follows:

$(0.5 < Z_a \quad 2.41)$
$I' = \exp[2.975 - (0.466 \times X_a) + (0.963 \times X_a^2) + (0.03 \times X_a^3) - (0.087 \times X_a^4)] \times W_a^{1/3}$
$(2.41 < Z_a \quad 6.0)$ (34)
$I' = \exp[0.911 + (7.26 \times X_a) - (7.459 \times X_a^2) + (2.960 \times X_a^3) - (0.432 \times X_a^4)] \times W_a^{1/3}$
$(6.0 < Z_a \quad 85)$
$I' = \exp[3.2484 + (0.1633 \times X_a) - (0.4416 \times X_a^2) + (0.0793 \times X_a^3) - (0.00554 \times X_a^4)] \times W_a^{1/3}$
$(85 < Z_a \quad 400)$
$I' = \exp[4.7702 - (1.062 \times X_a)] \times W_a^{1/3}$

The percentage of the PES intact is a function of the yield and PES type. The equivalent NEW (W) determined in Step 4 is the yield to be used. The following function is used to determine the percent damage.

$$D = a \times (Y - Y_0)^b \tag{35}$$

Where:
D = damage (fraction between 0 and 1)
Y = yield
Y_0= minimum yield (assume 1 lb.)
$a = 100/(Y_{100} - Y_0)^b$

Y_{100} = "plateau value" (one for each PES shown below)
b = curvature exponent (one for each PES shown below)

PES	Y_{100}	b
Pre-engineered metal building/hollow clay tile	8	1
Earth-covered magazine	2050	.9
Earth-covered magazine	2050	.9
Hardened aircraft shelter	7300	.9
Hardened aircraft shelter	7300	.9
Above-ground brick structure	1500	.9
Operating building	500	1
Ships	4850	1.1
Underground magazines (unavailable in v 1.0)	NA	NA

Table 4: PES Percent Damage Coefficients

PES	Length	Width	Height
Pre-engineered metal building/hollow clay tile	20	20	10
Earth-covered magazine	80	25	10
Hardened aircraft shelter	120	71	29
Above-ground brick structure	65	65	23.67
Operating building	65	65	23.67
Ships	100	30	50
Underground magazines (unavailable)	NA	NA	NA

Table 5: PES Assumptions

The following assumptions are made:
(1) percent intact = 1- (percent damage)
(2) no blast paneling or other venting/containment measures are considered except where an

Earth Covered Magazine (ECM) and Hardened Aircraft Shelter (HAS) orientation are considered

Outputs: adjusted (by PES) pressure and impulse (P’, I’), adjusted NEW, and % PES intact

7. Reduce adjusted P, I (due to ES).

Using an equation for adjusted P, I (due to the PES), an additional adjustment is made to the modified pressure and impulse due to the ES. The resultant values (P’’, I’’) describe the situation inside the ES. An adjustment is not made if the exposed personnel are in the open.

Calculate: $\Delta P2 = A(Y^{1/3})^{-B}$

ES Type	*DP2*
Reinforced concrete	$770.62(Y^{1/3})^{-0.4488}$
Tilt-up reinforced concrete	$109.2(Y^{1/3})^{-0.4488}$
Reinforced concrete and reinforced masonry	$166.2(Y^{1/3})^{-0.4488}$
Steel and masonry	$166.2(Y^{1/3})^{-0.4488}$
Reinforced masonry	$166.2(Y^{1/3})^{-0.4488}$
Brick	$792.1(Y^{1/3})^{-0.4488}$
Light steel frame	$28.34(Y^{1/3})^{-0.4488}$
Pre-engineered metal building	$108.9(Y^{1/3})^{-0.4488}$
Large/Heavy Timber	$21540(Y^{1/3})^{-1.9587}$
Timber	$21540(Y^{1/3})^{-1.9587}$
Modular/trailers	$28.34(Y^{1/3})^{-0.4488}$
Reinforced concrete offices/apartments (multi-story)	$53410(Y^{1/3})^{-1.4994}$
Reinforced concrete and masonry offices/apartments (multi-story)	$155.9(Y^{1/3})^{-0.4488}$
Steel frame offices/apartments (multi-story)	$18110(Y^{1/3})^{-1.283}$
Large pre-engineered metal building (industrial)	$108.9(Y^{1/3})^{-0.4488}$

(36)

Calculate: $\Delta I2 = C(Y^{1/3})^{1-(0.5964)B}$

ES Type	*DI2*
Reinforced concrete	$53.72(Y^{1/3})^{1-(0.5964)0.4488}$
Tilt-up reinforced concrete	$21.64(Y^{1/3})^{1-(0.5964)0.4488}$
Reinforced concrete and reinforced masonry	$25.98(Y^{1/3})^{1-(0.5964)0.4488}$
Steel and masonry	$25.98(Y^{1/3})^{1-(0.5964)0.4488}$
Reinforced masonry	$25.98(Y^{1/3})^{1-(0.5964)0.4488}$
Brick	$54.60(Y^{1/3})^{1-(0.5964)0.4488}$
Light steel frame	$12.71(Y^{1/3})^{1-(0.5964)0.4488}$
Pre-engineered metal building	$21.61(Y^{1/3})^{1-(0.5964)0.4488}$
Large/Heavy Timber	$1232(Y^{1/3})^{1-(0.5964)1.9587}$
Timber	$1232(Y^{1/3})^{1-(0.5964)1.9587}$
Modular/trailers	$12.71(Y^{1/3})^{1-(0.5964)0.4488}$
Reinforced concrete offices/apartments (multi-story)	$3115(Y^{1/3})^{1-(0.5964)1.4994}$
Reinforced concrete and masonry offices/apartments (multi-story)	$25.32(Y^{1/3})^{1-(0.5964)0.4488}$

(37)

Steel frame offices/apartments (multi-story)	$1027(Y^{1/3})^{1-(0.5964)1.283}$
Large pre-engineered metal building (industrial)	$21.61(Y^{1/3})^{1-(0.5964)0.4488}$

P" is calculated as follows:

$$P'' = P' - \Delta P2 \tag{38}$$

I" is calculated as follows:

$$I'' = I' - \Delta I2 \tag{39}$$

The yield used to determine ΔP2/ΔI2 is the adjusted yield from Step 6. It is therefore initially assumed that the conversion of other explosives types to TNT can be considered constant at the distance associated with the ES.

Outputs: adjusted (by ES) pressure and impulse (P'', I'')

8. Assess $P_{f(o)}$.

The probability of fatality due to the effects of overpressure and impulse ($P_{f(o)}$) can be considered a function of lung rupture or body displacement (or the combination of the two). Using a two-part probit function, the P", I" values determined in Step 7, and a curve-fit equation of the TNO[xvii] probit table, the $P_{f(o)}$ is determined.

To use the probit functions, scaled pressure and impulse must be calculated.

$$P_{sc} = (P'' \times 6.895) / (p_{ambient} \times .001) \tag{40}$$

$$I_{sc} = (I_{incident} \times 6.895 \times .001 \times 0.7673) \tag{41}$$

Where ambient pressure is assumed to be 14.5 psi (1×10^5 Pa) and the mass of an exposed person is 165 lbs (75 kg).

Fatalities due to lung rupture are a function of effective blast wave pressure, impulse, ambient pressure, and the mass of the exposed person.

$$S_{(lr)} = 4.2 / P_{sc} + 1.3 / I_{sc} \tag{42}$$

$$Pr_{(lr)} = 5.0 - (5.74 \times \ln S_{(lr)}) \tag{43}$$

$$P_{f(lung\ rupture)} = (112/\text{ð})\times(\text{ATAN}(1.55\times\text{SIGN}(Pr_{(lr)}-5)\times\text{ABS}(Pr_{(lr)}-5)^{1.32})+(\text{ð}/2))-6 \tag{44}$$

Fatalities due to body displacement are calculated similarly:

$$S_{(bd)} = 7380 / P'' + 1.3\times10^9 / (P'' \times I'') \tag{45}$$

$$Pr_{(bd)} = 5.0 - (2.44 \times \ln S_{(bd)}) \tag{46}$$

$$P_{f(body\ displacement)} = (112/\eth)\times(\text{ATAN}(1.55\times\text{SIGN}(\text{Pr}_{(bd)}-5)\times\text{ABS}(\text{Pr}_{(bd)}-5)^{1.32})+(\eth/2))-6 \qquad (47)$$

The two resultant values are independently summed as follows:

$$P_{f(o)} = 1- [1-P_{f(lung\ rupture)}] \times [1-P_{f(body\ displacement)}] \qquad (48)$$

Outputs: $P_{f(o)}$

9. <u>Determine adjusted P, I effect on ES (building collapse and glass hazard)</u>.

The probability of fatality due to P, I on an ES is broken into two parts: contributions due to 1) structural damage and 2) window breakage.[xviii] The probability of fatality due to window breakage, $P_{f(g)}$, is calculated based on user inputs for the average window size (none, unknown, small, medium or large), percent of glass on walls and the floor area of the building as follows:

- Determine $P_{f(g)}$ for the adjusted P, I (P',I' in Step 6) for the selected window size based on nominal glass P, I models
- Scale the nominal $P_{f(g)}$ for the percent of glass input by user. First, the building's Glass Area to Floor Area Ratio (GAR_{bldg}) is estimated:

$$\text{GAR}_{\text{bldg}} = (\%\ \text{glass}) \text{ x } [36/(\text{floor area})^{1/2}] \qquad (49)$$

- Then the nominal $P_{f(g)}$ is scaled for the building's GAR:

$$P_{f(g)} = P_{f(g)} \times [\text{GAR}_{\text{bldg}} / \text{GAR}_{\text{model}}] \qquad (50)$$

Note: If the user selects window size as none, $P_{f(g)} = 0$. If the user selects unknown, the window size is automatically assigned to the "small" window type, and the nominal amount of glass is assumed.

The probability of fatality due to structural damage, $P_{f(bc)}$, is calculated for the adjusted P, I (P', I' in Step 6) for the building type selected based on P, I models for generic buildings.

Three building types (pre-engineered metal building, lightly reinforced concrete building, and reinforced concrete building) have been analyzed to determine $P_{f/e}$ due to building collapse. The remaining ES building types have been defaulted to one of these three to determine the $P_{f/e}$ due to building collapse. The light steel frame, pre-engineered metal building, large/heavy timber, and modular/trailers ES types have been defaulted to the low strength default (pre-engineered metal building). The tilt-up reinforced concrete, steel and masonry, reinforced masonry, brick, steel frame offices/apartments (multi-story), and large pre-engineered metal building (industrial) ES types have been defaulted to the medium strength default (lightly reinforced concrete building). The reinforced concrete, reinforced concrete and reinforced masonry, reinforced concrete offices/apartments (multi-story), and reinforced concrete and masonry offices/apartments (multi-story) ES types have been defaulted to the high strength building (reinforced concrete building).

The percentage of the ES remaining intact is determined for the adjusted P, I (P', I' in Step 6) using stored P, I representations for each building type.

Outputs: $P_{f(g)}$, $P_{f(bc)}$, % ES Intact

10. Assess $P_{f(b)}$.

The contributions to fatality due to glass breakage and building damage ($P_{f(b)}$)calculated in Step 9 are combined (assuming independence) to determine the overall ES probability of fatality:

$$P_{f(b)} = P_{f(g)} + [(1 - P_{f(g)}) \times P_{f(bc)}] \tag{51}$$

Outputs: $P_{f(b)}$

11. Describe primary fragments.

The primary fragments for the "explosive event" are determined as follows. Using stored values for the stacking geometry (to obtain the number of weapons on the outer surface of the stack), maximum throw distance and fragment distribution (divided into kinetic energy [KE] "bins") for each weapon type, the event KE bin table is created. This identifies the quantity of fragments in each KE bin before encountering the PES. An assumption is made that 50% of the fragments created by weapons on the outer surface are directed outward and have a dangerous trajectory that will contribute to the fragment hazard.

Weapon Type	Max. Throw Range	Ave. NEW per weapon	Fragments Resulting from One Single Item									
			Bin #s									
			1	2	3	4	5	6	7	8	9	10
MK82	3600	192	0	0	0	0	7	49	226	746	1227	1738
M107	2560	15.1	0	0	0	0	0	4	34	165	372	667
Bulk/light case	2000	1	0	0	0	0	0	0	0	1	5	10

Table 6: Primary Fragment Distribution by KE Bins

The number of weapons (N_w) are calculated as follows:

$$N_w = \text{NEW} / \text{average NEW of one weapon} \tag{52}$$

To determine the percentage of weapons on the outer surface of the stack (N_{pos}) the following equation is used (initial analytical solution):

$$N_{pos} = 1.007 \times (N_w)^{-0.3564} \tag{53}$$

The number of weapons on the outer surface (N_{wos}) can then be calculated using the following equation:

$$N_{wos} = N_w \times N_{pos} \tag{54}$$

The number of primary fragments (N_{pf}) in the air is calculated as follows:

$$N_{pf} = \text{Number of fragments per weapon (Bin 1-10)} \times N_{wos} \times 0.5 \tag{55}$$

Note: The above method is for an initial analytical solution. For ranges, yields, and PES types covered by existing methods and/or empirical data, this analytical process may be superceded.

Examples of other available methods:
(1) Open PES - FRAGHAZ[xix] model
(2) ECM PES - Scale from empirical data[xx]
(3) Operating Building - DISPRE[xxi] (NEW < 5k)

This replacement of the initial analytical solution method applies through Step 15.

Outputs: calculated primary fragment table

12. <u>Calculate PES debris containment (post P, I)</u>.
PES fragment blockage is calculated as the product of %PES damaged and a PES fragment blocking (FB) value. The blocking factor is associated with the ability of the PES walls to contain individual debris pieces. A factor will be added to account for debris that flies through walls while the building remains intact.

For the initial algorithm, the PES fragment blocking (FB) values are all assumed to be 0.8 (80% of all primary fragments are blocked). Later, each PES types will have a stored fragment blocking value.

Note: The above method is for an initial analytical solution. For ranges, yields, and PES types covered by existing methods and/or empirical data, this analytical process would be superceded.

Outputs: adjusted FB

13. <u>Reduce number of primary fragments (due to PES)</u>.
The number of primary fragments not contained within the PES is calculated in Step 13 (N'_{pf}). The number determined in Step 12 is used to reduce the quantities of fragments in each of the primary fragment KE bins.

$$N'_{pf(bin\ n)} = N_{pf(bin\ n)} \times [1 - FB_{pf(bin\ n)}] \qquad \text{for bins 1-10} \tag{56}$$

NOTE: The above method is for an initial analytical solution. For ranges, yields, and PES types covered by existing methods and/or empirical data, this analytical process would be superceded.

Outputs: Adjusted primary fragment table

14. <u>Describe secondary fragments</u>.
To determine a secondary fragment KE bin table in the same format as the table for primary fragments, Table 7 is referenced which provides the total mass and the mass distribution (%) for

each PES type.

		Bin # (Average Fragment Mass, lbs)									
PES #	Mass of PES (lbs)	1 (75.4)	2 (31.5)	3 (13.4)	4 (5.61)	5 (2.38)	6 (1)	7 (0.42)	8 (0.18)	9 (0.08)	10 (0.03)
PEMB	12,096	0	0	5	5	5	10	15	10	5	5
ECM (F)	600,000	5	5	5	5	7.5	7.5	7.5	7.5	10	10
ECM (S/R)	500,000	5	5	5	5	7.5	7.5	7.5	7.5	10	10
HAS (F)	100,000	5	5	5	5	7.5	7.5	7.5	7.5	10	10
HAS (S/R)	200,000	5	5	5	5	7.5	7.5	7.5	7.5	10	10
Brick	150,000	0	5	5	10	40	5	5	5	5	5
Ops Bldg.	150,000	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Ship	1,800,000	5	5	5	5	5	5	5	5	5	5

Table 7: Percent of PES Mass Thrown

The mass of the PES thrown is adjusted by comparing the yield (from Step 4) to an initial breakout value and a total destruction value (shown in Table 8). If the yield is less than the initial breakout value, no PES mass is thrown; if the yield is greater than the total destruction value, all of the PES mass is thrown; and if the yield is between the two values, then the mass of the PES thrown = mass of PES × (1/(total destruction value-initial breakout value) × yield).

PES	Initial Breakout Value (lbs)	Total Destruction Value (lbs)	V (ft^3)		W/V cutoff ratio	Maximum Throw Equation (ft)	Post-equation value (ft)
PEMB	1	8			--		--
ECM (F)	50	500	20,000		0.29	$21660x(w/v)^{1.71}$	5100
ECM (S/R)	1000	10000	20,000		3.8	$1387x(w/v)^{0.71}$	3600
HAS (F)	40	1000	192,000	0.005	0.08	$5005x(w/v)^{0.235}$	3000
HAS (S/R)	1000	2000	192,000	0.005	0.08	$5005x(w/v)^{0.235}$	3000
Brick	20	70	100,000		0.33	$70130x(w/v)^{0.83}$	3600
Ops Bldg.	5	15	100,000		0.33	$70130x(w/v)^{0.83}$	3600
Ship	500	5000			--	4400	4400

Table 8: Primary Fragment Maximum Throw Range

The maximum throw distance of secondary fragments is determined using a weight/volume (W/V) cutoff ratio and post-equation value with the maximum throw equation. The actual W/V ratio is calculated and compared to the W/V cutoff ratio; if the calculated W/V is less than the ratio, the maximum range equation is used to determine maximum throw distance. If the W/V is greater than the ratio, the post-equation value is used for the maximum throw distance.

The number of secondary fragments (N_{sf}) is the product of the original mass of the PES, the percentage of the PES damaged (from Step 6), and the % of mass thrown (by KE bin) divided by the average mass for each KE bin.

$$N_{sf} = [\text{\% PES Damage (Step 6)} \times \text{Mass of PES (Table 14.1)} \times \text{\% each bin}] / (\text{average fragment mass each bin}) \tag{57}$$

Note: The above method is for an initial analytical solution. For ranges, yields, and PES types covered by existing methods and/or empirical data, this analytical process may be superceded.

Outputs: calculated secondary fragment table

15. Define expected arriving debris table.

The debris probability density (P_i) at the ES is determined for both primary and secondary fragments using the maximum throw distance and a bivariant normal distribution. It is recognized that the density may change depending on the type of fragment. This assumes that the largest ES dimension is small compared to the distance (D) between the PES and the ES.

$$P_i = [1 / (2 \times \pi \times \sigma^2)] \times \exp[-D^2 / (2 \times \sigma^2)] \tag{58}$$

where

$$s = \text{maximum throw} / 3 \quad \text{(for primary fragments and secondary fragments)} \tag{59}$$

Maximum throw of primary fragments is given in Step 11. Maximum throw for secondary fragments is calculated in Step 14.

Given the above probability density at the ES, the number of arriving fragments (N_{af}) can be determined as follows:

$$N_{af} = P_i \times \text{(area of the ES)} \times \text{(\# of departing fragments per bin)} \tag{60}$$

It should be noted that mathematically, the area of the ES (used here and in Step 18) is irrelevant because it will “cancel itself out," so it is assumed to be one. The expected number of primary fragments (N_{paf}) and expected number of secondary fragments (N_{saf}) are calculated as follows:

$$N_{paf(\text{bin } n)} = P_i \times N'_{pf(\text{bin } n)} \qquad \text{for bins 1-10} \tag{61}$$

$$N_{saf(\text{bin } n)} = P_i \times N_{sf(\text{bin } n)} \qquad \text{for bins 1-10} \tag{62}$$

Outputs: arriving fragment table

16. Combine PES debris.

The arriving primary and secondary fragments (N_{paf} and N_{saf}) are summed to determine the total quantity of fragments in the air (N_{cf}). The total quantity of fragments forms a combined debris table, based on the assumption that the properties for the primary and secondary fragments are similar.

$$N_{cf(\text{bin } n)} = N_{paf(\text{bin } n)} + N_{saf(\text{bin } n)} \qquad \text{for bins 1-10} \tag{63}$$

Outputs: combined (primary and secondary) arriving fragment table

17. Reduce debris due to ES.
For each of the three roof types, a "percentage invulnerable area" is looked up from a stored table. The invulnerable area is assumed to totally block arriving fragments from any and all KE bins. The invulnerable area will vary proportionally to the percentage of the ES that is intact.

The primary and secondary fragments "punch through" the roof of the ES, but their kinetic energy is reduced according to amount of kinetic energy that is absorbed by the roof of the ES. The amount of KE absorbed by each roof type is looked up from a stored table. The kinetic energy of the fragments will be reduced when the roof of the ES is encountered. This will cause the fragments to shift to a lower KE bin. To determine if fragments shift to another bin, the kinetic energy absorbed by the roof is subtracted from the average kinetic energy of each bin. If the result is less than zero, the roof stopped the fragments from penetrating; if the result is greater than the lower limit on the bin, the fragments remain in the current bin; if the result is less than the lower limit on the bin, the fragments are shifted to the bin below.

ES Roof Types	% Invulnerable area	KE absorbed by roof (ft-lbs)
4" Reinforced Concrete	10	10,000
Steel Panel / Corrugated Metal	10	1,000
Built-Up / Wood Panelized	15	500

Table 9: KE Absorbed by Roof

Once this adjustment is made, a new fragment table is created which describes the penetrating fragments (quantity per KE bin).

Outputs: calculated penetrating fragment table

18. Assess $P_{f(d)}$.
The probability of fatality due to fragmentation is determined using the calculated penetrating fragment description, the ratio of "vulnerable" area of an exposed human to the area of the ES, and the probability of lethality given a fragment "hit." The "vulnerable" area of the exposed human is assumed to be 4.5 ft^2 (the total area for an exposed human being is 6 ft^2). The lethality value is read from a lethality curve[xii] given in Figure 6 and is a function of the calculated KE.

For a given arriving fragment, the probability of fatality (P_f) is expressed as

$$P_f = (4.5\ \text{ft}^2 / \text{area of ES}) \times (\text{lethality curve value}) \tag{64}$$

The equation to generate the probability of fatality due to debris ($P_{f(d)}$) from all fragments in all KE bins is:

$$P_{f(d)} = (4.5\ \text{ft}^2/\text{area of ES}) \times \sum_{\text{KE bin} = 1}^{\text{KE bin} = 10} (\text{number fragments per bin}) \times (\text{lethality curve value}) \tag{65}$$

This value represents the probability a person has of being struck and killed by an incoming fragment.

It should be noted that mathematically, the area of the ES (used here and in Step 15) is irrelevant because it will "cancel itself out." It is presented here for clarity, but will not be required as a user input or stored value.

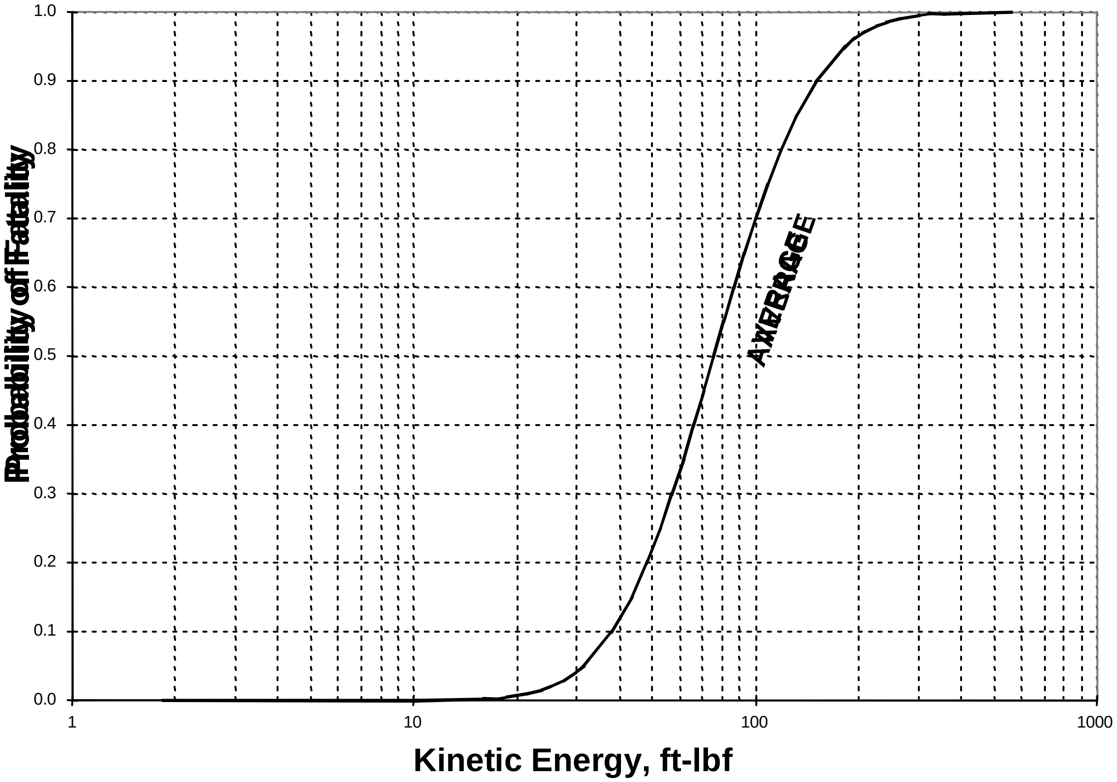


Figure 6: $P_{f/e}$ vs. KE

Outputs: $P_{f(d)}$

19. <u>Determine temperature generated</u>.

The fireball temperature, radius, and duration are determined as a function of NEW and weapon type. The fireball temperature, T_{fb}, is dependent only on explosives type, so the values are stored as follows:

Explosive Types	R
TNT	6030
H6*	6030
Composition B*	6030
ANFO*	6030

*assumes temperatures are equal to TNT for SAFER Version 1.0

Table 10: Fireball Temperature based on Explosives Type

The stored temperatures are based on TNT equivalence values published by Meyer.[xxii]

The fireball radius, r_{fb}, is determined as follows:

$$r_{fb} = A \times (0.272) \times (NEW)^{0.40} \tag{66}$$

where A is a coefficient associated with the weapon type and is assumed to be 1.0 for SAFER Version 1.0.

The duration of the fireball, Δt_{fb}, is calculated in a similar manner.

$$\Delta t_{fb} = B \times (7.04 \times 10^{-5}) \times (NEW)^{0.44} \tag{67}$$

where B is another coefficient associated with the weapon type and is assumed to be 1.0 for SAFER Version 1.0.

The methods for determining radius and duration are based on published material by Glasstone.[xxiii]

The information determined here will be used to calculate the thermal radiation that an exposed person receives in Step 21 and the duration of the exposure, which is considered in Step 22.

Outputs: T_{fb} *(R),* r_{fb} *(ft),* Dt_{fb} *(s)*

20. <u>Adjust temperature (due to PES)</u>.

The effect of the resultant PES on the temperature is considered here. The damage to the PES (X_{PES}) is obtained from Step 6 and reduced, if desired, by Step 12 (fragmentation effects).

$$X_{PES} = F \times (X_{PES}) \tag{68}$$

where F is a fragmentation reduction factor, which is assumed to be 1.0 for SAFER Version 1.0.

The current method does not create a "separate answer" at this point, because the method is dependent on the location of the human. Such a separate answer is not required for the solution. The adjustment will be considered as part of the equation in Step 21.

Outputs: X_{PES}

21. <u>Adjust temperature (due to ES)</u>.

The equilibrium temperature for an exposed person is calculated based on the fireball information. This temperature is referred to as the thermal radiation term, T_{tr}. A simplified solution is available if the exposed person is actually inside the fireball (whether protected by the ES or not).

The effect of the ES is introduced using resultant ES information generated earlier in Step 9.

The damage to the ES (X_{ES}) is obtained from Step 9 and reduced if desired by Step 17 (fragmentation effects).

$$X_{ES} = F \times (X_{ES}) \qquad (69)$$

where F is a fragmentation reduction factor, which is assumed to be 1.0 for SAFER Version 1.0.

For persons at distances greater than the fireball radius, T_{tr} is defined as:

$$T_{tr} = T_{fb} \times [\varepsilon_{fb} \times (r_{fb}^2/D^2) \times (e^{(-K(D- rfb))}) \times (X_{PES}) \times (X_{ES})]^{1/4} \qquad (70)$$

where:
ε_{fb} = emissivity of the fireball (0.2) (initial assumption)
D = entered distance from PES to ES
K = atmospheric adjustment (1×10^{-5} per foot) (initial assumption)

For persons at distances less than the fireball radius, T_{tr} is defined

$$T_{tr} = T_{fb} \times [\varepsilon_{fb} \times (X_{PES}) \times (X_{ES})]^{1/4} \qquad (71)$$

These relationships are derived from Glasstone's work.[xxiii]

Outputs: T_{tr} (R)

22. Assess $P_{f(t)}$.

$P_{f(t)}$, the probability of fatality due to thermal effects, is read from a curve family as a function of the fireball duration (Δt_{fb}) and thermal radiation temperature (T_{tr}, F). These curves are adapted from previous research.[xxiv]

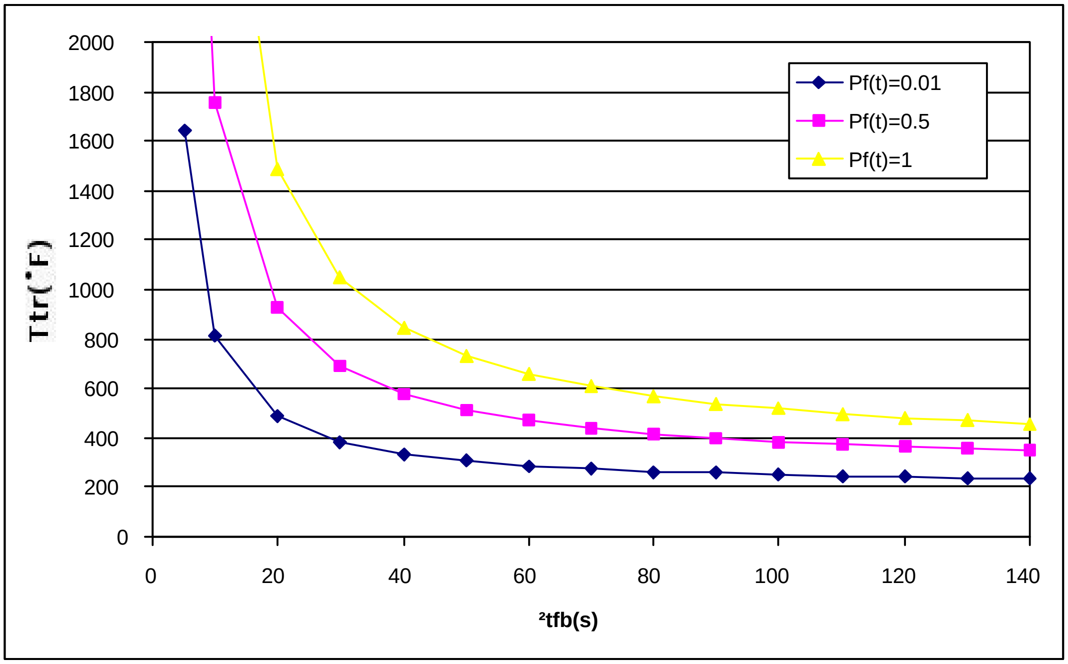


Figure 7: Fireball Duration vs. Thermal Radiation Temperature

The thermal radiation temperature is converted from Rankine (R) to Fahrenheit (F) using the following equation:

$$T(F) = T(R) \quad - 460 \tag{72}$$

Outputs: $P_{f(t)}$

23. <u>Sum $P_{f/e}$</u>.

The four fatality mechanisms, $P_{f(o)}$, $P_{f(b)}$, $P_{f(d)}$, $P_{f(t)}$, are summed independently to obtain the overall probability of fatality given an event, $P_{f/e}$. Results are stored for each applicable case, as defined in Step 4.

$$P_{f/e} \;=\; P_{f(o)} \;+[(1-P_{f(o)})\times P_{f(b)}] \;+[(1-P_{f(o)})\times(1-P_{f(b)})\times P_{f(d)}] \;+[(1-P_{f(o)})\times(1-P_{f(b)})\times(1-P_{f(d)})\times P_{f(t)}]$$
(73)

Outputs: $P_{f/e}$

24. <u>Calculate E_f for one ES-PES pair</u>.

The expected fatalities are calculated with each $P_{f/e}$ from Step 23, P_e from Step 2, and E_p from Step 3, using the following equation:

$$E_{f(ES)} = P_e \times P_{f/e} \times E_p \tag{74}$$

25. <u>Sum E_f values from a single PES</u>.

The expected fatalities from a single PES are calculated using the following equation:

$$E_{f(PES)} = \sum_{1}^{n} E_{f(ES)} \qquad \text{where n is the number of ES's.} \qquad (75)$$

Outputs: E_f for a single PES, maximum P_f from a single PES

26. Sum E_f values from all PES's (not available in SAFER Version 1.0).

The expected fatalities from all PES's are calculated using the following equation:

$$E_{f(site)} = \sum_{1}^{n} E_{f(PES)} \qquad \text{where n is the number of PES's.} \qquad (76)$$

Outputs: E_f for all PESs, maximum P_f from all PESs

Note: Methods that are not referenced in this section were developed by the RBESC Team.

2.3 Exposure Analysis

Personnel exposure is determined on an expected value basis to assess the average personnel exposure to an explosives event. Exposure is calculated by multiplying the number of people by the percentage of time they are at the site during the year. The exposure is determined for each exposed site (ES) where people are present. It is recognized that one PES may threaten several groups of people at different distances (exposed sites) and conversely, a group of people at a particular ES may be at risk from several PES's.

3.0 Assessing Overall Risk

The goal of criteria selection is to establish a standard which will have broad-based understanding, a strong legal precedent, and support within the technical community. A combination of information from regulations, historical precedence, and risk statistics were used to define each criterion chosen. The aim was to achieve a broad consensus of support for the criteria, recognizing that universal acceptance would not be initially possible. Figure 8 shows the different rationales that can be used to support criteria selection. As the number of rationales used to support a criterion increases, the level of acceptance also increases.

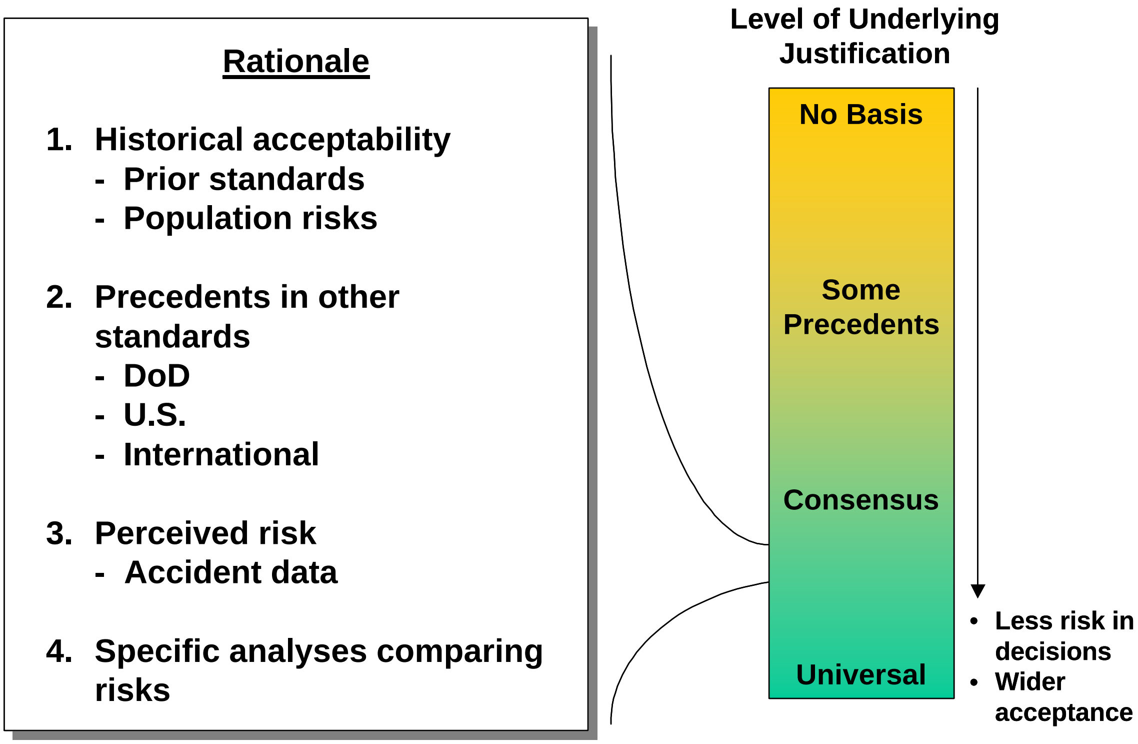


Figure 8: Basis of Criteria

3.1 Risk Measures

Risk measures define who or what is at risk, the consequences of the risk, and the time period of the risk. As shown in Figure 1 (Section 1.4), numerous measures were considered. Each measure has merit and would serve in varying degrees to achieve the desired purpose of assessing safety. The four measures that were selected are as follows:

(1) The expected fatalities (E_f) resulting from an explosive event at the potential explosion site (PES) on an annual basis assuming the annual average amount of explosive is present,
(2) Maximum expected fatalities, which are the same as (1) assuming that the explosive quantity present is at approved upper limit for the site,
(3) Individual probability of fatality (P_f), which is the annual probability of fatality for any

individual in the area surrounding the PES, assuming that the annual average quantity of explosive is present, and

(4) Peak individual probability of fatality, which is the same as (3) assuming that the explosive quantity present at the PES is at the approved upper limit for the site.

Each measure focuses protection on a different set of persons or conditions. By using a combination of these four measures, the decision maker has a broader understanding of the risks. These measures are applied to three categories of personnel: those whose jobs relate to the potential explosion site (related), persons who are exposed by virtue of employment (non-related), and all others not included in the previous definitions (public).

For initial implementation, the risk analysis should use the proposed explosives limit for the facility unless the annual average quantity of explosives is known. Also, initially the acceptable risk levels for non-related persons is established at the acceptable limit for the public.

3.2 Acceptance Criteria

The criteria shown in Figure 9 are for use as a supplement to the practice of applying quantity-distance (Q-D) measurements to determine explosives safety hazards. Nations participating in a North Atlantic Treaty Organization (NATO) AC/258 Risk Analysis Working Group (RAWG) are considering similar risk-based approaches.

Risk to:	**Draft Criteria**
Any 1 worker (Annual P_f)	• Limit maximum risk to 1 x 10^{-4}
All workers (Annual E_f)	• Limit maximum risk to 1 x 10^{-3}
Any 1 person (Annual P_f)	• Limit maximum risk to 1 x 10^{-6}
All public (Annual E_f)	• Limit maximum risk to 1 x 10^{-5}

Figure 9: Acceptance Criteria

3.3 Universal Risk Scale (URS)

Data were gathered relating to risk from a variety of sources. These data needed to be accumulated in a common format. This need led to the development of the Universal Risk Scales (URS).

The scales are used for comparison of relevant data to assist policy makers in selecting appropriate risk related criteria. Scales for each of the four criteria shown in Figure 9 have been developed.

The format chosen is important because it needs to 1) educate the reader as to the differences between the linear and logarithmic scale and 2) display a wide variety of data. This format allows the aggregate weight of the individual data points to be viewed at the same time.

The center bar of the URS is the scale. The logarithmic format was specifically selected to highlight the huge differences in the amount of risk that exist in a very small numerical space. The difference between zero and one on a linear scale is small; in fact, most people think of it in terms of the linear measure of percent. The linear paradigm, however, does not adequately support the understanding and selection of risk criteria. Instead, risk should be reviewed as orders of magnitude in order to achieve a proper perspective on relative risks.

The format shown in Figure 10 attempts to achieve that by allowing space for two types of precedents. On the right side is the actual accident experience (not necessarily acceptable). On the left side, governance precedents which regulate similar risks are shown in the same units of measure.

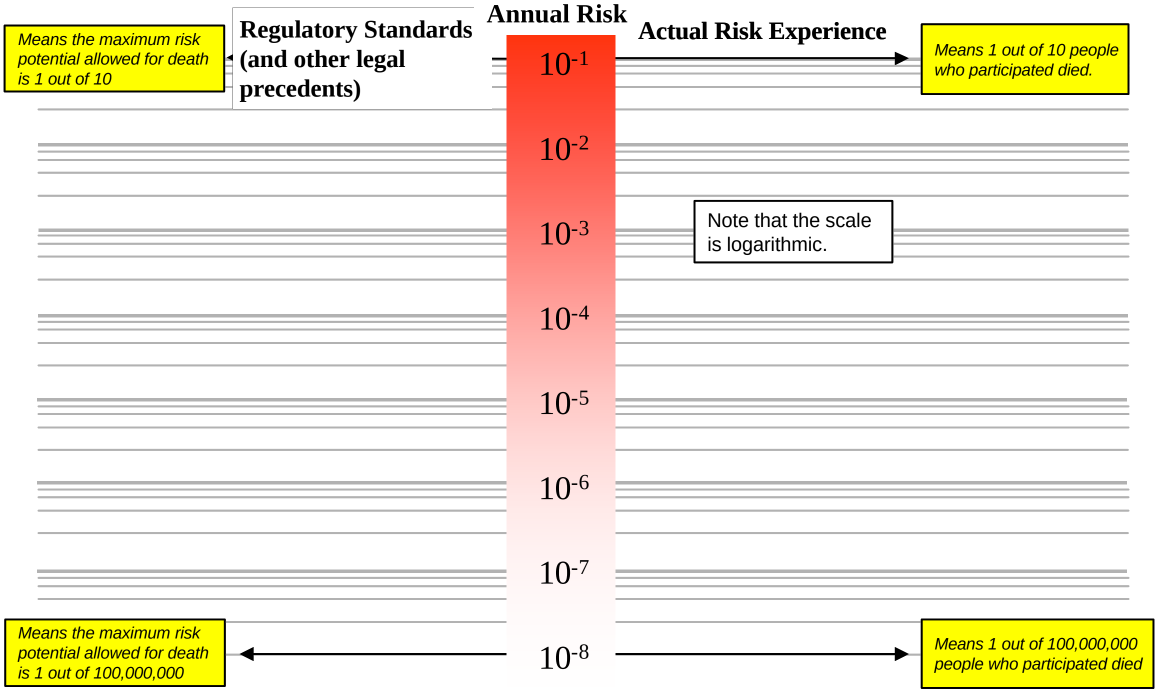


Figure 10: URS Format

3.4 Criteria Basis

This section describes the data supporting the selection of the four criteria. In the figures which follow, all data are shown in terms of annual risk. Each figure contains a star indicating the level of risk associated with the acceptance criteria developed. The surrounding data points are the product of research for relevant supporting data. Appendix A contains the sources referenced in the Universal Risk Scales.

3.4.1 Risk to Any One Worker

The scale supporting the protection criterion for any one worker is shown in Figure 11. This scale is labeled voluntary P_f because the risk associated with the action is accepted as a voluntary action taken by an individual. For example, when a person accepts a job with known risks it is "voluntary." Figure 11 plots the data on a URS. Supporting data are contained in Appendix B.

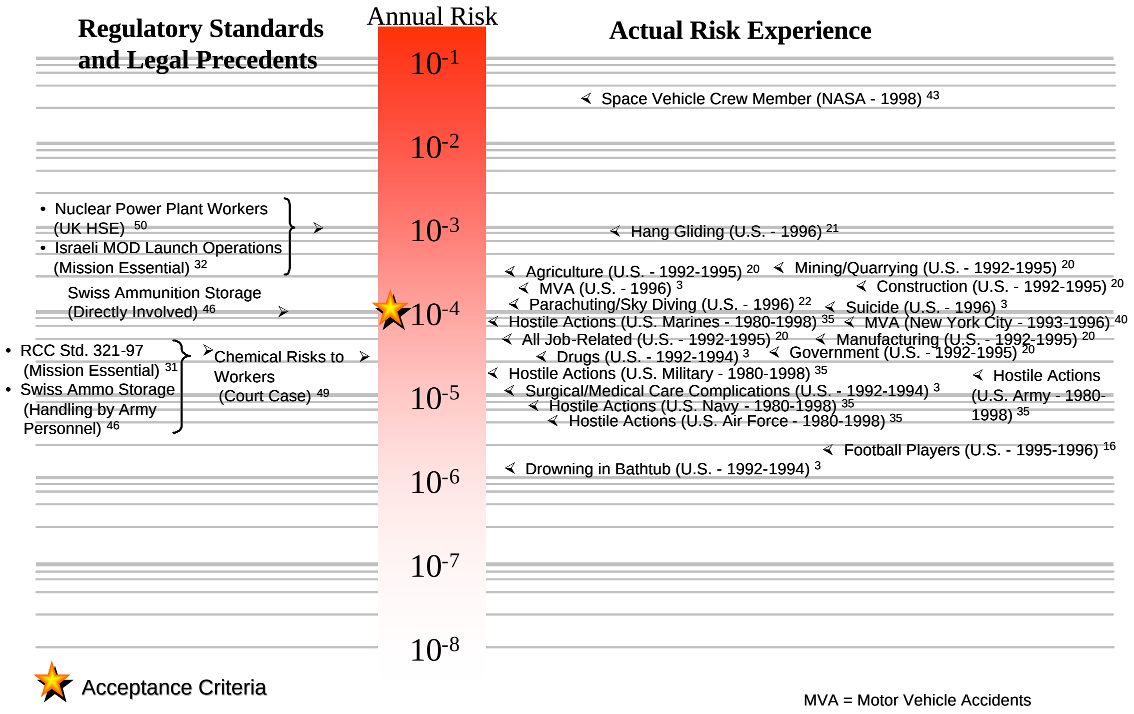


Figure 11: Voluntary Probability of Fatality

3.4.2 Risk to Any One Person

The scale supporting the protection criterion for any one person is shown in Figure 12. This scale is labeled involuntary P_f because the risk associated with the action is not accepted as a voluntary action taken by an individual. For example, victims of homicide, stroke or tornado generally do not die as the result of a voluntary decision to accept risk. These are "involuntary" actions. Figure 12 plots the data on a URS. Supporting data are contained in Appendix C.

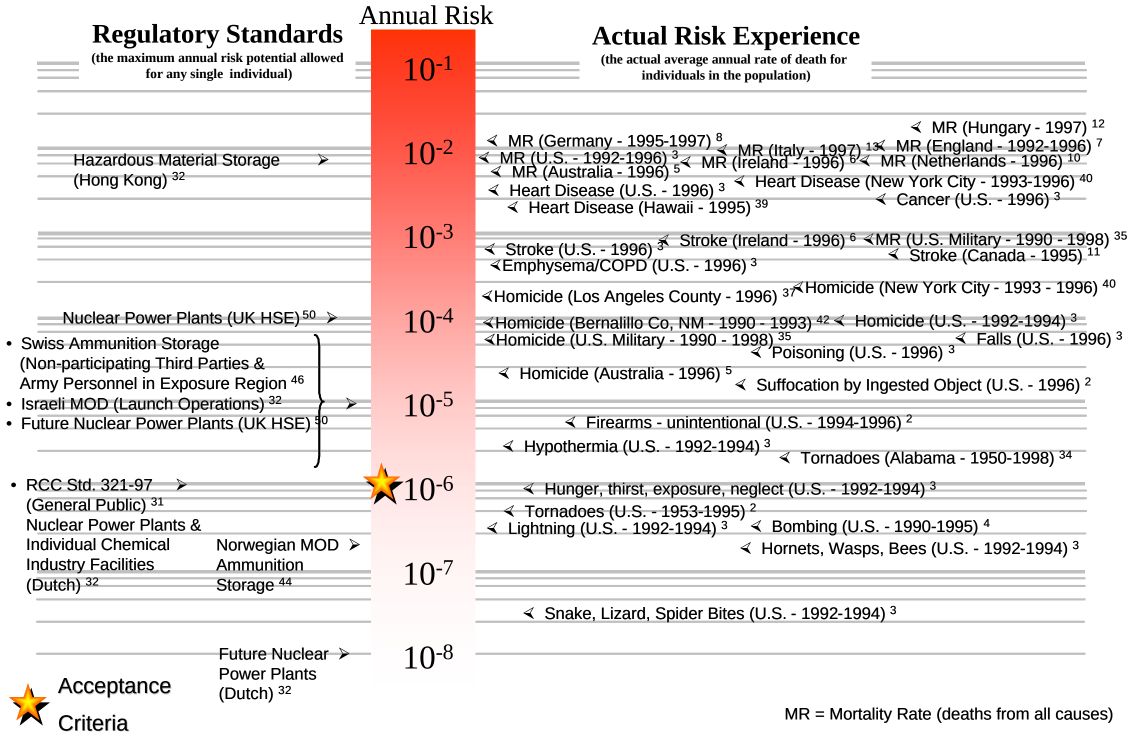


Figure 12: Involuntary Probability of Fatality

Note that mortality rates include all modes of fatality for the population reported. However, a mortality rate less than 1.00E-02 does not indicate that the people in that population live longer than 100 years. These numbers are affected by other statistics, including additions to the population through childbirth and increases or losses in population size due to immigration. With the exception of the mortality rate for the U.S. Military, each of the mortality rates includes and reflects the same elements in its derivation. (The U.S. Military mortality rate is not affected by childbirth and the average age and fitness level of the population is not comparable to the statistics for entire nations.) In other words, with the exception of the U.S. Military, this is a comparison of apples to apples. Relative to each other, these numbers are significant since they are a general indication of how probabilities of fatality are influenced by national and geographic factors. Mortality rates include fatalities from both involuntary and voluntary actions.

3.4.3 Risk to All Workers (Collective Risk)

The scale supporting the protection criterion for all workers is shown in Figure 13. The intent of these criteria is to provide aggregate protection for workers at a specific post, camp, or station or other explosives site. This scale is labeled voluntary E_f because the risk associated with the action is accepted as a voluntary action taken by an individual. For example, when a person accepts a job with known risks it is "voluntary." Figure 13 plots the data on a URS. Supporting data is contained in Appendix D.

Note that included on the scale, in bold italics, are statistics that have been normalized to a population of 1000 people to better illustrate their relevance to the regulatory standards. The implication of this normalization is that a typical post, camp, or station may have 1000 workers in the exposed population.

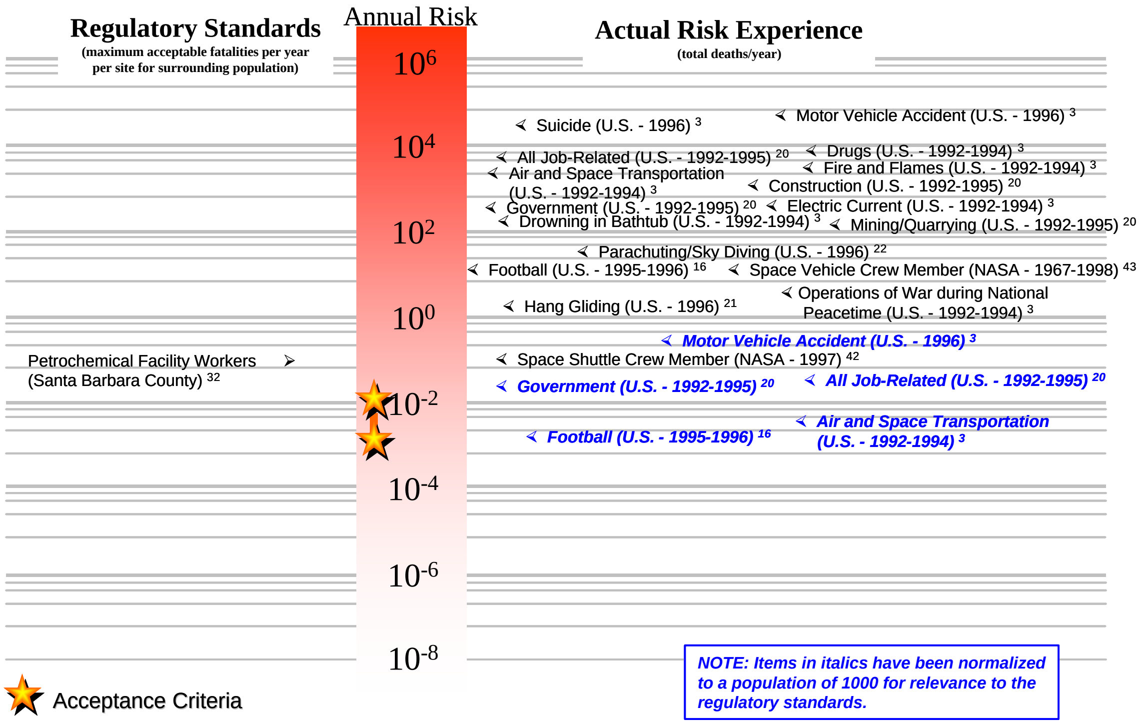


Figure 13: Voluntary Expected Fatalities

Note: The area between the two stars in Figure 13 is known as the “as low as reasonably practical” (ALARP) region. If risks are within the ALARP region, then the Service can prepare a waiver/exemption based on SAFER analysis. If risks are higher than the ALARP region, then the Service must determine if there are strategic or compelling reasons to justify the approval of a waiver/exemption.

3.4.4 Risk to All People (Public Collective Risk)

The scale supporting the protection criterion for all people is shown in Figure 14. This scale is labeled involuntary E_f because the risk associated with the action is not accepted as a voluntary action taken by the individuals. For example, death from cancer, homicide or lightning is generally not the result of a voluntary decision by an individual to accept risk and generally those risks are not acceptable, vast sums are directed to reducing the actual risks to an "acceptable," but undefined level. Figure 14 plots the data on a URS. Supporting data are contained in Appendix E.

Note that included on the scale, in bold italics, are statistics that have been normalized to a population of 1000 people to better illustrate their relevance to the regulatory standards. The implication of this normalization is that the number of persons surrounding a typical post, camp, or station may be 1000.

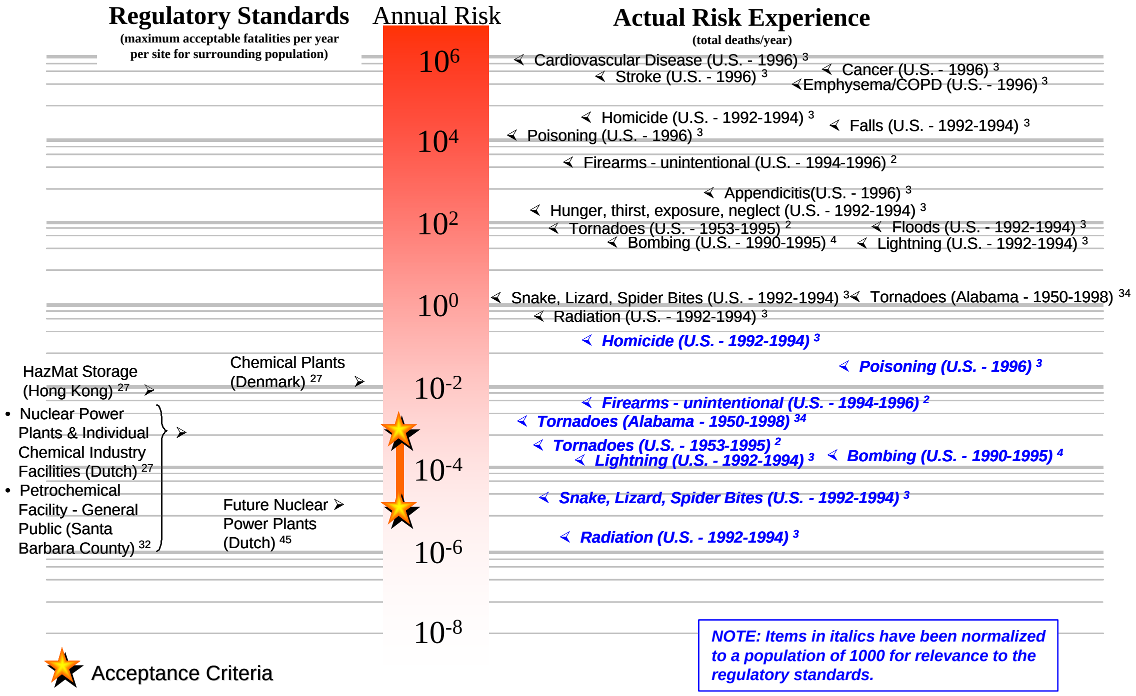


Figure 14: Involuntary Expected Fatalities

Note: The area between the two stars in Figure 14 is known as the “as low as reasonably practical” (ALARP) region. If risks are within the ALARP region, then the Service can prepare a waiver/exemption based on SAFER analysis. If risks are higher than the ALARP region, then the Service must determine if there are strategic or compelling reasons to justify the approval of a waiver/exemption.

4.0 Implementation

4.1 General

The previous chapters have summarized the technical background for the model that conducts risk-based explosives safety sitings, a description of the SAFER model, and the justification for establishing criteria against which to measure the results. This chapter will discuss the method to implement the risk-based approach to siting explosives facilities. The risk-based approach is not currently developed to supplant the Q-D tables, it is only to supplement them when Q-D criteria cannot be achieved. Also, SAFER can be used by the Services to justify and document decisions to waive or exempt facilities siting. SAFER can also be used by the Services to compare one siting alternative with another.

4.2 Risk Acceptance Logic

The method to implement risk-based sitings of explosive facilities is shown by the Risk Acceptance Logic Diagram in Figure 15.

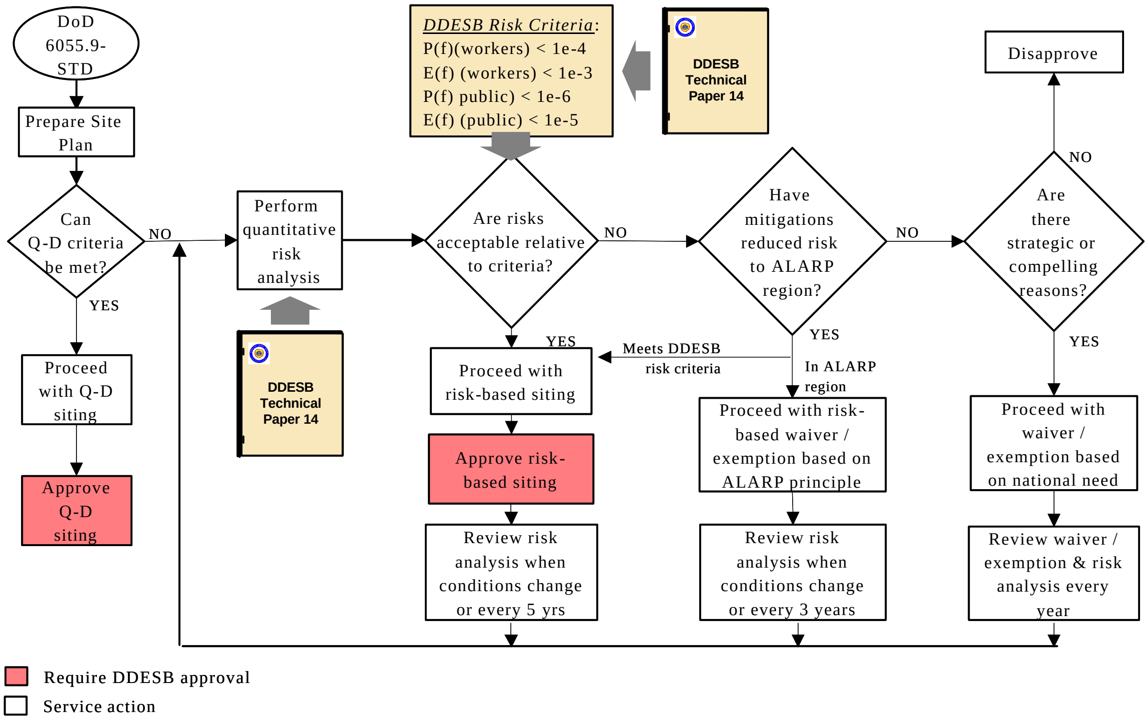


Figure 15: Risk Acceptance Logic Diagram

The logic in Figure 15 is described as follows:

The procedure starts with a determination of whether the facility to be sited can meet current Q-D criteria. All efforts should be made to meet these default distances. If it can, then a site plan is prepared and processed in the normal manner. If it cannot, then a risk analysis is performed using SAFER. Information on how to obtain the SAFER program and user manual may be obtained from the DDESB homepage www.hqda.army.mil/ddesb/esb.html.

The results of the SAFER analysis are compared to the risk criteria in Figure 9. There are two sets of results from a SAFER analysis. One is based on the explosive limit of the facility, and the other is based on the average amount of explosives contained in the facility over a year. Unless there are empirical data that support an average NEWQD, the explosive limit results should be used.

If all of the risks calculated by the SAFER analysis are less than the criteria, proceed with a site plan based on this analysis and submit it through Service channels to DDESB for approval. If any one of the risks calculated by SAFER is greater than the criteria, evaluate all feasible mitigations to decrease the risks. Re-calculate the risks using SAFER with the feasible mitigations in place. If all of the risks, with the mitigations, are less than the risk criteria, proceed with a site plan based on the mitigations and the SAFER analysis and submit it through Service channels to DDESB for approval.

If all of the risks, with the mitigations, are within the "as low as reasonably practical" (ALARP) region, then a Service waiver/exemption should be prepared using the SAFER analysis as supporting justification. If any one of the risks, with the mitigations, is higher than the ALARP region, the Services must determine whether there are strategic or compelling reasons that would justify the approval of the waiver/exemption.

If the Service determines that there are strategic or compelling reasons to justify the siting, then a waiver/exemption should be prepared based on the national need. The results of the SAFER analysis should be included with the request to assure that the decision-maker is aware of the risks that are being taken. If there are insufficient strategic or compelling reasons to justify the waiver or exemption, then the siting should be disapproved.

All siting justifications based on SAFER analyses needs to be reviewed periodically because conditions can change (i.e. an increase or decrease in exposure). The higher the risk that is being accepted, the more frequently the follow-up analyses should be conducted.

If a waiver or exemption was granted based on strategic or compelling reasons then a re-evaluation using SAFER must be accomplished each year. The results must be evaluated against the criteria and appropriate action initiated, based on that comparison.

If a risk-based waiver or exemption was granted because the SAFER analysis was within the ALARP region, then as a minimum a re-evaluation using SAFER is required every 3 years. The results should be evaluated against the criteria and appropriate action initiated based on that comparison.

If an approved risk-based siting was obtained, then as a minimum a re-evaluation using a SAFER analysis must be conducted every 5 years. The results should be evaluated against the criteria and appropriate action initiated based on that comparison. If the results show the risks are less than the criteria, then the SAFER analysis needs to be maintained at the installation to support the siting during DDESB surveys.

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Appendix B: Supporting Data for Risk to Any One Worker (see Figure 11)

Regulatory Standards

- Nuclear Power Plant Workers (UK HSE) – *1.00E-03.* In the *UK Health and Safety Executive – The Tolerability of Risk from Nuclear Power Stations*, this is stated as the "suggested maximum tolerable risk to workers in any industry…about the most risk that is ordinarily accepted under modern conditions for workers in the UK and it seems reasonable to adopt it as the dividing line between what is just tolerable and what is intolerable."
- Israeli MOD Launch Operations (Mission Essential) – *1.00E-03.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris,* this is the number used by the Israeli Ministry of Defense as an annual individual risk criterion for mission essential workers.
- Swiss Ammunition Storage – *1.00E-04.* From the *Swiss Technical Requirements for Storage of Ammunition (TLM 75), Part 2, Appendix 8-2,* this is the maximum allowable individual fatality risk per year for directly involved persons.
- Swiss Ammunition Storage (Handling by Army Personnel) – *3.00E-05.* From the *Swiss Technical Requirements for Storage of Ammunition (TLM 75), Part 2, Appendix 8-2,* this is the maximum allowable individual fatality risk per year for Army personnel handling ammunition and explosives.
- RCC Standard 321-97 (Mission Essential) – *3.00E-05.* From the *RCC Standard 321-97, Common Risk Criteria for National Ranges: Inert Debris*, this is the individual annual risk for mission essential personnel from the commonality criteria for national ranges, expressed in terms of expected fatalities.
- Chemical Risks to Workers (Court Case) – *2.20E-05.* The Occupational Safety and Health Administration regulates chemical risks when it can be shown that they pose a "significant risk." In the Supreme Court decision from the case of Industrial Union Department v. American Petroleum Institute, 448 U.S. 607 (1980), Justice Stevens stated that ". . .if the odds are one in a thousand. . . a reasonable person might well consider the risk significant and take appropriate steps to decrease or eliminate it." Based on a working lifetime of forty-five years, this translates into an annual individual risk of 2.2×10^{-5}. (Reproduced from the ACTA report to the Air Force, *Acceptable Risk Criteria for Launches from National Ranges: Rationale*.)

Actual Risk Experience

- Space Vehicle Crew Member (NASA) – *2.76E-02.* Obtained from a 1998 Knight Ridder, Associated Press report, this statistic is based on NASA deaths from 1967-1998. The average number of space vehicle crew member deaths per year has been 0.47 with an average annual population size of 17. 15 space vehicle crew members died during this period: 11 from accidents that occurred during space travel and 4 during preparations.
- Hang Gliding (U.S.) – *8.48E-04.* Based on statistics emailed to the author from the United States Hang Gliding Association, 7 of 8,250 reported hang gliders died in hang glider-related accidents in 1996.
- Mining/Quarrying (U.S.) – *2.72E-04.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 169 out of an average annual population of 621,100 miners and quarry workers died from job-related incidents.
- Agriculture (U.S.) – *2.40E-04.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 789 out of an average annual population of 3,289,583 agriculture workers died from job-related incidents.
- Motor Vehicle Accidents (U.S.) – *1.63E-04.* According to the National Center for Health Statistics, in 1996, 43,300 people died from Motor Vehicle Accidents (MVA) related accidents out of a reported population of 265,283,783.
- Construction (U.S.) – *1.55E-04.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 957 out of an average annual population of 6,172,581 construction workers died from job-related incidents.
- Parachuting/Sky Diving (U.S.) – *1.26E-04.* Based on statistics emailed to the author from the United States Parachute Association, 39 of 310,000 reported participants died in parachuting or sky diving accidents in 1996.
- Suicide (U.S.) – *1.18E-04.* According to the National Center for Health Statistics, during the years 1994 and 1996, an average of 31,022 people committed suicide out of an average population of 262,812,386.
- Hostile Actions (U.S. Marines) – *7.65E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998 an average of 14 out of an annual average of 188,251 active duty Marines died each year as a result of hostile actions.
- Motor Vehicle Accidents (New York City) – *7.47E-05.* According to the New York State Department of Health, from 1993-1996 an annual average of 560 people died from MVA-related accidents out of an average annual population of 7,493,400 commuters.
- All Job-Related (U.S.) – *4.00E-05.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 5,076 out of an average annual population of 126,906,250 workers died from job-related incidents.
- Manufacturing (U.S.) - *4.00E-05.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 694 out of an average annual population of 17,356,250 manufacturing workers died from job-related incidents.
- Government (U.S.) - *3.00E-05.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 543 out of an average annual population of 18,100,000 government workers died from job-related incidents.

- Drugs (U.S.) – *2.74E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 7,054 people died each year from drug-related accidents out of an average annual population of 257,733,843.
- Hostile Actions (U.S. Military) – *1.55E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 30 out of an annual average of 1,908,078 active duty members of the armed forces died each year as a result of hostile actions.
- Hostile Actions (U.S. Army) – *1.29E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 9 out of an annual average of 680,291 active duty Army personnel died each year as a result of hostile actions.
- Surgical/Medical Care Complications (U.S.) – *1.04E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 2,670 people died each year from surgical or medical care-related incidents out of an average annual population of 257,733,843.
- Hostile Actions (U.S. Navy) – *7.72E-06.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 4 out of an annual average of 524,521 active duty naval personnel died each year as a result of hostile actions.
- Hostile Actions (U.S. Air Force) – *4.47E-06.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 2 out of an annual average of 515,015 active duty Air Force personnel died each year as a result of hostile actions.
- Football Players (U.S.) – *1.71E-06.* Based on statistics from the *Annual Survey of Football Injury Research, 1931 – 1996* by F. O. Mueller and R.D. Schindler, an annual average of 14 football players die from directly-related football injuries out of an estimated 8,200,000 average annual participants. All of the deaths were high school students.
- Drowning in the Bathtub (U.S.) – *1.23E-06.* According to the National Center for Health Statistics, from 1992-1994, an average of 317 people drowned each year while in the bathtub, out of an average annual population of 257,733,843.

Appendix C: Supporting Data for Risk to Any One Person (see Figure 12)

Regulatory Standards

- Nuclear Power Plants (UK HSE) – *1.00E-04.* In the *UK Health and Safety Executive – The Tolerability of Risk from Nuclear Power Stations*, it is stated that this is the "suggested maximum tolerable risk to any member of the public from any large-scale industrial hazard." It is further explained that, "if the maximum tolerable risk for any worker is set at around 1 in 1000 per annum, it seems right to suggest that the maximum level that we [UK HSE] should be prepared to tolerate for any individual member of the public from any large-scale industrial hazard should be not less than ten times lower, i.e., 1 in 10,000 (1 in 10^4)."
- Swiss Ammunition Storage (Non-Participating Third Parties and Army Personnel in Exposure Region) – *1.00E-05.* From the *Swiss Technical Requirements for Storage of Ammunition (TLM 75), Part 2, Appendix 8-2,* this is the maximum allowable individual fatality risk per year for both non-participating third persons and for Army personnel in the exposure region of the facility dealing with ammunition and explosives.

- Israeli MOD Launch Operations (Uninformed General Public) – *1.00E-05*. From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is listed as the number established by the Israeli Ministry of Defense for the maximum annual individual fatality risk from launch operations for the non-participating, uninformed general public. Higher risk levels are tolerated for non-participating, uninformed workers in industrial facilities.
- Future Nuclear Power Plants (UK HSE) – *1.00E-05*. In the *UK Health and Safety Executive – The Tolerability of Risk from Nuclear Power Stations*, this is listed as the upper bound of the "range of risk to members of the public living near nuclear installation from normal operations." It is also listed as "the risk of death in an accident at work in the very safest parts of industry." In explanation, under the section, Safety in Operation, it is stated that "the annual risk of plant failure leading to an uncontrolled release at a modern station is of the order of 1 in a million. When we [UK HSE] reckon in the 'unquantifiable' sources of risk, we [UK HSE] must judge the chance overall to be in the region between 1 in 100,000 and 1 in 1 million per annum."
- British MOD Explosive and Ammunition Facilities (General Public) – *1.00E-06*. In accordance with *UK (ST) IWP 286 – Risk Management of MODUK Explosive Storage Activities*, this is the *de manifestis* individual risk standard for fatalities from operation of explosive storage facilities.
- RCC Standard 321-97 (General Public) – *1.00E-06*. From the *RCC Standard 321-97, Common Risk Criteria for National Ranges: Inert Debris*, this is the individual annual risk for the general public from the commonality criteria for national ranges, expressed in terms of expected fatalities.
- Nuclear Power Plants (UK HSE – *de minimis*) *Not Shown – 1.00E-06*. Although not specifically stated as *de minimis* in the *UK Health and Safety Executive – The Tolerability of Risk from Nuclear Power Stations*, this is stated as, "the level of risk below which, so long as precautions are maintained, it would not be reasonable to insist on expensive further improvements to standards." It is otherwise stated as "a broadly acceptable risk to an individual of dying from some particular cause." For determining *de minimis*, the question to ask is whether the risk level is high enough to warrant regulation. As such, this clearly qualifies as *de minimis*.
- Nuclear Power Plants & Individual Chemical Industry Facilities (Dutch) – *1.00E-06*. From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is listed as the acceptable risk standard used by Dutch industries for public individual fatality; applicable to established nuclear power plants and chemical industries.
- Norwegian MOD Ammunition Storage – *2.00E-07*. From *NO (ST) IWP 3-96, Storage of Ammunition – Quantitative Risk Assessment – Evaluation and Further Approach*, the Norwegian government has specified that this is the maximum permitted risk of death per year for a member of the public due to an accident in an ammunition storage area.
- British MOD Explosive and Ammunition Facilities (General Public - *de minimis*) *Not Shown – 1.00E-08*. In accordance with *UK (ST) IWP 286 – Risk Management of MODUK Explosive Storage Activities*, this is the *de minimis* individual risk standard for fatalities from operation of explosive storage facilities.
- Future Nuclear Power Plants (Dutch) – *1.00E-08*. From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is listed as the

acceptable risk standard used by Dutch industries for public individual fatality; applicable to future nuclear power plants.

Actual Risk Experience

- Mortality Rate (Hungary) – *1.38E-02.* The Hungarian Central Statistical Office reported that in 1997, 139,434 people died out of a population of 10,135,000. This includes all modes of fatality.
- Mortality Rate (England) – *1.09E-02.* The UK Office for National Statistics reported that from 1992-1996, an average of 529,525 people died each year out of an annual population average of 48,630,475. This includes all modes of fatality.
- Mortality Rate (Germany) – *1.07E-02.* The Federal Statistical Office of Germany reported that from 1995-1997, an average of 875,940 people died each year out of an annual population average of 81,962,366. This includes all modes of fatality.
- Mortality Rate (Italy) – *9.59E-03.* The Italian Instituto Nazionale in Statistics reported that in 1997, 564,679 people died out of a population of 58,882,065. This includes all modes of fatality.
- Mortality Rate (U.S.) – *8.73E-03.* The National Center for Health Statistics reported that from 1992-1996, an average of 2,271,966 people died each year, out of an annual population average of 260,248,117. This includes all modes of fatality.
- Mortality Rate (Netherlands) – *8.70E-03.* The Centraal Bureau voor de Statistick reported that in 1996, 135,434 people died out of a population of 15,567,107. This includes all modes of fatality.
- Mortality Rate (Ireland) – *8.69E-03.* The Central Statistics Office of Ireland reported that in 1996, 31,514 people died out of a population of 3,626,050. This includes all modes of fatality.
- Mortality Rate (Australia) – *7.03E-03.* The Australian Bureau of Statistics reported that in 1996, 128,726 people died out of a population of 18,311,000. This includes all modes of fatality.
- Heart Disease (U.S.) – *2.79E-03.* According to the National Center for Health Statistics, in 1994 and 1996, an average of 732,885 Americans died from heart disease. This is out of an average population of 262,812,386.
- Cancer (U.S.) – *2.04E-03.* According to the National Center for Health Statistics, in 1994 and 1996, an average of 536,922 Americans died from cancer. This is out of an average population of 262,812,386.
- Heart Disease (Hawaii) – *1.93E-03.* The Hawaiian State Department of Health, Office of Health Status Monitoring reported that in 1995, 2,286 Hawaiians died from heart disease. The US Census Bureau reported that the Hawaiian population that same year was 1,183,066. This probability of fatality was significantly lower than the national average.
- Mortality Rate (U.S. Military) – *8.87E-04.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 1,692 out of an annual average of 1,183,066 active duty military personnel died each year. This includes all modes of fatality.
- Stroke (Ireland) – *8.04E-04.* The Central Statistics Office of Ireland reported that in 1996, 2,917 people out of a population of 3,626,050, died from stroke.

- Homicide (Washington D.C.) – *5.98E-04.* The District of Columbia Department of Health State Center for Health Statistics reported that in 1995, 325 people out of a population of 543,213 were the victims of homicide.
- Stroke (U.S.) – *5.96E-04.* According to the National Center for Health Statistics, in 1994 and 1996, an average of 156,624 Americans died from stroke. This is out of an average population of 262,812,386.
- Stroke (Canada) – *4.81E-04.* According to Statistics Canada, in 1995 15,537 people died from stroke. This is out of a reported population of 32,301,455.
- Emphysema/COPD (U.S.) – *3.83E-04.* According to the National Center for Health Statistics, in 1996, 101,628 Americans died from complications of emphysema (chronic obstructive pulmonary disease). This is out of a population of 265,283,783.
- Homicide (New York City) – *1.86E-04.* The New York State Department of Health reported that, from 1993-1996, an average of 1,397 people out of an annual average population of 7,493,400 were victims of homicide.
- Homicide (Los Angeles County) – *1.49E-04.* For 1980-1998, the California Department of Justice, Criminal Justice Statistics Center reported that an annual average of 1,398 people out of 9,382,550 were victims of homicide.
- Homicide (U.S.) – *9.74E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 25,115 Americans were the victims of homicide. This is out of an average population of 257,733,843.
- Homicide (Bernalillo County, NM) – *9.14E-05.* The Government Information Sharing Project – Oregon State University reported that, from 1990-1993, an annual average of 45 out of 489,664 were the victims of homicide each year.
- Homicide (U.S. Marines) *Not Shown – 6.91E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 13 out of an annual average of 188,251 active duty Marines were the victims of homicide each year.
- Homicide (U.S. Army) *Not Shown – 6.03E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 41 out of an annual average of 680,291 active duty Army personnel were the victims of homicide each year.
- Falls (U.S.) – *5.32E-05.* According to the National Center for Health Statistics, in 1996, 14,100 people died from falls. This is out of a population of 265,283,783.
- Homicide (U.S. Navy) *Not Shown – 4.96E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 26 out of an annual average of 524,521 active duty Navy personnel were the victims of homicide each year.
- Homicide (U.S. Military) – *4.87E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-1998, an average of 93 out of an annual average of 1,908078 active duty military personnel were the victims of homicide each year.
- Poisoning (U.S.) – *3.92E-05.* According to the National Center for Health Statistics, in 1996, 10,400 people died from poisoning. This is out of a population of 265,283,783.
- Homicide (U.S. Air Force) *Not Shown – 2.52E-05.* Based on data from the DoD Washington Headquarters Services – Directorate for Information Operations and Reports, from 1980-

1998, an average of 13 out of an annual average of 515,015 active duty Air Force personnel were the victims of homicide each year.

- Homicide (Australia) – *1.80E-05.* The Australian Bureau of Statistics reported that, in 1996, 330 people out of a population of 18,311,000 were the victims of homicide.
- Suffocation by Ingested Object (U.S.) – *1.13E-05.* According to the National Center for Health Statistics, in 1996, 3,000 people died from suffocation by ingested object. This is out of a population of 265,283,783.
- Firearms – unintentional (U.S.) – *5.44E-06.* In the National Safety Council's *Accident Facts – 1997 Edition*, the average number of people who died each year from unintentional firearm accidents, from 1994-1996, was 1,429. This was out of an average annual population of 262,793,348 as reported by the US Census Bureau.
- Hypothermia (U.S.) – *2.37E-06.* According to the National Center for Health Statistics, from 1992-1994, an average of 611 people died each year from hypothermia. This is out of an average annual population of 257,733,843.
- Tornadoes (Alabama) – *1.81E-06.* According to statistics published by the National Weather Services Forecast Office, the average number of people who died in Alabama each year from tornadoes, from 1950-1998, was 7. This was out of an average annual population of 3,863,155 as reported by the US Census Bureau.
- Hunger, thirst, exposure, neglect (U.S.) – *8.15E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 210 people died each year from hunger, thirst, exposure or neglect. This is out of an average annual population of 257,733,843.
- Tornadoes (U.S.) – *4.08E-07.* In the National Safety Council's *Accident Facts – 1997 Edition*, the average number of people who died each year from tornadoes, from 1953-1995, was 88. This was out of an average annual population of 215,686,274 as reported by the US Census Bureau.
- Bombing (U.S.) – *2.77E-07.* According to statistics published by the FBI Explosives Unit Bomb Data Center, from 1990-1995, an average of 71 Americans were killed each year by bombings. The average annual population was 256,140,612 as reported by the National Center for Health Statistics. It should be noted that this statistics includes the Oklahoma City bombing in 1995.
- Lightning (U.S.) – *2.52E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 65 people died each year from lightning strikes. This is out of an average annual population of 257,733,843.
- Hornets, Wasps, Bees (U.S.) – *1.75E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 45 people died each year from hornet, wasp or bee stings. The average annual population was 257,733,843.
- Snake, Lizard, Spider Bites (U.S.) *2.72E-08.* According to the National Center for Health Statistics, from 1992-1994, an average of 7 people died each year from snake, lizard or spider bites. This is out of an average annual population of 257,733,843.

Appendix D: Supporting Data for Risk to All Workers (Collective Risk) (see Figure 13)

Regulatory Standards

- Petrochemical Facility Workers (Santa Barbara County) – *1.10E-01.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is the maximum annual societal fatality risk to workers at a petrochemical facility under guidelines imposed by the county of Santa Barbara in California.

Actual Risk Experience

- Space Vehicle Crew Member (NASA) – *2.76E-02.* Obtained from a 1998 Knight Ridder, Associated Press report, this statistic is based on NASA deaths from 1967-1998. The average number of space vehicle crew member deaths per year has been 0.47 with an average annual population size of 17. 15 space vehicle crew members died during this period; 11 from accidents that occurred during space travel and 4 during preparations.
- Hang Gliding (U.S.) – *8.48E-04.* Based on statistics emailed to the author from the United States Hang Gliding Association, 7 of 8,250 reported hang gliders died in hang glider-related accidents in 1996.
- Mining/Quarrying (U.S.) – *2.72E-04.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 169 out of an average annual population of 621,100 miners and quarry workers died from job-related incidents.
- Motor Vehicle Accidents (U.S.) – *1.63E-04.* According to the National Center for Health Statistics, in 1996, 43,300 people died in motor vehicle accidents, out of a reported population of 265,283,783.
- Construction (U.S.) – *1.55E-04.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 957 out of an average annual population of 6,172,581 construction workers died from job-related incidents.
- Parachuting/Sky Diving (U.S.) – *1.26E-04.* Based on statistics emailed to the author from the United States Parachute Association, 39 of 310,000 reported participants died in parachuting or sky diving accidents in 1996.
- Suicide (U.S.) – *1.18E-04.* According to the National Center for Health Statistics, during the years 1994 and 1996, an average of 31,022 people committed suicide out of an average population of 262,812,386
- All Job-Related (U.S.) – *4.00E-05.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 5,076 out of an average annual population of 126,906,250 workers died from job-related incidents.
- Government (U.S.) - *3.00E-05.* From 1992-1995, the Bureau of Labor Statistics reported that each year, an average of 543 out of an average annual population of 18,100,000 government workers died from job-related incidents.
- Drugs (U.S.) – *2.74E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 7,054 people died each year from drug-related accidents out of an average annual population of 257,733,843.
- Fire and Flames (U.S.) – *1.53E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 3,948 people died each year from fire and flame related incidents. The average annual population was 257,733,843.
- Air and Space Transportation (U.S.) – *3.91E-06.* According to the National Center for Health Statistics, from 1992-1994, an average of 1,009 people died each year in air and space transportation accidents. The average annual population was 257,733,843.
- Electric Current (U.S.) – *2.11E-06.* According to the National Center for Health Statistics, from 1992-1994, an average of 545 people died each year from incidents involving electrocution. The average annual population was 257,733,843.

- Football Players (U.S.) – *1.71E-06.* Based on statistics from the *Annual Survey of Football Injury Research, 1931 – 1996* by F. O. Mueller and R.D. Schindler, an annual average of 14 football players die from directly-related football injuries out of an estimated 8,200,000 average annual participants. All of the deaths were high school students.
- Drowning in the Bathtub (U.S.) – *1.23E-06.* According to the National Center for Health Statistics, from 1992-1994, an average of 317 people drowned each year while in the bathtub. The average annual population was 257,733,843.
- Operations of War during National Peacetime (U.S.) – *4.66E-08.* According to the National Center for Health Statistics, from 1992-1994, an average of 12 people were killed in operations of war even though the nation was at peace. The average annual population was 257,733,843.

Appendix E: Supporting Data for Risk to All People (Public Collective Risk) (see Figure 14)

Regulatory Standards

- Chemical Plants (Denmark) – *1.10E-02.* From the ACTA Report to the Air Force, *Acceptable Risk Criteria for Launches from National Ranges: Rationale*, reproduced from a report on quantitative and qualitative risk criteria for risk acceptance produced for MiljØstyrelsen, this is the upper limit of a defined region at which risks of annual fatality expectations become unacceptable, as recommended by a Danish national task force of engineers.
- Hazardous Material Storage (Hong Kong) – *7.00E-03.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is the *de manifestis* annual collective risk standard adopted by Hong Kong as an acceptable public fatality risk profile standard for facilities storing hazardous material.
- British MOD Explosive and Ammunition Facilities (General Public) – *6.00E-03.* In accordance with *UK (ST) IWP 286 – Risk Management of MODUK Explosive Storage Activities*, this is the *de manifestis* collective risk standard for fatalities from operation of explosive storage facilities.
- Nuclear Power Plants and Chemical Industries (Dutch) – *1.10E-03.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is listed as the acceptable risk standard used by Dutch industries for the collective public annual fatality risk.
- Petrochemical Facility – General Public (Santa Barbara County) – *1.00E-03.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is the maximum annual societal fatality risk to the general public surrounding a petrochemical facility under guidelines imposed by the county of Santa Barbara in California.
- Chemical Plants (Denmark – *de minimis*) *Not Shown – 1.10E-04.* From the ACTA Report to the Air Force, *Acceptable Risk Criteria for Launches from National Ranges: Rationale*, reproduced from a report on quantitative and qualitative risk criteria for risk acceptance produced for MiljØstyrelsen, this is the lower limit of a defined region at which risks of annual fatality expectations become acceptable, as recommended by a Danish national task force of engineers.

- Hazardous Material Storage (Hong Kong – *de minimis*) *Not Shown – 7.00E-05.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is the *de minimis* annual collective risk standard adopted by Hong Kong as an acceptable public fatality risk profile standard for facilities storing hazardous material.
- Future Nuclear Power Plants (Dutch) – *1.10E-05.* From the *RCC Standard 321-97 Supplement, Common Risk Criteria for National Ranges: Inert Debris*, this is listed as the acceptable risk standard used by Dutch industries for the collective public annual fatality risk; applicable to future nuclear power plants.

Actual Risk Experience

- Cardiovascular Disease (U.S.) – *3.58E-03.* According to the National Center for Health Statistics, in 1996, 950,164 people out of a population of 265,283,783 died from cardiovascular disease.
- Cancer (U.S.) – *2.04E-03.* According to the National Center for Health Statistics, in 1994 and 1996, an average of 536,922 Americans died each year from cancer. This is out of an average annual population of 262,812,386.
- Stroke (U.S.) – *5.96E-04.* According to the National Center for Health Statistics, in 1994 and 1996, an average of 156,624 Americans died each year from cancer. This is out of an average annual population of 262,812,386.
- Emphysema/COPD (U.S.) – *3.83E-04.* According to the National Center for Health Statistics, in 1996, 101,628 Americans died from complications of emphysema (chronic obstructive pulmonary disease). This is out of a population of 265,283,783.
- Homicide (U.S.) – *9.74E-05.* According to the National Center for Health Statistics, from 1992-1994, an average of 25,115 Americans were the victims of homicide. This is out of an average population of 257,733,843.
- Falls (U.S.) – *5.32E-05.* According to the National Center for Health Statistics, in 1996, 14,100 people died from falls. This is out of a population of 265,283,783.
- Poisoning (U.S.) – *3.92E-05.* According to the National Center for Health Statistics, in 1996, 10,400 people died from poisoning. This is out of a population of 265,283,783.
- Firearms – unintentional (U.S.) – *5.44E-06.* In the National Safety Council's *Accident Facts – 1997 Edition*, the average number of people who died each year from firearm accidents, from 1994-1996, was 1,429. This was out of an average annual population of 262,793,348 as reported by the US Census Bureau.
- Tornadoes (Alabama) – *1.81E-06.* According to statistics published by the National Weather Services Forecast Office, the average number of people who died in Alabama each year from tornadoes, from 1950-1998, was 7. This was out of an average annual population of 3,863,155 as reported by the US Census Bureau.
- Appendicitis (U.S.) – *1.60E-06.* According to the National Center for Health Statistics, in 1996, 424 people died from appendicitis. This is out of a population of 265,283,783.
- Hunger, thirst, exposure, neglect (U.S.) – *8.15E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 210 people died each year from hunger, thirst, exposure or neglect. This is out of an average annual population of 257,733,843.

- Floods (U.S.) – *3.69E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 95 people died each year flooding. This is out of an average annual population of 257,733,843.
- Tornadoes (U.S.) – *4.08E-07.* In the National Safety Council's *Accident Facts – 1997 Edition*, the average number of people who died each year from tornadoes, from 1953-1995, was 88. This was out of an average annual population of 215,686,274 as reported by the US Census Bureau.
- Bombing (U.S.) – *2.77E-07.* According to statistics published by the FBI Explosives Unit Bomb Data Center, from 1990-1995, an average of 71 Americans were killed each year by bombings. The average annual population was 256,140,612 as reported by the National Center for Health Statistics. It should be noted that this statistics includes the Oklahoma City bombing in 1995.
- Lightning (U.S.) – *2.52E-07.* According to the National Center for Health Statistics, from 1992-1994, an average of 65 people died each year from lightning strikes. This is out of an average annual population of 257,733,843.
- Snake, Lizard, Spider Bites (U.S.) *2.72E-08.* According to the National Center for Health Statistics, from 1992-1994, an average of 7 people died each year from snake, lizard or spider bites. This is out of an average annual population of 257,733,843.
- Radiation (U.S.) – *2.33E-09.* In *A Brief Chronology of Radiation and Protection* by J.E. Ellsworth III, it is noted that, from 1991-1995, an average of 0.6 people died each year due to radiation. The average annual population was 257,626,760.