Technical Paper

No. 14
Revision 3

APPROVED METHODS AND ALGORITHMS FOR DOD RISK-BASED EXPLOSIVES SITING

Approved for public release; distribution is unlimited.

Department of Defense Explosives Safety Board
Alexandria, VA
2 February 2007

Foreword

Technical Paper (TP) 14 provides Department of Defense Explosives Safety Board (DDESB) approved methodologies for calculating the risk associated with explosives operations and storage. The three elements of the methodology are the probability of event, probability of fatality given an event, and exposed personnel. This document will be kept current and will be updated as new methodologies are developed. The latest version of the document can be found on the DDESB Web-Page:

http://www.ddesb.pentagon.mil

The information in this document was based on the work of the DDESB-chartered Risk-Based Explosives Safety Criteria Team (RBESCT).

This TP has been reviewed by the DDESB Staff.

CURTIS M. BOWLING
Acting Chairman
DDESB

Disclaimer

The principles and techniques presented in this document are in the opinion of the DoD Explosives Safety Board (DDESB), the best available at the time of publication. Adherence to these principles should provide an acceptable level of safety during ammunition and explosives operations; however, use of this approach cannot ensure or guarantee a risk-free operation or address every situation that could be encountered. Because of the inherent danger in handling ammunition and explosives, neither the DDESB nor the contractors involved in the software development can be held responsible for any mishap or accident resulting from the use of this document.

Trial use of SAFER Version 3.0 is approved by the Department of Defense (DoD) Services until permanent policy is incorporated in DoD 6055.9-STD. The SAFER model is based on accident experiences, explosion effects, and structural response, and is for DoD application only.

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14. ABSTRACT
The DDESB has had an active role in the development of a risk-based model to use for explosives facilities siting. This document provides the description of the methods and algorithms contained within the risk-based model, Safety Assessment for Explosives Risk (SAFER) Version 3.0.

15. SUBJECT TERMS
SAFER Explosion Effects Risk-based analysis Human vulnerability Expected fatalities Probability of fatality Probability of major injury Probability of minor injury Expected major injuries Expected minor injuries

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Attachment 2: "Simplified Close-In Fatality Mechanisms (SCIFM)," Tech Memo CE1-16500, A-P-T Research, Inc., Huntsville, Alabama, February 2005.

Attachment 3: "Input Section," Tech Memo CE1-16200, A-P-T Research, Inc., Huntsville, AL, February 2005.

Attachment 4: "SAFER 3 Pressure and Impulse Branch," Tech Memo CE1-15800, A-P-T Research, Inc., Huntsville, AL, February 2005.

Attachment 5: "SAFER Injury Algorithms," Tech Memo CE1-16400, A-P-T Research, Inc., Huntsville, Alabama, February 2005.

Attachment 6: "SAFER 3 Glass Methodology," Tech Memo CE1-16000, A-P-T Research, Inc., Huntsville, AL, February 2005.

Attachment 7: "SAFER 3 Structural Response Methodology," Tech Memo CE1-15700, A-P-T Research, Inc., Huntsville, AL, February 2005.

Attachment 8: "SAFER 3 Debris Methodology," Tech Memo CE1-15900, A-P-T Research, Inc., Huntsville, AL, July 2005.

Attachment 9: "An Analytical Approach for Treating Uncertainty in Probabilistic Risk Assessments," Mensing, Dr. R.W., presented to the 31st Explosives Safety Seminar, 24-26 August 2004.

Attachment 10: "SAFER 3 P(e) Matrix," Tech Memo CE1-01000, A-P-T Research, Inc., Huntsville, Alabama, May 2002.

Attachment 11: "RBESCT Bibliography," Tech Memo CC1-02700, A-P-T Research, Inc., Huntsville, Alabama, September 2005.

Attachment 12: "Universal Risk Scale," 1st presented to the '99 Explosives Safety Seminar in Parari, then presented a 2nd time Updated to the 31st Explosives Safety Seminar, 24-26 August 2004.

Attachment 13: "Public Traffic Route Methodology," Tech Memo CC1-03600, A-P-T Research, Inc., Huntsville, Alabama, November 2005.

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Acronyms and Abbreviations

AASTP-4	Allied Ammunition Storage & Transport Publication 4 (NATO Risk Manual)
AGBS	Aboveground Brick Structure
CG	Compatibility Group
DDESB	Department of Defense Explosives Safety Board
DoD	Department of Defense
DTRA	Defense Threat Reduction Agency
ECM	Earth-Covered Magazine
ES	Exposed Site
HAS	Hardened Aircraft Shelter
HD	Hazard Division
HRD	High Range Damage
ICT	Integrated Combat Turn
IR	Individual Risk
ISO	International Standardization Organization
KE	Kinetic Energy
LAP	Load-Assemble-Pack
LRD	Low Range Damage
NATO	North Atlantic Treaty Organization
NEWQD	Net Explosive Weight For Quantity Distance
OCONUS	Outside Continental United States
PEMB	Pre-Engineered Metal Building
PES	Potential Explosion Site
P-I	Pressure-impulse
PWHFA	Potential Window Hazard Floor Area
QD	Quantity-Distance
R/C	Reinforced Concrete
RBESCT	Risk-Based Explosives Safety Criteria Team
RCC	Range Commander's Council
RL	Reduction Level
SAFER	Safety Assessment For Explosives Risk
TDY	Temporary Duty

Variable Names and Symbols

Variable Symbol	Variable Name/Explanation
$\%\ ES\ Hrs_{explosives}$	The percentage of hours that the group spends at the ES that explosives are also present at the PES
$\%\ ES_{roof\ damaged}$	Percentage of ES roof damaged
$\%\ ES_{roof\ intact}$	Percentage of ES roof intact
$\%\ ES_{wall\ damaged}$	Percentage of ES walls damaged
$\%\ ES_{wall\ intact}$	Percentage of ES wall intact
$\%\ mass$	Provided in Table A-20 - Table A-23
$\%\ material$	Provided in Table A-20 - Table A-23
a	1, $1/(Y_{100} - Y_0)^b$
A	Coefficient provided in Table A-2 - Table A-5, Table A-10, Table A-13, Table A-15 and Table A-17 Constant provided in Table 9 Crater mass coefficient
$Adj.\ P_{maji(bc)}$	Adjusted probability of major injury due to building collapse
$Adj.\ P_{mini(bc)}$	Adjusted probability of minor injury due to building collapse
$AHrs\ at\ ES_{group}$	The number of hours per year that the group is at the ES
$AIAR$	Adjusted Invulnerable Area for the ES Roof
$AIAW$	Adjusted Invulnerable Area for the ES Wall
a_{IV}	Constant provided in Table A-28, used to calculate initial velocity of secondary fragments
b	A constant given by Table A-6 through Table A-9
B	Coefficient provided in Table A-2 - Table A-5, Table A-10, Table A-13, Table A-15 and Table A-17 Constant provided in Table 9 Crater mass exponent
$B3$	Angle from height h to the base of the ES
c	Constant given by Table A-5
C	Coefficient provided in Table A-2 - Table A-5, Table A-10, Table A-13, Table A-15 and Table A-17
C_1	Constants given by Table A-2
C_2	Constants given by Table A-2
CA	Concern area, provided in Table A-27 - Table A-29
CC_a	Actual Continuity Correction
CC_{max}	Maximum Continuity Correction
$COV(.)$	Covariance
CP	Constant provided in Table 17, used to calculate maximum throw values for secondary fragments
$Crater\ ejecta\ mass$	Mass of the crater ejecta thrown
d	Distance between PES and ES

Variable Symbol	**Variable Name/Explanation**
$d1$	Distance between ES and ES barricade
$d2$	Distance between the PES and the ES barricade
D	Coefficient provided in Table A-2 - Table A-5
DR	Damage Region
Δt	The fraction of the time that explosives are present when exposures are also present
E	Coefficient provided in Table A-2 - Table A-5
$E1$	Constant provided in Table 17, used to calculate maximum throw values for secondary fragments
$E2$	Constant provided in Table 17, used to calculate maximum throw values for secondary fragments
E_f	Expected fatalities
$E_{f(pair)Group}$	Expected value of the group expected fatality distribution for a PES-ES pair
$E_{f(ES)Group}$	Expected value of the group expected fatality distribution for an ES
$E_{f(PES)Group}$	Expected value of the group expected fatality distribution resulting from a unique PES
$E_{f(PES\ Siting)Group}$	Expected value of the group expected fatality distribution resulting from all ESs within the Risk-based evaluation distanceof any PES
$E_{f(install)Group}$	Expected value of the group expected fatality distribution for the entire situation (all PES-ES pairs in the situation)
$Effects$	The four fatality mechanisms computed by the SAFER science algorithms
E_{i}	Denote the individual probability of fatality (pair) the distinct PES sites pose to the ES of interest.
E_j	Denote the individual probability of fatality (pair) the distinct PES sites pose to the ES of interest.
$E_{Maj\ (pair)\ Group}$	Point estimate for major injuries at a single ES caused by a single PES
$E_{Maj\ (ES)\ Group}$	Point estimate for major injuries for a unique ES caused by all PESs
$E_{Maj\ (PES)\ Group}$	Point estimate for major injuries resulting from a unique PES to all ESs (within the Risk-based evaluation distanceof the unique PES)
$E_{Maj\ (PES\ Siting)\ Group}$	Point estimate for major injuries at all ESs within the Risk-based evaluation distance of any PES (resulting from all PESs)
$E_{Maj\ (install)\ Group}$	Point estimate for major injuries over the entire situation (all PES-ES pairs in situation)
$E_{Min\ (pair)\ Group}$	Point estimate for minor injuries at a single ES caused by a single PES
$E_{Min\ (ES)\ Group}$	Point estimate for minor injuries for a unique ES caused by all PESs
$E_{Min\ (PES)Group}$	Point estimate for minor injuries resulting from a unique PES to all ESs (within the Risk-based evaluation distance of the unique PES)
$E_{Min\ (PES\ Siting)Group}$	Point estimate for minor injuries at all ESs within the Risk-based evaluation distance of any PES (resulting from all PESs)
$E_{Min\ (install)Group}$	Point estimate for minor injuries over the entire situation (all PES-ES pairs in situation)

Variable Symbol	**Variable Name/Explanation**
E	The exposure of personnel to an explosive event based on the number of people present in a facility during the year and the number of hours the exposed site is occupied
E_{o}	The distribution used to estimate the daily number of exposures
E_{oo}	Median of the lognormal distribution, E_o, representing the median number of daily exposures.
$E_{oo\ Group}$	Used for computing group risk at an ES from a specific PES
$E_{oo\ Individual}$	Used for computing individual risk at an ES 1.0 (by definition)
E_p	Annual exposure of one person to a particular PES
ES_{height}	Constant provided in Table A-11
exp_{iv}	Constant provided in Table A-28, used to calculate initial velocity of secondary fragments
$Exposure_{people\ group}$	Average daily number of exposures, calculated for each people group at an ES
F	Coefficient provided in Table A-2 and Table A-5
f	Reduced debris throw factor
FA_{ES}	Floor area of the ES (ft^2)
FB	Fragment blocking coefficient provided in Table 14
F_{HA}	High-angle fragments
F_{LA}	Low-angle fragments
F_r	Fireball radius
FV	Final Velocity
G	Coefficient provided in Table A-5
g	Crater radius coefficient
G_p	Percentage of glass on the ES
h	Height increment under evaluation in equation (132)
$h1$	Height of PES provided in Table 7
$h2$	Height of ES barricade (user input)
$h3$	Height of ES provided in Table A-11
H	Coefficient provided in Table A-5
HRD	High range damage
I	Unmodified impulse (psi-ms)
I'	Adjusted impulse (psi-ms) outside the PES
I''	Final impulse (psi-ms) inside the ES
IA	Impulse-adjusted probability of serious injury from glass breakage
IA_{roof}	Nominal invulnerable area of the roof, provided in Table 26
IA_{wall}	Nominal invulnerable area of the wall, provided Table 27
IFR	Injury to fatality ratio
IRR	Initial reduction ratio

Variable Symbol	Variable Name/Explanation
I_{scaled}	Impulse scaled
IV	Initial velocity
IV_c	Calculated initial velocity
IV_{max}	Maximum initial velocity
k	Bin number of first non-zero bin
$K\ factor$	Hazard factor or scaled range
KE	Kinetic energy
KE_a	KE adjustment
KE_R	Resulting kinetic energy
λ	The probability of an explosive event during a given year based on the type of explosives present and the activity performed at the explosives site, also referred to as P_e
$Local\ reduction$	Fraction of fly-through fragments blocked at height *h*
$Lower$	Lower projection angle of fragments from the PES to the ES
LRD	Low range damage
m	Upper bound multiplication factor
M	Coefficient provided in Table A-12 Median Nominal or Center Value In SAFER, characterizes nominal factor values in linear space
$maj_{(i)}DO$	Major injury damage offset, provided in Table 10
$maj_{(i)}PD$	Major injury plateau damage, provided in Table 10
$MAXInjury$	Constant set to 100%
$min_{(i)}DO$	Minor injury damage offset, provided in Table 10
$min_{(i)}PD$	Minor injury plateau damage, provided in Table 10
$MINInjury$	Constant set to 0
MOW	Model of the World
MT_c	Calculated maximum throw range Maximum throw range for concrete fragments
MT_m	Maximum throw range for multiple weapons
MT_{max}	Highest maximum throw range
MT_s	Maximum throw for a single weapon, Maximum throw for steel fragments
$M_{un\text{-}scaled}$	The center value for the un-scaled probability of event predicted from the accident data
N	Coefficient provided in Table A-12
N^*	Total quantity of fragments
N^*_{HA}	Total quantity of high-angle fragments
N^*_{LA}	Total quantity of low-angle fragments
N_{af}	Number of expected arriving fragments per square foot
N_{ce}	Number of crater ejecta fragments

Variable Symbol	Variable Name/Explanation
NEW	The Net Explosive Weight of hazardous material contributing to the event
N_{FT}	Number of fly-through fragments
N_{HA}	Number of high-angle fragments from equation (142)
NHA	Number of fragments that will be impeded by the roof
N_{LA}	Number of low-angle fragments from equation (146)
NFT	Number of fly-through fragments blocked by the wall
$Nom.\ P_{maji(bc)}$	Nominal $P_{maji(bc)}$
$Nom.\ P_{mini(bc)}$	Nominal $P_{mini(bc)}$
N_{pf}	Number of departing primary fragments
N'_{pf}	Number of primary fragments not contained in the PES
N_{pos}	Percentage of weapons on the outer surface of the stack
N_{sf}	Number of secondary fragments
N_{SI}	Number of side-impact fragments
NSI	Number of side-impact fragments blocked by the wall
Number of People	The quantity of people entered by the user
N_w	Number of weapons
N_{wos}	Number of weapons on the outer surface
P	Unmodified or open-air pressure (psi)
P'	Adjusted pressure (psi-ms) outside the PES
P''	Final pressure (psi-ms) inside the ES
$P_{(f/e)1}$	1.0, except for glass fatality mechanism, which is 0.1
$P_{(f/e)2}$	The nominal value calculated by SAFER Version 3.0
$P_{(sf)}$	Probability of skull fracture
$P_{ambient}$	Ambient pressure
P_{base}	Probability of a major injury from glass breakage
PD_{b}	Predicted building damage
$P_{dynamic}$	Dynamic pressure
P_e	Probability that an explosive event will occur per Potential Explosion Site per year
PES Annual Operating Hours	The typical hours per year that the PES is expected to house explosives based on the activity selected by the user.
PES mass thrown	Provided in Table A-20 - Table A-23
PES_{DC}	The fraction of debris (primary fragments contained by the PES
$PES_{damage(fw)}$	Fraction of PES front wall damage
$PES_{damage(roof)}$	Fraction of PES roof damaged
$PES_{damage(rw)}$	Fraction of PES rear wall damaged
$PES_{damage(sw)}$	Fraction of PES side walls damaged

Variable Symbol	Variable Name/Explanation
$PES_{fraction}$	Fraction of PES area by component provided in Table 15
PES_{intact}	The fraction PES intact following the explosive event
$PES_{intact(fw)}$	Fraction of PES front wall intact
$PES_{intact(roof)}$	Fraction of PES roof intact
$PES_{intact(rw)}$	Fraction of PES rear wall intact
$PES_{intact(sw)}$	Fraction of PES side walls intact
$PES_{totalDC}$	Total fraction of debris (primary fragments) contained by the PES
P_{event}	Probability of event
P_f	Annual probability of fatality
$P_{f(b)}$	Probability of fatality due to overall building damage
$P_{f(bc)}$	Probability of fatality due to building collapse, Probability of fatality as a function of structural damage
$P_{f(bc)1}$	Constant provided in Table A-15
$P_{f(bc)2}$	$P_{f(bc)2} = A + ((B \times W_2) / (C + W_2))$ If $P_{f(bc)2} > R_{2min}$, Then, $P_{f(bc)2} = P_{f(bc)2,}$ Else $P_{f(bc)2} = R_{2min}$
$P_{f(bd)}$	Probability of fatality due to whole body displacement
$P_{f(d)}$	Probability of fatality due to debris
$P_{f(d)high\text{-}angle}$	Probability of fatality due to debris from the combined high-angle penetrating debris table
$P_{f(d)low\text{-}angle}$	Probability of fatality due to debris from the combined low-angle penetrating debris table
$P_{f/e}$	The probability of fatality given an explosive event and exposure – this factor aggregates the effects of the fatality mechanisms: overpressure, debris, building collapse, and glass hazards, or thermal effects
$P_{f(pair)Individual}$	Expected value of the probability of fatality distribution for a PES-ES pair (Individual)
$P_{f(ES)Individual}$	Expected value of the probability of fatality distribution for a unique ES caused by all PESs
$P_{f(PES)Individual}$	Expected value of the probability of fatality distribution for all ESs in the Risk-based evaluation distance of a unique PES
$P_{f(PES\ Siting)Individual}$	Expected value of the probability of fatality distribution for all ESs within the Risk-based evaluation distance of any PES (resulting from all PESs)
$P_{f(install)Individual}$	Expected value of the probability of fatality distribution resulting from the entire situation (all PES-ES pairs in the situation)
$P_{f(g)}$	Probability of fatality due to window breakage
$P_{f(gi)}$	Initial probability of fatality due to window breakage
$P_{f(g)1}$	Constant provided in Table 9
$P_{f(g)2}$	Calculated by $(A + B \times \log_{10}(W_2)) \times (G_p / 10\%) \times (5000 / FA_{ES})^{1/2}$
$P_{f(lr)}$	Probability of fatality due to lung rupture
$P_{f(o)}$	Probability of fatality due to overpressure effects
$P_{f(o)}$	Probability of fatality due to the effects of pressure and impulse
$P_{f(sf)}$	Probability of fatality due to skull fracture

Variable Symbol	Variable Name/Explanation
$P_{f(t)}$	Probability of fatality due to thermal effects
$P_{f(to)}$	Nominal probability of fatality due to thermal effects
$P_{f(x)}$	Probability of fatality at range *x*
$P_{f(x)1}$	Set to 100% for most fatality mechanisms, with glass being the exception.
$P_{f(x)2}$	Probability of fatality determined at runtime, used for calculating the close-in fatality mechanisms
$P_{f\|e}$	Probability of fatality given an explosives event and the presence of a person
$P_{f\|koo}$	The median value of the lognormal distribution, *Pf|ko*, the epistemic uncertainty associated with evaluating the median value of the probability of fatality due to explosive effect, k, where *k* = 1, 2, 3, 4 represents the four fatality mechanisms: blast overpressure, building collapse, debris, and glass.
P_{gha}	Probability of a person being in the glass hazard area
P_{hit}	Probability of hit
$P_{hit(f)}$	Probability of hit for fatality
$P_{hit(maji)}$	Probability of hit for major injury
$P_{hit(mini)}$	Probability of hit for minor injury
P_i	Debris probability densities at the ES
$P_{Maj\ (pair)\ Individual}$	Point estimate of an individual's probability of a major injury for a PES-ES pair
$P_{Maj\ (ES)\ Individual}$	Point estimate of an individual's probability of a major injury at a unique ES resulting from all PESs
$P_{Maj\ (PES)\ Individual}$	Point estimate of the maximum individual probability of a major injury caused by a unique PES across all ESs within the Risk-based evaluation distance of that PES
$P_{Maj\ (PES\ Siting)\ Individual}$	Point estimate of the maximum individual probability of a major injury at any ES within the Risk-based evaluation distance of a unique PES caused by any PES
$P_{Maj\ (install)\ Individual}$	Point estimate of the maximum individual probability of a major injury at the installation (all PES-ES pairs in the situation)
$P_{Maj\|e}$	Probability of a major injury given an explosives event and the presence of a person
$P_{maji(b)}$	Probability of a major injury due to overall building damage
$P_{maji(bc)}$	Probability of a major injury due to building collapse
$P_{maji(bd)}$	Probability of a major injury from whole body displacement
$P_{maji(d)}$	Probability of a major injury due to debris
$P_{maji(g)}$	Probability of a major injury due to window breakage
$P_{maji(lr)}$	Probability of a major injury from lung rupture
$P_{maji(o)}$	Probability of a major injury due to overpressure effects
$P_{maji(sf)}$	Probability of a major injury due to skull fracture
$P_{maji(t)}$	Probability of a major injury due to thermal effects

Variable Symbol	**Variable Name/Explanation**
$P_{Min\ (pair)\ Individual}$	Point estimate of an individual's probability of minor injury for a PES-ES pair
$P_{Min\ (ES)\ Individual}$	Point estimate of an individual's probability of a minor injury at a unique ES caused by all PESs
$P_{Min\ (PES)\ Individual}$	Point estimate of the maximum individual probability of a minor injury caused by a unique PES across all ESs within the Risk-based evaluation distance of that PES
$P_{Min\ (PES\ Siting)\ Individual}$	Point estimate of the maximum individual probability of a minor injury at any ES within the Risk-based evaluation distance of a unique PES caused by any PES
$P_{Min\ (install)\ Individual}$	Point estimate of the maximum individual probability of a minor injury at the installation (all PES-ES pairs in the situation)
$P_{Min\|e}$	Probability of minor injury given an explosives event and the presence of a person
$P_{mini(b)}$	Probability of a minor injury due to overall building damage
$P_{mini(bc)}$	Probability of a minor injury due to building collapse
$P_{mini(d)}$	Probability of a minor injury due to debris
$P_{mini(g)}$	Probability of a minor injury due to window breakage
$P_{mini(lr)}$	Probability of a minor injury from lung rupture
$P_{mini(o)}$	Probability of a minor injury, Probability of a minor injury due to overpressure effects
$P_{mini(sf)}$	Probability of a minor injury due to skull fracture
$P_{mini(t)}$	Probability of a minor injury due to thermal effects
$P_{mini(wd)}$	Probability of a minor injury from whole body displacement
$P_{nominal}$	Nominal pressure
P_{pha}	Probability of a major injury given that the person is in the glass hazard area
$P_{reflected}$	Reflected pressure
P_{scaled}	Scaled pressure
$P_{(sf)}$	Probability of skull fracture
$PWHFA$	Potential window hazard floor area
r	Crater ejecta range coefficient
R	Range
R_1	Maximum plateau range
R_2	Minimum normal range
R_{2min}	Provided in Table A-15
R_A	d/R_M
RL	Reduction level
R_M	Final maximum throw values, Nominal maximum throw range
RV_{ave}	Average reduction value

Variable Symbol	Variable Name/Explanation
S	Environmental factor that increases the probability of an event based on extenuating circumstances at the site – such as operations in a remote area or under combat conditions
SD	Standard deviation, characterizes the spread or dispersion of factor values in linear space
S_o	Median of the lognormal distribution representing the P_e Environmental factor, S, that addresses the increase in risk due to extenuating circumstances.
SP	Constant provided in Table 17, used to calculate maximum throw values for secondary fragments
$T2$	Angle from height h to the top of the ES barricade
$T3$	Angle from height h to the top of the ES
TBF	Adjusted Thermal Blocking Factor
TBF_o	Thermal Blocking Factor based on the ES building type, provided in Table 32
Total angle	Span of angles at which fragments are ejected from PES
Total reduction	Total percentage of fragments blocked by the barricade
TP	Transition Point
UB	Upper Bounds or extreme value
$UB_{\text{environmental factor}}$	Provided in Table 34
$UB_{\text{un-scaled } Pe}$	The Upper Bound provided in Table 33
$UB_{\Delta t}$	Upper limit of Δt
UL	Upper Limit
$UL_{\Delta t}$	Upper limit on the number of personnel present at an ES at any time
Upper	Upper projection of fragments from the PES to the ES
V	Volume of PES
$VAVR$	Vent Area to Building Volume Ratio
$V_{f(pair)Individual}$	Variance of the individual probability of fatality distribution for a PES-ES pair
$V_{f(pair)Group}$	Variance of the group expected fatality distribution for a PES-ES pair
$V_{f(ES)Individual}$	Variance of the individual probability of fatality distribution for a specific ES
$V_{f(ES)Group}$	Variance of the group expected fatality distribution for a specific ES
$V_{f(PES)Individual}$	Variance of the individual probability of fatality distribution for a single PES
$V_{f(PES)Group}$	Variance of the group expected fatality distribution for a single PES
$V_{f(PES\ Siting)Individual}$	Variance of the maximum individual probability of fatality distribution for any ES within the Risk-based evaluation distance of any PES
$V_{f(PES\ Siting)Group}$	Variance of the expected fatality distribution for all ESs within the Risk-based evaluation distance of any PES caused by all PESs
$V_{f(install)Individual}$	Variance of the individual probability of fatality distribution for the entire situation (all PES-ES pairs)

Variable Symbol	**Variable Name/Explanation**
$V_{f(install)Group}$	Variance of the group expected fatality distribution for the entire situation (all PES-ES pairs)
W/V	Weight to Volume ratio
W_1	Yield of the event (lbs)
W_2	Equivalent NEW (lbs)
W_a	Adjusted weight (lbs)
X	Natural log of the hazard factor
X_a	Natural log of the adjusted hazard factor
X_o	Natural log of the effective hazard factor
Y	Effective Yield
Y_0	Constant provided in Table A-6 - Table A-9
Y_{100}	Constant provided in Table A-6 - Table A-9
Y_a	Actual yield
$Yield$	The percentage of the material contributing energy to the event
Y_n	Normal yield
Y_R	Ratio of the equivalent NEW (W_2) to the total destruction value (Y_{100})
Z	Hazard factor
Z_a	Adjusted hazard factor, Adjusted scaled distance (ft)
Z_o	Effective hazard factor
Z_t	Nominal thermal hazard factor
Z_{ta}	Adjusted thermal hazard factor
ΔKE_n	Values provided in Table A-25 and Table A-26
Δt	Percentage of time that personnel in an ES are exposed to a PES when explosives are present
Δt_o	Median of the lognormal distribution representing the percentage of time, Δt, when explosives are present at the PES that exposures are present at the ES
$\Delta t_{o\ Group}$	Used for computing group risk at an ES $\Sigma\ \Delta t_{people\ group}$
$\Delta t_{o\ Individual}$	Used for computing individual risk at an ES, the maximum {$\Delta t_{people\ group}$: across all people groups at the ES}
λ_{oo}	The median of the lognormal factor, δo, that describes the epistemic uncertainty in λo, the median number of explosive events per typical operating year at a given activity/facility. Previously known as un-scaled P_e.
μ	The mean In SAFER, characterizes nominal factor values in log space
ρ_{Ae}	The coefficient of correlation between PES activity and Exposure
ρ_{Ne}	The coefficient of correlation between NEW and Exposure
σ	Standard deviation In SAFER, characterizes the spread or dispersion of factor values in log space.

Variable Symbol	**Variable Name/Explanation**
$\sigma_{\Delta t}$	Standard deviation of the lognormal distribution representing the percentage of time, Δt, when explosives are present at the site that exposures are also present
σ_{λ}	Previously known as $\sigma_{un\text{-}scaled\ Pe}$
$\sigma_{\lambda o}$	The standard deviation of the lognormal factor, δo, that describes the epistemic uncertainty in λo, the median number of explosive events per typical operating year at a given activity/facility.
σ_e	Standard deviation of the lognormal distribution, Eo, representing the median number of daily exposures.
$\sigma_{e\ Group}$	$\mathrm{Ln}(UL_{\Delta t} / E_{oo}) / 3$
$\sigma_{e\ Individual}$	Ln(1.0 / 1.0) / 3 = 0.0 (also by definition)
σ_{e1}	Standard deviation of δ_{e1}, a lognormal multiplicative factor describing the random variation in λ due to exposure.
σ_{Eo}	Standard deviation of the lognormal distribution, Eo, of the epistemic uncertainty associated with the median number of daily exposures.
σ_{k}	The standard deviation of the lognormal distribution, δ_k, the random variation in $P_{f\mid e}$ due to effect k, where k = 1, 2, 3, 4, represents the four fatality mechanisms.
σ_{ko}	The standard deviation of the lognormal distribution, $\delta_{k\mathrm{o}}$, the epistemic uncertainty associated with evaluating the median value of the probability of fatality, $P_{f\mid e}$ due to effect k, where k = 1, 2, 3, 4, represents the four fatality mechanisms.
σ_{NEW1}	The standard deviation of δ_{NEW1}, a multiplicative factor describing the random variation in λ due to *NEW*.
σ_{NEW2}	The standard deviation of δ_{NEW2}, a multiplicative factor describing the random variation in $P_{f\mid e}$ due to *NEW*.
σ_S	The standard deviation of the lognormal distribution representing the P_e Environmental factor, S, that addresses the increase in risk due to extenuating circumstances. Previously known as $\sigma_{environmental\ factor.}$
σ_y	The Standard Deviation of the lognormal distribution, δ_y, a multiplicative factor describing the random variation in yield.
σ_{yo}	The Standard Deviation of the lognormal distribution, δ_{yo}, a multiplicative factor describing the epistemic uncertainty in yield.

Definitions

One of the largest difficulties in risk analyses is clear communications. Often words have many meanings leading to misunderstandings. In this document the definitions below are used.

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

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 fatality in ten million person years.

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

Group – The total number of people

- (1) A group of people in an ES with the same exposure information
- (2) All of the people in an ES
- (3) All of the people in all ESs exposed to significant individual risk from a PES
- (4) All of the people in all ESs exposed to significant individual risk from any PES
- (5) Related Group – All individuals in ESs exposed to significant individual risk from a PES to which they are related
- (6) Unrelated Group – All individuals in ESs exposed to significant individual risk from a PES to which they are unrelated

Group Risk – Sum of all significant individual risks from a PES

- (1) Related Group Risk – Sum of all related individual risks in the group
- (2) Unrelated Group Risk – Sum of all unrelated individual risks in the group

Hazard – Any real or potential condition that can cause injury, illness, or death of personnel, or damage to or loss of equipment or property.

Individual risk – The risk to an individual

- (1) The risk to any particular individual, either a worker or a member of the public. A member of the public can be defined as anyone not related to the explosives mission at the installation.
- (2) The sum of the individual risks to an individual in an exposed site from all PESs which presents significant risk to the individual ($\geq 1 \times 10^{-8}$).
- (3) Related Individual Risk – Sum of all significant risks to an individual in an ES from all PESs to which they are related
- (4) Unrelated Individual Risk – Sum of all significant risks to an individual in an ES from all PESs to which they are unrelated

Inhabited Building Distance (IBD) – Distance to be maintained between a PES and an inhabited building.

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

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-based evaluation distance – Distance from a PES at which all exposed sites must be evaluated. Determined by selecting the greater of Inhabited Building Distance or the SAFER Calculated Distance.

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

SAFER Calculated Distance (SCD) – Distance from a PES at which the individual risk for a single person, in the open, is $1x10^{-8}$ (the explosives at the PES are assumed to be the baseline Hazard Division (HD)).

Safety – Relative protection from adverse consequences. In this context, Safety = 1 – Risk.

Scenario – In the SAFER context, a scenario is a set of conditions that are under evaluation. In a scenario, conditions are not static.

Significant Individual Risk – Risk inside the Risk-based evaluation distance

Situation – In the SAFER context, a situation is the set of static conditions that are under evaluation similar to a scenario. Static refers to the period of time under evaluation (i.e. 1 year for SAFER).

1.0 INTRODUCTION

1.1 Purpose

The purpose of this technical paper is to present the underlying logic and algorithms used in risk-based explosives safety analyses, as implemented in the Safety Assessment for Explosives Risk (SAFER) Version 3.0 model.

1.2 Scope

The methodology as described herein applies to risk-based explosives safety analysis, as implemented in the SAFER Version 3.0 model.

1.3 Applicability

The SAFER Version 3.0 model may be used for risk-based explosives safety siting as allowed by the Department of Defense Explosives Safety Board (DDESB). The model may also be used for risk management purposes.

1.4 Background

Quantity-Distance (QD) criteria have been used as the primary means for the safe siting of facilities for more than 70 years. QD criteria consider only explosives quantity, Hazard Division (HD), and facility type to determine a safe separation distance. During the past 30 years, safety professionals have recognized that QD could be improved by considering other factors in the safety analyses to include type of activity, number of people, building construction, and environment to assess the overall risk of an operation.

The DDESB recognized the need to develop a risk-based approach for explosives safety analysis. In 1997, the DDESB chartered the Risk-Based Explosives Safety Criteria Team (RBESCT) to develop such an approach. The result of this effort was the SAFER model. DDESB approved SAFER for use in DoD safety analyses in 1999 on a trial basis through 2002.

The RBESCT delivered SAFER Version 1.0 in May 2000. This software allowed safety professionals to perform their own risk-based explosives analyses. Based on improvements identified during the development of SAFER Version 1.0, the RBESCT sought to produce a follow-on version. SAFER Version 2.0 was approved for distribution in May 2002 on an extended trial basis through December 2004; the trial period was later extended until such time as risk-based explosives siting criteria is incorporated into DoD 6055.9-STD. The methods described in this paper were developed by the RBESCT for the SAFER Version 3.0 model.

Software Version	Publication Date of Technical Paper
SAFER Version 1.0	Technical Paper #14, February 2000
SAFER Version 2.0	Technical Paper #14, May 2002
SAFER Version 2.1	Technical Paper #14, September 2003
SAFER Version 3.0	Technical Paper #14, February 2007

1.5 Related Reading

This document contains the description of SAFER Version 3.0 algorithms. As such, it makes no attempt to describe the background or rationale why certain approaches were selected. That related material is contained in other documentation that includes:

- Minutes of the RBESCT. Over 45 team meetings were held as part of the SAFER development process. Meeting minutes are available from team members in hard copy only. (They are currently being documented on CD). These minutes are used as references for a variety of purposes.
- Technical Memoranda and Reports prepared by the RBESCT and A-P-T Research, Inc. document the rationale for key decisions made as part of the development process. The memoranda have been included as attachments to this Technical Paper. These Memoranda and Reports provide referenceable sources explaining why certain decisions were made.
- Published papers relating to specific aspects of the software or criteria development. Numerous aspects of the development have been documented in published papers listed in the bibliography.
- The NATO manual on Risk Analysis (AASTP-4), which contains significant material on the methods used by participating nations for conducting explosives safety risk analysis (Ref 1). The risk-based methodology used in SAFER is summarized in AASTP-4.

1.6 Major Modifications in SAFER Version 3.0

The major modifications between SAFER Version 3.0 and previous versions include:

- Updated the probability of event matrix to include an additional 5 years of accident data,
- Developed simplified “close-in” fatality algorithms for each fatality mechanism,
- Included algorithms for determining major and minor injuries,
- Improved debris algorithms (high-angle and low-angle split, and low-angle fragments passing through distances less than maximum debris throw distance),
- Improved crater ejecta algorithm for large NEW cases,
- Improved concrete roof Pressure-impulse (P-I) diagrams and roof damage determination,
- Created scaled range dependencies on major injury to fatality ratios for glass algorithms,
- Included exposed site (ES) barricades,
- Included International Standardization Organization (ISO) container as PES option,
- Included calculation of risk to workers inside the PES, and
- Revised uncertainty model.

2.0 ANALYSIS METHODOLOGY

2.1 Origin and Overview

The general method adopted for use in the SAFER model is one that has origins in the 1600s and has been used since in a variety of forms worldwide. In 1662, the French mathematician Blaise Pascal wrote (Ref 2):

> *"Our fear of harm ought be proportional not only to the magnitude of the harm, but also the probability of the event."*

This provides the most basic formulation for risk:

$$Risk = Likelihood * Consequences \tag{1}$$

This basic equation serves as the mathematical origin of many specific risk equations that can be derived directly from the same source. Two such equations are used by SAFER. They both originate from this equation:

$$Risk = Likelihood * Consequences * Exposure \tag{2}$$

Equation (2) is a direct derivative of Pascal's equation where the likelihood of an explosives event is expressed in terms of a probability, and undesired consequences are expressed in terms of the probability of fatality given the presence of people. The basis of selecting fatality as the measure is described in Ref 3.

SAFER uses this basic formulation to calculate the product of three components to estimate the annual probability of fatality, P_f, as shown in the following equation:

$$Risk = P_f = P_e * P_{f|e} * E_p \tag{3}$$

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 and the presence of a person. E_p is defined as the exposure of one person to a particular PES on an annual basis.

A second measure that is associated with group risk is expected fatalities, E_f. This is defined as the summation of individual risks and provides an expectancy or expected value (i.e. the average number of fatalities expected per year) as shown:

$$E_f = \sum_n (P_e * P_{f|e} * E_p) \tag{4}$$

In Sections 2.2 to 2.4 each of the three terms of the risk equations (3) and (4) above are described.

2.2 Event Analysis

The first term of the risk equation is the probability of event, P_e. This term is used to assess the likelihood that an explosives event occurs. To incorporate the P_e into SAFER, a P_e matrix was developed using a compilation of historical explosives accident data from the U.S. Army, Navy, Air Force, and Marine Corps. The rationale used to develop the P_e matrix is documented in Ref 4.

The P_e is a function of three parameters:

- Activity at the PES (activity type)
- Storage Compatibility Group (CG)
- Environmental factors

Each of these parameters is described in Section 0.

2.3 Effects Analysis

The second term of the risk equation is the probability of fatality given the event occurs and a person is present, $P_{f|e}$. $P_{f|e}$ is determined by combining the potentially fatal effects of impulse and overpressure, building collapse, window breakage, debris (fragments from the explosives casing, building debris, and crater ejecta), and thermal effects. These potential fatality mechanisms are analyzed in parallel within the SAFER model and are grouped into four branches of sequential steps.

Branch 1 – Pressure and Impulse. The explosion produces a blast wave described by pressure and impulse. Pressure-impulse is defined using Kingery-Bulmash equations and the algorithms from the Blast Effects Computer (Refs 5, 6). The effects are followed in sequence from the event through the PES to the exposed site (ES) and finally to the exposed person(s) as detailed in Section 4.2.

Branch 2 – Structural Response. The pressure and impulse impinging on the ES from Branch 1 provides the input for Branch 2. Two effects are assessed here: building collapse and broken windows (flying glass). Each effect is treated as an independent source of injury or fatality as detailed in Section 4.3.

Branch 3 – Debris. The debris branch combines flying debris from three sources into a single table of debris density as a function of Kinetic Energy (KE). Lethality from this debris is then evaluated using the protocol previously developed by the Range Commanders Council (Ref 7). To accomplish this, primary debris (from the explosive item), secondary debris (from the PES), and ejecta (from the crater) are each evaluated. The details of this approach are in Section 4.4. The debris from the ES are evaluated in Branch 2.

Branch 4 – Thermal. The thermal branch is only used for Hazard Division (HD) 1.3 explosives (mass fire). Thermal effects are evaluated using a methodology presented in Attachment 1. The detailed algorithms are in Section 4.5.

2.4 Exposure Analysis

Exposure is a major factor in the risk equation. The units for exposure are person years per year or simply *people*. Individual exposure is measured as the probability of a person being present when the event occurs (i.e., a number between 0 and 1).

The SAFER Risk model includes two random variables related to exposure: Δt, the percentage of time that personnel are exposed to the PES that the PES is actually operating (housing explosives) and E_o, the distribution used to estimate the daily number of Exposures. These two variables are represented by lognormal distributions defined by their medians and standard deviations. Section 4.1.3.2 describes how these parameters are calculated from the user input.

2.5 Conservatism in the Model

In the context of this paragraph conservatism means biasing an analysis toward safe sided (higher risk) answers.

Pascal argued that risk should be considered as a mathematical formulation without adding bias (Ref 2). This means that equal concern should be given to an event which happens once in a thousand years killing a thousand people and an event happening once a year killing one. It also means that conservatism should not be added out of fear of certain consequences or for any other reason. This Pascalian-based principal is in direct competition with the widely recognized and accepted principle to *err on the safe side*. Pascal's thinking recognized that if the risks originating from fundamentally different sources are to be compared, the comparison can best be done without any biases.

In recognition of these fundamentally different requirements, SAFER has adopted the Pascalian principle with the model design goal of *best estimate* with the pragmatic addendum that where no analytical basis exists conservative estimates will be used. This philosophy is foundational to many of the analytical approaches described in later sections.

Although the model design goal has been to develop best estimate methodologies, for risk-based site plans, a conservative approach is taken. When submitting a risk-based site plan, the sited NEWQD must be entered even though the explosives might not be present for the entire year.

3.0 SAFER MODEL OVERVIEW

This section provides an overview of the architecture of the SAFER model. This architecture describes the organization of the methods executed by the model to determine the risk from an explosives event.

The SAFER model conducts a sequence of 26 steps to estimate the annual probability of fatality. These procedures are arranged in the architecture as presented in Figure 1. The architecture presented in Figure 1 is complicated. To facilitate discussion of the model, the 26 steps are divided into six functional groups:

Group 1	Steps 1-4	Situation Definition, Event and Exposure Analyses Includes user inputs that describe the situation (PES and ES) and calculates P_e, exposure, and yield
Group 2	Steps 5-8	Pressure and Impulse Branch Calculates the effect of the fatality mechanisms of pressure and impulse
Group 3	Steps 9-10	Structural Response Branch Calculates the effect of the fatality mechanisms of building collapse and broken windows (overall building damage)
Group 4	Steps 11-18	Debris Branch Calculates the effect of the fatality mechanisms for multiple types of flying debris
Group 5	Steps 19-22	Thermal Branch Calculates the effect of the fatality mechanism heat for HD 1.3 scenarios only
Group 6	Steps 23-26	Aggregation and Summation Aggregates the total effect of all fatality mechanisms, calculates the desired measures of risk, and assesses overall uncertainty

Section 4.0 describes the detailed algorithms used in each of the 26 steps to calculate the risk. Section 5.0 describes the algorithms used in estimating the uncertainty in the risk.

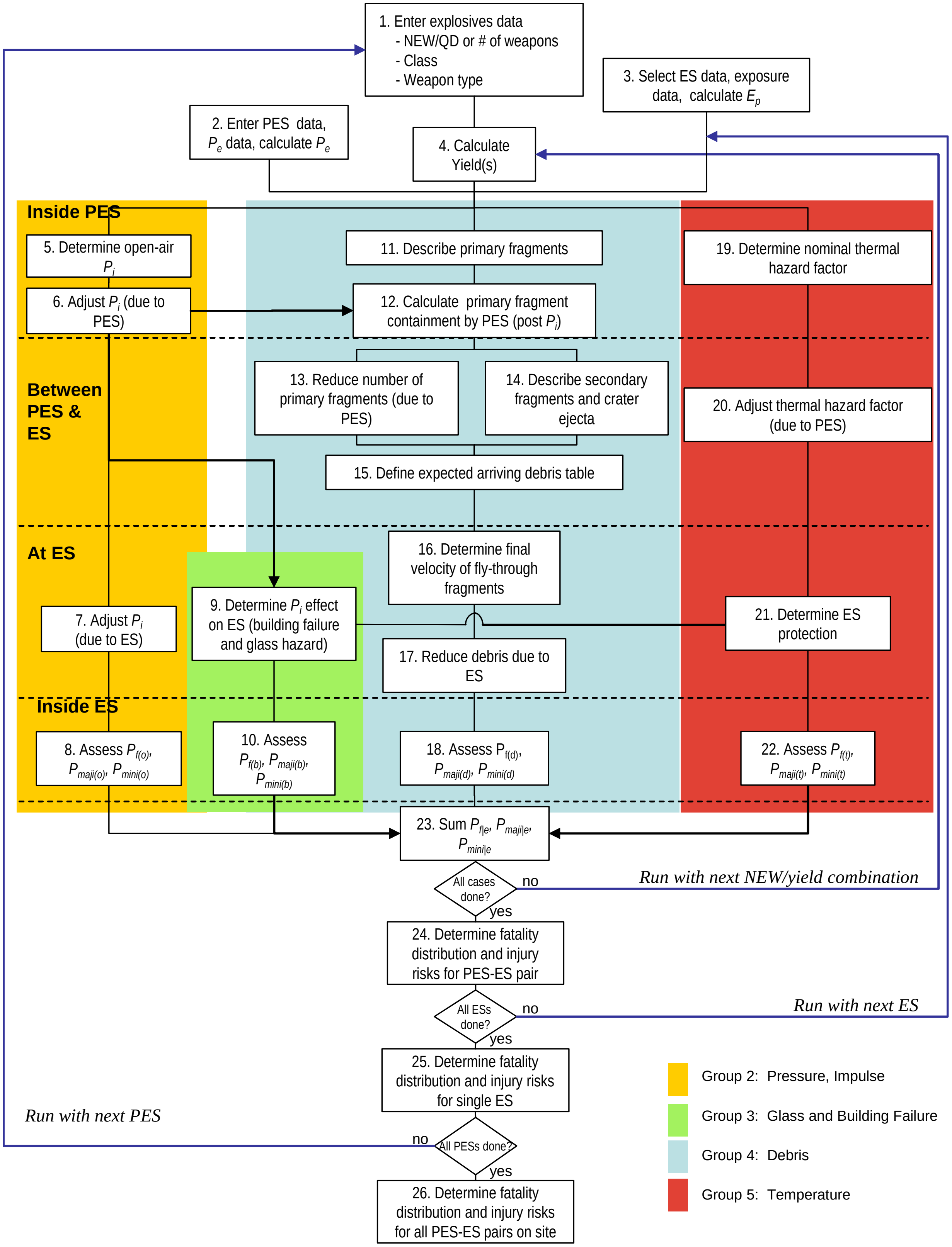


Figure 1. SAFER Version 3.0 Architecture

3.1 Close-In Fatality Mechanisms

In SAFER Version 1.0 the software was limited to distances at or beyond Public Traffic Route (PTR) distance. With each SAFER version, algorithms have been developed so the software would be applicable to distances closer to the PES. With SAFER Version 3.0, the software will calculate risk to the persons in the PES and exposed sites within close proximity of the PES.

The specific methodology for determining the probability of close-in fatality values will be discussed within the Step that each fatality mechanism is calculated in and Attachment 2 provides additional details. This section provides a top-level description of how the close-in fatality mechanisms are calculated.

SAFER Version 3.0 assumes that for distances in close proximity to the PES the probability of fatality will be equal to 1.0. This is defined as the "simplified close-in plateau" region. That distance has been defined for each of the fatality mechanisms and is described later in this paper in the Step where the calculation occurs. Another distance has been defined for each of the fatality mechanisms where the RBESCT is confident in the results of the scientific algorithms. This is defined as the "normal" region. The region in between the "simplified close-in plateau" and the "normal" region is defined as the "transition" region. If the distance under evaluation is in the "transition" region, SAFER will interpolate between the "simplified close-in plateau" and the "normal" region to determine the resulting probability of fatality value. The three regions are shown in Figure 2.

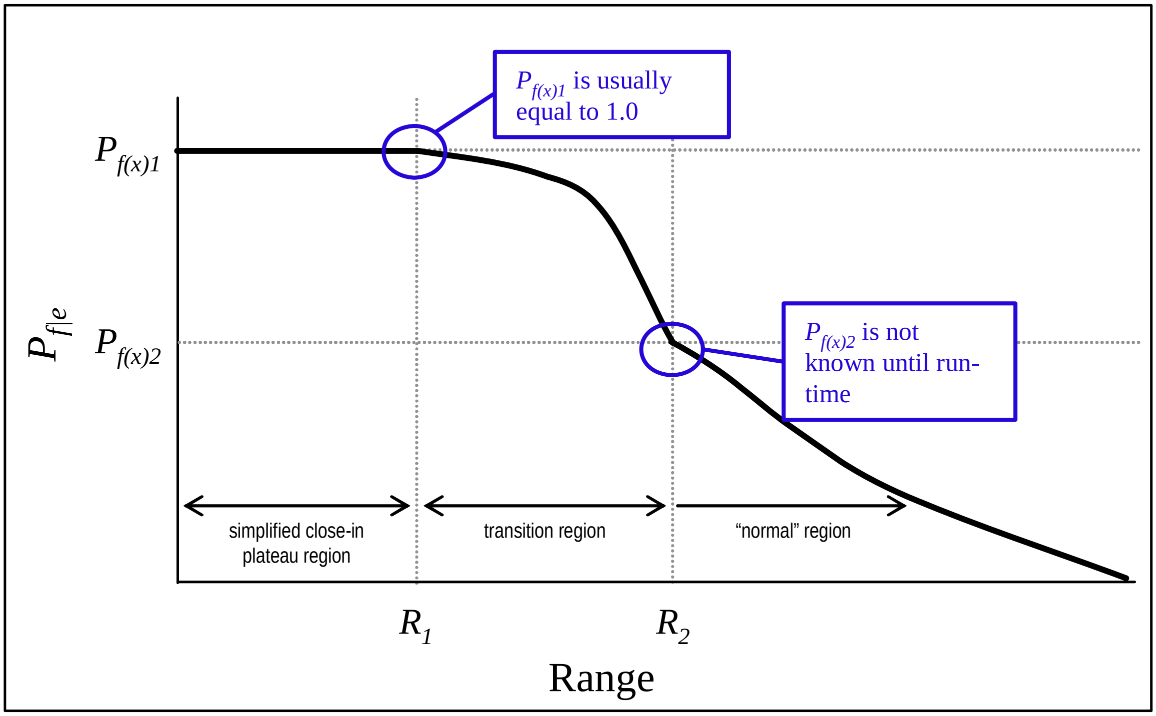


Figure 2. Determination of $P_{f(x)}$ Region

The determination of the probability of fatality at range x, $P_{f(x)}$, is based on the range (in terms of either scaled distance or simply distance, depending on the fatality mechanism) between the PES and ES. In SAFER Version 3.0, the determination of $P_{f(x)}$ is made by selecting which of the following three regions the range falls in:

1. the simplified “close-in” plateau region
2. the transition region (with new algorithms)
3. the “normal” region.

The appropriate region for determining $P_{f(x)}$ is based on the range (either the hazard factor, Z [ft/lb$^{1/3}$], or distance, d [ft]). The $P_{f(x)1}$ is set to 100% for most fatality mechanisms, with glass fatality being the exception. $P_{(f/e)2}$ is the nominal SAFER Version 3.0 $P_{(f/e)}$ at range = R_2. R_2 is determined at run-time for each fatality mechanism. Z is calculated at run-time in Step 5 or 6, depending on the PES building type, or is calculated in Step 19 or 20 if the Hazard Division is 1.3.

1. The general algorithm for determining $P_{f(x)}$ is described below.
2. If R (range) is less than the maximum plateau range, $R1$, then set the $P_{f(x)}$ to $P_{(f/e)1}$ (this is 1.0, except for the glass fatality mechanism, which is 0.1).
3. If R (range) is greater than or equal to the minimum normal range, R_2, then set the $P_{f(x)}$ to $P_{(f/e)2}$ (the nominal value calculated by SAFER Version 3.0).
4. Otherwise, Z is within the transition region, so $P_{f(x)}$ is calculated by:

$$P_{f(x)} = P_{f(x)1} + P_{f(x)2} - [(R - R_1) / (R_2 - R_1)]^2 * P_{f(x)1} \tag{5}$$

The specific implementation of this general algorithm is described for each fatality mechanism in Section 4.0. Attachment 2 contains additional details.

4.0 DETAILS OF SAFER ARCHITECTURE

This section presents the logic and algorithms used in the SAFER Version 3.0 model to determine risk due to an explosives event.

4.1 Group 1 Steps: Situation Definition, Event and Exposure Analyses

Group 1 includes Steps 1-4 of the SAFER architecture. These steps cause the user to input data describing the situation of interest – details about the PES and ES. Additionally, these steps perform event and exposure analyses to calculate P_e and exposure, the first and third terms of the risk equation. Finally, Step 4 calculates explosive yields that will be used in subsequent steps.

To enhance readability, selected reference tables of constants used in the Group 1 steps are located in Appendix A.

4.1.1 STEP 1: Enter explosives data

Step 1 queries the user for information needed to begin the definition of the situation to be analyzed.

SAFER prompts the user to make the following inputs:

- Sited Net Explosives Weight QD (NEWQD)
- Expected NEWQD
- Hazard Division (HD) of explosives

- Weapon type or description

Table 1, *Weapon Descriptions*, presents the weapon types considered by SAFER. The table presents the weapons by Hazard Division and provides a short description of the weapons. Rationale for the selection and inclusion of the weapon types considered by SAFER is detailed in Attachment 3.

Table 1. Weapon Descriptions

HD	Weapon Type	Weapon Description
1.1	MK82	Robust or thick-skinned bomb
	M107	Robust or thick-skinned 155-mm projectile
	Bulk/light case	Thin skinned
	MK83	Robust or thick-skinned bomb
	MK84	Robust or thick-skinned bomb
	AIM-7	Fragmenting or thin-skinned missile warhead
	Unknown (MK82)	Unknown (Robust or thick-skinned bomb)
1.2.1	M1 105 mm projectile	Robust or thick-skinned 105-mm projectile
1.2.2	40 mm projectile	Robust or thick-skinned 40-mm projectile
1.2.3	MK82 bomb – only 1 round detonates	Robust or thick-skinned bomb
1.3	Bulk propellant	Bulk propellant
1.4	NA	NA
1.5	Bulk/light case	Thin skinned
1.6	MK82 bomb – only 1 round detonates, consider only blast effects	Robust or thick-skinned bomb

SAFER does not perform an equivalent yield calculation for HD 1.4 items because the output for HD 1.4 cases is determined instead by definition; therefore, the calculation is not required.

HD 1.4 items are not evaluated in SAFER Version 3.0. The hazards associated with a PES containing solely HD 1.4 items are not considered life threatening. Injury algorithms have yet to be developed for HD 1.4 items.

Outputs of Step 1:

- Sited NEWQD (lbs)
- Expected NEWQD (lbs)
- Hazard Division
- Weapon type

4.1.2 STEP 2: Enter PES data, P_e data, and compute P_e.

Step 2 performs two functions in SAFER. In Step 2a, SAFER queries the user for information on the PES needed to define the situation. In Step 2b, SAFER calculates the probability of event, P_e.

4.1.2.1 Step 2a: User Inputs for PES

A description of each of the user inputs is provided in the following paragraphs.

Input data includes:

- PES building identifier

- PES building category and type
- Number of people at the PES
- Soil type
- Compatibility Group (CG) of explosives
- Activity type
- Applicable environmental factors
- Inhabited building distance (IBD)
- PES Operating Hours, *PES Annual Operating Hrs*

4.1.2.1.1 PES Building Identifier

The PES building identifier is the building name or number entered by the user. It is used for informational purposes only to identify the PES if multiple PESs are present in the situation.

4.1.2.1.2 PES Building Categories

PES building categories are used as inputs for subsequent steps. The building categories considered by SAFER were selected by the RBESCT to represent the majority of the facilities containing explosives within DoD. The building categories considered by SAFER Version 3.0 include:

- Open
- Earth-covered magazine (ECM)
- Aboveground brick structure (AGBS)
- Pre-engineered metal building (PEMB)
- Hollow clay tile
- Operating building (concrete)
- Hardened aircraft shelter (HAS)
- Ship
- ISO Container

Rationale for the selection and inclusion of the building categories considered by SAFER is detailed in Attachment 3.

4.1.2.1.3 PES Building Types

PES building types are used to distinguish between size and construction type. The building types considered by SAFER Version 3.0 are shown in Table 2.

Table 2. PES Building Categories and Types

PES Building Category	PES Building Types
Earth-covered magazine (ECM)	• Small Concrete Arch ECM • Medium Concrete Arch ECM • Large Concrete Arch ECM • Small Steel Arch ECM • Medium Steel Arch ECM • Large Steel Arch ECM
Aboveground Brick Structure (AGBS)	• Small AGBS (square) • Medium AGBS • Large AGBS
Operating Building (concrete)	• Small Concrete Building • Medium Concrete Building
Ship	• Small Ship • Medium Ship • Large Ship

4.1.2.1.4 Number of people at the PES

The user enters the number of people at the PES, the numbers of hours the people are present at the PES, and the percentage of time that people are present at the PES when explosives are present at the PES. These values are used to calculate the personnel exposure. Section 2.4 discusses inputs and calculations for exposure.

4.1.2.1.5 Soil Type

The user enters the soil type around the PES. The soil types considered by SAFER include concrete, rock or hard clay, and looser soils.

4.1.2.1.6 Activity Types

The activity type describes the primary operation that is performed at the PES. This input is used in determining the P_e. Historical data show that this factor can vary the P_e by up to four orders of magnitude.

The activity types considered by SAFER were selected by the RBESCT to represent the majority of the explosives activities within the DoD. The activity types considered by SAFER Version 3.0 include:

- Assembly
- Load-Assemble-Packout (LAP)
- Burning Ground
- Demolition
- Lab
- Training
- Inspection
- Painting / Packing
- Deep Storage
- In-Transit Storage.
- Disassembly
- Maintenance
- Demilitarization
- Disposal
- Test
- Loading / Unloading
- Manufacturing
- Renovation
- Temporary Storage

Rationale for the selection and inclusion of the activity types considered by SAFER is detailed in Attachment 3.

4.1.2.1.7 Compatibility Groups

The explosives storage Compatibility Groups are used to describe the types of explosives in the PES (see Chapter 3 in DoD 6055.9-STD for a description of the principle of hazard classification and Compatibility Groups) (Ref 8). This input is used in determining the P_e. This factor results in variations of P_e up to 1½ orders of magnitude. The Compatibility Groups are divided into three sets designated by Roman numerals in the matrix in Figure 3. 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*, *E,* and *N*.

If the CG is unknown, SAFER assigns a default CG of *D* to all Hazard Divisions except for HD 1.3 items. A CG of *C* is the default for HD 1.3 items.

Compatibility Groups *K* and *S* are not considered by SAFER. CG *K* is not considered because the predominant hazard from lethal chemical agents is toxicity and this is not addressed by SAFER. Compatibility Group *S* is not considered because it is assigned only to HD 1.4 items and there is no life-threatening hazard external to the shipping container.

4.1.2.1.8 Environmental Factors

Environmental factors are used to increase the P_e. The environmental factors consist of a variety of environmental circumstances. The RBESCT selected environmental factors to represent conditions that increase the probability of an event occurring. Each activity type has a set of applicable environmental factors for that particular activity. If more than one environmental factor applies, only one adjustment is made using the factor with the highest adjustment. The applicable environmental factors for each activity are shown in the second column of the matrix in Figure 3.

The environmental factors were divided into two groups: Group A represents a large increase in the probability of event (a factor of 10) and Group B represents a smaller increase in the probability of event (a factor of 3).

4.1.2.1.9 Inhabited Building Distance (IBD)

The user enters the Inhabited building distance. This is used to determine the Risk-based evaluation distance.

4.1.2.1.10 PES Operating Hours

The user enters the PES operating hours. This is the typical number of hours per year that the PES is expected to house explosives based on the activity selected by the user. This input is used to calculate personnel exposure. Typical operating hours are provided in Table 3.

Table 3. Typical PES Annual Operating Hours

Activity at PES	Explosives Present at PES (hours)
Burning Ground	1560
Demilitarization	1560
Demolition	1560
Disposal	1560
Maintenance	1560
Renovation	1560
Test	1560
Assembly	2080
Disassembly	2080
Load-Assemble-Packout (LAP)	2080
Lab	2080
Training	2080
In-Transit Storage	8736
Painting	1560
Packing	1560
Inspection	2080
Loading	1560
Unloading	1560
Manufacturing	6240
Temporary Storage	8736
Deep Storage	8736

4.1.2.2 Step 2b: P_e Determination

Using the activity type, storage compatibility group, and environmental factors, SAFER calculates the P_e using the P_e matrix shown in Figure 3. The P_e is determined for each PES in the situation.

To use the P_e matrix shown in Figure 3, the activity type and storage CG are used to determine the un-scaled P_e. The un-scaled P_e is then adjusted by applicable environmental factors, which results in the final P_e.

PES used primarily for:	Allowable Environmental Factors	Probability of Event (PES-year)		
		I	II	III
Burning Ground / Demilitarization / Demolition / Disposal	A1, A2, A5, A6, B2, B4	2.4E-02	2.4E-03	8.1E-04
Assembly / Disassembly / LAP / Maintenance / Renovation	A1, A4, A5, A6, A8, B1, B2	4.7E-03	4.7E-04	1.6E-04
Lab / Test / Training	A1, A2, A3, A4, A5, A6, A7, A8, B1, B2, B3, B4	4.3E-03	4.3E-04	1.4E-04
Manufacturing	A4, A5	1.7E-03	1.7E-03	1.7E-03
Inspection / Painting / Packing	A1, A2, A4, A6, A7, B1, B2, B4	8.2E-04	8.2E-05	2.7E-05
Loading / Unloading	A1, A2, A6, A7, B1, B2, B3, B4	5.7E-04	5.7E-05	1.9E-05
In-Transit Storage (hrs – few days)	A1, A2, A6, A7, B1, B2, B4	3.0E-04	1.0E-04	3.3E-05
Temporary Storage (1 day - 1 mth)	A1, A2, A6, A7, B1, B2, B4	1.0E-04	3.3E-05	1.1E-05
Deep Storage (1 month - year)	A1, A2, B1	2.5E-05	2.5E-05	2.5E-06

Environmental Factors

A. Increase P_e by a factor of 10 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 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

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

Notes: The elements in the matrix are comprised of Compatibility Groups. Definitions of the Compatibility Groups can be found in DoD 6055.9-STD. [Ref 5]

Figure 3. P_e Matrix.

This matrix is used to estimate the probability of an explosives event per PES-year.

4.1.2.2.1 Examples of Calculating P_e Using the P_e Matrix.

Example 1:

An assembly activity is performed at a PES on exposed explosives with a CG of *D*. The un-scaled P_e is 1.6E-4. Since the operation involves exposed explosives environmental factor *A8* applies. This would increase the un-scaled P_e by a factor of 10 and the final P_e would be 1.6E-3.

Example 2:

An earth-covered magazine is used to store explosives during the year. The CG is *A*. The unscaled P_e is 2.5E-5. None of the environmental factors are applicable, so the final P_e is also 2.5E-5.

Outputs of Step 2:

- PES building identifier
- PES building category
- PES building type
- Number of people at the PES
- Soil type
- Activity type
- Inhabited Building Distance (IBD)
- PES Operating Hours, *PES Annual Operating Hours*
- Compatibility Group (CG) of explosives
- Applicable environmental factors
- Probability of event, P_e

4.1.3 STEP 3: Enter ES data, exposure data, and calculate exposure.

Step 3 performs two functions in SAFER. In Step 3a, SAFER continues to query the user for information needed to define the situation. In Step 3b, SAFER calculates the personnel exposure.

4.1.3.1 Step 3a: User Inputs for ES

A description of each of the user inputs is provided in the following paragraphs.

Input data includes:

- ES building identifier
- ES building category
- ES building type
- ES roof type
- Type of glass on the ES
- Percentage of glass on ES
- Floor area of ES
- Distance between the PES and ES
- Orientation of PES to ES
- Barricade information
- Number of people at the ES
- Relationship of personnel in ES to PES
- Number of hours people are present at ES

- Percentage of time people are present in the ES when explosives are present in the PES
- Upper limit (largest number of people exposed at any time during year)

ES Building, Roof, and Wall Types

Table A-1, *Default Roof and Wall Types,* presents the ES building types considered by SAFER. The table presents building data by building category, building type, and associated default wall and roof types.

4.1.3.1.1 ES Roof Types

Table A-1, *Default Roof and Wall Types,* presents a default roof type that has been defined for each ES building type.

4.1.3.1.2 Type of Glass on the ES

SAFER queries the user to describe the type of glass present at the ES. Types of glass considered by SAFER Version 3.0 include:

- Annealed
- Dual-paned
- Tempered

4.1.3.1.3 Percentage of Glass on the ES

SAFER queries the user to identify the percentage of glass on all of the exterior walls of the ES (total glass area/total wall area), G_P. The range of acceptable values is 0% - 99%. If the ES is a vehicle, SAFER assumes there is no flying glass hazard, and sets the percentage of glass to 0%.

4.1.3.1.4 Floor Area of the ES

SAFER queries the user to input the floor area of the ES in square feet, FA_{ES}.

4.1.3.1.5 Orientation of the PES to the ES

If the PES building category is either an earth-covered magazine (ECM) or a hardened aircraft shelter (HAS), SAFER queries the user to describe the orientation of the PES relative to the ES. Valid orientation choices considered by SAFER Version 3.0 include:

- Front
- Side
- Rear

4.1.3.1.6 Distance between the PES and the ES

SAFER queries the user to input the distance, d, between the PES and ES in feet.

4.1.3.1.7 Exposure data at the ES

SAFER queries the user to enter the number of people at the ES, the relationship of the people in the ES to the PES (related or public), the number of hours the people are present at the ES, and the percentage of time that people are present at the ES when explosives are present at the PES. The user is also prompted to enter the largest number of person exposed at any time during the year. The values are used to calculate the personnel exposure. Section 2.4 discusses inputs and calculations for exposure.

4.1.3.1.8 ES Barricade Information

If an ES barricade is present, SAFER queries the user to enter the height of the barricade, *h2*, and the distance between the barricade and the exposed site (*d1*). Since the barricade is an ES barricade, the distance between the ES and the barricade must be less than the distance between the PES and the barricade.

4.1.3.2 Step 3b: Calculation of Personnel Exposure at the ES

Exposure data are entered for the Exposed Site (ES) in groups of one or more people having similar levels of exposure. The data needed for each group are the number of people present at the ES, the number of hours they are present during the year, and the percentage of that time that the PES is operating (housing explosives). The number of hours the PES operates in a typical year is also needed, but is implemented in SAFER as a lookup table (Table 3) based on the activity type at the PES. An example exposure computation is shown in Section 4.1.3.2.3.

4.1.3.2.1 Δt, Fraction of PES Operating Year with Exposures

The lognormal statistical distribution $\Delta t \sim LN(\Delta t_o, \sigma_{\Delta t})$ is defined by its median, Δt_o, and its standard deviation, $\sigma_{\Delta t}$. This section provides the equations used to calculate these two parameters when computing both Group and Individual Risk.[1]

The Δt_o is first calculated for each group as:

$$\Delta t_{\,people\ group} = AHrs\ at\ ES_{group} * \%\ ES\ Hrs_{explosives} \,/\, PES\ Annual\ Operating\ Hrs \tag{6}$$

where $AHrs\ at\ ES_{group}$ is the number of hours per year that the group is at the ES, $\%\ ES\ Hrs_{explosives}$ is the percentage of the hours that the group spends at the ES that explosives are also present at the PES, and *PES Annual Operating Hrs* is the typical number of hours per year that the PES is expected to house explosives based user input (from Step 2). The Δt_o used for computing Group Risk at the ES is then calculated as:

$$\Delta t_{o\ Group} = \Sigma\, \Delta t_{people\ group} \tag{7}$$

and the Δt_o used for computing Individual Risk at the ES is:

$$\Delta t_{o\ Individual} = \text{Maximum }\{\ \Delta t_{people\ group}\text{: across all people groups at the ES}\} \tag{8}$$

---

[1] In this section, the Individual Risk is defined as the risks to an individual in an ES from a specific PES. The Group Risk is defined as the sum of all the individual risks in an ES from a specific PES.

The computation of $\sigma_{\Delta t}$ assumes the possibility that exposure at the ES could exist at all times when explosives are housed at the PES. This assumption results in an Upper Limit of 1.0 for Δt that applies to both Group and Individual Risk computations. The equation used to compute $\sigma_{\Delta t}$ is then:

$$\sigma_{\Delta t} = \ln(\ UB_{\Delta t} \ /\ \Delta t_o\ )\ /\ 3 = \ln\ (\ 1.0\ /\ \Delta t_o\ )\ /\ 3 \qquad (9)$$

It should be noted that the value of $\Delta t_{o\ Group}$ is not allowed to exceed 1.0. This value indicates that exposures are present at all times during the year when explosives are housed at the PES. People groups should be defined so that group exposure times do not overlap. If the user were to erroneously input people groups whose exposure times overlapped, scenarios could exist where the standard calculation of $\Delta t_{o\ Group}$ results in values greater than 1.0. In these cases, SAFER resets the value to 1.0.

We have determined the parameters Δt_o and $\sigma_{\Delta t}$ that define the lognormal distribution $\Delta t \sim LN(\Delta t_o, \sigma_\Delta)$. This distribution is used in the SAFER model of the world to compile the Risk Distribution.

4.1.3.2.2 E_o , Daily Exposures

The lognormal statistical distribution $E_o \sim LN(E_{oo},\ \sigma_e\ )$ is defined by its median, E_{oo}, and its standard deviation, σ_e. This section provides the equations used to calculate these two parameters when computing both Group and Individual Risk.

The average daily number of exposures is first calculated for each people group as:

$$Exposure_{\ people\ group} = Number\ of\ People * \Delta t_{\ people\ group} \qquad (10)$$

where,

Number of People = the quantity of people input by the user for that group

$\Delta t_{\ people\ group}$ = the $\Delta t_{\ people\ group}$ computed for that group as described in Section 4.1.3.2.1.

The E_{oo} used for computing group risk at the ES is then calculated as:

$$E_{oo\ Group} = \Sigma\ (Exposure_{\ people\ group}\ )\ /\ \Sigma\ (\Delta t_{\ people\ group}\ ) \qquad (11)$$

and the E_{oo} used for computing individual risk at the ES is:

$$E_{oo\ Individual} = 1.0 \text{ (by definition)} \qquad (12)$$

The value of σ_e used to compute Group Risk is computed using the Upper Limit (*UL*) on the Number of People Exposed input by the user and the E_{oo} calculated. The equation used is:

$$\sigma_{e\ Group} = \ln(\ UL_{\Delta t} \ /\ E_{oo}\ )\ /\ 3 \qquad (13)$$

The σ_e used to compute Individual Risk uses an Upper Limit of 1.0 resulting in:

$$\sigma_{e\ Individual} = \ln\ (1.0\ /\ 1.0)\ /\ 3 = 0.0 \text{ (also by definition)} \qquad (14)$$

4.1.3.2.3 Exposure Example

In this example there are six groups of *public* personnel operating at the same ES shown in Table 4. The groups have 10, 5, 6, 8, 9, and 5 people who are present 2080, 500, 350, 156, 750.5, and 654 hours per year respectively.

Table 4. Exposure Example

People Group	Number of People	Annual Hours at ES	% of ES Hours that PES has explosives	Annual Hours Exposed	PES Operating Hours	ES Exposure as % of Operating Year (Δt)	Group Exposure per Operating Year
1	10	2080	50%	1040	1560	0.667	6.667
2	5	500	10%	50	1560	0.032	0.160
3	6	350	20%	70	1560	0.045	0.269
4	8	156	10%	15.6	1560	0.010	0.080
5	9	750.5	25%	187.625	1560	0.120	1.082
6	5	654	75%	490.5	1560	0.314	1.572
Total				1853.7	1560	1.188	9.831
Maximum Individual Exposure						0.667	

The exposure for each people group is first determined by computing the $\Delta t_{people\ group}$ and $Exposure_{people\ group}$ for each group as described in sections 4.1.3.2.1 and 4.1.3.2.2 above. The four parameters that define the Exposure related distributions are then computed as:

For Group Risk:

$$\Delta t_{o\ Group} = \Sigma\, \Delta t_{people\ group} = 1.188 \text{ which is reset to the maximum value of } 1.000$$

$$\sigma_{\Delta t} = \ln(\ UB_{\Delta t} / \Delta t_o\ ) / 3 = \ln\ (\ 1.0 / 1.0\ ) / 3 = 0.000$$

$$E_{oo\ Group} = \Sigma\ (\text{Exposure}_{\text{people group}}) / \Sigma\ (\Delta t_{\text{people group}}) = 9.831 / 1.118 = 8.27$$

and, assuming the user input a value of 10 for the Upper Limit on the number of personnel present at the ES at any time, then

$$\sigma_{e\ Group} = \ln(\ UL_{\Delta t} / E_{oo}\ ) / 3 = \ln(\ 10 / 8.27\ ) / 3 = 6.3\text{E-}02$$

For Individual Risk:

$$\Delta t_{o\ \text{Individual}} = \text{Maximum}\ \{\ \Delta t_{\text{people group}}\ \} = 0.667$$

$$\sigma_{\Delta t\ Individual} = \ln(\ UB_{\Delta t} / \Delta t_o\ ) / 3 = \ln\ (\ 1.0 / 0.667\ ) / 3 = 1.35\text{E-}01$$

$$E_{oo\ Individual} = 1.0 \text{ (by definition)}$$

$$\sigma_{e\ Individual} = \ln\ (1.0 / 1.0) / 3 = 0.0 \text{ (also by definition)}$$

The parameters E_{oo} and σ_e that define the lognormal distribution $E_o \sim LN(E_{oo},\sigma_e)$ have been determined. This distribution is used in the SAFER model of the world to compile the Risk Distribution.

Rationale for the selection of the SAFER input menus is detailed in Attachment 3.

Outputs of Step 3:

- ES building type
- ES roof type
- Type of glass on the ES
- Percentage of glass on the ES (%), G_P
- Floor area of the ES (ft^2), FA_{ES}
- Orientation of the PES to the ES
- Barricade height, $h2$
- Distance between the barricade and the ES, $d1$
- Distance between the PES and ES (ft), d
- Median, E_{oo}, and standard deviation, σ_e, of Exposure distribution

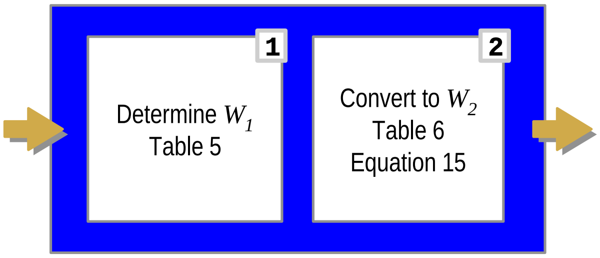
4.1.4 STEP 4: Calculate yields.

Step 4 calculates explosives yield values that will be used in subsequent steps.

This process is performed twice, first for the sited NEWQD and second for the expected NEWQD using parameters in Table 5, *Determination of* W_1, below.

Inputs to Step 4:

- NEWQD (lbs) [from Step 1], sited and expected NEWQD
- Hazard Division, HD [from Step 1]
- Weapon type [from Step 1]



Given the NEWQD, HD, and weapon type, calculate the yield[2] of the event, W_1, based on the instructions presented in Table 5, *Determination of* W_1. Rationale for the instructions presented in Table 5 is detailed in Attachment 3.

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[2] The terms "yield" and "weight" are mathematically equivalent throughout Section 4.0. The parameters are referred to by the term most appropriate for the context based upon common usage.

Table 5. Determination of W_1

Type	Sited or Maximum Yield (NEWQD)	Expected Yield (NEWQD)
1.1	100% of NEWQD	80% of NEWQD
1.2.1	Greater of: 50% of total NEWQD OR one M1-105 mm projectile	Greater of: 3% of total NEWQD OR 11% of one M1-105 mm projectile
1.2.2	Greater of: 50% of total NEWQD OR one MK 2 40 mm projectile	Greater of: 3% of total NEWQD OR 11% of one MK 2 40 mm projectile
1.2.3	One item (MK82)	11% of one item (MK82)
1.3	100%	100%
1.5	100%	80%
1.6	One item (MK82)	11% of one item (MK82)

Calculate the equivalent NEW, W_2, by:

$$W_2 = W_1 * TNT\ conversion\ factor \tag{15}$$

where the *TNT conversion factor* is taken from Table 6, *TNT Conversion Factors*. Rationale for explosive types and TNT conversion factors presented in Table 6 is detailed in Attachment 3.

Table 6. TNT Conversion Factors

Weapon Type	Explosive Type	TNT Conversion Factor*
MK82	Tritonal	1.07
M107	Composition B	1.11
Bulk/light case	TNT	1.0
MK83	Tritonal	1.07
MK84	Tritonal	1.07
AIM-7 Missile	Tritonal	1.35
M1 105 mm projectile	Composition B	1.11
40 mm projectile	Composition B	1.0

Notes: *assumes "TNT equivalence" does not vary with distance
** A TNT conversion factor of 1.0 is applied to HD 1.3 (bulk propellant).

Outputs of Step 4:

- Yield of the event (lbs), W_1
- Equivalent NEW (lbs), W_2

4.2 Group 2 Steps: Pressure and Impulse Branch

Group 2 includes Steps 5-8 of the SAFER architecture. These steps determine the effect of the fatality mechanisms of pressure and impulse. This branch applies to HD 1.1, 1.2.1, 1.2.2, 1.2.3, 1.5, and 1.6 scenarios.

Steps 5-7 calculate the pressures and impulses for the situation. Unmodified pressure and impulse values are calculated in Step 5. These values take into account only the effect of the weapon type – not the presence of a PES or an ES. Step 6 then adjusts the unmodified values to account for the PES, if a structure is present. A further adjustment is made due to the presence of an ES in Step 7.

Finally, Step 8 determines the probability of fatality due to the effects of pressure and impulse, $P_{f(o)}$. If no PES or ES is present in the situation, fatalities are based on pressure and impulse values determined in Step 5. If the situation includes a PES but no ES, fatalities are based on pressure and impulse values determined in Step 6. If the situation includes an ES, fatalities are based on pressure and impulse values determined in Step 7.

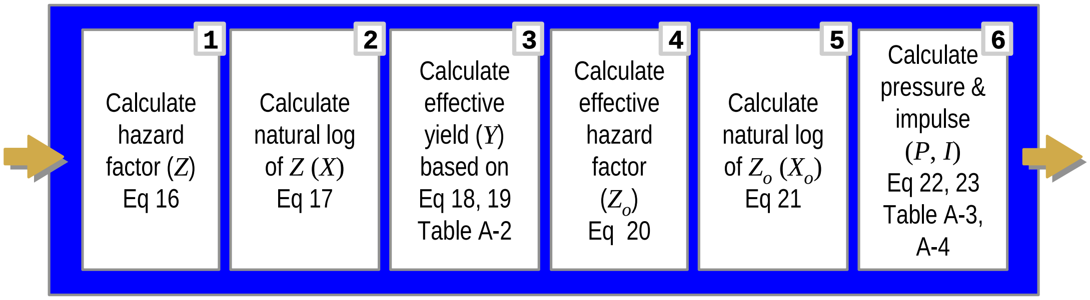
To enhance readability, selected reference tables of constants used in the Group 2 steps are located in Appendix A.

4.2.1 STEP 5: Determine open-air Pressure, Impulse (P, I).

Step 5 calculates the unmodified, or open-air pressure, P, and impulse I. Values for pressure and impulse are based on simplified Kingery-Bulmash hemispherical TNT equations (Ref 5).

Inputs to Step 5:

- Yield of the event (lbs), W_1 [from Step 4]
- Distance between the PES and ES (ft), d [from Step 3]
- Weapon type [from Step 1]



Pressure and impulse values for weapon types that are not classified as *bulk/light case* are based on the effective yield, Y. For *bulk/light case* weapon types, the pressure and impulse is calculated based on the effective yield, however, the effective yield is equal to the yield of the event. The following procedures are used to calculate effective yield and then open-air pressure and impulse.

Substep 1

Calculate the hazard factor,[3] Z, by:

$$Z = \frac{d}{(W_1)^{\frac{1}{3}}} \tag{16}$$

Substep 2

Given the value of Z from Eq. (16), calculate X as the natural log of the hazard factor:

$$X = \ln(Z) \tag{17}$$

---

[3] The hazard factor is also known as the scaled range or *K factor* in usage and literature.

Substep 3

Calculate the effective yield, Y. This is done by consulting Table A-2, *Effective Yield*, and selecting an appropriate method based on weapon type and scaled range (hazard factor). For some combinations of weapon type and scaled range, Table A-2, *Effective Yield*, provides the equation for Y in the form:

$$Y = C_1 * (W_1 / C_2) \tag{18}$$

where C_1 and C_2 are constants given in the table. For the remaining combinations of weapon type and scaled range, Table A-2, *Effective Yield*, provides the coefficients A, B, C, D, E, and F to be used in the following equation for Y:

$$Y = \left(\frac{W_1}{NEWQD\, of\ one\, weapon} \right) * e^{\left(A + B*X + C*X^2 + D*X^3 + E*X^4 + F*X^5\right)} \tag{19}$$

where the NEWQD of one weapon is provided in Table 12, *Primary Fragment Distribution by Mass Bins.*

Substep 4

Calculate the effective hazard factor, Z_o, by:

$$Z_o = \frac{d}{(Y)^{\frac{1}{3}}} \tag{20}$$

Substep 5

Calculate X_o as the natural log of the effective hazard factor by:

$$X_o = \ln(Z_o) \tag{21}$$

Substep 6

With the values of Z_o and X_o known, the unmodified values of pressure (psi) and impulse (psi-ms) can be determined.

Calculate unmodified pressure, P, by:

$$P = e^{(A + B*X_o + C*X_o{}^2 + D*X_o{}^3 + E*X_o{}^4)} \tag{22}$$

where the coefficients A, B, C, D, and E are provided in Table A-3, *Pressure Calculation Coefficients*, based on the range of Z_o.

Calculate unmodified impulse, I, by:

$$I = e^{(A + B*X_o + C*X_o{}^2 + D*X_o{}^3 + E*X_o{}^4)} * Y^{\frac{1}{3}} \tag{23}$$

where the coefficients A, B, C, D, and E are provided in Table A-4, *Impulse Calculation Coefficients*, based on the range of Z_o.

Rationale for this methodology to determine unmodified pressure and impulse is detailed in Attachment 4.

Outputs of Step 5:

- Unmodified pressure (psi), P
- Unmodified impulse (psi-ms), I

4.2.2 STEP 6: Adjust P, I due to PES.

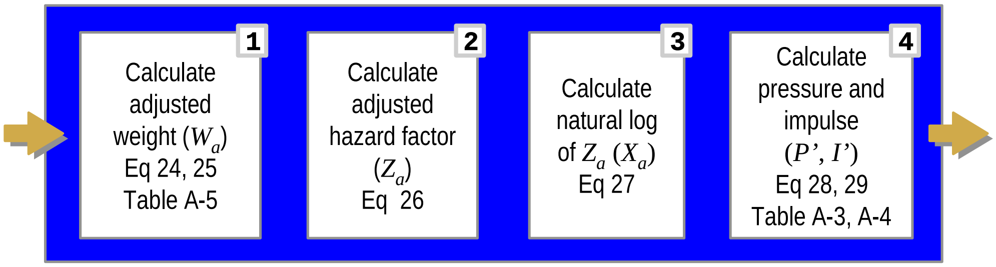
Step 6 performs two functions in SAFER. In Step 6a, SAFER calculates the pressure, P', and impulse, I', outside of the PES. Section 4.2.2.1. describes this process. In Step 6b, SAFER determines the damage to the PES by calculating percentages of the PES roof and walls that remain intact following an explosive event as described in Section 4.2.2.2.

Inputs to Step 6:

- Yield of the event (lbs), W_1 [from Step 4]
- Equivalent NEW (lbs), W_2 [from Step 4]
- Distance between the PES and ES (ft), d [from Step 3]
- Orientation of PES to ES [from Step 3]
- Effective hazard factor, Z_o [from Step 5]
- Natural log of effective hazard factor, X_o [from Step 5]
- PES building type [from Step 2]

4.2.2.1 Step 6a: Adjust P, I

This step calculates the pressure and impulse values outside of the PES. To perform the required calculations, SAFER uses the same logic as the Blast Effects Computer to determine an effective yield (Ref 6). Adjustments are not required if there is not a PES structure (i.e. open) or if the PES selected is a pre-engineered metal building or hollow clay tile building.



Substep 1

Calculate the adjusted weight, W_a. This is done by consulting Table A-5, *Adjusted Weight Coefficients*, and selecting an applicable method based on PES building type, the effective hazard factor (Z_o), and the orientation of the PES to the ES (when appropriate). For some combinations of weapon type and scaled range, Table A-5, *Adjusted Weight Coefficients*, provides the equation for W_a in the form:

$$W_a = c * W_1 \tag{24}$$

where *c* is a constant given in the table. For the remaining combinations of PES building type, the effective hazard factor (Z_o), and orientation, Table A-5, *Adjusted Weight Coefficients*, provides the coefficients *A*, *B*, *C*, *D*, *E*, *F*, *G*, and *H* to be used in the following equation for W_a:

$$W_a = W_1 * e^{\left(A+B*X_o+C*X_o^2+D*X_o^3+E*X_o^4+F*X_o^5+G*X_o^6+H*X_o^7\right)} \tag{25}$$

Substep 2

Calculate the adjusted hazard factor, Z_a, by:

$$Z_a = \frac{d}{(W_a)^{\frac{1}{3}}} \tag{26}$$

Substep 3

Calculate X_a as the natural log of the adjusted hazard factor by:

$$X_a = \ln(Z_a) \tag{27}$$

Substep 4

With the values of Z_a and X_a known, the adjusted values of pressure and impulse can be determined. The equations SAFER uses to calculate these values are in the same form as those used in Step 5.

Calculate adjusted pressure, P', by:

$$P' = e^{(A+B*X_a+C*X_a^2+D*X_a^3+E*X_a^4)} \tag{28}$$

where the coefficients *A*, *B*, *C*, *D*, and *E* are provided in Table A-3, *Pressure Calculation Coefficients*, based on the range of Z_a. For “open” PES cases, *P’* is set to the *P* value from Step 5.

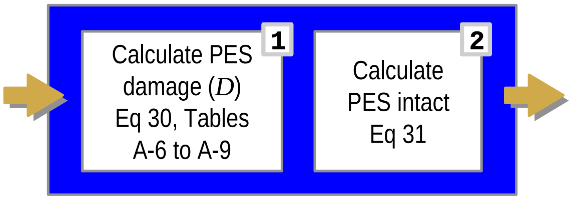
Calculate adjusted impulse, I'(psi-ms), by:

$$I' = e^{(A+B*X_a+C*X_a^2+D*X_a^3+E*X_a^4)} * W_a^{\frac{1}{3}} \tag{29}$$

where the coefficients *A*, *B*, *C*, *D*, and *E* are provided in Table A-4, *Impulse Calculation Coefficients*, based on the range of Z_a. For “open” PES cases, *I’* is set to the *I* value from Step 5.

4.2.2.2 Step 6b: Calculate PES Intact

The fraction of the PES intact is a function of the equivalent NEW (W_2) and the PES building type.



Substep 1

The fractional damage (a value between 0 and 1) of each PES component (roof, front wall, side walls, and rear wall) is determined. Calculate the fractional damage, PES_{damage}, by:

```
For $i$ = 1 to 4
    PES Component $i$:
    If $W_2 < Y_0$,
     Then $PES_{damage(i)} = 0$
    Else If $Y_0 \le W_2 \le Y_{100}$,
     Then
        $PES_{damage(i)} = a * (W_2 - Y_0)^b$        (30)
    Else $PES_{damage(i)} = 1$
    End If
Next $i$,
```

where $a = 1/(Y_{100} - Y_0)^b$, and the constants Y_0, Y_{100}, and b are provided in the appropriate table for the PES component: Table A-6, *Damage Coefficients for the PES Roof*; Table A-7, *Damage Coefficients for the PES Front Wall*; Table A-8, *Damage Coefficients for the PES Side Walls*; Table A-9, *Damage Coefficients for the PES Rear Wall*. Coefficients in the tables are based on the PES building type.

Outputs of *Substep 1*:

- Fraction of PES roof damaged, $PES_{damage(roof)}$
- Fraction of PES front wall damaged, $PES_{damage(fw)}$
- Fraction of PES side walls damaged, $PES_{damage(sw)}$
- Fraction of PES rear wall damaged, $PES_{damage(rw)}$

Substep 2

For each PES component, calculate the fraction PES intact following the explosives event, PES_{intact}, by:

```
For $i$ = 1 to 4
    PES Component $i$:
    $PES_{intact(i)} = 1 - PES_{damage(i)}$        (31)
Next $i$,
```

Outputs of *Substep 2*:

- Fraction of PES roof intact, $PES_{intact(roof)}$
- Fraction of PES front wall intact, $PES_{intact(fw)}$
- Fraction of PES side walls intact, $PES_{intact(sw)}$
- Fraction of PES rear wall intact, $PES_{intact(rw)}$

The following assumptions are made with respect to PES damage calculations:

- No blast paneling or other venting/containment measures are considered except where an earth-covered magazine (ECM) or hardened aircraft shelter (HAS) orientation is considered.
- Dimensions used in modeling the PES types in SAFER are presented in Table 7, *PES Assumptions*.

Table 7. PES Assumptions

PES Type	Length (ft)	Width (ft)	Height (ft)	Volume (ft^3)
Pre-engineered metal building	72	36	12	31,104
Hollow Clay Tile	72	36	12	31,104
HAS	120	66	29	229,680
Large Concrete Arch ECM	80	25	12.5	25,000
Medium Concrete Arch ECM	60	25	12.5	18,750
Small Concrete Arch ECM	40	25	12.5	12,500
Large Steel Arch ECM	80	25	12.5	25,000
Medium Steel Arch ECM	60	25	12.5	18,750
Small Steel Arch ECM	40	25	12.5	12,500
Large AGBS	62.67	86.33	25	135,258
Medium AGBS	66.33	66.33	24.42	107,440
Small AGBS (Square)	48	48	16	36,864
Medium Concrete Building	66.33	66.33	24.42	107,440
Small Concrete Building	48	48	16	36,864
Ship (large)	200	45	67	603,000
Ship (medium)	150	45	67	452,250
Ship (small)	100	30	50	150,000
ISO Container	20	8	8.5	1,360

Rationale for the methodology used in this substep is detailed in Attachment 4.

Outputs of Step 6:

- Adjusted pressure (psi), P'
- Adjusted impulse (psi-ms), I'
- Adjusted weight (lbs), W_a
- Adjusted scaled distance (ft), Z_a
- Fraction of PES roof intact, $PES_{intact(roof)}$
- Fraction of PES front wall intact, $PES_{intact(fw)}$
- Fraction of PES side walls intact, $PES_{intact(sw)}$
- Fraction of PES rear wall intact, $PES_{intact(rw)}$
- Fraction of PES roof damaged, $PES_{damage(roof)}$
- Fraction of PES front wall damaged, $PES_{damage(fw)}$
- Fraction of PES side walls damaged, $PES_{damage(sw)}$
- Fraction of PES rear wall damaged, $PES_{damage(rw)}$

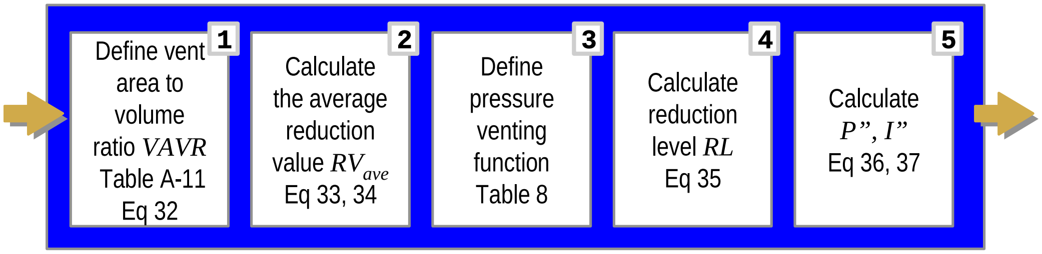
4.2.3 STEP 7. Adjust P, I (due to ES).

In Step 7, SAFER calculates the final pressure, P'', and final impulse, I'', values inside the ES. Given the adjusted pressure, P', and impulse, I', outside of the PES as determined in Step 6, another adjustment is made to determine the pressure and impulse inside the ES. If the situation has exposed personnel in the open, this adjustment is not made because there is no structure to reduce the pressure and impulse.

Inputs to Step 7:

- ES building type [from Step 3]
- Percentage of glass on the ES (%),G_P [from Step 3]
- Floor area of the ES (ft^2), FA_{ES} [from Step 3]
- Adjusted pressure (psi), P'[from Step 6]
- Adjusted impulse (psi-ms), I'[from Step 6]
- Adjusted weight (lbs), W_a [from Step 6]

The following 5 substeps describe this process.



Pressure and impulse reductions are determined from a pressure reduction function containing two line segments as illustrated in Figure 4.

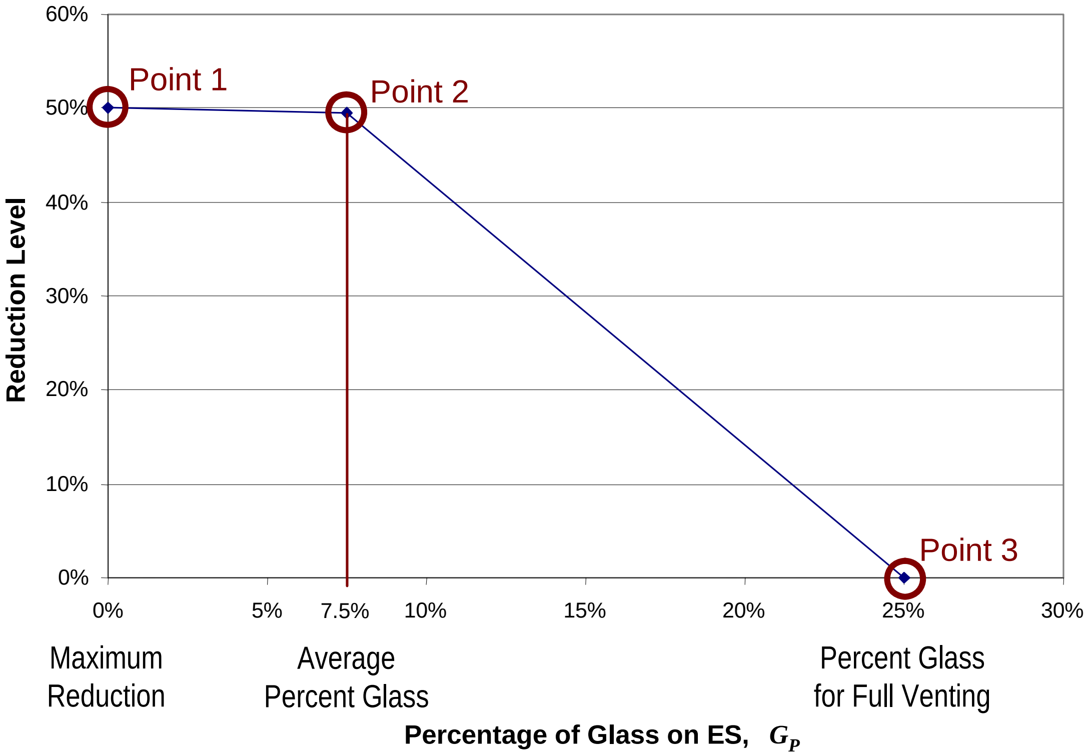


Figure 4. Reduction Function

The two line segments are defined by the three points characterized in Table 8 *Pressure Reduction Function Parameters*.

Table 8. Pressure Reduction Function Parameters

	Glass Fraction	Reduction Level
Point 1	0	Max Reduction (from Table A-11)
Point 2	Glass Fraction for Average Protection (from Table A-11)	*RVave* (calculated using Eq. (33) or (34))
Point 3	Glass Fraction for Full Venting (from Table A-11)	0

Substep 1

Calculate the vent area to building volume ratio, *VAVR*, by:

$$VAVR = \frac{(2.5\% + G_P)}{100} \div (FA_{ES} * ES\ height) \tag{32}$$

where *ES height* is taken from Table A-11, *Pressure and Impulse Reduction Values due to Glass Percentage*.

Substep 2

Calculate the average reduction value, RV_{ave}. If the *VAVR* is greater than 0.005, calculate the average reduction value by:

$$RV_{ave} = 0.3 * W_a^{\ 0.095} * P'^{-0.32} \tag{33}$$

If the *VAVR* is less than 0.005, calculate the average reduction value by:

$$RV_{ave} = (0.3 * W_a^{\ 0.095} * P'^{-0.32}) * (0.395 + 0.0568 * \log_{10}(W_a)) \tag{34}$$

Substep 3

The RV_{ave} calculated in Substep 2 is used to complete the definition of the 3 points of the pressure reduction function in Table 8, *Pressure Reduction Function Parameters*.

Substep 4

The reduction level, *RL*, is dependent on the percentage of glass that is entered by the user. The entered percentage of glass is compared to the average protection (shown in Table A-11, *Pressure and Impulse Reduction Values due to Glass Percentage*) to determine which line segment of the pressure reduction function (shown in Figure 4) is applicable. Then, using the line segment defined in Table 8 and the calculated average reduction level, the equation of the line is determined in the form:

$$RL = \left(slope * \frac{G_P}{100} \right) + y - intercept \tag{35}$$

Substep 5

This reduction level is used to calculate P'' and I''.

Calculate final pressure, P'', by:

$$P'' = (1 - RL) * P' \tag{36}$$

For “open” ES cases, *P”* is set to the *P’* value from Step 6.

Calculate final impulse, I'', by:

$$I'' = (1 - RL) * I' \tag{37}$$

For “open” ES cases, *I”* is set to the *I’* value from Step 6.

Rationale for the methodology used in this step is detailed in Attachment 4.

Outputs of Step 7:

- Final pressure (psi), P''
- Final impulse (psi-ms), I''

4.2.4 STEP 8: Assess $P_{f(o)}$, $P_{maji(o)}$, $P_{mini(o)}$.

Step 8 completes the Pressure and Impulse Branch by determining the probability of fatality, $P_{f(o)}$, probability of major injury, $P_{maji(o)}$, and probability of minor injury due to the effects of pressure and impulse, $P_{mini(o)}$. In determining the probability of fatality, major injury, and minor injury, SAFER calculates three consequences:

- Lung rupture
- Whole body displacement
- Skull fracture

Calculations in Step 8 are grouped in five parts. Step 8a performs additional pressure and impulse calculations; Step 8b determines the probability of fatality and injury from lung rupture; Step 8c determines the probability of fatality and injury from whole body displacement; Step 8d determines the probability of fatality and injury from skull fracture; and Step 8e aggregates all probabilities of fatality and injury to determine the overall probability of fatality and injury due to the effects of pressure and impulse, $P_{f(o)}$, $P_{maji(o)}$, and $P_{mini(o)}$

There are three potential input conditions:

Condition 1: Situation with no PES or ES

- Unmodified pressure (psi), P [from Step 5]
- Unmodified impulse (psi-ms), I [from Step 5]

Condition 2: Situation includes a PES but no ES

- Adjusted pressure (psi), P'[from Step 6]
- Adjusted impulse (psi-ms), I'[from Step 6]

Condition 3: Situation includes an ES

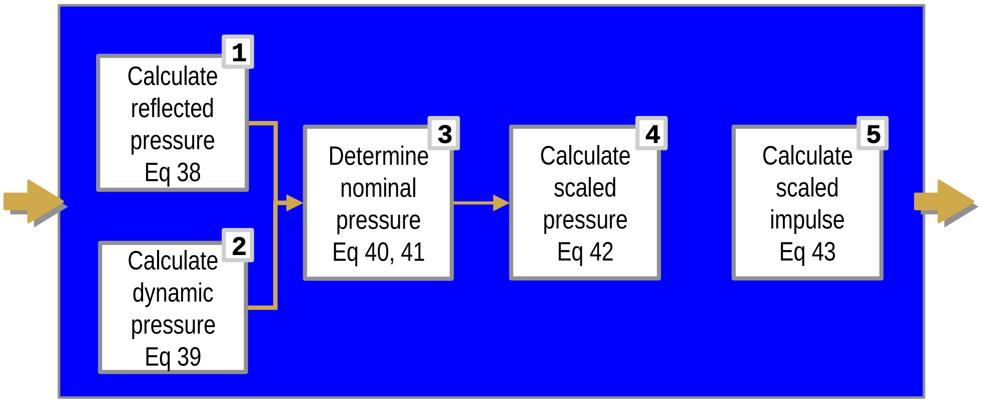
- Final pressure (psi), P''[from Step 7]
- Final impulse (psi-ms), I''[from Step 7]

With the values of pressure and impulse known (from Step 5, 6, or 7), the human vulnerability due to direct pressure and impulse effects is calculated.

SAFER considers the human vulnerability due to the effects of pressure and impulse to be a function of lung rupture, whole body displacement, or skull fracture (or the combination of the three). The probability of fatality due to lung rupture, body displacement, or skull fracture is based on the probit functions originally published by the Netherlands Organization for Applied Scientific Research TNO (Ref 9). Those functions determine the probability of fatality as a function of incident pressure and impulse, the ambient atmospheric pressure, and an assumed mass of the human body.

4.2.4.1 Step 8a: Pressure and Impulse Calculations

Prior to using the probit functions to determine the human vulnerability, SAFER must first calculate reflected pressure, dynamic pressure, nominal pressure, scaled pressure, and scaled impulse.



Substep 1

Calculate reflected pressure, $P_{reflected}$, by:

$$P_{reflected} = 2 * P'' * \left(\frac{(4 * P'') + (7 * P_{ambient})}{P'' + (7 * P_{ambient})} \right) \tag{38}$$

where the ambient pressure, $P_{ambient}$ is assumed to be 14.5 psi.

Substep 2

Calculate dynamic pressure, $P_{dynamic}$, by:

$$P_{dynamic} = \frac{2.5 * P''^2}{(7 * P_{ambient} + P'')} \tag{39}$$

where the ambient pressure, $P_{ambient}$ is assumed to be 14.5 psi.

Substep 3

If the ES in the situation is open, calculate the nominal pressure, $P_{nominal}$, by:

$$P_{nominal} = P'' + P_{dynamic} \tag{40}$$

otherwise, calculate the nominal pressure, $P_{nominal}$, by:

$$P_{nominal} = P_{reflected} = \frac{\left(2 * P'' * ((4 * P'') + (7 * P_{ambient}))\right)}{\left(P'' + (7 * P_{ambient})\right)} \tag{41}$$

Substep 4

Calculate the scaled pressure, P_{scaled}, by:

$$P_{scaled} = \frac{(P_{dynamic} * 6.895)}{(P_{ambient} * 0.001)} \tag{42}$$

Substep 5

Calculate the scaled impulse, I_{scaled}, by:

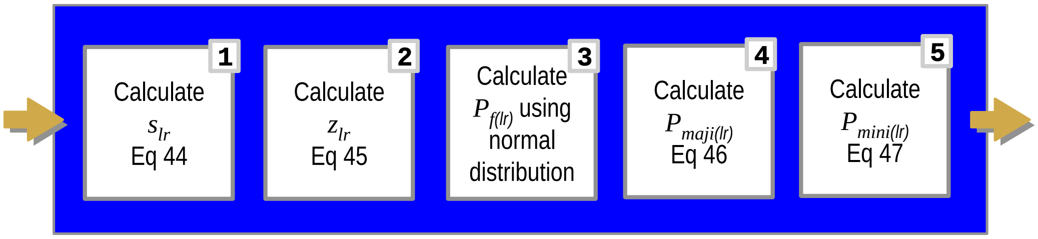
$$I_{scaled} = I'' * 0.005291 \tag{43}$$

where *I”* is from Step 7 and the constant is based on the conversion of pressure, time, and mass to the appropriate English units.

The parameters calculated in Step 8a are used as inputs to the remainder of Step 8 equations for calculating the probability of fatality or injury due to lung rupture, whole body displacement, and skull fracture.

4.2.4.2 Step 8b: Lung Rupture

Step 8b determines the probability of fatality and major and minor injuries resulting from lung rupture. This is accomplished by calculating the *s* and *z* parameters associated with a standard normal curve used in the TNO probit functions. The TNO probit functions are based on the standard normal distribution translated by subtracting 5 from the *z* value. However, SAFER uses the standard normal distribution without translation.



Substep 1

To determine the probability of fatality due to lung rupture, $P_{f(lr)}$, SAFER calculates s_{lr} by:

$$s_{lr} = \frac{4.2}{P_{scaled}} + \frac{1.3}{I_{scaled}} \tag{44}$$

Substep 2

Using the calculated s_{lr}, SAFER calculates z_{lr} by:

$$z_{lr} = -5.74 * \ln(s_{lr}) \tag{45}$$

Substep 3

Given the value calculated for z_{lr}, SAFER determines $P_{f(lr)}$ by using a normal distribution where $P_{f(lr)}$ is equal to the area under the standard normal distribution to the left of the z_{lr} value.

Substep 4

Using the pressure calculated from Step 7 (*P’’*), calculate the probability of a *major* injury from lung rupture ($P_{maji(lr)}$). The relationship between the pressure and the probability of major injury is estimated by curve-fitting actual data with the following linear function.

$$P_{maji\ (lr)} = 0.01 * P'' - 0.18 \tag{46}$$

Substep 5

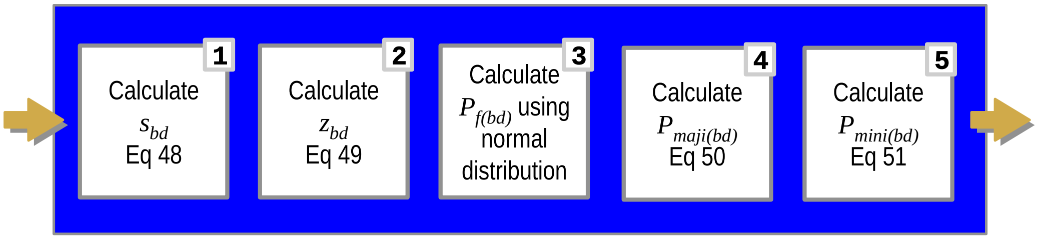
Using the pressure calculated from Step 7 (*P''*), calculate the probability of a *minor* injury from lung rupture ($P_{mini(lr)}$). The relationship between the pressure and the probability of minor injury is estimated by curve-fitting actual data with the following linear function.

$$P_{mini(lr)} = 0.032 * P'' - 0.046 \tag{47}$$

The probability of major injury and minor injury is based on available models and literature, as detailed Attachment 5.

4.2.4.3 Step 8c: Whole Body Displacement

Step 8c determines the probability of fatality, major injury, and minor injury resulting from whole body displacement. As in Step 8b, this is accomplished by calculating the *s* and *z* parameters associated with a standard normal distribution and the TNO probit functions.



Substep 1

To determine the probability of fatality due to body displacement, $P_{f(bd)}$, SAFER calculates s_{bd} by:

$$s_{bd} = \frac{7280}{(P_{nominal} * 6895)} + \frac{1.3 * 10^9}{((P_{nominal} * 6895) * (I'' * 6.895))} \tag{48}$$

where *I"* is from Step 7.

Substep 2

Using the calculated s_{bd}, SAFER calculates z_{bd} by:

$$z_{bd} = -2.44 * \ln(s_{bd}) \tag{49}$$

Substep 3

Given the value calculated for z_{bd}, SAFER determines $P_{f(bd)}$ by using a normal distribution where $P_{f(bd)}$ is equal to the area under the standard normal distribution to the left of the z_{bd} value.

Substep 4

Given the value for probability of fatality due to whole body displacement ($P_{f(bd)}$), SAFER determines the probability of a major injury from whole body displacement ($P_{maji(bd)}$).

$$P_{maji(bd)} = 1 - \exp(-7 * P_{f(bd)}) \tag{50}$$

Substep 5

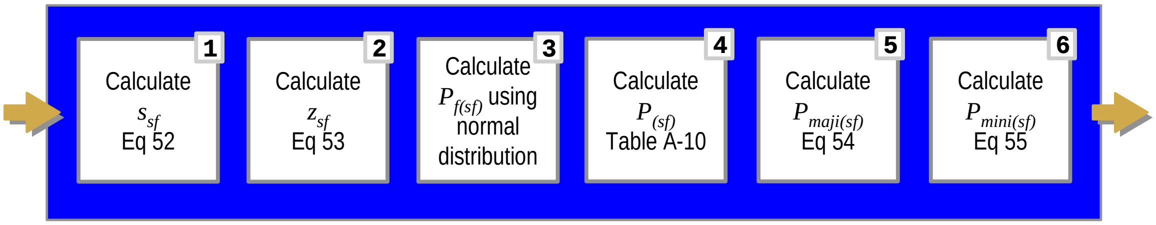
Given the value for probability of major injury from whole body displacement ($P_{maji(bd)}$), SAFER determines the probability of a minor injury from whole body displacement ($P_{mini(bd)}$).

$$P_{mini(bd)} = 1 - \exp(-7 * P_{maji(bd)}) \tag{51}$$

The probability of major injury and minor injury is based on available models and literature, as detailed Attachment 5.

4.2.4.4 Step 8d: Skull Fracture

Step 8d determines the probability of fatality, major injury, and minor injury resulting from skull fracture. As in Steps 8b and 8c, this is accomplished by calculating the *s* and *z* parameters associated with a standard normal distribution and the TNO probit functions.



Substep 1

To determine the probability of fatality due to skull fracture, $P_{f(sf)}$, SAFER calculates s_{sf} by:

$$s_{sf} = \frac{2430}{(P_{nominal} * 6895)} + \frac{4 * 10^8}{\left((P_{nominal} * 6895) * (I'' * 6.895)\right)} \tag{52}$$

Substep 2

Using the calculated s_{sf}, SAFER calculates z_{sf} by:

$$z_{sf} = -8.49 * \ln(s_{sf}) \tag{53}$$

Substep 3

Given the value calculated for z_{sf}, SAFER determines $P_{f(sf)}$ by using a normal distribution where $P_{f(sf)}$ is equal to the area under the standard normal distribution to the left of the z_{sf} value.

Substep 4

To determine the probability of major injury due to skull fracture, SAFER calculates the probability of skull fracture, $P_{(sf)}$. The probability of skull fracture uses the same hyperbolae interpolation methodology from Section 4.3.1.2, Substep 1. The skull fracture hyperbolae parameters are contained in Table A-10, *Pressure / Impulse Coefficients for* $P_{(sf)}$.

Substep 5

Given the value of probability of skull fracture, $P_{(sf)}$, the probability of *major* injury due to skull fracture, $P_{maji(sf)}$, is determined.

```
If $P_{(sf)} < 0.01$
 Then $P_{maji(sf)} = 0.25 \times P_{(sf)}$
Else                                                        (54)
 $P_{maji(sf)} = -1.34 \times P_{(sf)}^{2} + 2.09 \times P_{(sf)} + 0.25$
End If
```

Substep 6

Given the probability of major injury due to skull fracture, $P_{maji(sf)}$, calculate the probability of a *minor* injury from skull fracture ($P_{mini(sf)}$).

```
If $P_{maji(sf)} < 0.01$
 Then $P_{mini(sf)} = 10 \times P_{maj(sf)}$
Else                                                        (55)
 $P_{mini(sf)} = -1.34 \times P_{maji(sf)}^{2} + 2.09 \times P_{maji(sf)} + 0.25$
End If
```

The probability of major injury and minor injury is based on available models and literature, as detailed Attachment 5.

4.2.4.5 Step 8e: Aggregation of Consequences

Given the probability of fatality for skull fracture, whole body displacement, and skull fracture, calculate the probability of fatality due to the effects of pressure and impulse, $P_{f(o)}$, by:

$$P_{f(o)} = P_{f(lr)} + \left(\left(1 - P_{f(lr)}\right) * P_{f(bd)}\right) + \left(\left(1 - P_{f(lr)}\right) * \left(1 - P_{f(bd)}\right) * P_{f(sf)}\right) \tag{56}$$

Calculate the probability of major injury due to the effects of pressure and impulse, $P_{maji(o)}$, by:

$$P_{maji(o)} = P_{maji(lre)} + \left(\left(1 - P_{maji(lr)}\right) * P_{maji(bd)}\right) + \left(\left(1 - P_{maji(lr)}\right) * \left(1 - P_{maji(bd)}\right) * P_{maji(sf)}\right) \tag{57}$$

Calculate the probability of fatality due to the effects of pressure and impulse, $P_{mini(o)}$, by:

$$P_{mini(o)} = P_{mini(lr)} + \left(\left(1 - P_{mini(lr)}\right) * P_{mini(bd)}\right) + \left(\left(1 - P_{mini(lr)}\right) * \left(1 - P_{mini(bd)}\right) * P_{mini(sf)}\right) \tag{58}$$

Outputs of Step 8:

- Probability of fatality due to overpressure effects, $P_{f(o)}$
- Probability of major injury due to overpressure effects, $P_{maji(o)}$
- Probability of minor injury due to overpressure effects, $P_{mini(o)}$

4.3 Group 3 Steps: Structural Response Branch

Group 3 includes Steps 9-10 of the SAFER architecture. These steps analyze human vulnerability from building collapse and glass hazards.

Step 9 considers the effect of six human vulnerability mechanisms by calculating the probability of fatality, probability of major injury, and probability of minor injury due to window breakage, and the probability of fatality, probability of major injury, and probability of minor injury due to building collapse. Given these outputs, Step 10 calculates the probability of fatality due to overall building damage, $P_{f(b)}$, the probability of major injury due to overall building damage, $P_{maji(b)}$, and the probability of minor injury due to overall building damage, $P_{mini(b)}$.

To enhance readability, selected reference tables of constants used in the Group 3 steps are located in Appendix A.

4.3.1 STEP 9: Determine adjusted P, I effect on ES (building collapse and glass hazard).

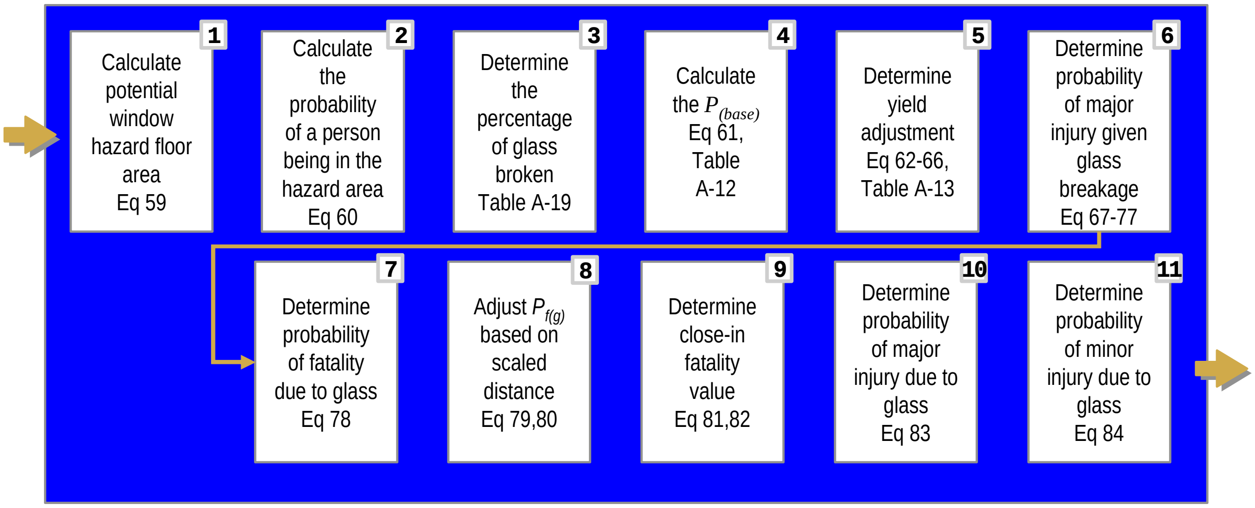
Step 9 performs three functions in SAFER. In Step 9a, SAFER calculates the probability of fatality due to window breakage, $P_{f(g)}$. Section 4.3.1.1 describes the procedures for this step. In Step 9b, SAFER calculates the probability of fatality due to building collapse, $P_{f(bc)}$. Section 4.3.1.2 describes the procedures for this step. In Step 9c, SAFER determines the damage to the ES by calculating percentages of the ES roof and walls that remain intact following an explosives event. Section 4.3.1.3 describes the procedures for this step.

Inputs to Step 9:

- ES building type [from Step 3]
- ES roof type [from Step 3]
- Type of glass on the ES [from Step 3]
- Distance between the PES and ES (ft), d [from Step 3]
- Percentage of glass on the ES (%), G_P [from Step 3]
- Floor area of the ES (ft^2), FA_{ES} [from Step 3]
- Adjusted pressure (psi), P' [from Step 6]
- Adjusted impulse (psi-ms), I' [from Step 6]
- Adjusted weight (lbs), W_a [from Step 6]
- Adjusted scaled distance (ft), Z_a [from Step 6]

4.3.1.1 Step 9a: Human vulnerability due to window breakage

This step determines the probability of fatality due to window breakage, $P_{f(g)}$, the probability of major injury due to window breakage, $P_{maji(g)}$, and the probability of minor injury due to glass breakage, $P_{mini(g)}$. To determine $P_{f(g)}$, SAFER calculates the probability of a person being in the glass hazard area followed by the probability of a major injury given that the person is in a glass hazard area. Finally, SAFER determines the probability of fatality based on the probability of major injury.



Substep 1

To determine the probability of a person being in the glass hazard area, SAFER calculates Potential Window Hazard Floor Area, *PWHFA*, by:

$$PWHFA = 22.5 * \left(\left(FA_{ES} * aspect\ ratio \right)^{1/2} + \left(FA_{ES} \div aspect\ ratio \right)^{1/2} \right) \qquad (59)$$

where the *aspect ratio* = 2 for all ES building types except *modular/trailers*. The *aspect ratio* = 3 for an ES building type of *modular/trailers*.

Substep 2

Calculate the probability of a person being in the glass hazard area, P_{gha}, by:

$$P_{gha} = \frac{G_P}{100} * \left(\frac{PWHFA}{FA_{ES}} \right) \qquad (60)$$

This equation simply represents the percentage of glass present multiplied by the ratio of the glass hazard area to the total area.

Substep 3

The pressure and impulse at the ES (P' and I') are used with stored Pressure-impulse diagrams to determine the percentage of glass broken, *% glass breakage* (Attachment 6). This method uses *P* and *I* coefficients from Table A-19, *Pressure-impulse Coefficients – Glass Breakage*, as described in Section 4.3.1.2, Substep 1.

Substep 4

To determine the probability of a major injury given that the person is in a glass hazard area, SAFER calculates the base probability of major injury, P_{base}, by:

$$P_{base} = M * \left(\%\, glass\, breakage \right)^{N} \qquad (61)$$

where the coefficients *M and N* are provided in Table A-12, *Power Curve Parameters for Major Injury as a Function of Glass breakage*, and are based on the type of glass on the ES.

Substep 5

The base probability of major injury, P_{base}, is associated with a fixed yield; therefore, it must be adjusted to the relative NEWQD experienced at the ES. A yield adjustment factor is calculated by:

$$Yield\,adjustment = (A * R) + B * G^{(C*R*S)} \tag{62}$$

where

$$R = \ln(Y_a / Y_n) \tag{63}$$

$$S = (Y_n / Y_a)^{\frac{1}{3}} \tag{64}$$

Y_a = W_a (lbs) from Step 6 (65)

Y_n = nominal yield = 50,000 (lbs)

$$G = 100 / \%\,glass\,breakage \tag{66}$$

Coefficients *A*, *B*, and *C* are provided in Table A-13, *Yield Adjustment Curve Parameters*, and are based on the type of glass on the ES.

Rationale for the yield adjustment curves and the associated parameters in this substep is detailed in Attachment 6.

Substep 6

SAFER Version 3.0 takes higher-velocity glass fragments into account for annealed or dual pane glass when the 100% glass breakage level is met or exceeded. For annealed and dual pane glass with less than 100% glass breakage and for tempered glass regardless of percent glass breakage, calculate the probability of a major injury given that the person is in the glass hazard area, P_{pha}, by:

$$P_{pha} = P_{base} * Yield\,adjustment \tag{67}$$

For annealed glass with 100% glass breakage, calculate the P_{pha} as follows:

Calculate the impulse-adjusted probability of major injury, *IA*, by:

$$IA = (8.1216 * Y_a^{0.015541}) * LN(I') - (18.103 * Y_a^{0.066969}) \tag{68}$$

To ensure a smooth transition region at the 100% glass breakage level, a continuity correction is introduced. Calculate the maximum continuity correction, CC_{max}, by:

$$CC_{max} = -0.337 + 0.26 * LN(Y_a) - 0.0103 * (LN(Y_a))^2 \tag{69}$$

Calculate the transition point, *TP*, by:

$$TP = exp(1.1924 + 0.66148 * LN(Y_a) - 0.010167 * (LN(Y_a))^2) \tag{70}$$

Calculate the actual continuity correction, CC_a, by:

$$CC_a = [(CC_{max} - 1) / TP] * d + 1 \tag{71}$$

Calculate the probability of major injury, P_{pha}, by:

$$P_{pha} = IA * CC_a \tag{72}$$

For dual pane glass with 100% glass breakage, calculate the P_{pha} as follows:

Calculate the impulse-adjusted probability of major injury, *IA*, by:

$$IA = (7.0757 * Y_a^{0.035394}) * LN(I') - (15.233 * Y_a^{00.086094}) \tag{73}$$

Calculate the maximum continuity correction, CC_{max}, by:

$$CC_{max} = -1.413 + 0.43 * LN(Y_a) - 0.0171 * (LN(Y_a))^2 \tag{74}$$

Calculate the transition point, *TP*, by:

$$TP = exp(0.89573 + 0.73204 * LN(Y_a) - 0.013288 * (LN(Y_a))^2 \tag{75}$$

Calculate the actual continuity correction, CC_a, by:

$$CC_a = [(CC_{max} - 1) / TP] * d + 1 \tag{76}$$

Calculate the probability of major injury, P_{pha}, by:

$$P_{pha} = IA * CC_a \tag{77}$$

Rationale for the yield adjustment curves and the associated parameters in this substep is detailed in Attachment 6.

Substep 7

SAFER uses the assumption that one glass fatality occurs per 30 major injuries. Therefore, SAFER calculates the initial probability of fatality due to window breakage, $P_{f(gi)}$, by:

$$P_{f(gi)} = P_{gha} * P_{pha} * \frac{1}{30} \tag{78}$$

Rationale for the methodology used in this substep is detailed in Attachment 6.

Substep 8

SAFER adjusts the $P_{f(gi)}$ based on the scaled distance. The glass adjustment, *G*, is calculated by:

$$G = 10.958 - 0.417 * Z_a \tag{79}$$

Then, the probability of fatality due to window breakage is calculated by:

$$P_{f(g)} = G * P_{f(gi)} \tag{80}$$

Rationale for the methodology used in this substep is detailed in Attachment 6.

Substep 9

If necessary, SAFER determines the probability of fatality due to glass in the "close-in" or transition region.

$$\begin{aligned} &\text{If } Z_a < R_1 \\ &P_{f(g)} = P_{f(g)1} \end{aligned} \tag{81}$$

```
Else If $Z_a \geq R_2$
 $P_{f(g)} = P_{f(g)}$ (from Substep 9)
Else If $R_1 \leq Z_a < R_2$
 $P_{f(g)} = P_{f(g)1} + P_{f(g)2} - [(Z_a - R_1) / (R_2 - R_1)]^2 * P_{f(g)1}$
End If
```

where R_1, R_2, $P_{f(g)1}$ are provided in Table 9, *Close-in Adjustment Parameters for Glass Fatality*, and are based on the type of glass on the ES. Then $P_{f(g)2}$ is calculated by:

$$P_{f(g)2} = (A + B \times \log_{10}(W_a)) \times (G_P/10\%) \times (5000/FA_{ES})^{1/2} \tag{82}$$

where A and B are provided in Table 9, *Close-in Adjustment Parameters for Glass Fatality*, W_a is from Step 5 or 6, G_P is from Step 3, and FA_{ES} is from Step 3.

Table 9. *Close-in Adjustment Parameters for Glass Fatality*

Window Type	R_1	R_2	$P_{f(g)2}$		$P_{f(g)1}$
			A	B	
Annealed	2	12	-0.00019264	0.00051619	10%
Dual Pane	5	12	-0.00010599	0.00078248	10%
Tempered	6	12	-0.00024899	0.00014097	10%

Substep 10

SAFER calculates the probability of major injury due to window breakage, $P_{maji(g)}$, by:

$$P_{maji(g)} = P_{f(g)} * 30 \tag{83}$$

Rationale for the methodology used in this substep is detailed in Attachment 5.

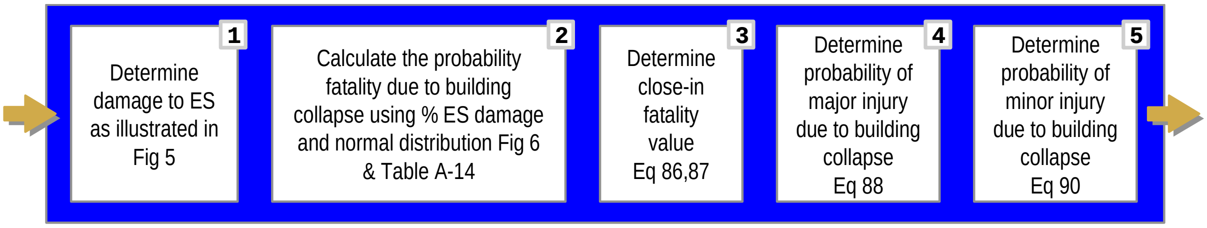
Substep 11

SAFER calculates the probability of minor injury due to window breakage, $P_{mini(g)}$, by:

$$P_{mini(g)} = P_{f(g)} * 500 \tag{84}$$

4.3.1.2 Step 9b: Human vulnerability due to building collapse

This step determines the probability of fatality due to building collapse, $P_{f(bc)}$, probability of major injury due to building collapse, $P_{maji(bc)}$, and probability of minor injury due to building collapse, $P_{mini(bc)}$.



Substep 1

ES damage is determined using standard pressure and impulse diagrams of the form shown in Figure 5 using the adjusted pressure, P', and adjusted impulse, I', from Step 6. Damage curves are hyperbolae, which are defined by the standard equation for a hyperbola:

$$C = (P - A) * (I - B) \tag{85}$$

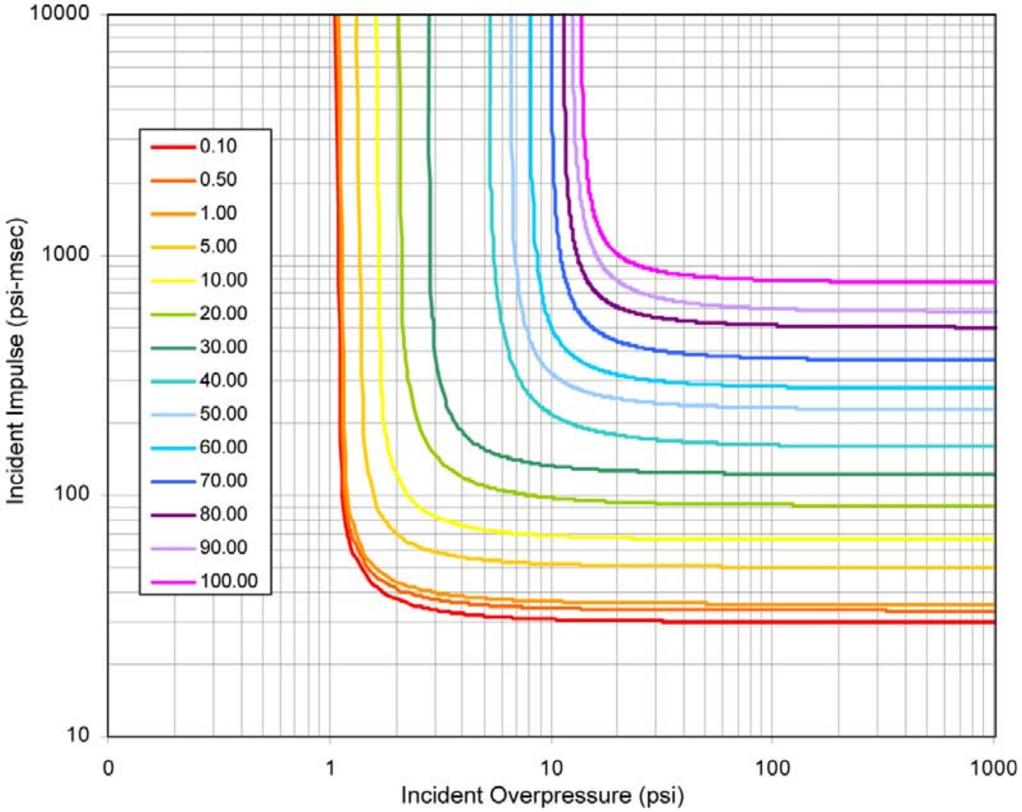


Figure 5. P-i Diagram Example

There are 16 families of these curves, one for each ES (Ref 10). Table A-17, *Pressure / Impulse Coefficients – ES Building Percent Damage*, provides the constants used to generate each family of hyperbolae. The damage to the ES is determined in SAFER using an interpolation routine. This interpolation results in the predicted ES building damage, PD_b.

Substep 2

Then, using the PD_b and the truncated normal distribution curves shown in Figure 6, the probability of fatality as a function of structural damage, $P_{f(bc)}$, is found. The parameters defining the truncated normal curves are shown in Table A-14, *Structure Damage / Fatality Normal Distribution Parameters*.

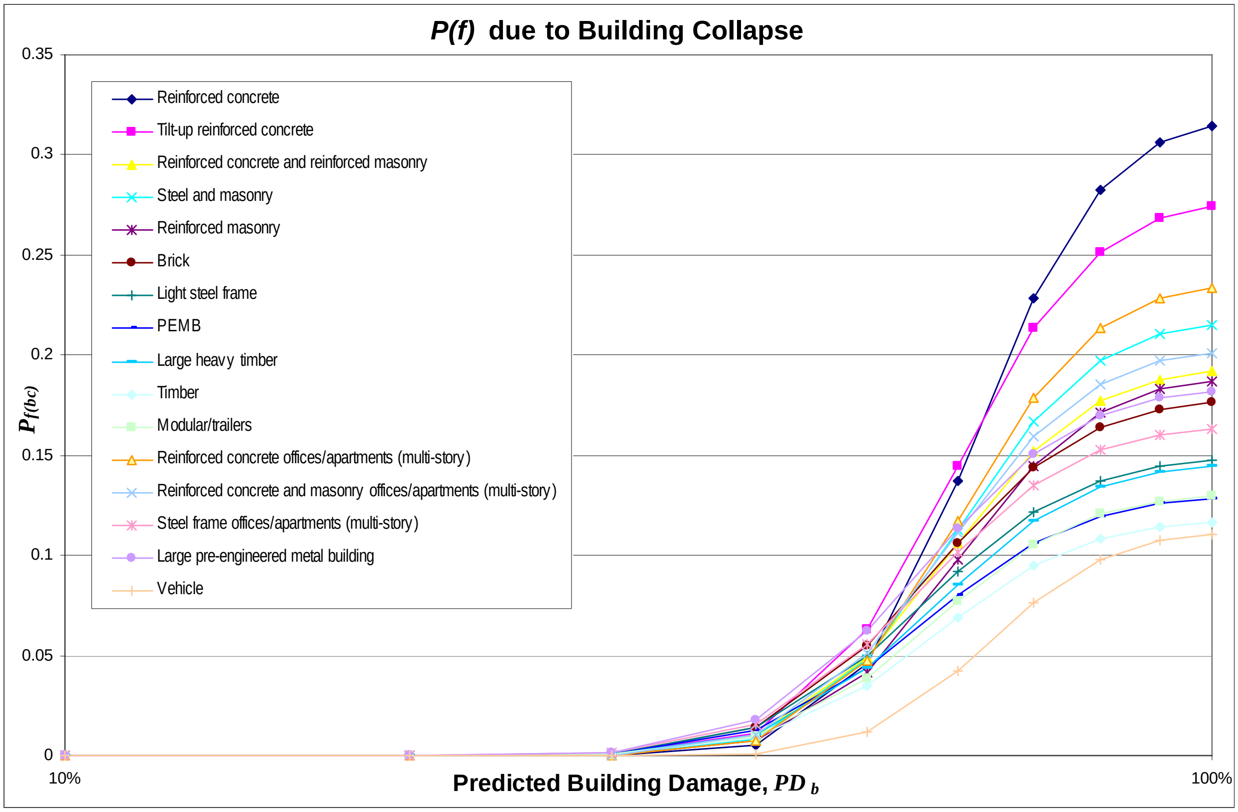


Figure 6. Building Collapse S-curves

Rationale for the methodology used in this substep is detailed in Attachment 7.

Substep 3

If appropriate, SAFER determines the probability of fatality due to building collapse in the "close-in" or transition region.

```
If $Z_a < R_1$
  $P_{f(bc)} = P_{f(bc)1}$
Else If $Z_a \geq R_2$
  $P_{f(bc)} = P_{f(bc)}$ (from Substep 2)                                    (86)
Else If $R_1 \leq Z_a < R_2$
  $P_{f(bc)} = P_{f(bc)1} + P_{f(bc)2} - [(Z_a - R_1) / (R_2 - R_1)]^2 * P_{f(bc)1}$
End If
```

where $P_{f(bc)1}$ and $P_{f(bc)2}$ are provided in Table A-15, Close-in Adjustment Parameters for $P_{f(bc)}$, R_1 is provided in Table A-16, Close-in Adjustment Parameters for Building Collapse Region Boundaries and R_2 is calculated by:

```
$R_2 = A + ((B \times W_a) / (C + W_a))$
If $R_2 > R_{2min}$
  Then $R_2 = R_2$
Else                                                                         (87)
  $R_2 = R_{2min}$
EndIf
```

where A, B, C and R_{2min} are provided in Table A-16, *Close-in Adjustment Parameters for Building Collapse Region Boundaries* and W_a is from Step 5 or 6.

Substep 4

SAFER calculates the probability of major injury due to building collapse, $P_{maji(bc)}$. First a nominal $P_{maji(bc)}$ is calculated by:

$$Nom.\ P_{maji(bc)} = [(maj_{(i)}PD - MINinjury) / (MAXinjury - maj_{(i)}DO) \times PD_b] - [(maj_{(i)}PD \times maj_{(i)}DO) / (MAXinjury - maj_{(i)}DO)] \qquad (88)$$

where the PD_b is from *Substep 1*, major injury damage offset, $maj_{(i)}DO$, and major injury plateau damage, $maj_{(i)}PD$, is from Table 10, *Major and Minor Injury Parameters for Building Collapse*. MAXInjury is a constant set to 100% and MINInjury is a constant set to 0.

An adjusted probability of major injury due to building collapse is determined by:

$$Adj.\ P_{maji(bc)} = IFR \times P_{f(bc)} \qquad (89)$$

where *IFR* is the injury to fatality ratio from Table 10, *Major and Minor Injury Parameters for Building Collapse*. A comparison is made between the $Nom.\ P_{maji(bc)}$ and $Adj.\ P_{maji(bc)}$. The variable with the highest value is assigned as the final $P_{maji(bc)}$.

Table 10. Major and Minor Injury Parameters for Building Collapse

ES Type	Major Injury		Minor Injury		Injury Fatality Ratio IFR
	Damage offset $maj_{(i)}DO$	Plateau damage $maj_{(i)}PD$	Damage offset $min_{(i)}DO$	Plateau damage $min_{(i)}PD$	
Small R/C (office building)	25	95	5	65	2.25
Large tilt-up R/C	22	90	4.4	66	2.5
Large unreinforced masonry	20	75	4	73	3
Medium reinforced masonry	22.5	85	4.5	68	3
Small reinforced masonry	22.5	80	4.5	72	3.25
Small unreinforced brick	15	70	3	75	3.1
Medium metal structure	15	70	3	75	3.75
Small metal structure	15	65	3	72	4
Medium wood structure	17.5	65	3.5	81	3.5
Small wood structure	17.5	60	3.5	86	4
Modular/trailers	17.5	62.5	3.5	83	3.75
Medium R/C	23.5	85	4.7	68	2.75
Medium unreinforced masonry	20	80	4	70	3.05
Medium Metal Stud	15	72.5	3	73	3.5
High Bay Metal	15	75	3	80	3.25
Passenger Vehicle	27.5	60	5.5	88	4

Substep 5

Similar to the calculation of probability of major injury due to building collapse, the probability of a minor injury from building collapse ($P_{mini(bc)}$) is determined. First a nominal $P_{mini(bc)}$ is calculated by:

$$Nom.\ P_{mini(bc)} = [(PD_b - min_{(i)}DO) / (min_{(i)}PD - min_{(i)}DO)] \times 100 \qquad (90)$$

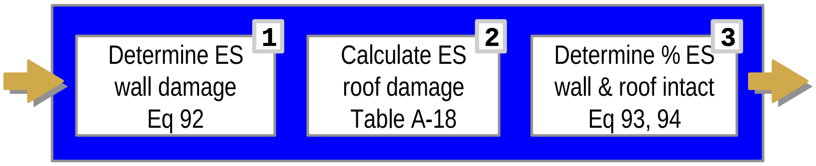
where the PD_b is from *Substep 1*, minor injury damage offset, $min_{(i)}DO$, and minor injury plateau damage, $min_{(i)}PD$, is from Table 10, *Major and Minor Injury Parameters for Building Collapse*.

An adjusted probability of major injury due to building collapse is determined by:

$$Adj.\ P_{mini(bc)} = IFR^2 \times P_{f(bc)} \tag{91}$$

where IFR is the injury to fatality ratio from Table 10, *Major and Minor Injury Parameters for Building Collapse*. A comparison is made between the $Nom.\ P_{mini(bc)}$ and $Adj.\ P_{mini(bc)}$. The variable with the highest value is assigned as the final $P_{mini(bc)}$.

4.3.1.3 Step 9c: ES Roof and Wall Damage



The percentage of the ES remaining intact (roof and walls) is determined for use in Step 17.

Substep 1

The wall damage is set equal to the predicted building damage, PD_b (from Section 4.3.1.2, Substep 1).

$$\%ES_{wall\ damaged} = PD_b \tag{92}$$

Substep 2

The roof damage, $\%ES_{roof\ damaged}$, uses the same hyperbolae interpolation methodology from Section 4.3.1.2, Substep 1. The roof hyperbolae parameters are contained in Table A-18, *Pressure / Impulse Coefficients – ES Roof Damage*.

Substep 3

The percentage of the walls and roof intact is the percentage not damaged, as shown by:

$$\%ES_{wall\ intact} = 100 - \%ES_{wall\ damaged} \tag{93}$$

$$\%ES_{roof\ intact} = 100 - \%ES_{roof\ damaged} \tag{94}$$

The development of the methodology for determining the percentage ES intact is detailed in Attachment 7.

Outputs of Step 9:

- Probability of fatality due to window breakage, $P_{f(g)}$
- Probability of major injury due to window breakage, $P_{maji(g)}$
- Probability of minor due to window breakage, $P_{mini(g)}$
- Probability of fatality due to building collapse, $P_{f(bc)}$
- Probability of major injury due to building collapse, $P_{maji(bc)}$
- Probability of minor injury due to building collapse, $P_{mini(bc)}$

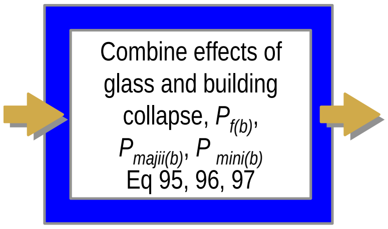
- Percentage of ES roof intact, $\%ES_{wall\ intact}$
- Percentage of ES walls intact, $\%ES_{roof\ intact}$

4.3.2 STEP 10: Assess $P_{f(b)}$, $P_{maji(b)}$, $P_{mini(b)}$.

Step 10 completes the Structural Response Branch by determining the probability of fatality due to overall building damage, $P_{f(b)}$, probability of major injury due to overall building damage, $P_{maji(b)}$, probability of minor due to overall building damage, $P_{mini(b)}$.

Inputs to Step 10:

- Probability of fatality due to window breakage, $P_{f(g)}$ [from Step 9]
- Probability of fatality due to building collapse, $P_{f(bc)}$ [from Step 9]
- Probability of major injury due to window breakage, $P_{maji(g)}$ [from Step 9]
- Probability of major injury due to building collapse, $P_{maji(bc)}$ [from Step 9]
- Probability of minor injury due to window breakage, $P_{mini(g)}$ [from Step 9]
- Probability of minor injury due to building collapse, $P_{mini(bc)}$ [from Step 9]



Calculate the probability of fatalities due to overall building damage, $P_{f(b)}$, by:

$$P_{f(b)} = P_{f(g)} + [(1 - P_{f(g)}) * P_{f(bc)}] \tag{95}$$

Calculate the probability of major injury due to overall building damage, $P_{maji(b)}$, by:

$$P_{maji(b)} = P_{maji(g)} + [(1 - P_{maji(g)}) * P_{maji(bc)}] \tag{96}$$

Calculate the probability of minor injury due to overall building damage, $P_{mini(b)}$, by:

$$P_{mini(b)} = P_{mini(g)} + [(1 - P_{mini(g)}) * P_{mini(bc)}] \tag{97}$$

Outputs of Step 10:

- Probability of fatality due to overall building damage, $P_{f(b)}$
- Probability of major injury due to overall building damage, $P_{maji(b)}$
- Probability of minor injury due to overall building damage, $P_{mini(b)}$

4.4 Group 4 Steps: Debris Branch

Group 4 includes Steps 11-18 of the SAFER architecture. These steps determine the lethal effects of flying debris.

SAFER considers three types of debris: primary debris, secondary debris, and ejecta. Primary debris originates from the explosives item. Secondary debris originates from the PES. The PES roof, front wall, sidewalls, and rear wall are sources of secondary debris. Ejecta are debris originating from the ground or foundation of the PES. The debris generated by the ES is addressed in the building collapse portion of the model in Group 3, Steps 9-10, Structural Response Branch.

All of the debris is characterized as a function of mass and kinetic energy (KE) in Steps 11-14. Steps 11-13 describe the primary fragments and determine maximum throw ranges and mass of the primary fragments that escape the PES. Step 14 describes the secondary fragments and ejecta and determines maximum throw ranges and mass of these fragments.

Steps 15-18 characterize the debris arriving at the ES and then determine the ultimate effect. Step 15 defines a debris density as a function of distance from the PES using a bivariate-normal distribution. Step 16 produces a combined KE table for all arriving fragments at the ES. Step 17 determines the arriving fragments that penetrate the ES and describes the KE of the fragments after penetrating the ES roof and walls. Finally, Step 18 calculates the probability of fatality due to debris, $P_{f(d)}$.

To enhance readability, selected reference tables of constants used in the Group 4 steps are located in Appendix A.

4.4.1 KE/Mass Bin Methodology

The goal of Steps 11-17 is to determine the KE for each bin of fragments at the location of the exposed personnel. This permits the calculation of the probability of fatality due to debris as a function of KE in Step 18.

To facilitate the characterization of debris KE, SAFER first defines ten bins in terms of KE, which will be useful in Step 18. Each bin is ½ order of magnitude in width. SAFER then defines the average mass that produces the KE midpoint for each bin, which allows for the creation of ten corresponding mass bins.

Table 11, *SAFER KE/Mass Bin Format*, presents these ten bins. Table 11 also shows the maximum and minimum KE values for each bin and the average mass of each departing fragment associated with the KE bins.

Table 11. SAFER KE/Mass Bin Format

Bin #	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
KE Min (ft-lbs)	100k	30k	10k	3k	1k	300	100	30	10	3
KE Average (ft-lbs)	173k	54k	17k	5k	1.7k	547	173	54	17	5
KE Max (ft-lbs)	≥ 300k	100k	30k	10k	3k	1k	300	100	30	10
Average Fragment Mass (steel) (lbs)	35.7	14.9	6.34	2.66	1.13	0.473	0.199	0.0852	0.0379	0.0142
Average Fragment Mass (concrete) (lbs)	75.4	31.5	13.4	5.61	2.38	1	0.42	0.18	0.08	0.03

4.4.2 STEP 11: Describe primary fragments.

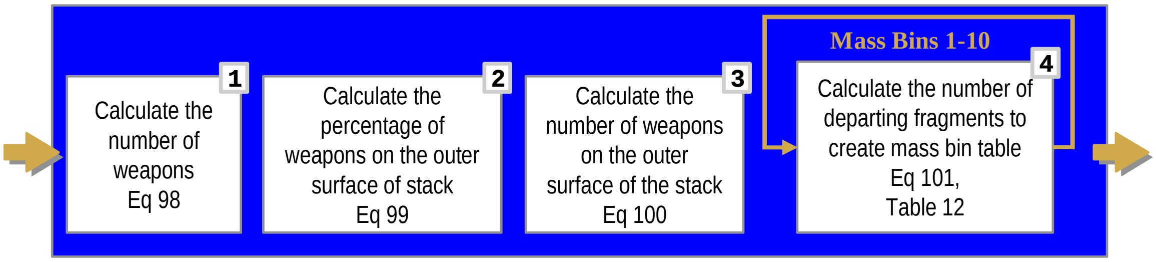
Step 11 begins the characterization of the primary fragments by performing two functions in SAFER. In Step 11a, SAFER determines the number of primary fragments distributed over ten mass bins. Section 4.4.2.1 describes the procedures for this step. In Step 11b, SAFER determines the maximum throw range of the primary fragments. Section 4.4.2.2 describes the procedures for this step.

Inputs to Step 11:

- W_1 (lbs), [from Step 4]
- Weapon type [from Step 1]

4.4.2.1 Step 11a: Primary Fragment Determination

Primary fragments result from the breakup of the explosives casing or packaging. The departing primary fragments for the explosive event are determined in five substeps.



Substep 1

Calculate the number of weapons, N_w, by:

$$N_w = \frac{W_1}{NEWQD\ of\ one\ weapon} \tag{98}$$

where the NEWQD of one weapon is provided in Table 12, *Primary Fragment Distribution by Mass Bins.*

Table 12. Primary Fragment Distribution by Mass Bins

Weapon Type	NEWQD of one weapon (lbs)	Fragments Resulting from One Single Item									
		Mass Bin #s									
		1	2	3	4	5	6	7	8	9	10
MK82	192	0	0	0	0	7	49	226	746	1227	1738
MK83	445	0	0	0	0	0	75	344	1134	1866	2643
MK84	945	0	0	0	0	1	72	338	1116	1835	2599
M107	15.1	0	0	0	0	0	4	34	165	372	667
Bulk/light case	1	0	0	0	0	0	0	0	1	5	10
AIM-7 missile	35	0	0	0	0	0	0	3	155	30	12
M1 (105 mm) projectile	5	0	0	0	0	0	2	20	99	224	401
MK2 (40 mm)	0.2	0	0	0	0	0	0	4	19	44	79

Substep 2

Calculate the proportion of weapons on the outer surface of the stack, N_{pos}, by:

$$N_{pos} = 3.8474 * N_w^{-1/3} \tag{99}$$

Rationale for Eq. (99) is detailed in Attachment 8.

Substep 3

Calculate the number of weapons on the outer surface, N_{wos}, by:

$$N_{wos} = N_w * N_{pos} \tag{100}$$

Note, if N_{wos} is greater than N_w, then N_{wos} is set equal to N_w.

Substep 4

SAFER next creates the departing primary fragment mass bin table. This table describes the number of departing primary fragments from the PES. The number of fragments is based on the weapon type, number of primary fragments, and number of weapons on the outer surface. SAFER determines the number of departing primary fragments, N_{pf}, for the mass bins of this table by using the following algorithm:

For n = 1 to 10

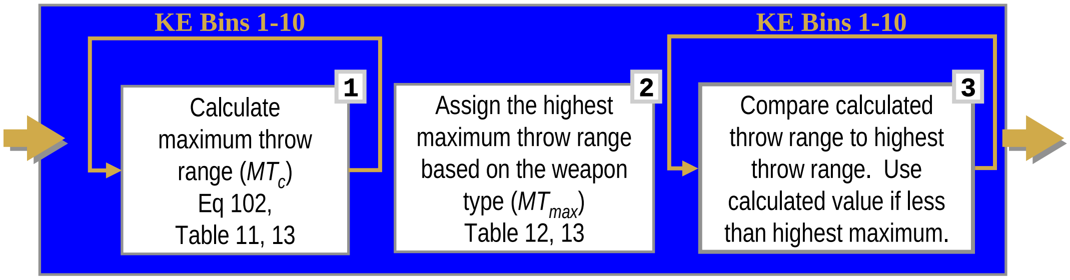
$$\text{Bin } n\text{: } N_{pf} = \mathit{Total\ No.\ of\ primary\ fragments} * N_{wos} * 0.75 \tag{101}$$

Next n,

where the *Total No. of primary fragments* is provided in Table 12, *Primary Fragment Distribution by Mass Bins.* Rationale for Eq. (101) is detailed in Attachment 8.

4.4.2.2 Step 11b: Primary Fragment Maximum Throw Determination

In Step 11b, SAFER creates the primary maximum throw range table.



Substep 1

Calculate the maximum throw range, MT_c, by:

For n = 1 to 10

$$\text{Bin } n\text{: } MT_c = 300 * IV^{0.36} * (\text{average fragment mass})^{0.21} \tag{102}$$

Next n,

where the initial velocity, IV, is provided in Table 13, *Primary Fragment Initial Velocity and Maximum Throw Values* and the *average fragment mass* for steel fragments is found in Table 11, *SAFER KE/Mass Bin Format.*

Table 13. Primary Fragment Initial Velocity and Maximum Throw Values

Weapon Type	IV (ft/s)	MT_s (ft)	MT_m (ft)
MK82	5200	3177	3812
MK83	6100	3288	3946
MK84	4710	3882	4658
M107	3430	2577	3092
Bulk/light case	4000	1870	1870
AIM-7 missile	6500	2200	2640
M1 (105 mm) projectile	4100	1939	2327
MK2 (40 mm)	3600	1095	1314

Substep 2

Assign the highest maximum throw range, MT_{max}, based on the weapon type.

```
If $W_1$ > NEWQD of one weapon,
    Then $MT_{max} = MT_m$
Else $MT_{max} = MT_s$                                   (103)
```

where *NEWQD of one weapon* is provided Table 12, *Primary Fragment Distribution by Mass Bins* and the maximum throw for multiple weapons, MT_m, and the maximum throw for a single weapon, MT_s, are provided in Table 13, *Primary Fragment Initial Velocity and Maximum Throw Values*.

Substep 3

SAFER compares the calculated maximum throw, MT_c, to MT_{max} to determine the final maximum throw values, R_M.

```
For $n$ = 1 to 10
        Bin n: If $MT_c > MT_{max}$,
            Then $R_M = MT_{max}$
                Else $R_M = MT_c$                        (104)
Next $n$,
```

Outputs of Step 11:

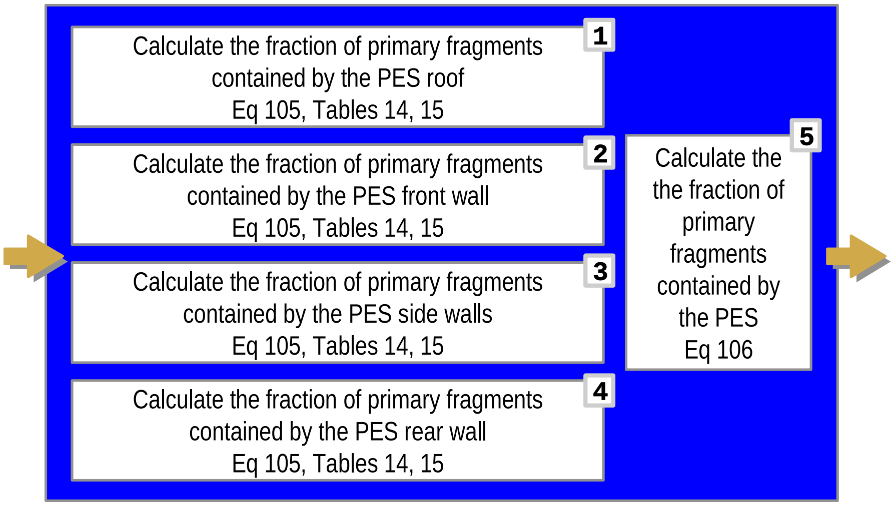
- Departing primary fragment mass bin table
- Primary maximum throw range table
- Primary fragment initial velocity, *IV*

4.4.3 STEP 12: Calculate primary fragment containment by PES (post P, I).

If the situation includes a PES structure, the components of the structure remaining after the explosives event may block departing primary fragments. Step 12 calculates the fraction of primary fragments blocked by the components of the PES structure (roof, front wall, side walls, and rear wall).

Inputs to Step 12:

- PES building type [from Step 2]
- Fraction of PES roof intact, $PES_{intact(roof)}$ [from Step 6]
- Fraction of PES front wall intact, $PES_{intact(fw)}$ [from Step 6]
- Fraction of PES side walls intact, $PES_{intact(sw)}$ [from Step 6]
- Fraction of PES rear wall intact, $PES_{intact(rw)}$ [from Step 6]



For the four PES components (roof, front wall, side walls, and rear wall), calculate the fraction of debris (primary fragments) contained by the PES, PES_{DC}, by:

$$PES_{DC} = PES_{intact} * FB * PES_{fraction} \tag{105}$$

where PES_{intact} is determined in Step 6 for each component, FB is the fragment blocking coefficient provided in Table 14, *Fragment Blocking Coefficients by PES Component*, based on the PES building type and $PES_{fraction}$ is the fraction of PES area by component provided in Table 15, *Ratio of Area of each PES Component Total PES Surface Area*, based on the PES building type.

Table 14. Fragment Blocking Coefficients by PES Component

PES	Roof	Front Wall	Side Walls	Rear Wall
Pre-engineered metal building	0.15	0.10	0.10	0.10
Large concrete arch ECM	0.8	0.6	0.9	0.9
Medium concrete arch ECM	0.8	0.6	0.9	0.9
Small concrete arch ECM	0.8	0.6	0.9	0.9
Large steel arch ECM	0.8	0.6	0.9	0.9
Medium steel arch ECM	0.8	0.6	0.9	0.9
Small steel arch ECM	0.8	0.6	0.9	0.9
Hardened aircraft shelter	0.8	0.6	0.8	0.9
Large aboveground brick structure	0.25	0.6	0.6	0.6
Medium aboveground brick structure	0.25	0.6	0.6	0.6
Small aboveground brick structure (square)	0.25	0.6	0.6	0.6
Medium concrete building	0.25	0.6	0.6	0.6
Small concrete building	0.25	0.6	0.6	0.6
Hollow clay tile	0.25	0.25	0.25	0.25
Ship (small)	0.2	0.2	0.2	0.2
Ship (medium)	0.2	0.2	0.2	0.2
Ship (large)	0.2	0.2	0.2	0.2
ISO Container	0.15	0.1	0.1	0.1

Table 15. Ratio of Area of each PES Component Total PES Surface Area

PES	Fraction Area Roof	Fraction Area Front Wall	Fraction Area Side Walls	Fraction Area Rear Wall
Pre-engineered metal building	0.5	0.0833	0.3333	0.0833
Large concrete arch ECM	0.4324	0.068	0.432	0.068
Medium concrete arch ECM	0.414	0.086	0.414	0.086
Small concrete arch ECM	0.381	0.119	0.381	0.119
Large steel arch ECM	0.432	0.068	0.432	0.068
Medium steel arch ECM	0.414	0.086	0.414	0.086
Small steel arch ECM	0.381	0.119	0.391	0.119
Hardened aircraft shelter	0.423	0.102	0.372	0.102
Large AGBS	0.421	0.168	0.244	0.168
Medium AGBS	0.404	0.149	0.298	0.149
Small AGBS (square)	0.429	0.143	0.286	0.143
Medium concrete building	0.404	0.149	0.298	0.149
Small concrete building	0.429	0.143	0.286	0.143
Hollow clay tile	0.5	0.08	0.33	0.08
Ship (large)	0.215	0.072	0.641	0.072
Ship (medium)	0.205	0.092	0.611	0.092
Ship (small)	0.188	0.094	0.625	0.094
ISO Container	0.2515	0.1302	0.4881	0.1302

Calculate total fraction of debris (primary fragments) contained by the PES, $PES_{TotalDC}$, by:

$$PES_{TotalDC} = \sum_{all\ components} PES_{DC} \tag{106}$$

Rationale for the methodology used in this step is detailed in Attachment 8.

Output of Step 12:

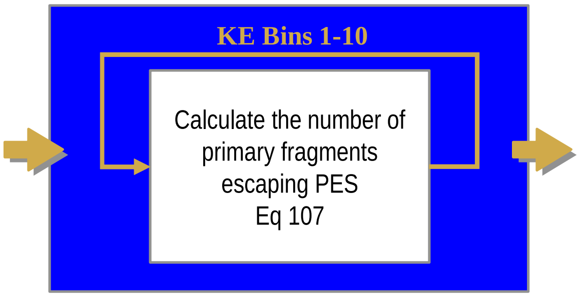
- Fraction of primary fragments contained by the PES, $PES_{TotalDC}$

4.4.4 STEP 13: Reduce number of primary fragments (due to PES).

Step 13 adjusts the departing primary fragment KE bin table to account for those fragments that are contained by the PES.

Inputs to Step 13:

- Departing primary fragment mass bin table [from Step 11]
- Fraction of primary fragments contained by the PES, $PES_{TotalDC}$ [from Step 12]



SAFER determines the number of primary fragments not contained by the PES, N'_{pf}, for each bin of the departing primary fragment KE bin table by using the following algorithm:

```
For $n$ = 1 to 10
 Bin $n$: $N'_{pf} = N_{pf} * (1 - PES_{TotalDC})$        (107)
Next $n$,
```

where the N_{pf} is the number of departing fragments, the value in each mass bin of the departing primary fragment mass bin table. The adjusted table represents the number of primary fragments escaping the (remains of the) PES.

Output of Step 13:

- Adjusted departing primary fragment mass bin table

4.4.5 STEP 14: Describe secondary fragments and crater ejecta.

Step 14 characterizes secondary fragments and ejecta by performing four functions in SAFER. In Step 14a, SAFER determines the number of secondary fragments distributed over ten KE bins. Section 4.4.5.1 describes the procedures for this step. In Step 14b, SAFER determines the maximum throw range of the secondary fragments. Section 4.4.5.2 describes the procedures for this step. In Step 14c, SAFER determines the number of ejecta fragments distributed over ten KE bins. Section 4.4.5.3 describes the procedures for this step. In Step 14d, SAFER determines the maximum throw range of the ejecta fragments. Section 4.4.5.4 describes the procedures for this step.

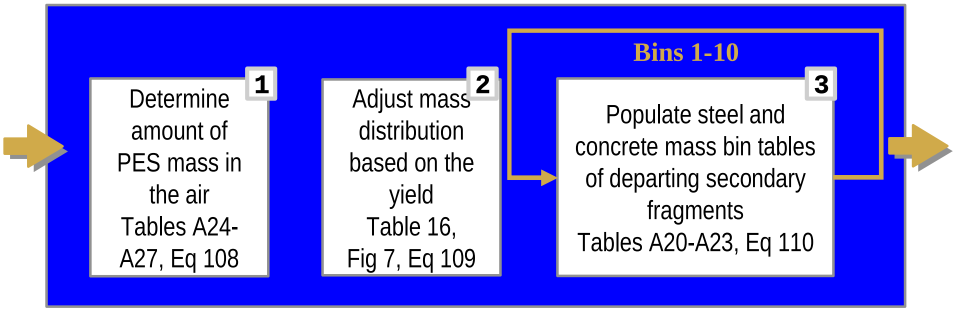
Inputs to Step 14:

- PES building type [from Step 2]
- Equivalent NEW (lbs), W_2 [from Step 4]
- Fraction of PES roof damaged, $PES_{damage(roof)}$ [from Step 6]
- Fraction of PES front wall damaged, $PES_{damage(fw)}$ [from Step 6]
- Fraction of PES side walls damaged, $PES_{damage(sw)}$ [from Step 6]
- Fraction of PES rear wall damaged, $PES_{damage(rw)}$ [from Step 6]

4.4.5.1 Step 14a: Secondary Fragment Determination

Secondary debris is defined as the debris resulting from the breakup of the PES. The departing secondary debris is stored in mass bin tables that are converted into KE bin tables. A separate table is created for each of the four PES components (roof, front wall, side walls, and rear wall).

The departing secondary debris is determined using four substeps.



Substep 1

For each PES component, the mass of the PES thrown is determined by comparing the equivalent NEW to an initial breakout value (Y_0) and a total destruction value (Y_{100}). If the equivalent NEW is less than the initial breakout value, no PES mass is thrown; if the equivalent NEW is greater than the total destruction value, all of the PES mass is thrown; and if the equivalent NEW is between the two values, Eq. (108) is used.

For each of the four PES components, SAFER adjusts the PES mass thrown by using the following algorithm:

```
For $i$ = 1 to 4
    PES Component $i$:
    If $W_2 < Y_0$,
     Then no PES mass is thrown
    Else If $Y_0 \le W_2 \le Y_{100}$,
     Then
       $Mass\ of\ PES\ thrown = mass\ of\ PES\ component * PES_{damage\ (i)}$          (108)
    Else all PES mass is thrown,
```

```
        End If
    Next $i$,
```

where W_2 is from Step 4, PES_{damage} is calculated for each component in Step 6, Y_0 and Y_{100} for each PES component are provided in the following tables: Table A-24, *Roof – Secondary Fragment Nominal Maximum Throw Range*, Table A-25, *Front Wall – Secondary Fragment Nominal Maximum Throw Range*, Table A-26, *Side Wall – Secondary Fragment Nominal Maximum Throw Range*, and Table A-27, *Rear Wall – Secondary Fragment Nominal Maximum Throw Range* and the mass of PES component by PES building type are provided in Table A-20, *Mass Distribution for PES Roof*, Table A-21, *Mass Distribution for PES Front Wall*, Table A-22, *Mass Distribution for PES Side Walls*, and Table A-23, *Mass Distribution for PES Rear Wall*.

Substep 2

The percentage of mass thrown per bin is determined by taking the nominal mass distribution (from Substep 1) and adjusting it based on the yield. As the yield increases beyond the total destruction value, the mass distribution percentages by bin are re-calculated. This method allows the modeling of the phenomena that produces more, smaller pieces in larger explosive events.

The methodology for this recalculation is as follows:

The ratio (Y_R) of the equivalent NEW (W_2) to the total destruction value (Y_{100}) is determined using Eq. (109):

$$Y_R = \frac{W_2}{Y_{100}} \tag{109}$$

where the Y_{100} values are provided in Table A-6, *Damage Coefficients for PES Roof*, Table A-7, *Damage Coefficients for PES Front Wall*, Table A-8, *Damage Coefficients for PES Side Wall*, and Table A-9, *Damage Coefficients for PES Rear Wall*. Y_R is compared to a stored parameter (for each bin) that represents the initial reduction ratio, *IRR*, shown in Table 16, *Initial Reduction Ratios for Each Bin*.

Table 16. Initial Reduction Ratios for Each Bin

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
IRR	1	64	729	4096	15625	46656	117649	262144	531441	1000000

If $Y_R > IRR$ for that bin, a reduction for that bin is calculated as shown in Figure 7. If $Y_R < IRR$, no adjustment is made (to this or any subsequent bins).

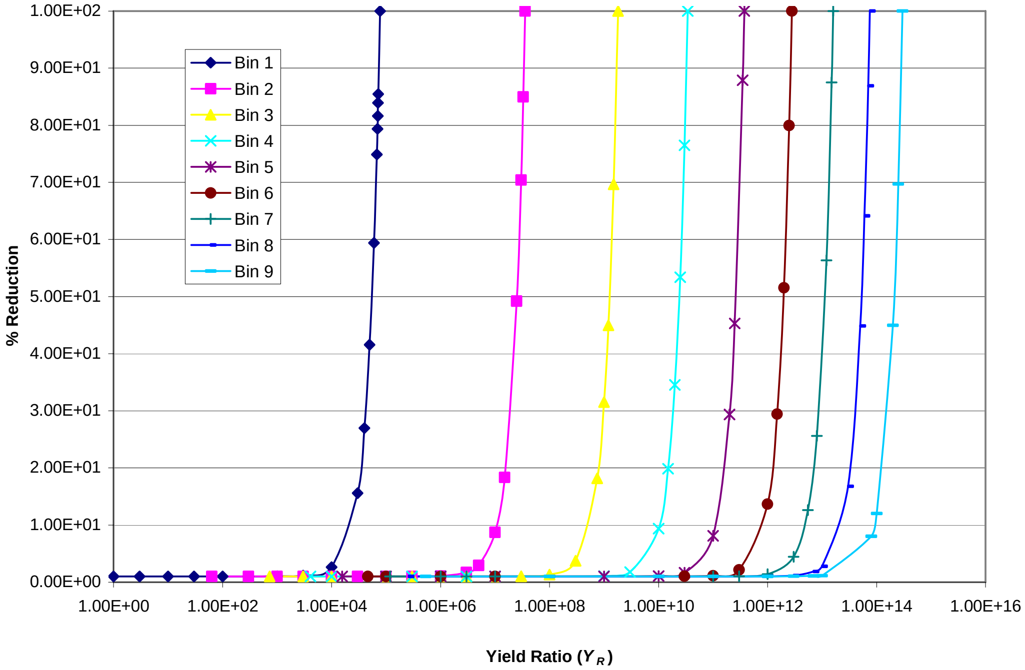


Figure 7. % Reduction by Bin

The reduced mass is redistributed evenly among the lower bins and then the process continues by comparing Y_R to the *IRR* value for the next bin.

Substep 3

Finally, SAFER creates departing secondary fragments mass bin tables. A unique table is created for each type of material (concrete and steel) in each PES component. Therefore, a total of eight departing secondary fragments mass bin tables are created from this procedure. The mass bin tables are created by using the following algorithm to determine the number of secondary fragments, N_{sf}, in each bin:

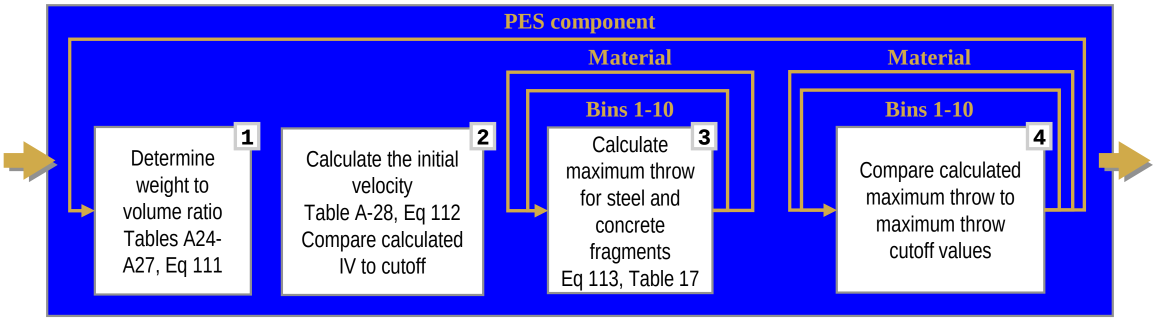
```
For $i$ = 1 to 4
    For $j$ = 1 to 2
        PES Component $i$ and Material $j$:
        For $n$ = 1 to 10
        Bin $n$:
        $N_{sf} = \frac{mass\,of\,PES\,thrown * (\%\,mass\,in\,bin \div 100)}{average\,fragment\,mass} * (\%\,material \div 100)$    (110)
        Next $n$,
    Next $j$,
Next $i$,
```

where *mass of PES thrown* is calculated in Substep 1, *% mass in bin* is calculated in Substep 2, *average fragment mass* is found in Table 11, *SAFER KE/Mass Bin Format*, and the percentages of material in each PES component, *% material*, are provided in the following tables: Table A-20, *Mass Distribution for PES Roof*, Table A-21, *Mass Distribution for PES Front Wall*, Table A-22, *Mass Distribution for PES Side Walls*, and Table A-23, *Mass Distribution for PES Rear Wall*.

Rationale for the methodology used in this Step 14a is detailed in Attachment 8.

4.4.5.2 Step 14b: Secondary Fragment Maximum Throw Determination

In Step 14b, SAFER creates a unique maximum throw range table for each type of material (concrete and steel) in each PES component. Therefore, a total of eight tables are created in Substep 14b. The maximum throw range for secondary fragments is accomplished in four substeps.



Substep 1

For each of the four PES components, calculate the weight-to-volume ratio, *W/V*, by using the following algorithm:

```
For $i$ = 1 to 4
    PES Component $i$: $W/V = W_2 / V$                (111)
Next $i$,
```

where the volumes of each PES component, *V*, by PES building type are provided in the following tables: Table A-24, *Roof – Secondary Fragment Nominal Maximum Throw Range*; Table A-25, *Front Wall – Secondary Fragment Nominal Maximum Throw Range*; Table A-26, *Side Wall – Secondary Fragment Nominal Maximum Throw Range*; and Table A-27, *Rear Wall – Secondary Fragment Nominal Maximum Throw Range*.

Substep 2

For each of the four PES components, an initial velocity is calculated, IV_c. The calculated velocity is compared to a maximum initial velocity value. If the calculated value is greater than the maximum value, the maximum value is used. Alternatively, if the calculated value is less than the maximum value, the calculated value is used. Calculate the initial velocity, IV_c, for each PES component as follows:

```
For $i$ = 1 to 4
    PES Component $i$:
        $IV_c = a_{IV} * (W_2 / V)^{\exp_{iv}}$                (112)
        If $IV_c > IV_{max}$
            Then $IV = IV_{max}$
        Else If $IV_c < IV_{max}$
            Then $IV = IV_c$
Next i,
```

where the constants a_{iv} and exp_{iv} and the initial velocity maximum value, IV_{max}, are provided for each PES component in Table A-28, *Secondary Fragment Initial Velocity*.

Substep 3

Create a throw range table for concrete and steel fragments for each PES component. Calculate the maximum throw range for the concrete fragments, MT_c, and steel fragments, MT_s, by:

```
For $i$ = 1 to 4
    PES Component $i$:
For $n$ = 1 to 10
  Bin $n$: $MT_c = CP * IV^{E1} * (average\ fragment\ mass\,(concrete))^{E2}$
    $MT_s = SP * IV^{E1} * (average\ fragment\ mass\,(steel))^{E2}$          (113)
    Next $n$,
Next $i$,
```

where the *average fragment mass* is found in Table 11, *SAFER KE/Mass Bin Format*, and *CP*, *SP*, *E1*, and *E2* are found in Table 17, *Secondary Maximum Throw Parameters*.

Table 17. Secondary Maximum Throw Parameters

PES	*SP*	*CP*	*E1*	*E2*
PEMB	236.2	127.4	0.304	0.264
Hollow Clay Tile	300	160	0.36	0.21
HAS	236.2	127.4	0.304	0.264
Large Concrete Arch ECM	300	160	0.36	0.21
Medium Concrete Arch ECM	300	160	0.36	0.21
Small Concrete Arch ECM	300	160	0.36	0.21
Large Steel Arch ECM	300	160	0.36	0.21
Medium Steel Arch ECM	300	160	0.36	0.21
Small Steel Arch ECM	300	160	0.36	0.21
Large AGBS	300	160	0.36	0.21
Medium AGBS	300	160	0.36	0.21
Small AGBS (Square)	300	160	0.36	0.21
Medium Concrete Building	300	160	0.36	0.21
Small Concrete Building	300	160	0.36	0.21
Ship (small)	236.2	127.4	0.304	0.264
Ship (medium)	236.2	127.4	0.304	0.264
Ship (large)	236.2	127.4	0.304	0.264
ISO Container	236.2	127.4	0.304	0.264

Substep 4

SAFER compares the calculated maximum throws for concrete and steel, MT_c and MT_s, to MT_{max} to determine the final maximum throw values for concrete and steel, R_M.

```
For $i$ = 1 to 4
    PES Component $i$:
    For $n$ = 1 to 10 (concrete maximum throw table)
        Bin n: If $MT_c > MT_{max}$,
```

```
          Then $R_M = MT_{max}$
               Else $R_M = MT_c$                                    (114)
          Next $n$,
             For $n$ = 1 to 10 (steel maximum throw table)
             Bin n: If $MT_s > MT_{max}$,
             Then $R_M = MT_{max}$
               Else $R_M = MT_s$                                    (115)
          Next $n$,
    Next $i$,
```

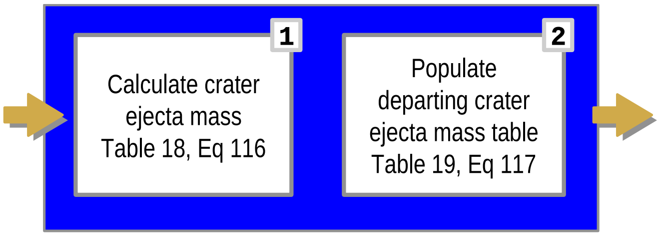
where MT_{max} is provided for each PES by component in Table A-29, *Secondary Fragment Maximum Throw Cutoff Values*.

4.4.5.3 Step 14c: Crater Ejecta Determination

Ejecta is debris originating from the ground or foundation of the PES. The departing ejecta fragments are stored in a mass bin table that is converted into a KE bin table.

Characterization of the ejecta is based on the type of soil around the PES. Soil types considered by SAFER are dependent on the PES building type. SAFER considers soil types of either *rock or hard clay* or *looser soils* for PES building types of *open*, *pre-engineered metal building*, or *hollow clay tile*. The looser soils option is for soil less densely packed than rock or hard clay and would be expected to break up into smaller pieces. For all other PES types (excluding ship) the default soil type is *concrete*. SAFER prompts the user to select an appropriate soil type as part of the situation definition.

Based on these user inputs, crater ejecta is determined using two substeps.



Substep 1

Calculate the mass of the crater ejecta thrown, *Crater ejecta mass*, by:

$$\text{Crater ejecta mass} = A * (W_2)^B \tag{116}$$

where the crater mass coefficient, *A*, and the crater mass exponent, *B*, are provided in Table 18, *Soil Type Parameters*, based on the soil type.

Table 18. Soil Type Parameters

	A	***B***	***g***	***r***
Rock or Hard Clay	104.0	1.04	1.0	75
Looser Soils	72.2	1.04	1.1	40
Concrete	2.7	1.16	0.5	50

Substep 2

SAFER completes Step 14c by creating the departing crater ejecta fragment mass table. SAFER determines the number of crater ejecta fragments, N_{ce}, for the mass bins of this table by using the following algorithm:

For n = 1 to 10

$$\text{Bin } n\text{: } N_{ce} = \frac{\left(Crater\ ejecta\ mass * fraction\ each\ bin\right)}{average\ \ fragment\ mass} \tag{117}$$

Next n,

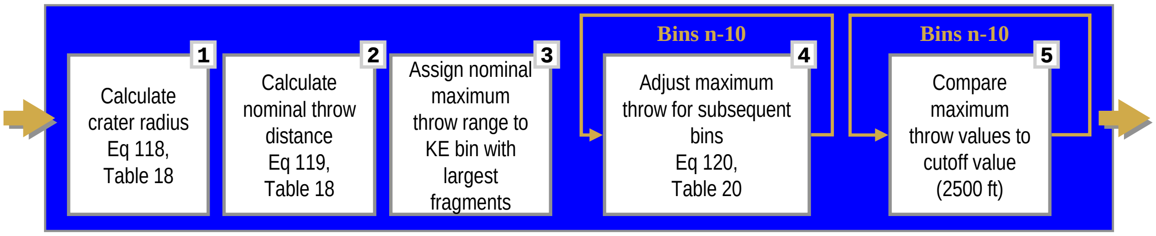
where the *fraction each bin* is provided in Table 19, *Fraction of Soil Thrown*, by soil type and the *average fragment mass* is found in Table 11, *SAFER KE/Mass Bin Format*.

Table 19. Fraction of Soil Thrown

Soil Type	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Rock or Hard Clay	0.1666	0.0417	0.0417	0.0417	0.0417	0.0833	0.0833	0.0833	0.1667	0.25
Looser soils	0.005	0.00125	0.00125	0.00125	0.00125	0.0025	0.0025	0.0025	0.56	0.4225
Concrete	0.05	0.05	0.05	0.05	0.075	0.075	0.075	0.075	0.1	0.4

4.4.5.4 Step 14d: Crater Ejecta Maximum Throw Range

In Step 14d, SAFER calculates the maximum throw range for crater ejecta.



Substep 1

Calculate the crater radius, *Crater radius*, by:

$$Crater\ radius = g * \left(W_2\right)^{\frac{1}{3}} \tag{118}$$

where the crater radius coefficient, g (ft/lb$^{1/3}$), is provided in Table 18, *Soil Type Parameters*, by soil type.

Substep 2

Calculate the nominal maximum throw range, R_M, by:

$$R_M = r * Crater\ radius \tag{119}$$

where the crater ejecta range coefficient, r, is provided in Table 18, *Soil Type Parameters*, by soil type.

Substep 3

Create a maximum throw range table for crater ejecta by assigning the nominal maximum throw range, R_M, to the lowest numbered bin that has fragments (first non-zero bin).

Substep 4

SAFER determines the maximum throw ranges, R_M, for the remaining bins of this table by using the following algorithm:

```
$k$ = bin number of first non-zero bin
For $n = k + 1$ to 10
  Bin $n$: $R_M = (R_M$ for bin $n - 1) * $ throw value for bin $n$          (120)
Next $n$,
```

where the ejecta throw values are provided in Table 20, *Nominal Maximum Throw Values for Ejecta*.

Table 20. Nominal Maximum Throw Values for Ejecta

Material	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Ejecta	1.00	0.84	0.83	0.82	0.82	0.81	0.81	0.81	0.81	0.77

Substep 5

SAFER compares the calculated maximum throw ranges for each bin to 2,500 feet. If the calculated maximum range is greater than 2,500 feet, the value is reset to 2,500 feet.

Rationale for the methodology used in Step 14d is detailed in Attachment 8.

Outputs of Step 14:

- 4 Departing secondary steel debris mass tables (one table for each PES component)
- 4 Departing secondary concrete debris mass tables (one table for each PES component)
- 4 Steel maximum throw tables (one table for each PES component)
- 4 Concrete maximum throw tables (one table for each PES component)
- Departing crater ejecta fragment mass table
- Maximum throw range table for crater ejecta
- Initial velocity for each PES component, *IV*

4.4.6 STEP 15: Define expected arriving debris tables.

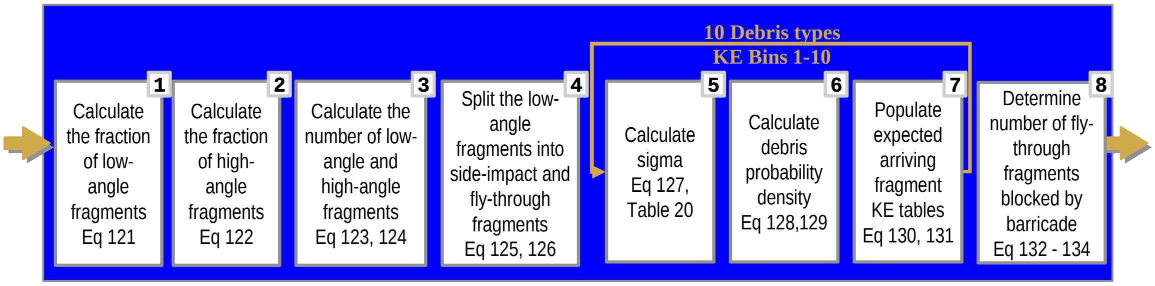
Steps 11 – 14 characterized debris fragments departing the PES. These fragments must now be translated from the donor to the target. Step 15 performs this task by creating arriving debris mass tables.

Inputs to Step 15:

- PES building type [from Step 2]
- Orientation of the PES to the ES [from Step 3]
- Distance between the PES and ES (ft), d [from Step 3]
- 10 departing fragment mass bin tables

  - Adjusted departing primary fragment mass bin table [from Step 13]
  - 4 Departing secondary steel debris mass tables [from Step 14]
  - 4 Departing secondary concrete debris mass tables [from Step 14]
  - Departing crater ejecta fragment mass table [from Step 14]
- 10 maximum throw tables
  - Primary maximum throw range table [from Step 11]
  - 4 Steel maximum throw tables [from Step 14]
  - 4 Concrete maximum throw tables [from Step 14]
  - Maximum throw range table for crater ejecta [from Step 14]

Translation of debris from departing to arriving fragments requires the calculation of debris probability densities at the ES, P_i, for primary, secondary, and crater debris.



Before SAFER calculates the probability densities, SAFER partitions the number of fragments departing the PES into high-angle and low-angle fragments. The low-angle fragments will impact the ES walls and the high-angle fragments will impact the ES roof in Step 17. The primary fragments are partitioned between high-angle and low-angle fragments in Substeps 1- 3. SAFER assumes that all PES roof material (steel and concrete) and crater ejecta are high-angle fragments. The steel and concrete from all other PES components (front wall, side walls, and rear wall) are assumed to be low-angle fragments. All low-angle fragments are further partitioned into side-impact and fly-through debris (Substep 4). After the fragments are partitioned into high-angle and low-angle, and further partitioned into side-impact and fly-through fragments, there will be 18 departing debris tables.

The sigma value, σ, is a measure of the spread or dispersion of the fragments under consideration and determined by using the maximum throw as an extreme value. For primary and secondary debris, the extreme maximum throw is equal to 3σ. For crater ejecta, the extreme maximum throw is 4σ. These values are based on empirical data. Rationale for selecting these maximum throw values is detailed in Attachment 8.

Values for P_i are based on the maximum throw distances and the spatial distribution of these fragments. SAFER assumes that arriving fragments follow a bivariate-normal distribution or pseudo-trajectory normal distribution. Rationale for selecting these distributions is detailed in Attachment 8.

Substep 1

For all primary fragments, calculate the fraction of low-angle fragments, F_{LA}, for each bin by using the following algorithm:

```
For $j$ = 1 to 10
    Maximum throw table $j$:
    For $n$ = 1 to 10
        Bin $n$:   If $0 < R_A \le 0.167$,
                    Then $F_{LA} = -2.395R_A + 0.9$

                   Else If $0.167 < R_A \le 1$,
                    Then $F_{LA} = -0.48R_A + 0.58$

                   Else If $1 < R_A \le 2$,
                    Then $F_{LA} = -0.1R_A + 0.2$

                   Else If $R_A > 2$,
                    Then $F_{LA} = 0$                                (121)
    Next $n$,
Next $j$,
```

where R_A is d/R_M.

Substep 2

For primary fragments, calculate the fraction of high-angle fragments, F_{HA}, for each bin by using the following algorithm:

```
For $j$ = 1 to 10
    Maximum throw table $j$:
    For $n$ = 1 to 10
        Bin $n$:  $F_{HA} = 1 - F_{LA}$                              (122)
    Next $n$,
Next $j$,
```

The relationship of high-angle and low-angle fragments (as a function of R_A) is summarized in Figure 8, *High-angle and Low-angle Fragment Relationship*.

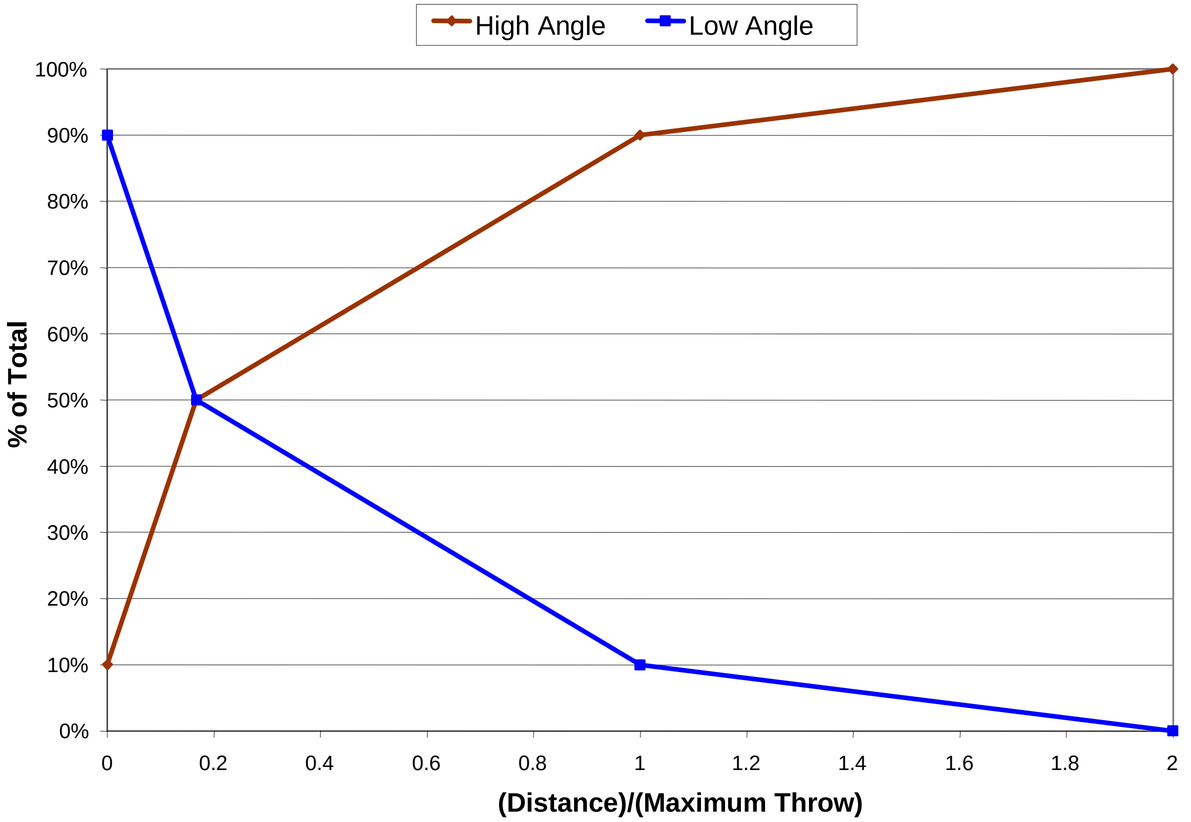


Figure 8. High-angle and Low-angle Fragment Relationship

The methodology and parameters associated with high- and low-angle fragments are described in Attachment 8.

Substep 3

For the primary fragment mass tables, SAFER determines the number of high-angle fragments, N_{HA}, and low-angle fragments, N_{LA}, in each bin. This procedure creates two debris tables: one table for low-angle fragments and one table for high-angle fragments. To create the high-angle fragment tables, SAFER calculates the number of high-angle fragments, N_{HA}, for each bin by using the following algorithm:

```
For $n$ = 1 to 10 (primary high-angle fragment table)
    Bin $n$:   $N_{HA} = N_{pf} * F_{HA}$          (123)
Next $n$,
```

where N_{pf} is the number of fragments in the bin of the departing fragment mass table.

To create the low-angle fragment tables, SAFER calculates the number of low-angle fragments, N_{LA}, for each bin using the following algorithm:

```
For $n$ = 1 to 10 (primary low-angle fragment table)
    Bin $n$:   $N_{LA} = N_{pf} * F_{LA}$          (124)
Next $n$,
```

where N_{pf} is the number of fragments in the bin of the departing fragment mass table.

Substep 4

SAFER partitions the low-angle fragments into side-impact and fly-through fragments. The side-impact fragments represent fragments that have reached terminal velocity and are falling when they hit a wall of the exposed site. The fly-through fragments are not falling at terminal velocity and are on their way up when they hit a wall of the exposed site. Note: The PES roof (steel and concrete) and crater ejecta fragments are not partitioned into fly-through and side-impact fragments; therefore, the low-angle partition applies to 7 out of the 10 fragment tables.

To create the fly-through and side-impact fragment tables, SAFER calculates the number of fly-through fragments, N_{FT}, for each bin using the following algorithm:

```
For $j$ = 1 to 7
    Fly-through fragment table $j$:
    For $n$ = 1 to 10
        Bin $n$:   $N_{FT} = N_{LA} * 0.5$          (125)
    Next $n$,
Next $j$,
```

where N_{LA} is the number of low-angle fragments for each bin.

To determine the number of side-impact fragments, N_{SI}, SAFER uses the following algorithm:

```
For $j$ = 1 to 7
    Side-impact fragment table $j$:
    For $n$ = 1 to 10
        Bin $n$:   $N_{SI} = N_{LA} - N_{FT}$          (126)
    Next $n$,
Next $j$,
```

where N_{LA} is the number of low-angle fragments and N_{FT} is the number of fly-through fragments.

Substep 5

For all departing debris types described in the 10 maximum throw tables, calculate a sigma value, σ, for each bin by:

```
For $j$ = 1 to 10
    Maximum throw table $j$:
    For $n$ = 1 to 10
        Bin $n$:  $\sigma = \frac{f * R_M}{\sigma \text{ value of extreme data}}$          (127)
    Next $n$,
Next $j$,
```

where R_M is the maximum throw range in each bin and the reduced debris throw factor, f, is provided in Table 21, *Reduced Debris Throw Factors,* by PES building type and debris type, and the σ *value of extreme data* is assumed to be three for primary and secondary fragments and four for crater ejecta fragments. For all other PES types f is equal to 1.0.

Table 21. Reduced Debris Throw Factors (f)

	Earth Covered Magazine		Hardened Aircraft Shelter	
Orientation	Front	Side/Rear	Front	Side/Rear
Primary	1	1	1	1
Roof	1	1	1	1
Front wall	1	0.01	1	0.01
Side walls	0.1	1	0.1	1
Rear	0.001	1	0.0001	1
Crater ejecta	1	1	1	1

Substep 6

For all high-angle and side-impact departing debris types described in the 11 departing fragment mass bin tables, calculate debris probability densities at the ES, P_i, for each bin by using the following algorithm:

```
For $j$ = 1 to 11
    Maximum throw table $j$:
    For $n$ = 1 to 10
        Bin $n$: $P_i = \frac{1}{\left(2\pi\sigma^2\right)} * e^{\left(\frac{-d^2}{2\sigma^2}\right)}$        (128)
    Next $n$,
Next $j$,
```

For all fly-through departing debris types described in the 7 departing fragment mass bin tables, calculate debris probability densities at the ES, P_i, for each bin using the following algorithm:

```
For $j$ = 1 to 7
    Maximum throw table $j$:
    For $n$ = 1 to 10
        Bin $n$: $P_i = \frac{1}{\left(2\pi\sigma_{FT}{}^2\right)} * e^{-0.5*\left(\frac{d}{\sigma_{FT}}\right)^2} * \left(\frac{2\pi\sigma_{FT}{}^2}{2\pi d + \pi}\right)^{(1-(d/3\sigma_{FT})^{0.5})}$        (129)
    Next $n$,
Next $j$,
```

where σ_{FT} is equal to $\sigma/2$.

Substep 7

SAFER creates arriving debris mass tables. Calculate the number of expected arriving fragments per square foot, N_{af}, for the high-angle and side-impact fragments described in the 11 departing fragment mass tables, as values for the mass bins of the arriving debris mass tables using the following algorithm:

```
For $j$ = 1 to 11
    Arriving debris mass table $j$:
    For $n$ = 1 to 10
        Bin $n$: $N_{af} = P_i * No.\ of\ departing\ fragments$        (130)
    Next $n$,
```

```
Next $j$,
```

where *No. of departing fragments* is the number of fragments in the respective bins of each departing fragment mass table.

Calculate the number of expected arriving fragments per square foot, N_{af}, for the fly-through fragments described in the 7 departing fragment mass tables, as values for the mass bins of the arriving debris mass tables using the following algorithm:

```
For $j$ = 1 to 7
    Arriving debris mass table $j$:
    For $n$ = 1 to 10
        Bin $n$: $N_{af} = P_i * No.\ of\ departing\ fragments$        (131)
    Next $n$,
```

Substep 8: Barricade Reduction of Low Angle Fragments

In this substep, SAFER determines the percentage of arriving low angle fragments that would be blocked by the presence of a fixed barricade of a given height and distance from the PES. The computations in this substep are based on a number of assumptions:

- the trajectories of arriving low angle fragments can be modeled as straight lines
- all fragments leaving the PES at low angle are constrained to impinge on the ES if not blocked by a barricade
- fragments that are dispersed from the wall of a PES depart within a fixed half angle from the normal to the PES wall
- fragments are dispersed uniformly both with respect to height on the PES wall and with respect to their angle of departure

The blocking routine considers fragments ejected from the wall in even increments of height up to the height of the PES. Fragments are assumed to be ejected from the PES at angles between the *normal + (plus) the specified half angle* and the *normal – (minus) the specified half angle.* At each height increment, the routine tests to determine whether the +/- half angles from normal impinge on the ES. If the full angular range (+/- the half angle) impinges on the ES, no adjustment is necessary. If not, the routine rotates the range of departure angles to ensure that all low angle fragments leaving the PES arrive at the ES.

At each height increment, a number of angles are computed as shown in Figure 9 (all are measured from zenith). These angles are used for two purposes: first, to determine the shift required to focus all low angle fragments onto the ES, and then to compute the percentage of the possible ejection angles that would be blocked by the barricade. After the blocked percentage is computed for each height increment, the percentage blocked is averaged over the entire height of the PES to determine the barricade effectiveness at blocking low angle PES fragments. The section below provides the equations used.

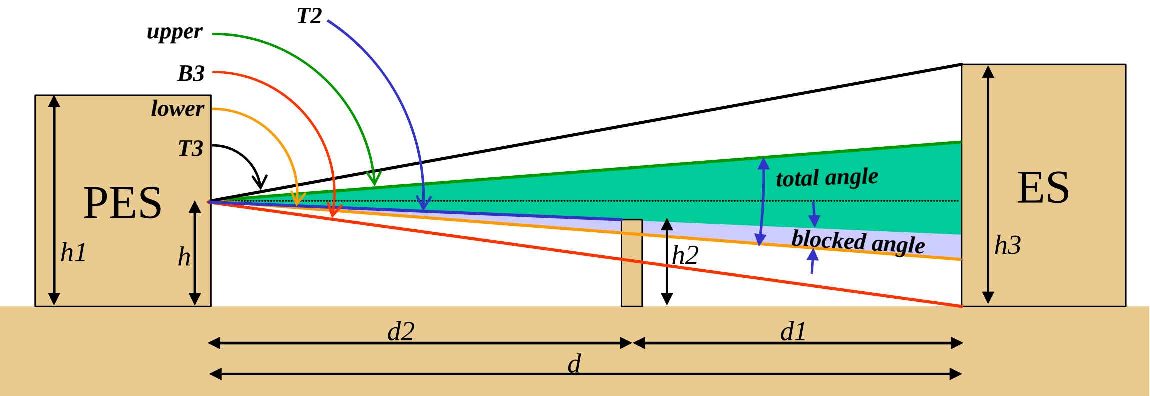


Figure 9. Parameters used in the ES Barricade Fragment Blocking Algorithm

SAFER calculates the percentage of fragments blocked by the barricade at varying heights until the PES height, *h1*, is reached by:

```
For $h$ = 0 to $h1$
    $T3 = \mathrm{ACOS}[\ (h3-h) / \mathrm{sqrt}(d^2 + (h3-h)^2\ )\ ]$
    $B3 = \mathrm{ACOS}[\ -(h) / \mathrm{sqrt}(d^2 + h^2\ )\ ]$
    $T2 = \mathrm{ACOS}[\ (h2 - h) / \mathrm{sqrt}(d2^2 + (h2 - h)^2\ )\ ]$
    If $B3 < (90 + ½\ \mathrm{angle})$
        Then $upper$ = Maximum $[(B3 - 2 * ½\ \mathrm{angle}), T3]$
    Else $upper$ = Maximum $[(90 - ½\ \mathrm{angle}), T3]$
    If $T3 > (90 - ½\ \mathrm{angle})$
        Then $lower$ = Minimum $[(T3 + 2 * ½\ \mathrm{angle}), B3]$
    Else $lower$ = Minimum $[(90 + ½\ \mathrm{angle}), B3]$
    $total\ angle = lower - upper$
    $blocked\ angle$ = Maximum [ 0, ($lower$ – Maximum [$T2$, $upper$])]
    $local\ reduction$ = Maximum [ 0, ($blocked\ angle / total\ angle$)]
Next $h$,
```

(132)

where *h1* is the height of the PES provided in Table 7, *PES Assumptions*, *h2* is the height of the barricade [from Step 3], *h3* is the height of the ES provided in Table A-11, *Pressure and Impulse Reduction Values due to Glass Percentage*, *h* is the height increment under evaluation, *d* is the distance between the PES and ES, *d1* is the distance between the barricade and the ES [from Step 3], *d2* is the distance between the barricade and the PES, *T3* is the angle from *h* to the top of the ES, *B3* is the angle from *h* to the base of the ES, *T2* is the angle from *h* to the top of the barricade, *upper* is the upper projection of fragments from the PES to the ES, *lower* is the lower projection angle of fragments from the PES to the ES, *total angle* is the span of angles at which fragments are ejected, and *local reduction* is the fraction of fly-through fragments blocked at height *h*. The *local reduction* value is stored for each value of *h*.

SAFER calculates the total percentage of fragments blocked by the barricade, *total reduction*, by:

$$total\,reduction = \frac{\sum local\,reduction}{number\,of\;height\,increments} \tag{133}$$

SAFER then reduces the number of fly-through fragments that have been blocked by the barricade by:

```
For $j$ = 1 to 7
    Arriving debris mass table $j$:
    For $n$ = 1 to 10
        Bin $n$: $N_{af} = N_{af} * total\,reduction$        (134)
    Next $n$,
```

where N_{af} is the number of fly-through fragments from Substep 7.

Rationale for the methodology used in this step and a comparison of SAFER predictions for arriving debris to empirical test data is detailed in Attachment 8.

Outputs of Step 15:

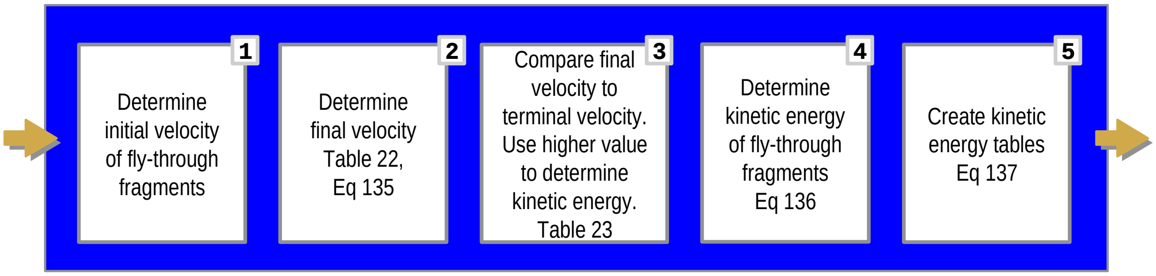
- Arriving primary fragment high-angle mass bin table
- Arriving primary fragment side-impact mass bin table
- Arriving primary fragment fly-through mass bin table
- 2 Arriving secondary high-angle debris mass tables (roof)
- 6 Arriving secondary side-impact debris mass tables (front wall, side wall, rear wall)
- 6 Arriving secondary fly-through debris mass tables (front wall, side wall, rear wall)
- Arriving crater ejecta high-angle debris mass table

4.4.7 STEP 16: Determine final velocity of fly-through fragments.

Since the fly-through fragments are not falling at terminal velocity, a final velocity is determined so the kinetic energy can be calculated and fragments placed in the appropriate kinetic energy bins. Side-impact and high-angle fragments use terminal velocity as the final velocity; therefore, those fragments are in the appropriate kinetic energy bin. *Substeps 1-5* describe how SAFER determines the final velocity of the fly-through fragments.

Inputs to Step 16:

- Primary fragment initial velocity, *IV* [from Step 11]
- Initial velocity for each PES component, *IV* [from Step 14]
- Arriving primary fragment fly-through mass bin table [from Step 15]
- 6 Arriving secondary fly-through debris mass tables (front wall, side wall, rear wall) [from Step 15]



Substep 1: Determine the initial velocity of the fly-through fragments

SAFER assigns the primary fragment *IV* determined in Step 11 from Table 13, *Primary Fragment Initial Velocity and Maximum Throw Values* to the fly-through primary fragments and assigns the secondary fragment initial velocities calculated in Eq. (112) in Step 14 to the fly-through secondary fragments.

Substep 2: Determine the final velocity of fly-through fragments

The final velocity, *FV*, of the fly-through fragments is calculated by:

```
For $j$ = 1 to 7
    Fly-through fragment table $j$:
    For $n$ = 1 to 10
        Bin $n$:   $FV = IV * \left(A * exp^{-(d*B)}\right)$        (135)
    Next $n$,
Next $j$,
```

where *A* and *B* are provided in Table 22, *Final Velocity Parameters* and *d* is the distance between the PES and ES.

Table 22. Final Velocity Parameters

Mass Bin	Steel Parameters		Concrete Parameters	
	A	B	A	B
1	0.99146	0.000312	0.97972	0.000653
2	0.97901	0.00039	0.96693	0.000837
3	0.96521	0.00049	0.96271	0.001105
4	0.95929	0.000663	0.95264	0.001448
5	0.94637	0.000979	0.92723	0.001838
6	0.89636	0.001218	0.90141	0.00238
7	0.899	0.001657	0.86595	0.003074
8	0.8168	0.002002	0.88862	0.004202
9	0.8171	0.002696	0.86728	0.005365
10	0.79687	0.003726	0.83715	0.007271

Substep 3: Compare final velocity to terminal velocity.

The final velocity calculated in Substep 2 is compared to the terminal velocity for the corresponding bins by material type, where the terminal velocity is found in Table 23, *Terminal Velocity (ft/s)*. The greater of the two values is used to calculate the kinetic energy in Substep 4.

Table 23. Terminal Velocity (ft/s)

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Steel	604.34	522.37	452.89	391.6	339.35	293.6	254.01	220.49	192.57	163.47
Concrete	366.93	317.17	274.98	237.76	206.04	178.27	154.22	133.88	116.92	99.25

The steel values are used when determining the terminal velocity of primary fragments.

Substep 4: Determine kinetic energy of fly-through fragments.

The fragment mass tables are translated to kinetic energy tables using the calculated kinetic energy. The calculated kinetic energy determines which bin the fragments are assigned to.

SAFER calculates the kinetic energy, *KE*, using the following algorithm:

```
For $j$ = 1 to 7
    Fly-through kinetic energy table $j$:
    For $n$ = 1 to 10
        Bin $n$:   $KE = 0.5 * (average\ \ fragment\ mass / 32.2) * FV^2$        (136)
    Next $n$,
Next $j$,
```

where the *average fragment mass* by bin is found in Table 11, *SAFER KE/Mass Bin Format*. The *KE* allows the creation of a kinetic energy table for each of the 7 fly-through fragment tables.

Substep 5: Create kinetic energy tables.

Using the kinetic energy calculated in *Substep 4,* the fragments are translated from mass bins to kinetic energy bins using the following algorithm.

```
For $j$ = 1 to 7 (KE table)
    For $n$ = 1 to 10 (bin in KE table)
        If minimum KE of bin $n$ < $KE$ < maximum KE of bin $n$
         Then add corresponding fragments to Bin $n$ of fragment table
        Else                                                        (137)
         Check next $n$
        End If
    Next $n$,
Next $j$,
```

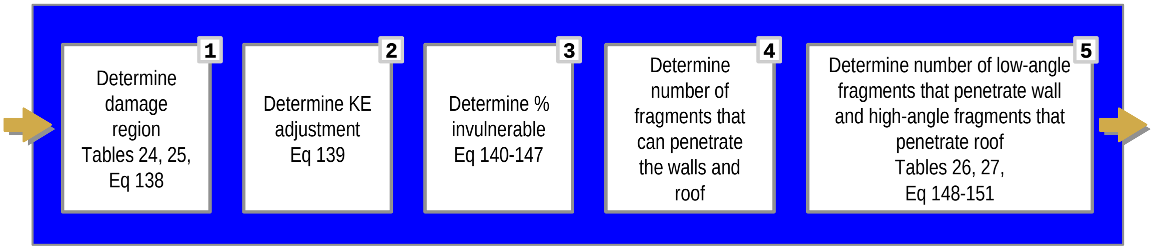
where the minimum and maximum KE for each bin is provided in Table 11, *SAFER KE/Mass Bin Format*.

Outputs of Step 16:

- Arriving primary fragment fly-through KE bin table
- 6 Arriving secondary fly-through debris KE tables (front wall, side wall, rear wall)

4.4.8 STEP 17: Reduce debris due to ES

Step 17 determines the amount of debris that penetrates the ES. The debris was divided into high-angle and low-angle debris in Step 15; in Step 17 the amount of debris that penetrates the roof and walls is determined.



SAFER first determines the amount of damage sustained by the walls and roof. This damage impacts the ability of the fragments to penetrate the walls and roof. Damage is classified by damage region. The damage region determines whether an adjustment is made to the amount of kinetic energy that the walls and roof can withstand. There are three damage regions. In damage region 1, the nominal KE values shown in Table 26 and Table 27 are used as the amount of KE that can penetrate the roof and walls. In damage region 2, the walls and roof have sustained greater damage so the nominal KE required to penetrate the structure is less and an adjustment is made to the nominal KE. In damage region 3, the building has sustained even greater damage so the nominal KE required to penetrate is adjusted lower and a percentage of the ES is assumed to have "voids" which allow debris to penetrate without obstruction.

This is accomplished in 5 substeps.

Inputs to Step 17:

- ES building type [from Step 3]
- ES roof type [from Step 3]
- Distance between the PES and ES (ft), d [from Step 3]
- Percentage of ES roof intact, $\%ES_{roof\ intact}$ [from Step 9]
- Percentage of ES walls intact, $\%ES_{wall\ intact}$ [from Step 9]
- Percentage of ES roof damaged, $\%ES_{roof\ damaged}$ [from Step 9]
- Percentage of ES walls damaged, $\%ES_{wall\ damaged}$ [from Step 9]
- 11 arriving fragment mass bin tables [all tables from Step 15]
  - Arriving primary fragment high-angle mass bin table
  - Arriving primary fragment side-impact mass bin table
  - 2 Arriving secondary high-angle debris mass tables (roof)
  - 6 Arriving secondary side-impact debris mass tables (front wall, side wall, rear wall)
  - Arriving crater ejecta high-angle debris mass table
- Arriving primary fragment fly-through KE bin table [from Step 16]
- 6 Arriving secondary fly-through debris KE tables (front wall, side wall, rear wall) [from Step 16]

Substep 1

SAFER determines the damage region, *DR* for the roof and walls. Table 24 and Table 25 show the damage values for the roof and walls. The percentage of the ES roof and wall damaged is compared to the values in Table 24 and Table 25 to determine which of the three damage regions are applicable.

```
If $\%ES_{roof\ damaged} \leq LRD$                                        (138)
  Then $DR = 1$
Else If $LRD < \%ES_{roof\ damaged} < HRD$
  Then $DR = 2$
Else $DR = 3$
End If
```

where the values for *LRD* (low range damage) and *HRD* are provided in Table 24, *Roof Damage Ranges.*

Similarly, the damage region is determined for the ES walls using Table 25, *Wall Damage Ranges*.

Table 24. Roof Damage Ranges

ES Roof Types	Low Range Damage *LRD*	High Range Damage *HRD*
4” Reinforced Concrete	40	65
Reinforced Concrete (>12”)	40	65
Plywood and Wood Joist	20	50
Gypsum/Fiberboard/Steel Joist	20	50
Wood Panelized	20	50
Lightweight Concrete/Steel Deck & Joists	30	50
Medium Steel Panel	15	30
Light Metal Deck	15	30
Steel (automobile)	15	30

Table 25. Wall Damage Ranges

ES Wall Types	Low Range Damage *LRD*	High Range Damage *HRD*
Steel Stud	15	25
Corrugated Steel	15	25
Unreinforced Masonry	15	25
8” Reinforced Masonry	25	50
8” Reinforced Concrete	25	50
Reinforced concrete (>12”)	25	50
6” Reinforced Concrete Tilt-up	25	50
Wood Stud	15	25
Steel (automobile doors)	25	35

Substep 2

SAFER determines the KE adjustment, KE_a, for the roof and walls based on the damage region by:

```
If $DR = 1$                                                    (139)
  Then $KE_a = \Delta KE_n$
Else If $DR = 2$
  Then $KE_a = \Delta KE_n * \%ES_{roof\ intact}$
Else If $DR = 3$
  Then $KE_a = \Delta KE_n * \%ES_{roof\ intact}$
End If
```

where ΔKE_n values are provided in Table 26, *Roof Protection Parameters* and Table 27, *Wall Protection Parameters*. Note that if the damage region is three, then a void is created and a percentage of fragments will pass through the ES without obstruction (the kinetic energy value that the walls and roof will withstand is zero).

Table 26. Roof Protection Parameters

ES Roof Types	% Invulnerable area (Nominal) IA_{roof}	KE absorbed by roof (ft-lbs) ΔKE_n
4” Reinforced Concrete	10	10,000
Reinforced Concrete (14”)	15	200,000
Plywood and Wood Joist	5	300
Gypsum/Fiberboard/Steel Joist	5	200
Wood Panelized	5	600
2” Lightweight Concrete/Steel Deck & Joists	7.5	2,000
Medium Steel Panel (18 gauge)	7.5	1,000
Light Metal Deck (22 gauge)	7.5	500
Steel (automobile)	2.5	200

Table 27. Wall Protection Parameters

ES Wall Types	% Invulnerable area (Nominal) IA_{wall}	KE absorbed by wall (ft-lbs) ΔKE_n
Steel Stud	2	500
Corrugated Steel	2	500
Unreinforced Masonry	2	4,500
8” Reinforced Masonry	2	15,000
8” Reinforced Concrete	2	50,000
Reinforced concrete (>12”)	2	200,000
6” Reinforced Concrete Tilt-up	2	37,500
Wood Stud	2	200
Steel (automobile doors)	4	1000

Substep 3

Each of the roof and wall types includes a *percentage invulnerable area*. The invulnerable area is assumed to totally block arriving fragments from any and all KE bins. The invulnerable area varies proportionally to the percentage of the ES that is intact; the nominal values (IA_{roof}, IA_{wall}) are shown in Table 26, *Roof Protection Parameters*, and Table 27, *Wall Protection Parameters*.

The adjusted invulnerable area for the ES roof, *AIAR*, is calculated by:

$$AIAR = IA_{roof} * \%ES_{roof\ intact} \tag{140}$$

The 4 high-angle arriving fragment tables are then adjusted by *AIAR*.

```
For $j$ = 1 to 4
     High-angle fragment table $j$:
     For $n$ = 1 to 10
          Bin $n$:   $N_{HA} = N_{HA} * (1 - AIAR)$          (141)
     Next $n$,
Next $j$,
```

Next, the number of fragments that will be blocked by the roof, *NHA*, is calculated by:

```
If $DR$ = 1 or $DR$ = 2                                      (142)
 Then $NHA = N_{HA}$
Else If $DR$ = 3
 Then $NHA = N_{HA} * \%ES_{roof\ intact}$
End If
```

If the damage region is three, it is assumed that a number of fragments are unimpeded by the structure, so an adjustment is made to remove these unimpeded fragments from the number of fragments that will be impeded by the roof. The unimpeded fragments are added back to the number of fragments that penetrate the roof in Substep 4.

Similarly, the adjusted invulnerable area for the ES wall, *AIAW*, is calculated by:

$$AIAW = IA_{wall} * \%ES_{wall\ intact} \tag{143}$$

The 14 low-angle arriving fragment tables are then adjusted by *AIAW*.

```
For $j$ = 1 to 7
     Side-impact fragment table $j$:
     For $n$ = 1 to 10
          Bin $n$:   $N_{SI} = N_{SI} * (1 - AIAW)$          (144)
     Next $n$,
Next $j$,
```

```
For $j$ = 1 to 7
     Fly-through fragment table $j$:
     For $n$ = 1 to 10
          Bin $n$:   $N_{FT} = N_{FT} * (1 - AIAW)$          (145)
     Next $n$,
Next $j$,
```

Next the number of side-impact fragments that will be blocked by the wall, *NSI*, is calculated by:

```
If $DR = 1$ or $DR = 2$                                              (146)
 Then $NSI = N_{SI} – (1-\%glass)$
Else If $DR = 3$
 $NSI = [N_{SI} – (1-\%glass)]$ *× $\%ES_{wall\ intact}$
End If
```

Next the number of fly-through fragments that will be blocked by the wall, *NFT*, is calculated by:

```
If $DR = 1$ or $DR = 2$                                              (147)
 Then $NFT = N_{FT} – (1-\%glass)$
Else If $DR = 3$
 $NFT = [N_{FT} – (1-\%glass)]$ *× $\%ES_{wall\ intact}$
End If
```

It is assumed that the windows will not provide protection from debris, so the number of side-impact and fly-through fragments that can pass through the windows are taken out of the blocked fragment count. The number of side-impact and fly-through fragments taken out is based on the percentage of windows on the ES. These fragments are added back to the number of fragments that penetrate the walls in Substep 4. If the damage region is three, it is assumed that a number of fragments are unimpeded by the structure, so an adjustment is made to remove these unimpeded fragments from the number of fragments that will be impeded by the walls. The unimpeded fragments are added back to the number of fragments that penetrate the wall in Substep 4.

Substep 4

SAFER creates 18 penetrating debris tables that describe the outcome of fragment impacts on the ES. This procedure determines if fragments are able to penetrate the ES and for those that do penetrate, it determines if the resultant KE causes the fragment to shift to a lower KE bin or remain in the current KE bin.

For all debris types described in the 4 high-angle fragment tables, SAFER calculates the resulting kinetic energy, KE_R, following impact with the roof. SAFER then determines penetrating fragments and their resulting KE by using the following algorithm:

```
For $j = 1$ to 10
    High-angle fragment table $j$:
    For $n = 1$ to 10
        Bin $n$:  $KE_R$ = Average KE of bin $n$ – KE absorbed by ES roof          (148)
                  If $KE_R \le 0$,
                   Then the ES roof stopped fragment penetration for bin $n$

                  Else If $KE_R \ge$ lower KE limit of bin $n$,
                   Then the fragment penetrates the roof and remains in current KE bin

                  Else If $KE_R <$ lower KE limit of bin $n$
                  Then the fragment penetrates the roof but shifts to a lower KE bin
    Next $n$,
Next $j$,
```

where the average (logarithmic) and lower KE limit of bin n is provided in Table 11, *SAFER KE/Mass Bin Format*, and the KE absorbed by the ES roof is provided in Table 26, *Roof Protection Parameters*.

Note, if the damage region is three then the unimpeded fragments are added back to the High-angle fragment tables in the appropriate KE bin.

For all debris types described in the 14 low-angle fragment tables, SAFER calculates the resulting kinetic energy, KE_R, following impact with an ES wall. SAFER then determines penetrating fragments and their resulting KE by using the following algorithm:

```
For $j$ = 1 to 7
    Side-impact fragment table $j$:
    For $n$ = 1 to 10
        Bin $n$:  $KE_R$ = Average KE of bin $n$ – KE absorbed by ES wall          (149)
                  If $KE_R \leq 0$,
                   Then an ES wall stopped fragment penetration for bin $n$

                  Else If $KE_R \geq$ lower KE limit of bin $n$,
                   Then the fragment penetrates an ES wall and remains in current KE bin

                  Else If $KE_R <$ lower KE limit of bin $n$
                   Then the fragment penetrates an ES wall but shifts to a lower KE bin
    Next $n$,
Next $j$,

For $j$ = 1 to 7
    Fly-through fragment table $j$:
    For $n$ = 1 to 10
        Bin $n$:  $KE_R$ = Average KE of bin $n$ – KE absorbed by ES wall          (150)
                  If $KE_R \leq 0$,
                   Then an ES wall stopped fragment penetration for bin $n$

                  Else If $KE_R \geq$ lower KE limit of bin $n$,
                   Then the fragment penetrates an ES wall and remains in current KE bin

                  Else If $KE_R <$ lower KE limit of bin $n$
                   Then the fragment penetrates an ES wall but shifts to a lower KE bin
    Next $n$,
Next $j$,
```

where the average (logarithmic) and lower KE limit of bin n is provided in Table 11, *SAFER KE/Mass Bin Format*, and the KE absorbed by the ES wall is provided in Table 27, *Wall Protection Parameters.*

The percentage of fragments that passed through the windows are added back to the low-angle fragment tables in the appropriate KE bin. If the damage region is three, then the unimpeded fragments are also added back to the appropriate KE bin.

Rationale for the methodology used in this Substep is detailed in Attachment 8.

Substep 5

SAFER sums the number of side-impact and fly-through fragments into one low-angle table for primary, secondary, and crater ejecta fragments.

```
For j = 1 to 7
    Low-angle fragment table j:
    For n = 1 to 10
        Bin n:   $N_{LA} = NSI + NFT$                                        (151)
    Next n,
Next j,
```

Outputs of Step 17:

- 11 penetrating debris tables
  - 2 high-angle fragment debris tables (primary, crater ejecta)
  - 1 high-angle fragment steel debris table (roof)
  - 1 high-angle fragment concrete debris table (roof)
  - 1 low-angle fragment debris table (primary)
  - 3 low-angle fragment steel debris tables (primary, front wall, side wall, rear wall)
  - 3 low-angle fragment concrete debris tables (primary, front wall, side wall, rear wall)

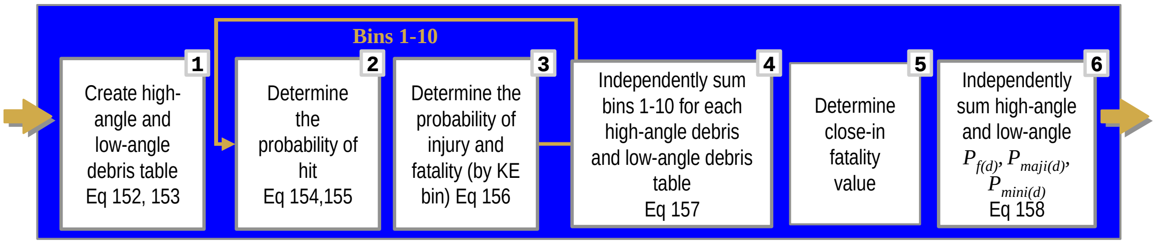
4.4.9 STEP 18: Assess $P_{f(d)}$, $P_{maji(d)}$, $P_{mini(d)}$.

Step 18 completes the Debris Branch by determining the human vulnerability from debris. All debris is defined in terms of the kinetic energy (KE) of penetrating fragments. SAFER estimates fatality, major injury, and minor injury as a function of KE. SAFER considers the penetrating fragment description, the vulnerable area of an exposed human, the probability of lethality, major injury, or minor injury given a fragment hit, and the probability of a hit. The vulnerable area of the exposed human is assumed to be 3.0 ft^2 as defined by RCC Standard 321 (Ref 7). The lethality value is a function of kinetic energy.

Inputs to Step 18:

- 11 penetrating debris tables [from Step 17]
  - 2 high-angle fragment debris tables (primary, crater ejecta)
  - 1 high-angle fragment steel debris table (roof)
  - 1 high-angle fragment concrete debris table (roof)
  - 1 low-angle fragment debris table (primary)
  - 3 low-angle fragment steel debris tables (primary, front wall, side wall, rear wall)
  - 3 low-angle fragment concrete debris tables (primary, front wall, side wall, rear wall)

Step 18 is accomplished in 6 substeps.



Substep 1

For the four high-angle penetrating debris tables, SAFER creates one combined high-angle penetrating debris table by summing the number of high-angle fragments, N_{HA}, across corresponding bins in each of the 4 high-angle penetrating debris tables. Calculate the total quantity of high-angle fragments, N^*_{HA}, in each bin of the combined table by using the following algorithm:

```
For $j$ = 1 to 4
    High-angle penetrating debris table $j$:
    For $n$ = 1 to 10
        $N^*_{HA} = N^*_{HA} + N_{HA}$ in bin $n$ of high-angle debris tables $j$        (152)
    Next $n$,
Next $j$,
```

The result of this procedure is a combined high-angle penetrating debris table.

Similarly, SAFER creates one combined low-angle penetrating debris table from the seven low-angle debris tables. Calculate the total quantity of low-angle fragments, N^*_{LA}, in each bin of the combined table by using the following algorithm:

```
For $j$ = 1 to 7
    Low-angle penetrating debris table $j$:
    For $n$ = 1 to 10
        $N^*_{LA} = N^*_{LA} + N_{LA}$ in bin $n$ of low-angle debris tables $j$        (153)
    Next $n$,
Next $j$,
```

The result of this procedure is a combined low-angle penetrating debris table.

Substep 2

SAFER calculates a probability of hit for each bin of the combined high-angle and combined low-angle tables. A unique probability of hit is calculated for the three consequences of fatality, $P_{hit(f)}$, major injury, $P_{hit(maji)}$, and minor injury, $P_{hit(mini)}$. These are stored in a P_{hit} table for each consequence.

Calculate the probability of hit, P_{hit}, for each bin of the high-angle combined table by using the following algorithm:

```
For $c$ = 1 to 3 (for each consequence – fatality, major injury, minor injury)
    For $n$ = 1 to 10 of combined high-angle penetrating debris table:
        $P_{hit} = 1 - e^{-(CA \times N^*_{HA})}$        (154)
    Next $n$,
```

```
    Next $c$,
```

where N^*_{HA} is from Substep 1 and CA is the concern area provided in Table 28, *Fatality Concern Area*, Table 29, *Major Injury Concern Area*, and Table 30, *Minor Injury Concern Area*. Note that the concern area for major injury and minor injury considers whether the person is in the open or inside a structure.

Similarly, the P_{hit}, for each bin of the low-angle combined table is calculated using the same methodology where N^*_{LA} is from Substep 1 and CA is provided in Table 28-Table 30.

```
    For $c$ = 1 to 3 (for each consequence – fatality, major injury, minor injury)
        For $n$ = 1 to 10 of combined low-angle penetrating debris table:
  $P_{hit} = 1 - e^{-(CA \times N^*_{HA})}$                                        (155)
        Next $n$,
    Next $c$,
```

where N^*_{HA} is from Substep 1 and CA is the concern area provided in Table 28-Table 30. Note that the concern area for major injury and minor injury considers whether the person is in an ES that is open or a structure.

Table 28. Fatality Concern Area

	Bin Number									
ES Type	1	2	3	4	5	6	7	8	9	10
All	3	3	3	3	3	3	3	3	3	3

Table 29. Major Injury Concern Area

	Bin Number									
ES Type	1	2	3	4	5	6	7	8	9	10
Open	5	4.78	4.56	4.33	4.11	3.89	3.67	3.44	3.22	3
Structure	7.5	7	6.5	6	5.5	5	4.5	4	3.5	3

Table 30. Minor Injury Concern Area

	Bin Number									
ES Type	1	2	3	4	5	6	7	8	9	10
Open	10	9.22	8.44	7.67	6.89	6.11	5.33	4.56	3.78	3
Structure	15	13.67	12.33	11	9.67	8.33	7	5.67	4.33	3

The result of this procedure is six probability of hit tables. Three probability of hit tables are defined for the 10 KE bins of a combined high-angle penetrating debris table. Three probability of hit tables are defined for the 10 bins of a combined low-angle penetrating debris table.

Substep 3

Calculate the probability of fatality due to debris, $P_{f(d)}$, probability of major injury due to debris, $P_{maji(d)}$, and probability of minor injury due to debris, $P_{mini(d)}$ for each bin in the two combined penetrating debris tables by using the following algorithm:

```
For $j$ = 1 to 2
    Combined penetrating debris table $j$:
    For $n$ = 1 to 10
    Bin $n$: $P_{f(d)} = CA^{*}\ lethality\ value * N^{*}$ for bin $n * P_{hit(f)}$ for bin $n$          (156)
    Bin $n$: $P_{maji(d)} = CA * major\ injury\ value * N^{*}$ for bin $n * P_{hit(maji)}$ for bin $n$
    Bin $n$: $P_{mini(d)} = CA * minor\ injury\ value * N^{*}$ for bin $n * P_{hit(mini)}$ for bin $n$
    Next $n$,
Next $j$,
```

where CA is the concern areas provided in Table 28-Table 30 and N^* is the total quantity of fragments (N^*_{HA} or N^*_{LA}) and P_{hit} is the probability of hit for each bin under consideration and the *lethality value, major injury value, and minor injury value* is determined by the lethality curve presented in Figure 10, $P_{f|e}$ *vs. KE*. Figure 10 is included for reference. It shows the probability of fatality as a function of the KE as distributed among the KE bins. The lethality/injury values used by SAFER for fatality, major injury, and minor injury by bin are provided in Table 31, *Debris Vulnerability Values.*

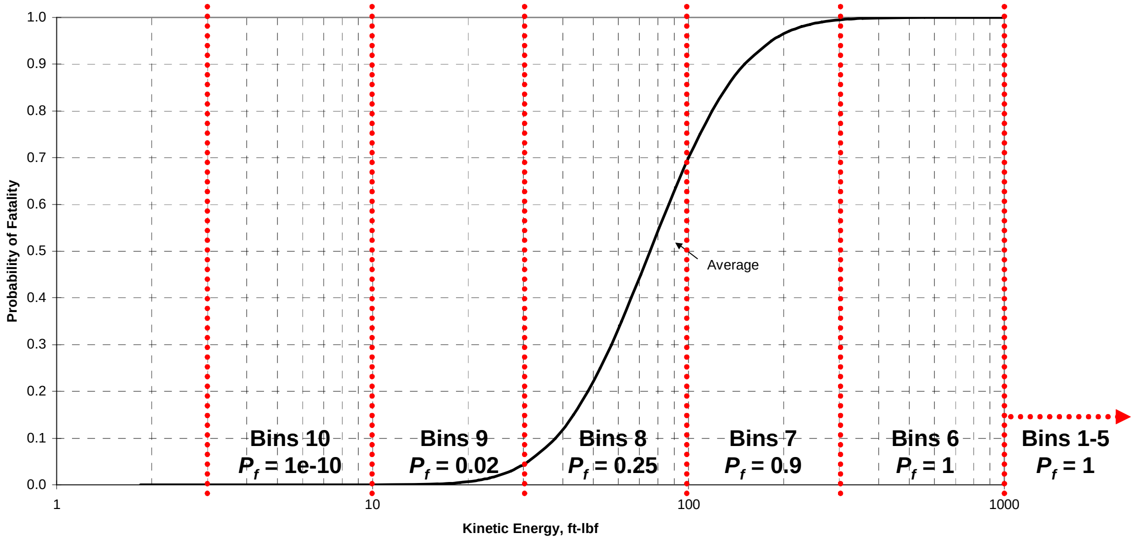


Figure 10. $P_{f|e}$ vs. KE

Table 31. Debris Lethality/Injury Values

Vulnerability	Bin Number									
	1	2	3	4	5	6	7	8	9	10
Fatality	1	1	1	1	1	1	0.9	0.25	0.02	1E-10
Major Injury	1	1	1	1	1	1	0.98	0.5	0.1	1E-04
Minor Injury	1	1	1	1	1	1	1	0.97	0.75	0.22

Substep 4

Using the additive rule for the union of non-mutually exclusive events, calculate a total probability of fatality due to debris from the combined high-angle penetrating debris table, $P_{f(d)high\text{-}angle}$. Calculate a total probability of fatality due to debris from the combined low-angle penetrating debris table, $P_{f(d)low\text{-}angle}$. For example, $P_{f(d)low\text{-}angle}$ is calculated by:

$$P_{f(d)low\text{-}angle} = P_{f(d)bin1} + (P_{f(d)bin2})(1 - P_{f(d)bin1}) + (P_{f(d)bin3})(1 - P_{f(d)bin1})(1 - P_{f(d)bin2})) + \ldots \tag{157}$$

Similarly, the total probability of major injury and minor injury from high-angle debris and low angle debris is calculated.

Substep 5

Determine if SAFER is in the "close-in" region. For the debris branch, the "close-in" region is determined based on the crater radius. The crater radius is calculated in Step 14. If the distance between the PES and ES is less than twice the crater radius then the probability of fatality, probability of major injury, and probability of minor injury due to debris is set to 1.0; otherwise the vulnerability values are the values calculated in Eq. (157).

Substep 6

Finally, SAFER calculates the overall probability of fatality due to debris, $P_{f(d)}$, by summing the high-angle and low-angle probabilities of fatalities using the additive rule for the union of non-mutually exclusive events. Solve for $P_{f(d)}$ by:

$$P_{f(d)} = P_{f(d)low-angle} + (1 - P_{f(d)low-angle})P_{f(d)high-angle} \tag{158}$$

$P_{f(d)}$ represents the probability a person has of being struck and killed by an incoming fragment. Similarly, SAFER calculates the overall probability of major injury due to debris, $P_{maji(d)}$, and the probability of minor injury due to debris, $P_{mini(d)}$.

Rationale for the methodology used in this step is detailed in Attachment 8.

Outputs of Step 18:

- Probability of fatality due to debris, $P_{f(d)}$
- Probability of major injury due to debris, $P_{maji(d)}$
- Probability of minor injury due to debris, $P_{mini(d)}$

4.5 Group 5 Steps: Thermal Branch

Group 5 includes Steps 19-22 of the SAFER architecture. These steps contribute to effects analysis by determining the effect of the fatality mechanism heat.

SAFER considers the effects and probability of fatality due to heat if the situation includes a HD 1.3 event. In this situation, SAFER does not consider the other fatality mechanisms (pressure and impulse, structural response, and debris) due to the lack of a blast wave being formed by a HD 1.3 event.

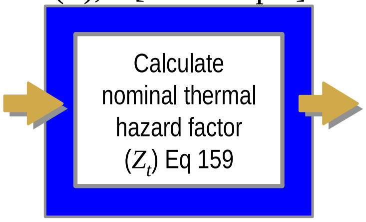
Step 19 determines a thermal hazard factor based on the yield and distance between the PES and the ES. Step 20 determines an adjusted thermal hazard factor due to the presence of the PES. Step 21 determines a thermal blocking factor that describes the thermal protection provided by the ES to personnel. Finally, Step 22 calculates the probability of fatality due to thermal effects, $P_{f(t)}$.

4.5.1 STEP 19: Determine nominal thermal hazard factor.

Step 19 determines a thermal hazard factor based on the yield and distance between the PES and the ES.

Inputs to Step 19:

- Yield of the event (lbs), W_1 [from Step 4]
- Distance between the PES and ES (ft), d [from Step 3]



The nominal thermal hazard factor, Z_t, is determined by using the entered amount of HD 1.3 material.

$$Z_t = \frac{d}{W_1^{\frac{1}{3}}} \tag{159}$$

Note that Z_t is identical to the hazard factor, Z, found in Step 5. The unmodified value of temperature is not expressly considered.

Output of Step 19:

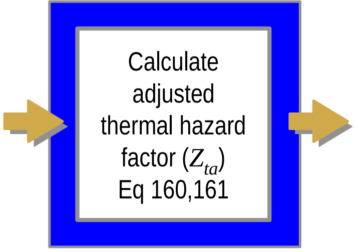
- Thermal hazard factor, Z_t

4.5.2 STEP 20: Adjust thermal hazard factor (due to PES).

Step 20 determines an adjusted thermal hazard factor due to the presence of the PES.

Inputs to Step 20:

- Distance between the PES and ES (ft), d [from Step 3]
- Adjusted weight (lbs), W_a [from Step 6]



Calculate the adjusted thermal hazard factor, Z_{ta}, by:

$$Z_{ta} = \frac{d}{W_a^{\frac{1}{3}}} \tag{160}$$

If there is no PES, or the PES type is a pre-engineered metal building or hollow clay tile,

$$Z_{ta} = Z_t \tag{161}$$

Note that Z_{ta} is identical to the adjusted hazard factor, Z_a, found in Step 6. The adjusted value of temperature is not expressly considered.

Rationale for the methodology used in this step is detailed in Attachment 1.

Output of Step 20:

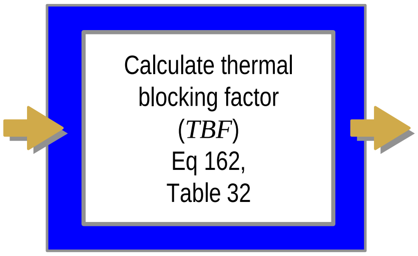
- Adjusted thermal hazard factor, Z_{ta}

4.5.3 STEP 21: Determine ES protection.

Step 21 determines a thermal blocking factor that describes the thermal protection provided by the ES to personnel within. This blocking factor considers the ES building type and the amount of windows (glass) in the structure.

Inputs to Step 21:

- ES building type [from Step 3]
- Percentage of glass on the ES (%), G_P [from Step 3]



Calculate the adjusted thermal blocking factor, *TBF*, by:

$$Thermal\,blocking\ factor = TBF = TBF_0 * \frac{100 - G_P}{100} \tag{162}$$

where TBP_0 is the thermal blocking factor based on the ES building type and is provided in Table 32, *Nominal Thermal Blocking Factors*.

Table 32. Nominal Thermal Blocking Factors

ES Building Type	Thermal Blocking Factor (TBF_o)
Reinforced concrete	1.0
Tilt-up reinforced concrete	1.0
Reinforced concrete and reinforced masonry	1.0
Steel and masonry	1.0
Reinforced masonry	1.0
Brick	1.0
Light steel frame	0.2
Large/heavy timber	0.2
Timber	0.2
Light steel frame	0.2
Modular/trailers	0.2
RC offices/apartments (multi-story)	1.0
Reinforced concrete and masonry offices/apartments (multi-story)	1.0
Steel frame offices/apartments (multi-story)	0.2
Large pre-engineered metal building	0.2
Vehicle	0.6

Rationale for the methodology used in this step is detailed in Attachment 1.

Output of Step 21:

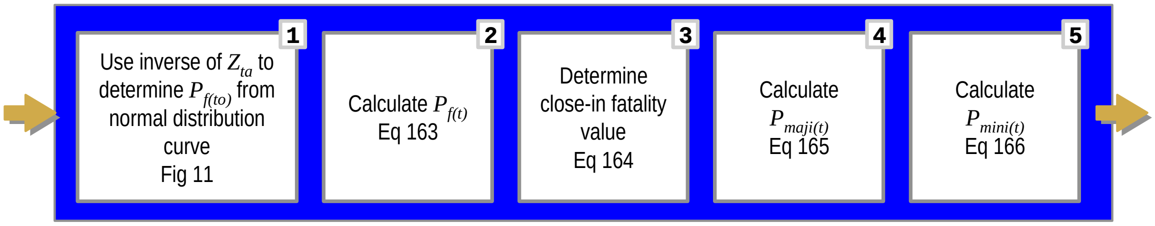
- Thermal blocking factor, *TBF*

4.5.4 STEP 22: Assess $P_{f(t)}$, $P_{maji(t)}$, $P_{mini(t)}$.

Step 22 completes the Thermal Branch by determining the probability of fatality due to thermal effects, $P_{f(t)}$, probability of major injury due to thermal effects, $P_{maji(t)}$, and probability of minor injury due to thermal effects, $P_{mini(t)}$.

Inputs to Step 22:

- Distance between the PES and ES (ft), *d* [from Step 3]
- Equivalent NEW (lbs), W_2 [from Step 4]
- Adjusted thermal hazard factor, Z_{ta} [from Step 20]
- Thermal blocking factor, *TBF* [from Step 21]



Substep 1

Using the inverse of the adjusted thermal hazard factor, Z_{ta}, determine the nominal probability of fatality due to thermal effects, $P_{f(to)}$, from the *S-curve* as presented in Figure 11.

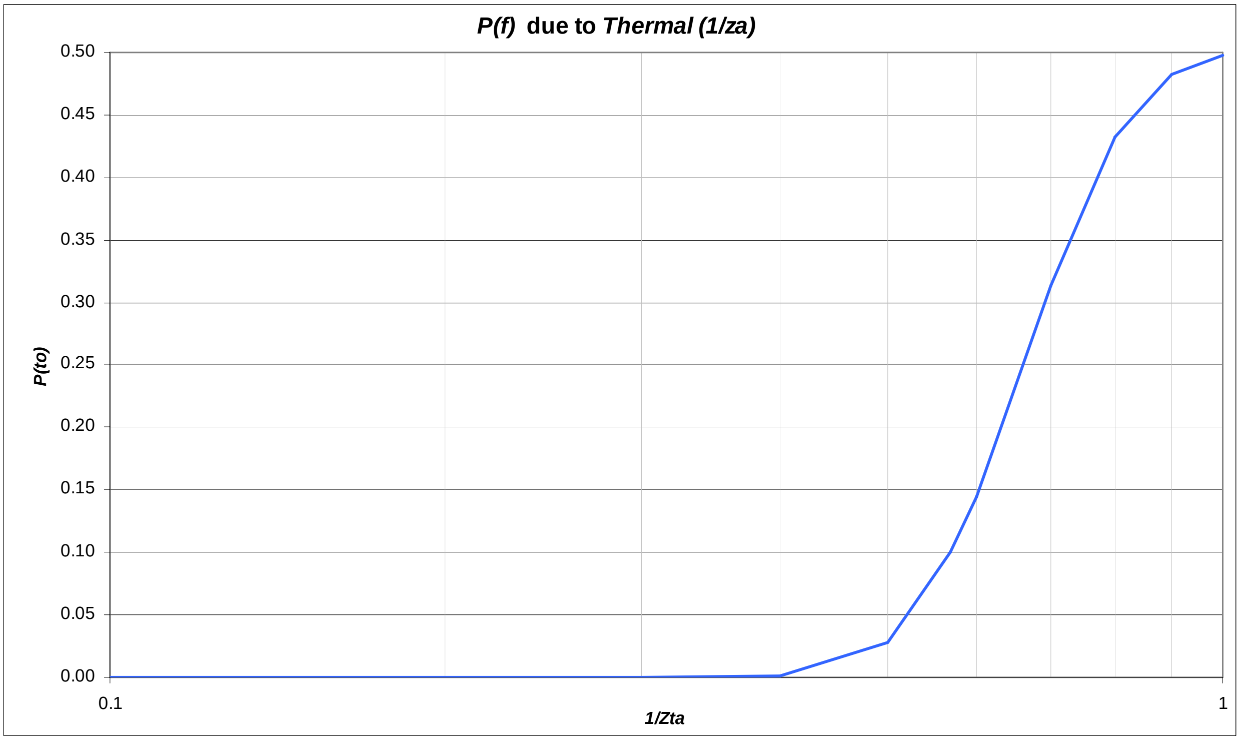


Figure 11. Nominal Probability of Fatality due to Thermal Effects

Substep 2

Calculate the probability of fatality due to thermal effects, $P_{f(t)}$, by:

$$P_{f(t)} = (1 - TBF) * P_{f(to)} \tag{163}$$

Substep 3

Determine if SAFER is in the "close-in" region. For the thermal branch, the "close-in" region is determined based on the fireball radius. Calculate the fireball radius, F_r, by:

$$F_R = 2.77 \times \left(\frac{W_2}{0.45} \right)^{0.36} \tag{164}$$

If the distance between the PES and ES is less than the fireball radius then the probability of fatality due to thermal effects, $P_{f(t)}$, is set to 1.0; otherwise the $P_{f(t)}$ is the value calculated from Eq. (163).

Substep 4

Calculate the probability of major injury due to thermal effects, $P_{maji(t)}$, by:

$$P_{maji(t)} = P_{f(t)} * 3 \tag{165}$$

Substep 5

Calculate the probability of minor injury due to thermal effects, $P_{mini(t)}$, by:

$$P_{mini(t)} = P_{f(t)} * 20 \tag{166}$$

Rationale for the methodology used in this step is detailed in Attachment 1.

Outputs of Step 22:

- Probability of fatality due to thermal effects, $P_{f(t)}$
- Probability of major injury due to thermal effects, $P_{maji(t)}$
- Probability of minor injury due to thermal effects, $P_{mini(t)}$

4.6 Group 6 Steps: Effects Aggregation and Risk Calculation

Group 6 includes Steps 23-26 of the SAFER architecture. Steps 23-26 are performed for both related and public personnel.

Step 23 completes the effects analysis by performing four SAFER runs using different combinations of the expected value and maximum value of two driving parameters: the amount of explosives present and the yield.

Step 24 uses the results of Step 23 to compute the risks (individual and group for related and public) for a given PES/ES pair. These risks are represented by the Expected Value and the Variance of the risk distributions. These risks have been termed Pair Risks and are calculated for each PES/ES pair in the situation. Pair Risks represent the risks between a single PES and a single ES only.

After the Pair Risks (Step 24) have been computed for all ESs within the hazard arc of a particular PES, Step 25 aggregates the risks (individual and group risks for related and public) that each PES poses to all ESs. These risks have been termed the PES risks and are calculated for each PES in the situation. Step 25 also aggregates the risks (individual and group risks for related and public) to each individual ES from all PESs to which it is exposed. These risks have been termed ES risks and are calculated for each ES in the situation. In addition to these, Step 25 also computes the total risks to all ESs within the hazard arc of each PES. These risks are termed PES Siting risks and are computed for individuals and groups of related and public personnel.

When the total PES risk (Step 25) has been determined for each PES, Step 26 aggregates the risks (individual and group risks for related and public) that all PESs in the situation pose to all the ESs. These risks have been termed Installation Risks. They represent the total risks of the situation analyzed.

4.6.1 STEP 23: $P_{f|e}$ for variations of AP and Y

Step 23 completes the effects analysis by compiling the effects probabilities of fatality due to Pressure-impulse, overall building damage, debris, and thermal effects for different combinations of Amount Present and Yield. Holding all other parameters fixed, four SAFER runs are performed as follows:

- Run 1: Maximum (Sited) Amount Present and Maximum Yield
- Run 2: Expected Amount Present and Expected Yield
- Run 3: Maximum (Sited) Amount Present and Expected Yield
- Run 4: Expected Amount Present and Maximum Yield

Run 1 is performed to compute the risk due to a maximum event. This is the risk measure contained in currently established Explosives Risk Criteria approved by the DDESB. The expected value computed in this run is denoted by the “sited NEWQD line” on the SAFER uncertainty display.

Run 2 computes the $P_{f|e}$ due to each of the effects for an event defined by the expected values of Amount Present and Yield. The results of this run are used in step 24 to determine the median values of $P_{f|e}$ for each effect. The total $P_{f|e}$ for this run is also used as the median value when determining the individual variations caused by increases in either Amount Present or Yield.

Run 3 computes the total $P_{f|e}$ when the Amount Present is set to the maximum (sited) value for the situation being analyzed. This information is used in step 25 to determine the variation due to Amount Present.

Finally, Run 4 computes the total $P_{f|e}$ when the Yield is set to the maximum value based on the type of explosive present. This information is used in step 25 to determine the variation due to Yield.

Inputs to Step 23:

- Situation data [from Steps 1 through 5]
- Expected and Maximum values for Amount Present and Yield [Steps 1, 2, and 4] Calculate the probability of fatality and injury given an explosives event and the presence of a person for each effects branch using Steps 5 through 22 and compute the total $P_{f|e}$, $P_{maji|e}$, and $P_{mini|e}$ for this PES/ES pair by:

$$P_{f/e} = P_{f(o)} + (P_{f(b)})(1-P_{f(o)}) + (P_{f(d)})(1-P_{f(b)})(1-P_{f(o)}) + (P_{f(t)})(1-P_{f(d)})(1-P_{f(b)})(1-P_{f(o)}) \tag{167}$$

$$\begin{gathered} P_{maji\,/e} = (1-P_{f/e})*[P_{maji\,(o)} + (P_{maji\,(b)})(1-P_{maji\,(o)}) + \\ (P_{maji\,(d)})(1-P_{maji\,(b)})(1-P_{maji\,(o)}) + (P_{maji\,(t)})(1-P_{maji\,(d)})(1-P_{maji\,(b)})(1-P_{maji\,(o)})] \end{gathered} \tag{168}$$

$$\begin{gathered} P_{mini\,/e} = (1-P_{f/e}-P_{mini\,/e})*[P_{mini\,(o)} + (P_{mini\,(b)})(1-P_{mini\,(o)}) + \\ (P_{mini\,(d)})(1-P_{mini\,(b)})(1-P_{mini\,(o)}) + (P_{mini\,(t)})(1-P_{mini\,(d)})(1-P_{mini\,(b)})(1-P_{mini\,(o)})] \end{gathered} \tag{169}$$

Outputs of Step 23:

- Probability of fatality given an explosives event and the presence of a person, $P_{f|e}$, for each effect and the total $P_{f|e}$ for each of the four runs described above
- Probability of major injury given an explosives event and the presence of a person, $P_{Maji|e}$, for each effect and the total $P_{Maji|e}$ for each of the four runs described above
- Probability of minor injury given an explosives event and the presence of a person, $P_{Mini|e}$, for each effect and the total $P_{Mini|e}$ for each of the four runs described above

4.6.2 STEP 24: Determine Fatality Distribution & Injury Risks for one PES-ES Pair

The risk due to an explosives event calculated by SAFER is a prediction. There are many sources of uncertainty in a given prediction. The estimate of risk determined by SAFER is a function of user input, assumptions, approximations, estimates, and mathematical algorithms. Each of these has variability that contributes to uncertainty. A major design goal for SAFER Version 2.0 was to *model uncertainty*. Since SAFER was designed to be a decision aide, the interest in uncertainty included all factors that contribute to uncertainty in the expected risk value. This includes the uncertainty in the model, uncertainty in the input, and uncertainty in the imbedded science. This broad design goal became a requirement that was first accomplished as part of the SAFER Version 2.0.

The uncertainty model within SAFER Version 2.0 operated as a post processor executed following completion of Step 26 of the architecture. The SAFER Version 3.0 risk model combines the computation of the Expected Risk with the uncertainty model in an integrated statistical model of the world that determines the distribution of Expected Fatality.

Step 24 calculates the expected fatality distribution for one PES-ES pair. The computations in this step are based on the results of an extended collaboration between the RBESCT and the Defense Threat Reduction Agency (DTRA). A detailed description and development of the statistical model of the world (MOW) are provided in the paper, *An Analytical Approach for Treating Uncertainty in Probabilistic Risk Assessments* by Dr. R. W. Mensing presented to the 31st Explosives Safety Seminar, 24-26 August 2004 (Ref. 11).

The sections below summarize the methodology used to estimate the expected fatalities and the associated uncertainty of this prediction in SAFER Version 3.0.

4.6.2.1 Uncertainty Methodology

The SAFER Version 3.0 uncertainty methodology considers both aleatory (random variation inherent in real life events) and epistemic (knowledge uncertainty inherent in the model of the world and associated scientific algorithms) uncertainties. The RBESCT and DTRA collaboration resulted in a Model of the World that incorporates both types of uncertainty into a combined risk model (as described in the paper cited above). To successfully use this resulting model, a parallel effort was conducted to develop the estimates of parameter uncertainties required as inputs to the uncertainty model. Formal expert elicitations and expert panels were used to estimate the uncertainties present in the scientific algorithms used to compute the probability of fatality and in the historical data used to compute the probability of an explosive event.

The Model of the World (MOW) leverages the risk equation in previous versions of SAFER to formulate the risk estimator for the expected number of fatalities per year (F):

$$F = \Delta t * S * \lambda(NEW,E) * P_{f|e}(NEW, Yield, Effects) * E \tag{170}$$

where the factors are lognormally distributed and,

Δt = the fraction of the time that explosives are present when exposures are also present,

λ = the probability of an explosive event during a given year based on the type of explosives present and the activity performed at the explosives site, also referred to as P_e,

S = an environmental factor that increases the probability of an event based on extenuating circumstances at the site – such as operations in a remote area or under combat conditions,

$P_{f/e}$ = the probability of fatality given an explosive event and exposure – this factor aggregates the effects of the fatality mechanisms: overpressure, debris, building collapse, and glass hazards, and thermal effects,

E = the exposure of personnel to an explosive event based on the number of people present in a facility during the year and the number of hours the exposed site is occupied

NEW= the Net Explosive Weight of hazardous material contributing to the event

Yield = the percentage of the material contributing energy to the event

Effects = the four fatality mechanisms computed by SAFER science algorithms

This risk estimator includes each of the elements of the SAFER Version 2.0 risk estimator and incorporates correlation effects such as the impact of:

- Net Explosive Weight (*NEW*) and Exposure (E) on the Probability of Event, λ
- *NEW* and explosive yield on the Probability of Fatality given an event, $P_{f/e}$

4.6.2.2 Model Input Descriptions and Derivation from SAFER User Inputs

Solving the MOW requires the input of twenty-eight (28) parameters that describe a number of lognormal distributions representing the various factors in the risk equation.

Inputs to Step 24:

Table 33 provides a listing of the input parameters and a short title describing what each parameter represents. A more detailed description of each parameter and the method used to compute each parameter is provided in the following paragraphs.

Table 33. Risk Model Input Parameters

Symbol	Short Title	Symbol	Short Title
Δt_o	median value of Δt	σ_y	standard deviation yield
$\sigma_{\Delta t}$	standard deviation of Δt	σ_{yo}	epistemic standard deviation yield
S_o	median value of environmental factor	ρ_{Ne}	correlation between NEW and exposure
σ_S	standard deviation of environmental factor	ρ_{Ae}	correlation between PES activity and exposure
λ_{oo}	median value of lambda	σ_{NEW1}	standard deviation NEW
$\sigma_{\lambda o}$	standard deviation of lambda	σ_{NEW2}	standard deviation NEW
E_{oo}	epistemic median daily exposure	σ_1	standard deviation for variation in o/p
σ_e	random variation standard deviation exposure	σ_2	standard deviation for variation in b/c
σ_{e1}	random variation in lambda due to exposure	σ_3	standard deviation for variation in debris
σ_{Eo}	epistemic standard deviation of exposure	σ_4	standard deviation for variation in glass
$P_{f\|1oo}$	epistemic median $P_{f\|e}$ blast	σ_{1o}	epistemic standard deviation for overpressure
$P_{f\|2oo}$	epistemic median $P_{f\|e}$ building damage	σ_{2o}	epistemic standard deviation for bldg damage
$P_{f\|3oo}$	epistemic median $P_{f\|e}$ debris	σ_{3o}	epistemic standard deviation for debris
$P_{f\|4oo}$	epistemic median $P_{f\|e}$ glass	σ_{4o}	epistemic standard deviation for glass

The remainder of this section describes the derivation of a value for each of these input parameters using the data input through the SAFER screens and the data resulting from runs 1 through 4 of Step 23.

4.6.2.2.1 Δt_o and $\sigma_{\Delta t}$

Δt_o and $\sigma_{\Delta t}$ are the median and standard deviation of the lognormal distribution representing the percentage of time, Δt, when explosives are present at the site that exposures are also present. The equations used to compute these two parameters are provided in Section 4.1.3.2.1.

4.6.2.2.2 S_o and σ_S

S_o and σ_S are the median and standard deviation of the lognormal distribution representing the P_e environmental factor, S, that addresses the increase in risk due to extenuating circumstances (ex. OCONUS or hostile area processing).

The RBESCT determined the center value and an upper bound value for each environmental factor. This information is shown in Table 34, *P_e Environmental Factor (S) Center Values and Upper Bounds*.

Table 34. P_e Environmental Factor (S) Center Values and Upper Bounds

Environmental Factors	Center Value (S_o)	Upper Bound ($UB_{environmental\ factor}$)
Outside Continental United States (OCONUS) operations in support of wartime actions	10	100
Operations involving dangerously unserviceable items awaiting destruction	10	25
Initial tests of new systems	10	15
Operation occurring in hazardous environments with gases, fibers, etc.	10	100
Required remote operations	10	25
Temporary Duty (TDY) activities during exercises/contingencies/alerts	10	15
Integrated Combat Turn (ICT) operations	10	15
Operations involving exposed explosives	10	25
Outdoor storage / operations normally done indoors	3.1	5
Home station activities during exercises / contingencies / alert	3.1	5
Flight line holding areas	3.1	5
TDY operations during peacetime	3.1	5

SAFER uses S_o and σ_S to characterize the Environmental Factor distribution. The standard deviation, σ_S is calculated by:

$$\sigma_S = \sigma_{environmental\ factor} = \frac{\ln(UB_{environmental\ factor}) - \ln(M_{environmental\ factor})}{3} \qquad (171)$$

where S_o and $UB_{environmental\ factor}$ are provided in Table 34, *P_e Environmental Factor (S) Center Values and Upper Bounds*.

4.6.2.2.3 λ_{oo} and $\sigma_{\lambda o}$

λ_{oo} and $\sigma_{\lambda o}$ are the median and standard deviation of the lognormal factor, δ_o, that describes the epistemic uncertainty in λ_o, the median number of explosive events per "typical" operating year at a given activity/facility. The factor λ_o was previously known as $P_{e\ Unscaled}$.

The RBESCT originally compiled the P_e Matrix and estimated upper bound or 3σ values for each activity type. In making these estimates the team considered the following contributors to P_e uncertainty:

- Amount of data supporting the original P_e,
- Variations in the definition of activity type,
- Variations within the type of activity, and
- Variations within the explosives type

In the case of λ_o (previously called unscaled P_e), the RBESCT used an upper bound multiplication factor to define the upper bound. The upper bound is found by multiplying the center value by the multiplication factor. Table 35, *Un-scaled P_e Center Values and Upper Bounds*, shows the center value, multiplication factor, and upper bound for each explosives activity type.

Table 35. Un-scaled Pe (λ_o) Center Values and Upper Bounds

Activity Types	Center Value (λ_{oo}) (Element I from P_e matrix)	Upper Bound Multiplication Factor	Upper Bound ($UB_{un\text{-}scaled\ Pe}$)
Assembly	4.7E-03	5	2.4E-02
Disassembly	4.7E-03	5	2.4E-02
LAP	4.7E-03	10	4.7E-02
Maintenance	4.7E-03	5	2.4E-02
Renovation	4.7E-03	5	2.4E-02
Burning Ground	2.4E-02	4	9.7E-02
Demilitarization	2.4E-02	5	1.2E-01
Demolition	2.4E-02	10	2.4E-01
Disposal	2.4E-02	10	2.4E-01
Lab	4.3E-03	6	2.6E-02
Training	4.3E-03	4	1.7E-02
Test	4.3E-03	4	1.7E-02
Loading	5.7E-04	5	2.9E-03
Unloading	5.7E-04	7	4.0E-03
Inspection	8.2E-04	4	3.3E-03
Painting	8.2E-04	4	3.3E-03
Packing	8.2E-04	4	3.3E-03
Manufacturing	1.7E-03	5	8.3E-03
Deep Storage	2.5E-05	3	7.6E-05
Temporary Storage	1.0E-04	5	5.0E-04
In-transit Storage	3.0E-04	7	2.1E-03

SAFER uses λ_{oo} and $\sigma_{\lambda o}$ to characterize the distribution of the probability of an explosive event. The "center value" in Table 35 is used for the median, λ_{oo}, and the standard deviation, $\sigma_{\lambda o}$ is calculated by:

$$\sigma_{\lambda o} = \sigma_{un-scaled\ P_e} = \frac{\ln(UB_{un-scaled\ P_e}) - \ln(\lambda_{oo})}{3} \qquad (172)$$

where λ_{oo} (previously un-scaled P_e) and $UB_{un\text{-}scaledPe}$ is the upper bound provided in Table 35, *Un-scaled P_e Center Values and Upper Bounds*.

4.6.2.2.4 E_{oo} and σ_e

E_{oo} and σ_e are the median and standard deviation of the lognormal distribution, E_o, representing the median number of daily exposures. Exposures are calculated both for the group and for the worst-case individual. The equations used to compute these parameters are provided in Section 4.1.3.2.2.

4.6.2.2.5 σ_{e1}

σ_{e1} is the standard deviation of δ_{e1}, a lognormal multiplicative factor describing the random variation in λ due to exposure. This parameter is based on the user input correlation between the PES activity type and the number of people present (ρ_{Ae}) and is computed by:

$$\sigma_{e1} = \sigma_e * \rho_{Ae} \tag{173}$$

where σ_e is determined in Section 4.1.3.2 and ρ_{Ae} is provided in Table 36.

Table 36. Correlation between PES Activity Type and the Number of People Present

Correlation	User Input	Correlation Coefficient (ρ_{Ae})
Does the PES activity vary on a periodic schedule which correlates to personnel exposure?	No Correlation	0.0
	Positive correlation	0.5
	Strong positive correlation	0.9

4.6.2.2.6 σ_{Eo}

σ_{Eo} is the standard deviation of the lognormal distribution, E_o, of the epistemic uncertainty associated with evaluating the median number of daily exposures.

This uncertainty is based on the confidence of the user in their estimate of the exposure. The user selects from the following choices: confident (0.0), somewhat confident (0.5), and not confident (0.9).

The σ_{Eo} parameter is then computed by:

$$\sigma_{Eo} = \text{Ln}\,(1+\text{confidence}) \tag{174}$$

4.6.2.2.7 $P_{f|koo}$

The median value of the lognormal distribution, $P_{f|ko}$, is the epistemic uncertainty associated with evaluating the median value of the probability of fatality due to explosive effect, k, where k = 1, 2, 3, 4 represents the four fatality mechanisms: blast overpressure, building collapse, debris, and glass.

Two values of $P_{f|koo}$ are generated: one to support computation of the “sited NEWQD” risk and one for the general risk model. The “sited NEWQD” value of $P_{f|koo}$ is taken from the $P_{f|e}$ computed in Run 1 for that fatality mechanism. The $P_{f|e}$ value computed in Run 2 is used in the general risk model. These are computed as $P_{f(o)}$ in Step 8, $P_{f(g)}$ and $P_{f(b)}$ in Step 10, and $P_{f(d)}$ in Step 18.

4.6.2.2.8 σ_y

σ_y is the standard deviation of the lognormal distribution, δ_y, a multiplicative factor describing the random variation in yield. For the “sited NEWQD” run where Amount Present and Yield are set to their maximum value, no variation due to yield is allowed and σ_y is set to zero (0). In the general risk model, the variation due to yield is derived from the Total $P_{f|e}$ computed for Run 2

(Expected Yield and Amount Present) and Run 4 (Expected Amount Present, Maximum Yield) and is calculated by:

$$\sigma_y = Ln(P_{f|eTotal\ for\ Run4} / P_{f|eTotal\ for\ Run2}) / 3 \qquad (175)$$

4.6.2.2.9 σ_{yo}

σ_{yo} is the standard deviation of the lognormal distribution, δ_{yo}, a multiplicative factor describing the epistemic uncertainty in yield. SAFER calculates σ_{yo} by:

$$\sigma_{yo} = 0.5 * \sigma_y \qquad (176)$$

when the weapon description is "unknown" and

$$\sigma_{yo} = 0.25 * \sigma_y \qquad (177)$$

when a specific weapon is selected as the explosive source.

4.6.2.2.10 ρ_{Ne}

ρ_{Ne} is the coefficient of correlation between NEW and Exposure. This parameter is selected by the user. The user choices and corresponding correlation coefficient are provided in Table 37. Negative correlations are not considered in SAFER.

Table 37. Correlation between Amount of Explosives Present and Exposure

Correlation	User Input	Correlation Coefficient ($\rho_{N\varepsilon}$)
Does the amount of explosives present correlate to the number of people on a periodic (daily or weekly) cycle?	No Correlation	0.0
	Positive correlation	0.5
	Strong positive correlation	0.9

4.6.2.2.11 σ_{NEW1}

σ_{NEW1} is the standard deviation of δ_{NEW1}, a multiplicative factor describing the random variation in λ due to NEW. SAFER currently sets σ_{NEW1} to zero (0). The ability to model this uncertainty has been included in the risk model for possible future use.

4.6.2.2.12 σ_{NEW2}

σ_{NEW2} is the standard deviation of δ_{NEW1}, a multiplicative factor describing the random variation in $P_{f|e}$ due to NEW.

For the "sited NEWQD" run where Amount Present and Yield are set to their maximum value, no variation due to NEW is allowed and σ_{NEW2} is set to zero (0). In the general risk model, the variation due to NEW is derived from the Total $P_{f|e}$ computed for Run 2 (Expected Yield and Amount Present) and Run 3 (Expected Yield, Maximum NEW) and is calculated by:

$$\sigma_{NEW2} = \mathrm{Ln}(P_{f|eTotal\ Run3} / P_{f|eTotal\ Run2}) / 3 \qquad (178)$$

4.6.2.2.13 σ_k and σ_{ko}

σ_k is the standard deviation of the lognormal distribution, δ_k, the random variation in $P_{f|e}$ due to effect k, where $k = 1, 2, 3, 4$ represents the four fatality mechanisms. σ_{ko} is the standard deviation of the lognormal distribution, δ_{ko}, the epistemic uncertainty associated with evaluating the median value of the probability of fatality, $P_{f|e}$, due to effect k, where $k = 1, 2, 3, 4$ represents the four fatality mechanisms.

For each fatality mechanism a $P_{f|e}$ distribution is assumed that has a median value calculated by SAFER as described in Section 4.6.2.2.7. The upper bound value is then found by multiplying the center value by an upper bound multiplication factor and the sigma is determined by the equation:

$$\sigma = \frac{\ln(UB) - \ln(M)}{3} \tag{179}$$

similarly to other sigmas used in the risk model. A key difference, however, is the fact that the Upper Bounds (*UBs*) for the $P_{f|e}$ mechanisms are found by multiplying the Median (*M*) by a factor. Utilizing this fact, the above equation can be rewritten as:

$$\sigma = \frac{\ln(m*M) - \ln(M)}{3} = \frac{\ln(m*M/M)}{3} = \frac{\ln(m)}{3} \tag{180}$$

where m is the Upper Bound Multiplication Factor provided in Table 38, *Fatality Mechanism Upper Bound Multiplication Factors*.

The RBESCT panel had previously examined the science used in SAFER Version 2.0 to determine multiplicative factors based on uncertainties found in the science for each fatality mechanism. For SAFER Version 3.0, the panel has further refined this approach to determine Upper Bound Multiplication Factors for both Aleatory (Real World) and Epistemic (Modeling) uncertainties. It should be noted that the multipliers previously defined for each of the four fatality mechanisms in SAFER Version 2.0 are the root sum squares of the two multipliers (aleatory and epistemic) used in SAFER Version 3.0.

The values of the multiplication factors determined by the panel are shown in Table 38, *Fatality Mechanism Upper Bound Multiplication Factors*.

Table 38. Fatality Mechanism Upper Bound Multiplication Factors

Fatality Mechanism	Upper Bound Multiplication Factor
Blast (aleatory)	3.5
ES Damage,Glass (aleatory)	8.8
ES Damage, Building damage (aleatory)	7.1
Debris (aleatory)	3.6
Thermal (aleatory)	16.6
Blast (epistemic)	8.3
ES Damage, Glass (epistemic)	17.9
ES Damage, Building damage (epistemic)	7.1
Debris (epistemic)	14.6
Thermal (epistemic)	11.1

The *Thermal* parameters are used only for calculations involving HD 1.3 items (burning). The other four parameters are used for all other events. An individual SAFER run will either use calculations for HD 1.3 items or calculations for all others but not both.

SAFER uses all of the inputs described in Section 4.6.2 and the equations described in Attachment 9 to estimate the Expected Values of the Expected Fatality distributions (Group and Individual) for one PES-ES pair, $E_{f(pair)Group}$ and $P_{f(pair)Individual}$ and the variances of the Expected Fatality distributions (Group and Individual) for one PES-ES pair, $V_{f(pair)Group}$ and $V_{f(pair)Individual}$.

4.6.2.3 Monte Carlo Approach Used to Validate Uncertainty Model

A Monte Carlo approach can be used to model distributions composed of randomly distributed input factors. Using this approach, a large number of replications of the model are run with values of the input factors randomly drawn from appropriate probability distributions at the beginning of each replication. The outputs of the model resulting from each replication are evaluated to determine expected values and measures of dispersion.

Since the MOW has several input factors that are random variates, its implementation in the analytical model can be evaluated using a Monte Carlo approach. This requires drawing random variates for all factors in the MOW and subsequent evaluation of the expected fatality estimate by the MOW. Multiple replications can be performed and the resulting expected fatalities (EF) and uncertainty (variation in expected fatalities) determined.

A two-loop Monte Carlo model was developed to evaluate the MOW as depicted in Figure 12 This two-loop experimental design addresses both epistemic and aleatory uncertainties. The outer loop considers those risk factors with known epistemic or modeling uncertainties. The inner loop considers those risk factors with known aleatory uncertainties due to random variation.

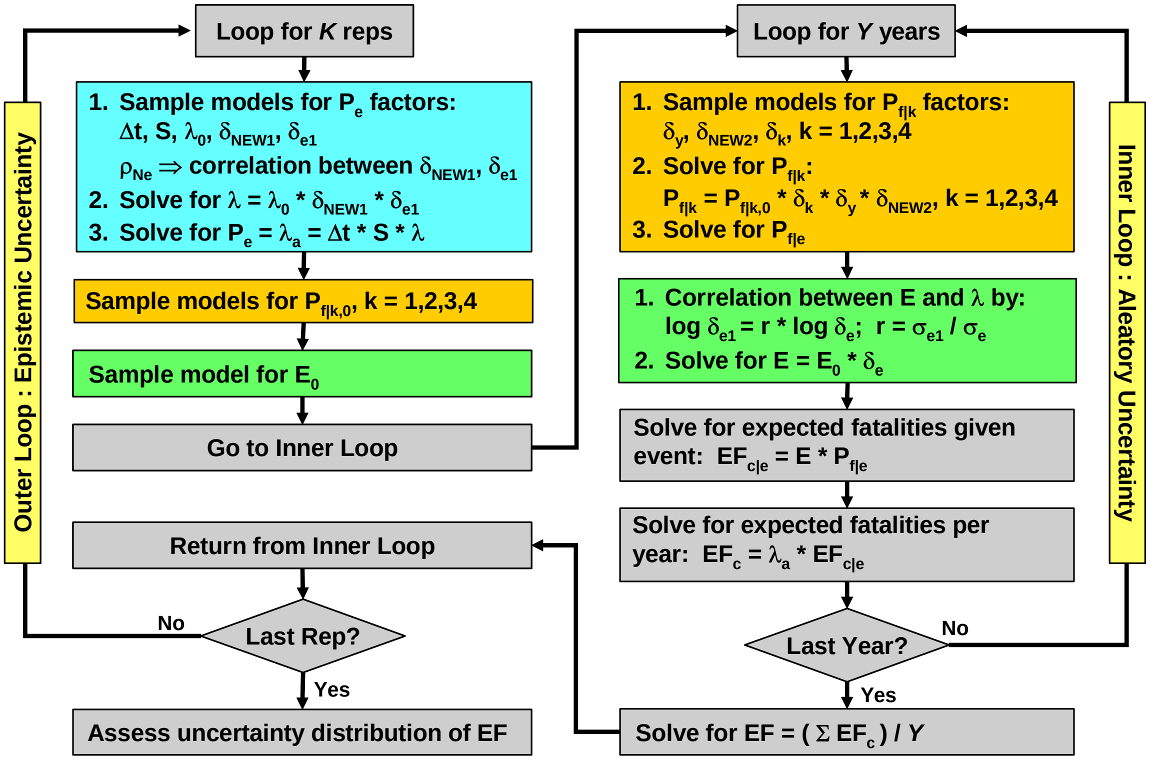


Figure 12. Two-Loop Monte Carlo Experiment to Evaluate SAFER MOW

The δ terms in the inner and outer loops are multiplicative factors that describe uncertainty or random variation as noted in Section 4.6.2.2. Values of the δ terms are random variates drawn from a lognormal distribution. For example, δ_y is a multiplicative factor describing the random variation in yield used in the inner loop. The distribution of the random variate δ_y is described by σ_y, the standard deviation of the lognormal distribution. A random draw of δ_y is determined by:

$$\delta_y = \text{Exp}\,[\text{Normal (mean} = 0\text{, standard deviation} = 1) * \sigma_y] \qquad (181)$$

Many thousand replications of the inner and outer loops were used to evaluate the MOW using the Monte Carlo approach. Several hours of computing time were required to run the needed replications.

4.6.2.4 Analytical Approach to Estimate Risk and Uncertainty

To eliminate the computation time needed to employ a Monte Carlo approach in SAFER, an analytical approach was developed to estimate risk and uncertainty. This analytical model was validated using the Monte Carlo approach described in Section 4.6.2.3 above. A comparison of results produced by the analytical model to those generated by the Monte Carlo analysis is included in the paper, *Uncertainty as Modeled in SAFER 3.0* by R. G. Baker presented to the 31st Explosives Safety Seminar, 24-26 August 2004 (Ref 12).

Four test cases that have become "standard" for SAFER testing were used in the evaluation. Three parameters of the risk distributions were compared for each of the four cases using the analytical model and the Monte Carlo approach. These parameters were: the mean, the standard deviation, and the 95th percentile value. When the values of these parameters were compared, the maximum difference was less than 2% across the four test cases. This excellent agreement provides high confidence in the ability of the analytical model to accurately determine the risk distribution based on the input distributions.

4.6.2.5 SAFER Version 3.0 Injury Risk Model

The paragraphs below provide the equations used to compute point estimates of the risk of major and minor injuries. SAFER uses the generic risk equation,

$$Risk = P_{event} * P_{harm\,|\,event} * Exposure \tag{182}$$

to compute the risks of major and minor injury. In the risk model described in Section 4.6.2.2, P_{event} is represented by the distributions λ and S and Exposure is represented by the distributions E_o and Δt. For the purposes of computing injury estimates, SAFER computes P_{event} and Exposure as:

$$P_{event} = E(\lambda) * E(S) = \lambda_{oo} * S_o * exp[0.5*(\sigma_\lambda^2 + \sigma_S^2)] \tag{183}$$

and

$$Exposure = E(\Delta t) * E(E_o) = \Delta t_o * E_{oo} * exp[0.5*(\sigma_{\Delta t}^2 + \sigma_e^2)] \tag{184}$$

The four point estimates of the potential for injury at a single ES caused by a single PES are then given by:

$$E_{Maj\ (pair)\ Group} = \lambda_o*S_o*exp[0.5*(\sigma_\lambda^2+\sigma_S^2)] * P_{Maj|e} * \Delta t_{o\ Group}*E_{oo\ Group}*exp[0.5*(\sigma_{\Delta t\ Group}^2+\sigma_{e\ Group}^2)] \tag{185}$$

$$P_{Maj\ (pair)\ Individual} = \lambda_o*S_o*exp[0.5*(\sigma_\lambda^2+\sigma_S^2)] * P_{Maj|e} * \Delta t_{o\ Individual}*E_{oo\ Individual}*exp[0.5*(\sigma_{\Delta t\ Ind}^2+\sigma_{e\ Ind}^2)] \tag{186}$$

and

$$E_{Min\ (pair)\ Group} = \lambda_o*S_o*exp[0.5*(\sigma_\lambda^2+\sigma_S^2)] * P_{Min|e} *\Delta t_{o\ Group}*E_{oo\ Group}*exp[0.5*(\sigma_{\Delta t\ Group}^2+\sigma_{e\ Group}^2)] \tag{187}$$

$$P_{Min\ (pair)\ Individual} = \lambda_o*S_o*exp[0.5*(\sigma_\lambda^2+\sigma_S^2)] * P_{Min|e} * \Delta t_{o\ Individual}*E_{oo\ Individual}*exp[0.5*(\sigma_{\Delta t\ Ind}^2+\sigma_{e\ Ind}^2)] \tag{188}$$

Outputs of Step 24:

- Expected Values of the Expected Fatality distributions (Group and Individual) for one PES-ES pair, $E_{f(pair)Group}$ and $P_{f(pair)Individual}$ computed using the inputs described in the entirety of Section 4.6.2.2 and the equations described in Attachment 9
- Variances of the Expected Fatality distributions (Group and Individual) for one PES-ES pair, $V_{f(pair)Group}$ and $V_{f(pair)Individual}$ computed using the inputs described in the entirety of Section 4.6.2.2 and the equations described in Attachment 9
- Point Estimates of Major Injury (Group and Individual), $E_{Maj\ (pair)\ Group}$ and $P_{Maj\ (pair)\ Individual}$
- Point Estimates of Minor Injury (Group and Individual), $E_{Min\ (pair)\ Group}$ and $P_{Min\ (pair)\ Individual}$

SAFER Version 3.0 includes a fully integrated statistical Model of the World that directly estimates the distribution of the Expected Fatality random variable using an analytical method.

The risk estimator and uncertainty model were developed in collaboration with DTRA and have been validated by Monte Carlo analysis. Point estimates for Major and Minor Injury are also computed. While no estimates of the variation in these risks are computed, available knowledge of variation in two of the three factors, *P(event)* and *Exposure*, is incorporated into the point estimate computation.

4.6.3 STEP 25: Aggregate all risks to each ES and all risks caused by each PES

Step 25 has been broken into two parts: Substep 1 which computes the total risk to an ES due to all PESs surrounding it, and Substep 2 which computes the total risks caused by a PES to all ESs surrounding it.

Substep 1

This step calculates the expected fatalities and injury point estimates at a unique ES. This is accomplished by aggregating the risk contributions of all PESs posing a hazard to that ES.

Inputs to *Substep 1*:

- Definition of the Group Risk distribution for all PES-ES pairs that share a common ES [from Step 24]. The distributions are defined by the Expected number of fatalities, $E_{f(pair)group}$, and the associated Variance, $V_{f(pair)group}$
- Definition of the Individual Probability of Fatality distribution for all PES-ES pairs that share a common ES [from Step 24]. The distributions are defined by the Probability of Fatality, $P_{f(pair)Individual}$, and associated Variance, $V_{f(pair)Individual}$
- Point estimates of the Group Risk of Major and Minor Injury for all PES-ES pairs that share a common ES [from Step 24], $E_{Maj\ (pair)\ Group}$ and $E_{Min\ (pair)\ Group}$
- Point estimates of the Individual Risk of Major and Minor Injury for all PES-ES pairs that share a common ES [from Step 24], $E_{Maj\ (pair)\ Individual}$ and $E_{Min\ (pair)\ Individual}$

Fatality Distributions

SAFER calculates the group expected fatalities at a unique ES, $E_{f(ES)Group}$, by:

$$E_{f(ES)Group} = \sum_{PES\ sites} E_{f(pair)Group} \tag{189}$$

and the Variance in the ES Group Risk distribution by:

$$V_{f(ES)Group} = \sum_{PES\ sites} V_{f(pair)Group} \tag{190}$$

SAFER calculates the individual expected fatalities at a unique ES, $P_{f(ES)Individual}$, by:

$$P_{f(ES)Individual} = \sum_{PESsites} E_i - \sum_{i\neq j} E_i E_j + \sum_{i\neq j\neq k} E_i E_j E_k \tag{191}$$

where the E_i and E_j denote the individual probability of fatality, $P_{f(pair)Individual}$, that distinct PES sites pose to the ES of interest.

Then SAFER calculates the Variance of the ES Individual Risk distribution by:

$$V_{f(ES)Individual} = \sum_{PESsites} V_i + \sum_{i \neq j} V_{ij} \tag{192}$$

with

$$V_{ij} = E^2_i V_j + E^2_j V_i + V_i V_j \tag{193}$$

where the E_i and V_i denote the Expected Values, $P_{f(pair)Individual}$, and Variances, $V_{f(pair)Individual}$, in the individual probability of fatality that distinct PES sites pose to the ES of interest.

In addition, SAFER calculates the Group expected fatalities due to all hazards for ESs within the Risk-based evaluation distance of any PES (PES Siting Risk), $E_{f(PES\ Siting)Group}$, by:

$$E_{f(PESSiting)Group} = \sum_{ES\ sites} E_{f(ES)Group} \tag{194}$$

and the Variance in the PES Group Risk distribution by:

$$V_{f(PESSiting)Group} = \sum_{ES\ sites} V_{f(ES)Group} \tag{195}$$

SAFER calculates the Individual expected fatalities due to all hazards for ESs within the Risk-based evaluation distance of any PES, $P_{f(PES\ Siting)Individual}$, by:

$P_{f(PES\ Siting)Individual}$ = Maximum{ $P_{f(ES)Individual}$: across all ESs within the Risk-based evaluation distance of any PES} (196)

and the Variance in the PES Individual Risk distribution by:

$V_{f(PES\ Siting)Individual}$ = the $V_{f(ES)Individual}$ associated with the ES having the maximum risk (197)

Injury Point Estimates

SAFER calculates the point estimates for Major Injuries at a unique ES by:

$$E_{Maj(ES)Group} = \sum_{PESs} E_{Maj(pair)Group} \tag{198}$$

$$P_{Maj(ES)Individual} = 1 - \prod_{PESs} (1 - P_{Maj(pair)Individual}) \tag{199}$$

and the point estimates for Minor Injuries at the ES by:

$$E_{Min(ES)Group} = \sum_{PESs} E_{Min(pair)Group} \tag{200}$$

$$P_{Min(ES)Individual} = 1 - \prod_{PESs} (1 - P_{Min(pair)Individual}) \tag{201}$$

Outputs of *Substep 1*:

- Expected fatality (Group Risk) distribution for each unique ES, defined by $E_{f(ES)Group}$ and $V_{f(ES)Group}$

- Maximum Individual Probability of Fatality distribution for each unique ES, defined by $P_{f(ES)Individual}$ and $V_{f(ES)Individual}$
- Expected fatality (Group Risk) distribution for all ESs within the Risk-based evaluation distance of any PESs (Siting Risk), defined by $E_{f(PES\ Siting)Group}$ and $V_{f(PES\ Siting)Group}$
- Maximum Individual Probability of Fatality distribution for all ESs within the Risk-based evaluation distance of any PESs (Siting Risk), defined by $P_{f(PES\ Siting)Individual}$ and $V_{f(PES\ Siting)Individual}$
- Point estimates for Major Injuries (Group and Individual) for each ES, $E_{Maj\ (ES)\ Group}$ and $P_{Maj\ (ES)\ Individual}$
- Point estimates for Minor Injuries (Group and Individual) for each ES, $E_{Min\ (ES)\ Group}$ and $P_{Min\ (ES)\ Individual}$

Substep 2

This step calculates the expected fatalities and point estimates of injuries caused by a unique PES. This is accomplished by aggregating the risks the PES poses to multiple ESs.

Inputs to *Substep 2*:

- Definition of the Group Risk distribution for all PES-ES pairs that share a common PES [from Step 24]. The distributions are defined by the Expected number of fatalities, $E_{f(pair)group}$, and its Variance, $V_{f(pair)group}$
- Definition of the Individual Probability of Fatality distribution for all PES-ES pairs that share a common PES [from Step 24]. The distributions are defined by the Probability of Fatality, $P_{f(pair)Individual}$, and its Variance, $V_{f(pair)Individual}$
- Point estimates of the Group Risk of Major and Minor Injury for all PES-ES pairs that share a common PES [from Step 24], $E_{Maj\ (pair)\ Group}$ and $E_{Min\ (pair)\ Group}$
- Point estimates of the Individual Risk of Major and Minor Injury for all PES-ES pairs that share a common PES [from Step 24], $P_{Maj\ (pair)\ Individual}$ and $P_{Min\ (pair)\ Individual}$

Fatality Distributions

SAFER calculates the Group expected fatalities caused by a unique PES, $E_{f(PES)Group}$, by:

$$E_{f(PES)Group} = \sum_{ES\ sites} E_{f(pair)Group} \qquad (202)$$

and the Variance in the PES Group Risk distribution by:

$$V_{f(PES)Group} = \sum_{ES\ sites} V_{f(pair)Group} \qquad (203)$$

SAFER calculates the Individual expected fatalities caused by a unique PES, $P_{f(PES)Individual}$, by:

$$P_{f(PES)Individual} = \text{Maximum}\{\ P_{f(pair)Individual} : \text{across all ESs exposed to the PES}\} \qquad (204)$$

and the Variance in the PES Individual Risk distribution by:

$$V_{f(PES)Individual} = \text{the } V_{f(pair)Individual} \text{ associated with the ES having the maximum risk} \qquad (205)$$

Injury Point Estimates

SAFER calculates the point estimates for Major Injuries at a unique PES as:

$$E_{Maj(PES)Group} = \sum_{ES\ sites} E_{Maj(pair)Group} \tag{206}$$

and

$P_{Maj(PES)Individual}$ = Maximum{ $P_{Maj(pair)Individual}$: across all ESs exposed to the PES} (207)

SAFER calculates the point estimates for Minor Injuries for a unique PES as:

$$E_{Min(PES)Group} = \sum_{ES\ sites} E_{Min(pair)Group} \tag{208}$$

and

$P_{Min(PES)Individual}$ = Maximum{ $P_{Min(pair)Individual}$: across all ESs exposed to the PES} (209)

Outputs of *Substep 2*:

- Expected fatalities (Group Risk) distribution caused by a unique PES, defined by $E_{f(PES)Group}$ and $V_{f(PES)Group}$
- Maximum Individual Probability of Fatality distribution for a single PES, defined by $P_{f(PES)Individual}$ and $V_{f(PES)Individual}$
- Point estimates for Major Injuries (Group and Individual) for each PES, $E_{Maj\ (PES)\ Group}$ and $P_{Maj\ (PES)\ Individual}$
- Point estimates for Minor Injuries (Group and Individual) for each PES, $E_{Min\ (PES)\ Group}$ and $P_{Min\ (PES)\ Individual}$

4.6.4 STEP 26: Sum E_f values from all PESs.

Step 26 is the final SAFER step where the total explosive risk for an entire situation (installation) is calculated. In this step, SAFER calculates expected fatalities and point estimates for the situation by summing the expected fatalities/injuries for all ES locations in the situation due to all PES sites that hazard them.

Inputs to Step 26:

- Definition of the Group Risk distribution for each ES location on the installation [from Step 25, *Substep 1*]. The distributions are defined by the Expected number of fatalities, $E_{f(ES)group}$, and the associated Variance, $V_{f(ES)group}$
- Definition of the Individual Probability of Fatality distribution for each ES location on the installation [from Step 25, *Substep 1*]. The distributions are defined by the Probability of Fatality, $P_{f(ES)Individual}$, and the associated Variance, $V_{f(ES)Individual}$

Fatality Distributions

SAFER calculates the expected fatalities (Group Risk) for the entire situation, $E_{f(install)Group}$, by:

$$E_{f\,(install)Group} = \sum_{ES\ sites} E_{f\,(ES)Group} \tag{210}$$

and its associated variance by:

$$V_{f(install)Group} = \sum_{ES\ sites} V_{f(ES)Group} \tag{211}$$

The individual probability of fatality (Individual Risk) for the situation, $P_{f(install)Individual}$, is then calculated as:

$$P_{f(install)Individual} = \text{Maximum}\{\, P_{f(ES)Individual} \text{ : across the installation}\} \tag{212}$$

and the Individual Risk distribution variance, $V_{f(install)Individual}$, is the variance associated with the ES having the maximum $P_{f(ES)individual}$.

Injury Point Estimates

SAFER calculates the point estimates for Major Injuries over the entire situation (installation) as:

$$E_{Maj(install)Group} = \sum_{ES\ sites} E_{Maj(ES)Group} \tag{213}$$

and

$$P_{Maj(install)Individual} = \text{Maximum}\{\, P_{Maj(ES)Individual} \text{ : across the installation}\} \tag{214}$$

and the point estimates for Minor Injuries over the installation as:

$$E_{Min(install)Group} = \sum_{ES\ sites} E_{Min(ES)Group} \tag{215}$$

and

$$P_{Min(install)Individual} = \text{Maximum}\{\, P_{Min(ES)Individual} \text{ : across the installation}\} \tag{216}$$

Outputs of Step 26:

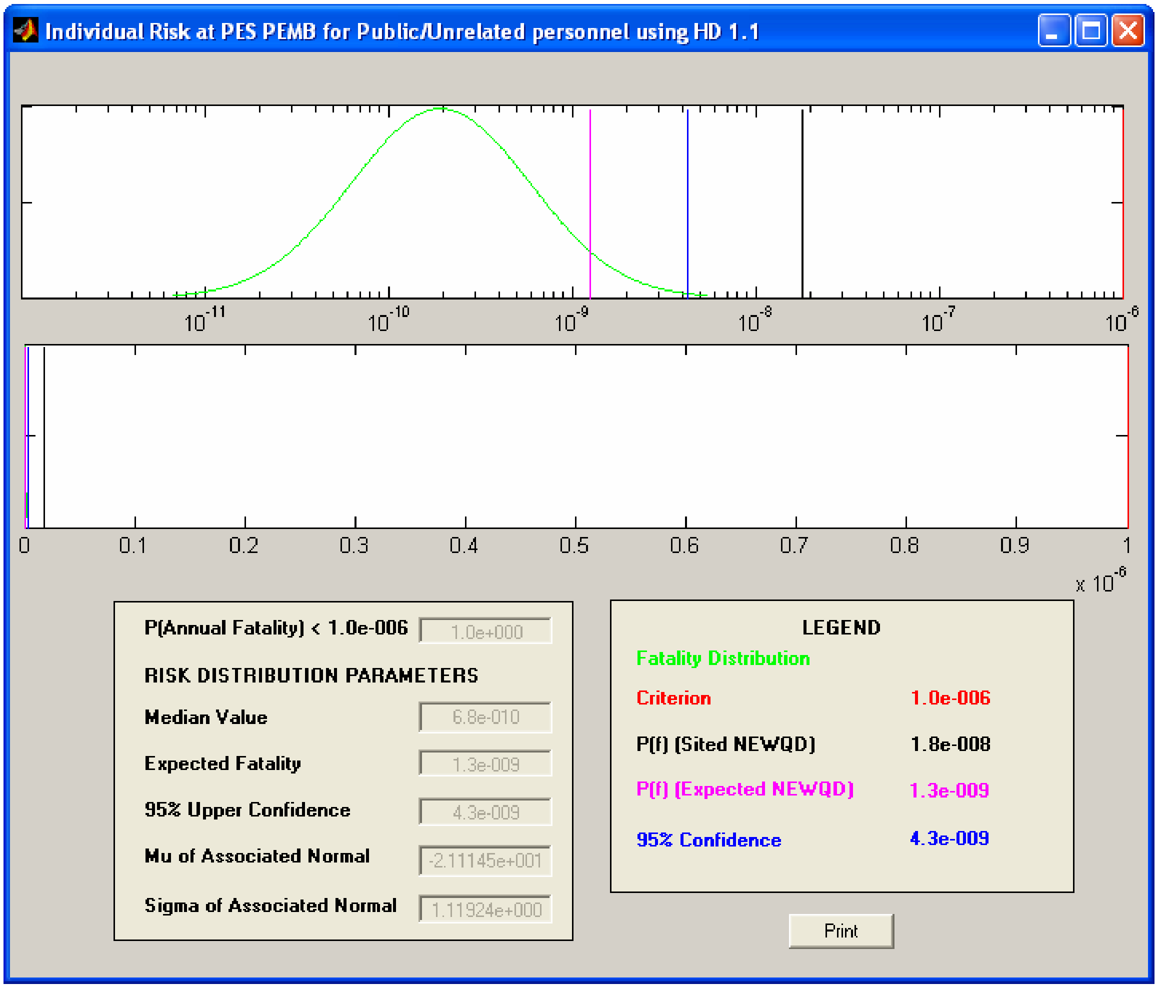
- Expected fatality distribution for the entire situation, defined by expected value, $E_{f(install)Group}$, and variance, $V_{f(install)Group}$
- Individual Probability of Fatality distribution for the entire situation, defined by expected value, $P_{f(install)individual}$, and variance, $V_{f(install)individual}$
- Point estimates for Major Injuries (Group and Individual) for the entire situation (installation), $E_{Maj\ (Install)\ Group}$ and $P_{Maj\ (Install)\ Individual}$
- Point estimates for Minor Injuries (Group and Individual) for each ES, $E_{Min\ (Install)\ Group}$ and $P_{Min\ (Install)\ Individual}$

After Step 26, all of the steps in the SAFER Architecture have been completed.

5.0 UNCERTAINTY DISPLAY

At this time, uncertainty criteria have not been developed or approved by the DDESB. The information on uncertainty provided in SAFER Version 3.0 is provided for informational purposes only. This section presents an overview of the uncertainty display SAFER Version 3.0 utilizes to communicate the results of the risk analysis and the use of the log-normal distribution for modeling risk.

The uncertainty model integrated within SAFER computes a variety of risk measures in Steps 24 through 26. The SAFER Version 3.0 uncertainty model provides an optional uncertainty display for group and individual risks associated with a single PES-ES pair and the PES Siting Risk. A sample of this display is shown in Figure 13. This display provides a graphical representation of the uncertainty distribution on both a logarithmic and a linear risk scale.



P(Annual Fatality) < 1.0e-006	1.0e+000
RISK DISTRIBUTION PARAMETERS	
Median Value	6.8e-010
Expected Fatality	1.3e-009
95% Upper Confidence	4.3e-009
Mu of Associated Normal	-2.11145e+001
Sigma of Associated Normal	1.11924e+000

LEGEND

Fatality Distribution	
Criterion	1.0e-006
P(f) (Sited NEWQD)	1.8e-008
P(f) (Expected NEWQD)	1.3e-009
95% Confidence	4.3e-009

Figure 13. SAFER Version 3.0 Uncertainty Display

The screen also displays several risk measures to assist in interpretation of the analysis results:

- Fatality distribution. This curve displays the combined effects of all uncertainty drivers that have been incorporated into the general risk model (E(f) for group risk or P(f) for individual risk based on the expected NEWQD).
- Criterion line. This is the level of risk that is acceptable without a waiver, exemption, or other informed decision to accept risk. The criterion is based on the threshold approved by the DDESB.
- E(f) or P(f) (Sited NEWQD) line (decision point). This line represents the risk value calculated by SAFER that is to be compared to the criterion. The decision point risk estimate is calculated by biasing two critical parameters to the conservative side: the Amount of Explosives Present and the Explosive Yield. To compute this risk, the median values of

amount present and yield are set to the maximum value (100% NEW and 100% yield) and the variances are set to 0.0.

- E(f) or P(f) (Expected NEWQD) line. This line represents the expected value of the group or individual risk distribution calculated by SAFER, which is the output of the general risk model. To compute this risk, the distribution of amount present (expected NEWQD and sited NEWQD) and the yield is calculated in Step 4 (Section 4.1.4).
- 95% Confidence. This line represents the 95% confidence point on the E(f) or P(f) output from risk distribution.
- The mean (μ) and standard deviation (σ) of the associated linear normal distribution. Each risk distribution computed by SAFER is represented by a lognormal distribution having an expected value (E(f) or P(f)) and variance (V). From these two parameters, the mean (μ) and standard deviation (σ) of the associated normal distribution can be computed as:

  $\mu = \ln \{ E^2 / \mathrm{Sqrt}(V+E^2) \}$ and $\sigma = \mathrm{Sqrt} \{ \ln [(V/E^2) + 1] \}$

  These are currently displayed on the uncertainty screen in the Risk Distribution Parameters box. Using μ and σ, the lognormal probability density function (distribution curve) of the risk and remaining parameters of the distribution can be computed as follows:

  Curve: $f(x) = \exp[-0.5^* \{(\ln(x) - \mu)/\sigma\}^2] / [\mathrm{Sqrt}(2\pi)\sigma x]$

  Mode: $\exp(\mu - \sigma^2)$

  Median: $\exp(\mu)$

  Mean: $\exp(\mu + 0.5\sigma^2)$

  Variance: $\exp[2(\mu+\sigma^2)] - \exp[2\mu + \sigma^2]$

- Other risk distribution parameters. Selected parameters describing the risk distribution are also presented on the display. These include:
  - Probability that the actual E(f) or P(f) is less than the criterion
  - Median and expected values of the expected fatality distribution
  - 95% upper confidence bound

References

1. Allied Ammunition Storage and Transport Publication (AASTP) - 4, Edition No. 1, *Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives*, dated August 1997, Change 1 dated 18 Feb 1998.
2. Arnauld, A. and Nicole, P., *Logic or the Art of Thinking*. 1996.
3. Pfitzer, T., "Use of Fatality as the Measure of Risk," Tech Memo E1-00300, A-P-T Research, Inc., Huntsville, AL, May 8, 2002.
4. Yutmeyer, P., "P_e Matrix," Tech Memo E1-01000, A-P-T Research, Inc., Huntsville, AL, May 8, 2002.
5. Kingery, C. and Bulmash, G., "Air Blast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst," Ballistics Research Labs, TR-02555, April 1984.
6. Swisdak, Michael M., DDESB Technical Paper #17, "DDESB Blast Effects Computer Version 6.0, User's Manual and Documentation," 10 March 2005.
7. RCC Standard 321-00, Common Risk Criteria for National Test Ranges; Inert Debris, published by Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, New Mexico 88002-5110., April 2000.
8. DoD 6055.9-STD., DoD Ammunition and Explosives Safety Standard, 5 October 2004.
9. Mercx, W., The impact of explosion–effects on structures, Prins Maurits Laboratorium TNO, June 1988.
10. Chrostowski, J., Wilde, P., and Gan, W., "Blast Damage, Serious Injury and Fatality Models for Structures and Windows," Technical Report No. 00-444/16.4-03, Revision 1, ACTA, Inc., Torrance, CA, July 2001.
11. Mensing, Dr. R.W., "An Analytical Approach for Treating Uncertainty in Probabilistic Risk Assessments," presented to the 31st Explosives Safety Seminar, 24-26 August 2004.
12. Baker, R.G., "Uncertainty as Modeled in SAFER 3.0," presented to the 31st Explosives Safety Seminar, 24-26 August 2004.

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Appendix A
Supplemental Tables

Table A-1. Default Roof and Wall Types

Building Category	Building Type & Default Roof[1,2]	ES Building Type	Wall Type (default – not a user selectable)	Default Roof Type
		Open	NA	NA
Reinforced Concrete	Small Reinforced Concrete (reinforced concrete roof)	Small Reinforced Concrete (Office/Commercial)	8" reinforced concrete	4" Reinforced Concrete
Reinforced Concrete	Medium Reinforced Concrete (light weight concrete roof)	Medium Reinforced Concrete (Office/Commercial)	8" reinforced concrete	2" Lt-Wt Concrete/steel deck & joist
Reinforced Concrete	Large Tilt-up Reinforced Concrete (wood panelized roof)	Large Reinforced Concrete Tilt-up (Commercial)	6" reinforced concrete tilt-up	Wood panelized
Reinforced Masonry	Small Reinforced Masonry (plywood/wood joist roof)	Small Reinforced Masonry (Office/Commercial)	8" reinforced masonry	Plywood/Wood joist
Reinforced Masonry	Medium Reinforced Masonry (steel panel roof)	Medium Reinforced Masonry (Office/Commercial)	8" reinforced masonry	Light Steel Panel (22 gauge)
Unreinforced Brick/Masonry	Small Unreinforced Brick (plywood/wood joist roof)	Small Unreinforced Brick (Office/Apartment)	8" unreinforced brick	Plywood/Wood joist
Unreinforced Brick/Masonry	Medium Unreinforced Masonry (wood panelized roof)	Medium Unreinforced Masonry (Office/Apartment)	8" unreinforced masonry	Wood panelized
Unreinforced Brick/Masonry	Large Unreinforced Masonry (gypsum/steel joist roof)	Large Unreinforced Masonry (Office)	8" unreinforced masonry	Gypsum/Fiberboard/
Steel PEMB	Small PEMB	Small PEMB (Office/Storage)	Corrugated Steel	Steel joist
Steel PEMB	Medium PEMB	Medium PEMB (Office/Commercial)	Corrugated Steel	Light Steel Panel (22 gauge)
Steel PEMB	Large PEMB	Large PEMB (Office/Storage/Hangar)	Corrugated Steel	Light Steel Panel (22 gauge)
Stud Wall Building	Small Wood Frame	Small Wood Frame (Residence)	Wood stud	Light Steel Panel (22 gauge)
Stud Wall Building	Medium Wood Frame	Medium Wood Frame (Residence/Apartment)	Wood stud	Plywood/Wood joist
Stud Wall Building	Medium Steel Stud (steel panel roof)	Medium Steel Stud (Office/Commercial)	Steel stud	Light Steel Panel (22 gauge)
Modular Bldg or Trailer	Wood Frame	Modular Building/Trailer (Office/Residence/Storage)	Wood stud	Plywood/Wood joist
Passenger Vehicle	Moving Vehicle	Vehicle Moving	Steel	Steel
Passenger Vehicle	Stationary Vehicle	Vehicle Stationary	Steel	Steel

[1] Small, medium, and large sizes refer to approximate area/floor in ft^2.
Small < 5000 ft^2
5,000 ft^2 < Medium < 20,000 ft^2
Large > 20,000 ft^{2}f
Modular Bldg or Trailer = approx 500 ft^2

[2] Default roof (in parenthesis) is automatically shown in *Roof type* window in *Define Exposed Site (ES) Information* Dialog. If the default roof is replaced by the user, then the user-defined roof will be used to calculate the risk from the PES fragment and debris.
The default roof is always used in the calculations for the building response to overpressure.

Table A-2. Effective Yield

Weapon Type	Z (Hazard Factor) (ft/lbs$^{1/3}$)	Yield Equation (lbs) $Y = C_1 * (W_1 / C_2)$	A	B	C	D	E	F
MK82	86 – 350	$Y = 275*(W_1 / 192)$						
	2.9 – 86	Equation (19)	4.44477	1.2902	-0.34374	0.025341	0	0
	1.2 – 2.9	$Y = 235*(W_1 / 192)$						
MK83	86 – 350	$Y = 590 * (W_1 /445)$						
	2.9 – 86	Equation (19)	5.5293	1.11439	-0.30437	0.021737	0	0
	1.2 – 2.9	$Y = 560 * (W_1 /445)$						
MK84	86 – 350	$Y = 1220 * (W_1 / 945)$						
	2.9 – 86	Equation (19)	6.3317	11.0624	-0.28844	0.019965	0	0
	1.2 – 2.9	$Y = 1200 * (W_1 / 945)$						
M107	86-350	$Y = 12.8 * (W_1 / 15.1)$						
	2.9 – 86	Equation (19)	3.7993	0.35294	-0.51476	0.11606	-0.0073289	0
	1.2 – 2.9	$Y = 42 * (W_1 / 15.1)$						
AIM-7	1.2 – 350	Equation (19)	4.43036	-0.838135	0.544216	-0.184942	0.019430	-0.000231
Bulk/light case		$Y = W_1 * 1$						
M1 (105 mm)	1.2 – 2.9	$Y = 6.5 * (W_1 / 5)$						
	2.9 – 350	Equation (19)	1.952732	-0.4599533	0.529341	-0.166752	0.020306	-0.0007978
MK2 (40 mm)	1.2 – 260	Equation (19)	-2.980723	1.944348	-0.293102	-0.173221	0.049327	-0.0035675
	260- 350	$Y = 0.06 * (W_1 / 0.2)$						

Table A-3. Pressure Calculation Coefficients

Z Range (ft/lbs$^{1/3}$)	A	B	C	D	E
0.5-7.25	6.9137	-1.4398	-0.2815	-0.1416	0.0685
7.25-60	8.8035	-3.7001	0.2709	0.0733	-0.0127
60-500	5.4233	-1.4066	0	0	0

Note: $Z = Z_o$ for Step 5 and $Z = Z_a$ for Step 6

Table A-4. Impulse Calculation Coefficients

Z Range (ft/lbs$^{1/3}$)	A	B	C	D	E
.5 – 2.41	2.975	-0.466	0.963	0.03	-0.87
2.41 – 6	0.911	7.26	-7.459	2.960	-0.432
6 - 85	3.2484	0.1633	- 0.4416	0.0793	-0.00554
85 - 400	4.7702	-1.062	0	0	0

Note: $Z = Z_o$ for Step 5 and $Z = Z_a$ for Step 6

Table A-5. Adjusted Weight Coefficients

	Z_a (ft/lbs$^{1/3}$)	Adjusted Weight (lbs) $W_a = c * W_1$	A	B	C	D	E	F	G	H
ECM-front (all sizes/types)	> 60	$W_a = 0.35 * W_1$								
	1.5 – 60	Equation (25)	-0.43864	-8.4165	16.7060	-12.7490	4.755400	-0.866790	0.061526	0
	< 1.5	$W_a = 0.10 * W_1$								
ECM – side (all sizes/types)	> 60	$W_a = 0.35 * W_1$								
	2 – 60	Equation (25)	-1.2832	-3.6111	5.4064	-3.1582	1.0194	-0.17738	0.012497	0
	< 2	$W_a = 0.13 * W_1$								
ECM – rear (all sizes/types)	> 60	$W_a = 0.20 * W_1$								
	2.5 – 60	Equation (25)	0.72068	-8.8511	10.700	-6.0891	1.8914	-0.30811	0.020299	0
	< 2.5	$W_a = 0.14 * W_1$								
HAS – front	> 63	$W_a = 0.68 * W_1$								
	3.5 – 63	Equation (25)	5.811198	-13.94288	11.12264	-4.566028	1.050035	-0.1293674	0.006702599	0
	< 3.5	$W_a = 0.38 * W_1$								
HAS – side (W> 250 lbs)	> 100	$W_a = 1.2 * W_1$								
	2.5 – 100	Equation (25)	-5.568345	2.664608	-0.6710276	0.4365081	-0.1465799	0.01495905	0	0
	< 2.5	$W_a = 0.03 * W_1$								
HAS – side (W < 250 lbs)	> 100	$W_a = 0.05 * W_1$								
	2.5 – 100	Equation (25)	8.572503	1.282287	0.180446	-0.2260388	.03947517	0	0	0
	< 2.5	$W_a = 0.01 * W_1$								
HAS – rear	> 50	$W_a = 0.07 * W_1$								
	2.67 – 50	Equation (25)	-7.345585	5.90604	-3.846292	1.787642	-0.4084985	0.03173365	0	0
	< 2.67	$W_a = 0.07 * W_1$								
AGBS (all sizes/types)	> 140	$W_a = 0.85 * W_1$								
	1.15 – 140	Equation (25)	-4.18694	2.28941	-0.16247187	-0.071019971	-0.00044634702	0.0018659168	0	0
	< 1.15	$W_a = 0.02 * W_1$								
Operating Building (all sizes/types)	> 140	$W_a = 0.85 * W_1$								
	1.15 – 140	Equation (25)	-4.18694	2.28941	-0.16247187	-0.071019971	-0.00044634702	0.0018659168	0	0
	< 1.15	$W_a = 0.02 * W_1$								
Ship (all sizes)	> 100	$W_a = 1.33 * W_1$								
	7.8 – 100	Equation (25)	-11.81948	16.42335	-8.991386	2.277275	-0.2687593	0.01236889	0	0
	< 7.8	$W_a = 0.5 * W_1$								
ISO Containers	> 100	$W_a = 0.47 * W_1$								
	2 – 100	Equation (25)	-0.7108375	-6.941476	10.85351	-6.73481	2.049523	-0.3048253	0.01772554	0
	< 2	$W_a = 0.12 * W_1$								

Table A-6. Damage Coefficients for the PES Roof

PES (roof)	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	*b*
PEMB	3	40	0.4
Hollow Clay Tile	1	8	0.25
HAS	1,000	2,000	0.9
Large Concrete Arch ECM	15	250	1.0
Medium Concrete Arch ECM	15	250	1.0
Small Concrete Arch ECM	15	250	1.0
Large Steel Arch ECM	15	250	1.0
Medium Steel Arch ECM	15	250	1.0
Small Steel Arch ECM	15	250	1.0
Large AGBS	1	16	0.5
Medium AGBS	1	16	0.5
Small AGBS (Square)	1	16	0.5
Medium Concrete Building	1	16	0.5
Small Concrete Building	1	16	0.5
Ship (small)	100	5,000	1.1
Ship (medium)	100	5,000	1.1
Ship (large)	100	5,000	1.1
ISO Container	3	40	0.4

Table A-7. Damage Coefficients for the PES Front Wall

PES (front wall)	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	*b*
PEMB	3	40	0.4
Hollow Clay Tile	1	8	0.25
HAS	40	2,000	0.9
Large Concrete Arch ECM	1	10	0.6
Medium Concrete Arch ECM	1	10	0.6
Small Concrete Arch ECM	1	10	0.6
Large Steel Arch ECM	1	10	0.6
Medium Steel Arch ECM	1	10	0.6
Small Steel Arch ECM	1	10	0.6
Large AGBS	1	8	0.25
Medium AGBS	1	8	0.25
Small AGBS (Square)	1	8	0.25
Medium Concrete Building	3	100	0.4
Small Concrete Building	3	100	0.4
Ship (small)	100	5,000	1.1
Ship (medium)	100	5,000	1.1
Ship (large)	100	5,000	1.1
ISO Container	3	40	0.4

Table A-8. Damage Coefficients for the PES Side Walls

PES (side walls)	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	*b*
PEMB	1	40	0.4
Hollow Clay Tile	1	8	0.25
HAS	1,000	2,000	0.9
Large Concrete Arch ECM	2,000	10,000	0.9
Medium Concrete Arch ECM	2,000	10,000	0.9
Small Concrete Arch ECM	2,000	10,000	0.9
Large Steel Arch ECM	2,000	10,000	0.9
Medium Steel Arch ECM	2,000	10,000	0.9
Small Steel Arch ECM	2,000	10,000	0.9
Large AGBS	1	8	0.25
Medium AGBS	1	8	0.25
Small AGBS (Square)	1	8	0.25
Medium Concrete Building	3	100	0.4
Small Concrete Building	3	100	0.4
Ship (small)	100	5,000	1.1
Ship (medium)	100	5,000	1.1
Ship (large)	100	5,000	1.1
ISO Container	1	40	0.4

Table A-9. Damage Coefficients for the PES Rear Wall

PES (rear walls)	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	*b*
PEMB	1	40	0.4
Hollow Clay Tile	1	8	0.25
HAS	2,000	10,000	0.9
Large Concrete Arch ECM	2,000	10,000	0.9
Medium Concrete Arch ECM	2,000	10,000	0.9
Small Concrete Arch ECM	2,000	10,000	0.9
Large Steel Arch ECM	2,000	10,000	0.9
Medium Steel Arch ECM	2,000	10,000	0.9
Small Steel Arch ECM	2,000	10,000	0.9
Large AGBS	1	8	0.25
Medium AGBS	1	8	0.25
Small AGBS (Square)	1	8	0.25
Medium Concrete Building	3	100	0.4
Small Concrete Building	3	100	0.4
Ship (small)	100	7,500	1.1
Ship (medium)	100	7,500	1.1
Ship (large)	100	7,500	1.1
ISO Container	1	40	0.4

Table A-10. Pressure-impulse Coefficients for $P_{(sf)}$

% Skull Fracture	A (psi)	B (psi-ms)	C (psi^2-ms)
0.1	0.347	10.821	4934.9
50	0.377	14.501	7097.7
99.9	0.497	19.613	8948.1

Table A-11. Pressure and Impulse Reduction Values due to Glass Percentage

ES Name	Max Reduction	Fraction Average Protection	Glass Fraction for Full Venting	Height of ES (ft)
Small Reinforced Concrete (Office/Commercial)	0.5	0.075	0.25	12
Medium Reinforced Concrete (Office/Commercial)	0.5	0.075	0.25	12
Large Reinforced Concrete Tilt-up (Commercial)	0.5	0.075	0.25	20
Small Reinforced Masonry (Office/Commercial)	0.5	0.075	0.25	12
Medium Reinforced Masonry (Office/Commercial)	0.5	0.075	0.25	12
Small Unreinforced Brick (Office/Apartment)	0.5	0.075	0.25	12
Medium Unreinforced Masonry (Office/Apartment)	0.5	0.075	0.25	12
Large Unreinforced Masonry (Office)	0.5	0.075	0.25	12
Small PEMB (Office/Storage)	0.5	0.075	0.25	12
Medium PEMB (Office/Commercial)	0.5	0.075	0.25	12
Large PEMB (Office/Storage/Hangar)	0.5	0.075	0.25	24
Small Wood Frame (Residence)	0.5	0.075	0.25	12
Medium Wood Frame (Residence/Apartment)	0.5	0.075	0.25	12
Medium Steel Stud (Office/Commercial)	0.5	0.075	0.25	12
Modular Building/Trailer (Office/Residence/Storage)	0.5	0.075	0.25	10
Vehicle	0.5	0.075	0.25	4

Table A-12. Power Curve Parameters for Major Injury as a Function of Glass Breakage

Glass Type	M	N
Annealed	7E-12	6.015
Dual Pane	1E-9	4.953
Tempered	0.0446	1.382

Table A-13. Yield Adjustment Curve Parameters

Glass Type	A	B	C
Annealed	0.0905	1.0556	0.5
Dual Pane	0.1476	1.1395	0.5
Tempered	0.032	1.0072	0.01

Table A-14. Structure Damage / Fatality Normal Distribution Parameters

ES Type	*Pf* @ 40%	*Pf* @ 90%	Sigma	Mean	*Pf* (max)
Small Reinforced Concrete (Office/Commercial)	0.0052	0.3064	0.08964	1.79354	0.318
Medium Reinforced Concrete (Office/Commercial)	0.0074	0.2282	0.09508	1.77894	0.2359
Large Reinforced Concrete Tilt-up (Commercial)	0.0114	0.2681	0.09815	1.77256	0.277
Small Reinforced Masonry (Office/Commercial)	0.0073	0.1829	0.09739	1.77418	0.189
Medium Reinforced Masonry (Office/Commercial)	0.0084	0.2106	0.0972	1.77384	0.2175
Small Unreinforced Brick (Office/Apartment)	0.0141	0.1729	0.10672	1.75264	0.17815
Medium Unreinforced Masonry (Office/Apartment)	0.0105	0.1970	0.10066	1.76608	0.20325
Large Unreinforced Masonry (Office)	0.0100	0.1878	0.10073	1.76625	0.1938
Small PEMB (Office/Storage)	0.0125	0.1257	0.10975	1.74484	0.12935
Medium PEMB (Office/Commercial)	0.0143	0.1444	0.11009	1.74562	0.14872
Large PEMB (Office/Storage/Hangar)	0.0177	0.1785	0.1096	1.74481	0.18365
Small Wood Frame (Residence)	0.0087	0.1144	0.10546	1.75473	0.11785
Medium Wood Frame (Residence/Apartment)	0.0107	0.1417	0.10541	1.75508	0.146
Medium Steel Stud (Office/Commercial)	0.0159	0.1602	0.10987	1.74513	0.1649
Modular Building/Trailer (Office/Residence/Storage)	0.0096	0.1271	0.1054	1.75505	0.13095
Vehicle	0.0009	0.1074	0.08434	1.80506	0.1117

Table A-15. Close-in Adjustment Parameters for $P_{f(bc)}$

ES Building Type	$P_{f(bc)1}$	$P_{f(bc)2}$
Small Reinforced Concrete (Office/Commercial)	100%	EXP(-330.43+100.96*(LN(W_a))-11.618*(LN(W_a))^2+0.59364*(LN(W_a))^3-0.011345*(LN(W_a))^4)
Medium Reinforced Concrete (Office/Commercial)	100%	EXP(-130.31+38.22*(LN(W_a)-4.2566*(LN(W_a))^2+0.21066*(LN(W_a))^3-0.0039012*(LN(W_a))^4)
Large Reinforced Concrete Tilt-up (Commercial)	100%	-0.1108+((0.38698* W_a)/(2330.4+ W_a))
Small Reinforced Masonry (Office/Commercial)	100%	-0.0128+((0.20231* W_a)/(14754+ W_a))
Medium Reinforced Masonry (Office/Commercial)	100%	-0.024+((0.24954* W_a)/(9160.1+ W_a))
Small Unreinforced Brick (Office/Apartment)	100%	0.18
Medium Unreinforced Masonry (Office/Apartment)	100%	-4.7904+((4.9933* W_a)/(29.996+ W_a))
Large Unreinforced Masonry (Office)	100%	-4.8294+((5.0222* W_a)/(38.228+ W_a))
Small PEMB (Office/Storage)	100%	-3.2784+((3.4088* W_a)/(39.217+ W_a))
Medium PEMB (Office/Commercial)	100%	-0.037719+((0.22199* W_a)/(4840+ W_a))
Large PEMB (Office/Storage/Hangar)	100%	-0.0341+((0.21859* W_a)/(5067.3+ W_a))
Small Wood Frame (Residence)	100%	-4.479+((4.5989* W_a)/(7.221+ W_a))
Medium Wood Frame (Residence/Apartment)	100%	-4.6697+((4.8108* W_a)/(29.434+ W_a))
Medium Steel Stud (Office/Commercial)	100%	EXP(274.49-173.58*(LN(W_a))+36.146*(LN(W_a))^2-3.426*(LN(W_a))^3+0.15323*(LN(W_a))^4-0.0026334*(LN(W_a))^5)
Modular Building/Trailer(Office/Residence/Story)	100%	0.13
Vehicle	100%	EXP(-1372.5+495.77*(LN(W_a))-70.975*(LN(W_a))^2+5.0232*(LN(W_a))^3-0.17563*(LN(W_a))^4+0.002425*(LN(W_a))^5)

Table A-16. Close-in Adjustment Parameters for Building Collapse Region Boundaries

ES Building Type	R_1 (ft/lbs$^{1/3}$)	R_2 (ft/lbs$^{1/3}$)			
		R_{2min} (ft/lbs$^{1/3}$)	A	B	C
Small Reinforced Concrete (Office/Commercial)	6	8	-4.128	11.874	43114
Medium Reinforced Concrete (Office/Commercial)	7	8	-2.9501	10.661	56396
Large Reinforced Concrete Tilt-up (Commercial)	8	11	0.16852	15.451	32550
Small Reinforced Masonry (Office/Commercial)	8	10	-0.13307	10.113	56344
Medium Reinforced Masonry (Office/Commercial)	7	10	0.80385	11.677	47077
Small Unreinforced Brick (Office/Apartment)	9	12	4.2209	11.907	776.41
Medium Unreinforced Masonry (Office/Apartment)	9	12	0.5839	11.725	3761
Large Unreinforced Masonry (Office)	8	11	0.25642	14.145	7926.6
Small PEMB (Office/Storage)	10	13	0.92458	13.068	4821.9
Medium PEMB (Office/Commercial)	9	12	0.03521	13.618	6796.8
Large PEMB (Office/Storage/Hangar)	9	12	0.14699	13.366	28431
Small Wood Frame (Residence)	8	11	1.0211	11.484	1453.8
Medium Wood Frame (Residence/Apartment)	8	11	0.28302	12.153	9128.4
Medium Steel Stud (Office/Commercial)	9	12	-0.28856	11.951	17108
Modular Building/Trailer(Office/Residence/Story)	9	12	3.7687	11.621	997.25
Vehicle	7	10	0.14699	13.366	28431

Table A-17. Pressure / Impulse Coefficients – ES Building Percent Damage

Small R/C Office Building, 8" R/C Shearwalls with R/C Roof/Beams

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	13.548	769.645	1540.17
90	12.319	581.692	1540.17
80	11.282	501.169	942.175
70	9.919	365.517	741.695
60	7.96	279.052	473.804
50	6.484	228.776	336.254
40	5.25	159.738	283.621
30	2.74	122.826	75.925
20	2.011	91.199	56.256
10	1.62	65.513	22.743
5	1.323	50.597	13.257
1	1.088	35.521	7.874
0.5	1.06	33.333	7.386
0.1	1.038	29.921	7.101

Medium R/C Office Building

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	13.835	824.891	1388.51
90	11.612	574.348	742.369
80	8.14	482.244	445.328
70	7.161	353.564	444.486
60	6.409	255.592	326.069
50	5.093	199.011	194.472
40	3.942	126.715	118.888
30	1.879	98.417	14.955
20	1.222	80.109	9.33
10	1.047	61.047	4.828
5	0.873	48.883	2.982
1	0.73	34.915	1.881
0.5	0.697	32.63	1.576
0.1	0.671	29.672	1.36

Large Tilt-up Structure (~40,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	4.336	326.124	48.313
90	2.23	259.322	48.313
80	1.575	215.228	48.313
70	1.316	147.447	48.313
60	1.193	118.912	36.178
50	1.072	99.9	25.804
40	0.924	76.5	24.456
30	0.797	58.898	19.87
20	0.683	44.951	14.59
10	0.565	33.467	9.037
5	0.492	28.325	5.391
1	0.348	21.754	3.274
0.5	0.304	20.191	2.891
0.1	0.267	18.281	2.011

Small Un-Reinforced Brick Structure (~2500 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	3.991	64.87	39.819
90	3.477	47.25	26.763
80	3.025	39.154	21.055
70	2.578	33.13	14.68
60	2.211	28.744	9.999
50	2.034	25.697	7.704
40	1.86	23.171	6.652
30	1.708	20.922	5.429
20	1.557	18.285	4.451
10	1.2	13.298	2.379
5	1.044	11.41	1.439
1	0.848	9.271	0.6
0.5	0.801	8.867	0.548
0.1	0.763	8.539	0.504

Medium Un-Reinforced Masonry Structure (~10,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	6.102	181.188	138.147
90	5.026	127.896	79.993
80	3.989	102.32	49.463
70	3.263	85.347	31.296
60	2.929	73.628	24.148
50	2.606	63.693	18.819
40	2.152	56.761	18.761
30	1.708	49.532	18.078
20	1.311	38.569	17.51
10	0.864	18.283	12.537
5	0.692	15.534	8.772
1	0.552	12.299	5.667
0.5	0.535	11.726	5.299
0.1	0.521	11.254	4.786

Large Un-Reinforced Masonry Structure (~40,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	4.401	195.396	178.427
90	3.724	152.319	87.837
80	3.066	131.75	53.449
70	2.488	116.108	26.268
60	2.243	105.458	20.493
50	2.03	90.461	19.328
40	1.832	73.968	19.328
30	1.448	60.699	19.328
20	1.088	30.825	19.328
10	0.969	14.211	7.185
5	0.816	12.066	4.944
1	0.642	9.538	2.936
0.5	0.62	9.126	2.572
0.1	0.603	8.791	2.28

Small Reinforced Masonry Structure (~2500 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	8.488	548.535	647.027
90	7.264	359.227	425.468
80	5.615	274.316	379.895
70	5.045	218.431	247.021
60	4.407	182.708	154.561
50	3.783	124.497	115.951
40	3.191	100.424	82.507
30	2.738	80.822	51.206
20	2.157	60.13	29.429
10	1.548	45.025	13.806
5	1.258	38.432	9.932
1	0.963	30.68	5.906
0.5	0.905	28.84	5.645
0.1	0.86	25.6	5.645

Medium Reinforced Masonry Structure (~10,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	5.753	419.224	265.436
90	5.064	327.054	225.03
80	4.264	244.854	225.03
70	3.83	192.804	147.086
60	3.229	157.437	86.21
50	2.69	123.823	64.33
40	2.201	93.443	37.638
30	1.253	76.701	12.401
20	1.02	62.813	7.594
10	0.904	48.077	3.906
5	0.754	39.228	2.413
1	0.602	29.277	1.262
0.5	0.575	27.024	1.07
0.1	0.553	24.212	0.906

Small Metal Structure (~2500 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	4.864	170.432	113.439
90	4.597	148.324	76.865
80	4.154	118.194	61.746
70	2.889	101.909	46.555
60	2.131	89.364	46.555
50	1.736	78.73	46.555
40	1.42	67.942	43.923
30	1.133	56.006	27.551
20	0.929	45.124	17.248
10	0.748	32.715	12.615
5	0.634	26.801	9.264
1	0.462	20.037	3.443
0.5	0.405	18.751	2.58
0.1	0.357	15.127	1.676

Medium Metal Structure (~10,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	4.949	199.059	163.399
90	4.652	170.906	101.626
80	4.2	155.967	68.98
70	2.889	141.967	40.766
60	2.138	126.101	40.766
50	1.743	105.287	40.766
40	1.426	82.491	40.766
30	1.136	64.629	27.63
20	0.931	51.936	17.28
10	0.749	35.698	11.267
5	0.635	28.302	9.237
1	0.462	20.378	3.297
0.5	0.405	19.155	2.479
0.1	0.357	15.127	1.676

Medium Metal Stud Structure (~10,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	6.425	318.938	319.479
90	6.144	254.791	239.142
80	5.905	223.619	190.457
70	5.304	202.971	141.023
60	4.65	186.178	76.942
50	2.785	171.043	76.942
40	2.382	153.3	76.942
30	2.107	131.829	76.942
20	1.783	95.462	76.942
10	1.217	70.219	54.612
5	0.979	49.235	39.515
1	0.789	33.056	24.174
0.5	0.766	29.952	21.733
0.1	0.747	27.363	19.729

High Bay Metal Structure (~40,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	5.157	339.305	169.627
90	4.786	255.568	137.88
80	4.326	211.005	109.787
70	2.906	182.79	48.295
60	1.761	146.951	48.295
50	1.376	104.018	34.599
40	1.044	85.76	15.799
30	0.842	66.043	6.073
20	0.795	52.533	5.44
10	0.649	39.818	3.54
5	0.544	31.751	2.228
1	0.461	22.828	2.228
0.5	0.412	19.337	2.228
0.1	0.358	15.242	1.685

Small Wood Structure (~2500 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	5.927	123.38	105.616
90	5.01	97.842	83.725
80	4.286	84.776	61.17
70	3.571	70.856	44.053
60	2.983	58.26	26.451
50	2.614	50.388	20.417
40	2.326	43.519	17.154
30	2.038	38.59	13.763
20	1.751	32.32	10.426
10	1.49	22.569	7.913
5	1.212	17.966	3.836
1	0.884	14	2.316
0.5	0.785	12.769	1.849
0.1	0.705	11.749	1.577

Medium Wood Structure (~10,000 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	5.844	239.949	208.186
90	4.693	186.537	119.597
80	3.581	152.348	66.841
70	2.816	126.154	37.14
60	2.387	114.638	27.264
50	2.007	96.008	26.248
40	1.75	78.331	23.164
30	1.511	64.626	17.965
20	1.153	53.68	10.967
10	0.843	39.528	8.074
5	0.692	31.071	7.294
1	0.552	21.777	6.038
0.5	0.535	19.621	5.381
0.1	0.521	17.812	4.837

Small Trailer (~500 sq ft)

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	4.31	75.862	46.335
90	3.586	62.907	33.363
80	2.873	50.998	22.605
70	2.348	40.57	14.679
60	2.044	33.728	12.738
50	1.819	31.077	10.014
40	1.595	27.653	8.18
30	1.371	24.26	6.408
20	1.175	20.733	4.939
10	0.933	16.561	2.974
5	0.78	14.346	2.233
1	0.635	12.193	1.612
0.5	0.611	11.115	1.32
0.1	0.549	10.201	1.144

Passenger Vehicle

Building Damage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	8.499	406.311	536.734
90	6.015	301.516	296.697
80	4.75	248.612	203.846
70	3.923	220.71	155.148
60	3.366	193.408	139.013
50	2.915	167.967	116.128
40	2.519	142.986	84.991
30	2.133	122.347	69.927
20	1.755	102.553	56.062
10	1.354	82.159	35.231
5	1.13	68.732	28.439
1	0.861	57.966	16.499
0.5	0.828	56.636	16.079
0.1	0.802	55.105	14.354

Table A-18. Pressure-impulse Coefficients – ES Roof Damage

4” Reinforced Concrete

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	1.46	128.44	209.38
50%	1.32	64.22	75.03
0%	0.73	20.81	14.14

14” Reinforced Concrete

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	9.64	360.18	1005.77
50%	8.67	180.09	366.77
0%	4.82	58.35	71.00

3/8” Plywood and 2 x 10 Joist at 16” o.c.

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	3.32	9.80	6.72
50%	1.86	6.47	3.39
0%	0.93	3.13	1.16

5/8” Gypsum Board

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	0.10	1.05	0.17

½” Plywood and 2 x 6 Joist at 24” o.c.

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	2.62	11.31	7.35
50%	1.49	7.47	3.79
0%	0.74	3.62	1.29

Lightweight Concrete and Steel Deck

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	1.47	150.90	265.98
50%	1.41	99.60	143.56
0%	1.12	48.29	49.12

Medium Steel Panel

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	2.67	72.00	91.26
50%	2.56	47.52	50.13
0%	2.05	23.04	17.78

Light Steel Panel

Roof Damage	A (psi)	B (psi-ms)	C (psi^2-ms)
100%	1.55	44.04	43.54
50%	1.49	29.07	23.89
0%	1.19	14.09	8.45

Table A-19. Pressure-impulse Coefficients – Glass Breakage

Dual Pane Windows

Glass breakage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	0.852	33.51	19.743
90	0.643	19.734	13.045
70	0.493	7.989	7.66
50	0.383	7.988	3.42
30	0.3	0.201	1
10	0.19	0.2	0.3
1	0.105	0.1	0.1

Annealed Windows

Glass breakage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	0.853	26.976	39.765
90	0.717	20.34	15.382
70	0.547	9.886	8.177
50	0.424	3.885	4.752
30	0.316	3.456	1.316
10	0.21	0	0.8

Tempered Windows

Glass breakage (%)	A (psi)	B (psi-ms)	C (psi^2-ms)
100	3.082	287.38	1117.9
90	3.007	224.92	626.41
70	2.702	131.12	389.13
50	2.477	8.325	197.8
30	1.727	8.324	29.077
10	1.343	8.323	8
1	1	0.102	7
0.10	0.8	0.101	5
0.01	0.65	0.1	3

Table A-20. Mass Distribution for PES Roof

		% Material		Percent Mass (%)									
PES #	Mass of PES roof (lbs)	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
PEMB	13,200	100	0	0	0	5	5	5	15	20	25	15	10
Hollow Clay Tile	51,800	5	95	0	0	5	5	5	15	20	25	15	10
HAS	1,722,600	10	90	20	15	7.5	7.5	10	10	10	10	5	5
Large Concrete Arch ECM	584,600	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Concrete Arch ECM	438,500	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Concrete Arch ECM	292,300	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large Steel Arch ECM	31,400	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Steel Arch ECM	23,600	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Steel Arch ECM	15,700	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large AGBS	305,900	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Medium AGBS	245,300	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small AGBS (Square)	126,400	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Medium Concrete Building	245,300	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small Concrete Building	126,400	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Ship (large)	183,800	100	0	5	5	5	5	5	5	5	5	20	40
Ship (medium)	137,800	100	0	5	5	5	5	5	5	5	5	20	40
Ship (small)	61,300	100	0	5	5	5	5	5	5	5	5	20	40
ISO Container	1,236 × NISO	100	0	0	0	5	5	5	15	20	25	15	10

*Mass distribution numbers in table are in percent (%)

Table A-21. Mass Distribution for PES Front Wall

		% Material		Percent Mass (%)									
PES #	Mass of PES front wall (lbs)	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
PEMB	2,201	100	0	0	0	5	5	5	15	20	25	15	10
Hollow Clay Tile	25,920	5	95	2.5	5	7.5	10	12.5	15	20	15	10	2.5
HAS	277,530	10	90	2.5	5	5	7.5	15	15	15	10	10	15
Large Concrete Arch ECM	48,737	13	87	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Concrete Arch ECM	48,737	13	87	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Concrete Arch ECM	48,737	13	87	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large Steel Arch ECM	37,775	16	84	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Steel Arch ECM	37,775	16	84	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Steel Arch ECM	37,775	16	84	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large AGBS	176,473	0	100	0	5	5	10	40	10	5	5	5	15
Medium AGBS	128,287	0	100	0	5	5	10	40	10	5	5	5	15
Small AGBS (Square)	60,592	0	100	0	5	5	10	40	10	5	5	5	15
Medium Concrete Building	147,891	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small Concrete Building	69,851	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Ship (large)	61,561	100	0	5	5	5	5	5	5	5	5	20	40
Ship (medium)	61,561	100	0	5	5	5	5	5	5	5	5	20	40
Ship (small)	30,627	100	0	5	5	5	5	5	5	5	5	20	40
ISO Container	640 × NISO	100	0	0	0	5	5	5	15	20	25	15	10

*Mass distribution numbers in table are in percent (%)

Table A-22. Mass Distribution for PES Side Walls

		% Material		Percent Mass (%)									
PES #	Mass of PES side walls (lbs)	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
PEMB	8,806	100	0	0	0	5	5	5	15	20	25	15	10
Hollow Clay Tile	103,680	5	95	2.5	5	7.5	10	12.5	15	20	15	10	2.5
HAS	1,513,800	10	90	20	15	7.5	7.5	10	10	10	10	5	5
Large Concrete Arch ECM	194,880	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Concrete Arch ECM	146,160	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Concrete Arch ECM	97,440	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large Steel Arch ECM	31,400	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Steel Arch ECM	23,550	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Steel Arch ECM	15,700	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large AGBS	255,484	0	100	0	5	5	10	40	10	5	5	5	15
Medium AGBS	256,574	0	100	0	5	5	10	40	10	5	5	5	15
Small AGBS (Square)	121,184	0	100	0	5	5	10	40	10	5	5	5	15
Medium Concrete Building	295,782	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small Concrete Building	139,702	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Ship (large)	547,210	100	0	5	5	5	5	5	5	5	5	20	40
Ship (medium)	410,408	100	0	5	5	5	5	5	5	5	5	20	40
Ship (small)	204,183	100	0	5	5	5	5	5	5	5	5	20	40
ISO Container	2,399 × NISO	100	0	0	0	5	5	5	15	20	25	15	10

*Mass distribution numbers in table are in percent (%)

Table A-23. Mass Distribution for PES Rear Wall

		% Material		Percent Mass (%)									
PES #	Mass of PES rear wall (lbs)	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
PEMB	2,201	100	0	0	0	5	5	5	15	20	25	15	10
Hollow Clay Tile	25,920	5	95	2.5	5	7.5	10	12.5	15	20	15	10	2.5
HAS	832,590	10	90	20	20	15	10	10	5	5	5	5	5
Large Concrete Arch ECM	32,176	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Concrete Arch ECM	32,176	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Concrete Arch ECM	32,176	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large Steel Arch ECM	36,920	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Medium Steel Arch ECM	36,920	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Small Steel Arch ECM	36,920	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Large AGBS	176,473	0	100	0	5	5	10	40	10	5	5	5	15
Medium AGBS	128,287	0	100	0	5	5	10	40	10	5	5	5	15
Small AGBS (Square)	60,592	0	100	0	5	5	10	40	10	5	5	5	15
Medium Concrete Building	147,891	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small Concrete Building	69,851	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Ship (large)	61,561	100	0	5	5	5	5	5	5	5	5	20	40
Ship (medium)	61,561	100	0	5	5	5	5	5	5	5	5	20	40
Ship (small)	30,627	100	0	5	5	5	5	5	5	5	5	20	40
ISO Container	640 × NISO	100	0	0	0	5	5	5	15	20	25	15	10

*Mass distribution numbers in table are in percent (%)

Table A-24. Roof - Secondary Fragment Nominal Maximum Throw Range

PES	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	V (ft^3)
PEMB	3	40	31,104
Hollow Clay Tile	1	8	31,104
HAS	1,000	2,000	229,680
Large Concrete Arch ECM	15	250	25,000
Medium Concrete Arch ECM	15	250	18,750
Small Concrete Arch ECM	15	250	12,500
Large Steel Arch ECM	15	250	25,000
Medium Steel Arch ECM	15	250	18,750
Small Steel Arch ECM	15	250	12,500
Large AGBS	1	16	135,258
Medium AGBS	1	16	107,440
Small AGBS (Square)	1	16	36,864
Medium Concrete Building	1	16	107,440
Small Concrete Building	1	16	36,864
Ship (large)	100	5,000	603,000
Ship (medium)	100	5,000	452,250
Ship (small)	100	5,000	150,000
ISO Container	3	40	1,360

Table A-25. Front Wall - Secondary Fragment Nominal Maximum Throw Range

PES	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	V (ft^3)
PEMB	3	40	31,104
Hollow Clay Tile	1	8	31,104
HAS	40	2,000	229,680
Large Concrete Arch ECM	1	10	25,000
Medium Concrete Arch ECM	1	10	18,750
Small Concrete Arch ECM	1	10	12,500
Large Steel Arch ECM	1	10	25,000
Medium Steel Arch ECM	1	10	18,750
Small Steel Arch ECM	1	10	12,500
Large AGBS	1	8	135,258
Medium AGBS	1	8	107,440
Small AGBS (Square)	1	8	36,864
Medium Concrete Building	3	100	107,440
Small Concrete Building	3	100	36,864
Ship (large)	100	5,000	603,000
Ship (medium)	100	5,000	452,250
Ship (small)	100	5,000	150,000
ISO Container	3	40	1,360

Table A-26. Side Wall - Secondary Fragment Nominal Maximum Throw Range

PES	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	V (ft^3)
PEMB	1	40	31,104
Hollow Clay Tile	1	8	31,104
HAS	1,000	2,000	229,680
Large Concrete Arch ECM	2,000	10,000	25,000
Medium Concrete Arch ECM	2,000	10,000	18,750
Small Concrete Arch ECM	2,000	10,000	12,500
Large Steel Arch ECM	2,000	10,000	25,000
Medium Steel Arch ECM	2,000	10,000	18,750
Small Steel Arch ECM	2,000	10,000	12,500
Large AGBS	1	8	135,258
Medium AGBS	1	8	107,440
Small AGBS (Square)	1	8	36,864
Medium Concrete Building	3	100	107,440
Small Concrete Building	3	100	36,864
Ship (large)	100	5,000	603,000
Ship (medium)	100	5,000	452,250
Ship (small)	100	5,000	150,000
ISO Container	1	40	1,360

Table A-27. Rear Wall - Secondary Fragment Nominal Maximum Throw Range

PES	Initial Breakout Value Y_0 (lbs)	Total Destruction Value Y_{100} (lbs)	V (ft^3)
PEMB	1	40	31,104
Hollow Clay Tile	1	8	31,104
HAS	2,000	10,000	229,680
Large Concrete Arch ECM	2,000	10,000	25,000
Medium Concrete Arch ECM	2,000	10,000	18,750
Small Concrete Arch ECM	2,000	10,000	12,500
Large Steel Arch ECM	2,000	10,000	25,000
Medium Steel Arch ECM	2,000	10,000	18,750
Small Steel Arch ECM	2,000	10,000	12,500
Large AGBS	1	8	135,258
Medium AGBS	1	8	107,440
Small AGBS (Square)	1	8	36,864
Medium Concrete Building	3	100	107,440
Small Concrete Building	3	100	36,864
Ship (large)	100	7,500	603,000
Ship (medium)	100	7,500	452,250
Ship (small)	100	7,500	150,000
ISO Container	1	40	1,360

Table A-28. Secondary Fragment Initial Velocity

PES	Roof		Front wall		Side wall		Rear wall		Cut-off values IV_{max} (ft/s)
	a_{iv}	exp_{iv}	a_{iv}	exp_{iv}	a_{iv}	exp_{iv}	a_{iv}	exp_{iv}	
PEMB	700	0.45	700	0.45	700	0.45	700	0.45	1,500
Hollow Clay Tile	700	0.45	700	0.45	700	0.45	700	0.45	1,500
HAS	6550	0.8	11900	0.8	6550	0.8	4990	0.8	1,500
Large Concrete Arch ECM	141.8	0.365	678.9	0.49	70.6	0.482	61.7	0.495	3,000
Medium Concrete Arch ECM	142.8	0.396	746.4	0.571	70.2	0.536	68.2	0.586	3,000
Small Concrete Arch ECM	139.4	0.444	863.3	0.657	68	0.585	78.3	0.662	3,000
Large Steel Arch ECM	234.9	0.361	295.7	0.313	88.3	0.489	39.9	0.313	3,000
Medium Steel Arch ECM	237.4	0.389	384.7	0.409	89.3	0.521	51.7	0.413	3,000
Small Steel Arch ECM	237.1	0.431	402.5	0.441	87.6	0.567	54.3	0.441	3,000
Large AGBS	1711	0.405	1731	0.47	2011	0.5074	1731	0.47	3,000
Medium AGBS	1575	0.4	2300	0.539	2300	0.539	2300	0.539	3,000
Small AGBS (Square)	1211	0.404	2004	0.6	2004	0.6	2004	0.6	3,000
Medium Concrete Building	1604	0.3975	2007	0.535	2007	0.535	2007	0.535	3,000
Small Concrete Building	1223	0.401	1746	0.596	1746	0.596	1746	0.596	3,000
Ship (large)	2130	0.45	2130	0.45	2130	0.45	2130	0.45	3,000
Ship (medium)	2130	0.45	2130	0.45	2130	0.45	2130	0.45	3,000
Ship (small)	2130	0.45	2130	0.45	2130	0.45	2130	0.45	3,000
ISO Container	700	0.45	700	0.45	700	0.45	700	0.45	1,500

Table A-29. Secondary Fragment Maximum Throw Cutoff Values

PES	Maximum Throw Cutoff Values			
	Roof (ft)	Front wall (ft)	Side wall (ft)	Rear wall (ft)
PEMB	Primary max.	Primary max.	Primary max.	Primary max.
Hollow Clay Tile	Primary max.	3600	3600	3600
HAS	3000	3600	3000	3000
Large Concrete Arch ECM	3600	5100	3600	3600
Medium Concrete Arch ECM	3600	5100	3600	3600
Small Concrete Arch ECM	3600	5100	3600	3600
Large Steel Arch ECM	3600	5100	3600	3600
Medium Steel Arch ECM	3600	5100	3600	3600
Small Steel Arch ECM	3600	5100	3600	3600
Large AGBS	3600	4700	4700	4700
Medium AGBS	3600	4700	4700	4700
Small AGBS (Square)	3600	4700	4700	4700
Medium Concrete Building	3600	4700	4700	4700
Small Concrete Building	3600	4700	4700	4700
Ship (small)	4400	4400	4400	4400
Ship (medium)	4400	4400	4400	4400
Ship (large)	4400	4400	4400	4400
ISO Container	4400	4400	4400	4400

Attachment 1 – Thermal

SAFER 3 Thermal

Prepared by – John Tatom (APT)
Mike Swisdak (NSWC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3 thermal branch. Specific questions addressed are:

1. Why are thermal effects only considered for 1.3 events?
2. Why aren't other effects/consequences considered in 1.3 events?
3. Why is an adjustment made if a PES is present?
4. What is the PES adjustment based on?
5. Why is PES damage not considered?
6. Why is an adjustment made if an ES is present?
7. What is the ES adjustment based on?
8. Why is ES damage considered?
9. How were the fatality (as a function of the inverse of the adjusted scaled range) curves derived?
10. Why is the maximum probability of fatality for thermal effects only 0.5?

REFERENCES

1. Swisdak, M. M., "DDESB Blast Effects Computer User's Manual And Documentation (Revision 1)," DDESB Technical Paper 17, 1 January 2005.
2. Edmondson, J. N. and Prescott, B. L., "The Thermal Radiation Effects From The Initiation Of HD 1.3 Explosives," RANN/2/49/00119/90, AEA Technology, March 1992
3. Briefings to RBESCT

DISCUSSIONS

1. *Why are thermal effects only considered for 1.3 events?*

   The assumption was made that the thermal effects from a high-explosives event would be insignificant (compared to other effects) if 1.3 items were not present.

2. *Why aren't other effects/consequences considered in 1.3 events?*

   The assumption was made that the blast-related effects (direct pressure and impulse, glass hazards, ES building failure, and debris) from a 1.3 event would be insignificant compared to thermal.

3. *Why is an adjustment made if a PES is present?*

   The adjustment to the yield is made in order to account for the effect the presence of the PES has on the yield "seen" outside of the PES.

4. *What is the PES adjustment based on?*

In SAFER 3, the yield adjustment in the thermal branch is made based on the logic for the yield adjustment in the pressure and impulse branch. The algorithms for determining the adjusted weight are based on the Blast Effects Computer (ref 1).

5. *Why is PES damage not considered?*

   In SAFER, building damage is not a design goal. PES damage is used to determine effects external to the building, and they are considered in sequence with thermal being the last. There is no provision in SAFER that the PES may actually contain an event and there are no other effects to be considered "after" thermal effects, therefore the damage to the PES does not need to be determined.

6. *Why is an adjustment made if an ES is present?*

   The protection afforded by the ES against thermal effects is considered in SAFER, unless the ES is "open" or 100% damaged.

7. *What is the ES adjustment based on?*

   The Science Panel determined the nominal thermal blocking factors based on the material type of the building and expert opinion.

8. *Why is ES damage considered?*

   It is assumed that although "blast effects" from a 1.3 event are not significant enough to consider fatalities from, such effects might be significant enough to compromise the protection the ES structure would provide to personnel inside. These "damage" levels would normally be small, and can be thought of as cracks or gaps that would allow an increase in temperature inside the ES.

9. *How were the fatality (as a function of the inverse of the adjusted scaled range) curves derived?*

   The Science Panel created the curves based on available literature (ref 2) describing the probability of third-degree burns as a function of the quantity of explosives. A relationship was developed to translate third-degree burns into probability of fatality and then the Science Panel plotted data points from the existing and developed equations. These data points were then used to fit a standard normal distribution describing the probability of fatality as a function of the inverse of the scaled adjusted range

10. *Why is the maximum probability of fatality for thermal effects only 0.5?*

    The information available (ref 2) predicted a maximum probability of fatality of approximately 0.5 and the Science Panel did not alter this value.

Attachment 2 – SCIFM

Simplified Close-In Fatality Mechanisms (SCIFM)

Prepared by – John Tatom (APT)
Mike Swisdak (NSWC)
Revision Date – 02-25-05

PURPOSE

This memorandum addresses the rationale and development of the Simplified Close-In Fatality Mechanisms (SCIFM).

Specific questions include:

1. What is SCIFM and why is it necessary?
2. How does SCIFM work?
3. What are the (X_1, Y_1) and (X_2, Y_2) parameters based on?
4. How was the shape of the transition region curve determined?
5. How were the plateau values established?
6. Are there step-functions in the SCIFM logic?
7. Does SCIFM affect injury determination?
8. Why doesn't SCIFM apply to direct blast fatality mechanisms?
9. Why are there fixed minimum values for X_2 in the building failure SCIFM logic?
10. Why does X_1=X_2 in the debris SCIFM logic?
11. Why aren't the X_1 and X_2 debris SCIFM values based on scaled range?
12. Why does X_1=X_2 in the thermal SCIFM logic?
13. Why aren't the X_1 and X_2 thermal SCIFM values based on scaled range?

REFERENCES (ATTACHED)

1. "SAFER 3 Algorithm Poster Session," DDESB Seminar 2004, APT CE1-09900, 13 August 2004.
2. "SAFER 3 Range of Validity Technical Memorandum," APT CE1-16000, 25 February 2005.
3. Briefings to RBESCT

DISCUSSION

1. *What is SCIFM and why is it necessary?*

   SCIFM is a conservative methodology designed to allow the use of SAFER at shorter distances than the original/nominal logic was intended.

2. *How does SCIFM work?*

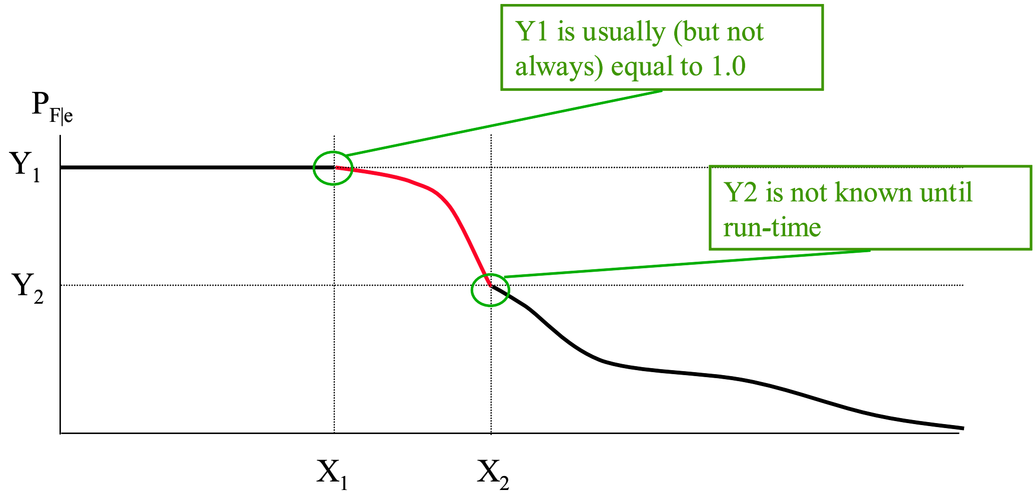
   With the introduction of the SCIFM logic, SAFER 3 has three distinct regions in which the probability of fatality is determined:

   Region 1 (close to the PES): plateau region with a constant value of Pf|e

   Region 2 (transition): Beyond the plateau, a region where Pf|e value is determined by a stored curve

Region 3: At ranges large enough to be in the range of validity for the normal SAFER equations, the Pf|e value is calculated using the standard SAFER logic for each branch

As shown in Figure 1 (Ref. 1), these three regions are delineated by the two points X_1 and X_2



SCIFM Region Visualization

The values for X_1 and X_2 are stored or calculated for each branch of the SAFER logic, as shown in Table 1.

Table 1. SCIFM Range Parameters

Mechanism	**X1**	**X2**
P & I		
Lung Rupture	n/a	n/a
WBD	n/a	n/a
Skull Fracture	n/a	n/a
Glass		
Annealed	K2	K12
Dual Pane	K5	K12
Tempered	K6	K12
Building Failure		
Sm RC	K6	$X2=A+((B*W_a)/(C+W_a))$ {min=8}
Tilt-up RC	K8	$X2=A+((B*W_a)/(C+W_a))$ {min=11}
L URM	K8	$X2=A+((B*W_a)/(C+W_a))$ {min=11}
Med RM	K7	$X2=A+((B*W_a)/(C+W_a))$ {min=10}
Sm RM	K8	$X2=A+((B*W_a)/(C+W_a))$ {min=10}
Sm UR Brick	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
Med Met	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
Sm Met	K10	$X2=A+((B*W_a)/(C+W_a))$ {min=13}
Med Wood	K8	$X2=A+((B*W_a)/(C+W_a))$ {min=11}
Sm Wood	K8	$X2=A+((B*W_a)/(C+W_a))$ {min=11}
Trailer	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
Med RC O/A	K7	$X2=A+((B*W_a)/(C+W_a))$ {min=8}
Med URM	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
Med Met Stud	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
L Met	K9	$X2=A+((B*W_a)/(C+W_a))$ {min=12}
Vehicle	K7	$X2=A+((B*W_a)/(C+W_a))$ {min=10}
Debris		
High Angle	2*(crater radius)	2*(crater radius)
Low Angle	2*(crater radius)	2*(crater radius)
Other		
Thermal	fireball radius	fireball radius

The building failure X_2 equations use stored parameters as shown in Table 2.

Table 2. X2 Equation Parameters

ES Type	A	B	C
Sm RC	-4.128	11.874	43114
Tilt-up RC	0.16852	15.451	32550
L URM	0.25642	14.145	7926.6
Med RM	0.80385	11.677	47077
Sm RM	-0.13307	10.113	56344
Sm UR Brick	4.2209	11.907	776.41
Med Met	0.035208	13.618	6796.8
Sm Met	0.92458	13.068	4821.9
Med Wood	0.28302	12.153	9128.4
Sm Wood	1.0211	11.484	1453.8
Trailer	3.7687	11.621	997.25
Med RC O/A	-2.9501	10.661	56396
Med URM	0.5839	11.725	3761
Med Met Stud	-0.28856	11.951	17108
L Met	0.14699	13.366	28431
Vehicle	0.14699	13.366	28431

The values for Y_1 and Y_2 are stored or calculated for each branch of the SAFER logic, as shown in Table 3. %Glass and FA are user inputs: the percentage of glass on the structure and the floor area of the structure.

Table 3. Y1 and Y2 Parameters

Mechanism	Y1	Y2
P & I		
Lung Rupture	1.0	n/a
WBD	1.0	n/a
Skull Fracture	1.0	n/a
Glass		
Annealed	0.1	$Y2=[-0.00019264+0.00051619(LOG(W_a))]*[\%Glass/10\%]*[5000/FA]1/2$
Dual Pane	0.1	$Y2=[-0.00010599+0.00078248(LOG(W_a))]*[\%Glass/10\%]*[5000/FA]1/2$
Tempered	0.1	$Y2=[-0.00024899+0.00014097(LOG(W_a))]*[\%Glass/10\%]*[5000/FA]1/2$
Building Failure		
Sm RC	1.0	$Y2=EXP(-330.43+100.96*(LN(W_a))-11.618*(LN(W_a))\hat{}2+0.59364*(LN(W_a))\hat{}3-0.011345*(LN(W_a))\hat{}4)$
Tilt-up RC	1.0	$Y2=-0.1108+((0.38698*W_a)/(2330.4+W_a))$
L URM	1.0	$Y2=-4.8294+((5.0222*W_a)/(38.228+W_a))$
Med RM	1.0	$Y2=-0.024+((0.24954*W_a)/(9160.1+W_a))$
Sm RM	1.0	$Y2=-0.0128+((0.20231*W_a)/(14754+W_a))$
Sm UR Brick	1.0	Y2=0.18
Med Met	1.0	$Y2=-0.037719+((0.22199*W_a)/(4840+W_a))$
Sm Met	1.0	$Y2=-3.2784+((3.4088*W_a)/(39.217+W_a))$
Med Wood	1.0	$Y2=-4.6697+((4.8108*W_a)/(29.434+W_a))$
Sm Wood	1.0	$Y2=-4.479+((4.5989*W_a)/(7.221+W_a))$
Trailer	1.0	Y2=0.13
Med RC O/A	1.0	$Y2=EXP(-130.31+38.22*(LN(W_a)-4.2566*(LN(W_a))\hat{}2+0.21066*(LN(W_a))\hat{}3-0.0039012*(LN(W_a))\hat{}4)$
Med URM	1.0	$Y2=-4.7904+((4.9933*W_a)/(29.996+W_a))$
Med Met Stud	1.0	$Y2=EXP(274.49-173.58*(LN(W_a))+36.146*(LN(W_a))\hat{}2-3.426*(LN(W_a))\hat{}3+0.15323*(LN(W_a))\hat{}4-0.0026334*(LN(W_a))\hat{}5)$
L Met	1.0	$Y2=-0.0341+((0.21859*W_a)/(5067.3+W_a))$
Vehicle	1.0	$Y2=EXP(-1372.5+495.77*(LN(W_a))-70.975*(LN(W_a))\hat{}2+5.0232*(LN(W_a))\hat{}3-0.17563*(LN(W_a))\hat{}4+0.002425*(LN(W_a))\hat{}5)$
Debris		
High Angle	1.0	SAFER 3.0 result
Low Angle	1.0	SAFER 3.0 result
Other		
Thermal	1.0	SAFER 3.0 result

3. *What are the (X_1, Y_1) and (X_2, Y_2) parameters based on?*

   The X_2 parameters are largely based on the range of validity of the algorithms, as described in a separate document (ref 2). The Y_2 values are generally a function of X_2. The (X_1, Y_1) values were conservatively established based on expert opinion.

4. *How was the shape of the transition region curve determined?*

   The curve was created to conservatively transition the $P_{f|e}$ values from (X_1, Y_1) to (X_2, Y_2) and is based on expert opinion.

5. *How were the plateau values established?*

   For purposes of conservatism, the value was set to 1.0 for all mechanisms other than glass. For glass, historical precedent suggested that glass hazards would never kill all occupants of normal ES types. The value of 0.1 for glass was based on expert opinion.

6. *Are there step-functions in the SCIFM logic?*

   In general, there are not. However, in cases where X_1 equals X_2 and Y_2 is less than Y_1, step-function results will occur.

7. *Does SCIFM affect injury determination?*

   Yes, in some cases (when injury levels are dependent on fatality levels and the fatality level has been affected by SCIFM).

8. *Why doesn't SCIFM apply to direct blast fatality mechanisms?*

   The direct blast fatality mechanisms were already designed to generate $P_{f|e}$ results as high as 1.0 if the scaled range was small enough. Therefore, the SCIFM logic was not necessary.

9. *Why are there fixed minimum values for X_2 in the building failure SCIFM logic?*

   Certain assumptions concerning the response of the ES were not considered accurate at scaled ranges smaller than the fixed minima; therefore the fixed minimum values were included for conservatism.

10. *Why does X_1=X_2 in the debris SCIFM logic?*

    The SAFER debris density function accounts for most ranges relatively well, but was not intended to apply inside the crater itself. Thus, the X_2 value (which represents the minimum range at which the standard algorithms can be used) could have been set to value as small as the crater radius, but was doubled for conservatism.

11. *Why aren't the X_1 and X_2 debris SCIFM values based on scaled range?*

    The crater radius is not expressed as a scaled range, so X_1 and X_2 cannot be, either.

12. *Why does X_1=X_2 in the thermal SCIFM logic?*

    The SAFER thermal logic was not intended to apply inside the fireball itself. Thus, the X_2 value (which represents the minimum range at which the standard algorithms can be used) was set to the fireball radius.

13. *Why aren't the X_1 and X_2 thermal SCIFM values based on scaled range?*

    The fireball radius is not expressed as a scaled range, so X_1 and X_2 cannot be, either.

Attachment 3 – Input

Input Section

Prepared by – John Tatom (APT)
Mike Swisdak (NSWC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3.0 input section. Specific questions addressed are:

1. Why were the weapon types shown in Table 1 chosen?
2. What guidance is there for choosing weapon types when the actual weapon is not a choice?
3. What are the weapon models based on?
4. Why were these PES types chosen?
5. What guidance is there for choosing PES types when the actual PES is unknown or not available as a choice?
6. What are the PES blast and debris parameters based on?
7. Why were these activity types chosen?
8. Why were these ES types chosen?
9. What guidance is there for choosing ES types when the actual ES is unknown or not available as a choice?
10. What are the ES models based on?
11. What guidance is there for choosing ES roof types when the actual ES roof is unknown or not available as a choice?
12. How were the methods for determining maximum/expected yields (by HD) derived?
13. How were the TNT conversion factors determined?

REFERENCES

1. Swisdak, M. M. and Ward, J. M., “DDESB Blast Effects Computer Users Manual And Documentation,” DDESB Technical Paper 17, 1 May 2003, in review.
2. Crull, Michelle and Swisdak, Michael, “Methodologies For Calculating Primary Fragment Characteristics,” DDESB Technical Paper 16, 1 December 2002.
3. Briefings to RBESCT
4. Chrostowski, Jon; Wilde, Paul and Gan, Wenshui, “Blast Damage, Serious Injury and Fatality Models for Structures and Windows”, ACTA, Torrance, CA, July 2001.

DISCUSSIONS

1. *Why were the weapon types shown in Table 1 chosen?*

The weapon choices available in SAFER are based on a philosophy developed for the Army’s “Worst Case Donor/Acceptor” Program: If testing or analysis is performed using a “worst case” donor munition as the explosion source, then the results would be applicable to all other munitions that present a lesser hazard.

For HD 1.1 munitions, several different items were identified as being potential worst cases from both a blast and fragmentation standpoint; it being up to the user to select the type that most closely represents the actual item. MK 80 series bombs (MK 82, MK 83, or MK 84) represent all large, robust munitions; M107 projectiles represent all small, robust munitions. The AIM-7 warhead represents all fragmenting or thin-skinned items.

For HD 1.2, the M1 projectile represents all HD 1.2.1 items, while the 40 mm projectile represents all HD 1.2.2 projectiles.

Thus, by using items that represent "worst" cases, the results can be applied to other, similar weapons in class. If calculations made for an item that was not "worst case", then the results obtained would only apply to that particular item. If SAFER analyses were performed with weapons that did not represent worst-case situations, then the results would be weapon specific and could not be applied to other weapons or situations.

2. *What guidance is there for choosing weapon types when the actual weapon is not a choice?*

   The user should know if his weapons are robust/non-robust, bombs/projectiles, lightly cased items, bare explosives, etc. With this general knowledge, choices can be made. As a rule, if the NEW is made up of a mixture of different types of items, select the "worst" case. If this cannot be easily determined, make multiple runs by varying the input weapon selection and then use the one that gives the highest probability of fatality.

3. *What are the weapon models based on?*

   The blast models use the same algorithms as the DDESB Blast Effects Computer[1].

   The fragmentation models use the algorithms and information described in DDESB TP 16[2].

4. *Why were these PES types chosen?*

   The intent was to provide as many options as possible under the following constraints: (1) either test data were available or (2) the buildings are typical of DOD storage and operational facilities even if no test data were available.

5. *What guidance is there for choosing PES types when the actual PES is unknown or not available as a choice?*

   As a rule, the debris hazard will dominate and therefore the user should select the closest match in terms of debris type and generation potential. If this cannot be easily determined, make multiple runs by varying the PES selection (between reasonable choices) and then use the one that produces the most conservative result.

   If the PES does not contribute significantly to the debris hazard, consider Table 1.

Table 1. *PES Selection Criteria*

PES Type	Blast Attenuation	Secondary Debris Mass
Open	None	None
PEMB	None	Minor
HCT	None	Moderate

6. *What are the PES blast and debris parameters based on?*

   Where available, test data were used to anchor the SAFER models. When test data were not available, the consensus expert opinion of the Science Panel was used. See Table 2 for a summary of the basis of the PES parameters for blast and debris hazards.

Table 2. PES Parameter Basis

PES Type	Blast	Debris
Open	N/A	N/A
PEMB	N/A	Expert Opinion
HCT	N/A	Expert Opinion
HAS	Distant Runner (E4, E5)	Distant Runner (E4, E5)
Large Concrete Arch ECM	Compiled test results	Inferred from Eskimo test series
Medium Concrete Arch ECM	Compiled test results	Inferred from Eskimo test series
Small Concrete Arch ECM	Compiled test results	Inferred from Eskimo test series
Large Steel Arch ECM	Compiled test results	Inferred from Eskimo 1
Medium Steel Arch ECM	Compiled test results	Eskimo 1
Small Steel Arch ECM	Compiled test results	Inferred from Eskimo 1
Large AGBS	Compiled test results	Inferred from 40 Tonne Trial
Medium AGBS	Compiled test results	Correlated to 40 Tonne Trial
Small AGBS	Compiled test results	Inferred from 40 Tonne Trial
Medium Concrete Ops Bldg	Compiled test results	Inferred from SciPan 1
Small Concrete Ops Bldg	Compiled test results	SciPan 1
Large Ship	Compiled test results	Inferred from MPS test
Medium Ship	Compiled test results	Inferred from MPS test
Small Ship	Compiled test results	Inferred from MPS test
ISO Containers	Compiled test results	Expert Opinion

See the Pressure and Impulse Tech Memo (APT # E1-00500) for more details on the blast attenuation models and the Debris Tech Memo (APT # E1-00600a) for further background on the PES debris models.

7. *Why were these activity types chosen?*

In 1997 when the probability of event task was undertaken, the RBESCT reviewed the DDESB accident database. The DDESB database used the activity types now in SAFER, to categorize the activity occurring when an accident occurred. The same activities are currently used in the Army maintained accident database ESMAM.

8. *Why were these ES types chosen?*

ES types were chosen to represent typical building construction and size. Previous consequence programs that modeled typical building types were consulted (e.g. BDAM, FACEDAP, and ERASDAC). Sizes were chosen to represent typical occupancies and uses. The highest priority for describing the building type in SAFER is the wall material (e.g. reinforced concrete, tilt-up reinforced concrete, wood frame, unreinforced masonry, pre-engineered metal). High priority was also placed on the size of the building. Most building types are provided with 3 floor area options (small = 2500 sf, medium = 10,000 sf, and large = 40,000 sf). An attempt was made to use the most typical roof construction for the type and size of building that was being modeled. Fifteen unique buildings and one automobile were chosen to represent the most common building types. Overall building response to overpressure is based on these unique building designs. See Reference 4 for a detailed description of the building types used in SAFER.

9. *What guidance is there for choosing ES types when the actual ES is unknown or not available as a choice?*

When the ES type is unknown or unavailable then typically weak or high-risk ES types should be evaluated and the worst case used to determine risk. Medium wood, large reinforced concrete, unreinforced masonry, and large metal building types should be considered in the evaluation unless it is known that the specific building type is not applicable. Because of its atypical strength, the small reinforced concrete building should only be chosen for a reinforced concrete building with a reinforced concrete roof. Also, because of its high risk, the large reinforced concrete building should only be used when the ES is known to be a tilt-up reinforced concrete structure.

10. *What are the ES models based on?*

The ES models are each based on specific designs. Structural damage, serious injury, and fatality are related to blast loads in P-I diagrams. The designs and procedures are described in Reference 4.

11. *What guidance is there for choosing ES roof types when the actual ES roof is unknown or not available as a choice?*

The selection of roof type will not affect the structural response fatality mechanism. Therefore, the user should select the closest match in terms of debris protection. If this cannot be easily determined, make multiple runs by varying the roof selection (between reasonable choices) and then use the one that produces the most conservative results.

12. *How were the methods for determining maximum/expected yields (by HD) derived?*

For HD 1.2, there is a reasonable amount of data upon which to base part of the yield uncertainty. For all of the following discussion, let N be the total number of rounds in the stack.

a. HD 1.2 items are non-mass detonating when stored alone; based on this definition, no more than 0.5*N can react at one time.

b. Based on tests conducted for the 105 mm round, the average number of rounds participating in the total event is 0.29*N (with a standard deviation of 0.14*N; N.B., this is based on 2,753 events).

c. If it is assumed that the full output of an HD 1.2 round is Y, then the average yield for an HD 1.2 event is 0.11*Y with a standard deviation of 0.15*N (based on 559 points).

Similar, hard information for accidental detonations involving only HD 1.1 is less common, although some anecdotal evidence available. At several accidents (Roseville & Benson) in the U.S. and a Russian accident at Severmorsk, the total number of rounds participating is not 100%, but something less (intact rounds have been thrown out). The opinion of the Science Panel based on experience is that the number participating for HD 1.1 might be 0.9*N. When they do participate, the yield is generally high -- perhaps the yield is 0.9*Y, where Y represents full output.

For mixed storage of HD 1.1 with HD 1.2 and HD 1.3, the amount participating probably drops to as low as 0.8*N, based on the results of the MPS test and also the USS Mount Hood accident (1944). For the MPS test, the yield was 0.6*Y.

13. *How were the TNT conversion factors determined?*

The equivalent weights that are assumed for each of the explosives are the same as those used in the Blast Effects Computer. An energetic material will have several equivalent weights—depending on the airblast parameter upon which the equivalence is determined. Usually, equivalences are reported for peak pressure and positive impulse and these two values may differ significantly. Moreover, the equivalence will vary with the range at which it is computed. The values used are based on peak pressure and are average values taken from numerous sources. Equivalent weights based on impulse are generally less than those based on peak pressure. Therefore, by using peak pressure values, a degree of conservatism is built into the impulse estimates.

Attachment 4 – Pressure Impulse

SAFER 3 Pressure and Impulse Branch

Prepared by – John Tatom (APT)
Mike Swisdak (NSWC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3 pressure and impulse branch. Specific questions addressed are:

1. Why were simplified Kingery-Bulmash equations used?
2. Have the open-air pressure and impulse predictions been validated?
3. Why is no adjustment made for open, PEMB, or HCT?
4. Why are orientation effects not considered for PES types other than ECM and HAS?
5. Why are weapon effects on pressure and impulse not considered if a PES is present?
6. Why are some pressure and impulse predictions higher when buildings are present as opposed to open-air predictions?
7. Have the adjusted (due to the presence of the PES) pressure and impulse predictions been validated?
8. How was the PES damage/intact algorithm derived?
9. How were the Y_0, Y_{100}, and b parameters chosen?
10. What is the pressure and impulse reduction (due to the ES) based on?
11. How was the average venting area percentage chosen?
12. Why is the percent glass involved in the pressure and impulse reduction (due to the ES) calculation?
13. Why do the parameters in the pressure and impulse reduction (due to the ES) calculation not vary by ES type?
14. Why isn't reflected impulse considered?
15. How does the SAFER 3 method for determining fatality due to whole body displacement differ from the TNO probit function for that consequence?
16. Why does the SAFER 3 method for determining fatality due to whole body displacement differ from the TNO probit function for that consequence?
17. How does the SAFER 3 method for determining fatality due to lung rupture differ from the TNO probit function for that consequence?
18. Why does the SAFER 3 method for determining fatality due to lung rupture differ from the TNO probit function for that consequence?
19. How does the SAFER 3 method for determining fatality due to skull fracture differ from the TNO probit function for that consequence?
20. Why does the SAFER 3 method for determining fatality due to skull fracture differ from the TNO probit function for that consequence?
21. Does the SAFER 3 method for determining fatality due to whole body displacement treat people in the open differently than people inside structures?
22. Does the SAFER 3 method for determining fatality due to lung rupture treat people in the open differently than people inside structures?
23. Does the SAFER 3 method for determining fatality due to skull fracture treat people in the open differently than people inside structures?

24. Why are the fatalities due to whole body displacement, lung rupture, and skull fracture considered (and summed) independently?

REFERENCES

1. Kingery, C. N. and Bulmash, G.; Air Blast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst; Ballistics Research Labs; TR-02555; April 1984.
2. Swisdak, M. M., "DDESB Blast Effects Computer User's Manual And Documentation (Revision 1)," DDESB Technical Paper 17, 1 January 2005.
3. Porzel, F. B., Technology Base Of The Navy Explosives Safety Improvement Program," Minutes of the 19th DoD Explosives Safety Seminar, September 1980.
4. Swisdak M. M., "Airblast From Earth Covered Magazines—Incorporation of Additional Data and Sttempts To Reduce The Scatter," US IWP/103/95, 3/24/95.
5. "Design Of Structures To Resist The Accidental Effects Of Explosions," Department of the Army Technical Manual TM5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22, Revision 1, November 1990.
6. Defense Ordnance Safety Group, "International 40 Tonne Trial Compendium Report," Data CD, March 2002
7. Britt, J. Robert, et. al., "BlastX Code, Version 4.2 Users Manual," ERDC/GSL TR-01-2, March 2001
8. Absil, L. H. J., et. al., "Inventory Of Damage And Lethality Criteria For HE Explosions," TNO Report PML 1998-C21, NO(ST) UGST/IWP 2-98, March 1998.
9. Methods For Estimating The Physical Effects Of The Escape Of Dangerous Materials (TNO Yellow Book)," Publication Of The Directorate General Of Labour, Ministry Of Social Affairs And Employment, The Netherlands, 1979.

DISCUSSIONS

1. *Why were simplified Kingery-Bulmash equations used?*

   The complete Kingery-Bulmash (ref 1) curves/equations were considered to be too complex to include in SAFER, given that the simplified equations produce results within 2%. Also, the simplified equations were used in the Blast Effects Computer (ref 2), which SAFER is intended to be in agreement with. The simplified Kingery-Bulmash equations are widely accepted and have been corroborated by numerous tests.

2. *Have the open-air pressure and impulse predictions been validated?*

   Yes. Figures 1-5 show a comparison between SAFER output and data for the following weapons detonated in the open (NB: These data are taken from Reference 2):

   - MK 82, MK 83, and MK 84 bombs
   - M107 155-mm projectiles
   - WAU-17 warhead

Comparisons are not shown for two weapons: M1 105-mm projectile and MK 2 40-mm projectile. The data for these two items were derived using the methodologies of Reference 3; therefore, there is a paucity of test data for these two items.

The algorithms in the Blast Effects Computer and thus in SAFER are generally based upon and derived from empirical data. The algorithms were selected to "match" the empirically predicted pressures and impulses within a few percent (generally less than 5%).

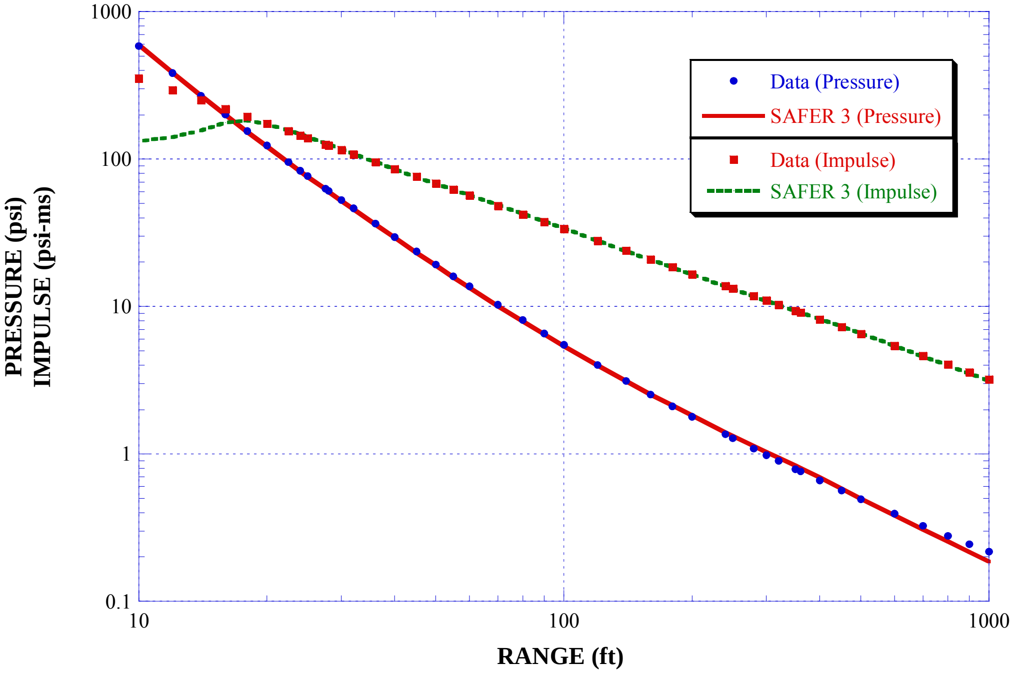


Figure 1. MK 82 Bomb

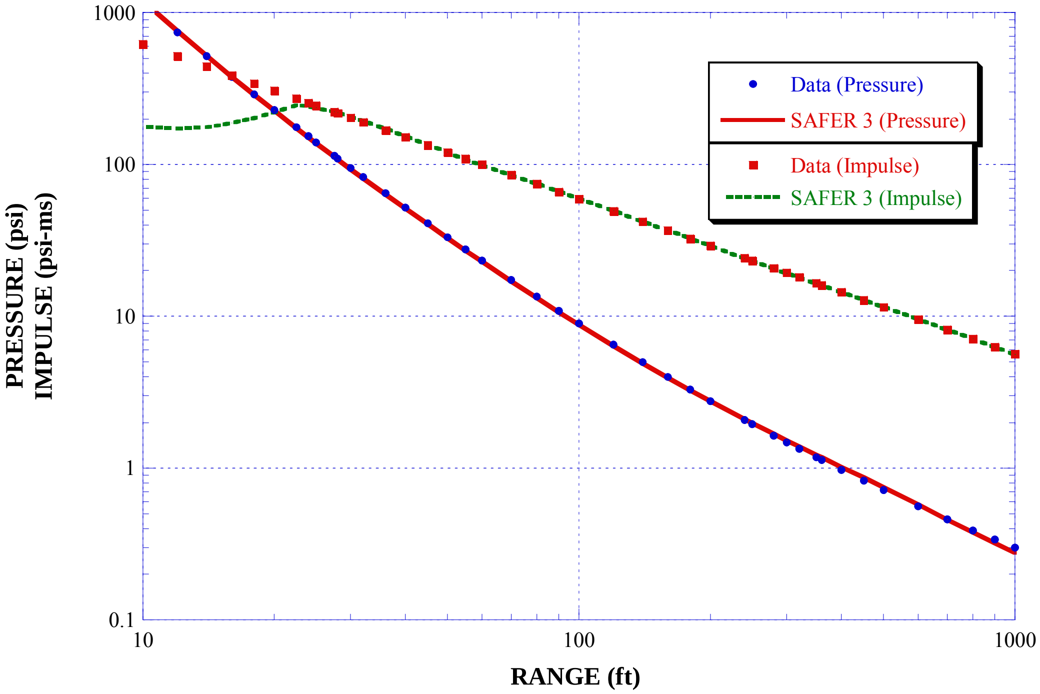


Figure 2. MK 83 Bomb

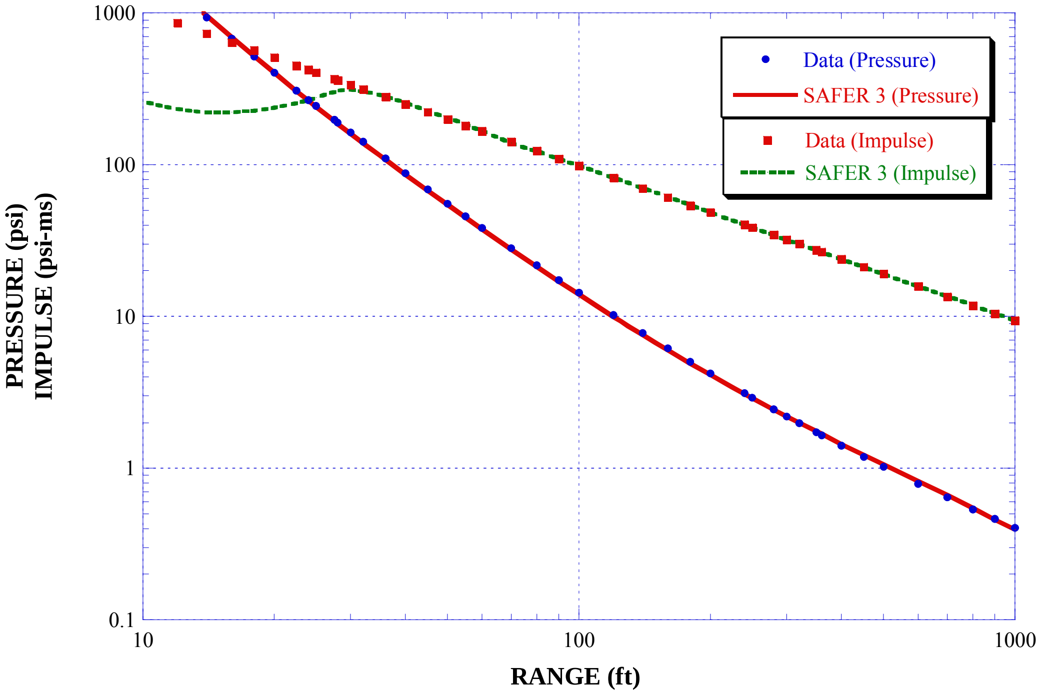


Figure 3. MK 84 Bomb

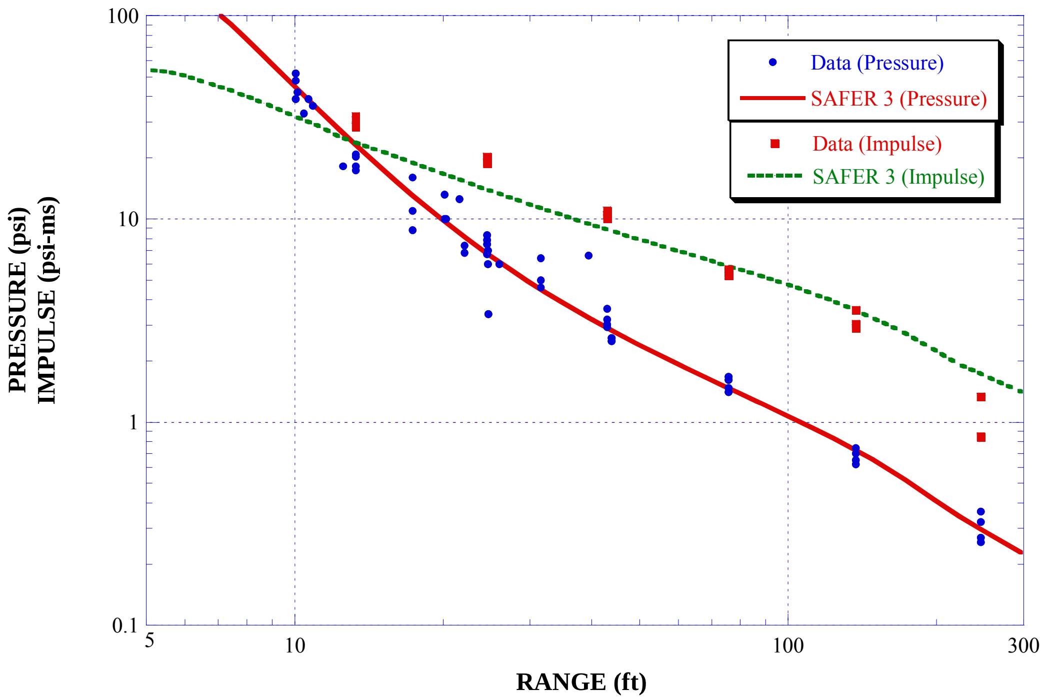


Figure 4. M107 155 mm Projectile

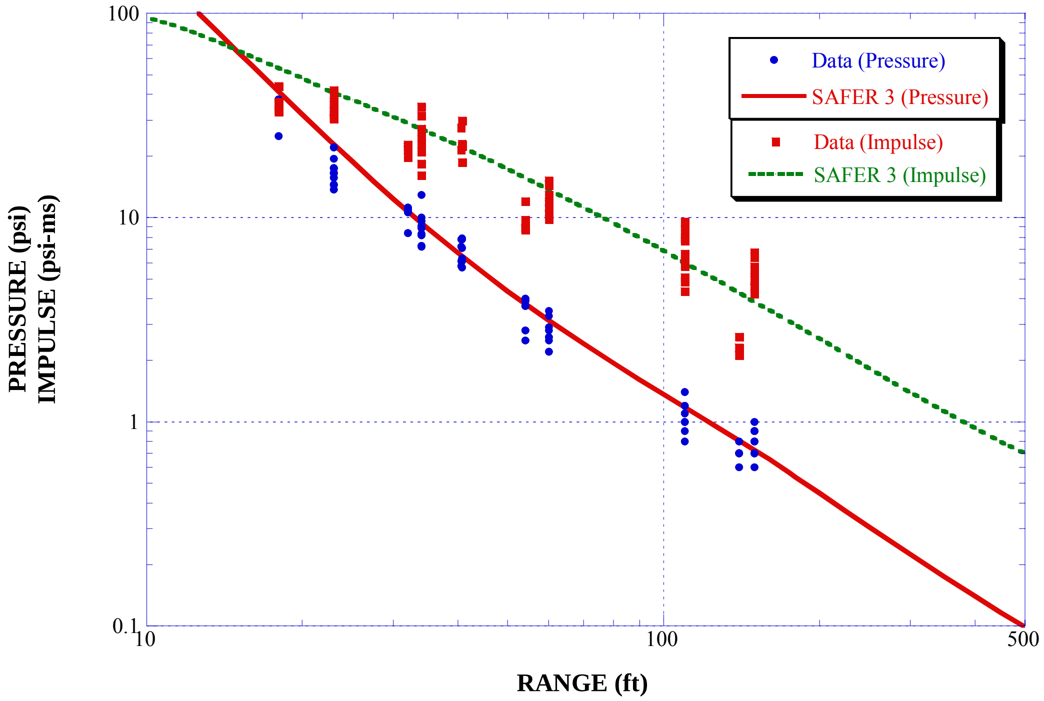


Figure 5. WAU-17 Warhead

3. Why is no adjustment made for open, PEMB, or HCT?

There is no adjustment made to consider the effects of the presence of the PES if there is no PES structure, or if that structure is so light as to be treated as if there were no containment effects. This is the case for pre-engineered metal buildings and hollow clay tile PES types. The secondary debris from these buildings is still considered; thus the absence of an adjustment (for a building without orientation) is conservative.

4. *Why are orientation effects not considered for PES types other than ECM and HAS?*

The "focusing" or "channeling" of pressure and impulse is based on test data. At this time, the only comprehensive data sets available are for earth-covered magazines and hardened aircraft shelters. Furthermore, PES types that have a square footprint (such as above-ground brick structures and operating buildings in SAFER) would not be expected to have orientation effects unless asymmetrical venting conditions were present.

5. *Why are weapon effects on pressure and impulse not considered if a PES is present?*

As part of a study performed for the DDESB in 1995 (ref 4), it was found that type of weapon and/or type of explosive had no effect on reducing the scatter in the observed data. The only variable that seemed to have an effect was the total weight of energetic material.

6. *Why are some pressure and impulse predictions higher when buildings are present as opposed to open-air predictions?*

This is due to "focusing" or "channeling" of pressure and impulse.

7. *Have the adjusted (due to the presence of the PES) pressure and impulse predictions been validated?*

Yes, see Figures 6-13 taken from Reference 2.

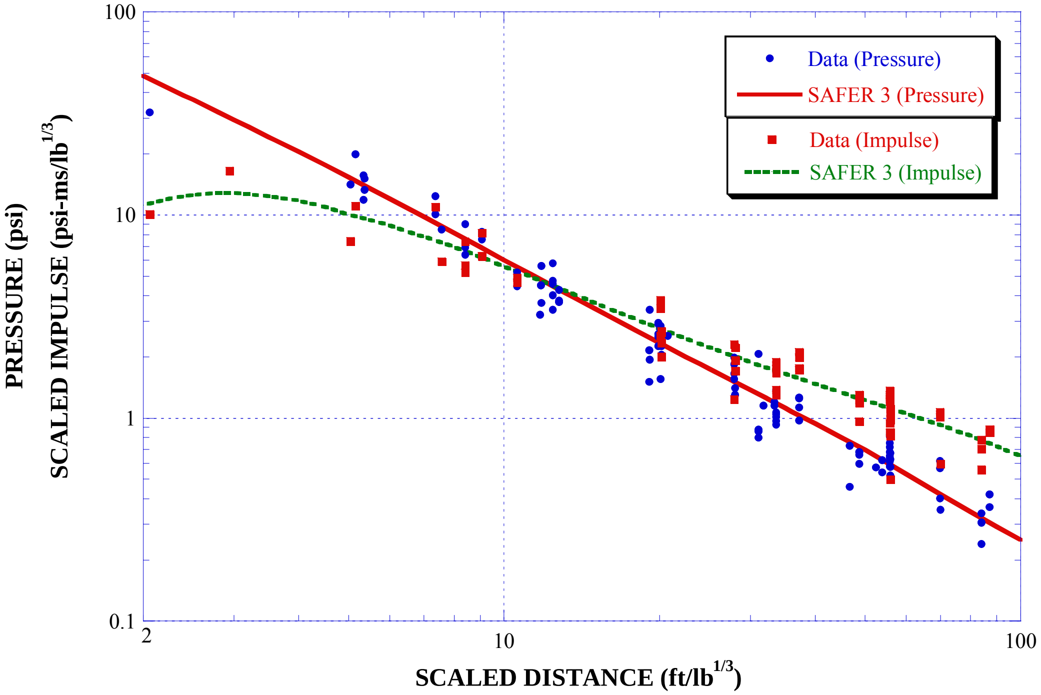


Figure 6. Aboveground Structure)

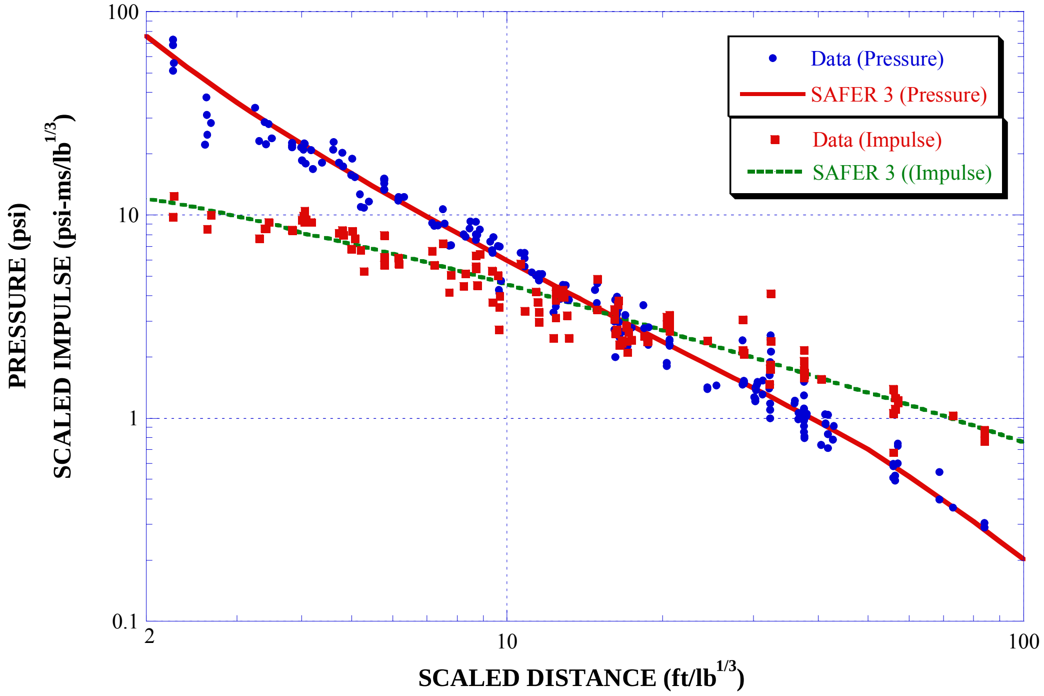


Figure 7. ISO Container & Ship

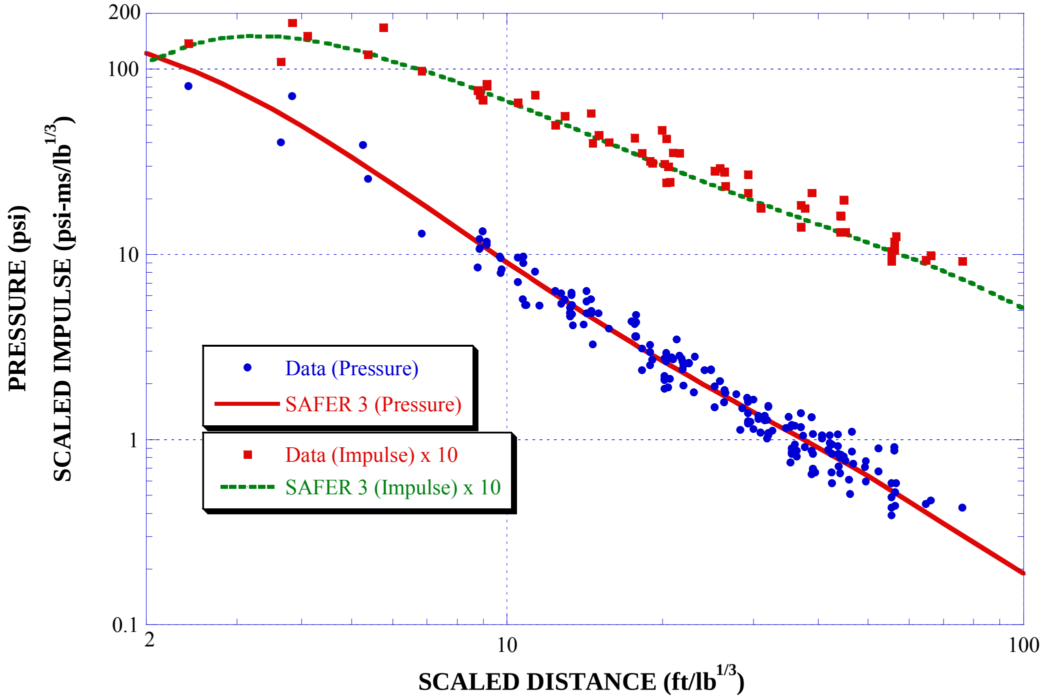


Figure 8. ECM Front

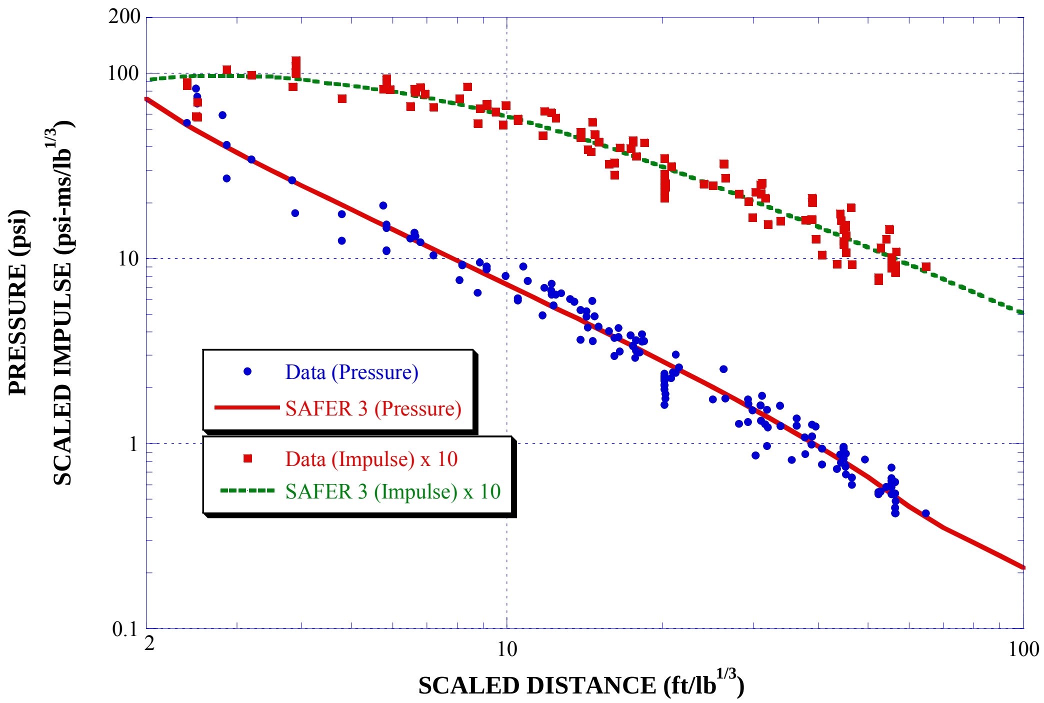


Figure 9. ECM Side

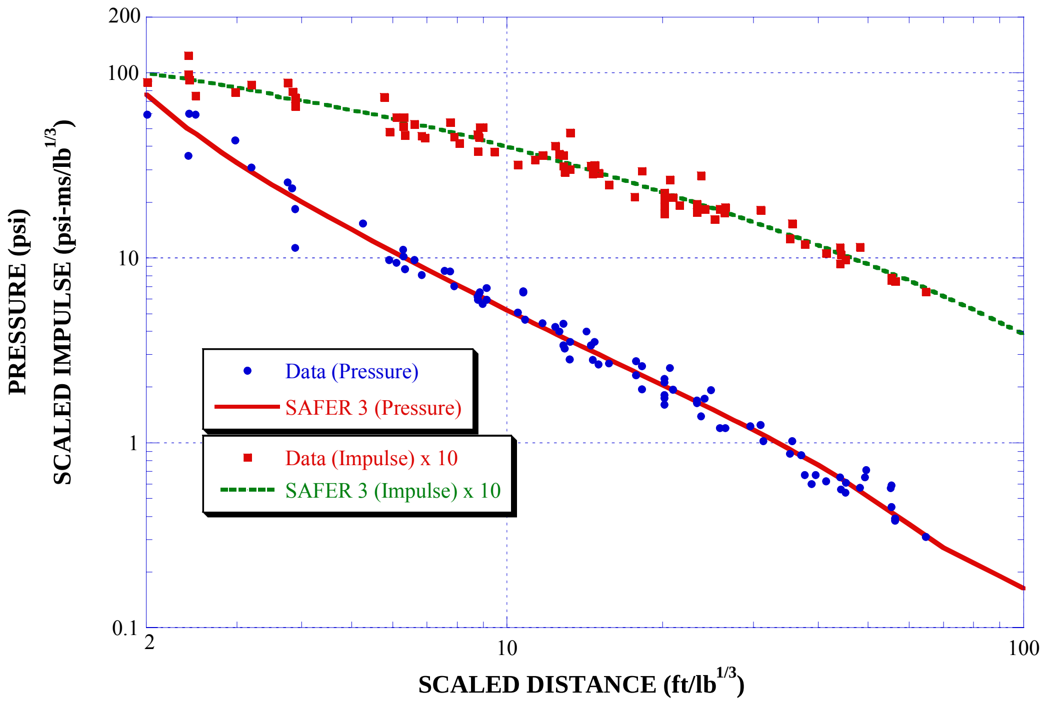


Figure 10. ECM Rear

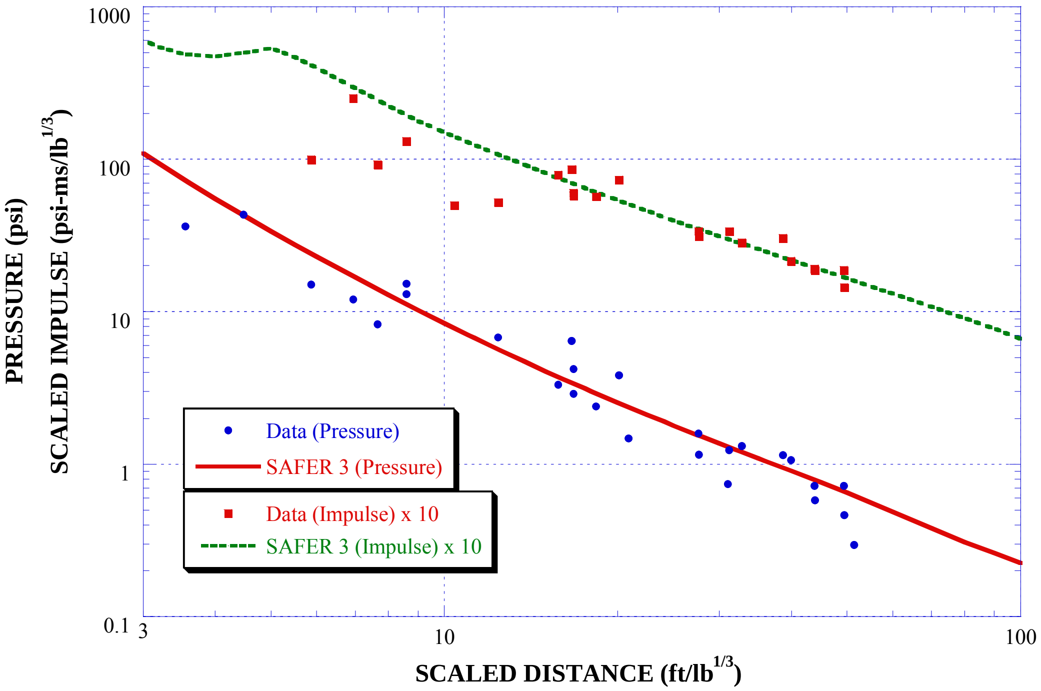


Figure 11. *HAS Front*

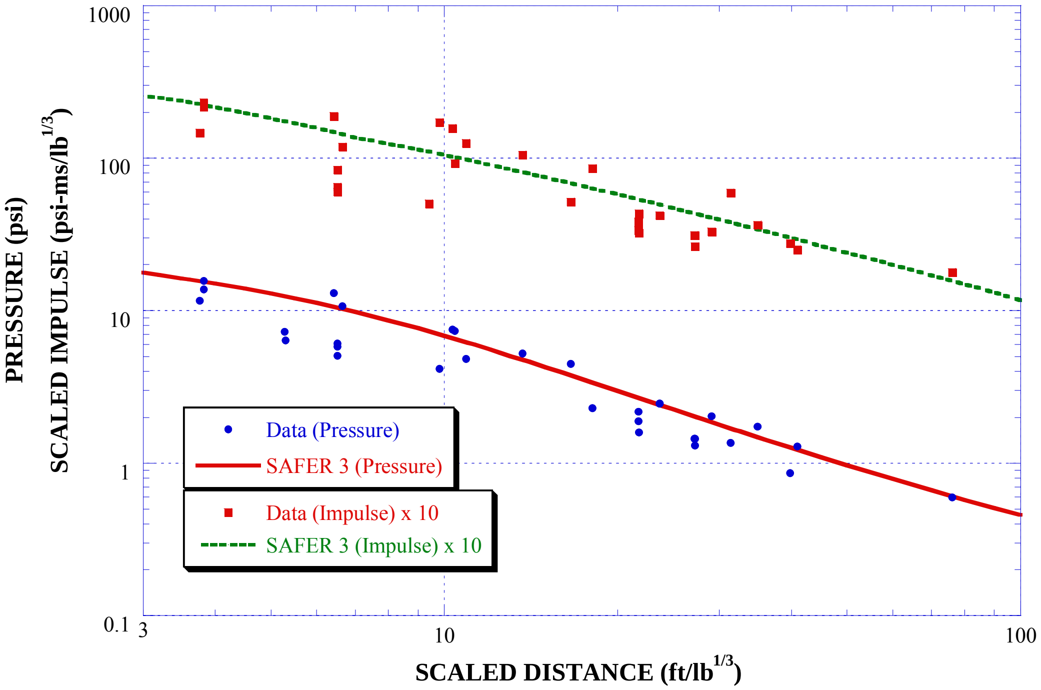


Figure 12. *HAS Side*

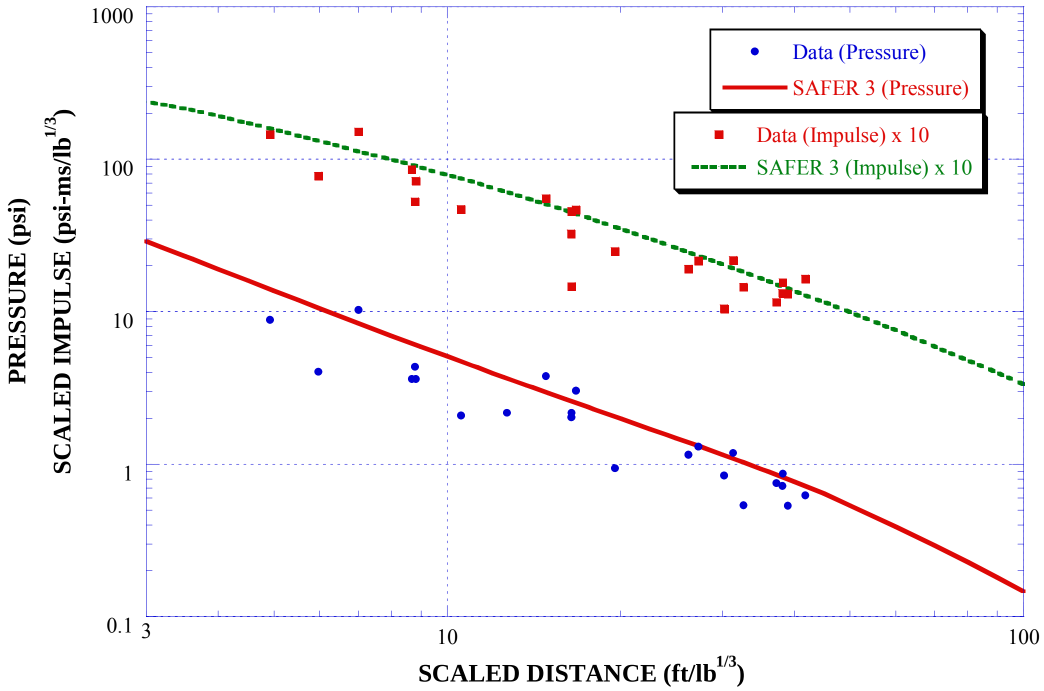


Figure 13. HAS Rear

8. How was the PES damage/intact algorithm derived?

The main reason for calculating the PES damage is to be able to determine the amount of PES mass in the air – in other words, secondary debris. In SAFER 3, this is done by analyzing the damage to four components of the PES: roof, front wall, side walls, and rear wall. The algorithm needed to be able to determine at what point any mass from a PES component became secondary debris, at what point the entire component becomes secondary debris, and what happens in between these two points. The Science Panel created an algorithm based on three parameters (Y_0, Y_{100}, and b) for each PES type and component, as shown in Figure 14.

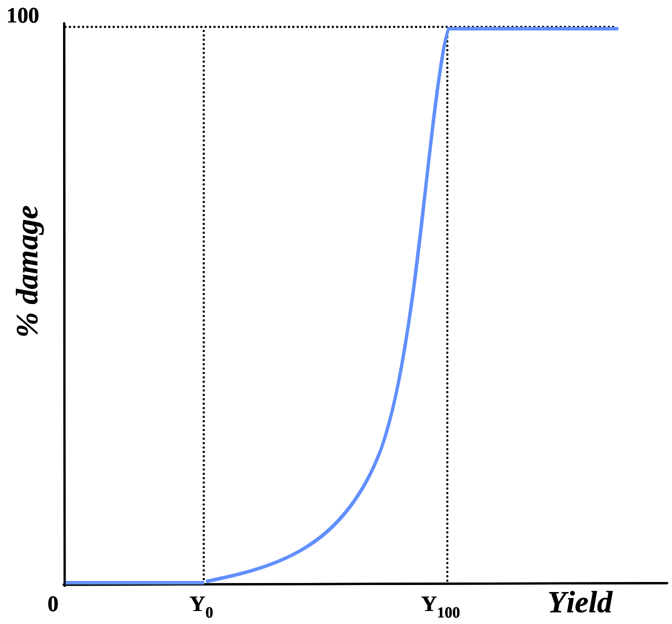


Figure 14. PES Damage Function

The curve is represented by the equation

$$D = a * (W_2 - Y_o)^b$$

where Y = W2, a = $1/(Y_{100} - Y_0)^b$, and the constants Y_0, Y_{100}, and b are provided in the appropriate table for the PES component: Table 1, Damage Coefficients for the PES Roof; Table 2, Damage Coefficients for the PES Front Wall; Table 3, Damage Coefficients for the PES Side Walls; Table 4, Damage Coefficients for the PES Rear Wall. Coefficients in the tables are based on the PES building type and were chosen to predict failure at conservative loads.

Table 1. Percent Damage Coefficients for the PES Roof

PES (roof)	**Y_0 [lbs]**	**Y_{100} [lbs]**	**b**
Pre-engineered metal building	3	40	0.4
Earth-covered magazine	15	250	1.0
Hardened aircraft shelter	1000	2000	0.9
Aboveground brick structure	1	16	0.5
Operating building	1	16	0.5
Hollow Clay Tile	1	8	0.25
Ship (small)	100	5000	1.1
Ship (medium)	100	5000	1.1
Ship (large)	100	5000	1.1

Table 2. Percent Damage Coefficients for the PES Front Wall

PES (front wall)	Y_0 [lbs]	Y_{100} [lbs]	b
Pre-engineered metal building	3	40	0.4
Earth-covered magazine	.5	10	0.6
Hardened aircraft shelter	40	2000	0.9
Aboveground brick structure	1	8	0.25
Operating building	3	100	0.4
Hollow Clay Tile	1	8	0.25
Ship (small)	100	5000	1.1
Ship (medium)	100	5000	1.1
Ship (large)	100	5000	1.1

Table 3. Percent Damage Coefficients for the PES Side Walls

PES (side walls)	Y_0 [lbs]	Y_{100} [lbs]	b
Pre-engineered metal building	1	40	0.4
Earth-covered magazine	2000	10000	0.9
Hardened aircraft shelter	1000	2000	0.9
Aboveground brick structure	1	8	0.25
Operating building	3	100	0.4
Hollow Clay Tile	1	8	0.25
Ship (small)	100	5000	1.1
Ship (medium)	100	5000	1.1
Ship (large)	100	5000	1.1

Table 4. Percent Damage Coefficients for the PES Rear Wall

PES (rear walls)	Y_0 [lbs]	Y_{100} [lbs]	b
Pre-engineered metal building	1	40	0.4
Earth-covered magazine	2000	10000	0.9
Hardened aircraft shelter	2000	10000	0.9
Aboveground brick structure	1	8	0.25
Operating building	3	100	0.4
Hollow Clay Tile	1	8	0.25
Ship (small)	100	7500	1.1
Ship (medium)	100	7500	1.1
Ship (large)	100	7500	1.1

9. *How were the Y_0, Y_{100}, and b parameters chosen?*

   The parameters used in the determination of PES component damage were determined based on test data, partially-confined internal loads and structural analysis, and Science Panel expert opinion. Values for the buildings were based on conservative calculations for internal loads and structural loads in representative PES building designs.

10. *What is the pressure and impulse reduction (due to the ES) based on?*

The protection afforded by the ES against direct pressure and impulse effects is based on techniques found in TM5-1300, Section 2-15.5 (ref 5), and was compared to test data (ref 6) and compared to another computer model, BlastX (ref 7).

11. *How was the average venting area percentage chosen?*

    The value of 2.5% was chosen for all ES types based on expert opinion of the Science Panel. This value is intended to represent vents, ducts, pipes, doorway "leakage", etc. – essentially all openings other than windows.

12. *Why is the percent glass involved in the pressure and impulse reduction (due to the ES) calculation?*

    It is assumed that the windows of a building provide no reduction in pressure and impulse, so the nominal venting area of the ES is combined with the percent glass of the ES to determine the total venting area of the ES.

13. *Why do the parameters in the pressure and impulse reduction (due to the ES) calculation not vary by ES type?*

    At the time the algorithms were created, there was no available test data or other basis to determine parameter variations among ES types. However, it was assumed that such variations might well exist. Therefore, the values were left in the form of a parameter table so that eventually such variations could be introduced by simply changing the parameter value.

14. *Why isn't reflected impulse considered?*

    It was not clear to the Science Panel how the term "reflected impulse" would be defined or derived and then used in conjunction with reflected pressure. The term was not expressly called for in the TNO literature (ref 8,9), either.

15. *How does the SAFER 3 method for determining fatality due to whole body displacement differ from the TNO probit function (ref 8,9) for that consequence?*

    After determining the S and z values, SAFER uses a standard normal distribution rather than a probit function to determine fatality levels.

16. *Why does the SAFER 3 method for determining fatality due to whole body displacement differ from the TNO probit function (ref 8,9) for that consequence?*

    SAFER requires higher fidelity than the probit function was designed for, especially at the extreme low end.

17. *How does the SAFER 3 method for determining fatality due to lung rupture differ from the TNO probit function (ref 8,9) for that consequence?*

    After determining the S and z values, SAFER uses a standard normal distribution rather than a probit function to determine fatality levels.

18. *Why does the SAFER 3 method for determining fatality due to lung rupture differ from the TNO probit function (ref 8,9) for that consequence?*

    SAFER requires higher fidelity than the probit function was designed for, especially at the extreme low end.

19. *How does the SAFER 3 method for determining fatality due to skull fracture differ from the TNO probit function (ref 8,9) for that consequence?*

After determining the S and z values, SAFER uses a standard normal distribution rather than a probit function to determine fatality levels.

20. *Why does the SAFER 3 method for determining fatality due to skull fracture differ from the TNO probit function (ref 8,9) for that consequence?*

    SAFER requires higher fidelity than the probit function was designed for, especially at the extreme low end.

21. *Does the SAFER 3 method for determining fatality due to whole body displacement treat people in the open differently than people inside structures?*

    No, except that there will be no pressure and impulse reduction in Step 7 if there is no ES and the nominal pressure will be determined differently (as described in Tech Paper 14). This forces the conservative assumption that people in the open are near trees, sidewalks, benches, tables, etc. – something that could cause blunt trauma wounds.

22. *Does the SAFER 3 method for determining fatality due to lung rupture treat people in the open differently than people inside structures?*

    No, except that there will be no pressure and impulse reduction in Step 7 if there is no ES and the nominal pressure will be determined differently (as described in Tech Paper 14).

23. *Does the SAFER 3 method for determining fatality due to skull fracture treat people in the open differently than people inside structures?*

    No, except that there will be no pressure and impulse reduction in Step 7 if there is no ES and the nominal pressure will be determined differently (as described in Tech Paper 14). This forces the conservative assumption that people in the open are near trees, sidewalks, benches, tables, etc. – something that could cause blunt trauma wounds.

24. *Why are the fatalities due to whole body displacement, lung rupture, and skull fracture considered (and summed) independently?*

    The separate mechanisms are considered independently to avoid double-counting of fatalities.

Attachment 5 – Injury

Injury

Prepared by – John Tatom (APT)
Michael Swisdak (NSWC)
APT POC – John Tatom
Revision Date – 02/25/05

PURPOSE

This memorandum addresses the rationale and development of the injury algorithms in SAFER 3.

Specific questions include:

1. What is the best technique for classifying injuries?
2. Is the AIS method widely accepted?
3. Is a more applicable method available?
4. Are there subjectivity issues associated with "hospitalization" that might prevent a fair comparison of the results from a predictive tool (such as SAFER) to real world data?
5. How does SAFER sequence the calculation/accounting of mechanisms and conditions?
6. How does SAFER account for multiple injuries from the same mechanism?
7. How does SAFER account for injuries from multiple mechanisms?
8. Does SAFER consider someone injured by one mechanism more susceptible to an injury from a different mechanism?
9. How does SAFER account for injuries from all mechanisms?
10. Should you report this condition and greater, or this condition and not greater?
11. What does SAFER calculate and report: The number of people injured or the number of injuries?
12. How is a major injury defined?
13. How is a minor injury defined?
14. What are the sources for the injury models in SAFER?
15. How does SAFER add insult to injury?

REFERENCES

1. "RBESCT Technical Issues Regarding Injury Modeling," APT CE3-00300, 26 February 2004
2. Copes WS, Sacco WJ, Champion HR, Bain LW, "Progress in Characterizing Anatomic Injury", In *Proceedings of the 33rd Annual Meeting of the Association for the Advancement of Automotive Medicine, Baltimore, MA, USA* 205-218CE3-00200 SAFER Injury Model Sources
3. "SAFER 3.0 Injury Algorithms," APT CE3-00200. 27 February 2004
4. Justice, Bart D., Tatom Ph.D., Frank B., "Comparisons of Real-World Data to the DIRE Model Predictions." Axois Solutions, Inc., Engineering Analysis, Inc., 25 February 2005
5. "Analysis of Death and Injuries Resulting from Explosions." DIRE User's Reference Manual. APT Document M-03-00600, 28 January 2003

6. Chrostowski, Jon D., Wilde, Paul D., Gan, Wenshiu. "Blast Damage, Serious Injury and Fatality Models for Structures and Windows." ACTA Report, March 2001.
7. Edmondson, J. N. and Prescott, B. L., "The Thermal Radiation Effects From The Initiation Of HD 1.3 Explosives," RANN/2/49/00119/90, AEA Technology, March 1992
8. Briefings to RBESCT

DISCUSSION

1. *What is the best technique for classifying injuries?*

The RBESCT decided to classify injuries based on AIS (Abbreviated Injury Scale) level (ref 1, 2).

AIS Level	Severity	Type of Injury
0	None	None
1	Minor	Superficial
2	Moderate	Reversible, Medical Attention Required
3	Serious	Reversible, Hospitalization Required
4	Severe	Life-threatening, Not fully recoverable with Medical Care
5	Critical	Non-reversible, Not fully recoverable even with Medical Care
6	Virtually Un-survivable	Fatal

2. *Is the AIS method widely accepted?*

The method seems to be used by many in risk analysis efforts, but medical professionals do not necessarily commonly use it.

3. *Is a more applicable method available?*

None has been found.

4. *Are there subjectivity issues associated with "hospitalization" that might prevent a fair comparison of the results from a predictive tool (such as SAFER) to real world data?*

Yes, but that is to be expected. SAFER is expected to represent generic rather than specific situations.

5. *How does SAFER sequence the calculation/accounting of mechanisms and conditions?*

SAFER considers fatalities from all mechanisms before considering injuries. Similarly, SAFER determines all major injuries before considering minor injuries (ref 1).

6. *How does SAFER account for multiple injuries from the same mechanism?*

SAFER counts multiple injuries from a single mechanism as a single injury (ref 1).

7. *How does SAFER account for injuries from multiple mechanisms?*

SAFER counts injuries from a multiple mechanisms as a single injury (i.e., considers only the most severe injury from any mechanism)(ref 1).

8. *Does SAFER consider someone injured by one mechanism more susceptible to an injury from a different mechanism?*

   No, SAFER considers each mechanism independently and then reports only the most severe single injury (ref 1).

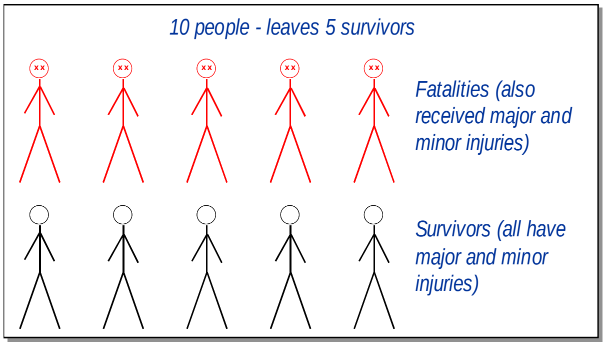
9. *How does SAFER account for injuries from all mechanisms?*

   SAFER does not "accumulate" injuries; i.e., some number of minor injuries does not equate to a major injury (ref 1).

10. *Does SAFER report (A) This condition and greater, or (B) This condition and not greater?*

    Example: An ES has 10 people in it. Assume an event leaves 5 survivors, all of whom have major injuries. Should the results be reported as A or B?

	A	B
Expected number of fatalities	**5**	**5**
Expected number of major injuries	**10**	**5**
Expected number of minor injuries	**10**	**0**



SAFER reports (B) (ref 1).

11. *What does SAFER calculate and report: The number of people injured or the number of injuries?*

    SAFER may calculate more than one injury for a given person; however, it only reports the number of people injured (ref 1).

12. *How is a major injury defined?*

    In SAFER, a major injury is AIS Level 3 or 4. This can be thought of as an injury requiring admittance to the hospital. (Note: AIS Levels 5 and 6 are considered a fatality by SAFER.)

13. *How is a minor injury defined?*

    In SAFER, a minor injury is AIS Level 1 or 2. This injury level can include emergency room treatment, but not admittance to the hospital.

14. *What are the sources for the injury models in SAFER?*

    The Science Panel reviewed existing injury models (when possible) and adapted them for use in SAFER (ref 3). Depending on the source and nature of the existing model, varying degrees of model modification was required. Some significant model sources include the DIRE software program (ref 4, 5), ACTA work (ref 6), and published UK MoD papers (ref 7).

15. *How does SAFER add insult to injury?*

    SAFER does not add insult to injury. SAFER is a follower of the principle: "Rebar and stones may break my bones, but words can never hurt me!"

Attachment 6 – Glass

SAFER 3 Glass

Prepared by – John Tatom (APT)
Jim Tancreto (NFESC)
Mike Swisdak (NSWC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3.0 glass methodology. Specific questions addressed are:

1. How/why is the SAFER 3.0 method different from the GLASS-CF method?
2. What assumptions are made about window coverings (blinds, curtains, drapes, etc.)?
3. What is the PWHFA and why are the corner areas “double-counted” in the hazard area calculation?
4. How was the perimeter distance chosen?
5. How were the parameters associated with the serious injury as a function of glass breakage derived?
6. Why is the yield adjustment made?
7. How were the parameters associated with the yield adjustment derived?
8. How was the relationship between fatality and serious injury determined?
9. What assumptions are made about emergency response?
10. Why are medium windows used rather than having a user-selectable size?
11. What are the assumptions on the dimensions of the window?
12. Can SAFER distinguish between the following cases?
    a. Case 1: An event with a yield and distance that generates 100% glass breakage
    b. Case 2: An event with a higher yield than Case 1 but the same distance
    c. Case 3: An event with a the same yield as Case 1 but a lesser distance
13. What is the “beyond 100% breakage” algorithm and what is it based on?
14. Why not use an impulse-based algorithm for all cases?
15. Is there a transition region where answers “jump” when the “beyond 100% breakage” algorithm is used?

REFERENCES

1. “Blast Damage, Serious Injury and Fatality Models for Structures and Windows.” Chrostowski, Jon D., Wilde, Paul D., Gan, Wenshiu. ACTA Report, March 2001.
2. Briefings to RBESCT

DISCUSSIONS

1. How/why is the SAFER 3.0 method different from the GLASS-CF (ref 1) method?

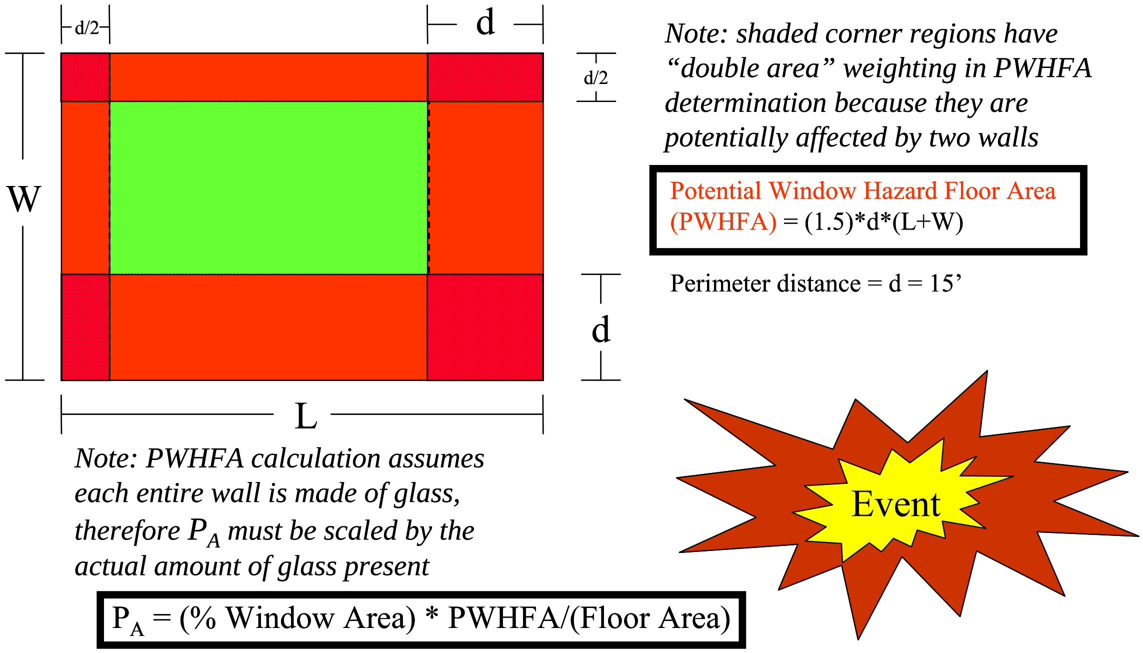
The glass model in SAFER is intended to allow the introduction of additional data sets as they become available. However, the primary data set currently relied on is the output of the GLASS-CF model. The SAFER model is more generic than the GLASS-CF model, based on the assumption that the SAFER user will generally not know the design specifics of the windows in the ES buildings involved in the SAFER run.

2. *What assumptions are made about window coverings (blinds, curtains, drapes, etc.)?*

   No direct factor is used to represent window coverings in SAFER 3.0. However, the methodology beyond K24 is based on models that assume approximately 50% of windows are protected by coverings of some type. Inside K12, SAFER considers window coverings to have no glass hazard mitigation capability. Between K24 and K12, the window protection is gradually removed (see Equations 79 & 80 in Technical Paper 14).

3. *What is the PWHFA and why are the corner areas "double-counted" in the hazard area calculation?*

   The potential window hazard floor area (PWHFA) represents the portion of the ES floor that would be hazarded by glass fragments. The corner areas are double-counted intentionally because the windows on more than one wall could affect those regions.



Note: shaded corner regions have "double area" weighting in PWHFA determination because they are potentially affected by two walls

Potential Window Hazard Floor Area (PWHFA) = (1.5)*d*(L+W)

Perimeter distance = d = 15'

Note: PWHFA calculation assumes each entire wall is made of glass, therefore P_A must be scaled by the actual amount of glass present

P_A = (% Window Area) * PWHFA/(Floor Area)

Figure 1. Glass Methodology

4. *How was the perimeter distance chosen?*

   The perimeter distance was set to 15 feet, which was intended to represent different buildings with varying floor areas. This value was chosen based on an initial assessment of typical buildings and available literature on a conservative average distance to the nearest interior wall.

5. *How were the parameters associated with the serious injury as a function of glass breakage derived?*

   The Science Panel used pressure-impulse diagrams for both glass breakage (Figures 2-4) and serious injury to create an equation for serious injury as a function of glass breakage. After all the test points had been plotted, the Science Panel created a curve to match the data, as shown in Figure 5. This curve is then represented in SAFER by the stored parameters.

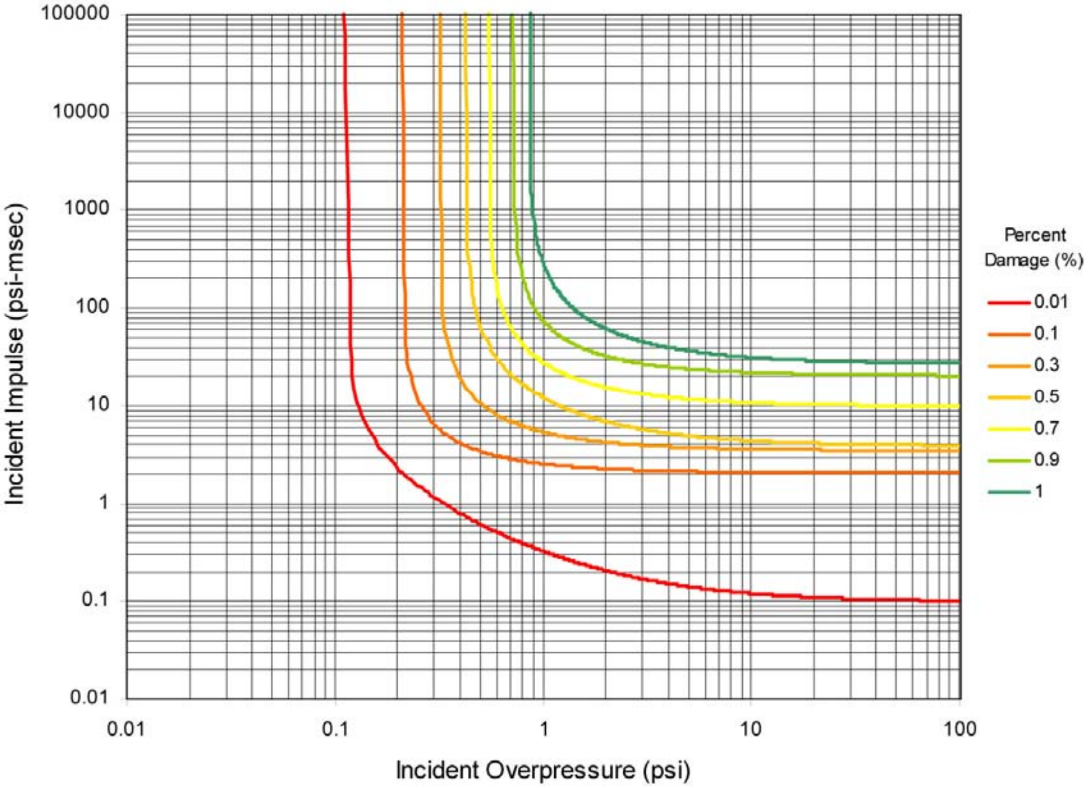


Figure 2. Annealed

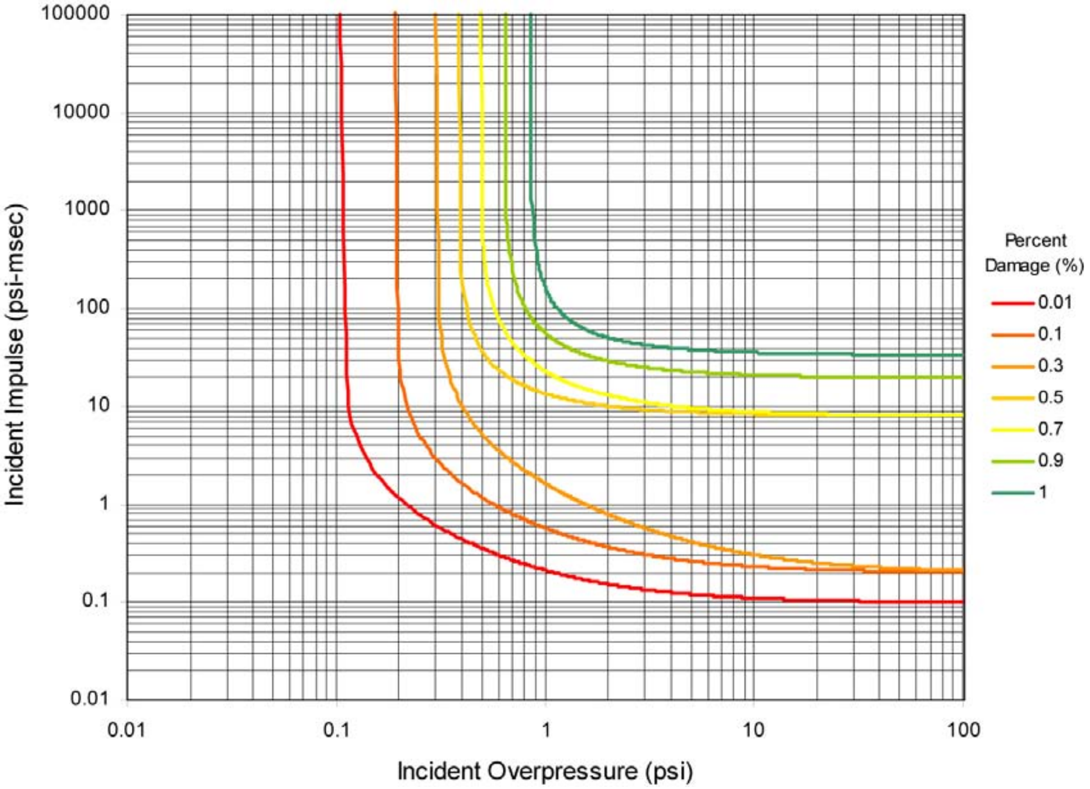


Figure 3. Dual Pane

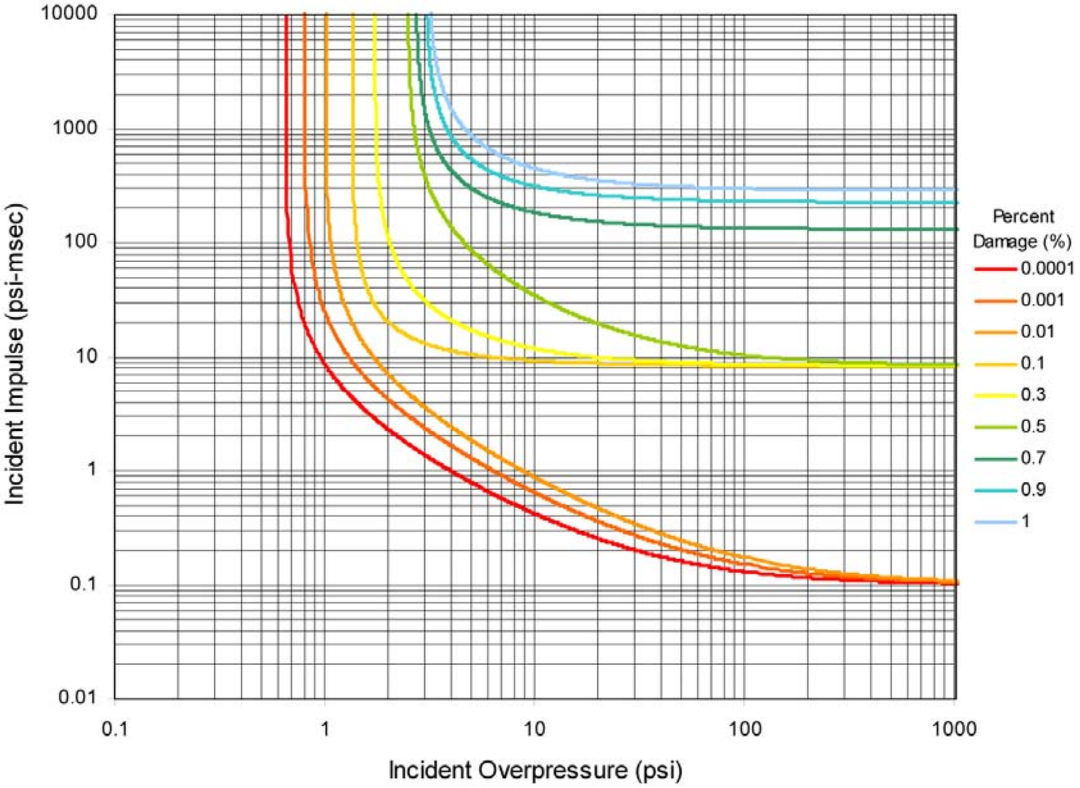
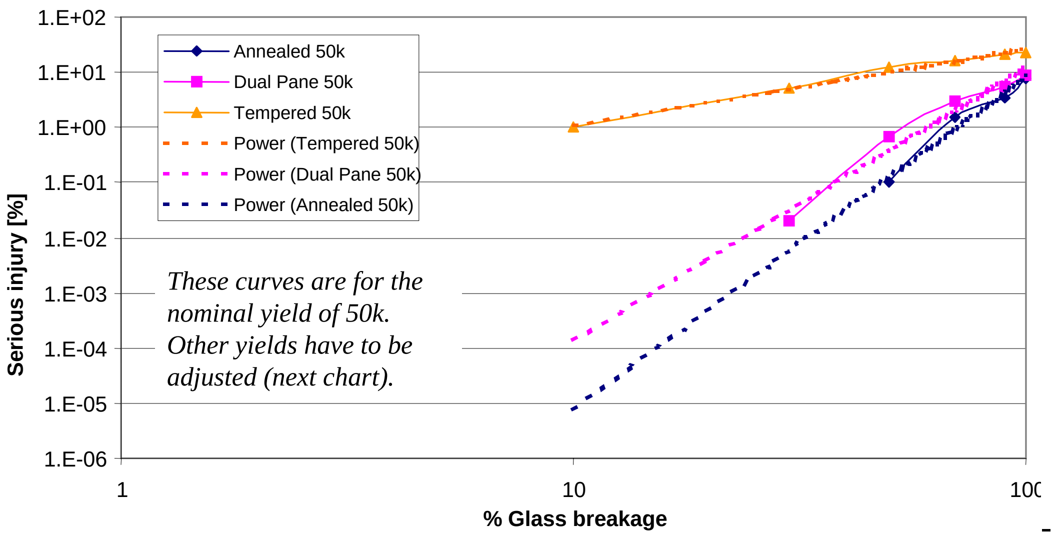


Figure 4. Tempered



These curves are for the nominal yield of 50k. Other yields have to be adjusted (next chart).

Note: Solid lines are data points from the Wilde model. Dashed lines represent the SAFER 3.0 equations.

Figure 5. Serious Injury Given Breakage

6. *Why is the yield adjustment made?*

The model prediction data used by the Science Panel (see Question 5) are yield dependant. The yield is not known until run-time, therefore a dynamic yield adjustment function needed to be created. The baseline curve used data points associated with a 50,000 lb yield, so the yield adjustment is made based on the ratio of the actual run yield to the baseline (or nominal) yield. The yield dependency can be seen in Figure 6.

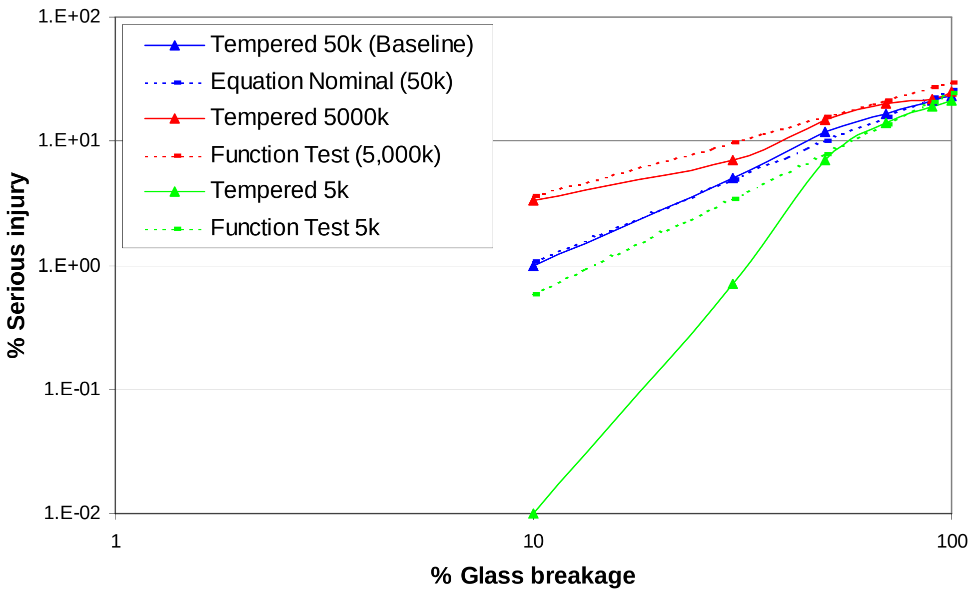


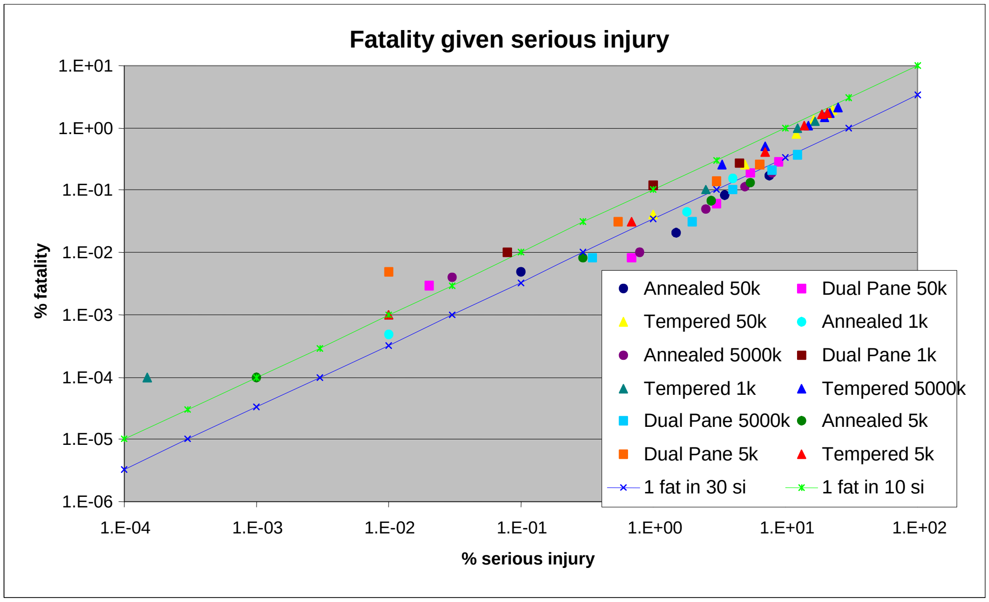
Figure 6. Yield Adjustment Test @ 5,000,000 lbs. & 5,000 lbs.

7. *How were the parameters associated with the yield adjustment derived?*

By plotting data sets from multiple yields, the Science Panel could then create an equation for adjusting from the nominal yield to the desired value. This adjustment is dependant on the percentage of glass broken as well as the yield. The parameters that describe this adjustment equation are then stored in SAFER.

8. *How was the relationship between fatality and serious injury determined?*

The Science Panel used pressure-impulse diagrams for fatalities [ref 1] along with the previously derived serious injury function to estimate a ratio of 1 fatality for every 30 serious glass injuries, as shown in Figure 7, for ranges beyond K24. This estimate was compared to other known data sources and discussed with the author of GLASS-CF, Paul Wilde. Inside K24, an adjustment function gradually increases the number of fatalities per serious injury to 1 in 15 at K12. Inside K12, the Simplified Close-In Fatality Mechanisms (SCIFM) logic applies (see Separate SCIFM Technical Memorandum APTCE1-16500).



SAFER Version 3.0: 1 fatality / 30 serious injuries

Pf(glass) = P_{sinj} / 30

Figure 7. Glass Fatality to Serious Injury Ratio

9. *What assumptions are made about emergency response?*

No direct factor was used in the development of the model (nor may be input by the user) to represent emergency response in SAFER 3.0. However, the data sets and validation effort on which the methodology is based (beyond K24) assumes approximately 67% of injuries serious enough to cause fatalities are averted by “average” emergency response conditions. Inside K12, SAFER considers emergency response to have no effect on the ratio of fatality to serious injury. Between K24 and K12, the emergency response “credit” is gradually removed (see Equation 79 & 80 in Technical Paper 14).

10. *Why are medium windows used rather than having a user-selectable size?*

    Because the user, in most applications of SAFER, will not know all of the design details of the windows (e.g. size, thickness and type of glazing, strength and stiffness of supports) a medium window size (4’ x 5’) was chosen to provide an average estimate of window response. Also, the step-functions associated with discrete modeling (such as 3 distinct window sizes) can produce undesirable results when transitioning from one option to another. Therefore a single window size was chosen until such time as a continuous function allowing for variation in glass specifics – including dimensions – can be developed and/or incorporated.

11. *What are the assumptions on the dimensions of the window?*

    The approximate dimensions of the window are 4’X5’.

12. *Can SAFER distinguish between the following cases?*

    Case 1: An event with a yield and distance that generates 100% glass breakage

    Case 2: An event with a higher yield than Case 1 but the same distance

    Case 3: An event with a the same yield as Case 1 but a lesser distance

    Yes, SAFER 3.0 can distinguish between all 3 cases. Case 2 would be different from Case 1 in two ways: the yield adjustment function (as previously described) and a “beyond 100% breakage” algorithm. This algorithm is used at scaled ranges that are less than the scaled range required to create 100% breakage. Case 3 would only be affected by the “beyond 100% breakage” algorithm (see Question 13).

13. *What is the “beyond 100% breakage” algorithm and what is it based on?*

    SAFER 3.0 uses a separate algorithm to determine probability of serious injury (due to glass breakage) when the pressure and impulse exceed the levels required to create 100% breakage. This algorithm is based on the impulse and the yield, rather than the breakage level and the yield. This removes the restriction of not being able to “go beyond” 100% breakage.

    The logic for this algorithm is shown in Figure 8.

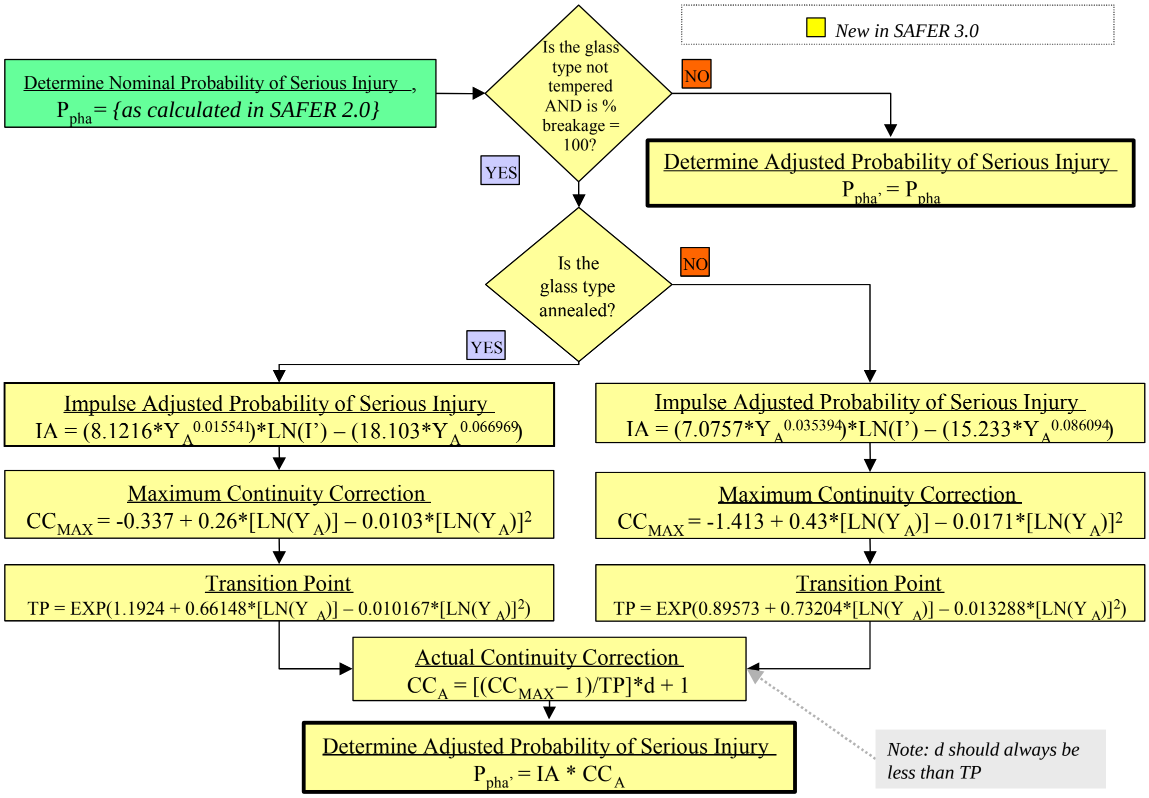


Figure 8. SAFER 3.0 Glass Logic

14. Why not use an impulse-based algorithm for all cases?

While it would be possible to determine serious injury (due to glass) for all scenarios using an impulse-based routine, SAFER 3.0 only uses such an algorithm in the "beyond 100% breakage" regime. This is because the existing (breakage-based) routine appears to work well for cases involving less than 100% breakage. In a future version of SAFER, a single routine for all cases could be developed, if desired.

15. Is there a transition region where answers "jump" when the "beyond 100% breakage" algorithm is used?

SAFER 3.0 has a continuity correction routine to reduce such an effect in the transition region, as shown in Figure 8.

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Attachment 7 – Structural Response

SAFER 3 Structural Response

Prepared by – John Tatom (APT)
Jim Tancreto (NFESC)
Mike Swisdak (NSWC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3.0 structural response methodology. Specific questions addressed are:

1. How is the ES damage/intact value determined for both the roofs and walls?
2. How/why is the SAFER method different from the ACTA method?
3. How were the SAFER curves derived?
4. Why is the probability of fatality less than 1.0 when building damage equals 100%?
5. What does 100% building damage mean?
6. How are cases that would cause "beyond 100% damage" handled?
7. Is the roof type entered by the user accounted for in the building failure models?
8. Is the ES floor area entered by the user accounted for in the building failure models?

REFERENCES

1. Chrostowski, Jon D., Wilde, Paul D., Gan, Wenshui, "Blast Damage, Serious Injury and Fatality Models for Structures and Windows," ACTA Technical Report No. 00-444/16.4-03, Revision 1, Contract No. N47408-99-P-6023, July 2001.
2. Briefings to RBESCT.

DISCUSSION

1. *How is the ES damage/intact value determined for both the roofs and walls?*

The ACTA building failure model (Ref. 1) uses pressure-impulse diagrams, Figures 1-16, to predict ES damage. SAFER refers to this ES damage as "composite damage" and is used in Step 10 to determine the number of fatalities. The separate values of wall and roof damage are needed to determine the protection the damaged ES provides against debris. Because the roof is user-selectable (for debris protection purposes), the method for determining damage to the roof needs to reflect the roof type chosen by the user at run-time. The building failure model does not consider the roof selected, but instead uses the default roof type for that ES. Therefore, a separate set of PI diagrams, Figures 17-24 (replace with new figures), is used to determine the damage to the roof selected by the user. The wall type is not a parameter the user can alter once an ES type is selected, thus the wall damage is based on the composite damage.

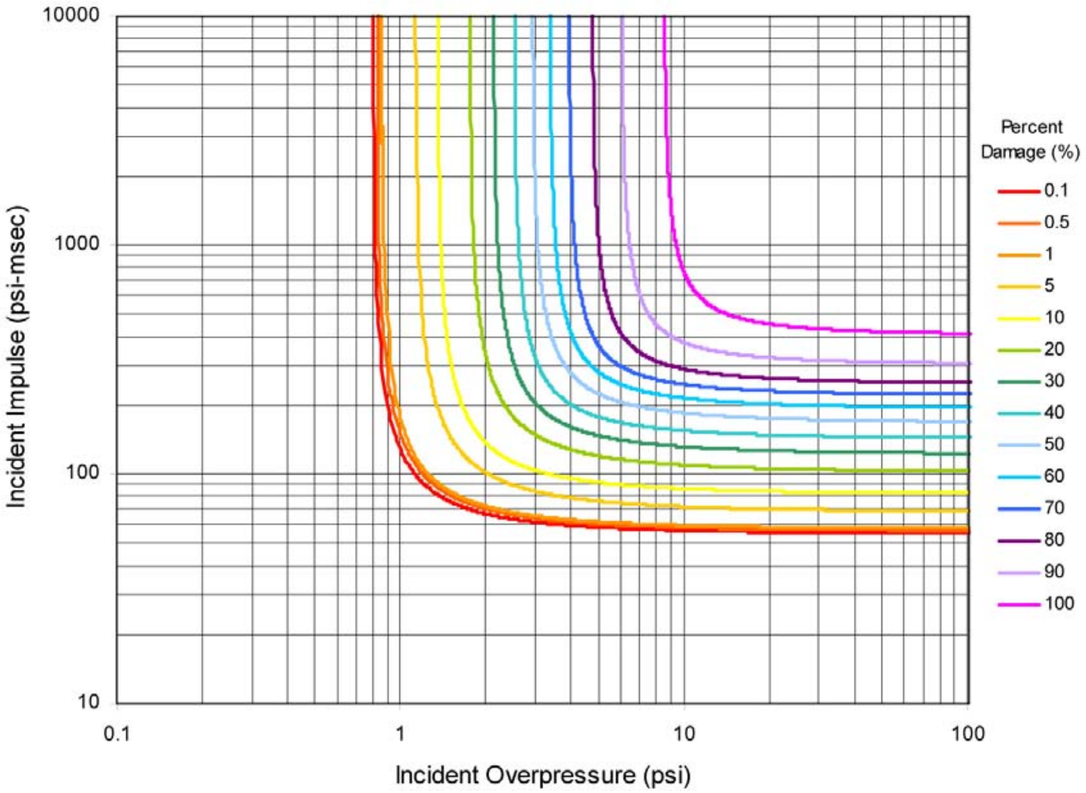


Figure 1. Passenger Vehicle

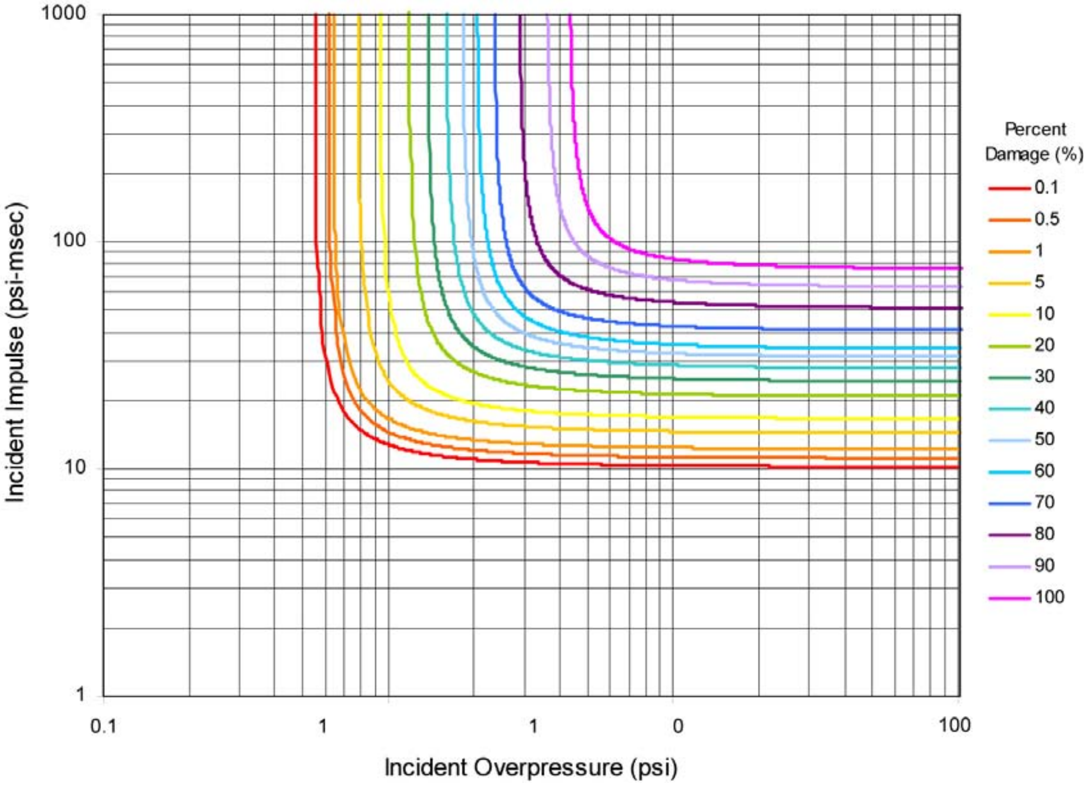


Figure 2. Small Trailer

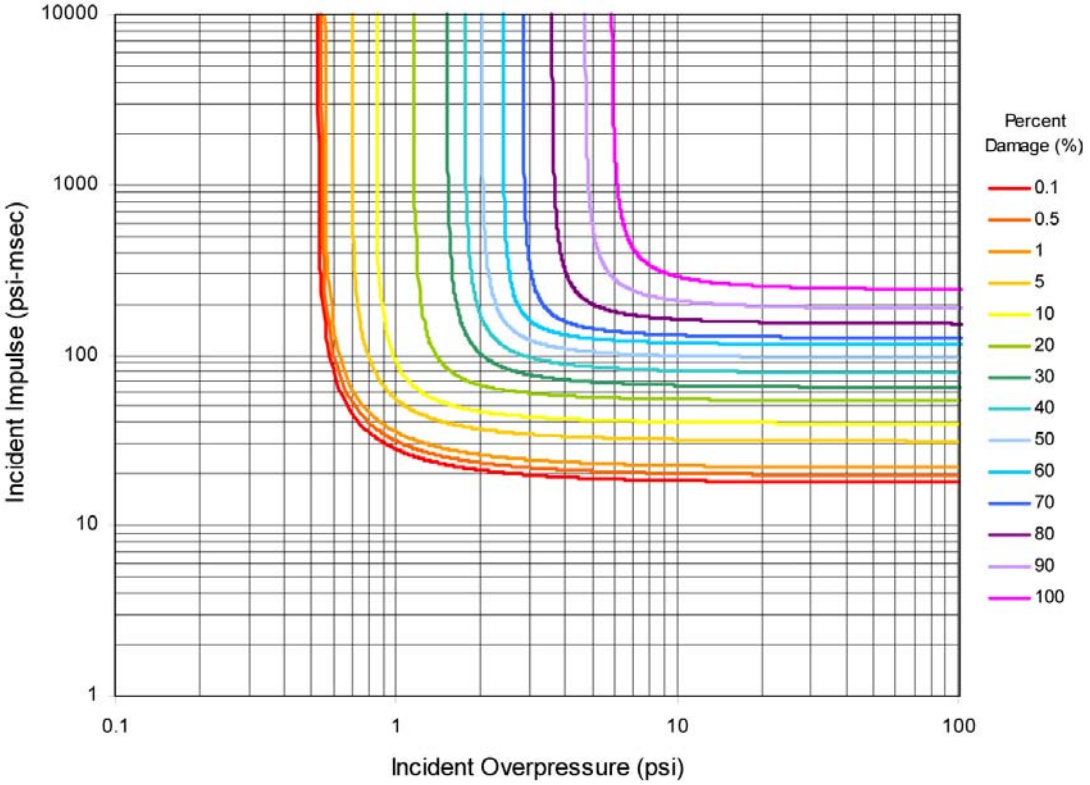


Figure 3. Medium Wood Structure

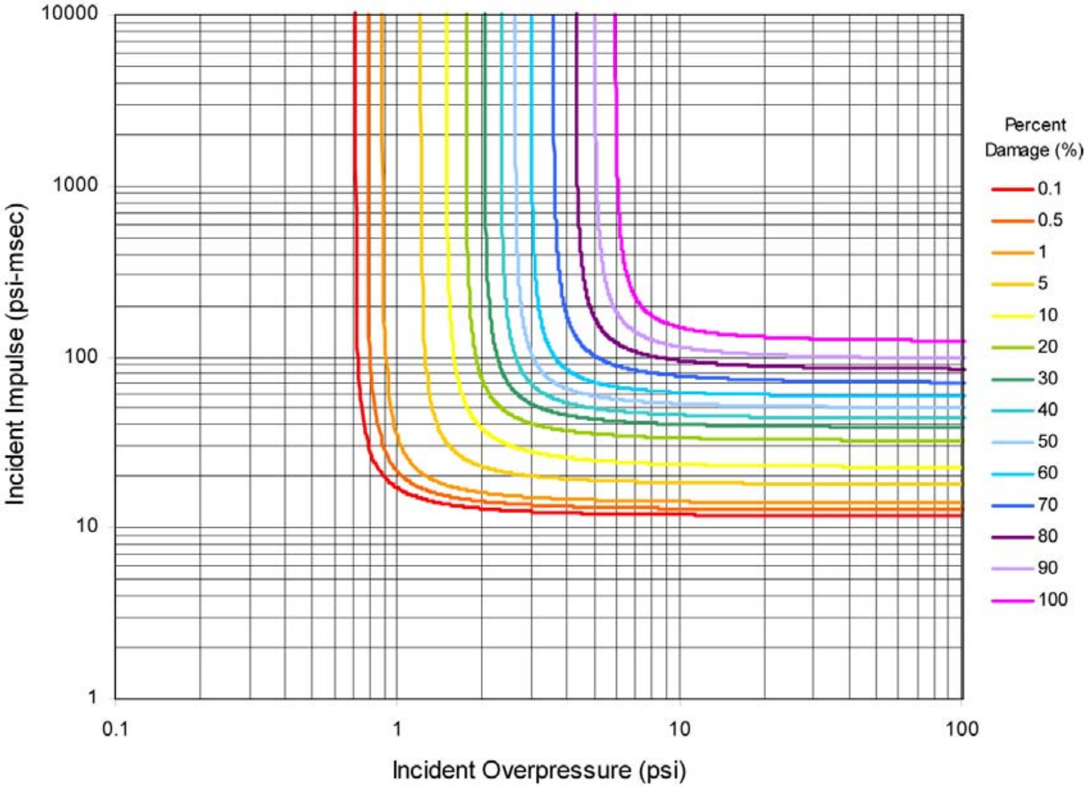


Figure 4. Small Wood Structure

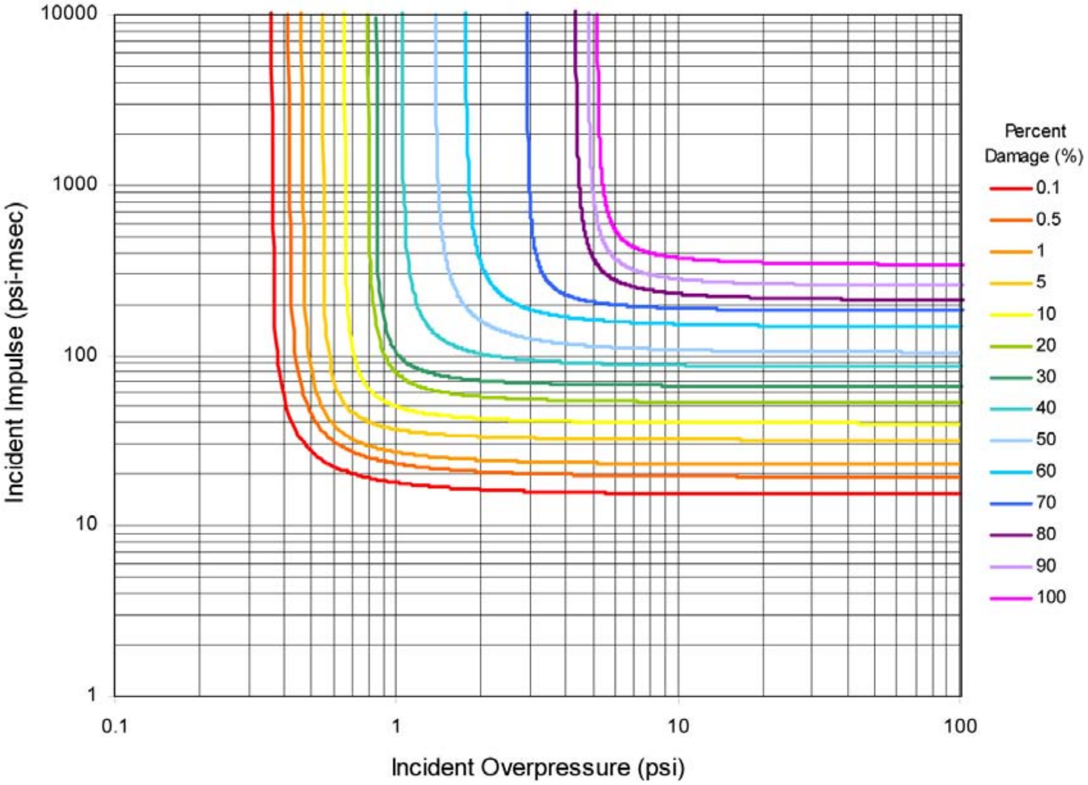


Figure 5. High Bay Metal Structure

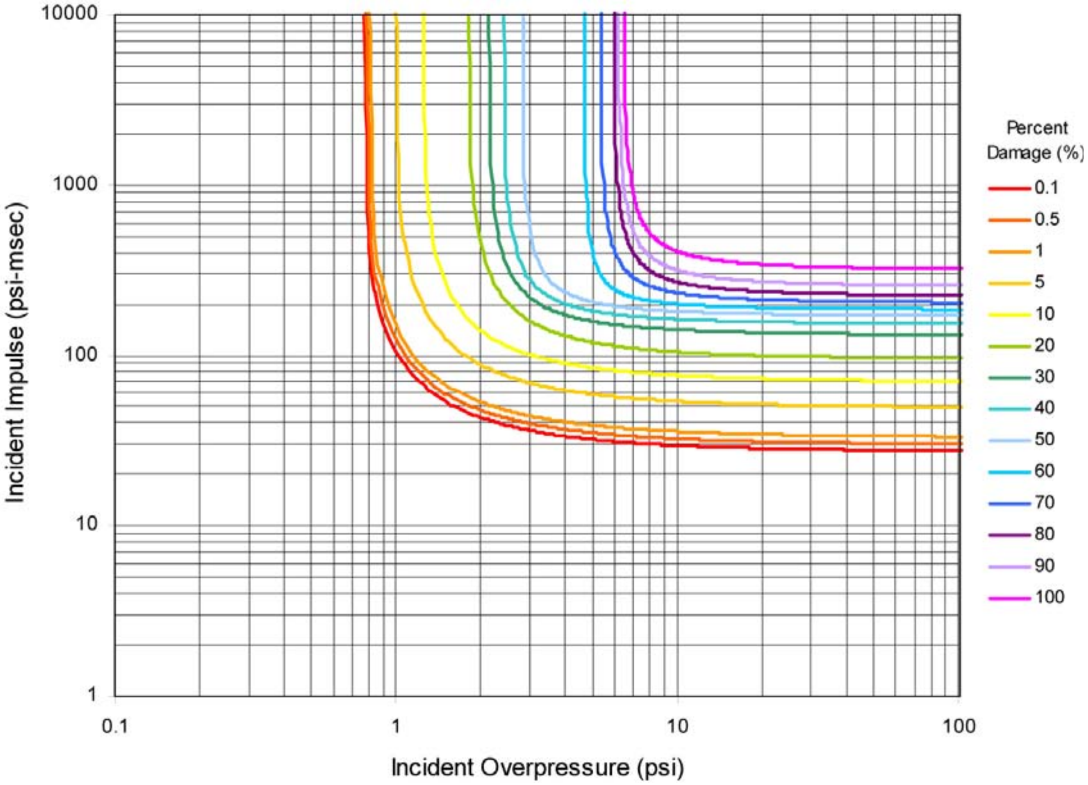


Figure 6. Medium Metal Stud Structure

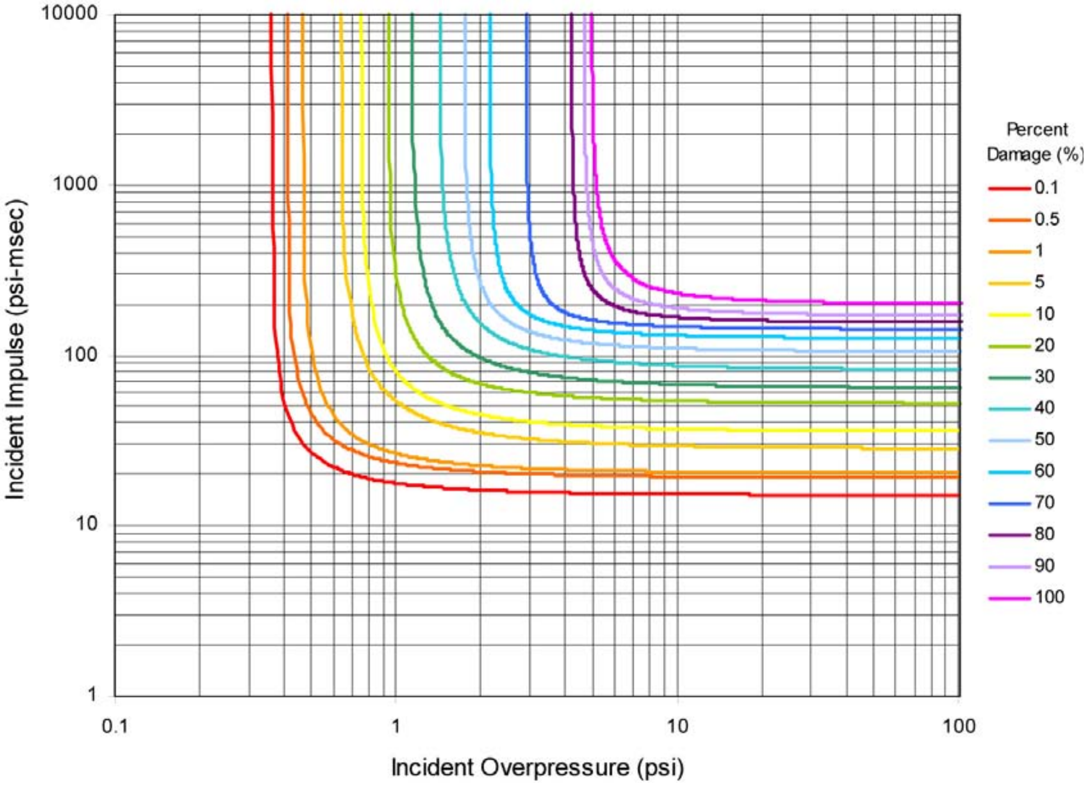


Figure 7. Medium Metal Structure

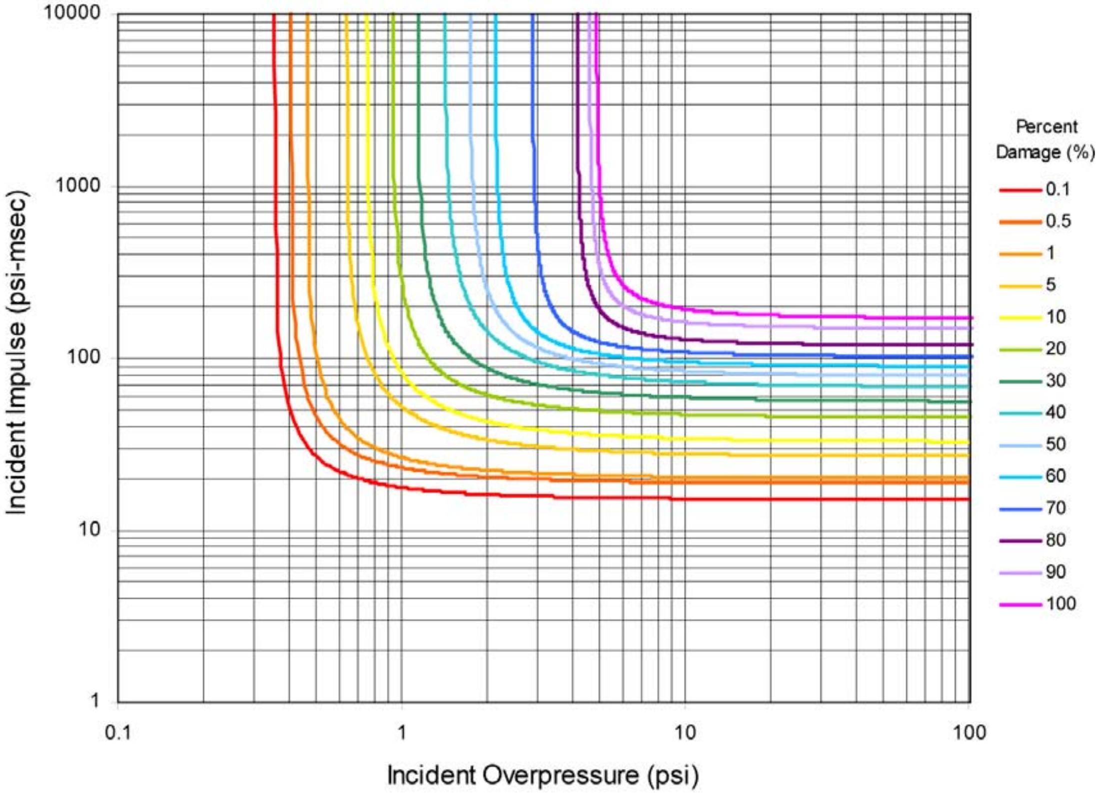


Figure 8. Small Metal Structure

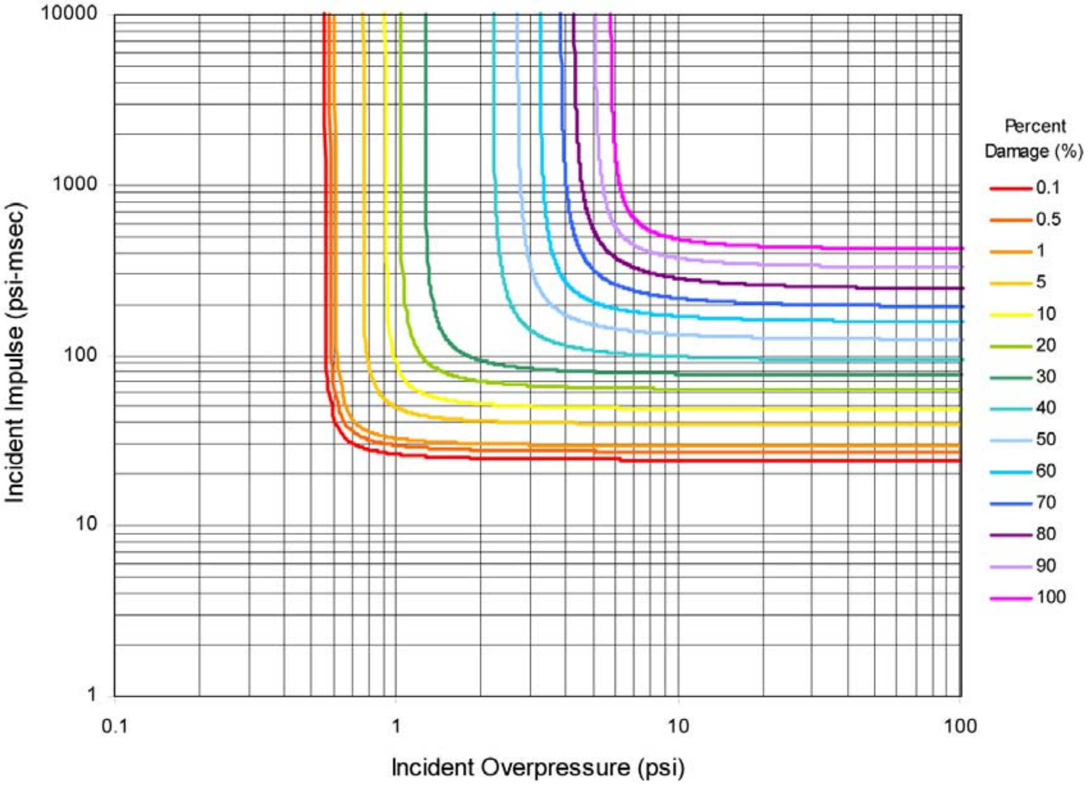


Figure 9. Medium Reinforced Masonry

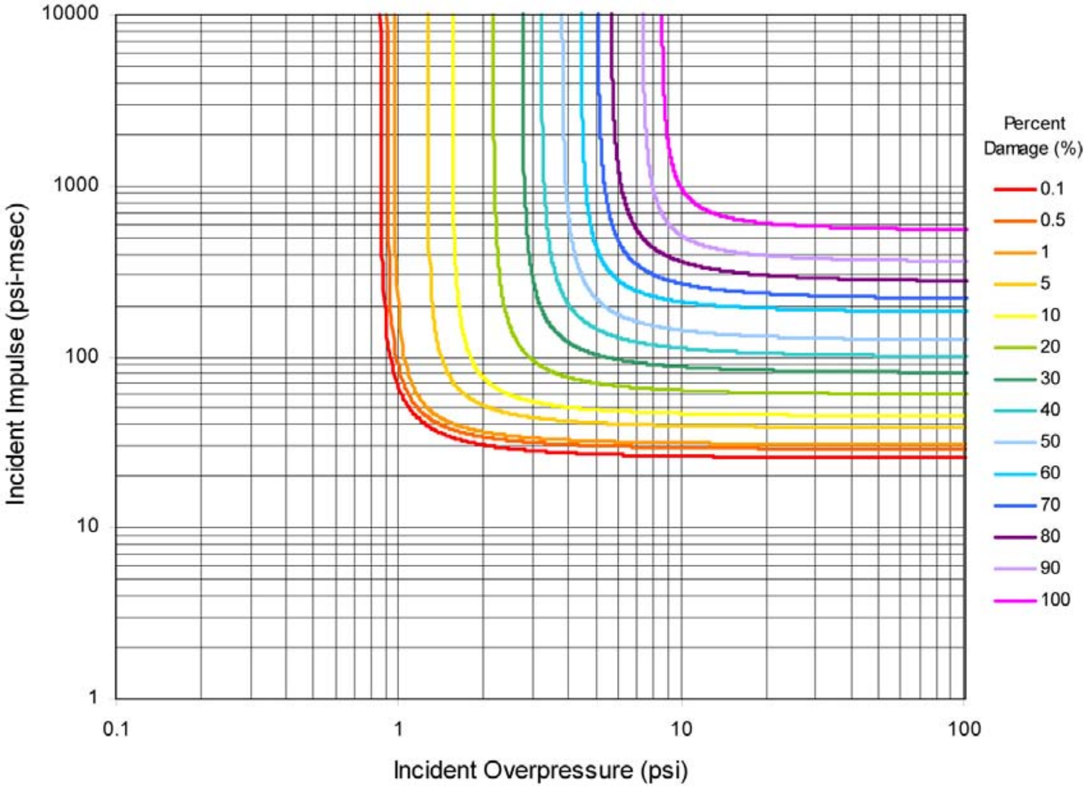


Figure 10. Small Reinforced Masonry

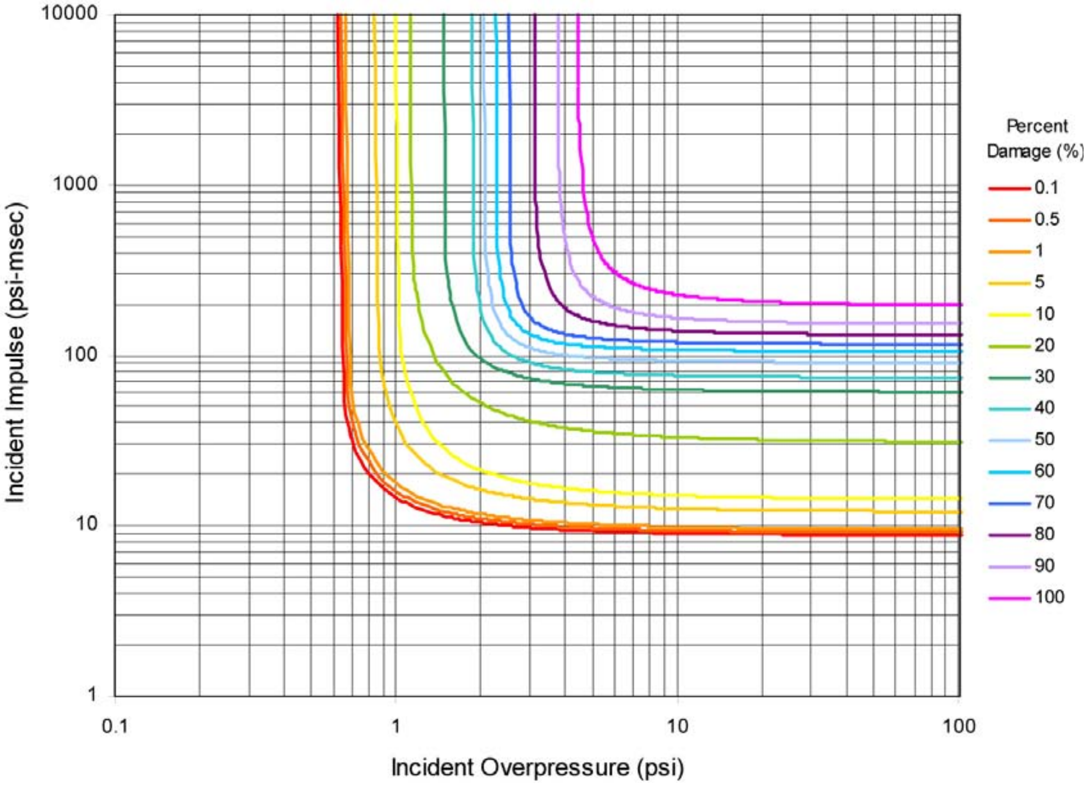


Figure 11. Large Un-reinforced Concrete Structure

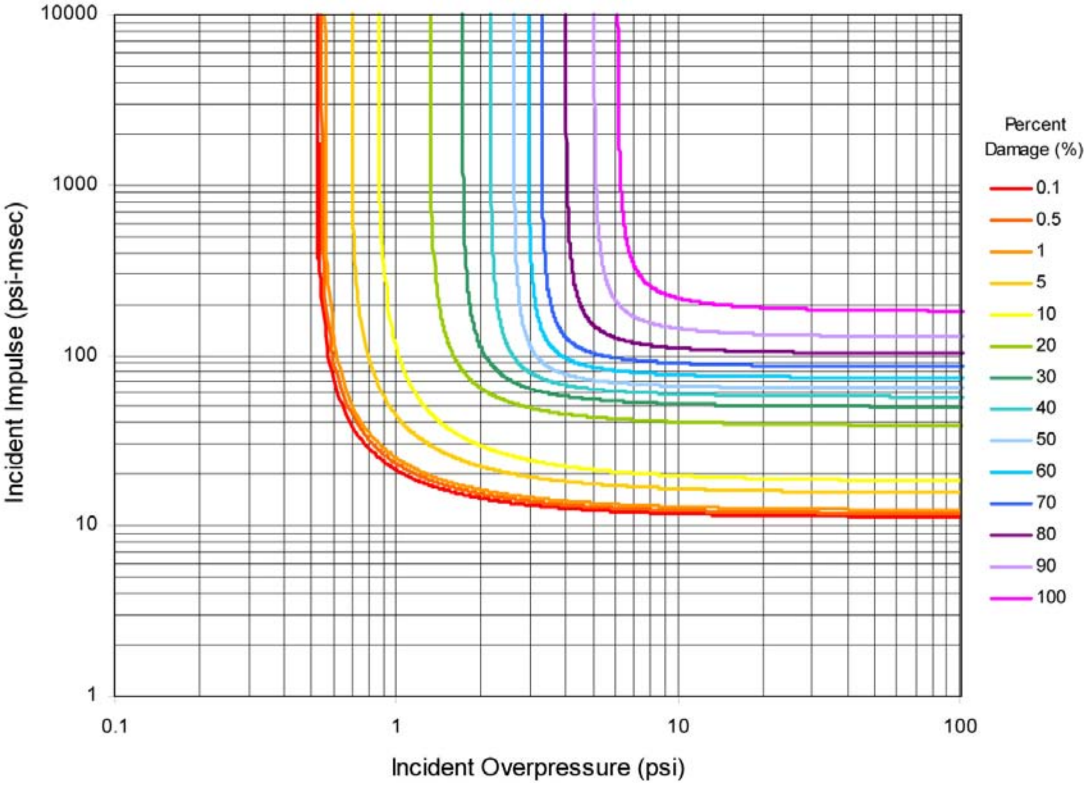


Figure 12. Medium Un-reinforced Concrete Structure

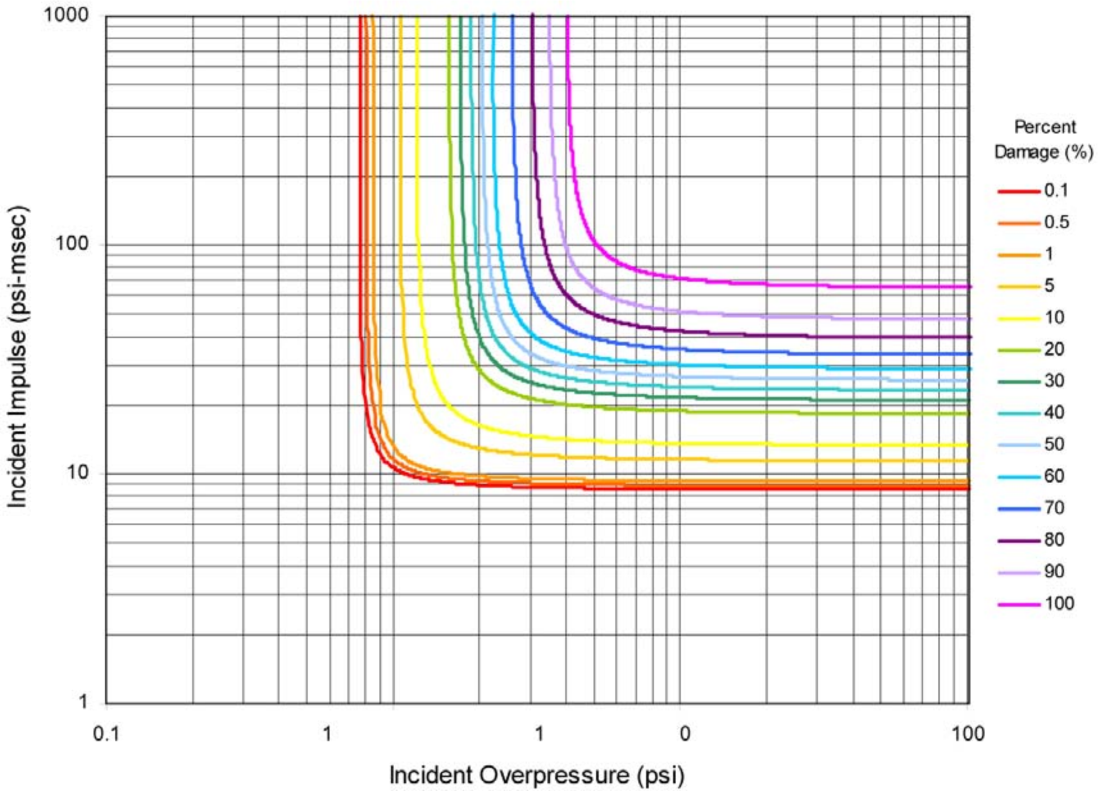


Figure 13. Small Un-reinforced Concrete Structure

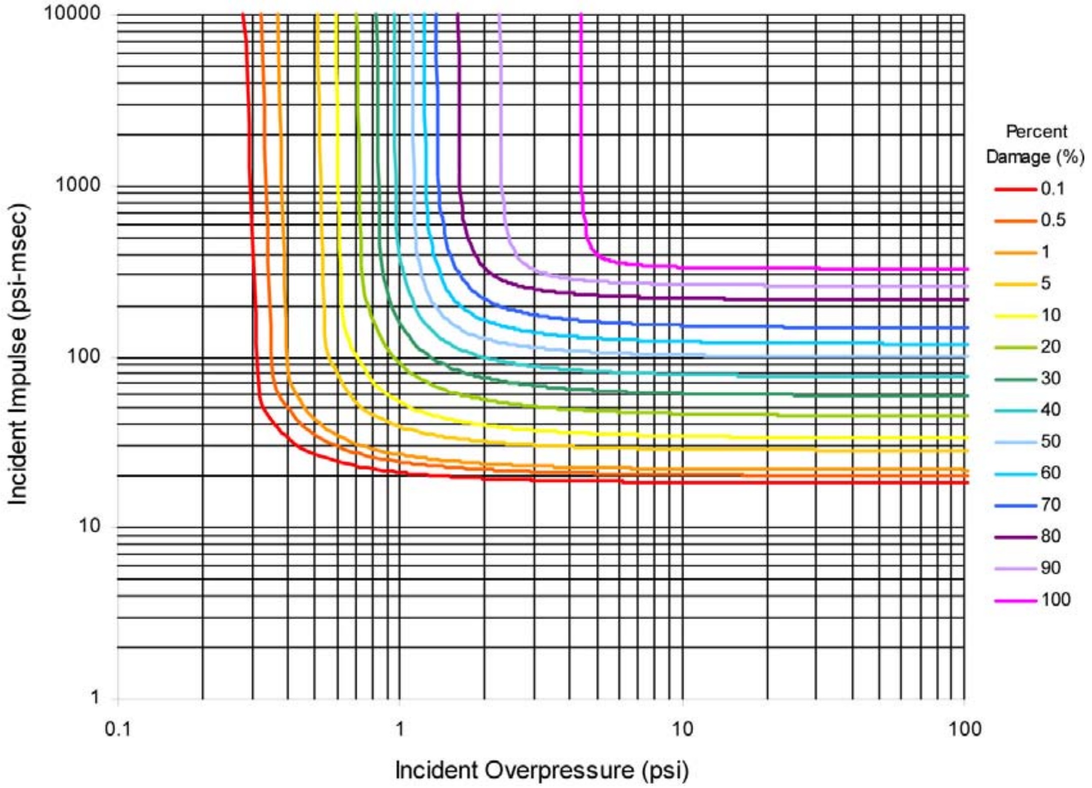


Figure 14. Large Tilt-up Structure

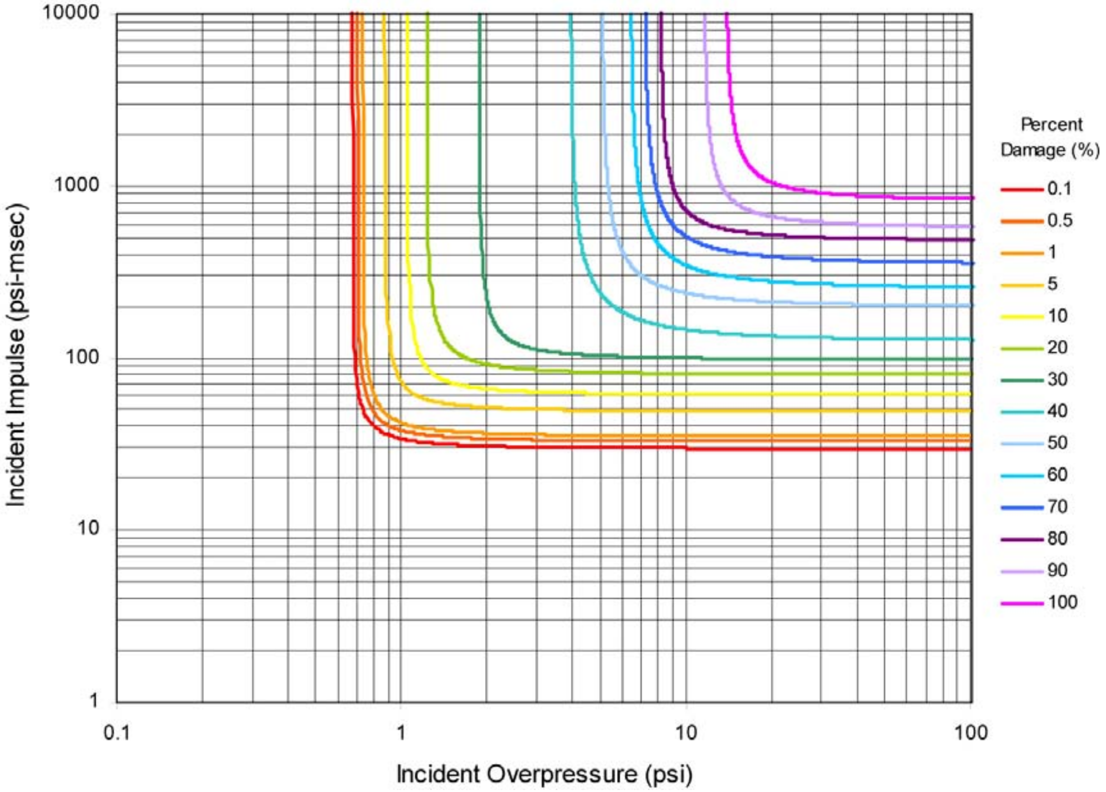


Figure 15. Medium R/C Office Building

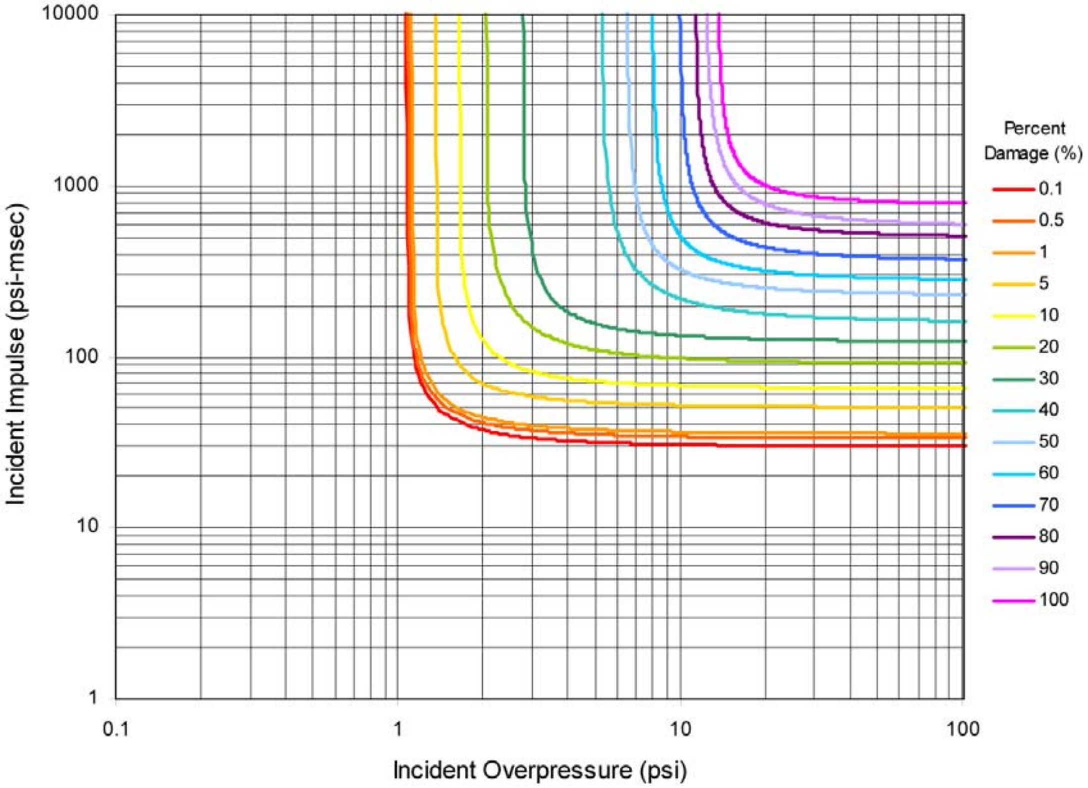


Figure 16. Small R/C Office Building

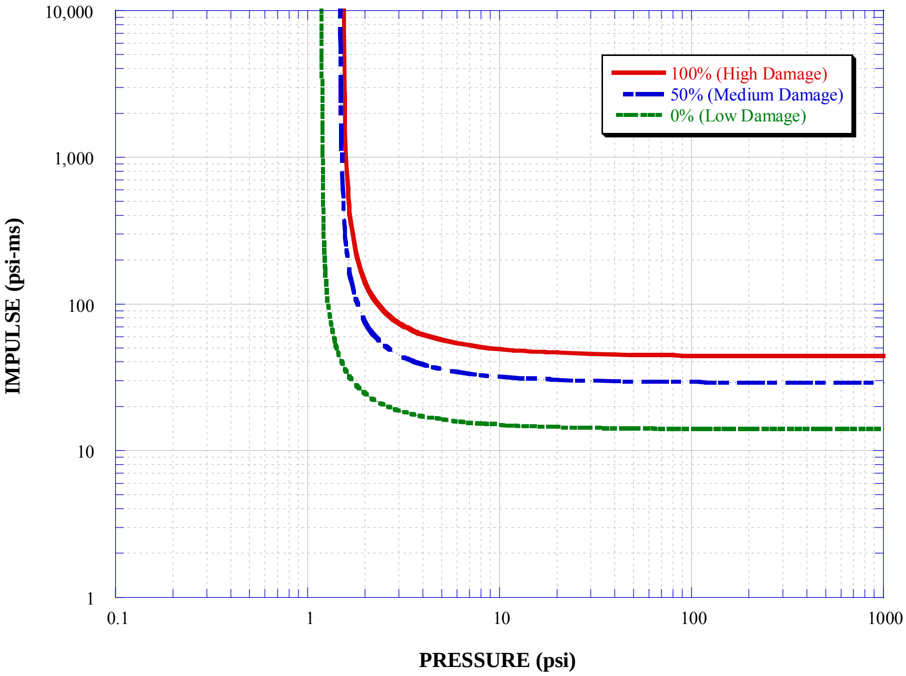


Figure 17. Metal Roof

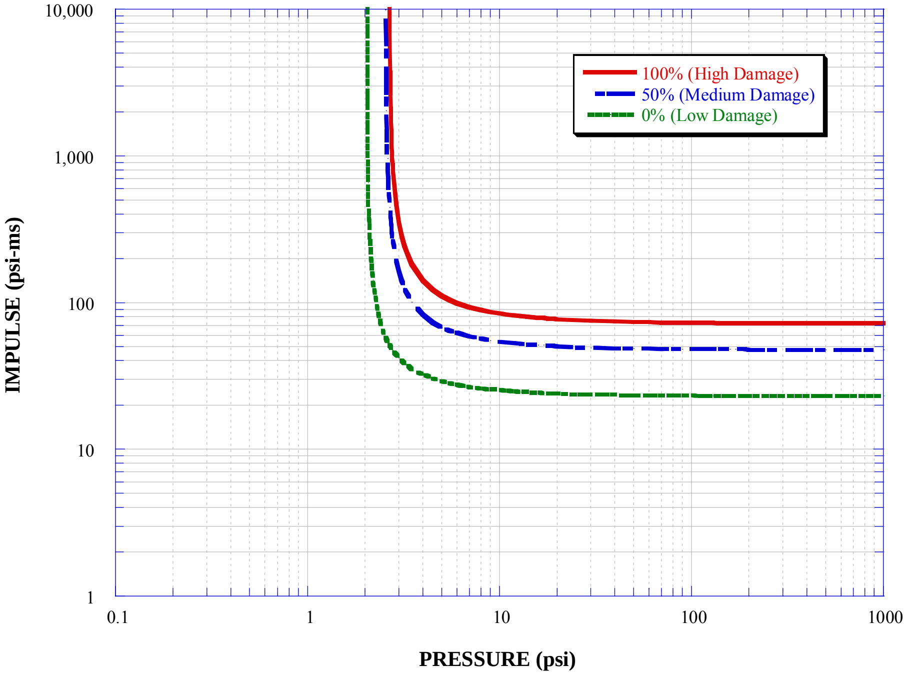


Figure 18. Steel Deck Roof

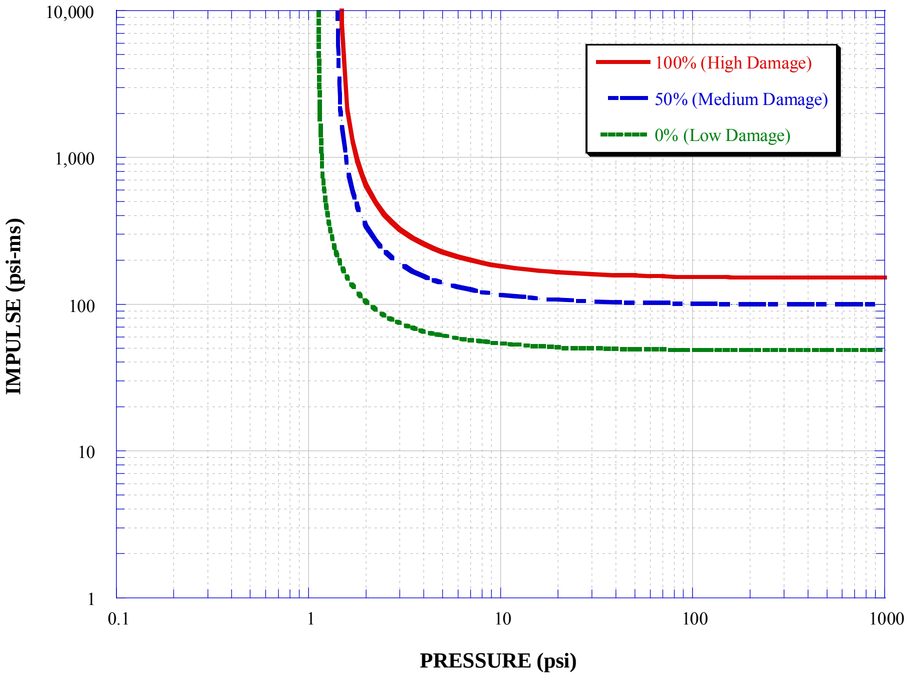


Figure 19. Lightweight Concrete Roof

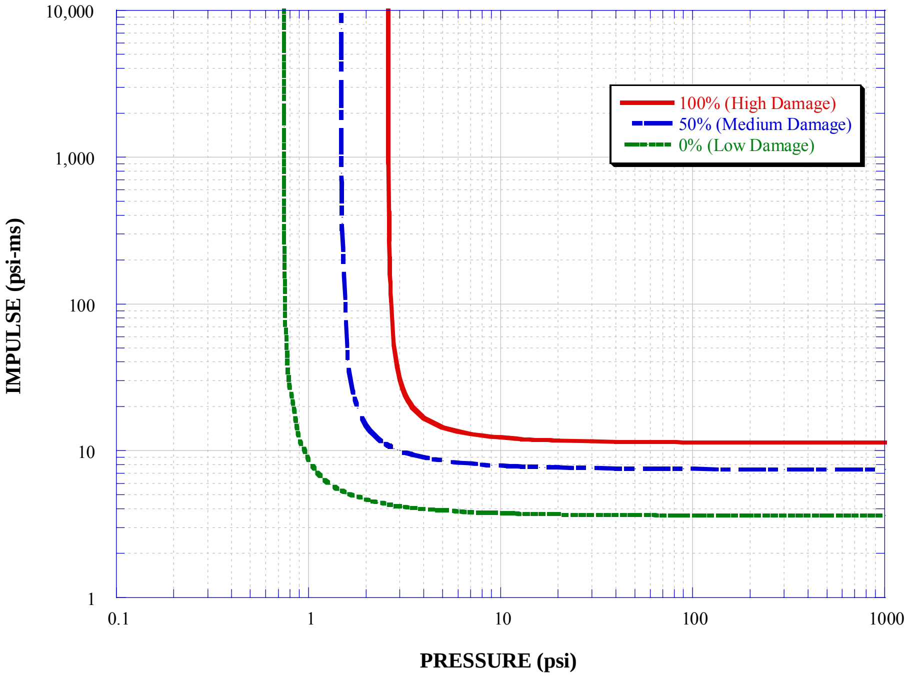


Figure 20. Wood Panel Roof

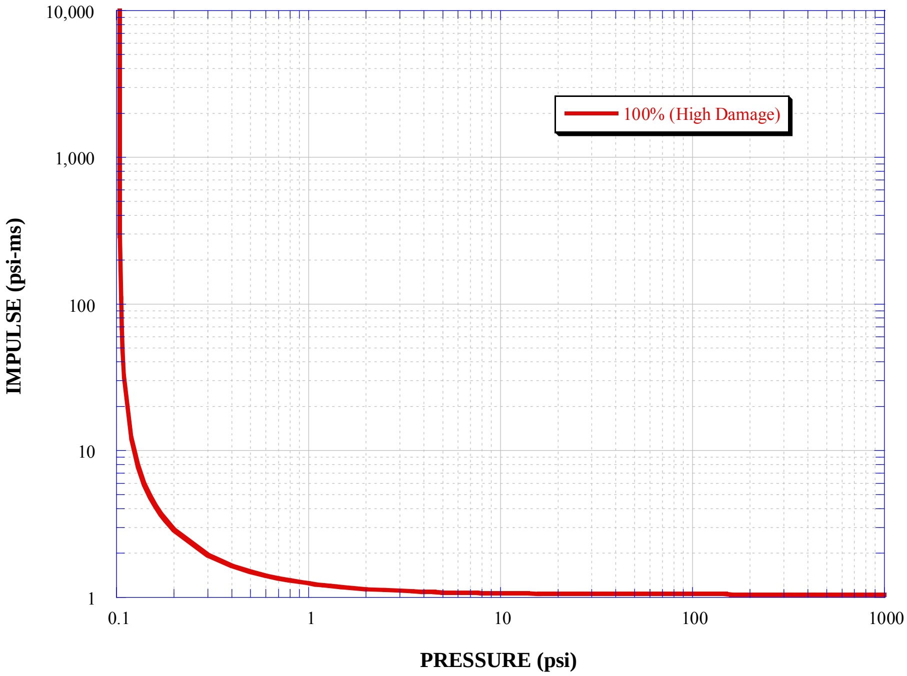


Figure 21. Flat Built-up Roof

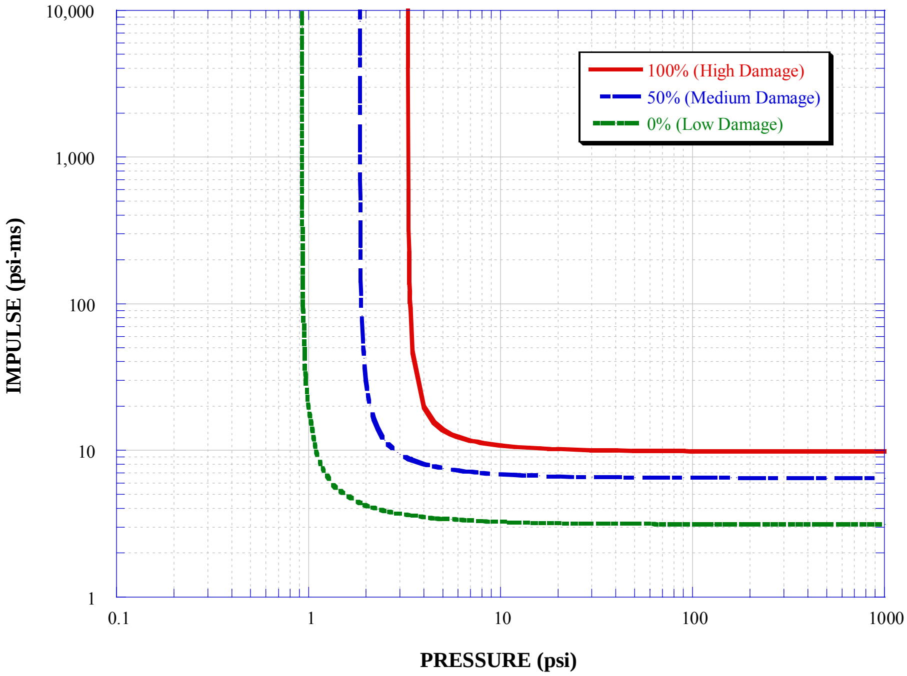


Figure 22. Wood Stud/Plywood Roof

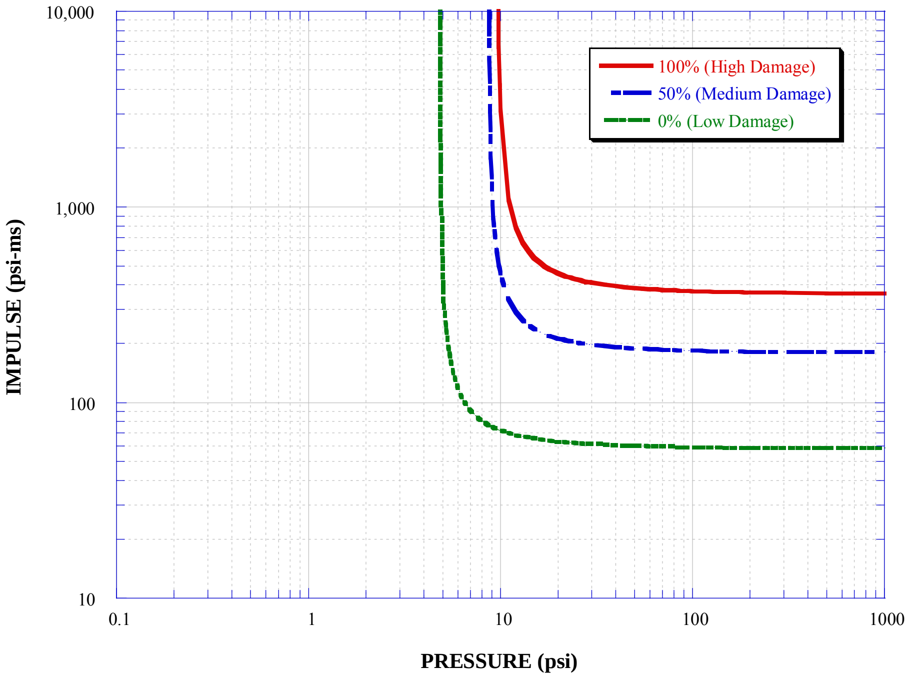


Figure 23. 12” Concrete Roof

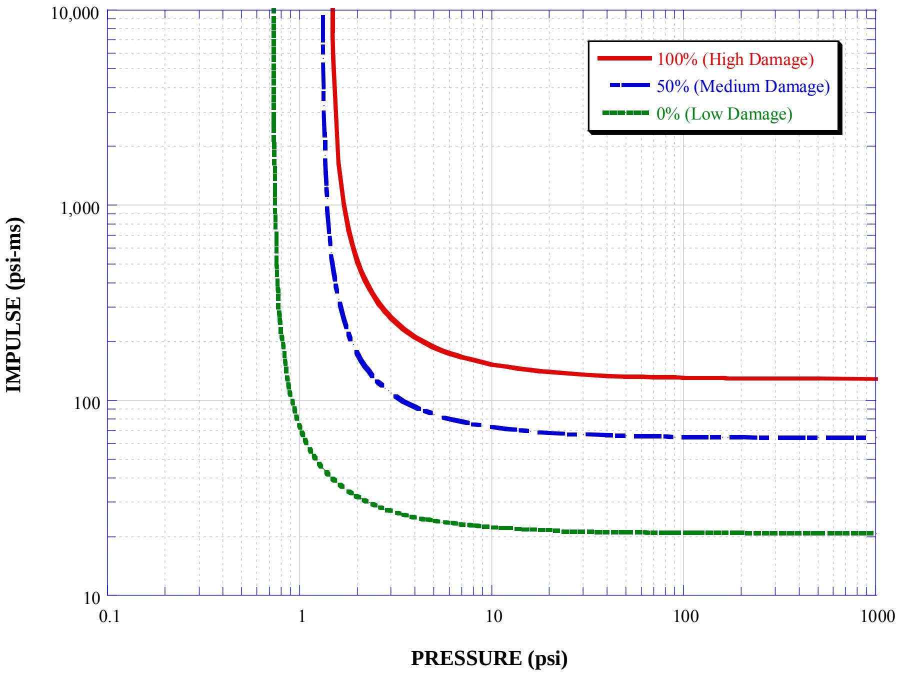


Figure 24. 4” Concrete Roof

2. How/why is the SAFER method different from the ACTA curves?

The ACTA P-I curves predict fatality as a function of pressure and impulse. The SAFER method represents probability of fatality as a function of building damage. SAFER 3.0

uses a standard normal distribution, therefore the ACTA curves could not be directly used to determine the probability of fatality. Instead, data points from the ACTA curves that do consider structural response were used to help anchor the standard normal distributions.

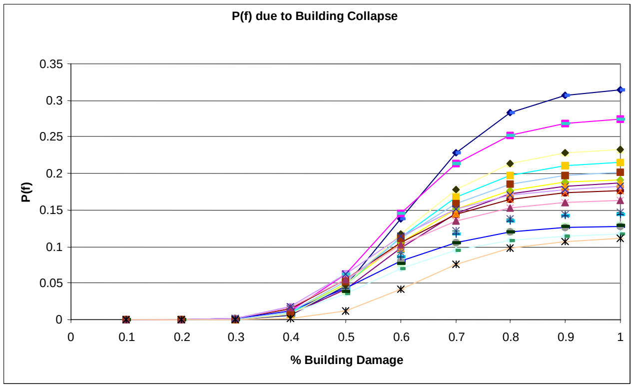
3. *How were the SAFER curves derived?*

The Science Panel used the ACTA data points and relationships derived by NFESC and ACTA to determine the probability of fatality at two damage levels, 40% and 90%. A standard normal distribution (adjusted for a logarithmic scale with a maximum set at less than 1.0) was then created to pass through the two points obtained from the data for each ES type. This process is depicted in Figure 25.

Building	%Injury	%Fat@D	
ID	at 100 BD	40	90
Sm R/C	95	0.52	30.64
Med R/C	85	0.74	22.82
Lrg R/Ctu	90	1.14	26.81
SmUnBr	70	1.41	17.29
MedUnCMU	80	1.05	19.70
LgUnCMU	75	1.00	18.78
SmRCMU	80	0.73	18.29
MedRCMU	85	0.84	21.06
SmMtlWall	65	1.25	12.57
MedMtlWall	70	1.43	14.44
Med Mtl Stud	72.5	1.59	16.02
LgMtl	75	1.77	17.85
SmWdFrame	60	0.87	11.44
MedWd Frame	65	1.07	14.17
Modular/Trailer	62.5	0.96	12.71
Auto	60	0.09	10.74

Determine statistical parameters

S-curve for each ES type stored in SAFER 3



Note: max < 1.0

Figure 25. SAFER Probability of Fatality Curve Creation Process

4. *Why is the probability of fatality less than 1.0 when building damage equals 100%?*

This is because of two reasons:

a. 100% damage does not necessarily mean that the building has completely collapsed. 100% damage does mean that the building is a complete loss economically and functionally. A building with 100% damage would have many elements that have collapsed but could also have structural elements that still support dead loads but could not support live loads.

b. even if most or all of the ES has collapsed, accidents have shown that there can be survivors.

5. *What does 100% building damage mean?*

100% damage, as a minimum, indicates that the major structural components have exceeded the design failure load and that many have failed and may have collapsed. The building is not functional and must be replaced.

6. *How are cases that would cause "beyond 100% damage" handled?*

   Such cases are addressed by the Simplified Close-In Fatality Mechanisms (SCIFM) logic (see separate SCIFM Tech Memo).

7. *Is the roof type entered by the user accounted for in the building failure models?*

   No. The building failure models always use the default roof type. A change in roof type (from the default) only affects the predicted PES debris hazard and risk.

8. *Is the ES floor area entered by the user accounted for in the building failure models?*

   No. The building failure models assume a default floor area because they are based on specific representative designs. The floor area only affects the glass hazard risk.

Attachment 8 – Debris

SAFER 3 Debris

Prepared by – John Tatom (APT)
Mike Swisdak (NSWC)
Jim Tancreto (NFESC)
Revision Date – 02/25/05

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER 3.0 debris branch. Specific questions addressed are:

1. How were the numbers of fragments for each weapon type determined?
2. What is the rationale for the choice of average mass values?
3. What is the basis for the equation that determines the number of weapons on the outer surface?
4. What is the basis for the nominal maximum throw range for each weapon?
5. Why do the smaller mass bins have lesser max throw ranges?
6. Why aren't additional weapon types included?
7. How were the nominal fragment blocking factors determined?
8. Why is the PES damage considered before the primary fragments are blocked by the PES?
9. How were the relative component areas calculated?
10. How were the nominal mass distributions determined for each PES component?
11. What are the nominal maximum throw ranges for each PES component based on?
12. How were the steel/concrete ratios for each PES component determined?
13. What is the reasoning behind the dynamic mass distribution adjustment?
14. On what are the weight-to-volume considerations based?
15. Why aren't all PES components dependent on weight-to-volume considerations?
16. How were the volumes for each PES determined?
17. Why aren't crater ejecta considered for all PES types?
18. What are the crater ejecta parameters based on?
19. What is the basis for the high/low angle separation?
20. Why is there a distinction among low-angle fragments?
21. Why was the bivariate normal distribution chosen as the probability density function for high-angle and low-angle (side impact) debris?
22. Have the arriving fragment tables been compared to test data?
23. How were the "f" values derived and why are they not always equal for HAS and ECM?
24. How are the maximum throw values and σ related?
25. How are the mass-based fragment tables converted to kinetic energy tables?
26. Why is terminal velocity assumed?
27. What are the ΔKE values for walls and roofs based on?
28. How were the invulnerable areas determined?
29. What is the basis for the probability of a hit?

30. Why was the fatality versus kinetic energy curve that is used by SAFER chosen?
31. What is the basis of the barricade logic?

REFERENCES

1. HNC-ED-CS-S-98-1, “Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives,” U. S. Army Corps of Engineers Engineering and Support Center, Huntsville, AL, January 1998.
2. "Joint Munitions Effectiveness Manual (Air-to-Surface): Weapons Characteristics", NAVAIR 00-130-ASR-2, September 1986.
3. Fugelso, L. E. and Rathman, C. E., “Effect Of Earth Cover On Far-Field Fragment Distributions,” Minutes of the 15th DoD Explosives Safety Seminar, September 1973.
4. Montanaro, P.E., “TRAJ – A Two Dimensional Trajectory Program for Personal Computers,” Minutes of the 24th Explosives Safety Seminar, August 1990.
5. Crull, Michelle and Swisdak, Michael, “Methodologies For Calculating Primary Fragment Characteristics,” DDESB Technical Paper 16, Revision 1, December 2003.
6. Swisdak, Michael M., Jr., “ESQD Arcs for Maritime Prepositioning Ships,” NAVSWC TR 91-630, 25 November 1991.
7. Swisdak, Michael M., Tancreto, James E., Tatom, John W., “SciPan 1 and SciPan 2—Response of Tiltup Concrete Construction to Blast Loading.” NFESC TM 2371, July 2004.
8. Weals, F. H., “ESKIMO 1 Magazine Separation Test,” NWC TP 5430, April 1973.
9. Bousek, R. R. (editor), Proceedings of the DISTANT RUNNER Results Symposium, DNA POR 7063, 2 September 1982.
10. Gould, Michael J. A., “The 1999 Multi-National 40 Tonne Donor/Acceptor Test – Fragment And Debris Collection And Analysis,” Minutes of the 29th DoD Explosives Safety Seminar, July 2000.
11. Anon., “SHOCK Users Manual, Version 1.0,” Naval Civil Engineering Laboratory, Port Hueneme, CA, January 1988.
12. Wager, P. and Connett, J., “FRANG User’s Manual,” Naval Civil Engineering Laboratory, Port Hueneme, CA, May 1989.
13. “Protective Structures Automated Design Systems (PSADS) Version 1.0,” September 1998.
14. Army TM 8-855-1, “Fundamentals Of Protective Design For Conventional Weapons,(CONWEP),” 20 August 1992.
15. Tatom, J. W., Swisdak, M., and Newton, K.”Comparison of SAFER Debris Density Predictions To Test Data,” Minutes of the 31st DoD Explosives Safety Seminar, August 2004.
16. “Crater and Ejecta Measurements for a Full-scale Missile Detonation in an Underground Cell.” A.D. Rooke, Jr., T.D. Chew, No. 1-853, November 1966.

17. Tancreto, James E., Tatom, John W. and Swisdak, Michael, "SPIDER—A Test Program To Determine The Response Of Typical Wall And Roof Panels To Debris Impact," Minutes of the 31st DoD Explosives Safety Seminar, August 2004.
18. Chrostowski, Jon D., Wilde, Paul D., Gan, Wenshui, Hasselman, Timothy K., "Building Occupant Fatality Models for Air Blast Loading," ACTA Technical Report No. 00-444/16.4-03, Contract No. N47408-99-P-6023, October 2000
19. Klein, P. F., Fragment and Debris Hazards, Technical Paper 12, Department of Defense Explosives Safety Board, July 1975.
20. Hackett, O. F. and Peterson, R. O., "Missile Hazards From Explosions In Ships, Minutes of the 19th DoD Explosives Safety Seminar, September 1980.
21. "RCC 321-00." Risk and Lethality Commonality Team Range Safety Group Range Commanders Council, Secretariat Range Commanders Council U.S. Army White Sands Missile Range, NM, April 2000.

DISCUSSIONS

1. *How were the numbers of fragments for each weapon type determined?*

   Where available, the numbers were taken from available reports (ref 1). The Science Panel performed a weapon analysis using the methodology of Reference 1 to determine the numbers for the MK82 and M107.

   Although other data sources, such as the Joint Munitions Effectiveness Manual (JMEM), have unclassified data for the MK 82 and the M107 (ref 2), the data may not be unclassified for the WAU-17 (Sparrow). In addition, the data for other weapons that might be added later might also be classified in the JMEM. For this reason, in order to have consistent numbers for all weapons, it was decided to use the Reference 1 methodology (Gurney). An initial comparison made between the Reference 1 estimates and the JMEM measurements showed that the Reference 1 estimates are the more conservative.

2. *What is the rationale for the choice of average mass values?*

   The average mass values were chosen because they create a direct correlation from mass bins to kinetic energy bins when terminal velocity is assumed. That is, a fragment from mass bin 1 at terminal velocity will belong in kinetic energy bin 1.

3. *What is the basis for the equation that determines the number of weapons on the outer surface?*

   The equations (taken from Reference 3) represent the number of items on the outer surface of a rectangular stack. Let N_w equal the total number of munitions in a rectangular stack with dimensions 3n x n x n (See Figure 1). This stack shape is approximately the one that would fit into a standard earth covered magazine.

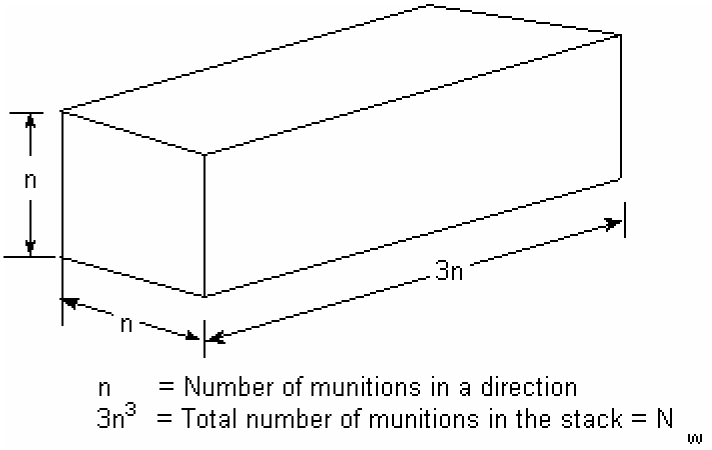


Figure 1. Figure 1. Theoretical Stack Geometry

Off the side of the stack:

$$N_{eff} = 3n^{2}$$

$$N_{pos} = \frac{3n^{2}}{3n^{3}} = 1.442\, N_{w}^{-1/3}$$

4. *What is the basis for the nominal maximum throw range for each weapon?*

The values are based on available published literature (reference 4,5).

5. *Why do the smaller mass bins have lesser max throw ranges?*

Trajectory analysis shows that larger pieces have a higher ballistic coefficient and are expected to travel the furthest. Therefore, a trajectory analysis tool, TRAJ (reference 4), was used to estimate the nominal max throw for smaller mass bins. This assumption appears to be supported by SciPan1 test data (reference 19).

6. *Why aren't additional weapon types included?*

The weapon choices available in SAFER are based on a philosophy developed for the Army's "Worst Case Donor/Acceptor" Program: If testing or analysis is performed using a "worst case" donor munition as the explosion source, then the results would be applicable to all other munitions that present a lesser hazard.

For HD 1.1 munitions, several different items were identified as being potential worst cases; it being up to the user to select the type that most closely represents the actual item. MK 80 series bombs (MK 82, MK 83, or MK 84) represent all large, robust munitions; M107 projectiles represent all small, robust munitions. The AIM-7 warhead represents all fragmenting or thin-skinned items.

For HD 1.2, the M1 projectile represents all HD 1.2.1 items, while the 40 mm projectile represents all HD 1.2.2 projectiles.

Thus, by using items that represent “worst” cases, the results can be applied to other, similar weapons in class. If calculations made for an item that was not “worst case”, then the results obtained would only apply to that particular item. If SAFER analyses were performed with weapons that did not represent worst-case situations, then the results would be weapon specific and could not be applied to other weapons or situations.

7. *How were the nominal fragment blocking factors determined?*

   The values are based on expert opinion by the Science Panel.

8. *Why is the PES damage considered before the primary fragments are blocked by the PES?*

   This sequencing ensures that the predictions are never non-conservative.

9. *How were the relative component areas calculated?*

   The relative component areas were determined by comparing the surface area of the component to the overall outer surface of the PES.

10. *How were the nominal mass distributions determined for each PES component?*

    Some test data have been analyzed (SciPan1, Distant Runner Event 4, Distant Runner Event 5, Eskimo 1, 40/27 Tonne Trials). Where no test data were available, SAFER uses expert opinion by the Science Panel based on their years of experience.

11. *What are the nominal maximum throw ranges for each PES component based on?*

    The nominal maximum throw ranges are based on available empirical data for:

    - ISO Containers, Ships (ref 6)
    - Concrete Operating Buildings (ref 7)
    - ECM types (ref 8)
    - HAS (ref 9)
    - AGBS types (ref 10)

    The maximum throw ranges for open, PEMB, and HCT are controlled by the primary fragment maximum throw range.

12. *How were the steel/concrete ratios for each PES component determined?*

Expert opinion by the Science Panel based on typical design of each PES type. In PES components where both steel and concrete are present, a conservative (high) estimate for the percentage of steel was made.

13. *What is the reasoning behind the dynamic mass distribution adjustment?*

There is a certain yield (Y_{100} in SAFER) at which all of the mass of a PES component becomes potential secondary debris. However, at yield levels beyond Y_{100}, the component would be expected to break-up in a different manner. As the yield gets higher, the component will tend to break up into smaller pieces. Therefore, the dynamic mass distribution allows SAFER to adjust the nominal mass distribution assigned to each PES component based on the yield entered by the user.

14. *On what are the weight-to-volume considerations based?*

Computer models, including SHOCK and FRANG (ref 11, 12), were used to account for the effects of weight-to-volume (W/V) on loads and initial debris velocity, and also to calculate a conservative estimate of debris throw distance. The Science Panel then used empirical data to establish maximum debris range.

15. *Why aren't all PES components dependent on weight-to-volume considerations?*

If a PES had no supporting test data, no weight-to-volume considerations were made. Test data are generally available for all heavier PES types.

16. *How were the volumes for each PES determined?*

The PES volumes were based on the component dimensions (volume = length * width * height), using rectilinear approximations when necessary.

17. *Why aren't crater ejecta considered for all PES types?*

Crater ejecta are not considered for ships, because it is assumed that the ship is in water. Ejecta are considered for all other PES types.

18. *What are the crater ejecta parameters based on?*

The Science Panel created equations based on available models and data. The parameters for these curves are stored in SAFER. The majority of the information was taken from recent literature (ref 13), CONWEP (ref 14), and test results. SAFER crater dimension estimates were shown to be reasonable (slightly on the conservative side) in a validation effort (see Figures 2- 10).

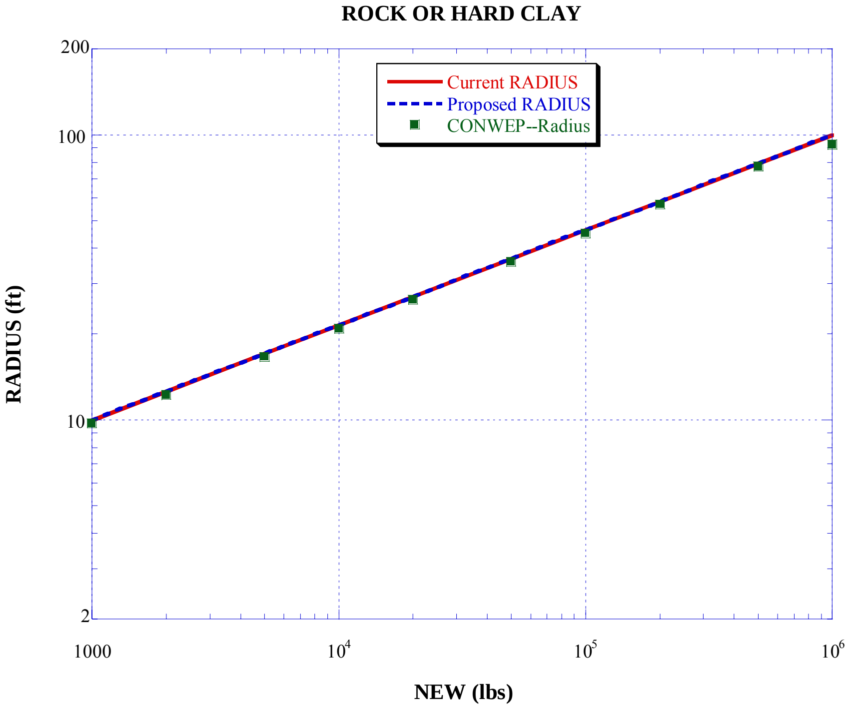


Figure 2. SAFER Crater Radius Prediction Validation (Rock or Hard Clay)

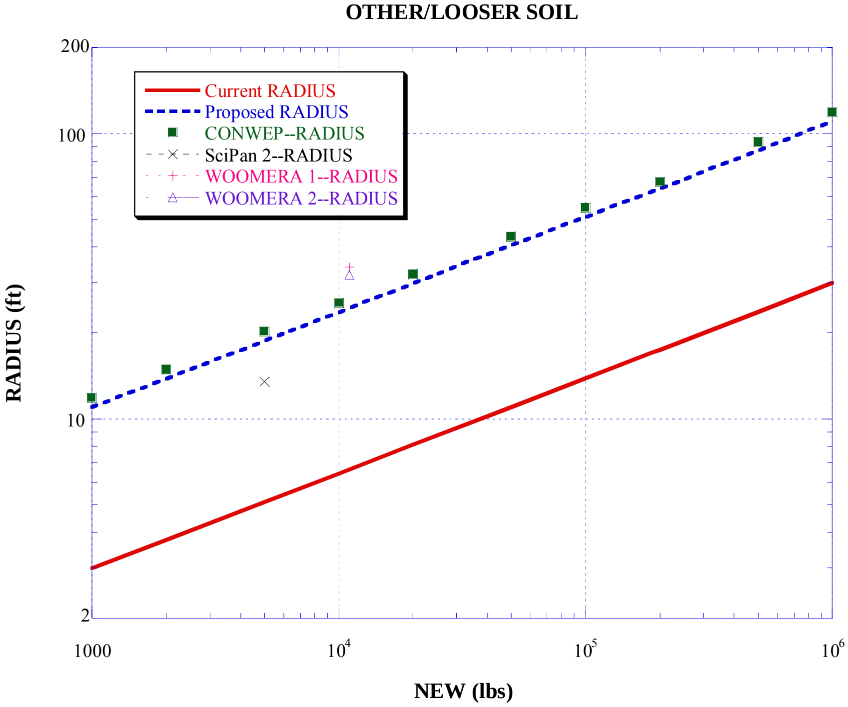


Figure 3. SAFER Crater Radius Prediction Validation (Looser Soils)

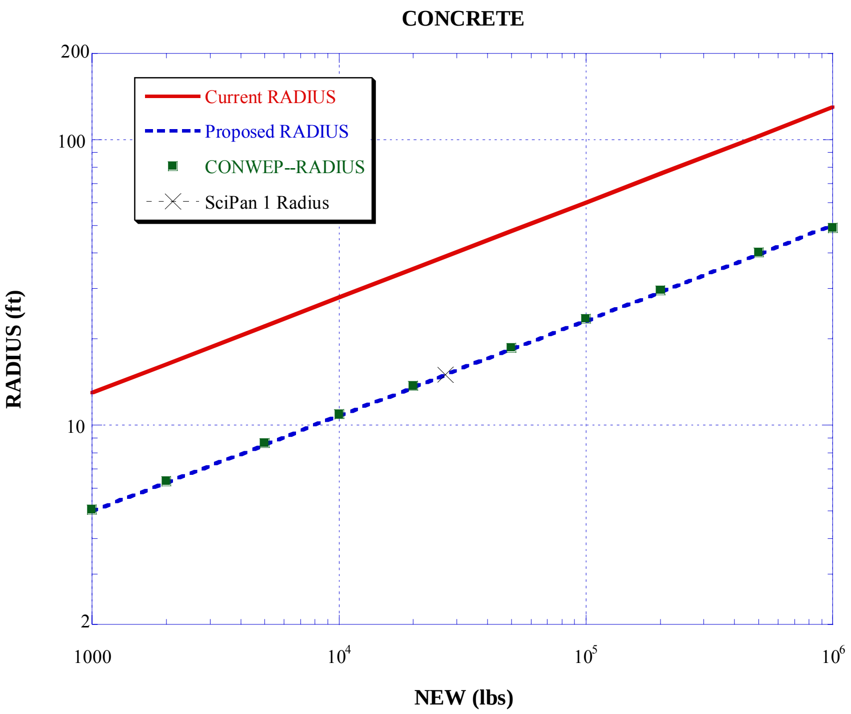


Figure 4. SAFER Crater Radius Prediction Validation (Concrete)

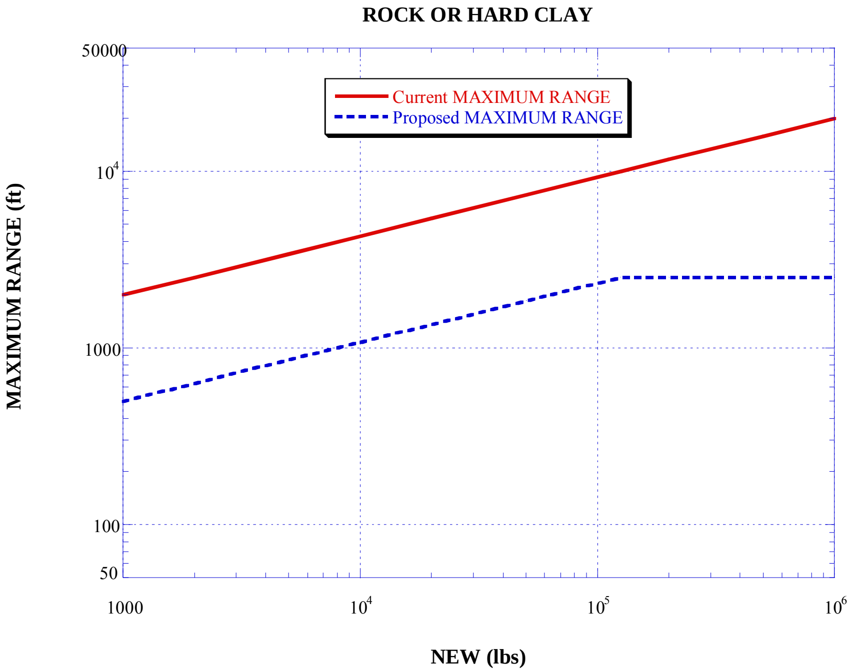


Figure 5. SAFER Maximum Crater Ejecta Range Prediction Validation (Rock or Hard Clay)

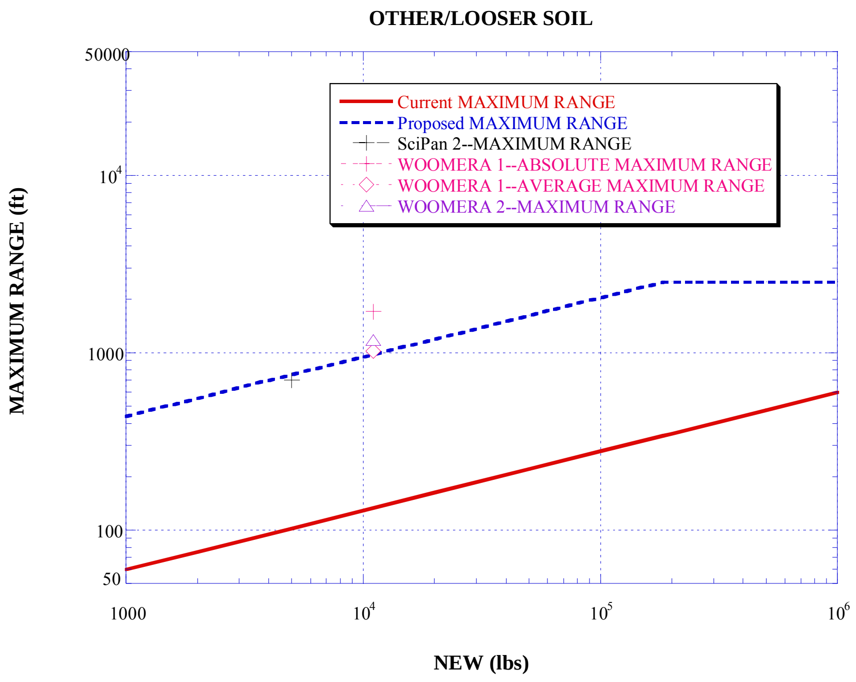


Figure 6. SAFER Maximum Crater Ejecta Range Prediction Validation (Looser Soil)

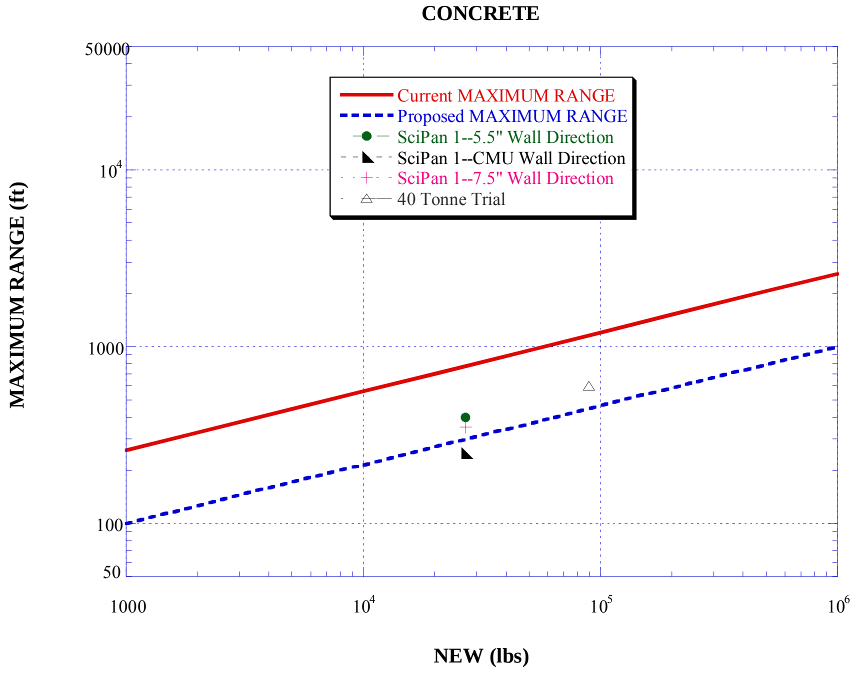


Figure 7. SAFER Maximum Crater Ejecta Range Prediction Validation (Concrete)

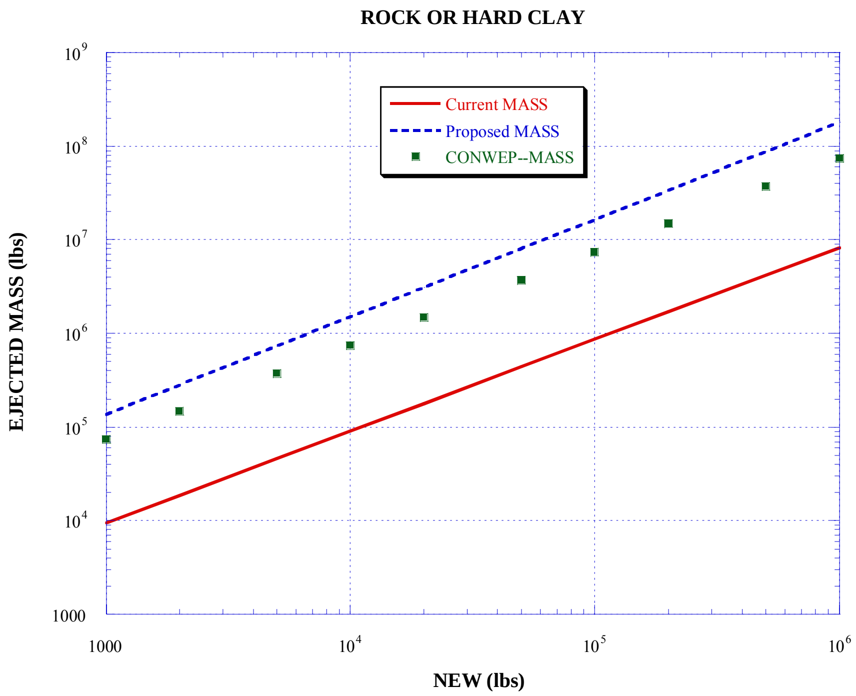


Figure 8. SAFER Crater Ejecta Mass Prediction Validation (Rock or Hard Clay)

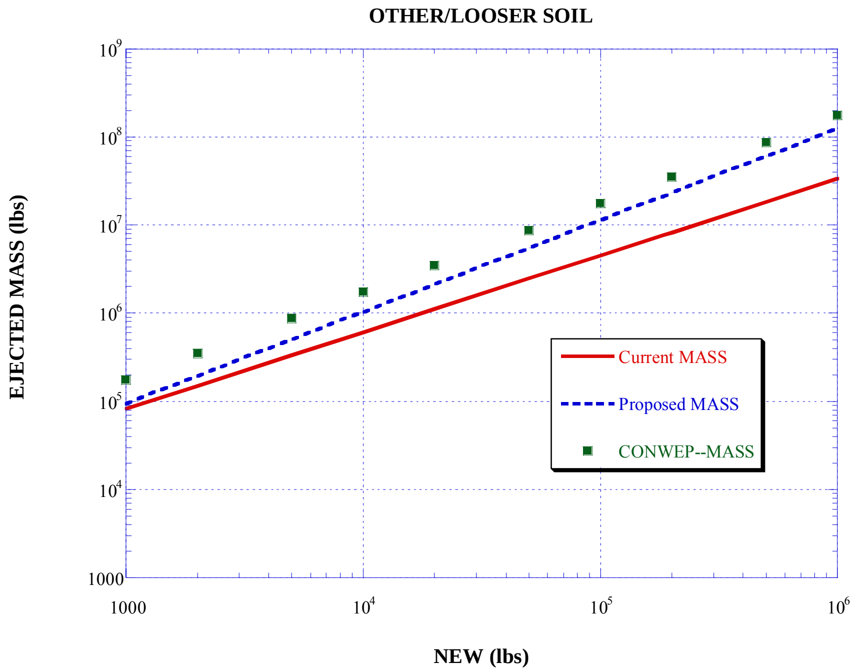


Figure 9. SAFER Crater Ejecta Mass Prediction Validation (Looser Soil)

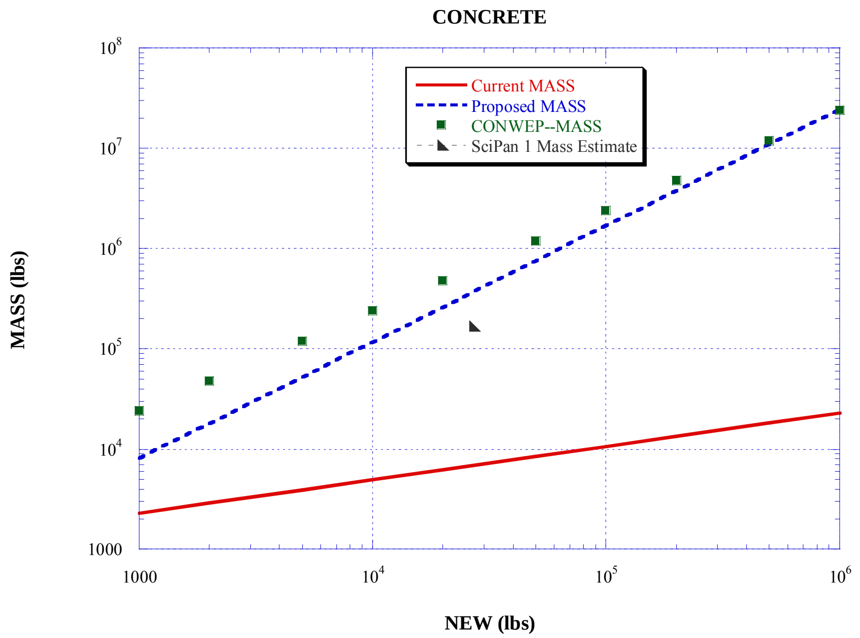


Figure 10. SAFER Crater Ejecta Mass Prediction Validation (Concrete)

19. What is the basis for the high/low angle separation?

For primary fragments, the Science Panel performed an initial trajectory analysis study using TRAJ (ref 4), and then revised the curves based on expert opinion and test data.

The Maximum Throw Range represents the 3σ value. This means that there is a small, but finite, probability that there will be debris landing beyond the Maximum Throw Range when the ratio (Distance/Maximum Throw) is greater than 1. Because there is a finite probability that there will be debris beyond the Maximum Throw Range, the high/low angle separation of the total number of fragments at these extreme ranges still must be calculated (small for low angle trajectories and, consequently, large for high angle trajectories).

SAFER 3 assumes all secondary debris from the roof and all crater ejecta are high angle fragments. SAFER 3 further assumes that all fragments from the PES walls are low angle hazards. These assumptions are based on trajectory analysis and observation of test videos.

20. Why is there a distinction among low-angle fragments?

Some fragments that are falling at or near terminal velocity (but still have a horizontal component to their trajectory) will impact the walls of an ES rather than the roof. These are considered “side-impact” fragments. The remaining low-angle fragments are traveling with a dominant horizontal trajectory component and strike the ES walls at a potentially higher velocity. These are considered “fly-through” fragments.

21. Why was the bivariate normal distribution chosen as the probability density function for high-angle and low-angle (side impact) debris?

The use of the bivariate normal is the most common assumption that is used to model debris originating from an isotropic source. The ability to vary the dispersion makes it a versatile choice. The choice of a distribution for SAFER is very different than the choice of a distribution for a site-specific analysis. If the orientation of the building is known, for example, the characteristic "maltese cross" or cruciform pattern can be modeled. The problem is that the model is being developed for any site and therefore site-specific knowledge should not drive the choice of distributions. The fact that a specific set of debris data has visible patterns is an interesting point; to justify the use of some other distribution for that site, however, the proper data to evaluate for selecting the SAFER distribution would be debris from a large set of events with a random orientation in azimuth. The RBESCT Science Panel believes this would show that a bivariate normal to be the most utilitarian choice.

22. *Have the arriving fragment tables been compared to test data?*

Yes. The arriving fragment densities predicted (ref 15) by SAFER have been compared against several test debris data sets. Figure 11 show a sample of the comparisons that are found in the reference.

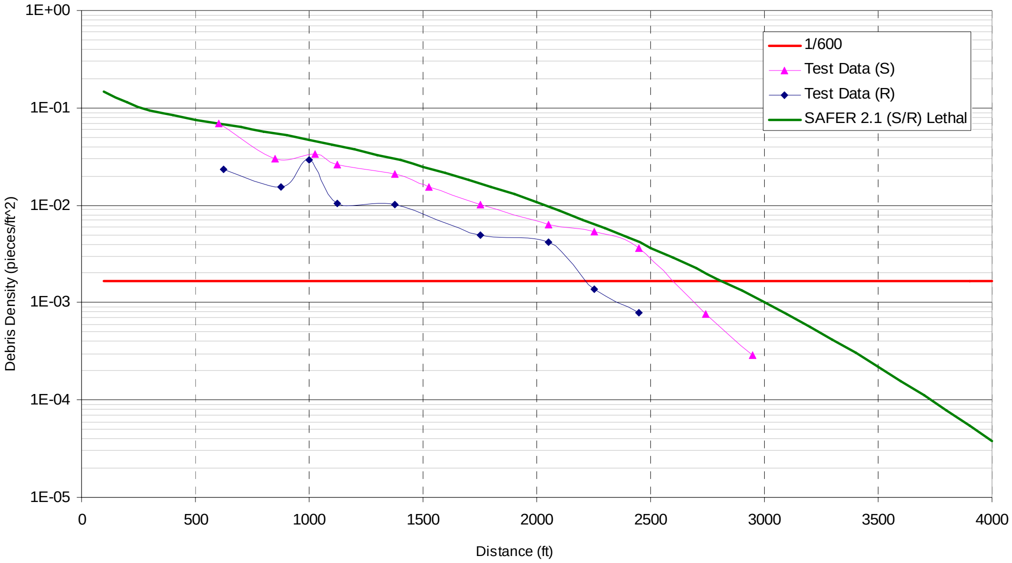


Figure 11. *SAFER Debris Density Prediction Comparison to ESKIMO 1 Data*

23. *How were the "f" values derived and why are they not always equal for HAS and ECM?*

The "f" value allows SAFER to account for orientation effects. Essentially, it prevents most fragments from one side of a building from traveling across the event and out the other side. For example, pieces from the front wall of a PES would not be expected to fly in the rearward direction, and vice-versa. The Science Panel assessed the "f" values on a component-by-component basis that accounted for the PES volume, PES component dimensions, and asymmetry considerations. Therefore, HAS component "f" values and ECM components "f" values would not necessarily be the same.

24. How are the maximum throw values and σ related?

They are related by the equation: maximum throw = n * σ. The “n” value is thus a measure of the spread of the data.

The n values were selected based on test data and expert opinion. The value of 3 (for all fragment types other than crater ejecta) is the standard value. The value of 4 (for crater ejecta) is based on test data (ref 16) and indicates a greater spread in the crater ejecta than in other debris types.

25. How are the mass-based fragment tables converted to kinetic energy tables?

For high-angle fragments and side-impact low-angle fragments, the mass-based fragment tables are converted to KE tables by using the terminal velocity for the material type in question. Concrete fragments and crater ejecta convert directly from mass to KE bins, whereas steel fragments are one bin higher because of their increased terminal velocity.

For fly-through low-angle fragments, the mass-based fragment tables are converted to KE tables by using the calculated impact velocity for the material type in question at that range.

26. Why is terminal velocity assumed?

Terminal velocity is assumed for high-angle fragments and side-impact low-angle fragments because they are considered to be falling from a sufficient elevation to achieve such a velocity (due to being lobbed from the donor to the ES).

27. What are the ΔKE values for walls and roofs based on?

These values were provided by ACTA (ref 15) and are being tested as part of the SPIDER program (ref 17).

28. How were the invulnerable areas determined?

These values were provided by ACTA (ref 18) and expert opinion by the Science Panel.

29. What is the basis for the probability of a hit?

When fragments and/or debris are ejected it is often necessary to calculate the probability of their impacting a particular target. Work by Klein and Hackett (ref 19, 20) give the hit probability equation as:

$$P = 1 - \exp^{(-q*A_T)}$$

where,

P = Probability of hit

q = Area density of fragments (number of fragments per area) at the range and direction of the target

A_T = Area of target

Note: q and A_T must be in consistent units

30. *Why was the fatality versus kinetic energy curve that is used by SAFER chosen?*

The primary reason is that another government agency (the Range Commanders Council) had previously considered this issue in some detail. Their research had established a commonality method that has been adopted by several agencies as an industry standard (ref 21). After the RBESCT reviewed their research, the same approach was adopted.

31. *What is the basis of the barricade logic?*

The purpose of the barricade logic is to determine the percentage of low angle (PES wall) fragments that are blocked by the barricade. This is done by determining the percentage of fragments ejected at even increments of PES height that are blocked assuming that all ejected fragments would hit the ES if not for the presence of the barricade.

At each height increment, a number of angles are computed as shown in Figure 12 (all are measured from zenith). These angles are used for two purposes: first, to determine the shift required to focus all low angle (PES wall) fragments onto the ES, and then to compute the percentage of the possible ejection angles that would be blocked by the barricade. After the blocked percentage is computed for each height increment, the percentage blocked is averaged over the entire height of the PES to determine the barricade effectiveness at blocking low angle PES fragments. The section below provides the equations used.

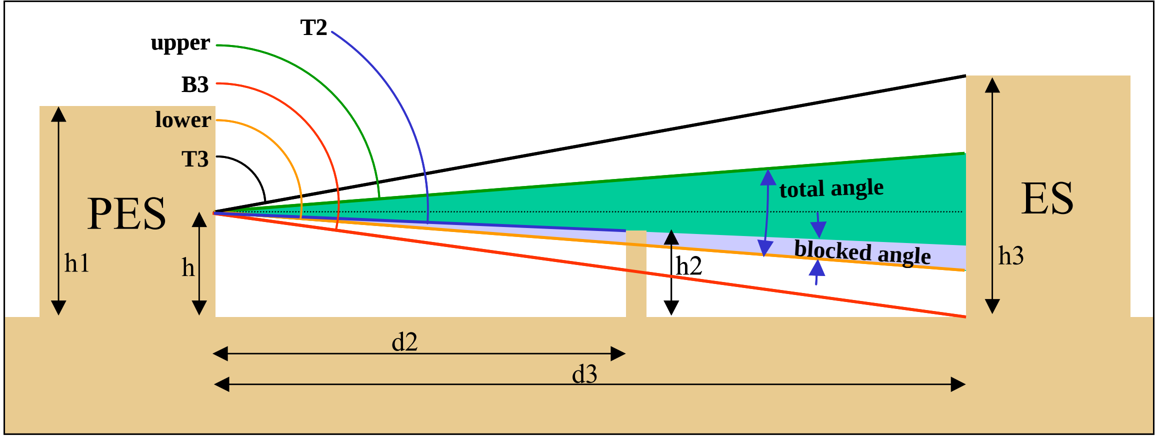


Figure 12. Question 31 – Parameters used by Blocking Algorithm

Starting at h=0 and proceeding until the height of the PES (h1) is reached, compute:

T3 = ACOS[(h3-h) / sqrt($d3^2$ + $(h3\text{-}h)^2$)] = angle to the top of the ES

B3 = ACOS[-h / sqrt($d3^2$ + h^2)] = angle to the base of the ES

T2 = ACOS[(h2 – h) / sqrt($d2^2$ + $(h2 - h)^2$)] = angle to the top of the barricade

upper = IF[B3<90+ ½angle , Max(B3 – 2 * ½angle,T3), Max(90 – ½angle, T3)]
= upper projection angle of fragments from the PES to the ES

lower = IF[T3>90 – ½angle, Min(T3 + 2 * ½angle,B3), Min(90+ ½angle, B3)]
= lower projection angle of fragments from the PES to the ES

total angle = lower – upper = equals the span of angles at which fragments are ejected

blocked angle = Max[0, lower – max(T2,upper)]

local reduction = Max[0, blocked angle / total angle]

When the top of the PES (h1) is reached, the Total Reduction due to the barricade is calculated by:

Total Reduction = [Σ local reductions] / # height increments
= the average local reduction

The Total Reduction is then used to reduce the number of fly-through fragments departing the PES by:

```
    For j = 1 to 7
        Arriving debris mass table j:
        For n = 1 to 10
Bin n: $N_{af}' = N_{af} * (1 - Total\ Reduction)$
    Next n,
Next j.
```

Question 31 is the final question of this memorandum, SAFER 3 Debris.

Attachment 9 – Mensing

An Analytic Approach for Treating Uncertainty in Probabilistic Risk Assessments

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Abstract

When performing probabilistic risk assessments and estimating Risk, it is necessary to recognize and properly accounted for both random variations (aleatory uncertainties) and epistemic uncertainties. To do this, the analysis generally involves extensive computer calculations and simulations including sampling from probability and uncertainty distributions. Occasionally, such extensive computations can be avoided if some simplifying assumptions can reasonably be made. This paper outlines a statistically rigorous analytical approach for estimating Risk and Risk uncertainty when such assumptions are justifiable. The approach, albeit tedious, can be executed on a spreadsheet without the use of simulations. It is illustrated for a risk analysis of fatalities for operations involving explosives in structures at military facilities.

Dr. Mensing has more than 30 years of experience in educational and research environments in theoretical and applied statistics and probability. For more than 15 years, his primary focus has been in risk/safety/hazard analysis, including methods, model development and applications. He also was involved in the development and application of formal expert elicitation techniques, when little or no data is available, for deriving model inputs for risk analyses.

Introduction

The principal element of a quantitative probabilistic risk assessment (PRA) of a potential catastrophic situation is the estimation of Risk, i.e., the expected value of loss due to the occurrence of a catastrophic event. An example is the estimation of the expected number of fatalities at exposed sites (ESs) due to the occurrence of an explosive event at a potential explosion site (PES) within a military facility. Recognizing that the occurrence of the catastrophic event (explosive event) and the loss (number of fatalities) are aleatory (random) variables, Risk (R) is commonly quantified by:

> R = (Expected number of occurrences of the catastrophic event per risk period) x
> (Expected value of loss per occurrence).

When quantifying Risk, it is important to recognize that the expected values in the definition of Risk are generally not known with certainty. Hence, it is important that this knowledge, or epistemic, uncertainty be identified and quantified as part of the Risk estimation process. In a previous paper,[1] a two-phased simulation methodology for estimating Risk, which accounted for both the inherent random variations of the risk environment and the epistemic uncertainties inherent to the estimation process, was outlined. If simulations are not practical, it may be possible, if rea-

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[1] Mensing, R. W. and A. D. Barondes, "Treatment of Uncertainty in the Estimation of Risk," *Proceedings of the 30th U. S. DoD Explosives Safety Seminar*, Atlanta, GA, 2002.

sonable assumptions can be made, to develop an analytical approach to estimating Risk. This paper outlines such an analytical approach, recognizing both aleatory (random) variation and epistemic (knowledge and modeling) uncertainties, for developing point and bounding estimates of Risk. The approach is illustrated for estimating the Risk, i.e., expected number of fatalities at exposed sites (ESs), associated with the occurrence of an explosive event at a potential explosion site (PES).

Risk Estimation

The process of estimating Risk involves a number of steps when both the random variations inherent to the risk scenario and the uncertainties associated with modeling such a scenario are recognized. The first step in the Risk estimation process is development of a mathematical/probabilistic model of the environment and risk source of interest, i.e., to develop a model of the physical situation of interest, referred to as the model of the world (MOW). The MOW includes deterministic models, e.g., structural models, as well as probabilistic models, e.g., occurrence of the catastrophic event, magnitude of the event, extent of structural damage, magnitude of loss, etc. Such an MOW forms the basis for estimating Risk. An example of a risk scenario is the risk associated with operations, e.g., storage or maintenance, involving explosives at sites within a military facility. For this scenario one risk of interest is the number of fatalities at exposed sites (ESs) within the vicinity of a potential explosion site (PES). For this case, the MOW would include models of:

- Physical characteristics of the ES and PES structures,
- Temporal distributions of the quantity of explosives at the PES and the number of personnel at the ES,
- Occurrence and magnitude of explosive events at the PES,
- Severity of the explosive effects at the ES,
- Occurrence of fatalities at the ES.

A reasonable MOW could be based on the following assumptions:

1. Risk period:

   Generally, the risk period of interest is a ‘typical’ calendar year (365 days or 8760 hours). Because explosive materials may not be present at a PES during the entire year, the time explosives are present in the PES in a ‘typical’ year will vary between different types of sites and facilities. For example, a ‘typical’ year for a long-term storage site is likely to involve explosive materials being in the site all year. On the other hand, for a maintenance site in which operations may go on only 8 hours a day, 5 days a week, explosives may only be present approximately 24 percent of the year.

2. The quantity of explosive materials or net explosive weight (NEW) at a PES and the number of exposures (E) at an ES:

   When present, the operational quantity of explosives at a PES, denoted NEW, is assumed to be constant. However, for some sites, it is assumed that there could be some day-to-day variation in the NEW involved in the operations. It is assumed that the amount of NEW will affect both the probability of an explosive event occurring and, given the event occurs, the probability that an individual at an ES is a fatality. The effect of the day-to-day variation on the probability an explosive event occurs is assumed to be described by a lognormal distribution (0, σ_{NEW1}) [see Item 3 below]. The effect of the day-to-day variation on the probability of a fatality, when an explosive event occurs, is also assumed to be described by a lognormal distribution (0, σ_{NEW2}) [see Item 5 below].

The number of exposures, E, in an ES is assumed to be constant throughout the fraction of the operating year when exposures are present except for some day-to-day variation. The temporal random variation in E between days is assumed to have a lognormal probability distribution. The parameters of the distribution are a fixed number of exposures, considered to be the median daily number of exposures, E_o, and the standard deviation, σ_e, of the logarithm of a multiplicative factor, δ_e, describing the day-to-day variation in the number of daily exposures, E. Thus E is modeled as

$$E = E_o * \delta_e$$

where δ_e is a lognormal random variable with parameters (0, σ_e). It is assumed that, in some situations, the day-to-day variation of E would affect the expected number of explosive events, λ. The effect of this day-to-day variation on the probability an explosive event occurs is assumed to be described by a lognormal distribution (0, σ_{e1}) [see Item 3 below].

The effects of the random variation of the quantity of explosives at the PES and the number of exposures at the ES are assumed to be correlated random variables[see Item 3 below].

3. Occurrence of an explosive event at a PES:

Explosive events at a PES are assumed to occur at ‘random’ throughout the ‘operating’ year of a PES (where operating time refers to time when explosives are present at the PES and the potential exists for an explosive event to occur). Thus, the number of explosive events per operating year is assumed to follow a Poisson distribution with parameter λ, the expected number of explosive events per operating year. [Note: Given the Poisson assumption, the probability that exactly one event occurs per year is $\lambda e^{-\lambda}$ ($\approx \lambda$)] If explosives are present for only a fraction of a calendar year, the expected number of explosive events per ‘typical’ year would be the fraction times λ. It is assumed that the expected number of explosive events per year, denoted by λ, refers to the adjusted value of λ, i.e., the expected number of explosive events per ‘typical’ year.

For each type of site, e.g., maintenance or storage, there may be circumstances that would cause the expected number of explosive events at a particular site to vary from the nominal expected number. This is modeled by a multiplicative scaling factor, S, applied to the nominal λ for the appropriate facility type. Examples are facilities located outside the CONUS or facilities at which the explosives are exposed to the environment.

If loss is the number of fatalities among an exposed population (exposures) at an ES, the consequence of the explosive event is significant, i.e., fatalities may occur, only if the exposures are present at the time of the explosive event. Thus, if exposures are present for a fraction, Δt, of time explosives are present at a PES, Δt represents the portion of the operating year when the loss could be greater than zero. For example, suppose the PES is a maintenance site operating 8 hours a day, 5 days of the week, and exposures are present in the ES during the same hours of the year. Then, $\Delta t = 1$. Alternatively, if explosives are present at the PES 16 hours a day, 5 days a week, and exposures are present at an ES for 8 hours a day, 5 days a week, then, $\Delta t = 0.5$. Note that it is assumed that λ has been adjusted to account for the 24 percent of the year the explosives are present in the PES.

During the portion of the year when explosives are present at the PES and exposures are present at the ES, the expected number of explosive events, λ, is assumed to be a function of NEW and E, and hence a temporal random variable. It is assumed that the random variation in λ is modeled by a lognormal distribution. Hence, λ is modeled as:

$$\lambda = \lambda_o * \delta_{NEW1} * \delta_{e1}$$

where λ_o is the nominal value of the expected number of explosive events per typical year, assumed to be the median value of λ and δ_{NEW1}, δ_{e1} are the joint random effects of NEW and E, modeled by a joint lognormal distribution $[(0,0); \sigma_{NEW1}, \sigma_{e1}, \rho_{Ne}]$, where ρ_{Ne} represents the correlation between the logarithms of δ_{NEW1} and δ_{e1}

4. Effects of the Explosive Event at an ES

   Given an explosive event, the yield and all effects, i.e., overpressure and impulse, glass breakage, building collapse and debris, are random variables. The effect of the random variation in yield and individual effects on the probability of a fatality, when an explosive event occurs, is assumed described by lognormal distributions [See Item 5 below]

5. Number of Fatalities at an ES

   Given an explosive event, the number of fatalities at an ES is assumed to be a binomial random variable with parameters $n = E$, $p = p_{f|e}$, which is a function of the probabilities of a fatality, $p_{f|k}$, $k = 1,2,3,4$, associated with the four effects. The probability $p_{f|e}$ is the probability that an individual is a fatality due to at least one of the effects, i.e.,

$$\begin{aligned} p_{f|e} &= p_{f|1} + (1- p_{f|1})* p_{f|2} + (1- p_{f|1})*(1- p_{f|2})* p_{f|3} + (1- p_{f|1})*(1- p_{f|2})*(1- p_{f|3})* p_{f|4} \\ &= \Sigma_k\, p_{f|k} - \Sigma_{i\neq k}\, p_{f|i}\, p_{f|k} + \Sigma_{i\neq j\neq k}\, p_{f|i}\, p_{f|j}\, p_{f|k} - \Pi_k\, p_{f|k} \end{aligned}$$

   Each of the probabilities, $p_{f|k}$, is a function of NEW, yield and the corresponding effect. The variation in each of the probabilities, $p_{f|k}$, due to the random variation in yield and the corresponding effect, as well as the day-to-day variation in NEW, is assumed to have a distribution, which is approximated by a lognormal probability distribution. Specifically, it is assumed that:

$$p_{f|k} = p_{f|ko} * \delta_k * \delta_y * \delta_{NEW2}$$

   where $p_{f|ko}$ is the median value of $p_{f|k}$, δ_k is the variation due to the random variation in the k^{th} effect, δ_y is the variation due to the random variation in yield and δ_{NEW2} is the variation due to the day-to-day variation in NEW. The multiplicative factor, δ_k has a lognormal distribution with parameters $(0, \sigma_k)$, δ_y has a lognormal distribution with parameters (0, σ_y) and δ_{NEW2} has a lognormal distribution with parameters (0, σ_{NEW2}). The three multiplicative factors are assumed to be independent.

6. Correlations

   Because λ and $p_{f|k}$ are both functions of the random variable NEW, it is possible that these random variables are themselves correlated. This would be modeled by assuming that the effects of the random variation of NEW on λ and $p_{f|k}$, δ_{NEW1} and δ_{NEW2}, respectively, are correlated. However, the variable λ characterizes the occurrence of an explosive event, whereas $p_{f|k}$ relates to the probability of a fatality given an event occurs. It seems reasonable that the effect of the temporal random variation in NEW will not necessarily translate in a linearly related way relative to the random variation in λ and $p_{f|k}$. Thus, the model assumes the effects of the random variation in NEW on λ and $p_{f|k}$, respectively, are independent.

   Since λ is a function of the random variable E, it is assumed that, as random variables, λ and E are correlated. The correlation is modeled by assuming that there is a linear relation between the logarithm of the δ terms characterizing the effects of the random temporal variation in the number of exposures at an ES. Specifically, it is assumed that $\ln \delta_{e1} = r^*\ln \delta_e$, where r is the ratio of the standard deviations of the two logarithms, i.e., $r = \sigma_{e1}/\sigma_e$.

The above assumptions form the basis for developing the MOW.

The second step of the risk estimation process is quantifying the MOW. The MOW involves a number of probability distributions each with its appropriate parameters. Thus, quantification of the MOW involves specifying models and values for the model parameters. Generally there is uncertainty associated with specifying the models and values of the parameters due to incomplete information. Therefore, in addition to specifying the MOW, it is necessary to quantify the knowledge or epistemic uncertainties associated with creating the MOW. This could include allowance for more than one version of a deterministic model (e.g., structure) or for an expression of the uncertainties associated with specifying the values of the model parameters (e.g., the parameters of the probability distributions describing the random variation modeled in the MOW).

The following assumptions are made regarding epistemic uncertainties associated with developing the MOW for the risk analysis of explosive events at a PES. The illustration is limited to assuming the principal uncertainty in specifying the probability models in the MOW is the state of knowledge about values of parameters and values of the median of a lognormal random variable:

1. The epistemic uncertainty associated with evaluating λ_o, the median expected number of explosive events per ‘typical’ year, is reasonably described by a lognormal distribution. The parameters of the uncertainty distribution are the median, λ_{oo}, and the standard deviation, $\sigma_{\lambda o}$, of the logarithm of a multiplicative factor, $\delta_{\lambda o}$. Thus, the uncertainty in λ_o is described in terms of the identity:

   $$\lambda_o = \lambda_{oo}{}^*\delta_{\lambda o}$$

   where $\delta_{\lambda o}$ has a lognormal uncertainty distribution with parameters (0, $\sigma_{\lambda o}$).

2. The epistemic uncertainty associated with assessing the appropriate value of the scaling factor, S, is reasonably described by a lognormal distribution. The parameters of the uncertainty distribution are the median of S, S_o, and the standard deviation, σ_S, of the logarithm of a multiplicative factor, δ_S. Thus, the uncertainty in S is described in terms of the identity:

   $$S = S_o*\delta_S$$

   where δ_S has a lognormal uncertainty distribution with parameters $(0, \sigma_S)$.

3. The epistemic uncertainty associated with evaluating Δt, the fraction of the operating year that exposures are present in the ES, is reasonably described by a lognormal distribution. The parameters of the uncertainty distribution are the median of Δt, Δt_o, and the standard deviation, $\sigma_{\Delta t}$, of the logarithm of a multiplicative factor, $\delta_{\Delta t}$. Thus, the uncertainty in Δt is described in terms of the identity:

   $$\Delta t = \Delta t_o*\delta_{\Delta t}$$

   where $\delta_{\Delta t}$ has a lognormal uncertainty distribution with parameters $(0, \sigma_{\Delta t})$.

4. The epistemic uncertainty associated with evaluating the median number of daily exposures in an ES, E_o, is reasonably described by a lognormal distribution. The parameters of the uncertainty distribution are the median value, E_{oo}, and the standard deviation, σ_{Eo}, of the logarithm of a multiplicative factor, δ_{Eo}. Thus, the uncertainty in the median E_o is described in terms of the identity:

   $$E_o = E_{oo}*\delta_{Eo}$$

   where δ_{Eo} has a lognormal uncertainty distribution with parameters $(0, \sigma_{Eo})$.

5. For each of the four effects, k = 1,2,3,4, the epistemic uncertainty associated with evaluating the median of the probability of a fatality due to effect k, $p_{f|k,o}$, is assumed to be based on uncertainty in modeling the effects as well as uncertainty in assessing the median yield of the explosive event. The overall epistemic uncertainty in $p_{f|k,o}$ is reasonably described by a lognormal distribution. The parameters of the uncertainty distribution are the medians of $p_{f|k,o}$, $p_{f|k,oo}$, and the standard deviations, σ_{ko} and σ_{yo}, of the logarithm of multiplicative factors, δ_{ko} and δ_{yo}, respectively. That is, the epistemic uncertainty in specifying the median $p_{f|k,o}$ can be described in terms of the identity:

   $$p_{f|k,o} = p_{f|k,oo}*\delta_{ko}*\delta_{yo}$$

   where δ_{ko} has a lognormal uncertainty distribution with parameters $(0, \sigma_{ko})$ and δ_{yo} has a lognormal uncertainty distribution with parameters $(0, \sigma_{yo})$. It is assumed that the effects of the uncertainties in assessing the median yields on the median probabilities of a fatality, modeled by δ_{yo}, are independent between the different effects.

Analytical Approach

Given the MOW and descriptions of the epistemic uncertainties, the third step of the Risk estimation process is evaluation of the estimate of Risk. Because of the complexity of the analysis, the most common approach is based on sampling from epistemic uncertainty distributions and MOW models and performing computer simulations to estimate Risk. Alternatively, based on the reasonableness of the simplifying assumptions, an analytical expression may be developed.

The analytical approach to estimating Risk is based on starting with the generally accepted definition of Risk or the expected value of loss, e.g., the expected number of fatalities per risk period. For example, consider a scenario in which a catastrophic event occurs as a Poisson (λ) event over time and, given an event occurs, the number of fatalities due to the event is reasonably modeled as a binomial (n,p) random variable. The parameter n is the number of exposures and p is the probability that an individual is a fatality. In this scenario the Risk, F, i.e., the expected number of fatalities per risk period is

$$F = \lambda * n * p$$

Since F is a function of the parameters of the probability distributions describing the random variation, it can be evaluated if the values of the parameters are known with certainty. However, these values are seldom known with certainty. They are generally subject to knowledge (epistemic) uncertainty. Given the uncertainty associated with the models and model parameters, F can be treated as an epistemic uncertain variable. That is, F can be treated as a Risk estimator. The epistemic uncertainty distribution of F, comparable to the sampling distribution of an estimator in statistical estimation, provides a basis for developing point and bounding estimates of Risk. In particular, the epistemic expected value and standard deviation of F can be assessed. These parameters, along with specification of an appropriate distribution family for the uncertainty distribution, provide point and uncertainty bound estimates of Risk for PRAs. Specifically, the expected value of the epistemic uncertainty distribution of F provides a point estimate of Risk and the appropriate percentiles of the uncertainty distribution provide bounding estimates of Risk.

To illustrate development of such estimates, consider the estimation of Risk at ES due to explosive events at a PES containing explosives, as modeled in the previous section. Based on the assumptions outlined in the previous section, for fixed values of the random variables, E, NEW, yield and effects, the conditional expected number of fatalities per year is

$$F = \Delta t * S * \lambda(\mathrm{NEW}, E) * p_{f|e}(\mathrm{NEW}, \text{yield}, \text{effects}) * E \tag{1}$$

Risk, i.e., the (unconditional) expected number of fatalities per year, is the expected value of F, taken with respect to the distributions of the random variables. Thus, Risk is

$$E\mathrm{F} = \Delta t * S * E(\lambda * E) * E(p_{f|e}) \tag{2}$$

The notation *E*(.) refers to the expected value of the respective random variable (or uncertain model parameter). Based on the assumptions outlined in the previous section,

$$E(\lambda * \mathrm{E}) = \lambda_o * E_o * \exp[0.5(\sigma^2_{NEW1} + (r+1)^2 * \sigma^2_e + 2(r+1) * \rho_{Ne} * \sigma_{NEW1} * \sigma_e)] \tag{3}$$

$$E(p_{f|e}) = \Sigma_k\, p_{f|k,o} * \exp(0.5\sigma^2_{k1}) - \Sigma_{i \neq k}\, p_{f|i,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ik}) + \Sigma_{i \neq j \neq k}\, p_{f|i,o} * p_{f|j,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ijk}) - \{\Pi_k\, p_{f|k,o}\} * \exp(0.5\sigma^2_{1234}) \tag{4}$$

Notationally,

$\sigma^2_{k1} = \sigma^2_k + \sigma^2_y + \sigma^2_{NEW2}$

$\sigma^2_{ik} = \sigma^2_i + \sigma^2_k + 4(\sigma^2_y + \sigma^2_{NEW2})$

$\sigma^2_{ijk} = \sigma^2_i + \sigma^2_j + \sigma^2_k + 9(\sigma^2_y + \sigma^2_{NEW2})$

$\sigma^2_{1234} = \Sigma_k\sigma^2_k + 16(\sigma^2_y + \sigma^2_{NEW2})$.

If the values of the parameters in Equations (2) through (4) are known without (epistemic) uncertainty, these identities provide the value of Risk. Given this is not the case, it is appropriate to develop estimates of Risk, which recognize the uncertainties associated with assessing Risk.

Given that the parameters, Δt, S and the median values λ_o, E_o, and the $p_{f|k,o}$; k=1,2,3,4 are subject to epistemic uncertainty, the expression of *E*F in Equation (2) through (4) identifies an (epistemic) estimator of Risk. The epistemic uncertainty is quantified by the uncertainty distribution of the estimator *E*F. Based on risk estimation with uncertainty, a point estimate of Risk is the expected value of the estimator *E*F, i.e., the expected value of the uncertainty distribution. The epistemic variance of *E*F provides a basis for developing uncertainty bound/interval estimates of Risk. The following are the expected value and variance of the uncertainty distribution based on assuming epistemic uncertainty in the parameters Δt, S, λ_o, E_o and the $p_{f|k,o}$; k=1,2,3,4 as outlined in the previous section.

1. Expected Value

   Based on the epistemic uncertainty models outlined in the previous section and assuming independence between the epistemic uncertainties of the four terms in *E*F, the expected value of the uncertainty distribution of the epistemic estimator *E*F, denoted, $E_{ep}(EF)$, is

   $$E_{ep}(EF) = E_{ep}(\Delta t)*E_{ep}(S)*E_{ep}[E(\lambda*E)]*E_{ep}[E(p_{f|e})]$$
   $$= \Delta t_o*\exp(0.5\sigma^2_{\Delta t})*S_o*\exp(0.5\sigma^2_S)*E_{ep}[E(\lambda*E)]*E_{ep}[E(p_{f|e})].$$

   The individual expected values are

   $E_{ep}(\Delta t) = \Delta t_o*\exp(0.5\sigma^2_{\Delta t})$

   $E_{ep}(S) = S_o*\exp(0.5\sigma^2_S)$

   $E_{ep}[E(\lambda*E)] = \lambda_{oo}*E_{oo}*\exp[0.5(\sigma^2_{\lambda o} + \sigma^2_{Eo} + \sigma^2_{NEW1} + (r+1)^2*\sigma^2_e + 2(r+1)*\rho_{Ne}*\sigma_{NEW1}*\sigma_e)]$

   $E_{ep}[E(p_{f|e})] = \Sigma_k p_{f|k,oo}*\exp[0.5(\sigma^2_{k1}+\sigma^2_{ko1})] - \Sigma_{i\neq k}p_{f|i,oo}*p_{f|k,oo}*\exp[0.5(\sigma^2_{ik}+\sigma^2_{iko})] + \Sigma_{i\neq j\neq k}\, p_{f|i,oo}*p_{f|j,oo}*p_{f|k,oo}*\exp[0.5(\sigma^2_{ijk} + \sigma^2_{ijko})] - (\Pi_k p_{f|k,oo})*\exp[0.5(\sigma^2_{1234} + \sigma^2_{1234o})]$.

   The variances in the identity for $E_{ep}[E(p_{f|e})]$ are respectively

   $\sigma^2_{k1} = \sigma^2_k + \sigma^2_y + \sigma^2_{NEW2}$

   $\sigma^2_{ko1} = \sigma^2_{ko} + \sigma^2_{yo}$

   $\sigma^2_{ik} = \sigma^2_i + \sigma^2_k + 4(\sigma^2_y + \sigma^2_{NEW2})$

   $\sigma^2_{iko} = \sigma^2_{io} + \sigma^2_{ko} + 4\sigma^2_{yo}$

   $\sigma^2_{ijk} = \sigma^2_i + \sigma^2_j + \sigma^2_k + 9(\sigma^2_y + \sigma^2_{NEW2})$

$\sigma^2_{ijko} = \sigma^2_{io} + \sigma^2_{jo} + \sigma^2_{ko} + 9\sigma^2_{yo}$

$\sigma^2_{1234} = \Sigma_k \sigma^2_k + 16(\sigma^2_y + \sigma^2_{NEW2})$

$\sigma^2_{1234o} = \Sigma_k \sigma^2_{ko} + 16\sigma^2_{yo}$

2. Variance

Based on the epistemic uncertainty models outlined in the previous section and assuming independence between the epistemic uncertainties of the four terms in EF, the variance of the epistemic estimator EF, denoted, $V_{ep}(E\mathrm{F})$, is

$V_{ep}(E\mathrm{F}) = V_{ep}[\Delta t * S * E(\lambda * E) * E(p_{f|e})]$

$= E^2_{ep}(\Delta t) * E^2_{ep}(S) * E^2_{ep}[E(\lambda * E)] * E^2_{ep}[E(p_{f|e})] * \{CV^2_{\Delta t} + CV^2_S + CV^2_{E(\lambda * E)} + CV^2_{E(pf|e)} + CV^2_{\Delta t} * CV^2_S + CV^2_{\Delta t} * CV^2_{E(\lambda * E)} + CV^2_{\Delta t} * CV^2_{E(pf|e)} + CV^2_S * CV^2_{E(\lambda * E)} + CV^2_S * CV^2_{E(pf|e)} + CV^2_{E(\lambda * E)} * CV^2_{E(pf|e)} + CV^2_{\Delta t} * CV^2_S * CV^2_{E(\lambda * E)} + CV^2_{\Delta t} * CV^2_S * CV^2_{E(pf|e)} + CV^2_{\Delta t} * CV^2_{E(\lambda * E)} * CV^2_{E(pf|e)} + CV^2_S * CV^2_{E(\lambda * E)} * CV^2_{E(pf|e)} + CV^2_{\Delta t} * CV^2_S * CV^2_{E(\lambda * E)} * CV^2_{E(pf|e)}\}$.

For any term X:

$CV^2_X = V_{ep}(X)/E^2_{ep}(X)$.

The individual variances are

$V_{ep}(\Delta t) = \Delta t^2_o * \exp(\sigma^2_{\Delta t}) * [\exp(\sigma^2_{\Delta t}) - 1]$

$V_{ep}(S) = S^2_o * \exp(\sigma^2_S) * [\exp(\sigma^2_S) - 1]$

$V_{ep}[E(\lambda * E)] = \exp[\sigma^2_{NEW1} + (r+1)^2 * \sigma^2_e + 2(r+1) * \rho_{Ne} * \sigma_{NEW1} * \sigma_e] * E^2_{ep}(\lambda_o) * E^2_{ep}(E_o) * [CV^2_{\lambda o} + CV^2_{Eo} + CV^2_{\lambda o} * CV^2_{Eo}]$

- $E_{ep}(\lambda_o) = \lambda_{oo} * \exp(0.5\sigma^2_{\lambda o})$
- $E_{ep}(E_o) = E_{oo} * \exp(0.5\sigma^2_{Eo})$
- $V_{ep}(\lambda_o) = \lambda^2_{oo} * \exp(\sigma^2_{\lambda o}) * [\exp(\sigma^2_{\lambda o}) - 1]$
- $V_{ep}(E_o) = E^2_{oo} * \exp(\sigma^2_{Eo}) * [\exp(\sigma^2_{Eo}) - 1]$

$V_{ep}(E(p_{f|e})) \cong V_{ep}\{\Sigma_k\, p_{f|k,o} * \exp(0.5\sigma^2_{k1})\} + V_{ep}\{\Sigma_{i \neq k}\, p_{f|i,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ik})\} + {}_{ep}\{\Sigma_{i \neq j \neq k}\, p_{f|i,o} * p_{f|j,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ijk})\} + V_{ep}\{\Pi_k\, p_{f|k,o} * \exp(0.5\sigma^2_{1234})\}$.

The individual terms in the identity for $V_{ep}(E(p_{f|e}))$ are

$V_{ep}\{\Sigma_k\, p_{f|k,o} * \exp(0.5\sigma^2_{k1})\} = \Sigma_k\, p^2_{f|k,oo} * \exp(\sigma^2_{k1} + \sigma^2_{ko1}) * [\exp(\sigma^2_{ko1}) - 1] + 2\Sigma_{i \neq k}\, p_{f|i,oo} * p_{f|k,oo} * \exp(0.5(\sigma^2_{i1} + \sigma^2_{io1} + \sigma^2_{k1} + \sigma^2_{ko1})) * [\exp(\sigma^2_{yo}) - 1]$

$V_{ep}\{\Sigma_{i \neq k}\, p_{f|i,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ik})\} = \Sigma_{i \neq k}\, p^2_{f|i,oo} * p^2_{f|k,oo} * \exp(\sigma^2_{ik} + \sigma^2_{iko}) * [\exp(\sigma^2_{iko}) - 1] + 2\Sigma_{i \neq k,\, j \neq l} \exp(0.5(\sigma^2_{ik} + \sigma^2_{jl})) * COV(p_{f|i,o}\, p_{f|k,o};\, p_{f|j,o}\, p_{f|l,o})$.

The covariance, COV(.), has one of two forms:

- $i \neq k \neq j \neq l$: $COV(p_{f|i,o}\, p_{f|k,o};\, p_{f|j,o}\, p_{f|l,o}) = (\Pi_k\, p_{f|k,oo}) * \exp(0.5(\Sigma_k \sigma^2_{ko} + 4\sigma^2_{yo})) * [\exp(4\sigma^2_{yo}) - 1]$

- $i \neq k$, $i \neq l$; i.e., two subscripts are the same: $\mathrm{COV}(p_{f|i,o}\, p_{f|k,o};\ p_{f|i,o}\, p_{f|l,o}) =$ $p^2_{f|i,oo} * p_{f|k,oo} * p_{f|l,oo} * \exp(0.5(2\sigma^2_{io} + \sigma^2_{ko} + \sigma^2_{lo} + 4\sigma^2_{yo})) * [\exp(\sigma^2_{io} + 3\sigma^2_{yo}) - 1]$

  $V_{ep}\{\Sigma_{i \neq j \neq k}\, p_{f|i,o} * p_{f|j,o} * p_{f|k,o} * \exp(0.5\sigma^2_{ijk})\} = \Sigma_{i \neq j \neq k}\, p^2_{f||i,oo} * p^2_{f|j,oo} * p^2_{f|k,oo} * \exp(\sigma^2_{ijk} + \sigma^2_{ijko}) * [\exp(\sigma^2_{ijko}) - 1] + 2\Sigma_{i \neq j \neq k,\ i \neq j \neq l}\, p^2_{f|i,oo} * p^2_{f|j,oo} * p_{f|k,oo} * p_{f|l,oo} * \exp(0.5(\sigma^2_{ijk} + \sigma^2_{ijl})) * \exp(0.5(2\sigma^2_{io} + 2\sigma^2_{jo} + \sigma^2_{ko} + \sigma^2_{lo} + 12\sigma^2_{yo})) * [\exp(\sigma^2_{io} + \sigma^2_{jo} + 7\sigma^2_{yo}) - 1]$

  $V_{ep}\{\Pi_k\, p_{f|k,o} * \exp(0.5\sigma^2_{1234})\} = \Pi_k\, p^2_{f|k,oo} * \exp(\sigma^2_{1234} + \sigma^2_{1234o}) * [\exp(\sigma^2_{1234o}) - 1]$.

Given the expected value and variance of the uncertainty distribution, the expected value provides a point estimate of Risk. Given a choice of a distribution family for the uncertainty distribution, the percentiles of the distribution, which are functions of the expected value and standard deviation, provides a basis for developing uncertainty bounds for Risk. For example, suppose it is reasonable to treat EF as a lognormal uncertain variable. Given the uncertainty information, calculate $E_{ep}(E\mathrm{F})$ and $V_{ep}(E\mathrm{F})$. Using the identities for the lognormal distribution for a lognormal variable X:

$$E(X) = \exp[E(\ln X) + 0.5 * V(\ln X)]$$

$$V(X) = E^2(X) * [\exp(V(\ln X)) - 1],$$

solve for:

$$V(\ln X) = \ln[(V(X)/E^2(X)) + 1]$$

$$E(\ln X) = \ln[E(X)] - 0.5 * V(\ln X).$$

The αth percentile for X is

$$X_\alpha = \exp[E(\ln X) + U_\alpha * SD(\ln X)]$$

where U_α is the αth percentile of the standard normal distribution and $SD(.)$ refers to the standard deviation.

Discussion

The analytical approach is based on:

1. identifying the epistemic estimator of Risk as the expected value of loss, evaluated with respect to the inherent random variation,
2. developing point and bounding estimates of Risk based on evaluating the epistemic expected value and variance of the epistemic estimator of risk, along with a model of the uncertainty distribution of the estimator.

Successful application of the methodology relies, significantly, on development of the MOW and modeling of the epistemic uncertainties associated with the MOW. The quality of the Risk estimator and its ability to provide useful estimates for Risk decision making will be limited to how well the MOW depicts the actual physical environment being analyzed. The more the MOW deviates from reality, the less useful the analysis will be. This is always a concern with using mathematical/probability models to model reality, whether an analytical or computational/simulation approach to risk assessments is used.

Similarly, the uncertainty distributions, describing the current state of knowledge in developing and quantifying the MOW, are critical to the quality of both analytical and computational risk analyses. Whereas the computational approach requires each of the uncertainty distributions to be identified, the analytical approach only requires the epistemic expected values and variances of the parameters of the MOW to be identified. However, as discussed in the previous section of the paper, to construct bounding estimates of Risk, an appropriate type of distributional family depicting the epistemic uncertainty of the Risk estimator must be identified. Due to the complexity of the Risk estimator and the mixing of a large number of uncertainty distributions, no one family of distributions is obvious. Certainly, the distribution must be defined over positive space and one might expect the distribution to be skewed, i.e., have a long tail toward higher values. Some potential candidate distributions might include the lognormal, gamma, Weibull and extreme value distributions, which are all fairly robust distributional families. Choice of the uncertainty distribution is critical to providing useful bounding estimates of Risk and the successful application of the analytical approach.

Acronyms and Symbols

CONUS	continental United States
COV	covariance
CV	coefficient of variation
E	exposures (personnel)
E	expected value
e	explosive event
ES	exposed site
exp(.)	exponential function
F	fatalities
i,j,k	indices of fatality causing effects
ln	natural logarithm
MOW	model of the world
n	number of occurrences
NEW	net explosive weight
$p_{f\|e}$	probability of a fatality given an explosive event occurs
$p_{f\|k}$	probability of a fatality given the k^{th} effect
PES	potential explosion site
R	Risk
S	scaling factor
SD	standard deviation
t	time
U_α	αth percentile of the standard normal distribution
V	variance
X	random variable
δ	variation multiplicative factor
λ	expected frequency of occurrence
σ^2_X	variance of random variable X
ρ	correlation
Π	product function

Σ	summation function

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Attachment 10 – P(e) Matrix

P(e) Matrix

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Revision Date – 091205

PURPOSE

This memorandum addresses major technical and analytical decisions made as part of the SAFER Version 3.0 P(e) matrix. Specific questions addressed are:

1. Where did the data come from?
2. Did all the Services provide data?
3. Why do we not have different matrixes for each Service?
4. How were the activity types selected?
5. Why are there different probabilities of event based on storage and transportation compatibility group?
6. How were the groups of CGs chosen?
7. Why were environmental factors developed?
8. How were the environmental factor categories chosen?
9. How were environmental factor numbers determined?

REFERENCES

1. Final IOC Risk Report Volumes I, II, and III, "Industrial Operations Command Safety and Security Risk Analysis," prepared by Quantitech, Inc. for the U.S. Army Industrial Operations Command (IOC), 28 February 1997.
2. Final Phase I report, "Risk-Based Explosives Safety Criteria," prepared by APT Research, Inc., 15 September 1998.
3. RBESCT Minutes.
4. Statistical analyses of background P(e) data presented at RBESCT meetings

DISCUSSIONS

WHAT IS THE P(E) MATRIX?

A P(e) Matrix is used by SAFER to determine the probability of an explosive event, P(e), at a Potential Explosive Site (PES). The matrix is based on the type of explosive involved, the type of operation being performed and other environmental factors that effect the likelihood of an unplanned explosive event occurring.

1. Where did the data come from?

   Two data sources were used as the original foundation for the P(e) estimates. They are the DDESB accident database and the Army Industrial Operations Command (IOC) Risk Report. The SAFER Version 3.0 matrix contained additional information from the Army, Navy, Air Force, and Marine Corps. This data is shown following the questions and responses in this memo.

2. Did all the Services provide data?

   Yes. After the original matrix was developed the Air Force questioned if the data was applicable to the Air Force, Navy and Marines because the majority of the data used to develop the matrix came from the Army and reference 1. Therefore, the Services were tasked to research their Services' specific accident databases and number of PESs by activity type. The Services' data was used to determine if a new matrix needed to be developed.

3. Why do we not have different matrixes for each Service?

The RBESCT considered developing Service unique matrixes. After reviewing the accident data provided by each of the Services, it was determined that there were insignificant differences in the accident rates by PES activity type, so unique matrices were not warranted.

4. How were the activity types selected?

Activity types were chosen based on the activities used in the DDESB database. Some of the activities were similar and therefore the RBESCT decided to group some these activities to eliminate confusion. The final list of activities were reviewed by the RBESCT and approved.

5. Why are there different probabilities of event based on storage and transportation compatibility group (CG)?

The RBESCT realized that not all explosives have the same sensitivities to external stimuli. It was decided by the RBESCT to use the explosives' Storage Compatibility Groups (CG) to account for different sensitivities. The CG was chosen because:

a. All explosives have a CG assigned during the Hazard Classification process,
b. CGs are well defined and should be understood by the persons using SAFER, and
c. CGs can be grouped by sensitivity as described in question 6.

6. How were the groups of CGs chosen?

The CGs were divided into three sensitivity groups. Group I was considered the most sensitive to external stimuli and includes CGs L, A, B, G, H, J, and F. Group II is considered having an average sensitivity. Group II includes CG C and includes all propellants. In storage, Group II (propellants) is considered the most sensitive because propellants having depleted stabilizer can autoignite. Group III was considered the least sensitive and includes CGs D, E and N.

7. Why were environmental factors developed?

Environmental factors were developed to account for circumstances that increased the probability of event. (e.g. hostile environments, initial testing, inclement weather.)

8. How were the environmental factor categories chosen?

The Services developed situations that activities might be performed in that would increase the probability of an event occurring. This list was divided into two categories. The first group was considered to have a major effect on the probability of event and was assigned a environmental factor of 10 (representing 1 order of magnitude increase in risk). The second group was considered to have a minor effect on the probability of event and was assigned a environmental factor of 3 (representing ½ order of magnitude increase in risk).

9. How were environmental factor numbers determined?

The RBESCT determined the magnitude of the environmental factors based on experience.

FY97 – FY02 Army Explosive Mishap Summary

PES used primarily for	Paragraph	Number of Mishaps A-C D-H
Assembly/Disassembly/LAP/Maintenance/Renovation	1 – 12	12
Burning Ground/Demil/Demolition/Disposal	13 – 14	2
Lab/Test/Training		
Loading/Unloading		
Inspection/Painting/Packing	15	1
Manufacturing	16 – 18	3
Deep Storage (longer than 1 month)	19	1
Temporary Storage (1 day to 1 month)		
TOTAL A, B, C, D & H MISHAPS		19

Paragraphs 1 – 19 are class A, B, C, D & H mishaps.

1. Assembly - Lathing LX-19 bullet liner. No injuries.
2. Assembly - Consolidation of explosives into sub-munition. No injuries.
3. Assembly - Warhead pressing. No injuries.
4. Assembly - Warhead pressing. No injuries.
5. Assembly - Fire destroyed (?) plus buildings. No injuries.
6. Assembly - Blending operation. No injuries.
7. Assembly - M55 detonator detonation. 1 injury.
8. Assembly - Detonation during M55 detonator production. 1 injury.
9. Assembly - Flash fire during 120MM mortar illumination mix production. No injuries.
10. Assembly - .50 caliber discharge in packing area. 1 injury.
11. Assembly - Defuzing M67 fragmentation grenades. 2 injuries.
12. Assembly - Rocket motor ignited during removal from M155MM RAP round. No injuries.
13. Burning Ground - Bulldozer ran over 60 mm causing detonation on OD range. No injuries.
14. Burning Ground - Low order explosion during burning of primers. No injuries.
15. Inspection - Fire/explosion in conditioning chamber (60 mm). No injuries.
16. Manufacturing - Fire during propellant extrusion. No injuries.
17. Manufacturing - Explosion during nitroglycerin mixing. No injuries.
18. Manufacturing - Detonation during pre-mix NG2. 3 injuries.
19. Deep Storage - Igloo fire involving stored propellant. No injuries.

FY87 – FY02 Air Force Explosive Mishap Summary

This data will be used to determine the Probability of Event (P_e) table for the Department of Defense Explosives Safety Board (DDESB) sponsored Risk-Based Explosives Safety Criteria Team project, Safety Assessment for Explosives Risk (SAFER). This data is for FY87 through FY02.

PES used primarily for	Paragraph	Number of Mishaps A-C	D-H
Assembly/Disassembly/LAP/Maintenance/Renovation	1 – 5	3	2
Burning Ground/Demil/Demolition/Disposal	6 – 20	13	2
Lab/Test/Training	21 – 29	3	6
Loading/Unloading	30 – 34	3	2
Inspection/Painting/Packing		0	0
Manufacturing	35	1	0
Deep Storage (longer than 1 month)	36	1	0
Temporary Storage (1 day to 1 month)		0	0
TOTAL A, B, C, D & H MISHAPS		24	12

Paragraphs 1 – 36 are class A, B, C, D & H mishaps.

1. C – MJU-7/B flare ignited during build-up.

2. A – Inadvertent actuation of MJU-7 flares in munitions storage area.

3. C – LCBAS forced bgg out due to excess pressure.

4. D – Fire consumed 5000 lbs of propellant.

5. D – Pressure blew ballistic gas generator to floor.

6. C – Safety fuse contacted blasting caps.

7. C – Worker used unauthorized method to detonate GBS-4 LWD.

8. B – Titan 34D booster propellant ignited.

9. B – Jammed 30mm round detonated.

10. C – Functioning of BDU-33 spotting charge.

11. C – Pre-ignition of magnesium/aluminum during demolition.

12. C – Worker burned while improperly disposing black powder.

13. C – MK-199 exploded and injured worker.

14. C – Fuzes detonated while being moved.

15. C – Worker was disposing powder from dud grenade and was burned.

16. C – Ignition of rocker motor during disposal of Minuteman II countermeasure rockets.

17. D – Dud BDU-33 detonated in truck.

18. H – Demolition explosive detonated prematurely on disposal range (16 Feb 99).

19. C – Secondary explosion occurred after destruction of target identification bomb during range clearance of unexploded ordnance (7 Apr 99).

20. C – Black powder flashed during unauthorized disposal on disposal range (25 Jun 99).

21. D – Inadvertent firing of gas generator.

22. D – Inadvertent functioning of MAU-169 gas grain gen during test.

23. D – Thermal battery fired during testing.

24. C – Inadvertent flare activation from aircraft on the flightline (18 Oct 96).

25. D – Inadvertent flexible confined detonating cord on drone during checkout (26 Nov 96).

26. D – Inadvertent flexible confined detonating cord on drone during checkout (28 Jan 97).

27. C – Inadvertent flare activation from aircraft on the flightline (16 Mar 98).

28. D – Inadvertent flare activation from aircraft on the flightline (2 Aug 99).

29. C – AIM-9 missile exploded during aging and surveillance test firing (30 Jun 00).

30. C – Ale-40 system activated during ops check.

31. C – Inadvertent jettison of flare from A-10A aircraft in HAS.

32. C – M-206 flares inadvertently ignited during load.

33. D – Battery firing device inadvertently activated.

34. D – GBU-12 battery firing device fired during install.

35. A – Peacekeeper motor ignited and destroyed AF property.

36. C – 40,000 lb of propellant ignited in storage igloo.

FY87 – FY02 Air Force PES Summary

This data will be used to determine the Probability of Event (P_e) table for the Department of Defense Explosives Safety Board (DDESB) sponsored Risk-Based Explosives Safety Criteria Team project, Safety Assessment for Explosives Risk (SAFER). This data is for FY87 through FY02.

Primary Activity at PES	Time Period	No. of Facilities
Assembly / Disassembly / LAP / Maintenance / Renovation	FY87 – FY02	397
Burning Ground / Demil / Demolition / Disposal	FY87 – FY02	50
Lab / Test / Training	FY87 – FY02	111
Loading / Unloading	FY87 – FY02	800
Inspection / Painting / Packing	FY87 – FY02	206
Manufacturing	FY87 – FY02	0
Deep Storage (longer than 1 month)	FY87 – FY02	4,340
Temporary Storage (1 day to 1 month)	FY87 – FY02	-
In-Transit Storage (hrs to a few days)	FY87 – FY02	-

NAVY EXPLOSIVE MISHAP SUMMARY

FY97-02 NAVY EXPLOSIVE MISHAP SUMMARY

The following descriptions of 27 class A, B and C explosive mishaps were gleaned from COMNAVSAFCEN Letter 8020 Serial 43/0675 of 4 May 1999 and a follow on email generated 18 class D explosive mishaps. This data was used to establish the Probability of Event (P_e) table for the Department of Defense Explosives Safety Board (DDESB) sponsored Risk-Based Explosives Safety Criteria Team project.

	PES used primarily for	Paragraph	Number of Mishaps	
			A-C	D
A	Assembly/Disassembly/LAP/Maintenance/Renovation	13, 15, 20, 21, 22, 28, 29, 45	5	3
B	Burning Ground/Demil/Demolition/ Disposal	2, 8, 10, 23, 24, 27, 33, 34, 35, 41	6	4
C	Lab/Test/Training	1, 3, 4, 5, 6, 9, 16, 18, 26, 30, 31, 36, 39, 40, 42, 43, 44	9	8
D	Loading/Unloading	12	1	0
E	Inspection/Painting/Packing	7, 19	2	0
F	Manufacturing	17, 32, 37, 38	1	3
G	Deep Storage (1 month - year)	11, 14	2	0
H	Temporary Storage (1 day - 1 month)	25	1	0
	TOTAL A, B, C & D MISHAPS = 45		27	18

Paragraphs 1-27 are class A, B & C mishaps, 28-45 are class D.

1. C - A premature detonation of a MK 37 arming device occurred during a functional test.

2. B - The black powder in a dud saluting charge ignited during the demilitarization process.

3. C - MJU-22/B flares ignited in test fixture during environmental testing.

4. C - Explosive material detonated while being processed into a suitable configuration for a test.

5. C - A MK66 detonator detonated during the demilitarization process.

6. C - A black powder train was improperly initiated during training exercise.

7. E - A decoy flare was intentionally initiated at a segregation site.

8. B - Premature initiation of scrap propellant at a burning site.

9. C - Premature warhead detonation at a test facility.

10. B - Detonation of improperly marked material at a burning site.

11. G - Magazine detonation.

12. D - Tractor trailer ignited while being blocked and braced.

13. A - A CXU-3 CAD detonated during a MK 76 practice bomb buildup.

14. G - Magazine deflagration/detonation.

15. A - Initiator detonated during disassembly.

16. C - Torpedo after body exploded during testing.

17. F - Explosion in manufacturing facility.

18. C - Inadvertent firing of a MK-6 MOD 4 gas generator during testing.

19. E - Ejection seat inadvertently fired during receipt inspection.

20. A - Inadvertent CAD firing during seat assembly.

21. A - Rocket motor ignited during disassembly.

22. A - Chaff counter measure ignited during disassembly.

23. B - Rocket propellant ignited during demilitarization.

24. B - Detonation of item during preparation for demilitarization.

25. H - Sonobuoys ignited in ready service locker.

26. C - A MK 30 MOD 0 arming firing device initiated during testing.

27. B - Explosive material inadvertently mixed with inert scrap for burning.

28. A - A sonobouy squib was activated during disassembly.

29. A - A mine lanyard was improperly removed during maintenance.

30. C - Cartridges heated in conditioning oven ignited due to improper temperature setting.

31. C - Igniter material ignited due to rough handling.

32. F - Improper equipment setup caused ignition of propellant during machining operation.

33. B - Material exploded during thermal treatment.

34. B - Small arms round thrown off station during thermal treatment.

35. B - Canopy ejected during seat removal while preping aircraft for salvage.

36. C - Assumed spent cartridge ignited during disassembly for test analysis.

37. F - Improper equipment setup caused ignition of propellant during machining operation.

38. F - Molding powder ignited during pressing operation.

39. C - Rockets with warheads jettisoned onto runway prior to takeoff.

40. C - Rockets with warheads jettisoned onto runway prior to takeoff.

41. B - Premature detonation off material at thermal treatment area.

42. C - Test sample ignited due to improper grounding.

43. C - Firing system malfunctioned during test demonstration.

44. C - Rockets with warheads jettisoned onto runway prior to takeoff.

45. A - Torpedo starter cartridge ignited during maintenance.

FY97-02 NAVY EXPLOSIVE MISHAP SUMMARY

The following descriptions of 10 class A, B and C explosive mishaps and 23 Class D explosive mishaps were gleaned from COMNAVSAFCEN Letter 8020 Serial 43/0215 of 6 Mar 2003, which provided FY97-FY02 explosive mishap data for Navy mishaps and Marine Corps Aviation mishaps (Marine Corps Ground mishaps are being provided separately to the Marine Corps RBESCT member). This information is to be used to update the Probability of Event (P_e) Matrix for the Safety Assessment for Explosives Risk (SAFER) Model. This summary does not include explosive mishaps that occurred on ships, in moving aircraft, or on range. C/D 1.4 mishaps in parked aircraft, in test cells, on flight lines, in paralofts (e.g., CAD initiation resulting in deployed parachutes, fire extinguishing agent release, actuating guillotine cartridges; signal cartridges in practice bombs) were not included; however, C/D 1.4 events that resulted in injuries or that that occurred during Lab/Test or Assembly/Disassembly operations were included.

	PES used primarily for	Paragraph	Number of Mishaps A-C	 D
A	Assembly/Disassembly/LAP/Maintenance/Renovation	17, 18, 19, 20, 21, 23, 26, 28, **29**	1	8
B	Burning Ground/Demil/Demolition/ Disposal	**5**, 6, **13**, **16**, 22	3	2
C	Lab/Test/Training	1, **2**, **3**, **4**, 8, 9, 10, 12, **14**, 15, 24, 25, 27, 30, 31, 32, 33	4	13
D	Loading/Unloading		0	0
E	Inspection/Painting/Packing	**7**	1	0
F	Manufacturing	**11**	1	0
G	Deep Storage (1 month - year)		0	0
H	Temporary Storage (1 day - 1 month)		0	0
	TOTAL A, B, C & D MISHAPS		10	23

Note: In the table above, paragraph numbers for Class A, B, & C mishaps are in bold print; paragraph numbers for Class D mishaps are not in bold print.

1. D – Mk 104 rocket motor sustainer propellant ignited during remote machining operation. No injuries.

2. **C** – At grenade training range, pin was pulled from grenade; grenade was dropped (before it was thrown); it detonated. Two injuries.

3. **C** – Propellant being removed from rocket motor by remotely operated lathe ignited and burned. Smoke entered control room – two operators were treated for smoke inhalation.

4. **C** – During breakdown of AN/ALQ-190(V) Chaff Countermeasure (**1.4S**) for surveillance testing, 18th round (of 18 total) initiated. One injury (thumb laceration required reconstructive surgery).

5. **C** – Mixed load of rocket motor casings and empty metal barrels were heated as a final explosives decontamination step, and an explosion occurred in the furnace. No injuries.

6. D – During thermal treatment of hydrazine mononitrate and nitrocellulose in the same treatment pan (remotely ignited), the material exploded. No injuries.

7. **C** – While performing inventory prior to shipment, technician dropped item (**1.4B**) on metal floor (4-foot drop). Item detonated when he picked it up. One injury.

8. D – 12 CADs (**1.4C**) loaded with squibs and percussion primers, but not output charges, were electrically and mechanically fired; after inspection to ensure items had fully functioned, they were cut with a hacksaw for primer seal inspection; primer ignited on 3rd cartridge. No injuries.

9. D – During dissection (using a piano wire) of a section of a foreign rocket motor, the propellant ignited. No injuries.

10. D – During remote pellet pressing operation of an experimental explosive (39 pellets); 31st pellet deflagrated as press ram was advanced to ejected pellet from die. No injuries.

11. **A** – During remote RDX grinding operation in 150-gallon horizontal mixer, a detonation occurred. No injuries.

12. D – During preparation for laboratory test, ignition occurred during transfer of a sample of A1A ignition material from a conductive container to a metal cup, due to lack of proper grounding. No injuries.

13. **C** – Detonation occurred during burning of trash and explosive packaging left from demolition operations. One injury.

14. **C** – During electrical resistance testing of armed MK-30 Mod 0 Arming Firing Device (**1.4D**), initiation occurred after removal of shorting plug during attachment of electrical connector. One injury.

15. D – Helo-launched exercise torpedo that failed to run was recovered and brought to torpedo facility. In washdown area, fresh water applied from a flushing hose entered battery compartment; exercise torpedo battery powered up and cause igniter and propellant grain (**1.4S**) to activate. One injury.

16. **C** – During disposal operations, ignition occurred while operator was manually transferring catocene-based propellant (1.3) from vehicle to disposal site. One injury.

17. D – During assembly of Mk 76 Practice Bomb (**1.4G**), an obstruction hampered insertion of firing pin assembly into bomb body, the operator attempted to force it, and the MK 4 signal cartridge initiated. One injury.

18. D – During preparation for assembly of fire extinguisher cartridges, when operator removed tray of BBU-43/A detonators (**1.4B**) from the oven, an initiation occurred. Investigation identified excessive oven temperature as cause. One injury.

19. D – Operator noticed aft canopy jettison control handle sitting on desk, unpinned, he picked item up and JAU/25A mechanical initiator (**1.4C**) detonated. One injury.

20. D – During disassembly of M257 warhead (1.3G), operator was removing the igniter system per SOP, and the igniter and candle functioned. Igniter did not have an out-of-line design configuration in violation of Navy Policy, but in 1979 the warhead had erroneously been assigned the same stock number as warheads with out-of-line igniters. One injury.

21. D – During final assembly of red smoke signals as part of a product improvement program, initiation of a signal occurred while operator was manually installing striker assembly. No injuries.

22. D – Army ammunition manager conducted unauthorized demilitarization of 5.5 pounds of explosives (1.2.1): placed explosive on ground next to a building, ignited the explosive, ran around corner and waited for it to burn – detonation occurred. No injuries.

23. D – During refurbishment of WGU-4A/B G&C section, thermal battery and gas generator were initiated during servo test. Technician inadvertently soldered 27-volt internal test line to thermal battery circuit board terminal vice attaching wires from servo unit to circuit board in umbilical base block. No injuries.

24. D - Propellant being machined by vertical band saw (remote operation) from wedges of dissected rocket motor slipped in vise; this created metal-to-metal contact between band saw blade and metal case of wedge, and caused ignition. No injuries.

25. D – During inerting operation, remotely operated lathe was used to remove PBXN-109 from IM test assembly; operator misestimated depth of cavity; cutting tool contacted bottom end of test assembly fill cavity; and heat from cutter ignited explosive. No injuries.

26. D – Ignition occurred during loading of CCU-36/A delay cartridge (**1.4C**). Operator did not successfully seat three-hole orifice disc in top of delay column before attempting to stake disc in place. No injuries.

27. D - During cleaning of residual felt “whiskers” from surface of MTV pellet with acetone-dampened rag, pellet ignited. One injury.

28. D – LUU-2B/B Flare (1.3G) was being loaded in SUU-25 Flare Pod, Tube 2. When large amount of resistance was encountered, operator used flare tool to try to unload tube, and timer was activated on forward flare. No injuries.

29. **C** – During removal of signal cartridges (**1.4G**) from practice bombs and subsequent bomb storage operations, an operator inadvertently picked up bomb with cartridge still installed and placed it in storage crate nose first. The cartridge detonated as firing pin hit bottom of crate. The operator, who had removed his PPE prior to the mishap, was injured.

30. D – During machining operation of MK4 Low Voltage Initiator (pyrotechnic material), operator did not follow SOP (neglected to turn on cooling air flow), resulting in initiation. Lathe shield enclosure contained effects of explosion - no injuries or equipment damage.

31. D – BQM-74E was being prepared for launch in support of missile exercise. During M-117 JATO resistance check, a JATO bottle was inadvertently fired, BQM-74E impacted ground 25 feet from launcher and sustained structural damage. No injuries.

32. D – Detonation occurred while drilling out a lead azide pellet from a Mk 32 Arming Device - due to procedural non-compliance (cleaning steps not conducted in SOP sequence). Minor injury (operator wore face shield, but being tall - he had to look down and turn his head in such a way that his ear was exposed).

33. D – Ignition occurred during remote compression molding of developmental composition as billet was being ejected from the die. No injuries.

FY00-03 MARINE CORPS EXPLOSIVE MISHAP SUMMARY

	PES used primarily for	Paragraph	Number of Mishaps A-C	D
A	Assembly/Disassembly/LAP/Maintenance/Renovation			
B	Burning Ground/Demil/Demolition/ Disposal			
C	Lab/Test/Training		5	
D	Loading/Unloading			
E	Inspection/Painting/Packing			
F	Manufacturing			
G	Deep Storage (1 month - year)			
H	Temporary Storage (1 day - 1 month)			
	TOTAL A, B, C & D MISHAPS		5	

Primary Activity at PES	Time Period	No. of Facilities
Assembly / Disassembly / LAP / Maintenance / Renovation	FY00 – FY03	
Burning Ground / Demil / Demolition / Disposal	FY00 – FY03	
Lab / Test / Training	FY00 – FY03	338
Loading / Unloading	FY00 – FY03	
Inspection / Painting / Packing	FY00 – FY03	
Manufacturing	FY00 – FY03	
Deep Storage (longer than 1 month)	FY00 – FY03	
Temporary Storage (1 day to 1 month)	FY00 – FY03	
In-Transit Storage (hrs to a few days)	FY00 – FY03	

Attachment 11 – Bibliography

Purpose

This memorandum provides a bibliography of the papers that have been published in support of the Risk-Based Explosives Safety Criteria Team.

Date	Title	Author(s)	Symposium
August 1999	Risk-Based Explosives Safety Criteria Overview	Paul Price, Tom Pfitzer	DoD Explosives Safety Seminar, Orlando, Florida
August 1998	Risk-Based Explosives Safety Methods	Tom Pfitzer, Meredith Hardwick	DoD Explosives Safety Seminar, Orlando, Florida
November 1999	Status of the Risk-Based Explosives Safety Criteria Team	Jerry Ward, Tom Pfitzer, Paul Price, Meredith Hardwick	Parari '99, Canberra, Australia
November 1999	Risk-Based Explosives Safety Modeling	Meredith Hardwick, John Tatom, Mike Swisdak	Parari '99, Canberra, Australia
November 1999	Criteria Selection for Risk-Based Explosives Safety Standards	Tom Pfitzer, Jerry Rufe, Jerry Ward	Parari '99, Canberra, Australia
August 2000	Governing Safety Using Risk-Based Methods	Tom Pfitzer, Meredith Hardwick	International System Safety Conference, Orlando, Florida
July 2000	Status of Risk-Based Explosives Safety Criteria Team	Tom Pfitzer, Meredith Hardwick, Jerry Ward, Paul Price	DoD Explosives Safety Seminar, New Orleans, Louisiana
July 2000	Comparison of International QRA models on the basis of the "Setup and Results of The Joint UK / Australian 40 tonne Donor / Acceptor Trial	Philip van Dongen, Meredith Hardwick, David Hewkin, Peter Kummer, Hans Oiom	DoD Explosives Safety Seminar, New Orleans, Louisiana
July 2000	Risk-Based Explosives Safety Modeling	John Tatom, Meredith Hardwick	DoD Explosives Safety Seminar, New Orleans, Louisiana
August 2001	Criteria Selection for Risk-Based Explosives Safety Standards	Tom Pfitzer, Jerry Rufe	International System Safety Conference, Huntsville, Alabama
October 2001	Assessing Risk at Ports, A Risk-Based Approach to evaluating port operations using the SAFER model	Meredith Hardwick, Pete Yutmeyer, Tom Pfitzer	Parari '01, Canberra, Australia
October 2001	Assessing Risks from Explosives, An Overview of Methods Developed for use by NATO Countries	Jerry Ward, Tom Pfitzer, Meredith Hardwick	Parari '01, Canberra, Australia
October 2001	Comparison of 40 Tonne Test Debris Data to the SAFER Model Predictions	John Tatom, Kristy Newton, Tom Pfitzer, Mike Swisdak	Parari '01, Canberra, Australia
August 2002	SAFER Analysis for Shannon Explosives LTD.	Meredith Hardwick, Pete Yutmeyer, Tom Pfitzer, John Tatom	DoD Explosives Safety Seminar, Atlanta, Georgia
August 2002	Siting of Explosives Storage at Kwajalein Missile Range Using SAFER Version 2.0	Kenyon Williams, Bruce Harris, Meredith Hardwick	DoD Explosives Safety Seminar, Atlanta, Georgia
August 2002	Uncertainty as Modeled in SAFER Version 2.0	Bob Baker, Kristy Newton, John Hall, Tom Pfitzer	DoD Explosives Safety Seminar, Atlanta, Georgia
August 2002	SAFER Analysis for Shannon Explosives LTD.	Meredith Hardwick, Tom Pfitzer, Pete Yutmeyer, John Tatom	DoD Explosives Safety Seminar, Atlanta, Georgia

Date	Title	Author(s)	Symposium
August 2002	SAFER Version 1.0 Analysis of Minuteman III Silo Locations	Lea Ann Cotton, John Tatom	DoD Explosives Safety Seminar, Atlanta, Georgia
August 2002	Comparison of SAFER Debris Predictions with Various Test Data	Mike Swisdak, John Tatom, Kristy Newton	DoD Explosives Safety Seminar, Atlanta, Georgia
October 2003	RBESCT Program Plan / Vision	Eric Olson, Jerry Ward, Meredith Hardwick, Tom Pfitzer	Parari '03, Canberra, Australia
October 2003	Safety Assessment for Explosives Risk (SAFER) Model Status	Jerry Ward, Tom Pfitzer, Meredith Hardwick	Parari '03, Canberra, Australia
October 2003	Sequential Operations Protocol	Meredith Hardwick, Danielle DeBraccio, Pete Yutmeyer	Parari '03, Canberra, Australia
October 2003	NATO Model Comparison – SAFER/US Perspective	Tom Pfitzer, Meredith Hardwick	Parari '03, Canberra, Australia
October 2003	Status of Testing Program to Benefit Explosives Safety Standards Development in the United States Department of Defense	John Tatom, Mike Swisdak, Jim Tancreto	Parari '03, Canberra, Australia
October 2003	SCIPAN I — Test Description and Debris Characterization For Typical Aboveground Non-Earth-Covered Structures	John Tatom, Mike Swisdak, Jim Tancreto	Parari '03, Canberra, Australia
August 2004	Are All Risk Criteria Created Equal And Used Equally?	Tom Pfitzer, Meredith Hardwick, Bill Pfitzer	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	RBESCT Program Plan /Vision	Eric Olson, Dr. Jerry Ward, Tom Pfitzer, Meredith Hardwick	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Universal Risk Scales – A Tool For Developing Risk Criteria By Consensus	Tom Pfitzer, Meredith Hardwick, Bill Pfitzer	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Safety Assessment For Explosives Risk (SAFER) Model Status	Meredith Hardwick, Tom Pfitzer, Dr. Jerry Ward	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Comparison Of SAFER Debris Density Results To Test Data	John Tatom, Mike Swisdak, Kristy Newton	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Status Of Testing Program To Benefit Explosives Safety Standards Development In The United States Department Of Defense	John Tatom, Mike Swisdak, Jim Tancreto	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Spider - A Test Program To Determine The Response Of Typical Wall And Roof Panels To Debris Impact	Jim Tancreto, John Tatom, Mike Swisdak	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	SCIPAN 1 and SCIPAN 2—Response of Reinforced Concrete Tiltup Construction To Blast Loading	Mike Swisdak, Jim Tancreto, John Tatom	DoD Explosives Safety Seminar, San Antonio, Texas
August 2004	Uncertainty As Modeled In SAFER 3	Bob Baker, Dr. John Hall, Tom Pfitzer, Kristy Newton	DoD Explosives Safety Seminar, San Antonio, Texas

Attachment 12 – URS

Criteria Selection for Risk-Based Explosives Safety Standards

Tom Pfitzer, Jerry Rufe, and Dr. Jerry Ward

This document reviews one aspect of the work performed by the Risk-Based Explosives Safety Criteria Team (RBESCT) during fiscal year 1999 toward implementation of risk-based standards for explosives safety in the United States. In this paper, the authors summarize the research, precedents, and existing information that led to the selection of draft explosives safety criteria for use by the DoD Explosives Safety Board (DDESB). The review includes an assessment of comparable risks in other human endeavors, as well as a survey of comparable standards used in other areas of safety. The RBESCT developed the data under the sponsorship of the DDESB and the United States (U.S.) Army, Navy, Air Force, and Marines. The draft criteria are scheduled for trial implementation in fiscal year 2000. The RBESCT invites the international explosives safety community to provide additional data to help refine the criteria during fiscal year 2000. Such data can be provided electronically to mhardwick@apt-research.com.

1.0 Introduction

The work documented in this paper is sponsored by the Risk-Based Explosives Safety Criteria Team (RBESCT). The RBESCT is a team of government and industry professionals sponsored by the Department of Defense Explosives Safety Board (DDESB) and the four U.S. military services to develop and implement risk-based criteria for explosives safety in the U.S. An important part of their work is to gather background data and document the selected personnel protection criteria. This paper addresses the background data. Two other papers describing the work of the RBESCT are also being presented at PARARI '99.

2.0 Draft Criteria

The draft criteria shown in Figure 1 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 The North Atlantic Treaty Organization (NATO) Risk Analysis Working Group 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)	· Attempt to lower risk to 1 x 10^{-3} · Accept above 1 x 10^{-2} with significant national need only
Any 1 person (Annual P_f)	· Limit maximum risk to 1 x 10^{-6}
All public (Annual E_f)	· Attempt to lower risk if above 1 x 10^{-5} · Accept above 1 x 10^{-3} with significant national need only

Figure 1: Draft Criteria

The goal of criteria selection is to establish a standard which will have broad based understanding, a strong legal precedence, and support within the technical community. The RBESCT used a combination of information from other regulations, historical precedence, and risk statistics 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 2 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.

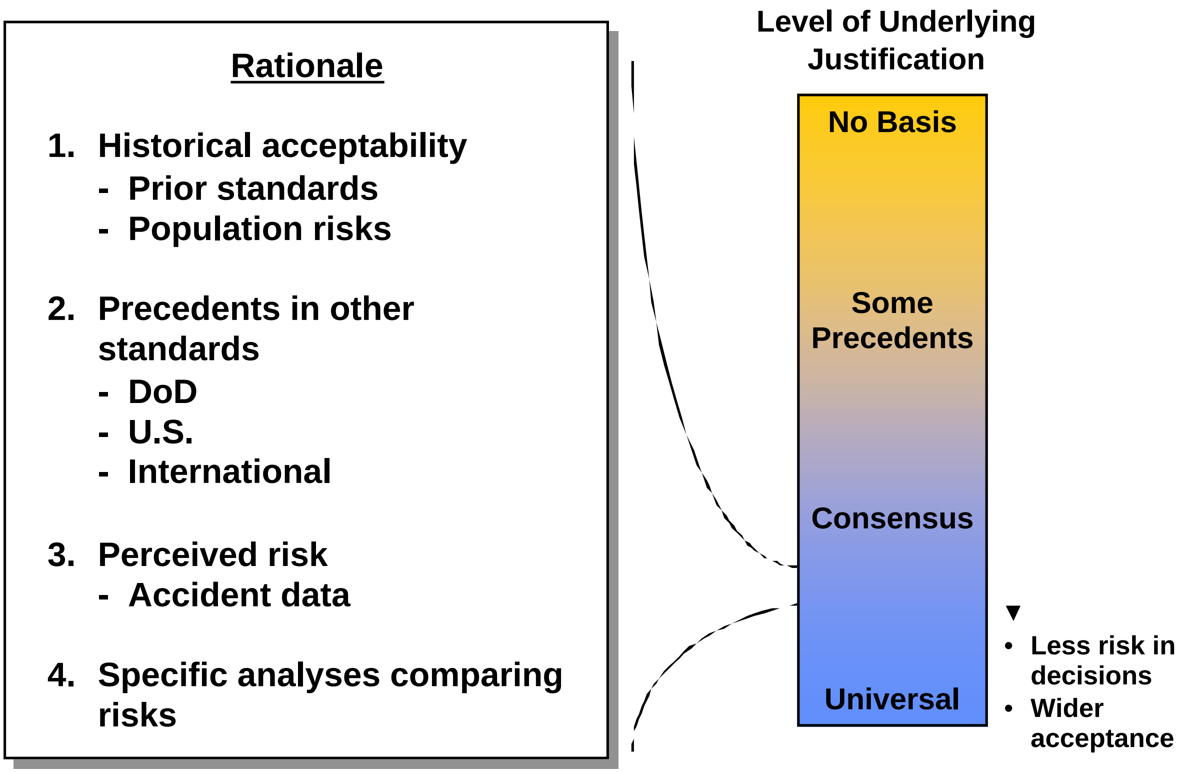

Figure 2: Basis of Criteria

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 3, numerous measures were considered by the RBESCT. Each measure has merit and would serve in varying degrees to achieve the desired purpose of assessing safety. The four measures that the RBESCT selected are as follows:

- 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,
- Maximum expected fatalities, which are the same as (1) assuming that the explosive quantity present is at approved upper limit for the site,
- 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 amount of explosive is present, and
- Peak individual probability of fatality, which is the same as (3) assuming that the explosive quantity present at the PES is at 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).

Measure Selection	Selected	Considered
Who or what is protected?	People (3 categories: related, non-related, public)	· 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 3: Measures Considered

3.0 Universal Risk Scale (URS)

Data were gathered relating to acceptable 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), which are a byproduct of research undertaken by the RBESCT.

The scales have been used to compare relevant data to assist policy makers in selecting appropriate risk related criteria. During the past year the team has developed scales for each of the four criteria shown in Figure 1. *Note: These criteria are in draft form and have not been officially approved by the DoD Explosives Safety Board.*

The format chosen was important because it needed to 1) educate the reader as to the differences between the linear and logarithmic scale and 2) display a wide variety of sometimes disparate 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 to achieve a proper perspective on relative risks.

The format shown in Figure 4 attempts to achieve that by allowing space for two types of precedents. On the right side is the actual accident experience. On the left side, governance precedents which regulate similar risks are shown in the same units of measure.

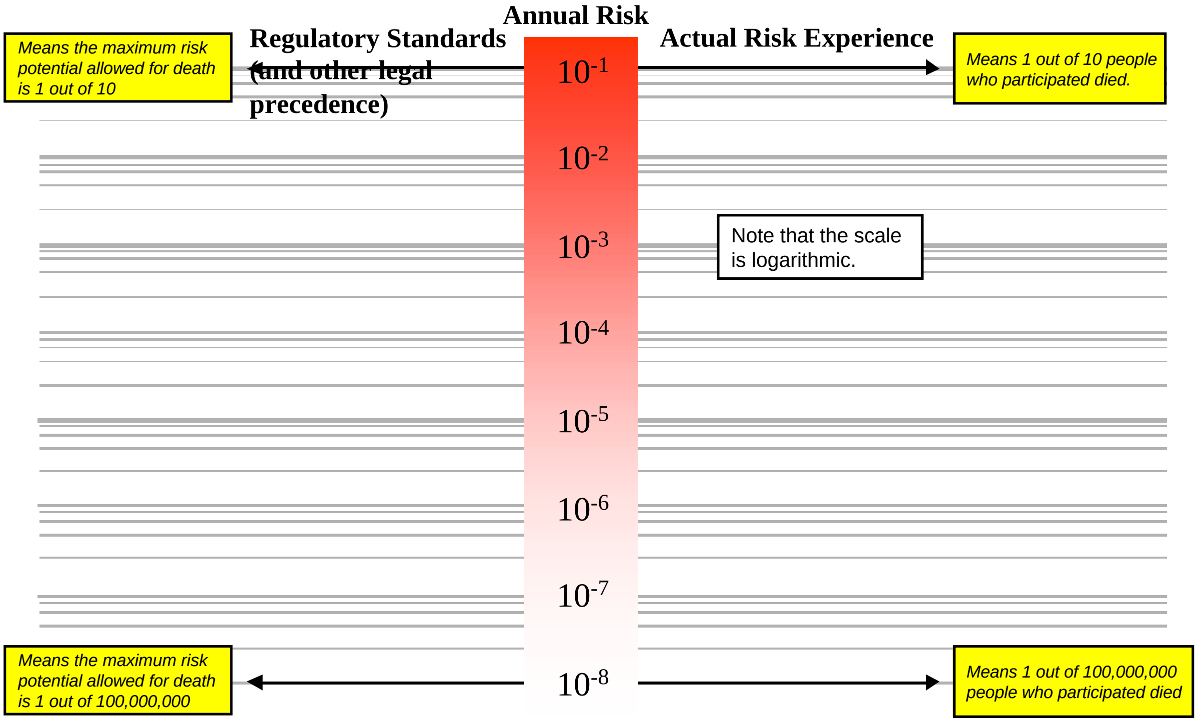

Figure 4: URS Format

4.0 Data Description

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 draft criteria developed by the RBESCT. The surrounding data points are the product of research for relevant supporting data. Many data points are shown because individual readers may ascribe more or less relevance to each data point.

4.1 Risk to any One Worker

The scale supporting the protection criterion for any one worker is shown in Figure 5. 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 5 plots the data on a URS and the following paragraphs describe each data point.

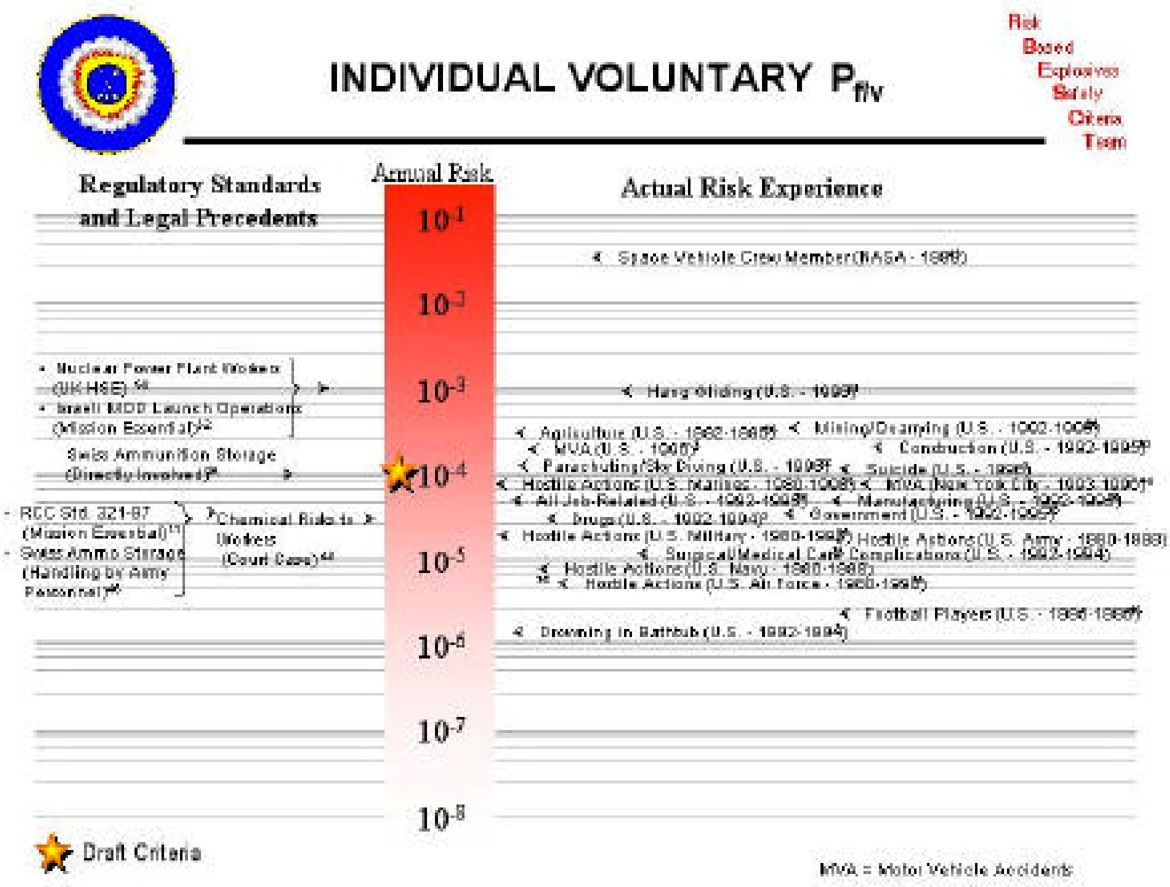

Figure 5: Voluntary Probability of Fatality

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 x 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.

4.2 Risk to any One Person

The scale supporting the protection criterion for any one person is shown in Figure 6. 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 6 plots the data on a URS and the following paragraphs describe each data point.

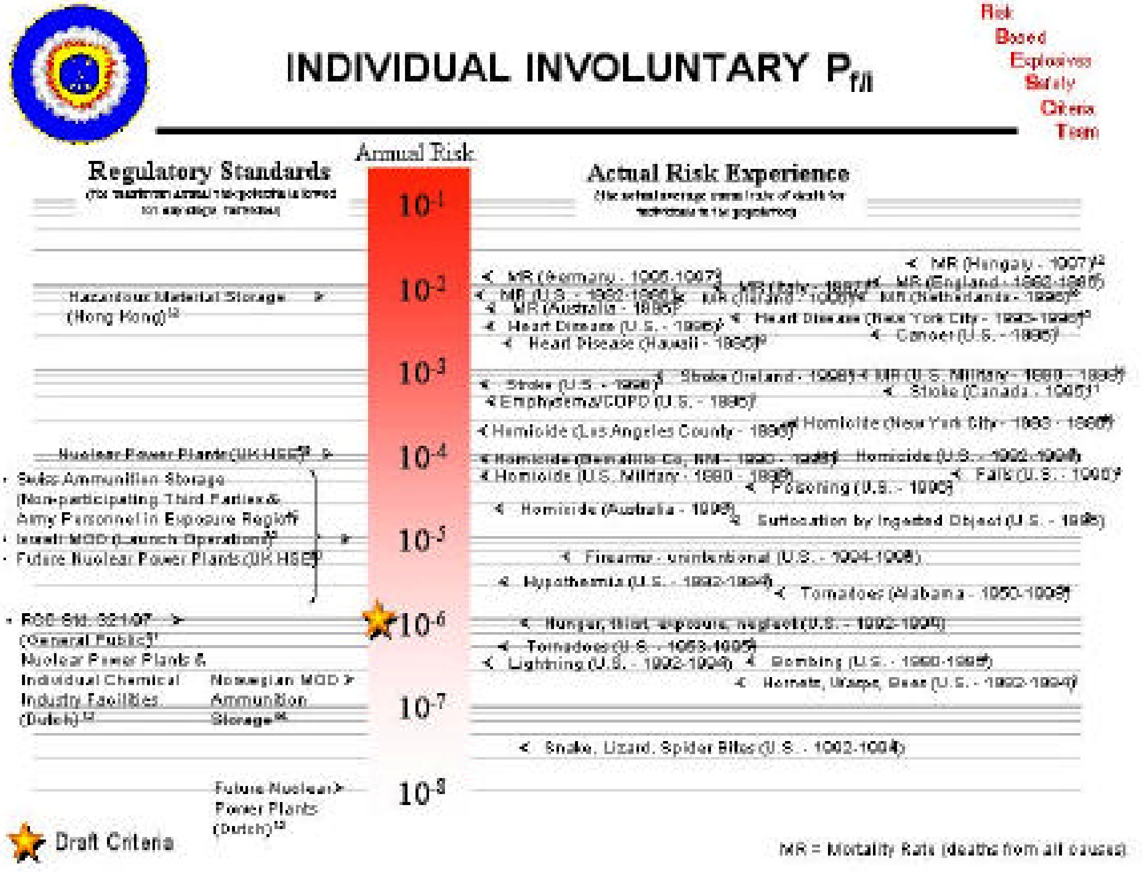

Figure 6: Involuntary Probability of Fatality

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.

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."
- 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.
- 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. The average annual population was 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. The average annual population was 257,733,843.

4.3 Risk to All Workers (Collective Risk)

The scale supporting the protection criterion for all workers is shown in Figure 7. 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 7 plots the data on a URS and the following paragraphs describe each data point.

Note that included on the scale, in blue (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.

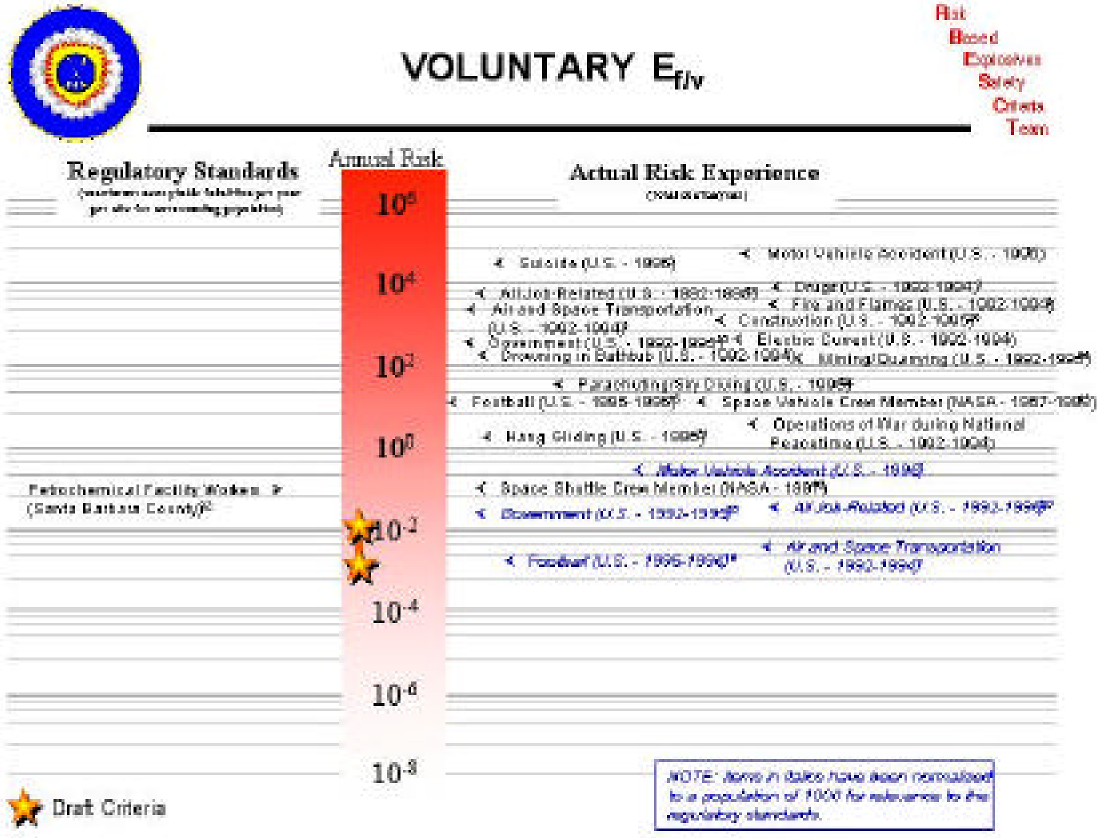

Figure 7: Voluntary Expected Fatalities

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.

4.4 Risk to all People (Public Collective Risk)

The scale supporting the protection criterion for all people is shown in Figure 8. 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. Figure 8 plots the data on a URS and the following paragraphs describe each data point.

Note that included on the scale, in blue (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.

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.
- 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.

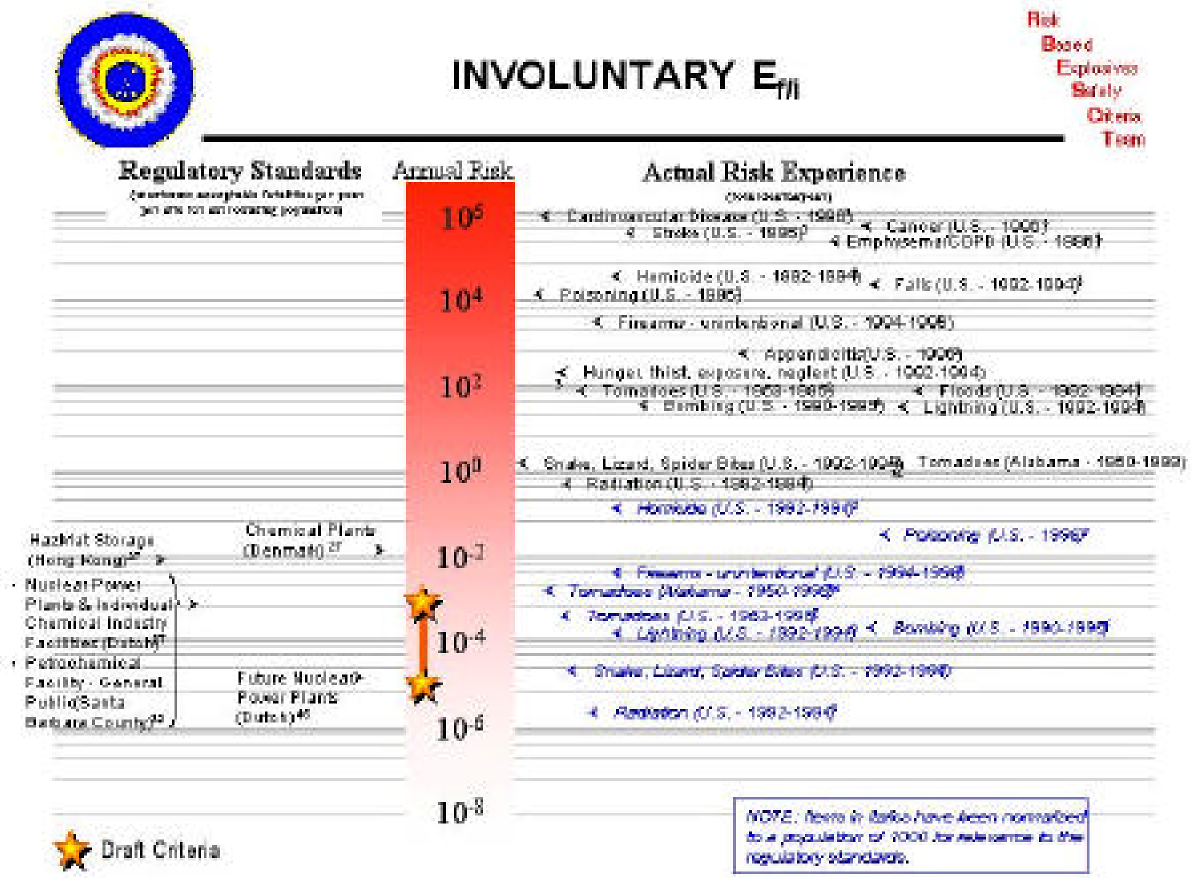

Figure 8: Involuntary Expected Fatalities

- 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.

5.0 Conclusions

The RBESCT has been conducting research for data on which to base the criteria chosen for personnel protection. Accident data, regulations, and legal precedents have been reviewed to identify data relevant to the level of personnel protection. These data have been plotted on the Universal Risk Scales. A foundation has been laid which can benefit the international explosives safety community, as well as other safety communities, who are using risk-based analyses and numerical risk criteria. We invite the international explosives safety community to review the universal risk scales and offer additional data for incorporation into the scales. Such comments can be forwarded to mhardwick@apt-research.com.

The Appendix contains the sources referenced in the Universal Risk Scales.

Appendix – Documents and Organizations Referenced in Figures 5 - 8

[1] National Center for Health Statistics. National Health Interview Survey, 1994. *Vital and Health Statistics.* Item 10 (93).

[2] National Safety Council. 1997. *Accident Facts - 1997 Edition.* Itasca, IL: NSC

[3] National Center for Health Statistics. “Vital and Health Statistics of the United States.” http://www.cdc.gov/nchswww October 1998 (5 January 1999)

[4] FBI Explosives Unit Bomb Data Center. “Annual Bombing Statistics in the United States.” http://www.fbi.gov/lab/bomsum/eubdc.htm August 1998 (21 December 1998)

[5] Australian Bureau of Statistics. “Victims of Crime Recorded by Police.” http://www.statistics.gov.au/websitedbs February 1998 (5 January 1999)

[6] Central Statistics Office of Ireland. “Principle causes of death, crude death rates and age-standardised mortality rates.” http://www.doh.ie/stats/b07.htm 17 December 1998 (22 December 1998)

[7] United Kingdom Office for National Statistics. “Table B Components of population change, mid-1996 to mid-1997.” http://www.ons.gov.uk/data/popltn/table_b.htm November 1998 (22 December 1998)

[8] Federal Statistical Office Germany. “Population development and life expectancy.” http://www.statistik-bund.de/basis/e July 1998 (22 December 1998)

[9] Instituto Nacional de Estadistica. “Number of deaths by major causes of death.” http://www.ine.es/htdocs/dacoin/dacoinci/sanitari August 1998 (22 December 1998)

[10] Centraal Bureau voor de Statistick. “Key figures Statistics Netherlands / population.” http://www.cbs.nl/eng/kfig/sbv0611x.htm 11 December 1998 (5 January 1999)

[11] Statistics Canada. “Selected leading causes of death, by sex.” http://www.statcan.ca/english/Pgdb/People/Health/health36.htm May 1998 (5 January 1999)

[12] Hungarian Central Statistical Office. “Hungary in Figures – Population.” http://www.ksh.hu/eng/free/e7maor/ftartj.html February 1998 (22 December 1998)

[13] Instituto Nazionale in Statistica. “Popolazione.” http://www.istat.it/Anumital/Astatset/pop.htm May 1998 (22 December 1998)

[14] National Association of State Boating Law Administrators. “Accident Statistics.” http://www.nasbla.org 1998 (10 February 1999)

[15] National Transportation Safety Board. “NTSB Aviation Accident/Incident Database.” http://nasdac.faa.gov/lib February 1999 (5 February 1999)

[16] Mueller, F.O. & Schindler, R.D. 1997. *Annual Survey of Football Injury Research, 1931-1996*. Overland Park, KS: NCAA

[17] Federal Railroad Administration. “Accident/Incident Graphs & Charts.” http://safetydata.fra.dot.gov/officeofsafety January 1999 (12 January 1999)

[18] Fatal Accident Reporting System. “FARS Data Workbooks:1993 – 1997.” http://www.fars.idinc.com January 1999 (12 January 1999)

[19] Bureau of Justice Statistics. “Number of persons executed in the United States, 1930–97.” http://www.ojp.usdoj.gov December 1998 (21 December 1998)

[20] Bureau of Labor Statistics. “Census of Fatal Occupational Injuries Summary” http://stats.bls.gov August 1997 (25 January 1999)

[21] United States Hang Gliding Association. E-mail to author. 27 January 1999.

[22] United States Parachute Association. E-mail to author. 27 January 1999.

[23] Consumer Product Safety Commission. “Consumer Product-Related Statistics.”

http://www.cpsc.gov/library/data.html January 1999 (26 January 1999)

[24] Danmarks Statistik. "Data on Denmark 1999." http://www2.dst.dk/internet/startuk.htm January 1999 (5 January 1999)

[25] National Sporting Goods Association. "Industry Research and Statistics." http://nsga.org/guests/research/research-stats.html February 1999 (5 March 1999)

[26] Memorial Day 1993 Speech by Lt. Gen. Barry R. McCaffrey, reproduced in Pentagram, 6/4/93.

[27] ACTA. 1997. *Acceptable Risk Criteria for Launches from National Ranges: Rationale.* Torrance, CA: USAF.

[28] Korean War Museum. "Korean/Vietnam War Casualty Statistics Comparison." http://www.theforgottenvictory.org/kwstats.html 1998 (21 December 1998)

[29] National Archives and Records Administration. "Military Service and Pension Records." http://www.nara.gov December 1998 (21 December 1998)

[30] National Aeronautics and Space Administration. 1997. *Guidelines and Assessment Procedures for Limiting Orbital Debris.* NSS 1740.14.

[31] Range Commanders Council. 1997. *Common Risk Criteria for National Test Ranges: Inert Debris*. RCC Standard 321-97.

[32] Range Commanders Council. 1997. *Common Risk Criteria for National Test Ranges: Inert Debris*. RCC Standard 321-97 Supplement.

[33] US Census Bureau. "Resident Population and State Population Estimates." http://www.census.gov/population February 1999 (1 March 1999)

[34] National Weather Service Forecast Office. "Tornadoes . . . Nature's Most Violent Storms." http://www.nws.noaa.gov/om/tornado.htm July 1998 (17 March 1999)

[35] DoD Washington Headquarters Services - Directorate for Information Operations and Reports. "Department of Defense – Military Casualty Information." http://web1.whs.osd.mil December 1998 (13 April 1999)

[36] U.S. Commissioner of Pensions Annual Report. "Department of Defense - Historical Background and Notes." http://web1.whs.osd.mil/mmid/m01/sms223rr.htm December 1998 (13 April 1999)

[37] California Department of Justice, Criminal Justice Statistics Center. "California Crime Index, 1996." http://www.caag.state.ca.us/cjsc/datatabs.htm March 1999 (13 April 1999)

[38] District of Columbia Department of Health State Center for Health Statistics. "Vital Statistics Data Sheet 1995." http://www.dchealth.com/preview/schs/reports.stm September 1996 (13 April 1999)

[39] Hawaii State Health Department of Health, Office of Health Status Monitoring. "Cause of Death by Sex: 1995." http://www.hawaii.gov/doh April 1999 (13 April 1999)

[40] New York State Department of Health. 'County Health Indicator Profiles (1992 – 1996)." http://www.health.state.ny.us/nysdoh/cfch/pnys.htm July 1998 (13 April 1999)

[41] Alabama Department of Archives & History. "1994 Health Statistics for Madison County." http://www.asc.edu/archives/stats/health/madiso.html December 1998 (13 April 1999)

[42] Government Information Sharing Project – Oregon State University. "Population Estimates – New Mexico Home Page." http://govinfo.library.orst.edu/cgi-bin October 1998 (13 April 1999)

[43] Knight Ridder. "1 out of 36 people who launch into space die in a space-related accident*."* *Tribune Information Services*, October 25, 1998.

[44] Norwegian Department of Defence. 1996. *Storage of Ammunition - Quantitative Risk*

Assessment - Evaluation and Further Approach. NO (ST) IWP 3-96.

[46] *Swiss Technical Requirements for Storage of Ammunition.* TLM 75, Part 2, Appendix 8-2 (Rev. 90).

[47] Air Quality Management District of the South Coast Basin. *New Source Review of Carcinogenic Air Contaminants for a New Facility.* California: Rule 1401.

[48] Air Quality Management District of the South Coast Basin. *New Source Review of Carcinogenic Air Contaminants for a Single Facility.* California: Rule 1402.

[49] *Industrial Union Department v. American Petroleum Institute.* Item 448 U.S. 607. Washington, D.C., 1980.

[50] United Kingdom Health and Safety Executive. 1988. *The Tolerability of Risk from Nuclear Power Stations.* London: Her Majesty's Stationery Office.

UNIVERSAL RISK SCALES – A TOOL FOR DEVELOPING RISK CRITERIA BY CONSENSUS

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Abstract

In 1999, the Risk-Based Explosives Safety Criteria Team (RBESCT) developed the Universal Risk Scales (URS) to assist in the job of selecting appropriate criteria for defining "How safe is safe enough?" The URS summarizes legal precedents and standards that contain criteria for risk acceptance. These data are plotted as points alongside a logarithmic scale quantifying risk. Also plotted on the scale are numerous points representing actual risk statistics derived from historical accident data. The URS was the foundation for selection of the risk criteria currently used to perform risk-based explosives safety siting assessments with the U.S. Department of Defense. This paper provides an update to the previously published URS.

1.0 INTRODUCTION

In 1999, the Department of Defense (DoD) sponsored the initial development of risk criteria for use in risk-based management of explosive materials. Initially, these criteria were to be used on a trial basis for decisions associated with siting of explosives facilities. To support the development of these criteria, various data relating to risk-acceptability were gathered from a variety of sources. To be compared, these data needed to be accumulated in a common format. This need led to the development of the URS.

The URS proved to be a valuable tool in reaching consensus within the RBESCT on the risk criteria used for siting explosives facilities. The scales have also been used to compare relevant data to assist policy makers in selecting appropriate risk related criteria in other areas. As the use of risk-based techniques expands within the area of explosives safety, and into other areas where hazards to the public reside, further research is needed to support the development of risk criteria applicable to these areas. This paper provides an update on the RBESCT's continuing research into the fundamental question - "How safe is safe enough?"

2.0 THE URS FORMAT

The answer to this question, "How safe is safe enough?" is an essential ingredient in establishing any risk criterion. Though the question is fundamental to achieving the practical goal of establishing risk criteria, it is also a somewhat philosophical question, in that it requires individuals to make subjective interpretations of legal precedents, societal values and past risk experiences. Opinions vary widely as to what types of information should be considered when making these judgments, and these differences of opinion become all the more pronounced when the relative importance of individual data points is considered. For this reason, consensus decisions regarding risk criteria are particularly difficult to achieve. To facilitate decisions of this type, the URS was developed to display on a single scale a wide variety of information for the purpose of comparison. The intent is to display as much information as practical, with the hope that the individual participants in the decision will find among the data, information they consider relevant. There are two primary types of information shown on the URS. The first, is various risk-related legal precedents and governmental standards which may be considered relevant to the case at hand, the second is real-world statistical data derived from documented accident experience.

Figure 1: URS Format

Figure 1 shows the format of the URS. The logarithmic scale was chosen because it can display a wide variety of disparate data and allows the aggregate weight of the individual data points to be viewed at once. This scale also enables large differences in the amount of actual risk to be displayed in a small numerical space. For instance, the difference between the values of zero and one on a linear scale is small; in fact, most people think of this numerical space in linear terms of percent. The linear paradigm, however, does not provide the necessary perspective for a useful understanding of the concept of risk. Measured risk is better viewed logarithmically; as orders of magnitude, to allow comparisons of relative risk. The URS format attempts to achieve this perspective so that the concept of relative risk can be more properly understood.

3.0 THE DDESB RISK CRITERIA

In the course of their research and deliberations the RBESCT developed a set of four risk criteria for managing explosives risk at DoD facilities. These four risk criteria were approved by the DDESB in December 1999. The criteria are shown in Figure 2.

Risk to:	Criteria
Any 1 worker (Annual P_f)	• Limit maximum risk to 1 x 10^{-4}
All workers (Annual E_f)	• Attempt to lower risk to 1 x 10^{-3} • Accept above 1 x 10^{-2} with significant national need only
Any 1 person (Annual P_f)	• Limit maximum risk to 1 x 10^{-6}
All public (Annual E_f)	• Attempt to lower risk if above 1 x 10^{-5} • Accept above 1 x 10^{-3} with significant national need only

Figure 2: Risk Criteria Developed by RBESCT

As a by-product of their work, the team also developed a set of four generalized URS scales to fit the four more specific criteria for explosives risk. When considering the types of protection the criteria should provide, the team decided the criteria should address the protection of individuals, and of groups of individuals, and that also the criteria should address the protection of persons who have voluntarily accepted some level known risk, and of persons who have not voluntarily accepted the risk.

4.0 THE FOUR URS SCALES

In the figures that follow, all data are shown in terms of annual risk. Each figure contains a star indicating the level of risk associated with the DDESB criteria. The surrounding data points are the product of research for relevant supporting data. Many data points are shown because individuals may ascribe more or less relevance to each data point.

4.1 RISK TO ANY ONE WORKER

The scale supporting the criterion for protection of any one worker is shown in Figure 3. This scale is labeled “individual voluntary” because the risk to the individual is accepted voluntarily as a condition of employment. Figure 3 plots the data on a URS and the following paragraphs describe each data point.

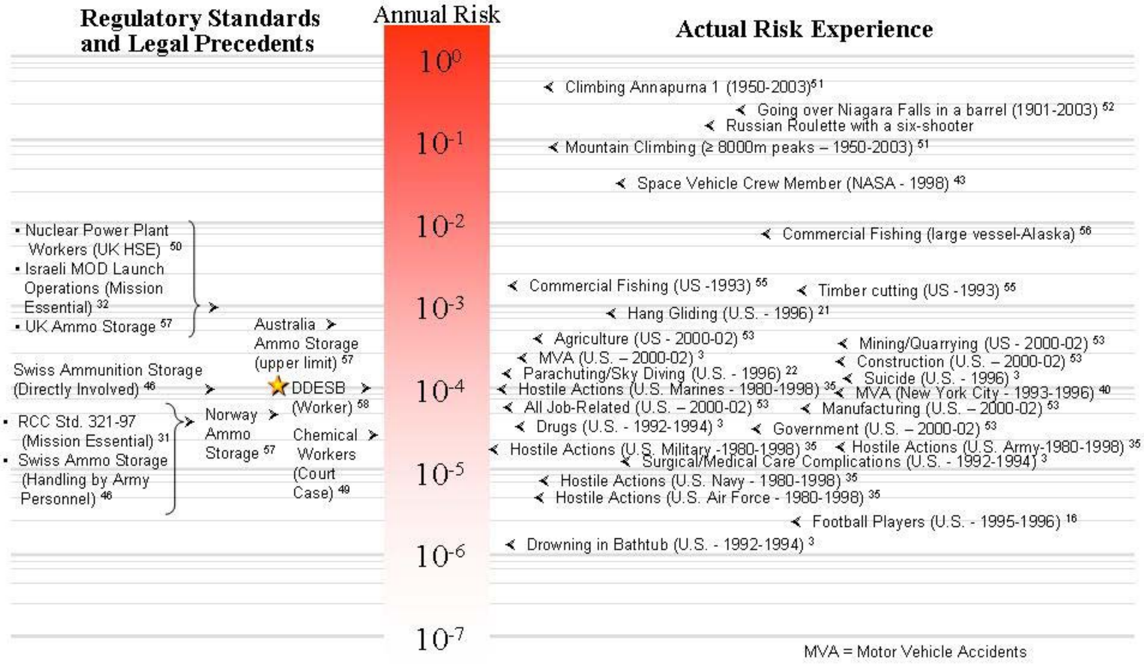


Figure 3: Individual Voluntary

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 x 10^{-5}. (Reproduced from the ACTA report to the Air Force, *Acceptable Risk Criteria for Launches from National Ranges: Rationale*.)
- UK Ammunition Storage (UK HSE) – *1.00E-03.* From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for a worker; applicable to storage of ammunition.
- Norway Ammunition Storage – *4.00E-05.* From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for a worker; applicable to storage of ammunition.
- Australia Ammunition Storage – *5.00E-04.* From the *AASTP-4, Part I,* this is the maximum allowable (upper limit) individual fatality risk per year for a worker; applicable to storage of ammunition.

Actual Risk Experience

- Climbing Annapurna 1 – *4.23E-01* - Between 1950 and 2003 there were ~130 attempts to ascend Annapurna 1 (a Himalayan peak of ≥ 8000m). Of these attempts, 55 (42.3%) ended in the death of the climber.
- Going Over Niagara Falls in a Barrel – *2.00E-01* - Since 1901 there have been 15 daredevil attempts to negotiate Niagara/American Falls in a barrel-type floatation device. Of these attempts, three (20%) resulted in the death of the daredevil. *(Stunting at the falls now carries a maximum fine of $10,000.)*
- Russian roulette - *1.67E-01*. Playing one round only, using a six-shot revolver. Chance of fatality -- one-in-six.
- Mountain Climbing (all peaks ≥8000m, world-wide) – *9.2E-02* - Between 1950 and 2003 there were ~6332 attempted ascents of mountain peaks ≥ 8000 meters. Of these attempts, 582 (9.2%) resulted in the death of the climber.
- Commercial Fishing (Alaska - vessel length >79ft) – 7.*14E-03* - According to a 1991 study by the National Academy of Sciences, between 1982 -1987 there was an average of ~20 fatalities/year among an average population of ~2800 workers aboard large commercial fishing vessels in Alaskan waters.
- Commercial Fishing (US – 1993) – *1.55E-03* - According to the Bureau of Labor Statistics "commercial fisher" was at the top of the list of high risk occupations.
- Timber Cutters (US – 1993) – *1.33E-03* - According to the Bureau of Labor Statistics "timber cutter" was second on the list of high risk occupations.
- 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.) – *2.94E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Agriculture (U.S.) – *2.10E-04*. *F*or three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Motor Vehicle Accidents (U.S.) – *1.57E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Construction (U.S.) – *1.28E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.) – *1.06E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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 population of 7,493,400 commuters.
- All Job-Related (U.S.) – *3.70E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Manufacturing (U.S.) - *3.00E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Government (U.S.) – *2.40E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.

4.2 RISK TO ANY ONE PERSON

The scale supporting the protection criterion for any one person is shown in Figure 4. This scale is labeled “individual involuntary” because the risk 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. Figure 4 plots the data on a URS and the following paragraphs describe each data point.

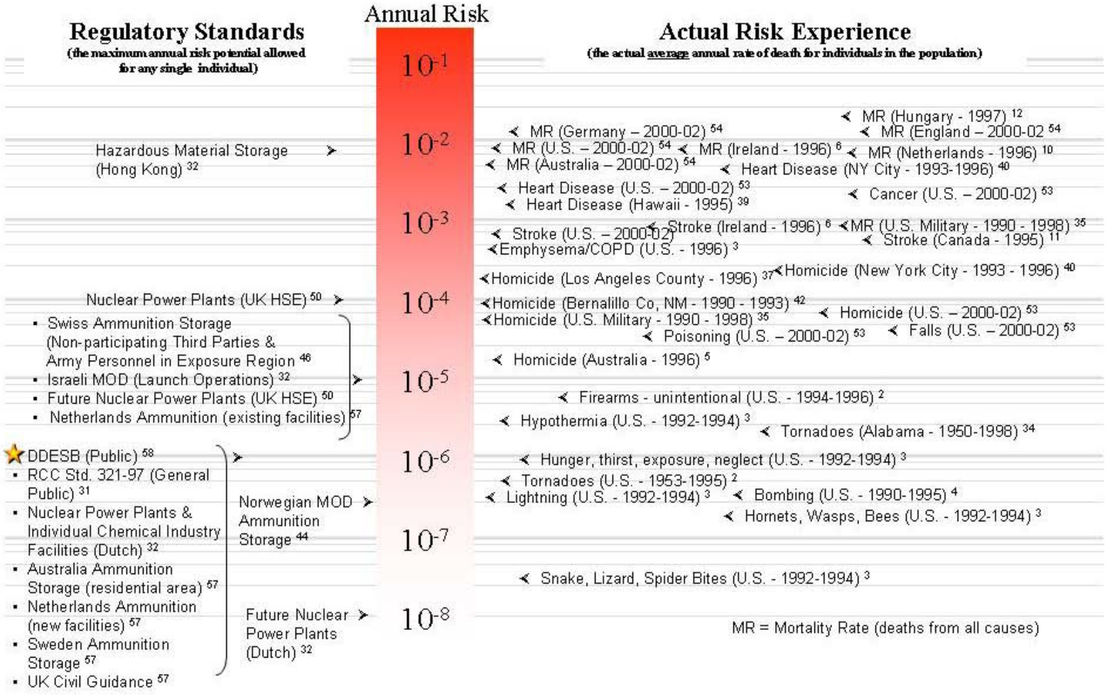


Figure 4: Individual Involuntary

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."
- 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.
- 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.
- Australia Ammunition Storage – *1.00E-06*. From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for public individual fatality at a residence; applicable to storage of ammunition.
- The Netherlands Ammunition Storage (new facilities) – *1.00E-06*. From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for public individual fatality; applicable to storage of ammunition.
- Sweden Ammunition Storage – *1.00E-06*. From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for public individual fatality; applicable to storage of ammunition.
- UK Civil Guidance - – *1.00E-06*. From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for public individual fatality; applicable to storage of ammunition.
- The Netherlands Ammunition Storage (existing facilities) – *1.00E-05*. From the *AASTP-4, Part I,* this is the maximum allowable individual fatality risk per year for public individual fatality; applicable to storage of ammunition.

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) – *1.06E-02*. For three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- Mortality Rate (Germany) – *1.05E-02. F*or three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- 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*. For three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- 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) – *6.92E-03*. For three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- Heart Disease (U.S.) – *2.58E-03*. For three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- Cancer (U.S.) – *2.01E-03*. For three year period 2000-2002. From National Safety Counsel publication *International Injury Facts*.
- 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.) – *6.09E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.) – 7*.94E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Falls (U.S.) – *4.80E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Poisoning (U.S.) – *4.62E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts.*
- 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.) – *1.6E-05*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.

- 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. The average annual population was 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. The average annual population was 257,733,843.

4.3 RISK TO ALL WORKERS (COLLECTIVE RISK)

The scale supporting the protection criterion for all workers is shown in Figure 5. 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 "group voluntary" because the risk is accepted as a voluntary action taken by the individuals in the group. For example, when a person accepts a job with known risks it is voluntary. Figure 5 plots the data on a URS and the following paragraphs describe each data point.

Note that included on the scale, in blue (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.

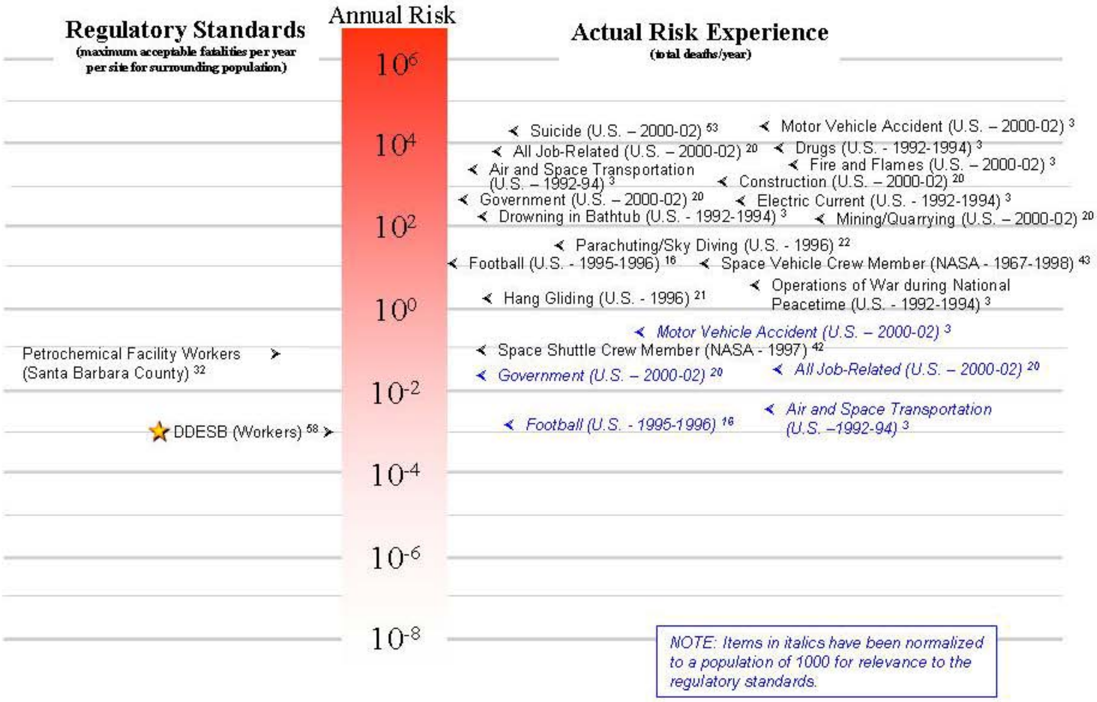


Figure 5: Group Voluntary

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.) – *2.94E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Motor Vehicle Accidents (U.S.) – *1.57E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Construction (U.S.) – *1.28E-04*. For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.

- 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.) – *1.06E-04.* For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- All Job-Related (U.S.) – *3.70E-05.* For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- Government (U.S.) – *2.40E-05.* For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.) – *1.2E-05.* For three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.

  The risk associated with various modes of transportation is often expressed in terms of fatalities per passenger/mile. According to National Safety Counsel publication *Injury Facts*, when averaged over the 10 year period from 1991 to 2000, the risk of passenger fatality due to air travel was *~3.0E-02 per 10.0E+08 miles traveled*.
- Electrocution (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 electric current. 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.

4.4 RISK TO ALL PEOPLE (PUBLIC COLLECTIVE RISK)

The scale supporting the protection criterion for all people is shown in Figure 6. This scale is labeled “group involuntary” because the risk is not accepted as a voluntary action taken by the individuals in the group. For example, death from cancer, homicide or lightning is generally not the result of a voluntary decision by an individual to accept risk. Figure 6 plots the data on a URS and the following paragraphs describe each data point.

Note that included on the scale, in blue (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.

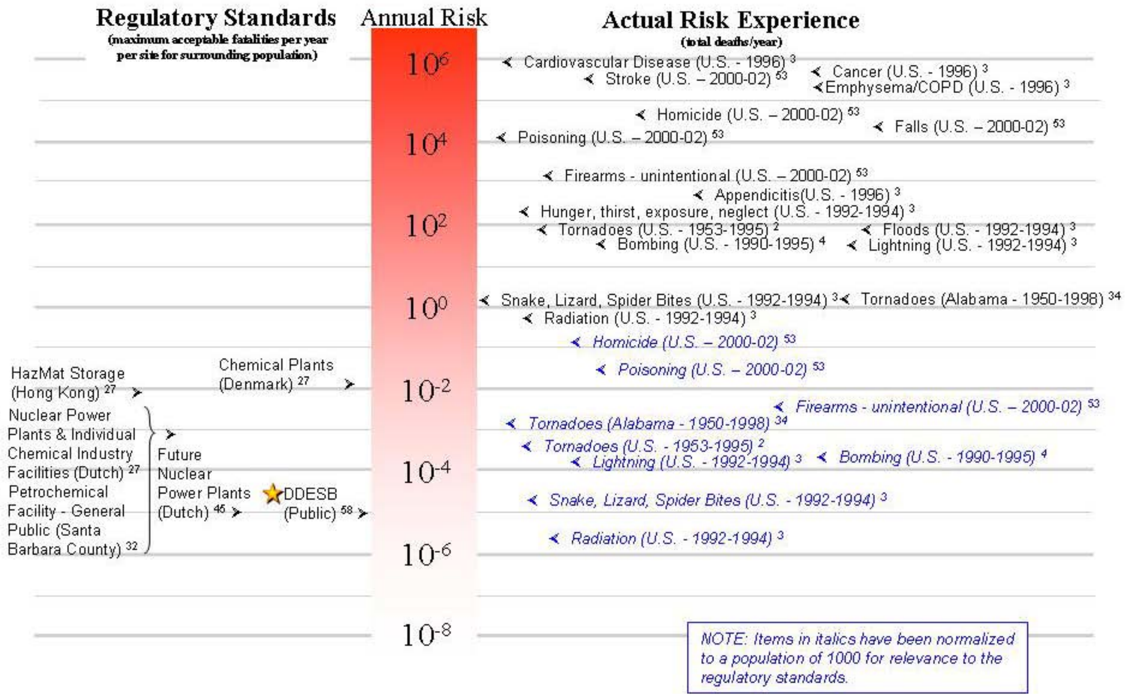


Figure 6: Group Involuntary

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.
- 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.) – *6.09E-04.* 159,791 fatalities annually for three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.) – *7.94E-05.* 19,252 fatalities annually for three year period 2000-2002. From National Safety Counsel *Injury Facts* publication.
- Falls (U.S.) – *4.80E-05.* 13,462 fatalities annually for three year period 2000-2002. From National Safety Counsel *Injury Facts* publication.
- Poisoning (U.S.) – *4.62E-05.* 13,125 fatalities annually for three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.) – *3.4E-06.* 810 fatalities annually for three year period 2000-2002. From National Safety Counsel publication *Injury Facts*.
- 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.

4.5 CATASTROPHIC RISK SCALE

The RBESCT has also been developing a URS for Catastrophes as shown in figure 7. On the right-hand side of the figure are data gathered by the team in compiling a survey of past catastrophic events. These catastrophic events are grouped into three categories: 1) pre-historic natural catastrophes, 2) historic natural disasters, and 3) human-caused disasters (which include some human-induced natural disasters).

The scale across the bottom right of Figure 7 indicates approximately when the event occurred in years before present (ybp). The scale in the center of the figure indicates the approximate number of fatalities associated with the event (NA for prehistoric events). On the left side of Figure 7 a few of the more notable historic governance milestones in management of catastrophic risk are listed.

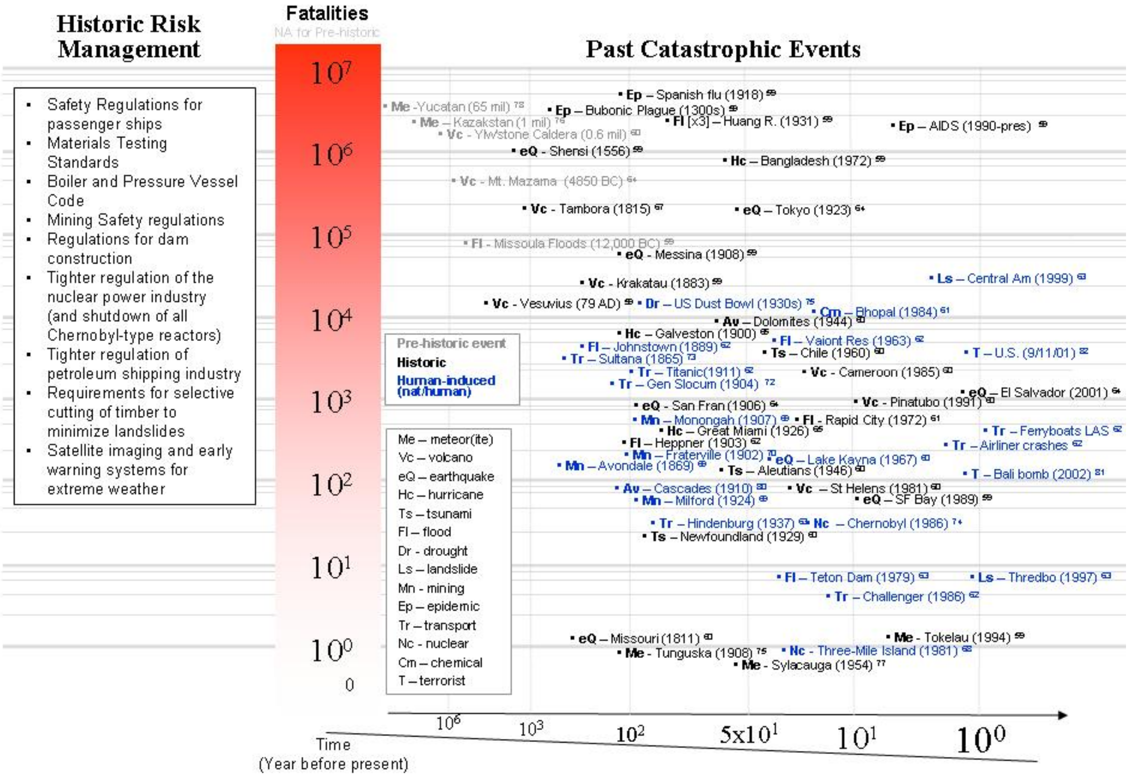


Figure 7: URS for Catastrophes

The RBESCT has not found a catastrophic criterion in use by other U.S. agencies or nations. At this time the RBESCT is not recommending a criterion for a catastrophic event.

5.0 CONCLUSIONS

The RBESCT has been conducting research for data to support the criteria chosen for personnel protection. Accident data, regulations, and legal precedents have been reviewed to identify data relevant to the level of personnel protection. These data have been plotted on the Universal Risk Scales. A foundation has been laid that can benefit the international explosives safety community, as well as other safety communities who are using risk-based analyses and numerical risk criteria. We invite the international explosives safety community to review the universal risk scales and offer additional data for incorporation into the scales. Such comments can be forwarded to mhardwick@apt-research.com.

The Appendix contains the sources referenced in the Universal Risk Scales.

Appendix – Documents and Organizations Referenced in Figures 3 - 7

[1] National Center for Health Statistics. National Health Interview Survey, 1994. *Vital and Health Statistics.* Item 10 (93).

[2] National Safety Council. 1997. *Accident Facts - 1997 Edition.* Itasca, IL: NSC.

[3] National Center for Health Statistics. “Vital and Health Statistics of the United States.” http://www.cdc.gov/nchswww October 1998 (5 January 1999).

[4] FBI Explosives Unit Bomb Data Center. “Annual Bombing Statistics in the United States.” http://www.fbi.gov/lab/bomsum/eubdc.htm August 1998 (21 December 1998).

[5] Australian Bureau of Statistics. “Victims of Crime Recorded by Police.” http://www.statistics.gov.au/websitedbs February 1998 (5 January 1999).

[6] Central Statistics Office of Ireland. “Principle causes of death, crude death rates and age-standardised mortality rates.” http://www.doh.ie/stats/b07.htm 17 December 1998 (22 December 1998).

[7] United Kingdom Office for National Statistics. “Table B Components of population change, mid-1996 to mid-1997.” http://www.ons.gov.uk/data/popltn/table_b.htm November 1998 (22 December 1998).

[8] Federal Statistical Office Germany. “Population development and life expectancy.” http://www.statistik-bund.de/basis/e July 1998 (22 December 1998).

[9] Instituto Nacional de Estadistica. “Number of deaths by major causes of death.” http://www.ine.es/htdocs/dacoin/dacoinci/sanitari August 1998 (22 December 1998).

[10] Centraal Bureau voor de Statistick. “Key figures Statistics Netherlands / population.” http://www.cbs.nl/eng/kfig/sbv0611x.htm 11 December 1998 (5 January 1999).

[11] Statistics Canada. “Selected leading causes of death, by sex.” http://www.statcan.ca/english/Pgdb/People/Health/health36.htm May 1998 (5 January 1999).

[12] Hungarian Central Statistical Office. “Hungary in Figures – Population.” http://www.ksh.hu/eng/free/e7maor/ftartj.html February 1998 (22 December 1998).

[13] Instituto Nazionale in Statistica. “Popolazione.” http://www.istat.it/Anumital/Astatset/pop.htm May 1998 (22 December 1998).

[14] National Association of State Boating Law Administrators. “Accident Statistics.” http://www.nasbla.org 1998 (10 February 1999).

[15] National Transportation Safety Board. “NTSB Aviation Accident/Incident Database.” http://nasdac.faa.gov/lib February 1999 (5 February 1999).

[16] Mueller, F.O. & Schindler, R.D. 1997. *Annual Survey of Football Injury Research, 1931-1996*. Overland Park, KS: NCAA.

[17] Federal Railroad Administration. “Accident/Incident Graphs & Charts.” http://safetydata.fra.dot.gov/officeofsafety January 1999 (12 January 1999).

[18] Fatal Accident Reporting System. “FARS Data Workbooks:1993 – 1997.” http://www.fars.idinc.com January 1999 (12 January 1999).

[19] Bureau of Justice Statistics. “Number of persons executed in the United States, 1930–97.” http://www.ojp.usdoj.gov December 1998 (21 December 1998).

[20] Bureau of Labor Statistics. “Census of Fatal Occupational Injuries Summary” http://stats.bls.gov August 1997 (25 January 1999).

[21] United States Hang Gliding Association. E-mail to author. 27 January 1999.

[22] United States Parachute Association. E-mail to author. 27 January 1999.

[23] Consumer Product Safety Commission. “Consumer Product-Related Statistics.” http://www.cpsc.gov/library/data.html January 1999 (26 January 1999).

[24] Danmarks Statistik. “Data on Denmark 1999.” http://www2.dst.dk/internet/startuk.htm January 1999 (5 January 1999).

[25] National Sporting Goods Association. “Industry Research and Statistics.” http://nsga.org/guests/research/research-stats.html February 1999 (5 March 1999).

[26] Memorial Day 1993 Speech by Lt. Gen. Barry R. McCaffrey, reproduced in Pentagram, 6/4/93.

[27] ACTA. 1997. *Acceptable Risk Criteria for Launches from National Ranges: Rationale.* Torrance, CA: USAF.

[28] Korean War Museum. “Korean/Vietnam War Casualty Statistics Comparison.” http://www.theforgottenvictory.org/kwstats.html 1998 (21 December 1998).

[29] National Archives and Records Administration. “Military Service and Pension Records.” http://www.nara.gov December 1998 (21 December 1998).

[30] National Aeronautics and Space Administration. 1997. *Guidelines and Assessment Procedures for Limiting Orbital Debris.* NSS 1740.14.

[31] Range Commanders Council. 1997. *Common Risk Criteria for National Test Ranges: Inert Debris*. RCC Standard 321-97.

[32] Range Commanders Council. 1997. *Common Risk Criteria for National Test Ranges: Inert Debris*. RCC Standard 321-97 Supplement.

[33] US Census Bureau. “Resident Population and State Population Estimates.” http://www.census.gov/population February 1999 (1 March 1999).

[34] National Weather Service Forecast Office. “Tornadoes . . . Nature’s Most Violent Storms.” http://www.nws.noaa.gov/om/tornado.htm July 1998 (17 March 1999).

[35] DoD Washington Headquarters Services - Directorate for Information Operations and Reports. “Department of Defense – Military Casualty Information.” http://web1.whs.osd.mil December 1998 (13 April 1999).

[36] U.S. Commissioner of Pensions Annual Report. “Department of Defense - Historical Background and Notes.” http://web1.whs.osd.mil/mmid/m01/sms223rr.htm December 1998 (13 April 1999).

[37] California Department of Justice, Criminal Justice Statistics Center. “California Crime Index, 1996.” http://www.caag.state.ca.us/cjsc/datatabs.htm March 1999 (13 April 1999).

[38] District of Columbia Department of Health State Center for Health Statistics. “Vital Statistics Data Sheet 1995.” http://www.dchealth.com/preview/schs/reports.stm September 1996 (13 April 1999).

[39] Hawaii State Health Department of Health, Office of Health Status Monitoring. “Cause of Death by Sex: 1995.” http://www.hawaii.gov/doh April 1999 (13 April 1999).

[40] New York State Department of Health. ‘County Health Indicator Profiles (1992 – 1996).” http://www.health.state.ny.us/nysdoh/cfch/pnys.htm July 1998 (13 April 1999).

[41] Alabama Department of Archives & History. “1994 Health Statistics for Madison County.” http://www.asc.edu/archives/stats/health/madiso.html December 1998 (13 April 1999).

[42] Government Information Sharing Project – Oregon State University. “Population Estimates – New Mexico Home Page.” http://govinfo.library.orst.edu/cgi-bin October 1998 (13 April 1999).

[43] Knight Ridder. “1 out of 36 people who launch into space die in a space-related accident*.” Tribune Information Services*, October 25, 1998.

[44] Norwegian Department of Defence. 1996. *Storage of Ammunition - Quantitative Risk Assessment - Evaluation and Further Approach.* NO (ST) IWP 3-96.

[46] Swiss Technical Requirements for Storage of Ammunition. *TLM 75, Part 2, Appendix 8-2 (Rev. 90)*.

[47] Air Quality Management District of the South Coast Basin. *New Source Review of Carcinogenic Air Contaminants for a New Facility*. California: Rule 1401.

[48] Air Quality Management District of the South Coast Basin. *New Source Review of Carcinogenic Air Contaminants for a Single Facility*. California: Rule 1402.

[49] *Industrial Union Department v. American Petroleum Institute.* Item 448 U.S. 607. Washington, D.C., 1980.

[50] United Kingdom Health and Safety Executive. 1988. *The Tolerability of Risk from Nuclear Power Stations.* London: Her Majesty’s Stationery Office.

[51] AdventureStats.com. “Total Ascents and Fatalities on 8000 meter Mountains”. 10/03/03.

[52] Niagara Parks Commission. “Stunting at the Falls,” 01/06/04.

[53] National Safety Council. *Injury Facts,* 2000-2002 Editions. Itasca, IL:NSC.

[54] National Safety Council. *International Accident Facts*, 2002 Edition. Itasca, IL:NSC.

[55] Bureau of Labor Statistics List of High Risk Occupations (1993).

[56] National Academy of Sciences. Commission on Engineering and Technical Systems *Fishing Vessel Safety: Blueprint for National Program* (1991).

[57] North Atlantic Treaty Organization AC/258 Allied Ammunition Storage and Transport Publication AASTP- 4, *Explosives Safety Risk Analysis Part I*, April 16, 2003.

[58] DDESB Policy Letter dated 9 December 1999.

[59] Abbott, Patrick L., *Natural Disasters*, McGraw-Hill, 4th edition, 2003

[60] Harris, Stephen L. Agents of Chaos: Earthquakes, Volcanoes, and Other Natural Disasters. Missoula: Mountain Press Publishing Co., 1990.

[61] Davis, Lee Allyn. *Environmental Disasters: a Chronicle of Individual, Industrial, and Governmental Carelessness***.** New York, NY : Facts on File, 1998.

[62] Davis, Lee Allyn. *Manmade Catastrophes : From the Burning of Rome to the Lockerbie Crash***.** New York, NY: Facts on File, 1993.

[63] Eastlake, Keith. *World Disasters: Tragedies in the Modern Age*. New York, NY: Fitzroy Dearborn, 2001.

[64] Alexander, David. *Natural Disasters*. New York: Chapman and Hall, 1993.

[65] *The Associated Press Library of Disasters***,** Danbury, CT: Grolier Educational, 1998.

[66] Laskin, David. Braving the Elements: The Stormy History of American Weather. New York: Doubleday, 1996.

[67] Stommel, Henry, and Stommel, Elizabeth. *Volcano Weather: The Story of 1816, The Year Without a Summer*. Newport: Seven Seas Press, 1983.

[68] Harris, Stephen L. *Fire and Ice: The Cascade Volcanoes*, revised ed. Seattle: The Mountaineers, 1980

[69] Public Broadcasting System, *American Experience: Meltdown at Three Mile Island*, Program Description Compiled by Tony Baratta, Professor Nuclear Engineering, PhD, Pennsylvania State University.

[70] Bureau of Mines Bulletin 586; Historical Summary of Major Coal-Mine Disasters in the United States: 1810-1958.

[71] Bureau of Mines I.C. 7493, Bulletin 586; Major Disasters at Metal and nonmetal Mines and Quarries in the U.S. (Excluding Coal Mines).

[72] Article for the Maritime Industry Museum: *General Slocum Disaster* http://www.maritimeindustrymuseum.org/slocum.htm.

[73] Ambrose, Steven, Remembering Sultana, Expedition Journal, May 2001.

[74] Nuclear Energy Agency Report, Chernobyl: Assessment of Radiological and Health Impact, 2002 Update of Chernobyl: Ten Years On.

[75] Worster, Donald. *Dust Bowl: The Southern Plains in the 1930s*. New York: Oxford University Press, 1979.

[76] Planetary and Space Science Centre, University of New Brunswick, Earth Impact Database, *Impact Cratering on Earth*, http://www.unb.ca/passc/ImpactDatabase/essay.html.

[77] B. M. French, 1998, *Traces of Catastrophe*, Lunar and Planetary Institute, Houston TX, 120 p.

[78] T. Gehrels (ed.), 1994, *Hazards Due to Comets and Asteroids*, University of Arizona Press, Tucson, 1300 p.

[79] A.R. Hildebrand, 1993, *The Cretaceous/Tertiary Boundary Impact*, Journal of the Royal Astronomy Society of Canada, v. 87, p.77-118.

[80] Ferguson, Sue, *96 Killed in Unknown Avalanche: The Wellington Landslide*, The Avalanche Review, Vol.6, No. 4, March 15, 1988.

[81] CNN Special Report, *Bali Bombings: Horror in Paradise* http://edition.cnn.com/SPECIALS/2002/bali/.

[82] CNN Special Report*, 9/11: Attack on America* http://edition.cnn.com/SPECIALS/2001.

Attachment – 13 Public Traffic Route Methodology

Public Traffic Route Methodology

Prepared by – Meredith Hardwick, Megan Stroud (APT)
Reviewed by – Pete Yutmeyer (APT)
Revision Date – 011206

PURPOSE

This memorandum describes the methodology used in SAFER Version 3.0 for addressing risk to public traffic routes. Specific questions addressed are:

1. Why are all traffic routes considered public?
2. Why does SAFER calculate the risk within a 2IBD arc?
3. How is the P(e) calculated?
4. How are the physical effects and consequences calculated?
5. How is the personnel exposure calculated?
6. What are the inputs to the uncertainty model?
7. How are the number of fatalities, major injuries, and minor injuries calculated?

DISCUSSIONS

1. Why are all traffic routes considered public?

In accordance with DoD 6055.9-Std, all exposures on sited traffic routes are considered public exposures.

2. Why does SAFER calculate the risk within a 2IBD arc?

Since traffic routes are areas that have short intervals of exposure, a 2IBD arc was selected in order to increase the exposure interval.

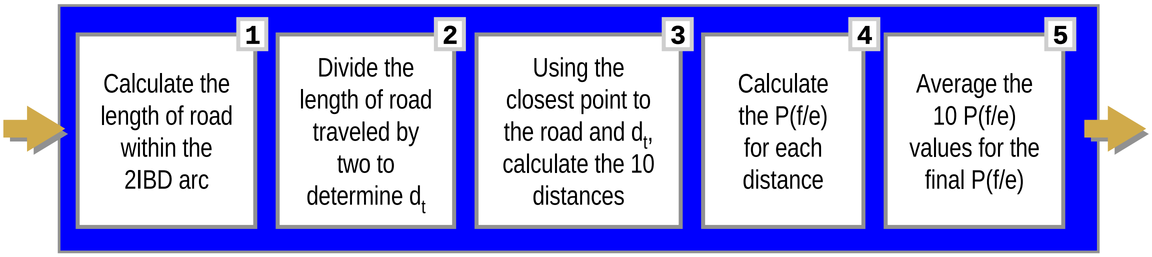
3. How is the P(e) calculated?

The P(e) is determined using the same methodology that is used for non-PTR cases. See Section 4.1.2 of Technical Paper #14 for more details on the P(e) determination.

4. How are the physical effects and consequences calculated?

The physical effects and consequences are calculated using the same methodology that is used for non-PTR cases; however, SAFER calculates 10 distances within 2IBD that are evaluated. For each of these 10 distances a $P_{f/e}$ is determined. A building model that represents a passenger vehicle is included in SAFER in order to calculate structural response.

The 10 $P_{f/e}$ values are calculated using 5 substeps.



Inputs:

- Length of Road Within 2IBD Arc (ft), L, calculated by SAFER
- Distance between PES and closest point to the road, user input

Substep 1

Calculate the length of road within 2IBD by:

$$\mathrm{L} = 2 * \left(\sqrt{(2\mathrm{IBD})^2 - (\text{distance between PES and closet point})^2} \right) \tag{1}$$

where the distance between PES and closest point is entered by the user and 2IBD is calculated by SAFER.

Substep 2

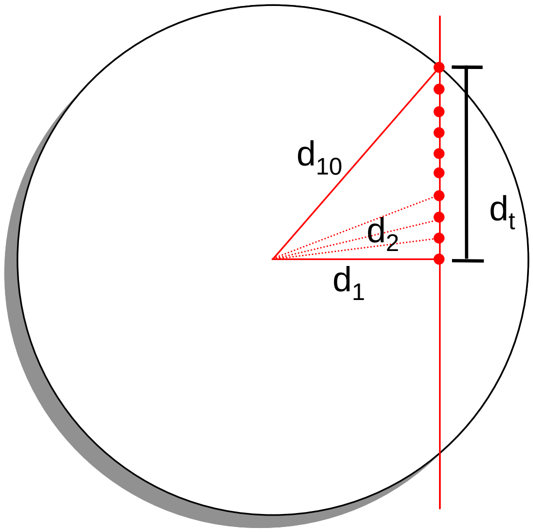
Divide the length of road within 2IBD by 2 to determine dt.

$$\mathrm{d}_{\mathrm{t}} = \mathrm{L}/2 \tag{2}$$

Substep 3

SAFER calculates the 10 distance increments by:

$$\text{Distance Increment} = \frac{\left[\sqrt{\left(\frac{\mathrm{L}}{2}\right)^2 + (\text{distance between PES and closet point})^2} \right] - (\text{distance between PES and closet point})^2}{9} \tag{3}$$



$P_{f/e} = \text{average of } 10\ P_{f/e}$

$d_1 = \text{closest distance between PES and road}$

$d_2 = \sqrt{(d_1)^2 + [(d_t/9)*(2-1)]^2}$

$d_3 = \sqrt{(d_1)^2 + [(d_t/9)*(3-1)]^2}$

$d_n = \sqrt{(d_1)^2 + [(d_t/9)*(n-1)]^2}$

$d_{10} = 2\mathrm{IBD}$

Substep 4

Using the 10 distances calculated in above, SAFER will calculate the physical effects and consequences for each distance.

Substep 5

SAFER calculates the final $P_{f/e}$ by averaging the results of the 10 distance runs in Substep 4.

$$P_{f/e} = \frac{\sum_{\text{distance1}}^{\text{distance10}} (P_{f/e})}{10} \tag{4}$$

Outputs:

- Probability of fatality given an event, $P_{f/e}$
- Probability of major injury given an event, $P_{maji/e}$
- Probability of minor injury given an event, $P_{mini/e}$

5. How is the personnel exposure calculated?

The personnel exposure is calculated for both the group and an individual. In addition to the exposure determination, a standard deviation for both is calculated.

Inputs:

- Length of Road Within 2 IBD Arc (ft), L, user input or calculated by SAFER
- Number of cars per day, user input
- Maximum number of cars per hour, user input
- Average number of people per car, user input
- Maximum number of people per car, user input
- Average speed (mph), user input
- Minimum speed (mph), user input
- Number of trips per day (for an individual), user input
- Maximum number of trips per day (for an individual), user input

Substep 1

Calculate the group exposure by:

$$\text{group exposure} = \frac{(\text{distance travelled}/5280) * \text{expected cars per hour} * \text{number of people per car}}{\text{average car speed}} \tag{5}$$

where the distance traveled is determined by SAFER (or entered by the user), expected cars per hour is calculated by dividing the number of cars per day by 24 hours, the number of people per car is entered by the user, and the average speed is entered by the user.

Substep 2

Next, the upper bound group exposure is determined:

$$\text{upper bound group exposure} = \frac{(\text{distance travelled}/5280) * \text{maximum cars per hour} * \text{maximum number of people per car}}{\text{minimum car speed}} \tag{6}$$

where the distance traveled is determined by SAFER (or entered by the user), maximum cars per hour is entered by the user, the maximum number of people per car is entered by the user, and the minimum speed is entered by the user.

The standard deviation in the group exposure is calculated by:

$$\text{standard deviation (group exposure)} = \frac{\ln(\text{upper bound exposure}/\text{group exposure})}{3} \tag{7}$$

Substep 3

Calculate the individual exposure by:

$$\text{individual exposure} = \frac{(\text{distance travelled}/5280) * (\text{trips per day}/24)}{\text{average car speed}} \tag{8}$$

where the distance traveled is determined by SAFER (or entered by the user), trips per hour calculated by SAFER using the user input of average trips per day, and the average speed is entered by the user.

Substep 4

The upper bound individual exposure is determined by:

$$\text{upper bound individual exposure} = \frac{(\text{distance travelled}/5280) * (\text{maximum trips per day}/24)}{\text{minimum car speed}} \tag{9}$$

where the distance traveled is determined by SAFER (or entered by the user), maximum trips per day is entered by the user, and the minimum speed is entered by the user.

The standard deviation in the group exposure is calculated by:

$$\text{standard deviation (individual exposure)} = \frac{\ln(\text{upper bound individual exposure}/\text{individual exposure})}{3} \tag{10}$$

Outputs:

- Group exposure
- Standard deviation in group exposure
- Individual exposure
- Standard deviation in individual exposure

6. What are the inputs to the uncertainty model?

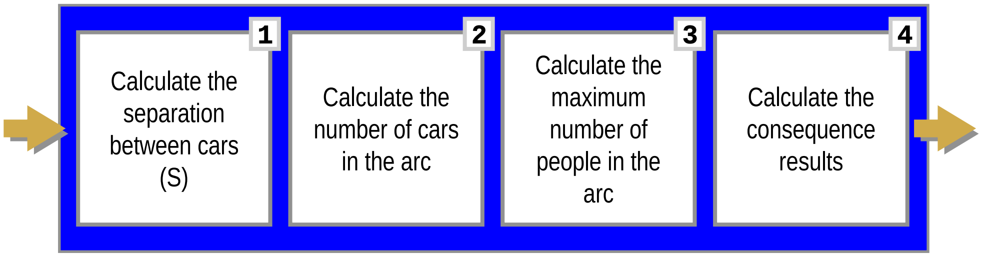
The standard deviation inputs related to personnel exposure were described in Question #5 above. All other uncertainty inputs are determined in the same manner as in non-PTR cases. The complete listing of uncertainty inputs is shown in the table below.

Symbol	Short Title	Methodology
Δt_o	median value of Δt	*assume delta t is equal to one for PTR cases*
$\sigma_{\Delta t}$	standard deviation of Δt	*see Technical Paper #14*
S_o	median value of environmental factor	*see Technical Paper #14*
σ_S	standard deviation of environmental factor	*see Technical Paper #14*
λ_{oo}	median value of lambda	*see Technical Paper #14*
$\sigma_{\lambda o}$	standard deviation of lambda	*see Technical Paper #14*
E_{oo}	epistemic median daily exposure	*see Technical Paper #14*
σ_e	random variation standard deviation exposure	*see Technical Paper #14*
σ_{e1}	random variation in lambda due to exposure	*NA*
σ_{Eo}	epistemic standard deviation of exposure	*NA*
$P_{f\|1oo}$	epistemic median $P_{f\|e}$ blast	*based on average of 10 distance runs*
$P_{f\|2oo}$	epistemic median $P_{f\|e}$ building damage	*based on average of 10 distance runs*
$P_{f\|3oo}$	epistemic median $P_{f\|e}$ debris	*based on average of 10 distance runs*

Symbol	Short Title	Methodology
$P_{f\|4oo}$	epistemic median $P_{f\|e}$ glass	*based on average of 10 distance runs*
σ_y	standard deviation yield	*see Technical Paper #14*
σ_{yo}	epistemic standard deviation yield	*see Technical Paper #14*
ρ_{Ne}	correlation between NEW and exposure	*NA*
ρ_{Ae}	correlation between PES activity and exposure	*NA*
σ_{NEW1}	standard deviation NEW	*Set to 1.0.*
σ_{NEW2}	standard deviation NEW	*NA*
σ_1	standard deviation for variation in o/p	*see Technical Paper #14*
σ_2	standard deviation for variation in b/c	*see Technical Paper #14*
σ_3	standard deviation for variation in debris	*see Technical Paper #14*
σ_4	standard deviation for variation in glass	*see Technical Paper #14*
σ_{1o}	epistemic standard deviation for overpressure	*see Technical Paper #14*
σ_{2o}	epistemic standard deviation for bldg damage	*see Technical Paper #14*
σ_{3o}	epistemic standard deviation for debris	*see Technical Paper #14*
σ_{4o}	epistemic standard deviation for glass	*see Technical Paper #14*

7. How are the number of fatalities, major injuries, and minor injuries calculated?

To calculate the number of fatalities, major injuries, and minor injuries, SAFER must calculate the number of people in the 2IBD arc at any moment in time. SAFER uses the number of people in the arc and the probability of fatality, probability of major injury, and minor injury to calculate the consequences. SAFER does this in 4 substeps:



Inputs:

- Length of Road Within 2 IBD Arc (ft), L, calculated by SAFER
- Maximum Cars per hour, Max_{cars}, user input
- Minimum Speed (mph), Min_{speed}, user input
- Maximum number of people, Max_{people}, user input
- Probability of fatality given an event, $P_{f/e}$, calculated by SAFER
- Probability of major injury given an event, $P_{maji/e}$, calculated by SAFER
- Probability of minor injury given an event, $P_{minii/e}$, calculated by SAFER

Substep 1

SAFER calculates the Separation between Cars, S, by:

$$S = Min_{speed} / Max_{cars} * 5280 \text{ ft/mile} \quad (11)$$

Substep 2

SAFER calculates the number of Cars in the Arc by:

$$\text{Cars in Arc} = L / S \quad (12)$$

where L is the total distance traveled within the 2IBD arc and S is calculated in *Substep 1* above.

Substep 3

SAFER calculates the maximum number of people in the arc by:

$$\text{Exposure (number of people)} = \text{Cars in Arc} * Max_{people} \quad (13)$$

where the cars in the arc are calculated in Substep 2 above and the maximum number of people per car, Max_{people}, is entered by the user.

Substep 4

Calculate the number of fatalities, major injuries, and minor injuries by:

$$\begin{aligned} &\text{Number of fatalities} = P_{f/e} * \text{Exposure (number of people)} \\ &\text{Number of major injuries} = P_{maji/e} * \text{Exposure (number of people)} \\ &\text{Number of minor injuries} = P_{mini/e} * \text{Exposure (number of people)} \end{aligned} \quad (14)$$

Outputs:

- Number of fatalities
- Number of major injuries
- Number of minor injuries

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Revision 3

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