Risk-Based Explosives Safety Modeling

Oilfield Explosive Safety/Security Seminar

sponsored by Marathon Oil Company

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Background

- The American Table of Distances was first established for inhabited buildings and public railways in December 1910 based on available empirical data.
- The highway distance portion of the table was approved by the Institute of Makers of Explosives in 1914.
- Periodic review of the table has not resulted in significant changes to the table.
- The Quantity-Distance, (Q-D) tables determine separation distance by quantity of explosives, hazard class, (high explosives & ANFO/ blasting agents), barricading, (if any), and the type of structure or location at risk in order to determine the safe separation distance.
- Structures or locations at risk include inhabited buildings, public highways, passenger railways and magazine separation.

Background, (cont'd)

- Although the American Standard Table of Distances has been used successfully for many years, there are a number of specific cases where the tables do not apply.
- In the oilpatch, the operation of a gun loading shop on a compound owned or leased by a major oil company may entail a number of unrelated activities may be operating in the nearby vicinity to explosives operations.
- The availability of real estate for explosive operations may be severely limited in some locations, requiring a very detailed quantitative safety assessment be performed to minimize risk to operating personnel and those persons not directly related to the explosive operations.
- During the Technical Committee Meeting on 2 June 2003 at the Spring Meeting of the Institute of Makers of Explosives, a sub-committee was formed to investigate the application of risk-based safety modeling to commercial explosives manufacturing, transportation and storage.
- The RBESCT Meeting at APT Research was attended by an I.M.E. member company representative on 23-24 July 2003.
- The attached briefing summarizes the subject software affiliated with the computation of risk-based safety analysis regarding explosives.

Recent Global Safety Assessment Trends

- Recently, some nations have investigated the use of improved methodologies to locate explosive storage or explosive operations or evaluate risk at existing sites
  - » Switzerland; 1960s, ammunition storage drove the implementation of quantified risk analysis. Regulations were adopted and organizations established to evaluate risk
  - » United Kingdom; 1983, evaluate upper bound on the risk of individual fatality via $P_{explosive\ event} X P_{consequence.}$
  - » Norway; 1970s, risk-based safety analysis employed to reduce number of waivers for storage locations
  - » Australia; risk analysis is used to provide analysis for waiver assessment
  - » United States; DoD Explosives Safety Board formed the Risk-Based Explosives Safety Criteria Team to study the utility of risk-based explosives safety criteria.

U.S. Approach to Risk Assessment

- In August 1997, the Risk-Based Explosives Safety Criteria Team was formed by the DoD Explosives Safety Board to examine the feasibility and utility of risk-based explosive safety criteria.
- The RBESCT has since developed software for the Safety Assessment for Explosives Risk, (SAFER) and established safety criteria for personnel
- The RBESCT is composed of members of the DDESB, Navy, Marine Corps, Air Force, Army with support from APT Research, Inc of Huntsville, Alabama.
- In December 1999, the DDESB approved a three year trial period using the SAFER model. During FY 2000, SAFER version 1.0 was published and distributed to the RBESCT. Trial period ended December 2004.
- SAFER version 2.1 incorporated changes based on recent sensitivity studies. SAFER version 3.0 includes improved probability of event algorithms and improved science algorithms and "risk of injury" computation as well as "risk of fatality" computation.

Types of Risk-Based Safety Software

- DIRE Version 1.0; Death & Injuries Resulting from Explosions; calculates human vulnerability to overpressure/specific impulse, building failure, and debris and fragment impact. Effects include lung damage, whole-body motion, skull fracture, impact from primary and secondary fragments, and glass shards. DIRE predicts the number of fatalities, major injuries and minor injuries, building damage percentage and glass breakage.
- SAFER Version 2.1 & 3.0; Safety Assessment for Explosives Risk calculates a quantitative risk to people for death or injury from a potential explosion by computing the probability of the event, explosives effects and personal exposure to people in inhabited buildings, public traffic routes and intraline distances.
- BREEZE HEXDAM for WINDOWS®; High Explosive Damage Assessment Model computes the damage to structures as a result of a primary and possibly secondary explosions

SAFER Version 2.1

- Safety Assessment For Explosives Risk
  - » The SAFER software model was developed to provide a quantitative assessment of the overall risk to persons from explosives operations. Safe siting of explosive operations has been traditionally been met by the use of the American Table of Distances to locate explosives operations from public roads, inhabited buildings, passenger railroads and magazine separation distance. A waiver system or exemption was required when the precise nature of the operation was not covered by the Q-D tables or could not be met by other constraints. SAFER provides the basis for a waiver request or covers unusual or peculiar situations not found in the Q-D tables.
  - » SAFER calculates the statistical expectation of the loss of life from an unplanned explosive incident. SAFER 3.0, (the basis for the commercial risk model), will also include risk of injury as well as fatality risk.
  - » Personnel categories considered in the SAFER model include; worker criteria apply to personnel involved in explosive activity and non-related/public criteria apply to personnel nearby but not associated with the explosive activity.

SAFER Input Parameters

- Donor or Potential Explosive Source, (PES)
  - » Building Number or identifier
  - » Building category; open blast source, pre-engineered metal building, brick, hollow clay tile, earth-covered magazine, hardened aircraft shelter, small, medium and large ship, operating building
  - » number of people at the potential explosive site
  - » Soil type for open blast; hard or soft clay, other donors assume concrete.
- Explosive Operation
  - » Type of operation; assembly, disposal, loading, LAP, test, training, storage (temp or deep), inspection, de-mil, etc.
  - » Scaling factor; a pre-determined factor that can alter risk levels such as inclement weather, or performing operations in the open normally done indoors, etc.
  - » Hazard Division and explosive type
  - » Compatibility Group
  - » Expected and sited net explosive weight

SAFER Input Parameters (cont'd)

- Target or Exposed Site, (ES)
  - » Building Identifier
  - » Target Building; open, reinforced concrete, reinforced masonry, un-reinforced masonry, metal wall building, stud wall building, modular building or trailer, passenger vehicle.
  - » Roof Types; 4" reinforced concrete, >12" reinforced concrete, plywood, gypsum/ fiberboard, wood panel, lightweight concrete, medium steel panel, light steel panel, automobile steel, unknown.
  - » Glass Type; annealed, tempered, dual pane, none
  - » Percent glass area in target building
  - » Floor Area (in square feet)
  - » Distance from the explosive donor to the nearest edge of the target building.
  - » Number of people in the target building, (assumed evenly distributed)
  - » Number of stories in the target building
  - » Orientation; used with earth-covered magazine or hardened aircraft shelter; used to specify the orientation of the donor to the target.

Sample of a SAFER Run

- PES Input/Output

Report for PES MeltPour

PES Inputs

Number of people at PES:	2
Building Type:	Small Concrete Building
Soil Type:	Concrete
Activity Type:	Assembly
Scaling Factor:	No scaling factor will be applied.

Summary of PES Outputs:

Explosives Input for Hazard Division 1.1:

Weapon Type:	Bulk/light case
Weapon Description:	Thin skinned
Sited NEWQD:	50
Expected NEWQD	50
Compatibility Group:	D

Explosives Output for Hazard Division 1.1:

Sample of a SAFER run, (cont'd)

- Sited NEWQD/ES Input

Sited NEWQD		Expected NEWQD	
Maximum P(f) Public:	5.2e-010 (ES OilRig) 3.8e-010 (ES OilRig)		Maximum P(f) Public:
P(f) Public Criteria:	1.0e-006		
Maximum P(f) Related:	0.0e+000	Maximum P(f) Public:	0.0e+000
P(f) Related Criteria:	1.0e-004		
Summed E(f) Public:	3.1e-009	Summed E(f) Public:	2.3e-009
E(f) Public Criteria:	1.0e-005		
Summed E(f) Related:	0.0e+000	Summed E(f) Related:	0.0e+000
E(f) Related Criteria:	1.0e-003		

ES OilRig

ES Inputs

Building Type:	Open
Distance from PES:	670 ft

Warning Flags:

SAFER answers for whole body displacement and skull fracture may be conservative for ES type Open because exposed people are assumed to be near rigid perpendicular objects, which may not be the case for people in the

Sample of a SAFER run, (cont'd)

- Personnel Exposure

Personnel Type: Public	# People	# Hours
Group 1	6	600.00
Group 2	0	0.00
Group 3	0	0.00
Group 4	0	0.00
Group 5	0	0.00
Group 6	0	0.00

Personnel Type: Related	# People	# Hours
Group 1	0	0.00
Group 2	0	0.00
Group 3	0	0.00
Group 4	0	0.00
Group 5	0	0.00
Group 6	0	0.00

OUTPUT:

Maximum Individual Exposure		Annual Exposure	
Public:	6.8e-002	Public:	4.1e-001
Related:	0.0e+000	Related:	0.0e+000

Explosives Input for Hazard Division 1.1:

Weapon Type:	Bulk/light case
Weapon Description:	Thin skinned
Sited NEWQD:	50
Expected NEWQD	50
Compatibility Group:	D

Explosives Output for Hazard Division 1.1:

Sample of a SAFER run, (cont'd)

- Sited NEWQD & Blast Effects

Sited NEWQD		Expected NEWQD	
P(f|e) Lung Rupture:	9.9e-010	P(f|e) Lung Rupture:	9.9e-010
P(f|e) Body Displacement:	9.9e-010	P(f|e) Body Displacement:	9.9e-010
P(f|e) Skull Fracture:	9.9e-010	P(f|e) Skull Fracture:	9.9e-010
P(f|e) Overpressure:	**3.0e-009**	**P(f|e) Overpressure:**	**3.0e-009**
P(f|e) Glass:	0.0e+000	P(f|e) Glass:	0.0e+000
P(f|e) Building Collapse:	0.0e+000	P(f|e) Building Collapse:	0.0e+000
P(f|e) Structural:	**0.0e+000**	**P(f|e) Structural:**	**0.0e+000**
P(f|e) Horizontal Debris:	7.6e-006	P(f|e) Hor. Debris:	5.7e-006
P(f|e) Vertical Debris:	6.9e-005	P(f|e) Vert. Debris:	4.9e-005
P(f|e) Debris:	**7.6e-005**	**P(f|e) Debris:**	**5.5e-005**
P(f|e) Thermal:	0.0e+000	P(f|e) Thermal:	0.0e+000
P(f|e) Overall:	**7.6e-005**	**P(f|e) Overall:**	**5.5e-005**
Max Yield:	50 lbs	Expected Yield:	40 lbs
Pressure:	1.4e-001 psi	Pressure:	1.3e-001 psi
Impulse:	1.5e+000 psi-ms	Impulse:	1.3e+000 psi-ms

Warning Flags:

At this scaled range, the pressure and impulse calculations may be too low to have been validated by empir

SAFER Version 3.0

- The SAFER Version 3.0 software by APT Research will be the basic platform for the commercial explosive risk assessment model, and will provide an estimate for the risk to an individual or group of individuals from an unplanned explosive event.
- The basis for the risk computation is the combined probability as:

$$P_{f(max)} = E_{p(max)} \times P_{f/e} \times P_e$$

where:

$P_{f(max)}$ is defined as the maximum probability of fatality for an individual.
$E_{p(max)}$ is defined as the maximum exposure of an individual
$P_{f/e}$ is defined as the probability of a fatality given an event
P_e is defined as the probability of an event

and

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

where:

E_f is the expected fatality count
E_p is the exposure of an individual

P_e Development

- Of the three factors in the probability equations on the previous page, none is more difficult to quantify than P_e and is the most uncertain.
- Three factors affect the probability of an explosive event; the activity at the PES, the Compatibility Group at the PES and environmental circumstances that can alter the probability of occurrence.
- A matrix was constructed with the PES activity indicated on the first column elements, scaling factors on the second column elements and Compatibility Group as elements in the matrix. The remaining column headers are event probabilities per year from 1E-6 to 3E-1 in a series of twelve range values.
- Two types of scaling factors increase the P_e by a factor of 3 and 10 respectively. The scaling factors relate primarily to ammunition type of activities.
- Three Compatibility Groups are considered; I (comprising groups L, A, B, G, H, J, F); II (comprising group C); and III (comprising groups D and E).
- The P_e matrix is the result of a compilation of historical explosives accident data and 175 explosive events.

$P_{f/e}$ Development

- A number of mechanisms can lead to a fatality or injury in an explosive event
- Those considered in SAFER are; specific impulse/ overpressure, building collapse, flying glass, debris impact (primary and secondary fragments), and in the case of some materials such as propellants, thermal, (fireball), effects.
- The physical effects of the above threats are summed to determine the probability of fatality or injury.

E_p Development

- Personnel exposure to an unplanned explosive event is determined by multiplying the number of people by the percentage of time they are located at an exposed site, (ES), per annum.
- Three classifications of people are considered; related, non-related, and public.
- Two exposure calculations are performed for each classification of people; the exposure for all people at the ES is determined and the other is the exposure to one person per year.
- The SAFER model recognizes that one PES may threaten more than one group of people at different ESs, and conversely one ES may be threatened by more than one PES donor.

SAFER Input

- Input Explosives Data
  - » There are two input screens in SAFER; one for a single class of explosive and one for a mixture of explosives.
  - » The explosive's weight, hazard Division and Compatibility Group is entered.
  - » Weapons types can be entered for Hazard Division 1.1
- Potential Explosive Site, (PES) Data
  - » Options are open explosion, earth-covered magazine, brick structure, butler building, ship, hardened aircraft structure, and an operating building
- Activity Options at the PES
  - » Options include assembly, LAP, renovation, de-mil, disposal, test, loading, inspection, deep storage, in-transit storage, disassembly, maintenance, burning ground, demolition, laboratory, training, manufacturing, and temporary storage.

SAFER Input (cont'd)

- Compatibility Group Input
  - » The user chooses the compatibility group of the donor explosive
- Exposed Site Input
  - » The options are open site, tilt-wall reinforced concrete, steel and masonry, brick, pre-engineered metal building, timber, multi-story reinforced concrete offices/apartments, multi-story steel frame, reinforced concrete, reinforced masonry, light steel frame, large/heavy timber, modular buildings and trailers.
- Roof Types
  - » Roof type options include built-up wood panel, steel panel/corrugated metal panel, and 4" reinforced concrete.

SAFER Internal Computations

- Internal Calculations
  - » Determination of open-air overpressure and specific impulse
  - » Determination of adjusted P, I for specified PES
  - » Determination of adjusted P, I for specified ES
  - » Assess fatality probability due to P, I
  - » Determination of P, I on Building Collapse and Glass Breakage
  - » Primary fragment description and ES containment, originating with stored explosives, "fly-through" fragments and fragments with vertical trajectories
  - » Secondary fragment description comprising debris originating from PES structure
  - » Maximum Throw table computation and form combined debris table
  - » Assess fatality probability due to primary and secondary fragments.
  - » Determination of temperature of fireball, its radius and duration
  - » Adjust temperature due to PES and ES.
  - » Assess probability of fatality due to thermal effects
  - » Summation of probabilities for each threat mechanism

SAFER Output

- SAFER Output
  - » The output from SAFER is viewable in two formats
    - An output screen depicting the probability of E_f and P_f for each category of personnel entered in the input file.
    - A printer friendly report presenting the E_f and P_f for each ES described in the input file. The output format for printing also includes the input PES and ES data descriptions.
  - » A data log file is generated to keep track of the runs performed.
  - » A tree of PESs and ESs comprises the left-hand window for keeping a running record of the sites modeled.

Individual Levels of Risk

- Levels of Risk per Individual per Annum
  - » All external causes of mortality; 5.49×10^{-4}
  - » All unintentional injuries; 3.55×10^{-4}
  - » Motor vehicle accident; 1.698×10^{-4}
  - » Falls; 4.84×10^{-5}
  - » Exposure to fire, smoke and flames; 1.226×10^{-5}
  - » Accidental drowning and submersion; 1.274×10^{-5}
  - » Intentional self-harm; 1.06×10^{-4}
  - » Assault; 6.08×10^{-5}
  - » Explosion of materials other than fireworks; 6.06×10^{-7}
  - » Exposure to electric current, radiation, pressure, or temperatures of man-made origin; 1.52×10^{-6}
- "How safe is safe"
  - » Many factors are involved in determining "how safe is safe" including sociological and cultural factors which are very subjective in nature. No mere computational code can compute that.

SAFER and Group/Individual Risk Levels

Risk to:	Draft Criteria
Any 1 worker (Annual P_f)	Limit max. risk to $1x10^{-4}$
All workers (Annual E_f)	Lower risk to $1x10^{-3}$ Accept $1x10^{-2}$ with national emergency only
Any 1 person, non-related or public (Annual P_f)	Limit max. risk to $1x10^{-6}$
All public (Annual E_f)	Lower risk to $1x10^{-5}$ Accept $1x10^{-3}$ with national emergency only

SAFER Summary

- A useful tool for estimating the quantitative risk assessments for a variety of PESs and ESs.
- SAFER was developed by the Department of Defense Explosives Safety Board primarily to assess risks during operations involving explosives by and for the military.
- Funding levels are approximately one-half million dollars per year divided amongst five agencies, Army, Navy, Air Force, Marine Corps and the DDESB.
- System Requirements
  - » 486- based processor or above using a WINDOWS 98, NT 4.0, 2000, or XP operating system
  - » Display screen resolution at least 800 X 600 pixels
  - » No other software packages are required; SAFER operates standalone.
- Cost and Availability; DoD only, by personnel trained in its use.

Breeze HEXDAM 5.2

- Developed by Engineering Analysis, Inc., HEXDAM 5.2 is the fifth version of the High Explosive Damage Assessment Model was conceived with industrial facilities in mind as well as military sites.
- Capabilities:
  - » Prediction of blast effects on 104 basic structure types
  - » Prediction of bodily injury to 28 basic body components
  - » Capability to handle shielding effects of nearby structures
- Input
  - » Primary explosion source, location and yield
  - » Individual structures, location and orientation and size
  - » Human body location and orientation
- System Requirements
  - » IBM PC, WINDOWS 95 or later. Will run in DOS 3.2
- Software cost is $7,495.00 per seat.

Breeze HEXDAM 5.2 (cont'd)

- HEXDAM 5.2 Output
  - » 3-D projection of structures prior to explosion
  - » Damage/Injury Table
  - » 3-D display of structures after the blast
  - » Damage/injury as a function of distance graph
  - » 3-D projection of pressure contours
  - » Parametric analysis of variation of dynamic pressure and damage to a single structure as a function of yield and burst location

Risk-Based Explosive Safety, the I.M.E., and the Commercial Explosives Industry

- Major issues with current software
  - » DIRE does not treat the probability of the unplanned explosive event
  - » SAFER was conceived and developed to address quantitative risk assessments within the DoD, (CONUS and OCONUS locations).
  - » For appropriate applications to the commercial explosives sector, the historical data for commercial incidents will be accumulated and used to develop the P_e model. This requires the cooperation of the commercial explosives industry and the cognizant regulatory agencies.
- Possible Actions within the commercial explosives industry
  - » Do nothing and wait until a regulatory body develops a risk assessment model
  - » Monitor the progress of the QRA models within the DoD and DoE.
  - » Individual companies purchase or develop risk assessment models for their own specific applications.
  - » Establish a program within the Institute of Makers of Explosives and its member companies and with the assistance of APT Research and the cognizant Federal regulatory agencies, develop a commercial version of SAFER.
  - » The IME and its member companies elected the last course of action; that is to develop a commercial version of SAFER with the active involvement of APT- Research, IME member companies and the Federal regulatory agencies.

The Risk-Based Safety Software Development Program

- The initial investigation into the SAFER software occurred in 2002 2003.
- Discussions and approvals within the IME and its participating companies were completed in the Fall of 2004. Funding through member company contributions was agreed upon.
- On 31 January and 1 February 2005, a program kick-off meeting was held with IME, its member company representatives, APT-Research and representatives of the ATF in Washington, D.C. to plan the software development program.
- Although no one realistically expected every Federal agency involved in explosive regulation to "endorse" the program, they committed to cooperate by sharing data and assisting by participation in progress meetings. U.S.D.O.T. and NRCanada were very enthusiastic about the concept of risk-based explosive safety.

The Risk-Based Safety Software Program Timeline

- Milestones - two year software development program
  - » 31 January - 1 February 2005; kickoff Meeting; completed
  - » 25 March 2005; complete all input for incident reporting, PESs, ESs and exposure levels.
  - » 10 May 2005; freeze software design requirements
  - » Nov 2005; complete final PES models, complete final ES models, run sensitivity models
  - » January 2006; deliver prototype model
  - » April 2006; develop software test plan
  - » September 2006; complete software testing
  - » November 2006; complete sensitivity studies
  - » December 2006; deliver commercial version of SAFER

Details of the Commercial Risk Assessment Model

- Potential Explosive Sites for Commercial Users
  - » ATF Specification Magazines
  - » Perforating Gun Loading Shop
  - » Bulk Trucks; (blasting agents)
  - » ANFO silo, bin or shed
  - » Division 1.1 manufacturing plant
  - » Commercial trucks, ships, rail cars, or planes
- Potential Exposed Sites for Commercial Users
  - » Oil rigs
  - » Roads, vehicles
  - » Mining machines

Summary

- The IME needs your assistance and cooperation in making the commercial version of SAFER a useful tool to enhance oilfield explosive safety by supplying:
  - » PES and ES descriptions
  - » incident data including all relevant data whether or not injuries or fatalities occurred
- APT Research, (mhardwick@apt-research.com is the collection point for PES, ES and incident data or mail to:

APT Research, Inc.

4950 Research Drive

Huntsville, AL 35805

Attn: Ms. Meredith Hardwick