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A Risk Assessment and Management Methodology for the Improvement of Safety and Protection of Ammunition and Explosive Facilities

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Abstract

Ammunition and Explosive (A&E) facilities are inherently prone to high hazard potential because of internal accidental explosion that can lead to tremendous and irreversible consequences to life and property. This research introduces the development and the implementation of a comprehensive risk analysis model for a typical A&E facility subjected to accidental explosion. The risk analysis model incorporates blast-response models and a Benefit-to-Cost-Ratio (BCR) analysis that assesses the economic benefits of the alternative protective solutions across the expectancy of casualty, the direct and indirect economic losses. The model consists of four phases: (1) scenario analysis – six different scenarios were developed and analyzed as follows: Three TNT charges at the weight of 1, 10, and 50 Kgs were detonated, each at two positions: (I) Spherical charge, at one meter above the floor surface; and (II) Hemispherical charge at the floor level. The blast waves arises from the examined scenario were simulated and analyzed by BLASTX software for two cases: typical A&E building with or without openings. (2) Pressure impulse diagrams analysis – the assessment of personnel harmed at different levels of severity (body and lung damage); (3) Risk Analysis and (4) Benefit-to-Cost-Ratio-Analysis (BCRA) for the examination of the economic feasibility of several alternative protective solutions such as: addition of steel plates to exterior walls and interior partitions, polymer sheets, or reinforced concrete (RC) internal partitions. Based on the literature review, the annual probability of an accidental explosion in A&E facilities was assumed to be 4.7×10^{-3}-4.7×10^{-2}. The BCR ratios of all the suggested alternative protective solution ns were found to be between 1.25 (1 Kg - opened openings A&E building) and 14.75 (50 Kg - opened openings A&E building). The risk analysis reveals that all protective solutions examined are highly effective in terms of expectancy of risk. It is recommended that the Safety regulations of A&E facilities be upgraded in light of the current research.

Keywords: Accidental Explosion; Ammunition and Explosive Facilities; Pressure-Impulse Diagrams; Risk.

1. Introduction

Interior explosion, is the most common extreme event that occurs in ammunition and explosive (A&E) facilities during industrial processes such as: processing, manufacturing, maintenance, renovation, demilitarization and similar operations. The explosion can lead to different kind of failures, from localized failure up to cascading failure in and out the facility thus, it can lead to tremendous and irreversible consequences to life and property. The principal effects of the explosion to be considered are: blast pressure, primary and secondary fragments and thermal hazards [1]. High pressure, for example, can cause irreparable damage as eardrum rupture and lethality due to lung damage. It also might cause building to collapse and turn into debris and rubbles. Primary and secondary fragments might fly with high velocity and shock wave (moving through the structure or the ground) might cause people overturned or fall down with possible injuries or fatalities.[2, 3] therefore, there is a need to design those structures to resist the effects of interior accidental explosions and to accomplish personnel protection. This research introduces the development and the implementation of a comprehensive risk analysis model for a typical A&E facility subjected to accidental internal explosion.

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2. Methodology

The suggested risk analysis model incorporates blast-response models and a Benefit-to-Cost-Ratio-Analysis (BCRA) analysis that investigates the economic benefits of the alternative protective solutions across the expectancy of casualty, the economic loss and the loss of the production activities. The model consists of four phases as presented in Figure 1.

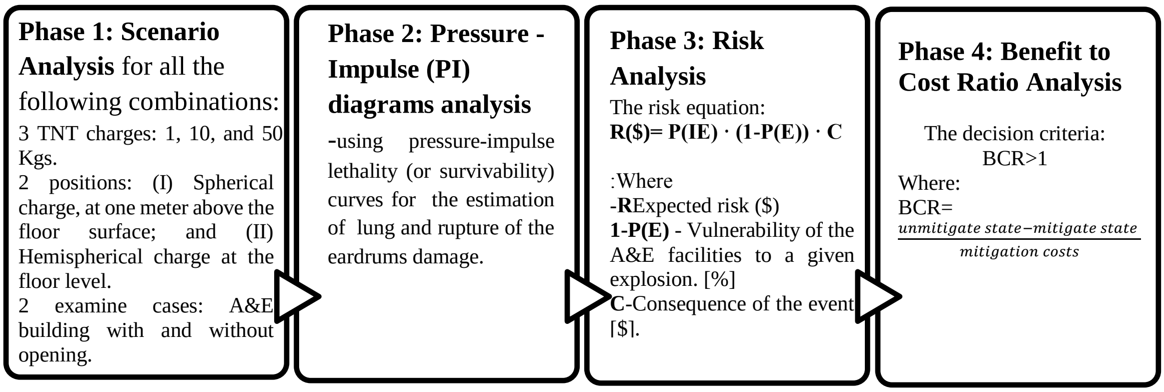

Figure 1: Risk Analysis flow chart.

The following paragraphs delineates the four Phases:

Scenario analysis – six different scenarios were developed and analyzed as follows: Three TNT charges at the weight of 1, 10, and 50 Kg were detonated, each at two positions: (I) Spherical charge ,at one meter above the floor surface; and (II) Hemispherical charge on the floor level. The blast waves arises from the examined scenario were calculated by BLASTX software for two discrete cases: typical A&E building with or without openings that because, when an explosion occurs within a structure, the peak pressure associated with the initial shock front will be extremely high and, in turn, will be amplified by reflections within the structure. In addition, the accumulation of gases from the explosion will exert additional pressures and increases the load duration within the structure. The combined effects of both pressures eventually may destroy the structure if it is not strengthened sufficiently or if adequate venting for the gas and shock pressure is not provided, or both. For structures that have one or more strengthened walls, venting for relief of excessive gas or shock pressures, or both, may be provided by means of openings in or frangible construction of the remaining walls or roof, or both. This type of construction will permit the blast wave from an interior explosion to spill over onto the exterior floor surface. These pressures, referred to as exterior or leakage pressures, once released from their confinement, expand radially and act on structures or persons, or both, on the other side of the barrier. Figure 2 represents the reprehensive facility for the scenario analysis. The doors and windows at the exterior walls were considered as opened or closed. The regular steel doors between the rooms are assumed to be opened. The facility floor, walls, and roof are assumed as rigid for the blast simulation based on BLASTX and the exterior wall No. 16 of room 1 was considered to be with or without opening of 456 by 456 cm (half wall area). The simulation results, for each scenario alternative, provide pressure and impulse values at selected points (points 1 to 26 at figure 2). That will be the input for Phase 2.

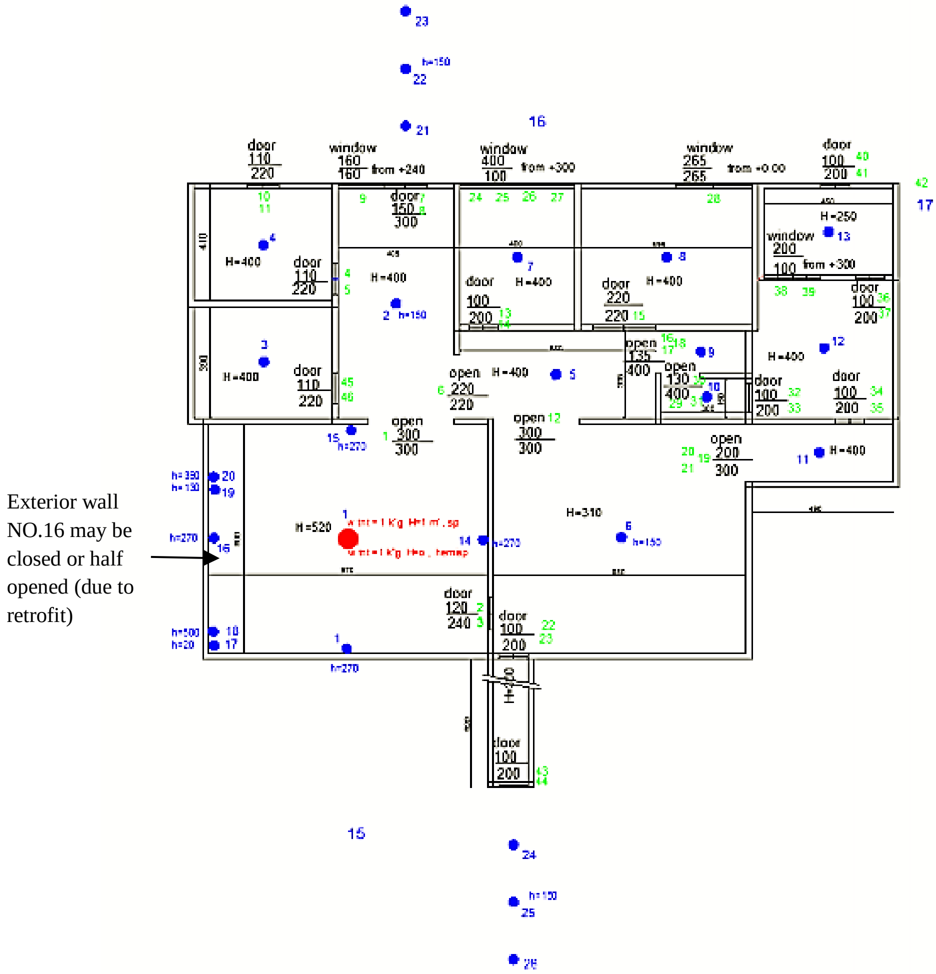

Figure 2-A reprehensive A&E facility and 26 selected study points ( ) for the blast simulations of: 1, 10, and 50kg of TNT Spherical charge, at one meter above the floor surface; and of 1, 10, 50kg Hemispherical charge at the floor level (presented as red point)

Pressure impulse diagrams analysis - The assessment of personnel blast damages was calculated, according to the simulation results at point 1 to 26, by Pressure and Impulse (PI) diagrams (Fig.3). Pressure and impulse diagram is a useful design tool that provides tangible and transparent assessment of the response to a specified load. With a maximum displacement or defined damage level, the diagram indicates the combinations of load and impulse that will cause failure or a specific damage level. To assess the expected mortality and injury rate we used pressure-impulse lethality (or survivability) curves (Fig 3) [4]. Personnel are sensitive to the incident, reflected and dynamic overpressures, the rate of rise to peak overpressure after arrival of the blast wave, and the duration of the blast wave [5-9]. Parts of the body where there are the greatest differences in density of adjacent tissues are the most susceptible to primary blast damage. Thus, the air-containing tissues of the lungs are more susceptible to primary blast than any other vital organ. Other harmful effects that have been considered in this research were the rupture of the eardrums and the damage to the middle ear (Fig.4) [10-13]. Every test point, from each of the six scenarios, was classified to damage level and to the expected costs according to the classification presented in Table 1.

Table 1. Damage category, rate of survival and cost expectancy.

Damage Category	Rate of survival	Cost ($)
Mortality	<0.01	1,000,000
Severe injury	0.01-0.5	1,200,000
Moderate injury	0.51-0.90	100,000
Light injury	0.91-0.99	10,000
No injury	1.00	0

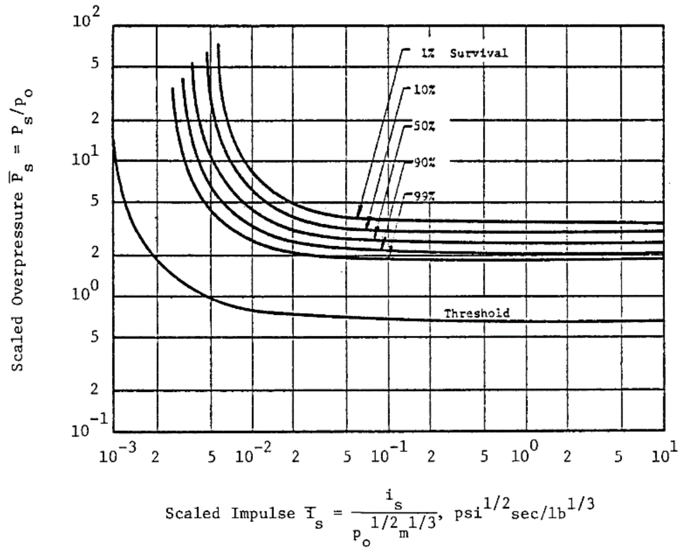

Figure 3-P-I curves for lung damage [4]

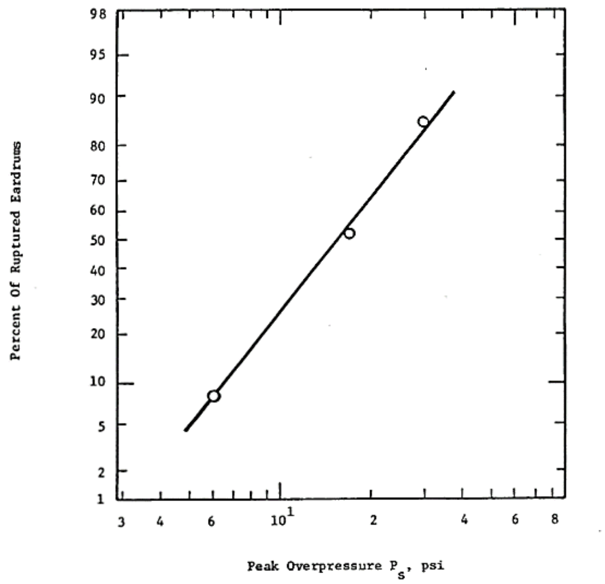

Figure 4-Eardum rapture damage as function of peak overpressure [4]

Risk analysis- the risk expectancy (for every test point, from each of the six scenarios) was calculated using Equation 1 as follows:

$$R = P(IE) \cdot (1-P(E)) \cdot C \qquad (1)$$

Where:
R - Risk expectancy associated with the Interior Explosion event [$];
P (IE) - Probability/Likelihood of the Interior Explosion event
P (E) - Effectiveness of the protective system to prevent the event
(1-P(E)) - Vulnerability of the Ammunition and explosive facilities to a given explosion, derived from the ineffectiveness of the protection system

C - Consequence of the event [$].

The probability of the Interior Explosion event, P(IE), was found to be according to the literature [14-17] around 4.7×10^{-3}. The consequences assessment includes estimation of the expectancy of casualties and injuries [18-21], and the economic loss due to damage to the facility (direct loss) and the loss of the production activities (indirect loss). The protective effectiveness percentage was accomplished by analyzing the expected damage to the structure stability based on [23].

Benefit-to-Cost-Ratio (BCR) -The economic viability of the proposed solutions (with or without opening) was carried out using the Benefit-to-Cost-Ratio-Analysis (BCRA) as follows:

$$\frac{Benefit}{Cost} = \frac{R(Unmitigated\ \ state) - R(mitigated\ \ state)}{Mitigation\_Cost} > 1 \qquad (2)$$

3. Results

The Risk expectancy results for all the six mitigation scenarios are depicted in Table 2. The finding of the analyses reveals that explosions of one kg of TNT caused only minor structural damage, the 10Kg TNT explosion caused moderate structural damage, while the 50 kg. TNT explosion caused severe structural damage. The risk analysis reveals that all protective solutions examined are highly effective in terms of expectancy of casualty. All the protective solutions were found to be economic since BCR ratios ranged between 1.25 (for 1 kg- opened openings) and 14.75 (50 kg– opened openings) as shown in Table 3.

Table 2- Risk expectancy oƆ the six mitigation alternatives.

Mitigation alternative	Consequences (NIS)	P(IE)	1-P(E)	Risk (NIS)	Cost of Protection (NIS)	Total (NIS)
1 kg, opened windows	12,738,800	0.0047	0.05	29,936	141,000	170,936
1 kg, closed windows	39,734,400	0.0047	0.15	280,155	30,000	310,156
10 kg, opened windows	34,811,120	0.0047	0.3	490,836	141,000	631,837
10 kg, closed windows	46,953,600	0.0047	0.4	882,727	30,000	912,728
50 kg, opened windows	99,047,400	0.0047	0.9	4,190,847	141,000	4,331,847
50 kg, closed windows with additional opening	106,233,920	0.0047	0.9	4,493,694	158,000	4,651,695

Table 3- Benefit to Cost Ratio (B.C.R.) analysis of mitigation alternatives.

Mitigation alternatives	Benefits (NIS)	Costs (NIS)	BCR
1 kg, opened windows	139,220	111,000	1.25
10 kg, opened windows	280,891	111,000	2.53
50 kg, opened windows	1,300,955	111,000	11.72
50 kg, closed windows with additional opening	748,282	128,000	5.84

4. Summary and conclusions

Interior Explosions in A&E facilities might cause massive consequences to life and property. That why there is a need to develop a comprehensive risk analysis model, to assess whether the prevailing risks in A&E facilities exposed to Interior Explosions are acceptable and whether a reduction in the prevailing risk as a result of a risk mitigation strategy worth the additional investment, and, if so, to what extent. Various retrofit and protective solutions such as protective doors can be used in order to improve protection and safety to prevent fatalities, and to strengthen the structure with its dynamic capabilities. The methodology can be applied for any similar facility. The findings of the BCRA indicate that the existing protection standards for A&E facilities should be reviewed and reassessed in light of the high risk expectancy and the economic viability of upgrading and protection alternatives. Additional safety and protection measures such as openings are to be considered and be required in the regulations.

Further research is recommended to investigate the effectiveness and economic efficiency of protective alternatives such as sheets (such as P.V.C.), steel partitions, and other advanced protective solutions.

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