In the Proceedings of the EFEE second world conference on explosives and blasting technique,
10-12 September 2003, Prague, Czech Republic

EXPLOSION AND FIRE HAZARD ASSESSMENT FOR EXPLOSIVES, AMMUNITION AND FERTILIZING AGENTS FACILITIES AFTER EU DIRECTIVE 96/82/EC “SEVESO II”:

Contribution for guidelines proposal

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ABSTRACT: The European Directive 96/82/EC, “Seveso II”, requires the quantification of the impact induced in the event of a major accident. However, for explosive materials, no Eurocode, procedures, algorithms nor specific reference values for damage calculations were specified within the Directive. In order to confirm the validity of “Seveso II Risk Assessments” damage calculations, EU Member States can only refer back to their own previously existing legislation on explosives. But calculation methods, scaling laws, and reference values for safety distances vary from one Member State to the other one. Also the progress that has been made in improving the quality and safety of modern explosives has not necessarily been reflected in all state legislation, some of which is more than 50 years old. A strong need exists, within Europe, for the adoption of a harmonised approach for assessing the potential damage from major accidents involving explosives. This article illustrates a methodology suitable for use as the basis of achieving a consistent approach within Europe. The procedure presented here is a development of a method first used for undertaking the explosion and fire hazard assessments for mass detonating explosives, which was published in the March/April 2003 issue of the “Journal of Explosives Engineering”. The original method has been further refined, by experience from the consideration of ammunition and oxidizing agents, and also extended to include not only the maximum possible impact of an accident but also the maximum probable impact. Formulae for the first approximation calculation of the effects induced in the surroundings by impacting factors due to the occurrence of the accident are proposed. Threshold values for each impacting factors are given with reference to damage severity levels. A graphical representation of the results from the hazard assessment is achieved by the use of iso-damage areas in which boundaries of the severity damage levels are fixed for each given probability of occurrence of the major accident.
For those interested in further reading, I have included a list of bibliographic references.

1 INTRODUCTION

In order to achieve a consistent, reliable and effective approach for the undertaking of “Seveso II” risk assessments at explosives plants, I developed a method and algorithm for the first approximation quantification of four “impacting factors”, air overpressure, fragmentation, ground vibration and gas release, at various distances from the potential sources of explosion, or “spots”, within a facility. By setting threshold values at levels of increasing damage severity, for each of these impacting factors, a set of iso-damage curves for five predefined “damage severity levels” could be drawn for each explosion spot in the facility. The iso-damage area of the entire facility was considered as the envelope of all the single “iso-damage areas” [Folchi, 2003]. The calculation of the extent of the induced effects was carried out using a systematic approach for the worst case scenario. It was assumed that each explosion spot not only contained the maximum allowed quantity of explosive, at the spot, but also all the explosive material present at the spot had the greatest explosion energy of all the materials likely to be found at the spot.

After considering explosives plants and magazines, I then used the same approach for risk assessments for production and storage of fertilisers, ammunition facilities, explosives and ordnance demilitarization facilities. It soon became clear that my original "worst case scenario" hypothesis needed to be adapted to take proper account of the hazards connected with products classified as "explosives" but with no risk of mass detonation (for example, ammunition with UN Classification 1.3, 1.4, etc., and also "non explosive" products that may explode, such as nitrates.

Consequently, it was necessary to develop my original method also including a "combustion" scenario in the analysis. This resulted in the:

- introduction of "stationary thermal radiation" as a fifth impacting factor;
- introduction of the "maximum throw distance" to define the "reversible damage area" extension for the impacting factor "primary fragmentation";
- introduction of the probability of occurrence of the major accident and, in chain, of occurrence of the single "impacting factor";
- drawing of results in sets of iso-damage areas with each set related to a given probability of occurrence.

2 RISKS CONNECTED WITH THE PRESENCE OF FLAMMABLE AND/OR EXPLOSIVE PRODUCTS AND OF NITRATES

2.1 Introduction

Risks related to the presence of explosives, ammunition and nitrates in a facility are due to:

- combustion (non mass detonating explosives and nitrates if ignited);
- chemical explosion (mass detonating explosives).

Combustion impacts the environment with:

- release of dangerous gases;
- stationary thermal radiation.

Chemical explosion impacts the environment with:

- air overpressure wave and consequent projection of the fragments of structures "acceptor" hit by the blast wave (also called secondary fragmentation);
- projection of fragments of the container "donor" (primary fragmentation);
- release of dangerous gases;
- elastic/seismic waves in the ground (in case of heavy confinement of the charge such as those of buried or underground depots);
- instantaneous thermal radiation;
- electromagnetic radiation.

Instantaneous thermal radiation and electromagnetic radiation are not relevant and can be ignored.

2.2 Combustion

Oxidizing and explosive products are normally very stable. Apart from sabotage or self ignition due to the presence of impurities acting as catalysts, a strong and close external ignition source is required to start a combustion process. Potential causes of combustion include:

1. People smoking;
2. Propagation of fire from outside;
3. Short circuit;
4. Use of non anti-spark equipment or no protection on engines.

2.3 Explosion

When subjected to anomalous conditions such as fire or violent forces, explosive products can explode, either detonate or deflagrate. Apart from sabotage, the explosion may be initiated by:

1. Prolonged combustion;
2. High energy sparks;
3. Lightning impact;
4. High energy impact of a projectile / fragment;
5. Strong friction forces, such as those caused by process machinery breakdown.

2.4 Probability of occurrence of the accident

An accident will occur when certain "mistakes" take place in a sequential chain. For example, for the accidental detonation of PETN powder due to an electrostatic spark, the following "mistakes" may be required:

- One worker does not wear anti static equipment	10^{-2}/y
- Colleagues do not notice his failure	10^{-2}/y
- The worker handles explosive powder and a spark strikes	10^{-3}/y
- System " spark explosive" permits ignition	10^{-1}/y

The probability of occurrence of the accident equals 10^{-8}/y, the chain of the probability of the single events. However the quantity of explosive that may be involved in the accident will not always be constant. Perhaps the maximum quantity allowed in the working area will only be present for few days in the year. The probability of an accident involving the maximum quantity allowed is therefore likely to be lower, for example, by another factor equal to $5*10^{-1}$/y. The resulting probability of the accident involving the maximum quantity will then be equal to $5*10^{-9}$/y.

3 IMPACTING FACTORS AND DAMAGE EXTENSION FOR SEVERITY LEVELS

3.1 Threshold values for damage areas calculation

Each impacting factor will produce decreasing damages at increasing distances. To allow the drawing of iso-damage areas, threshold values for each impacting factor are given for predefined damage severity levels, see Table 1.

	Damage Area				
	1 **Highly Lethal**	**2** **Lethal Boundary**	**3** **Irreversible Injury**	**4** **Reversible Injury**	**5** **Domino Effect**
Peak air overpressure and secondary fragmentation (people in the structures): distance were the positive peak overpressure reaches ...	55 kPa	24 kPa	16 kPa	8 kPa	2.750 kPa
Primary fragmentation (in open spaces): throw distance of ...		1*		1**	
Ground vibrations (people in non reinforced structures): distance were the peak particle velocity reaches ...	300 mm/s	250 mm/s	200 mm/s	100 mm/s	
Dangerous gas release (absorbed dose): distance were the gas concentration reaches ... (in ppm)	LC50 (30min, hmn) NO_x = 315 CO = 5647 CO_2 =50k		IDLH NO_x=100 CO = 1200 CO_2=40k		
Stationary thermal radiation: distance were the specific energy irradiated reaches ...)	12,5 kW/m^2	7 kW/m^2	5 kW/m^2	3 kW/m^2	12,5 kW/m^2

* Dangerous fragment in an area of 56 m^2
** Fragment (maximum fragments throw).

Table 1: Threshold values for the five severity levels

3.2 Air overpressure and secondary fragmentation

This impacting factor is related to the mass explosion of high and low explosives. Ammunition is mostly in forms, both of design and packaging, which do not allow mass explosion. Also smokeless powders, with a reaction rate in metres per second, should not generally be considered as reacting so rapidly to cause a mass explosion.

For damage assessments, the relevant parameters are positive peak overpressure and associated impulse, or also energy and duration of the impulsive load on structures. Mounds do not produce a substantial modification of the induced blast overpressure wave except for an area of about 10 times the height of the mound itself. Peak overpressure and associated impulse at various distances can be calculated, in first approximation, by referring to normalized graphs for the specific explosive product or, where no specific data exists, in TNT equivalent, see Figures 1 and 2 [Baker 1973].

The blast overpressure wave propagates almost uniformly around the explosion spot and consequently a 100% probability of occurrence can be attributed to the calculated peak overpressure and impulse at a given distance. The probability of occurrence of peak overpressure and impulse for the maximum quantity of explosive allowed is equal to the probability of the accident involving the maximum quantity (in the paragraph 2.4. example, equal to $5*10^{-9}$/y).

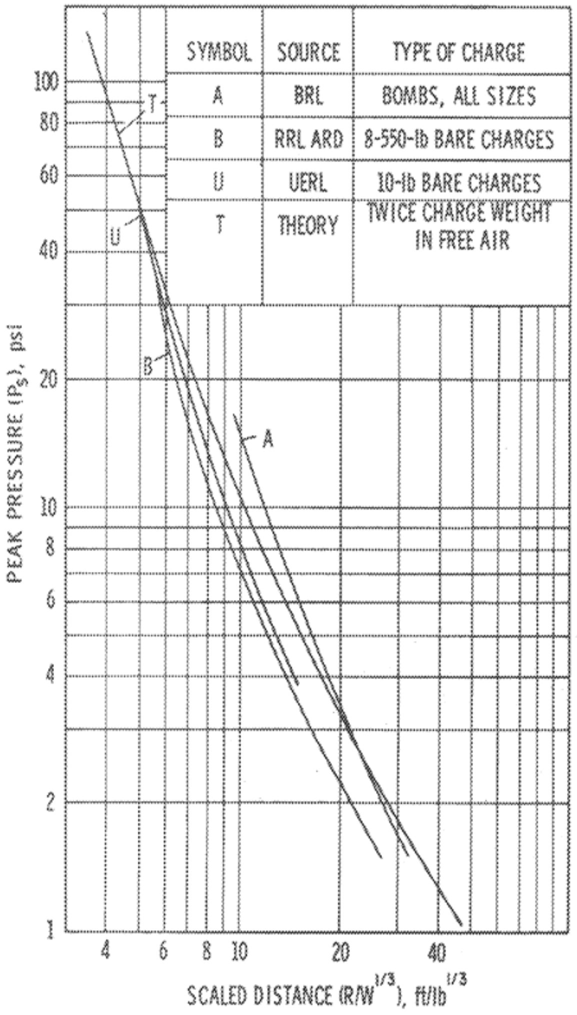

Figure 1: Peak overpressure versus distance scaled on the cube root of the explosive charge in TNT for various configurations [Baker 1973].

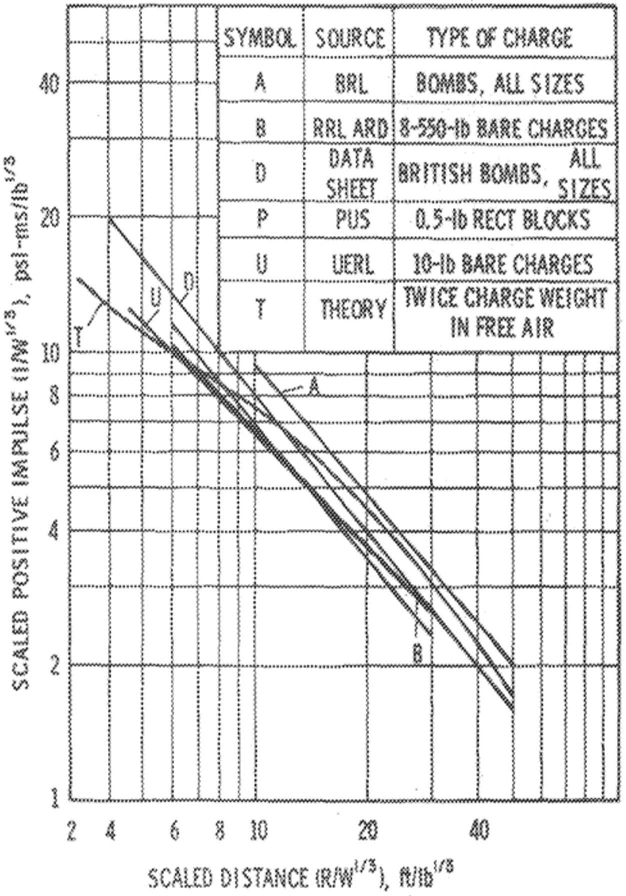

Figure 2: Impulse scaled on positive peak overpressure versus scaled distance for TNT [Baker 1973].

3.3 Primary fragmentation

The fragments projected by the blast create a high potential danger for nearby structures and people. People, and also electronic equipment, are very vulnerable to projectile impact compared with the low vulnerability of structures and machinery. Explosives are also very sensitive and fragmentation is considered to be the principal priming source for domino effects (the propagation of the detonation from one magazine to the adjacent one). Metals and masonry will be thrown around at supersonic speed and will hit against the mound at velocities in the order of thousands of m/s. The depth of the mounds is generally large enough to catch all of these fragments so that almost all primary fragmentation will be confined within the boundary of the mound. Some of the fragments, projected beyond the mound, will escape.

The throw distance of dangerous fragments and maximum throw distance can be calculated in the first approximation with the following [U.S.A.S.C. 2000]:

R_{df} (m) = -252 + 119 ln NEQ; (>50 m);

R_f (m) = 130 $NEQ^{1/3}$

where NEQ is the net explosive quantity in kg.

Fragments are not thrown uniformly around the explosion spot and therefore, the calculated throw distance may be not attributed a 100% of probability of occurrence. The probability of being struck by a fragment depends on the number of fragments thrown to that distance, Figure 3, and on their radial distribution. In the case of 30 fragments projected to a distance of 200 m, the probability for a person to be struck is equal to about 10^{-2}.

The occurrence of the fragment impact at the given distance, if calculated for the maximum quantity of explosive allowed, is equal to the probability of the accident involving the maximum quantity ($5*10^{-9}$ in the paragraph 2.4. example) reduced by 10^{-2}, therefore equal to $5*10^{-11}$/y.

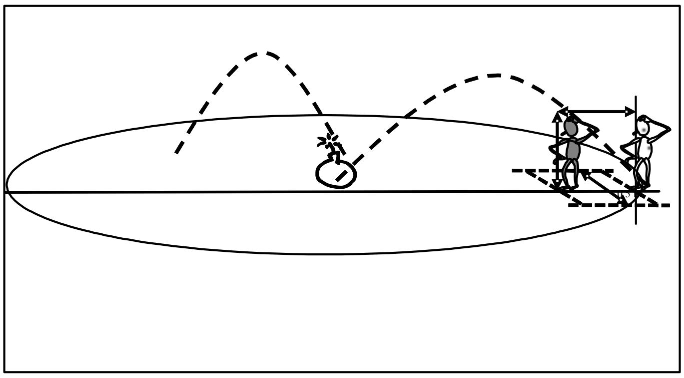

Figure 3: Primary fragmentation striking a person at distance from the accidental explosion.

3.4 Seismic waves

A highly confined explosion will cause ground motion and seismic waves. Peak particle velocity caused by a confined explosion can be calculated, in the first approximation, with the following:

$V = 9.000 * (R/NEQ^{1/3})^{-3}$

where V is one of the x, y, z component of the velocity of vibration in mm/s, NEQ is the net explosive quantity in kg .

Seismic waves propagate uniformly around the explosion spot so that to the calculated peak particle velocity at a given distance can be attributed as a 100% of probability of occurrence. The probability of occurrence of peak particle velocity at the given distance, if calculate for the maximum quantity of explosive allowed in the spot, is equal to the probability of the accident involving the maximum quantity (in the paragraph 2.4. example is so equal to $5*10^{-9}$/y).

3.5 Dangerous Gas release

In the case of an explosion, gases are released instantaneously and uniformly around the spot and because the explosion will have destroyed any structure that may have been able to confine the gases, a hemispherical dilution model may be adopted. However in the case of combustion, the confining structure tends to trap the gases within its boundaries and the hemispherical dilution model tends to became hyper-conservative. This impacting factor, which is generally not relevant in the case of an explosion, can be significant with combustion. Consequently, the dilution model has to be adjusted by taking into account the confinement due to the "donor" structure. This is particularly true when considering fertilizers where thousands of tons of material are involved.

For combustion, it is necessary to fix a burning rate, to take into account the progression in gas release and diffusion. This depends on the substance involved, on its physical form (especially on the specific surface), storage configuration, etc.

3.6 Stationary thermal radiation

The principles used for gas release arising from combustion can also be adopted for thermal radiation.

3.7 Iso-damage areas for each probability of occurrence

Iso-damage area envelopes for each "damage severity level" can be drawn for each probability of occurrence, see Figure 4 and 5.

The recommended output for the risk assessment analysis should contain a set of drawings, each for one predefined probability of occurrence, with:

- "highly lethal" iso-damage curves for each dangerous spot.
- "lethal boundary" iso-damage curves for each dangerous spot.
- "irreversible injury" iso-damage curves for each dangerous spot.
- "reversible injury" iso-damage curves for each dangerous spot.
- "Domino effect" iso-damage curves for each dangerous spot.
- Envelopes of the iso-damage curves for each dangerous spot, for each of the five severity damage levels.

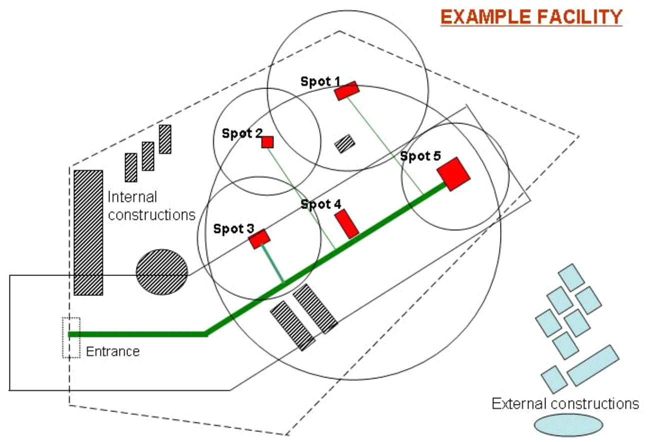

Figure 4: Iso-damage areas for "reversible injury" with a probability of occurrence equal to $5*10^{-9}$/y.

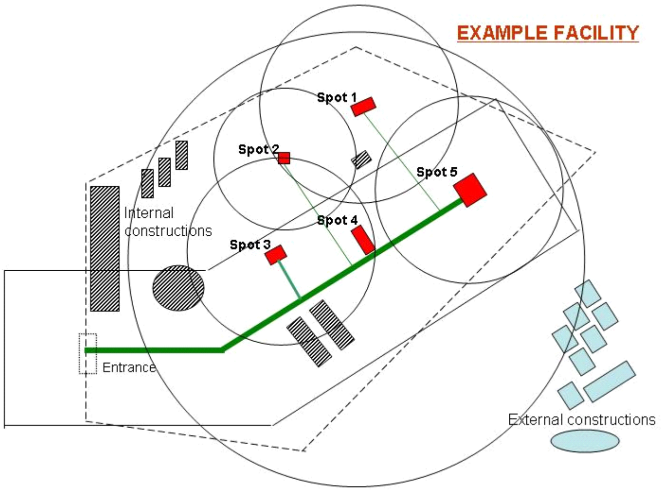

Figure 5: Iso-damage curves for "reversible injury" with a probability of occurrence equal to $5*10^{-11}$/y.

4 CONCLUSIONS

An explosion and hazard assessment has to be tailored for each single facility and every facility is different due to differences in the internal and external infrastructures, plant, equipment, materials, expertise, organization, procedures, safety systems, etc.. A parametric method and common reference values, as illustrated in this article, should be adopted to maximize visibility in the risk assessment process, to ensure consistency of approach, to allow visual evidence of the efficiency of any proposed mitigation features and also to allow comparisons between various design solutions.

This is a need to standardise on method and reference values in order to ensure that valid comparisons can be made between hazard assessments conducted at different sites.

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Acknowledgment

Sincere thanks to David Jordan for his patient and competent teaching, suggestions and support.