RISK ASSESSMENT OF EXPLOSIVE ATMOSPHERES IN WORKPLACES

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ABSTRACT

The application of the Directive 99/92/EC deals with the safety and health protection of workers potentially exposed to explosive atmospheres and requires the assessment of explosion risks. These can arise by the release of inflammable substances typical of industries classified as major hazards, but they often may be generated in other industries where inflammable materials are handled. Risk assessment of explosive atmospheres is required in both cases, for this purpose, in this article a quantitative approach has been proposed. The paper describes the main aspects of the methodology, based on a probabilistic risk assessment, and finally its application to a case-study.

1 INTRODUCTION

In the framework of the General Directive 89/391/CE, the term ATEX (from the French *Atmospheres Explosibles*) is the name commonly given to the framework for controlling explosive atmospheres and the standards of equipment and protective systems used for this purpose. Concerning the control of explosion risk there are two European Directives: Directive 99/92/EC or ATEX 137 and the Directive 94/9/EC or ATEX 95.

According to this legislation the employer has the obligation to prevent the formation of explosive atmospheres adopting all the technical-organizational measures required. When the formation of such inflammable clouds can not be avoided, the ignition must be prevented and the potential damage caused by an explosion must be reduced to the minimum. The employer has to classify the areas in which the formation of explosive atmospheres is possible. Then the *document of evaluation of the risk due to explosive atmospheres* (in this work named *document of evaluation of the ATEX risk*) has to be redacted and, periodically, updated. Such document must undergo to the least requisites fixed by the decree law mentioned before the Italian D.L. 81/08 and must include a section in which the risk is evaluated using specific methodologies. Measures to avoid the formation of explosive atmospheres and ignition sources must also be indicated, finally the characteristics of the equipment used in the workplace must be specified.

Concerning industries classified at major risk, *Safety Reports* include the risk assessment related to the explosions of great magnitude for industries classified as major hazards. The estimation of the risk due to lower magnitude explosions, characterized by lower magnitude, which could potentially involve workplace, is included in the document of the risk assessment of the workplace and in the document of evaluation of the ATEX risk. The approach applied for the explosion risk assessment in the workplaces is generally qualitative (Benintendi et al. 2006) or semi-quantitative (Pezzo et al. 2006). The application of a qualitative method often causes an underestimation of the risk associated with the explosion of flammable clouds arising from small releases, particularly, in confined spaces.

It is important to remember that the evaluation of risk should be completed with the judgement about its acceptability. Some criteria are necessary, the judgement is made on the bases of the experience relative to knowledge of the technology.

2 METHODOLOGICAL APPROACH

In this work a quantitative procedure for the assessment of the explosion risk has been described, it is based on a probabilistic approach. A flow-chart of the procedure is in figure 1.

The application of the procedure requires a detailed knowledge of the system (workplace and activity). The first step of the analysis is the classification of the hazardous areas this can be made by taking into account the quantity of substances released and the probability of release. The risk evaluation will be possible after the quantification of the probability of ignition, the potential damage caused by the explosion and the probability of the presence of workers. The procedure is completed with the evaluation of the acceptability of the risk.

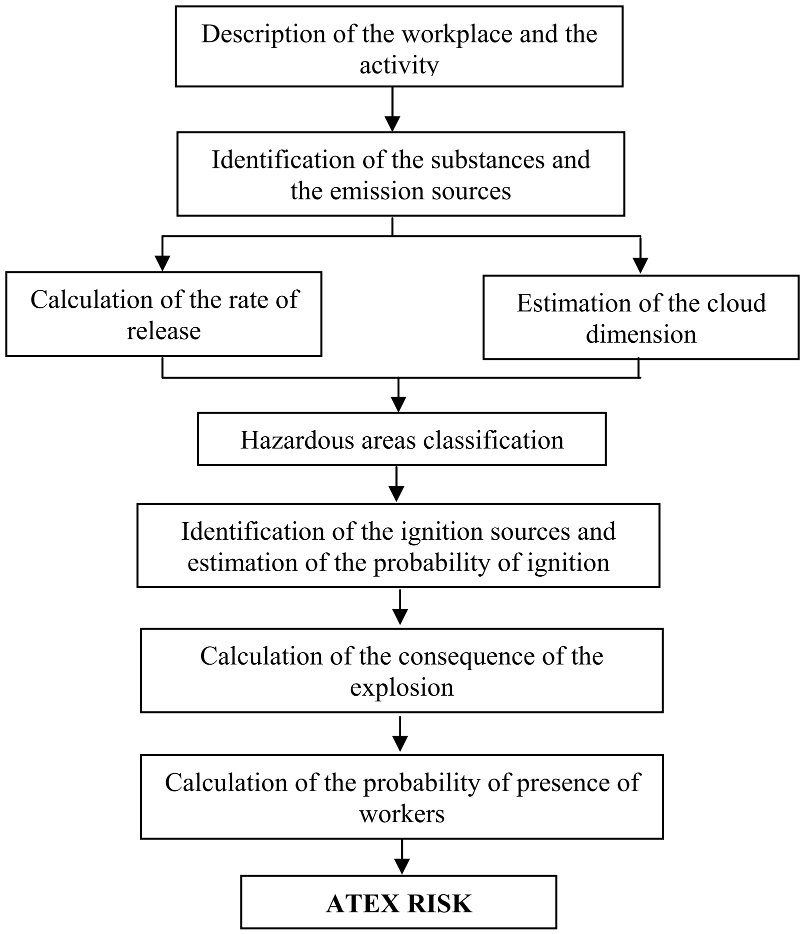

Figure 1. Flow-chart for the evaluation of risk due to the presence of explosive atmospheres.

Some advantages are related to the use of a quantitative approach for risk analysis. It allows an improvement of the overall safety levels, at the same time, in the case of industries at major hazards, the method avoids the underestimation of the risk associated with explosive atmospheres and to identify the correct preventive and protection measures for each case.

2.1 Classification of hazardous areas

An explosive atmosphere is defined as a mixture of inflammable substances with air, under atmospheric conditions. If an ignition has occurred, combustion spreads to the entire unburned mixture. Atmospheric conditions are commonly referred to ambient temperatures and pressures. This means temperatures of – 20 °C to 40 °C and pressures of 0.8 to 1.1 bar.

The classification of the areas has the purpose of establishing the presence of zones characterized by the explosion hazard, in which technical and organizational provisions must be adopted with the aim to make the risk due to the presence of explosive atmospheres negligible. In order to classify the areas, the establishment must be divided into units and it is necessary to define the zones where inflammable substances can be released due to the normal operation of the plant, process deviations or during maintenance activities.

The methodology EN 60079-10 (CEI 31-30, 1996) must be used for zone classification. The method needs to be applied together with two guidelines, Guide CEI 31-35 and Guide CEI 31-35/A, and identifies the hazardous zones of table 1.

Table 1. Probability and duration of explosive atmospheres.

Zone	Probability, P	Duration, t
	Year^{-1}	Hour/year
Zone 0: the presence of an explosive atmosphere is continuous	$P > 0.1$	$t > 1000$ h
Zone 1: an explosive atmosphere is likely to occur during normal operating conditions	$0.1 > P > 10^{-3}$	10 h < t < 1000 h
Zone 2: an explosive atmosphere is unlikely to occur in normal operating conditions or occurs infrequently for short periods of time	$10^{-3} \geq P > 10^{-5}$	0.1 h < t < 10 h

2.2 Probability of presence of ignition sources

An important phase of the risk analysis is the ignition of the sources identification. The standards UNI EN 1127-1 (2001) lists the following main causes of ignition of inflammable atmospheres:

- Hot surfaces;
- Flames and hot gases or particles;
- Mechanical sparks;
- Electrical networks;
- Stray currents;
- Cathode protection;
- Static electricity;
- Lightning;
- Ohmic heating of electric cables;
- Radio-frequency waves;
- Electromagnetic waves;
- Ionizing radiation;
- Ultrasound;

- Adiabatic compression and shock waves;
- Exothermic reactions.

In order to quantify the probability of occurrence of each ignition source, literature data or, preferably, specific studies for the plant under analysis can be used. Methods, such as historical analysis, fault tree analysis, FMEA or FMECA, or specific analytic procedures, could also be applied to assess the probability or the likely effectiveness of each of the ignition sources listed above.

2.3 Consequences of the explosion

The consequences of the explosion must be estimated for each emission source identified through the classification of the areas and for each unit of the establishment. This phase consists in the estimation of the overpressure vs. the distance from the source (the point where ignition occurs). The complexity of the phenomenon would require a fluidynamic study using an appropriate simulation code. The purposes of the work the use of simplified and conservative models which give the pressure peak vs. the distance is sufficient.

Many simplified models for the estimation of the overpressure caused by an explosion are available in Lees 1996 and in the Yellow Book 1997. The most common methods are the *equivalent TNT model* and the *equivalent piston model*, all the methods allow the quantification of the distance where a pressure wave reaches the value of 0.03 bar. The overpressure is the threshold limit causing reversing lesions.

2.4 Presence of workers

The presence of personnel in workplace depends on the number working in the potential damage zone and on their probable of presence. The number of workers involved in a potential explosion can be calculated using the damage zones obtained through the consequence analysis. The probability of presence is calculated according to the worker task (for example shift-workers, head-shifts, maintenance staff). Thus the presence of workers p_w (the parameter is a probability) is calculated using equation (1):

$$p_w = \left(A_i / A_{est} \right) p_i \qquad (1)$$

where A_i = impact zone of the explosion; A_{est} = whole area of the establishment; p_i = probability of the presence of personal in the establishment.

3 ATEX RISK

In this work equation (2) has been proposed for the calculation of the risk index associated with the potential presence of explosive atmospheres, R_{ae} (*ATEX risk*):

$$R_{ae} = p_e \cdot p_a \cdot p_w \qquad (2)$$

where p_e = probability of release of an inflammable substance from an emission source; p_a = probability of the presence of an ignition source; p_w = presence of workers in the impact area.

4 APPLICATION

The methodology proposed in this paper has been applied to a real establishment. The case study is a petrochemical plant (confidential). The area of the establishment is approximately 400 hectares and consists of 15 manufacturing plants, 10 of auxiliary service, 4 of air pollution protection, 2 of water pollution protection, fire alarm systems, a wide area for the movement of products and general service areas (offices, control room, lunch room, laboratories, etc.). In order to assess the risk the establishment has been divided into 27 units. Figure 2 shows the layout of a unit of the establishment. This is the desulphuration plant, which consists of two reactors, a number of storage tanks, the gas/liquid separation drum, etc.

The quantity of substances released and the probability of formation of an explosive atmosphere have been calculated. Using these data the classification of areas has been carried out. Results of the classification of the areas for a part of the unit of Figure 2 are shown in Figure 3(a). The part under analysis is the gas/liquid separation drum.

The next step is the identification of potential ignition sources (SA). Reconnaissance of the workplace and interviews with workers have allowed the exclusion some of the potential sources of ignition listed in Lees 1996. Nine potential sources of ignition have been taken into account: 1) hot surfaces, 2) flames and hot gases or particles, 3) mechanical sparks, 4) electrical system, 5) cathodic protection, 6) static electricity, 7) lightning, 8) electric-overload due to clouds, 9) heating cables. For each SA the likelihood of ignition has been calculated using historical and fault tree analysis or, sometimes, specific calculation procedures. Subsequently, for each SE the effects of an explosion due to the presence of at least one SA have been calculated.

The consequences analysis has been done using the *equivalent mass of TNT model*. The information required for the consequences assessment, using both the method, are the flow rate Q (*kg/s*) of the released substance and the *distance of permanence* of the cloud d_z (*m*). To define this last parameter it is necessary to note that after the release the cloud exists for a certain time in the area and, in the presence of ignition sources, can potentially cause an explosion. The *distance of permanence* indicates the maximum dimension of the explosive cloud. The application of the TNT model is very simple, it is based on the estimation of *equivalent mass of TNT* (m_{TNT}) for a certain explosion, using equation (3), and then on the calculation of the distance (x), using a specific correlation such as equation (4):

$$m_{TNT} = \eta \cdot \frac{\Delta H_C}{4{,}196 \cdot 10^6} \cdot m_{cloud} \qquad (3)$$

$$x = m^{1/3} e^{\left[3.5031 - 0.724 \ln O_p + 0.0398 \left(\ln O_p\right)^2\right]} \qquad (4)$$

where m_{TNT} = equivalent mass of TNT (kg); η = yield factor; ΔH_C = enthalpy of combustion of the explosive (*kJ/kg*); m_{cloud} = mass of the explosive (*kg*); x = distance (*feet*); O_p = overpressure (*psi*).

The classification of the areas for the unit under analysis has been given in Figure 3(a), the results of the consequence assessment for an emission source are shown in Figure 3(b).

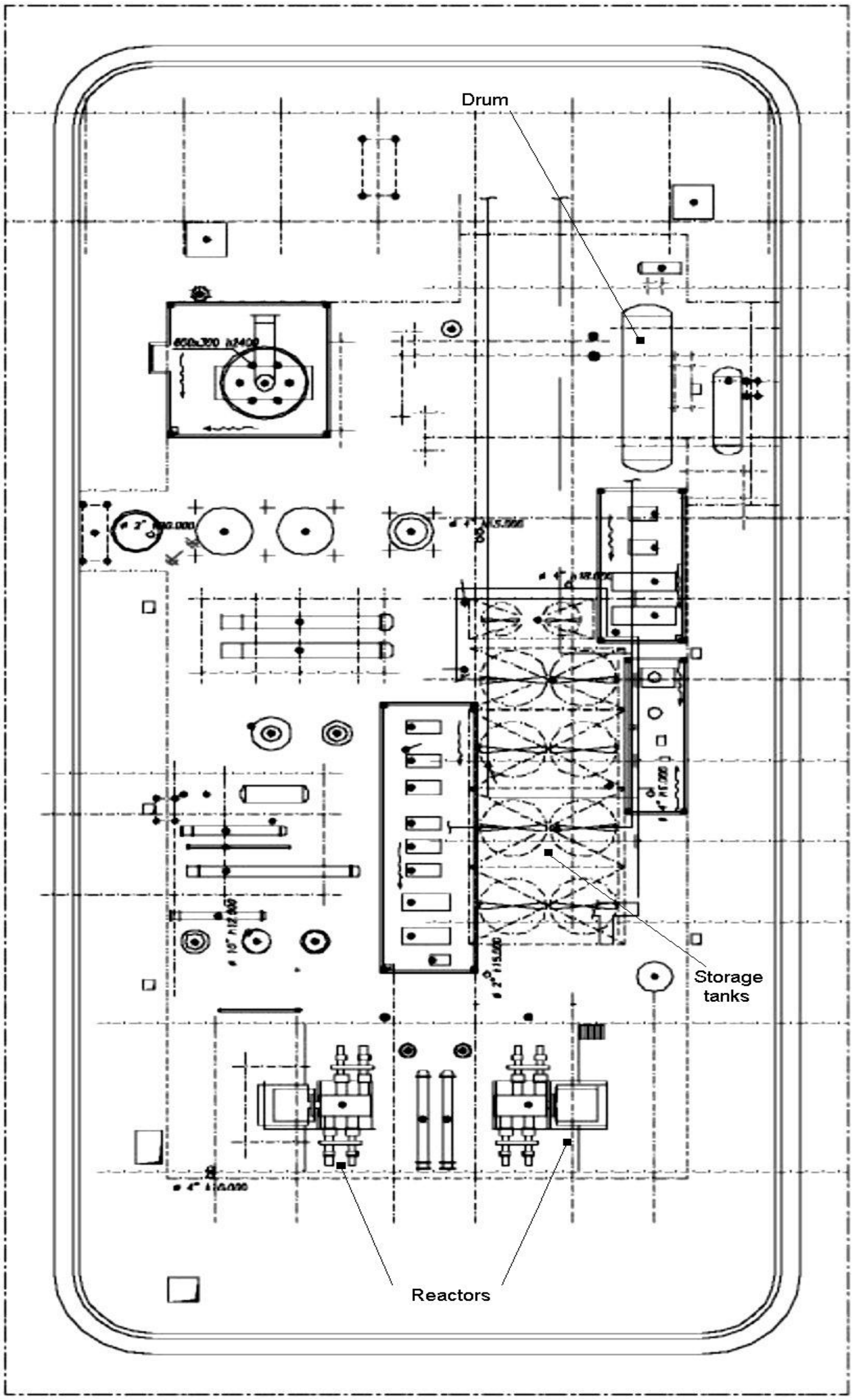

Figure 2. Layout of a unit of the establishment.

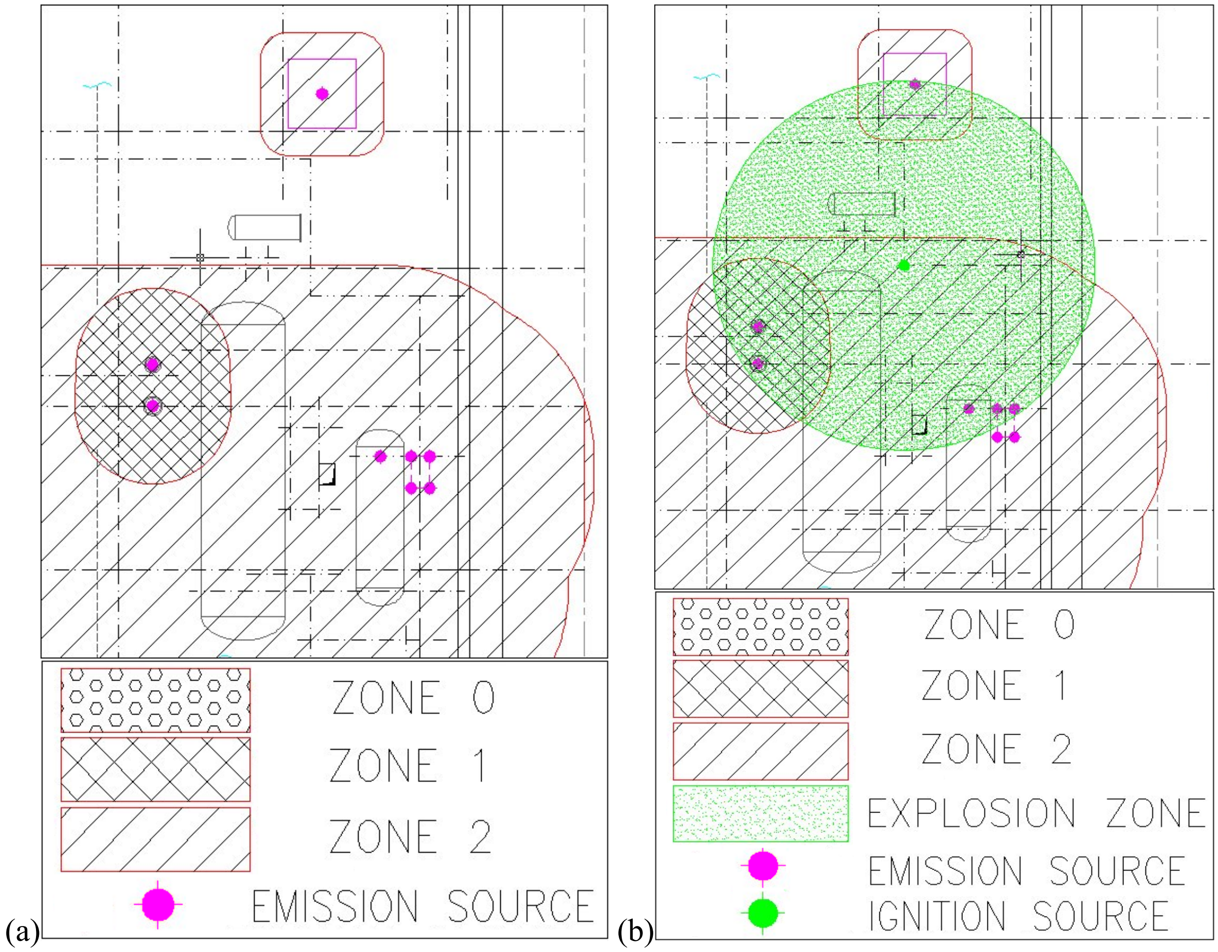

Figure 3. (a) Classification of the areas; (b) Results of consequence analysis.

The presence of personnel has been calculated taking into account three different worker tasks. Table 2 shows the probability of presence for shift workers, foremen and maintenance staff.

Table 2. Probability of presence of workers.

Task	Probability of presence p_i
	n. hours per day
shift worker	0.91
foreman	0.33
maintenance staff	0.11

Given the values for the probability of release of inflammable substances, of the presence of ignition sources and the presence of workers, the risk has been evaluated according to equation (2).

The graph of Figure 4 shows the values of the index risk R_{ae} calculated for each emission source of the unit of Figure 2. The graph shows how is simplified the identification of critical points where actions to reduce the risk are necessary.

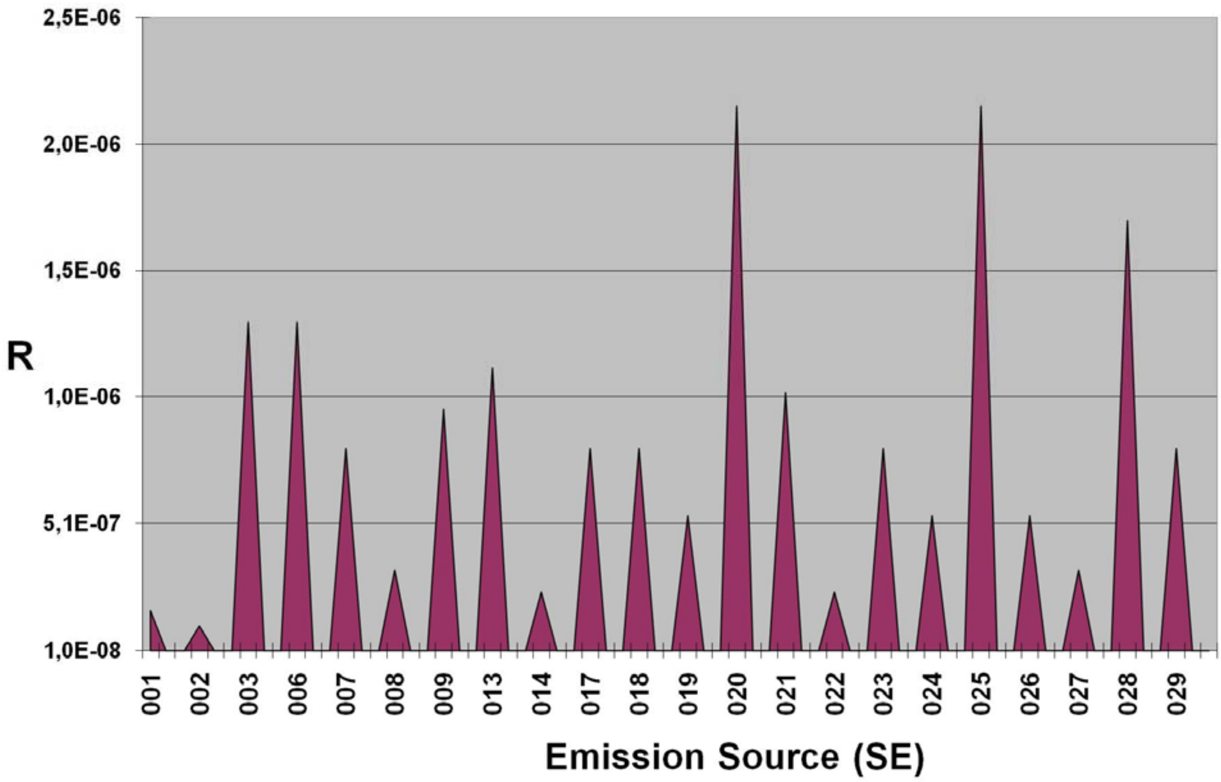

Figure 4. Risk Index (R_{ae}).

5 RISK ACCEPTABILITY

After risk analysis it is necessary to make decisions about existing hazardous or potentially hazardous establishment. Usually these decisions are delegated to organizations with recognized expertise in the area. For existing technology, that expertise will rely on past experience, including incidental statistics (also "near-miss") for hazardous facilities. This experience must provide threshold limits in order to define the acceptability and the tolerability of the risk.

Taking into account of the typology of the accidents, in this paper the same threshold values used to judge the risk acceptability in industries at major risk have been applied. Explosions analyzed in the Safety Reports are originated by great releases of inflammable substances and, consequently, they impact on large areas. For establishments not at major risk, the explosions have a smaller impact area and involve only the workers. Since both the type of explosions can be studied in the same way it is opportune to uniform the approaches of risk evaluation.

Unfortunately the Italian normative does not defined acceptability criteria for industries classified at major hazard, the risk judgment is made referring to the threshold values of frequency and consequences reported in the Italian D.P.R. 126. Concerning the explosion risk, in this work, it has been proposed to refer to the risk acceptability criterion adopted in the United Kingdom and described in the Italian D.P.C.M. of the 25th February 2005 and in the Guide CEI 31-35/A. The threshold values of risk are:

$R_{ae} < 10^{-6}$ *risk is acceptable*;

$10^{-6} < R_{ae} < 10^{-4}$ *risk must be reduced as low as technically and economically possible*;

$R_{ae} > 10^{-4}$ *risk is not acceptable*.

According to this criterion and this analysis, based on the risk assessment and combined with on-site inspections, the necessity of further implementation of protective and preventive measures can be verified. In order to make this objective a detailed check-list has been drawn.

6 CONCLUSIONS

The proposed methodology permits to identify the critical points in the system (technical and procedural) and decreases the exposure of the workers as low as possible. In particular the quantitative approach allows to not underestimate the risks for the exposed workers. The quantitative evaluation of the explosion risk also allows to obtain an improved effective in the prevention and protection interventions adopted by the company.

A tool for the risk assessment has been created, it permits to repeat the calculations and a faster verifications of the possible improvement of the measures of risk prevention and mitigation for the system under analysis.

Finally through the quantitative analysis it is possible a detailed study of the accidental scenarios due to small releases. For industries at major risk a detailed analysis of such events is essential because they can represent potential sources of domino effects.

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