Risk assesment of LPG storage in Greece

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Quantified risk assessment in major industrial areas is a valuable tool, which can be used in order to both assess the existing risk as well as to rationalize emergency preparedness and land use planning. Thriassion Plain and Thessalonica are the two major industrial regions in Greece. They both have a significant concentration of industries, which lie under the Seveso II directive. Specifically, installations that produce, store, bottle and distribute LPG are considered to pose significant risks to the surrounding areas. Quantified risk assessment has been performed for those two areas and is presented in this study.

1. Introduction

Greece adopted Seveso I Directive during the late eighties. Since then and within the context of the regulations, all large chemical installations have prepared safety assessments regarding the potential and the consequences of major chemical accidents. Moreover, the Greek government has prepared an emergency preparedness and response plan for three major industrial areas of the country (Kiranoudis et al, 1999). Recently, Greece adopted Seveso II Directive. According to Article 12 of the directive, land use planning should take into account the risks posed by dangerous installations. Specifically, this article introduces the concept of risk quantification since it refers to appropriate distances that must separate installations from all other installations and civilian activities so as to minimize the risk to the surrounding population.

Up to now there exist no guidelines or limit values regarding quantitative risk assessment in Greece. Land use planning does not explicitly take into account possible chemical risks. Whenever such issues arise, the authorities follow a case-by-case basis. However, the lack of guidelines as well as limit values, either in the form of risk or standard distances, tends to obscure the situation and create misunderstandings between the authorities, the installations and the surrounding population.

An initial quantified risk assessment of LPG installations has been undertaken in order to both obtain more specific information regarding the risks posed to the population and to assist the authorities in their effort to reduce the risk and to rationalize land use planning by incorporating information related to chemical risks.

2. Description of the areas under consideration

Thriassion Plain is located northwest of Athens and covers an area of approximately 180 km^2. The area is limited south by the sea, north by mountains, east by the city of Athens and west by Peloponesus peninsula. The whole area is divided to four municipalities with a total population of about 50,000 people. It is a heavy industrialized area with two oil refineries, six LPG storage and distribution facilities and dozens of other potentially dangerous chemical installations. During working hours the population of the area is tripled due to the people who live in Athens but work at the area. It is crossed by a main motorway that joins Athens with the south and western areas of the country and is loaded with heavy traffic especially during weekends and holidays. In many cases the motorway passes just a few meters outside the fences of dangerous chemical installations. Major public works are currently under construction at the area involving the improvement of the motorway. Other works include new railway lines and a major railway cargo station.

The people living at the area have risen environmental and safety issues. The Greek government undertook a major project aiming in managing chemical emergency at the region (Kiranoudis, 1999), specially concerning installations that are subject to Seveso Directives. This project, codenamed SATAME, included the preparation of an emergency response plan and the establishment of an emergency operational center.

In the area there are installed 71 tanks storing LPG, propane and butane with a total inventory of 44,544 m^3. The size of the tanks ranges from 30 to 4,000 m^3. It is noted that large volumes of LPG are transferred through the road network of the area while there also exist a 5 in. pipeline connecting some of the LPG installations with one of the refineries.

The industrial area of Thessalonica lies on the west side of the city. The area is limited south to the sea and east by the city of Thessalonica. North and west of the industrial area there exist extensive agricultural areas. The particularity of this industrial region is that residential areas are located quite close to the installations. It covers an area of about 95 km^2. The area belongs to the western municipalities of Thessalonica with a total population of about 60,000 people. The region is crossed by the railway tracks, which join the city of Thessalonica with Athens, and by a motorway joining the city with western Macedonia. It is the second most significant industrial area of Greece. It includes dozens of large and medium chemical installations, among them an oil refinery and five LPG storage and distribution facilities. In the area there are installed 44 tanks storing LPG, propane and butane with a total inventory of 12,800 m^3.

Although no major accident with LPG has been recorded so far within these areas, several accidents have occurred in the oil refineries. Among them one accident at the one of the oil refineries at Thriassion Plain resulted in 13 fatalities (all within the premises of the company) in 1992.

3. LPG Risk Assesment

LPG is an extremely flammable mixture of propane and butane, which is usually stored under pressure in either cylindrical or spherical tanks. Such tanks are recognized to be potential sources of major accidents, which may harmfully affect the area off site the premises of an installation. There have been recognised five possible hazardous situations from the rupture of an LPG storage vessel. The impacts of three of them (pool fire, jet fire and flash fire) are expected to be limited within a relatively small distance from the source of the release and are not examined further.

The most severe accident though, is the phenomenon known as BLEVE (Boiling Liquid Expanding Vapor Explosion). It usually occurs when a tank of LPG is engulfed in fire for time enough to increase the temperature of LPG within the tank and thus, to increase the pressure above the structural strength of the tank. Vapour cloud explosion (VCE) may also have off site effects due to overpressure. The magnitude of the consequences depends largely on the volume of LPG that escapes and the confinement of the area around the release point.

In this study, risk assessment is carried out by taking into account the probability and the consequences of BLEVE and VCE accidents, since these are expected to have off site effects. The algorithms used to estimate the consequences, the individual risk (IR) and the societal risk (SR), are described briefly in the following paragraphs. The definitions of individual and societal risk are not discussed here since they are considered to be straightforward. A detailed analysis of these terms can be found in the relevant references (Kirchsteiger, 1999 and Egidi 1995).

3.1 BLEVE algorithm

LPG is stored in atmospheric temperature, which means, according to the thermophysical properties of the substance, that the pressure in the tank is about 3-5 bar, depending on the season of the year. If a tank is engulfed in fire, the temperature and thus the pressure increase rapidly and, unless the fire is stopped, BLEVE follows in a matter of a few minutes. The immediate effect of the accident is a fireball, which releases intense heat flux and projectiles. The projectiles are either major pieces of the tank or are generated by the acceleration of nearby objects. The range of the projectiles is difficult to be estimated and is not taken under consideration in this study. The estimation of heat flux is conducted using the TNO published methodology (TNO, 1997). The heat flux ($J/m^2/s$) at a certain distance from the centre of fireball is calculated:

$$Q(x, y) = SEP * F_{view} * \tau_a \qquad (3.1)$$

where τ_α : is the atmospheric transmissivity which is calculated as a function of the relative humidity (RH) and the distance from the surface area of the flame

SEP : is the surface emissive power ($J/m^2/s$) and

F_{view} : is the view factor that is related to the radius of the created fireball and geometrical features

The received dose is a function of both the heat flux and the duration of the fireball and is given by the expression:

$$D(x,y) = [Q(x,y)]^{4/3} t \qquad (3.2)$$

where t : is the duration of the BLEVE.

To calculate the individual risk, a probit function is used:

$$Y = A + Bln[D(x,y)] \qquad (3.3)$$

where A, B are empirical constants with values: A = -14.9 and B = 2.56

The frequency, f_{BLEVE}, of a BLEVE accident is considered to be $0.8*10^{-6}$ events per year. This value is considered to be constant for all tank sizes and types and has been extracted particularly for the area of Thriassion Plain (Papazoglou, 1999).

The risk of death for a human who has received a dose D(x,y) is given by the integral:

$$R(x, y) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y-5} e^{-\frac{u^2}{2}} du \qquad (3.4)$$

where Y is the Probit function of the dose.

3.2. VCE algorithm

Estimation of the overpressure produced during a VC explosion is based on Multi Energy Method (TNO, 1997). The layout of each installation was examined in order to estimate the volume of the obstructed region (V_{ob}) within the tank farms and the possible location of the flammable vapour cloud. Then, the volume of the flammable cloud (V_c) was estimated by assuming that LPG is released either by a 2, 3, or 4-inch pipe crack and mixes stoichiometrically with air (4%). The size of the crack was been selected after taking into account the sizes and types of pipe connections used in the examined installations. In most of the cases the obstruction region was equal or larger than the volume of the cloud. For those cases that the volume of the cloud was larger than the volume of the obstruction region, two separate blast strength classes were selected following the recommendations of the relevant references (TNO, 1997).

To calculated the individual risk a probit function is used:

$$Y = A + B\ln(S) \qquad (3.5)$$

Where S depends on the type of damage encountered. In this study the type of damage encountered is head injury. In this case, S is calculated using the equation:

$$S = \frac{2430}{P_s} + \frac{4*10^8}{P_s * I_s} \quad \text{(valid for } P_s < 500{,}000 \text{ Pa and } r > r_o\text{)} \qquad (3.6)$$

The risk of death for a human is calculated using the equation (3.4).

The frequency f_{VCE} of a VCE accident is considered to be $1.7*10^{-6}$ events per year. This value is considered to be constant for all tank sizes and types and for all substances examined (Papazoglou, 1999).

The total individual risk, taking into account both BLEVE and VCE accidents, is calculated using the equation:

$$R_{total}(x,y) = f_{BLEVE} * \sum_{i=1}^{n} R_{BLEVE,i}(x,y) + f_{VCE} * \sum_{i=1}^{n} R_{VCE,i}(x,y) \qquad (3.7)$$

Where i refers to the i^{th} source of accident (LPG tank) [i = 1,2,…,n]

4. Conclusions

The results are given in Figures 4.1-2 in the form of negative decimal logarithm of the individual risk curves, which have been superimposed on the GIS maps of the areas. Each curve indicates a certain probability of an individual death per year. Specifically, Figure 4.1 shows the whole industrial area of Thriassion Plain and Figure 4.2 shows the whole industrial area of Thessalonica.
The risk outside the premises of the installations is estimated to be less than 10^{-5} deaths/year for all cases. The major contribution to individual risk originates from BLEVE accidents. The risk of a VCE explosion is mostly limited inside the premises of each installation. Nevertheless, installations located just next to the motorway do pose the probability of an explosion that will affect the passing by cars. Generally, the distances separating different installations are not considered to be adequate. In the case of a major accident, its consequences may trigger domino accidents in neighboring facilities. Although emergency management plans do exist for the areas under consideration, land use management plans do not explicitly take into account the risk posed by the installations.

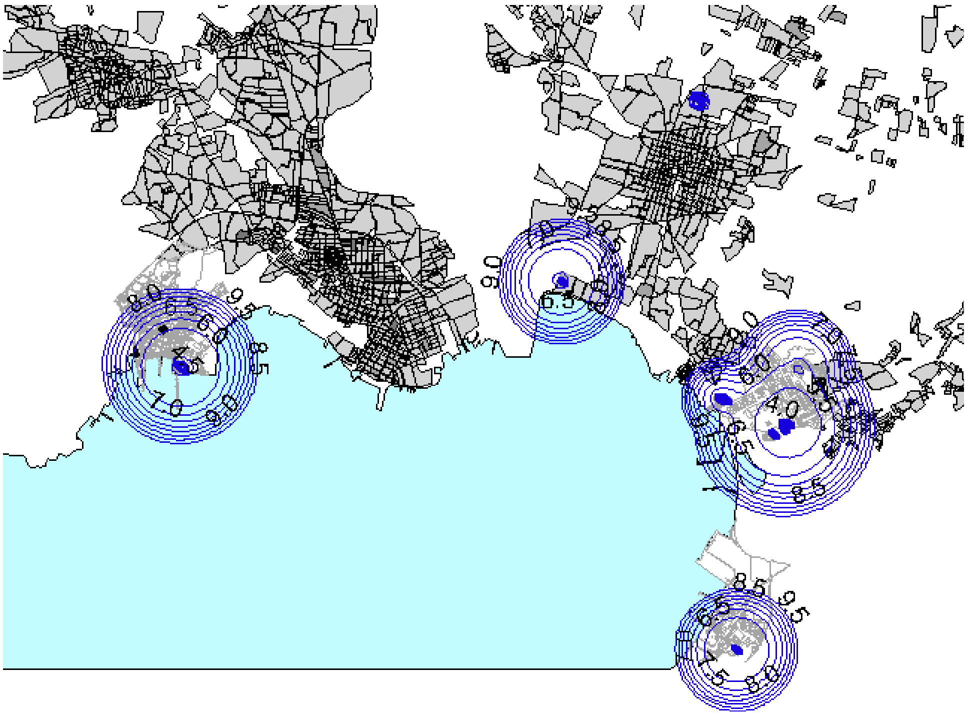

Figure 4.1: Risk curves for Thriassion Plain industrial area

The analysis of the results for the area of Thriassion Plain indicates that there exists considerable risk in parts of the motorway. Specifically, the risk for about 10 km of the motorway, in three different segments, is in the order of 10^{-5} – 10^{-6} deaths/year since most of the installations are located along the sides of the road. It is noted that, for the time being, this is the only motorway of the area and is congested during several hours of the day due to the people going or coming back from their jobs as well as weekend travelers. On the other hand, the risk posed to residential areas is quite small, within the range of 10^{-7} – 10^{-8} deaths/year, and mainly to the area northeast of one of the refineries (municipality of Aspropyrgos).

The industrial area of Thessalonica is located close to urban and densely populated areas. Thus, the estimated societal risk is quite high. This is evident by looking at the F-N curves in Figure 4.3. Generally, it is suggested that the authorities should examine the development of road and railway networks taking into consideration the risks posed by the probability of a major LPG accident.

Furthermore, it is suggested that land use planning for each of the examined areas should impose minimum distances that must separate each installation from the others as well as from the nearest residential areas.

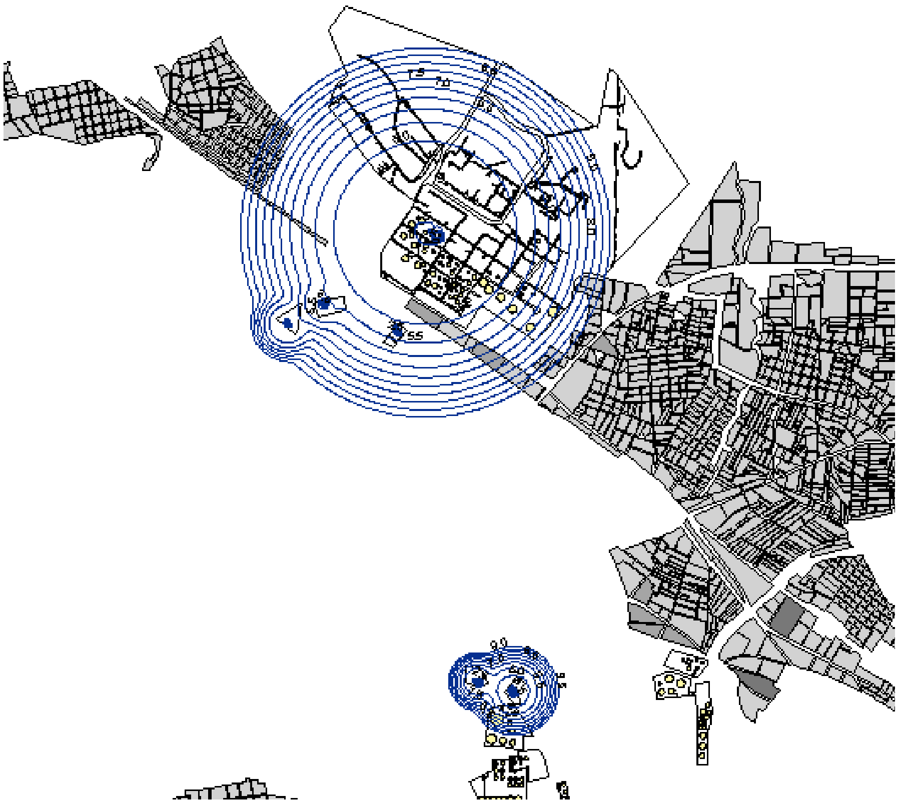

Figure 4.2: Risk curves for Thessalonica industrial area

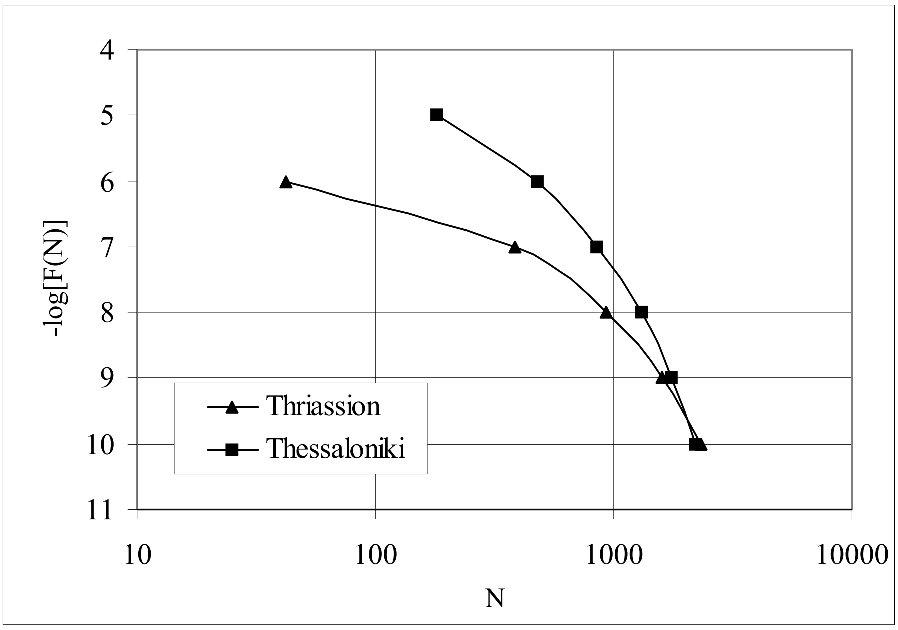

Figure 4.3: F-N curves for Thriassion Plain and Thessalonica regarding BLEVE and VCE from LPG tank accidents

5. References

Egidi, D., Foraboschi, F.P., Spadoni, G. and Amendola, A., 1995, Reliability Engineering and System Safety 14, 75-89

Kiranoudis, C. T., Kourniotis, S. P., Christolis, M., Markatos, N.C., Zografos, K. G., Giannouli, I. M., Androutsopoulos, K. N., Ziomas, I., Kosmidis, E., Simeonidis, P., Poupkou, N., 2002, J. Haz. Mat. A89, 141-161

Kirchsteiger, C., 1999, J. Loss Prev. Proc. Ind. 12, 399-419

Papazoglou, I. A., Nivolianitou, Z., Aneziris, O., Christou, M. D., Bonanos, G., 1999, J. Haz. Mat. A67, 111-144

TNO, 1997. Methods for the calculation of physical effects (Yellow book), Part 1 & 2, Third edition, RIVM, Netherlands