QUANTITATIVE RISK ASSESSMENT FOR ACCIDENTS AT WORK IN THE CHEMICAL INDUSTRY AND THE SEVESO II DIRECTIVE

I. A. PAPAZOGLOU

System Reliability and Industrial Safety Laboratory
National Center for Scientific Research "DEMOKRITOS"
Aghia Paraskevi, Attiki 153 10, Greece

1 Introduction

The purpose of this presentation is to propose and describe a methodology for the implementation, and in essence the extension, of the principles and objectives of the EC directive SEVESO-II [1] to persons working in the chemical industry. Although the presentation will be confined to the chemical industry, the presented concepts and principles are applicable to a wide spectrum of work related risks.

According to the first Article of the SEVESO directive [1]: "This Directive is aimed at the *prevention* of *major accidents* which involve dangerous substances, and the *limitation of their consequences* for man and the environment, with a view to ensuring high levels of protection throughout the Community in a consistent and effective manner".

To satisfy this objective one needs to define the terms: "major", in other words to be able to "measure" the "size" of an accident; "prevention" and suggest ways to measure the degree to which an accident is prevented; and "limitation of consequences" and propose a way to measure the degree to which a consequence has been limited.

This presentation outlines a methodology for quantifying and consequently for measuring the "size of an accident", the degree of "prevention" and the degree of "consequence mitigation" achieved by a certain set of measures and/or policies. Furthermore, the concepts and principles of this methodology can be used to optimize the risk at work.

2 Quantitative Risk Assessment and the SEVESO directive.

2.1 The concept of risk

The concept of risk refers to events that are possible but which do not occur with certainty. For this reason they are characterized as random events. If they do occur, however, they result in adverse

consequences. Usually we refer to such possible events as possible "accidents". The random nature of these events is of paramount importance because all our planning and actions against such events are based on the fact that if they occur they will result into undesired consequences, but simultaneously on the fact that such events are not expected with certainty: they might occur or not in the future. The randomness of an accident is measured by the probability (or the relative frequency) with which we expect it to occur. The consequences of an accident can be measured by the degree of the severity of the adverse health effect or by the number of persons affected in a particular way. The risk (R) associated with a particular activity is therefore, a function of the potential consequences (**c**) and the probability (p) with which these consequences are expected. A mathematical expression of this concept is:

$$R = f\{p,\mathbf{c}\}$$

The exact form of function *f* depends on the preferences and the value tradeoffs of those exposed to the risk and in general of those responsible for the relevant decision making.

The concept of risk is necessary for a rational assessment of the degree to which the objectives of the SEVESO directive are satisfied by a given installation or for the comparative assessment of the various measures, actions or policies aiming at satisfying the SEVESO directive. The degree to which such a measure or policy contributes to the limitation of the consequences can be measured by the resulting change in the magnitude of the consequences. The degree, however, to which a measure or a policy is contributing to the objective of "prevention", can be only measured in terms of the resulting change in the probability of occurrence of the accident. Finally comparison between alternative installations, measures and policies is only possible when the function *f* has been determined.

2.2 Quantitative Risk Assessment

A brief outline of the procedural steps leading to a quantitative risk assessment (QRA) follows while more information can be found in references [2,3]:

2.2.1 Sources of Risk Major Accidents

The sources of risk that is, the existence and the corresponding quantity of a dangerous substance within a given installation are determined. A table in ANNEX I of the SEVESO directive determines which substances and in what quantities can characterize an installation as being subject to this directive. Consequently, it can be argued that an accident can be considered as "major" if it involves one of the substances of Annex I of the directive in a quantity equal or greater than the

limits provided in that Annex. This could create a problem, however, since an accident does not always involve the totality of the substance.

2.2.2 Accident Sequences and Probabilities

This step analyzes the various safety systems or in general the "barriers" in the installation engineered or implemented with the objective to impede the release of the dangerous substance from its containment. Series of hardware failures and/or human errors are determined forming sequences of events that if all of them happen then the containment of the dangerous substance is lost. Each of these sequences is called "accident sequence" or "scenario" and does not necessary involve the totality of the substance contained in the containment. Next the probability of occurrence of each of the basic events in each accident sequence is estimated and from those the joint probability of each and every accident sequence is calculated. This estimation is based on the performance characteristics of hardware and humans but also on the safety management system of the installation since the latter affects the probability of failure of hardware and/or human error.

2.2.3 Consequences of an accident on health and the environment

The third major step determines and simulates the physical phenomenon that follows the loss of containment (dispersion of toxic cloud, detonation, fire, and explosion) and establishes the extreme environmental conditions with the potential to harm health and the environment: concentration of toxic substance, thermal radiation for fires and explosions and overpressure for explosions. The intensity of these phenomena coupled with the duration of the exposure to them, determines the "dose" that a human can receive in every point in the neighborhood of the installation. Finally from existing "dose-response" relations the probability of a specific level of harm is established (e.g. probability of death, probability of severe injury)

2.2.4 Risk Integration

The final step of the quantitative risk assessment consists in the combination of the results of the previous steps to determine the possible range of consequences but also the probability with which each possible value is expected. (e.g. [0, 1, 10 , 100,.. 1000] deaths with corresponding probabilities [0.99, 10^{-3}, $4x10^{-4}$, 10^{-4},…,10^{-5}]). These types of results correspond to the c and p components of the risk, respectively. To complete the assessment of risk one must still determine the function *f*. This more involved but two measures usually used are:

- *Individual Risk of Death.* Defined as the probability of death for a person in a specific point in the general area of an installation, as a result of an accident that will occur in the installation.

- *Group Risk of Death.[f(N) curve]* Defined as the probability of death for more than N persons, as a result of an accident that will occur in the installation.

3 External and Internal Risk

One of the potential problems in the implementation of the SEVESO directive is due to the distinction of the consequences to those *internal* to the installation and to those *external* to the installation where external and internal is determined by the fence of the installation. At first glance this distinction seems justified since the external risk refers to the general public while the internal risk refers to those working in the plant.

3.1 Distinct competent authorities for internal and external risk

In most member states of the EU there are different authorities for the implementation and compliance of the SEVESO directive for external and internal consequences and risk. In Greece for example, the acceptability of the external risk is judged by the Ministry of Environment, Physical Planning and Public Works (ΥΠΕΧΩΔΕ), while the acceptability of the internal risk (risk to the employees) lies in the jurisdiction of the Ministry of Labor and Social Security. A similar approach is taken in the Netherlands.

If this distinction in the regulatory functions is not accompanied by a very good communication and coordination there is a risk of ending up with an imbalance on the way internal and external risks are evaluated and managed, with the more active agency tipping the balance in favor of the external or internal risk. For example, if the prevailing position is that the "size" of an accident is characterized by the extent of the possible consequences and there is an active environmental or physical planning agency, then "major accidents" could be labeled only those with consequences outside the fence of the installation regardless of the probability with which they are expected. Such an approach de facto characterizes all accidents with consequences only on those working inside the fence of an installation as "minor" regardless of their expected frequency.

There is, therefore, a need for a unified view of risk, a view based on a systematic and consistent assessment of the risk regardless of the physical spatial limits where the consequences are observed.

3.2 Quantified assessment of all risks to the workers

The methodology outlined in section 2 can be applied for quantifying the risks to those working in installations handling or storing dangerous substances according to the SEVESO directive. The necessary adjustments include:

- Scenarios or accident sequences involving lower quantities of dangerous substances than those required to have consequences outside the fence of the installation.
- Inclusion of operation phases beyond and above the "full power nominal operation", like maintenance or repair under full or reduced power or shutdown.
- Inclusion of the Safety Management System related to the additional operational states.

The QRA methodology is not applicable only to the risks to workers from the accidental release of dangerous substances and associated significant doses, but also to other risks as:

- *Chronic exposure* to relatively low concentrations of dangerous substances or other factors that can harm the health of the workers. In this case the step of scenario assessment is less important than the step of the dose assessment. There might exist, however, accident sequences that lead to exposures and doses higher than those associated with normal conditions. The remaining basic steps are similar to those for accidental releases and are shown in Figure 1. First the pathways through which the substance reach the human body are assessed and then the resulting doses and corresponding probabilities. Risk integration and risk management follows.
- *Injury causing accidents* of various degrees (falls, cutting crashes, etc.). The methodological steps remain the same, the only difference being that accidents take another form and the nature of safety systems changes (e.g. protective barriers, restraining systems, protective clothing). The nature of dose also changes and adapts to the specific type of accident (e.g. height of fall and angle of impact).

4 Risk management

Quantitative Risk Assessment does not only offer a consistent measure of the risk to which a person or a group of persons or the environment is exposed, but also a rational framework for the evaluation and effectiveness assessment of various proposed risk reducing measures and policies. The latter is achieved through the detailed assessment of all the components of the risk (specific systems, procedures and practices that could lead to an accident, as well as, their consequences and probability of occurrence).

Risk management collectively refers to those technical or managerial measures and policies aiming at the reduction of risk. A number of such measures are dictated by the SEVESO directive and some of them are particularly important to the internal safety.

4.1.1 Additional safety measures

The most obvious category of additional measures for risk reduction is the addition of new safety measures or barriers between the hazard source and the potential recipients. This means that to the present state of the installation something new is added or something existing is replaced with something new.

- *Engineered safety systems* aiming either at the *prevention* (e.g. refrigeration system of refrigerated ammonia storing tank) or at the *mitigation* (e.g. fire detection and fire fighting systems) of accidents.
- *New maintenance and repair policies* of existing systems and components (e.g. test and preventive maintenance frequency)
- *Managerial measures* (e.g. change of the necessary internal work permits to start work on maintenance and/or repair, training of personnel, communication to the employees of the safety related principles and rules).

4.1.2 Inspections

This is probably the most important category of the risk management measures dictated by the SEVESO directive. A system of inspections and testing is suggested with objective to assure that the state of the installation remains at the same levels (from the technical and management point of view) as assessed through the corresponding Safety Study.

Inspections and testing refers to components, procedures and personnel competence that affect both internal and external safety, as well as all types of risks (accidental high or chronic low doses of dangerous substances or other accidents). Inspections and testing contribute both to prevention and mitigation of accidents since they refer to all important components, procedures, practices and personnel. A QRA allows the prioritization of inspections and testing as well as the rational setting of the corresponding frequencies.

Inspections and testing are being performed mainly by operator of the installation but the over all plan and inspections and testing to verify adherence to such plan are the responsibility of the regulatory authorities. According to the Greek legislation inspections and testing lies in the jurisdiction of the Ministry of Development. Such a plan has not yet been established or studied in Greece.

4.1.3 Emergency Response Plans

Emergency response plans refers to plans for the removal (evacuation) or protection of the population outside the plan (external emergency plans) or of the workers in an installation (internal

emergency plans). Consequently they are by nature mitigating measures and are applicable only after the onset of an accident. The SEVESO directive dictates the development of both internal and external emergency plans.

In Greece, the external emergency plans are the responsibility of the ministry of ΥΠΕΧΩΔΕ and they are distinguished to *general* emergency plans referring to greater industrial areas, and *specific* referring to the immediate area around an installation. The general plans have been developed, while the specific -falling under the responsibility of regional government- are under development.

Internal emergency plans affect the risk of workers and are drawn by the operator of the installation. All the Greek SEVESO installations have internal emergency plans.

4.1.4 Land Use Planning

Land use planning is a mitigating measure aiming at the limitation of the consequences of an accident outside the fence of an installation. This is achieved by controlling the population density around the installation trough the control of the uses of land and the types of buildings and activities in the areas that can be affected by an accident.

It is noteworthy that land use planning can be also a prevention tool when it refers to the selection of the location of an installation (to minimize threats from natural phenomena as earthquakes, floods, hurricanes) or to the required distances among dangerous facilities to avoid DOMINO phenomena.

In Greece no specific land use requirements have been established with regards to the SEVESO directive.

5 SUMMARY AND CONCLUSIONS

- The SEVESO directive aims at the prevention of major accidents and the mitigation of their consequences.
- Quantitative risk assessment constitutes a rational and self-consistent framework for evaluating and managing risk. QRA consists in the determination of the range of possible *consequences* of an accident but also of the *probability* with which each value in this range is expected to occur.
- “Major accidents” could be accidents that have consequences outside and/or inside an installation. Implementation of the SEVESO directive should pay the necessary attention to consequences inside the installation regardless of whether accidents have or not the potential for external consequences. “Major accidents” are not only the accidents with external consequences.

- Quantitative risk assessment is applicable and should be applied to all types of risks to the workers in order to achieve optimization of risk reduction.
- In Greece the highest priority risk reducing measures in the SEVESO installations are those involving the establishment and control of an inspection and testing program by the competent authority, in order to assure the present state of safety to the workers and the general public.

6 References

1. European Union Council Directive 96/82/EC of 9 December 1996 “On the control of major-accidents hazards involving dangerous substances”.
2. "Probabilistic Safety Analyses of Chemical Installations" (I. A. Papazoglou et al.) J. Loss Prev. in Process Ind., Vol5, No 3, 1992, pp.181-191.
3. "On the Management of Severe Chemical Accidents. DECARA: A computer code for consequence analysis in chemical installations; case study Ammonia Plant". (I. A. Papazoglou et al.) Journal of Hazardous Materials, Vol 31, 1992 pp. 135-153

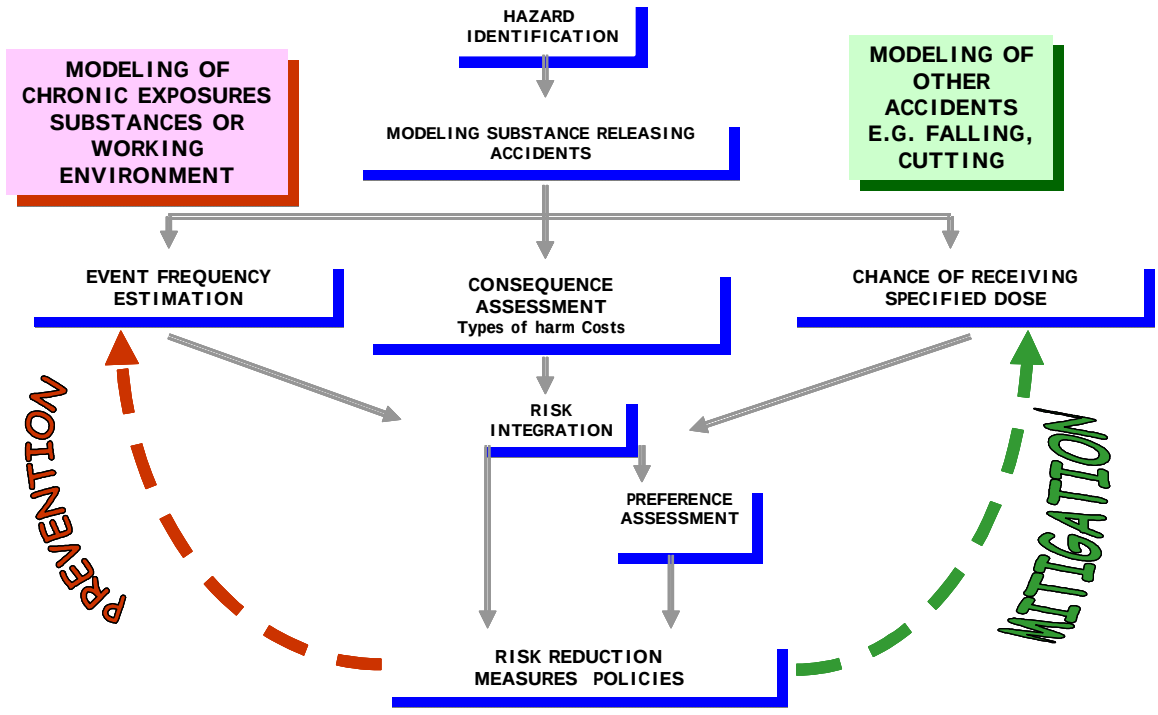

Figure 1. Major Procedural steps for quantified risk assessment and management.