THE CONTROL OF MAJOR CHEMICAL HAZARDS IN SWITZERLAND IN THE FRAMEWORK OF SUSTAINABLE DEVELOPMENT - LIQUEFIED PETROLEUM, AMMONIA AND CHLORINE AS EXAMPLES

Felix K. Gmünder[1], Patrick Meyer[1], and Martin Schiess[2]

[1]Basler & Hofmann, Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland
[2]Swiss Agency for the Environment, Forests and Landscape (SAEFL), Safety of Installations, CH-3003 Berne, Switzerland

ABSTRACT

In this paper, risk-based decision making in the control of chemical hazards in Switzerland is presented. The focus of the hazard and risk management process is on the protection of the population and the environment from the consequences of major accidents occurring at industrial facilities handling toxic substances, processing or storing flammables and explosives. These risks are covered by the Ordinance on "Protection against Major Accidents" (OMA, 1991) that came into force on April 1, 1991. The objectives of the OMA are:

- To protect the public or the environment against serious damage resulting from major accidents that may occur during the operation of an establishment (plant)
- To inform the public about existing risks

The procedure to control and assess relevant hazard potentials and risks consists of two steps. In the first step, the owner of a facility submits a *summary report* containing an assessment of hazards. On the basis of the hazard assessment in the summary report, the enforcement authority decides whether, in a second step, a *quantitative risk assessment* has to be performed.

The risk control process including the risk analysis is demonstrated using an ammonia refrigeration process in a public ice skating rink as a first example. The other two examples include chlorine gas used for water treatment in swimming pools (quantities > 200 kg), and liquefied petroleum gas used as an energy source (quantities > 20 tons).

The risk control process covered by the OMA was found to be very helpful in designing systems that are optimal with regard to protection of the environment and public safety.

KEYWORDS

Risk management, Decision making, Risk policy, Switzerland, Control of major chemical hazards

INTRODUCTION

The legal framework on which risk control is based in Switzerland is provided by article 10 of the "Law Relating to the Protection of the Environment" (LPE, 1983) which deals with protection against disasters. In the aftermath of the fire of November 1, 1986 in Schweizerhalle near Basel with the subsequent catastrophic pollution of the Rhine river, political pressure increased to improve provisions on protection against serious damage resulting from major accidents. As a consequence, the Ordinance on "Protection against Major Accidents" (OMA, 1991) came into force on April 1, 1991.

The issues of concern are the protection of the population, surface and ground water, soil and property. Other issues of concern may arise in special cases such as the protection of natural parks, livestock, recreational areas or ecosystems of particular value.

OUTLINE AND SCOPE OF THE OMA

The Ordinance reflects well-established procedures in risk control, in particular those used in the Netherlands in the context of the environmental control policy. At the same time, the OMA requires implementation of state-of-the-art safety technology in agreement with the German practice.

The OMA applies to all facilities in which (i) the threshold quantities for a defined set of substances are exceeded (examples of threshold quantities are 200 kg of chlorine, 2'000 kg of ammonia, 20'000 kg of liquefied petroleum gas or 200'000 kg of petrol [2]) or in which (ii) dangerous natural or genetically modified micro-organisms are being contained. Furthermore, OMA applies to (iii) transport routes used for the shipping of dangerous goods (railway lines, roads, and Rhine river).

Terminology

The OMA provides the following definition for "hazard potential" and "risk":

- Hazard Potential means the sum of all the consequences which substances, products, special wastes, micro-organisms or dangerous goods could have as a result of their quantity and properties.
- Risk shall be determined by the extent of the possible damage to the population or the environment, caused by major accidents and by the probability of the latter occurring.

Note that risk is defined merely as a function of damage extent and probability of occurrence. The mathematical relationship between these two parameters is not specified.

Procedure

The procedure to control and assess relevant hazard potentials and risks consists of two steps (Figure 1).

In the first step, the owner of a facility submits a *summary report* containing an assessment of hazards.

On the basis of the hazard assessment in the summary report, the enforcement authority decides whether, in a second step, a *quantitative risk assessment* has to be performed.
Summary Report and Risk Assessment Study

The summary report with the hazard assessment contains the following main items:

- A list with the maximum amount of any potentially hazardous substance kept at the facility at any given time and for which the threshold value specified by the OMA is exceeded
- A detailed description of existing safety measures
- An estimation of the extent of possible damage to the public and the environment resulting from major accidents at the facility, regardless of the (un-)likelihood of the accident(s) (maximum probable loss, see also section 3.3).

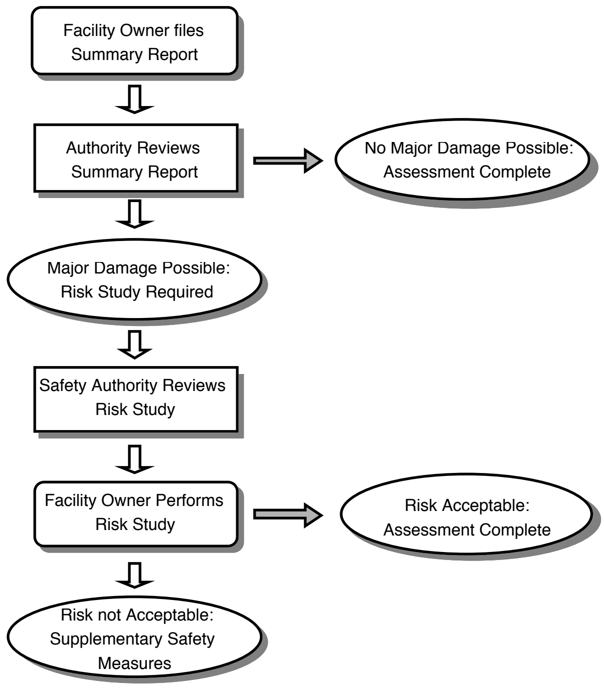

Figure 1.Two-step Procedure for hazard and risk assessment for facilities and installations falling under the OMA (SAEFL, 1996a).

If, in the first assessment step, the enforcement authority concludes that serious damage to the public or to the environment from major accidents must be expected, it orders a *quantitative risk assessment* to be performed. If serious damage is not to be expected, the assessment procedure is completed after the first step.

In 1996, when the Swiss Agency for the Environment, Forests and Landscape (SAEFL) began its systematic data collection, some 2'477 facilities in Switzerland were recorded as falling under the OMA. In 40% of all cases, the summary report had been reviewed and classed. For 163 facilities, a risk assessment has been or will be performed (SAEFL, 1996a).

The need for consistency in the application of the OMA throughout the different types of facilities and throughout the different regions of Switzerland was recognized at an early stage. Consequently, the SAEFL published a series of guidance documents for risk analysts and reviewers (i.e. enforcement authorities):

- *Handbooks* with the status of guidelines, explaining the technical hazard and risk assessment process to meet the OMA. In addition, separate guidelines have been published covering the evaluation of the extent of damage and the risk evaluation (SAEFL, 1996c).
- *Manuals*, which are specific to one type of installation (such as liquid gas storage tanks) and which contain detailed technical information on how to perform hazard and risk assessment for that particular installation. Manuals contain technical background information on the physical phenomena involved in the accidents to be analyzed as well as a prototype event-tree/fault-tree risk model for a fictitious facility. So far, manuals have been published for LPG storage (Basler & Hofmann, 1992), high-pressure natural gas pipelines (SNCG, 1997) and large oil storage facilities (Carbura, 1999).
- *Case studies* for fictitious facilities. These are reference studies containing models and data meant to be transferred and/or adapted to a similar case involving the same type of facility. Some case studies contain reference computer codes for solving the event-tree/fault-tree models. So far, a case study for liquid petroleum storage facilities has been published (SAEFL, 1996b) and a case study for ammonia cooling units has been drafted (SAEFL, 1999).

The risk assessment is used to (i) control the risk level in facilities where major accidents with severe consequences for the population and/or the environment could occur and to (ii) inform the public about existing risks. It is but one element in a strategy aimed at protecting the population and the environment from the consequences of major accidents. The facilities and installations falling under the hazard and risk control regime are described above.

The hazard and risk assessment studies are reported to the enforcement authorities. A digest of each risk assessment study is available publicly on request. The digest contains the main results and findings of the study. The OMA requires an update of the summary report when significant changes occur at the facility. Examples of significant changes are when the production or storage capacity is raised, new equipment is installed or backfitted or when safety-relevant modifications are made to the production and/or storage processes. Based on the updated summary report, the authority decides whether the risk assessment needs to be updated, following to the two-step process described above.

Considerable effort has been put into making the hazard and risk assessment simple and accessible to the facility owners. Still, it is expected that both risk analysts and reviewers (enforcement authorities) be knowledgeable in the principles of quantitative risk assessment. Usually, the owners of facilities contract a specialized engineering firm to perform the risk assessment. There are no requirements for the risk analyst to formally document his or her competence.

Legal/Policy Issues

OMA requires the owner of a facility to take all appropriate measures to reduce risk consonant with the state of the art of safety technology and personal experience. Owners must also take all economically viable measures to reduce hazards, to prevent accidents and limit the consequences of possible accidents should they occur. In addition, OMA defines a risk control process described before. The nature of the risk reduction measures (if such measures are necessary) is not prescribed. This is perceived as an advantage, because it allows the owners of facilities to choose between a range of alternative solutions to reduce risk.

Manuals and Case Studies

The *manuals* and *case studies* of the guidance documentation accompanying the OMA define the state-of-the-art for hazard and risk assessment for a particular type of facility or installation. The fact that the guidance documents are developed in a joint effort by industry and enforcement authorities guarantees a consensus over what should be considered state-of-the-art. If the state-of-the-art changes because technology evolves, the guidance documents have to be revised. The initiative for such revisions can come from industry or from the enforcement authorities.

Description of Summary Reports and Risk Studies

Hazard Identification

The *summary report* with the hazard assessment must contain the following main items:

- A list with the maximum amount of any potentially hazardous substance kept at the facility at any given time and for which the threshold value given in the OMA is exceeded (note: the thresholds defined are the same as or lower than those of the Seveso-Directive (EC Directive 82/501/EEC [Seveso-Directive] and EC Directive 90/219/EEC)).
- A description of safety measures in place at the facility or installation
- An estimation of the extent of possible damage to the public or the environment resulting from major accidents, regardless of the (un-)likelihood of the accident(s) (maximum probable loss)

Appendix I of the OMA (1991) contains a list of potentially hazardous substances and products. Above all, it contains criteria for the identification of potentially hazardous substances. These include toxicity, ecotoxicity, flammability, explosion hazard as well as criteria for dangerous micro-organisms. If the quantities of substances stored at a stationary facility exceed the substance-specific thresholds of OMA (appendix I), they must be included in the summary report discussed above.

Only those damage indicators relevant to the case at hand need to be assessed (Table 1). For instance, for the three examples appearing in this paper (LPG, chlorine and ammonia), the number of fatalities (indicator n1) proved to be the only relevant damage indicator.

TABLE 1
OMA DAMAGE INDICATORS AS GIVEN IN SAEFL (1996C).

Man	
n_1	Number of fatalities [people]
n_2	Number injured [people]
Natural resources	
n_3	Polluted surface water [m^3 or km^2]
n_4	Polluted ground water [person x months]
n_5	Polluted soil [km^2]
Property	
n_6	Damage to property [SFr]

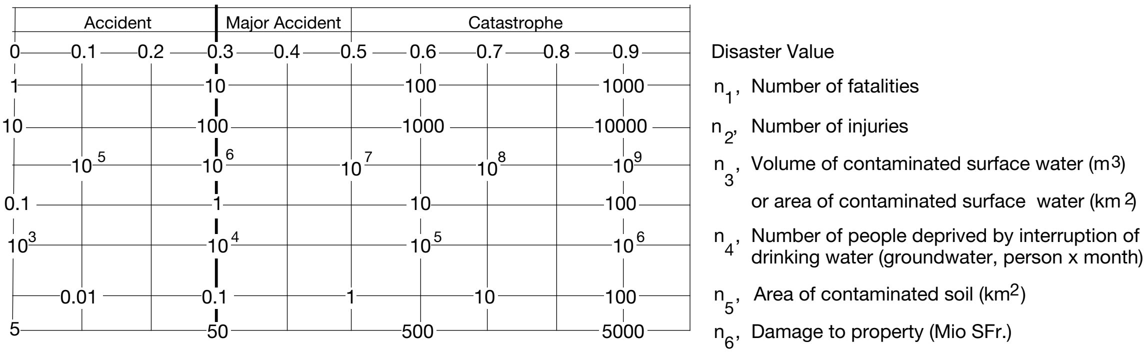

Figure 2: Scale of extent of damage indicators (assignment of disaster values) (SAEFL, 1996c)

Figure 2 shows the mapping of damage indicators into the three categories "Accident", "Major Accident" and "Catastrophe". If a disaster value of 0.3 is reached or exceeded for any one of the relevant damage indicators, the authority orders the owner to perform and submit a risk study.

Event Scenario Assessment

Event scenario assessment generally consists of the following steps:

- Identification of the *main accident scenarios* to be considered for the type of facility. The main accident scenarios are described at the phenomenological level and represent the link to consequence assessment (example: the occurrence of a BLEVE is a main accident scenario considered for LPG storage).
- Description of the *event sequences* associated with the main accident scenarios. These refer to facility-specific events (starting with the causes or initiating events) which must occur for the main accident scenarios to take place (example: a fire under the tank leads to a catastrophic tank rupture, which leads to a large and rapid release of liquefied gas which can trigger a BLEVE). The event sequences are the basis for the fault-tree/event-tree models.
- Modeling of the event sequences with of fault-trees and event-trees. To reduce the complexity of the event tree model (number of event trees, number of event sequences), *functional events* are sometimes defined (in the LPG example below, they correspond to the release categories; in the chlorine and ammonia examples, the functional events coincide with the main scenarios). The frequency of each functional event is calculated with a fault tree.

Event sequences can be identified in a top-down approach by searching for all possible ways to trigger one of the main accident scenarios. Alternatively, a bottom-up approach can be used in which malfunctions are systematically identified and analyzed for their potential to trigger a scenario leading to unwanted consequences (FMEA, HAZOP and similar approaches). In practice, the top-down and bottom-up approaches are often used in combination.

As an example, Table 2 lists the main accident scenarios and the corresponding event sequences for the LPG, ammonia and chlorine examples (SAEFL, 1996b & 1999, Basler & Hofmann, 1999).

TABLE 2

MAIN ACCIDENT SCENARIOS AND FUNCTIONAL EVENTS FOR LPG. FOR AMMONIA AND CHLORINE, FUNCTIONAL EVENTS COINCIDE WITH MAIN SCENARIOS (SAEFL, 1996B & 1999, BASLER & HOFMANN, 1999).

LPG		**Ammonia and Chlorine**
Main scenarios	Release categories (functional events)	Main scenarios
BLEVE	Large (catastrophic) leakage	Large (catastrophic) release
Flash fire	Large (catastrophic) leakage; continuous leakage	Large continuous release
		Small continuous release
Vapor cloud explosion	(none identified)	
Fire torch	continuous leakage	
Flying debris	(consequence of BLEVE scenario)	

When performing event sequence identification, the analyst is expected to refer to the guidance documentation (*manuals*, *case studies*) which explicitly identify the main accident scenarios and event sequences and which propose a generic fault-tree/event-tree model.

Human factors are considered to some extent through the modeling of human actions. Human actions are identified in the accident sequences and the corresponding failure events are quantified using Human Error Probabilities (HEP) found in the literature for similar actions. The risk models included in the *manuals* and *case studies* contain example human actions as well as reference HEPs.

Safety culture and organizational factors are among the human factors not explicitly addressed in the risk assessment process.

Consequence Assessment

The methods and models used for consequence assessment depend on the physical processes involved and on the event sequence scenarios considered. However in general, the following items are assessed for each scenario:

1. Quantity of hazardous substance(s) involved
2. (Time dependent) intensity or concentration over the area exposed, taking into account the effect of terrain features and structures
3. Exposure (i.e. number of people exposed, exposure time)
4. Possible consequence mitigation measures

Below, the approach to consequence assessment in each of the three examples (LPG, chlorine and ammonia) is briefly outlined for one representative scenario:

<u>LPG, BLEVE scenario</u>: In a first step, the amount of LPG participating in the BLEVE is determined. From this, the fireball radius (R) can be calculated. Next, mortality rates are derived for people within the fireball

radius R and within a three-fold fireball radius (3R). Different mortality rates are applied for people outside (directly exposed to the fireball) and for people inside buildings. Evacuation is usually not considered feasible in the scenario due to the absence of a useful warning time.

Chlorine, large catastrophic release (tank rupture): The propagation of the chlorine gas from the ruptured tank is calculated with the help of a computer model. The time-dependent distribution of the chlorine concentration (Fig. 3a and Fig. 3b) is obtained including such factors as the surface roughness of the ground and the speed and direction of the prevailing wind at the time of the accident. A dose-consequence relationship (probit function) is used to determine mortality as a function of the chlorine concentration and exposure time. For nearby buildings, separate chlorine concentrations are calculated assuming a constant air substitution rate. Evacuation is credited in the assessment of exposure times in scenarios where the warning time is sufficient to allow people to react and escape from the dangerous zone.

Ammonia, large (catastrophic) release: Similarly to the chlorine scenario described above, the time-dependent concentration of ammonia is calculated using a propagation program. A minimum required concentration for lethal exposure is used to delimit the perimeter within which exposure must be considered. Due to the speed with which the scenario develops, no credit is taken for evacuation.

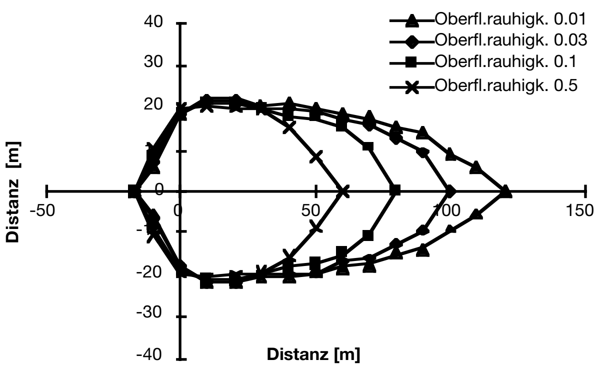

Figure 3a: Chlorine distribution for a 60 kg leakage from a storage tank. Lines of equal concentration (1000 ppm) for different values of surface roughness.

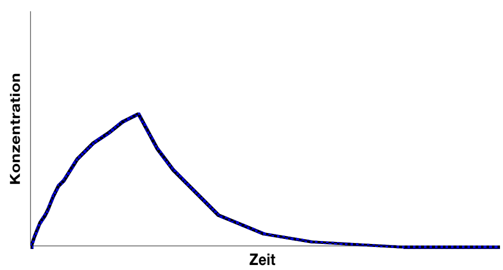

Figure 3b: Time-dependent chlorine concentration in a building as the cloud passes by.

Consequence mitigation measures can be (and should be, if adequate) included. They include the intervention of the fire brigade and evacuation of the population at risk. Credit can be taken for the fire brigade if it can be shown that there is a sufficient warning time for it to deploy. The success of evacuation generally depends on the warning time and on the population density in the exposed area as well as in the emergency evacuation routes (see also the examples of consequence assessment in section 5.1).

Risk Estimation and Risk Comparison

The likelihood of effects is expressed quantitatively in terms of the frequencies of the accident scenarios.

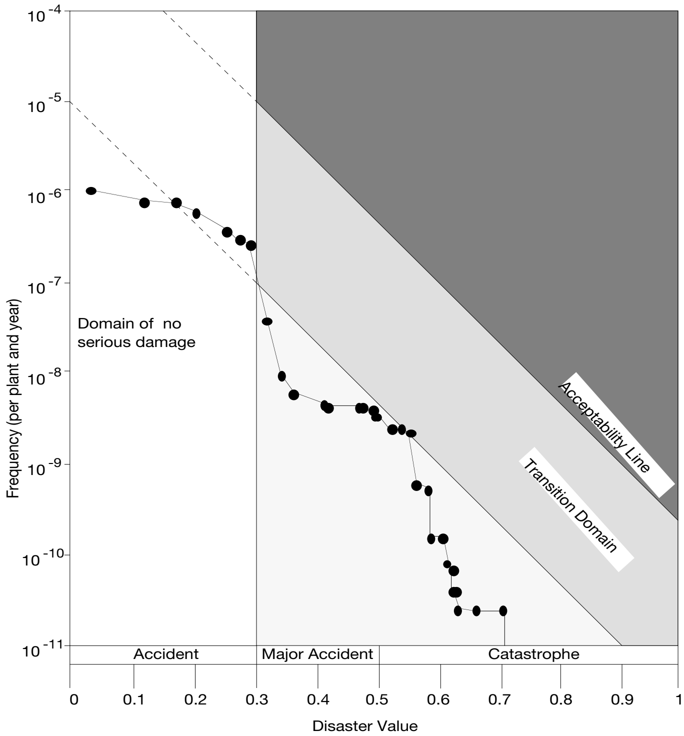

Figure 4: Societal risk criteria for major accidents (SAEFL, 1996c). Cumulative frequency diagram showing the number of fatalities (n_1) for the LPG storage example. The dots represent individual accident sequences.

The diagram in Figure 4 is divided into four domains:

- no serious damage
- acceptable
- transition
- unacceptable

The slope of the boundary lines separating the three domains ‘acceptable’, ‘transition’ and ‘unacceptable’ is quadratic. This is to account for the risk aversion commonly associated to accidents with large consequences.

In risk estimation and risk comparison, the yearly frequencies of the relevant scenarios are plotted against the disaster values in a cumulative frequency distribution (Figure 4). From the cumulative frequency distribution, the acceptability or non-acceptability of the risk can be readily determined. Note that the slope of the boundary lines separating the three domains ‘acceptable’, ‘transition’ and ‘unacceptable’ is quadratic. This is to account for the risk aversion commonly associated to accidents with large consequences.

The enforcement authority evaluates the risk as follows (Figure 4).

1. If the cumulative frequency curve enters the unacceptable domain the owner of the facility is asked to reduce the risk, else the authority is empowered to take actions including operational restrictions

or shutdown.

2. If the cumulative risk curve enters the transition domain, the enforcement authority will measure the interests of the facility owner against the needs of the public and the environment for protection from accidents. Depending on the outcome of these considerations, the risk has to be reduced to a level defined by the authority.
3. If the cumulative risk curve lies in the acceptable domain all through, the risk assessment procedure is complete. However, the owner must still take all appropriate measures to reduce risk (s. below).

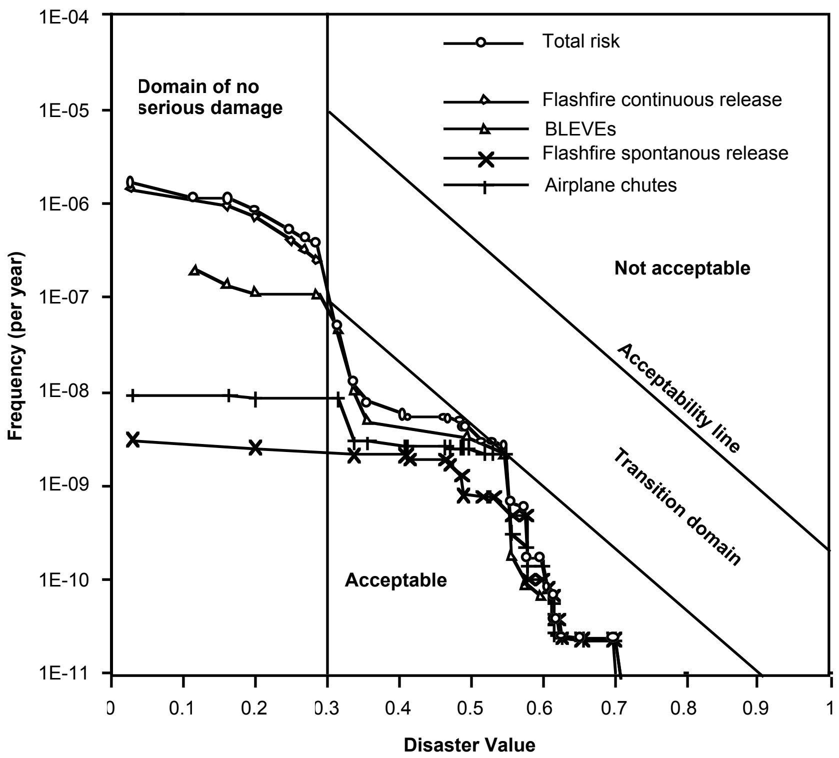

Figure 5: Cumulative frequency distribution showing the contribution of the different scenarios to the number of fatalities (n1) for the LPG storage example.

To obtain more insights on dominant risk contributors, separate curves can be plotted in the cumulative frequency diagrams grouping scenarios, which take their origin in the same initiator (Fig. 5). A risk outlier can be defined as representing a substantial fraction of the total risk, where "substantial" is not further defined. A vulnerability is a risk outlier whose cause can be attributed to a system, type of component or operational practice of the installation under scrutiny. A vulnerability would further exist if a significant amount of risk were due to one particular type of accident.

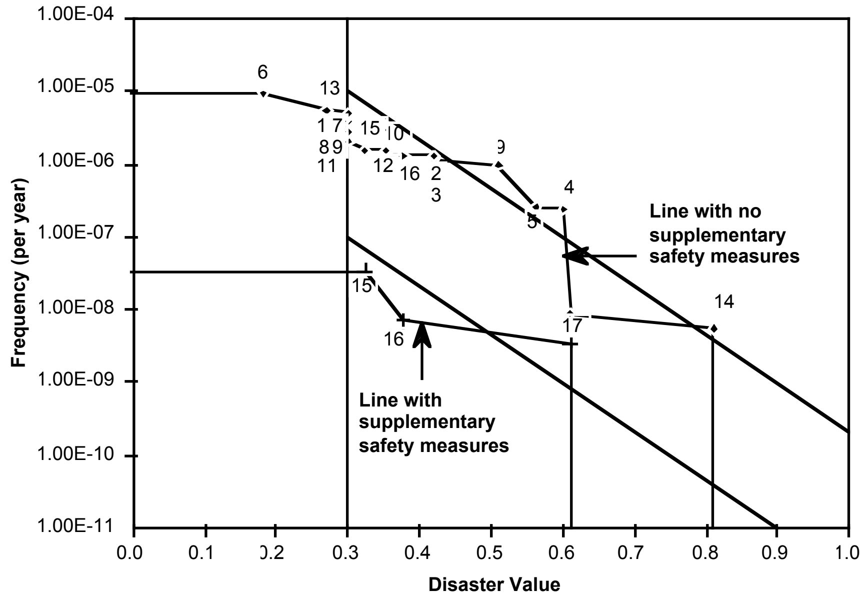

Figure 6: Cumulative frequency distribution showing the number of fatalities (n1) for the example of the ammonia refrigeration plant in a public ice skating rink. The upper curve shows the risk before, the lower curve the risk after implementation of supplementary safety measures. The numbers correspond to individual accident scenarios.

CONCLUSIONS

- In Switzerland the Ordinance on Protection against Major Accidents (OMA, 1991) has been in force since 1 April 1991.
- Accompanying handbooks and guidelines published by the Swiss Agency for the Environment, Forests, and Landscape (SAEFL) which include an example of a summary report and a risk study as well as risk evaluation criteria have enhanced substantially the enforcement delegated to the Cantons.
- Hazard potentials have been reduced by many establishments with dangerous substances, products or special wastes below the quantity thresholds set by the OMA (e.g. 200 kg chlorine, 2'000 kg ammonia, 20'000 kg liquefied petroleum gases, 200'000 kg petrol) to evade coming under the OMA.
- Safety measures in the great majority of establishments are now more thoroughly checked and updated if necessary.
- The OMA has initiated education and development of knowledge with regard to risk and safety. In particular, the Federal Institute of Technology at Lausanne and Zurich and at the University of St. Gall started postgraduate education in 1994 and many companies are keen to improve expertise.
- Information of the public is one of the main goals. However, the intention of the OMA is to disclose just the summary of the risk study on request. This rather restrictive information policy results from public indifference on the one hand and new regulations on privacy on the other.

REFERENCES

Basler & Hofmann (1992). *Manual for LPG Storage Vessels regarding the Summary Report and the Risk Study in Relation to Protection Against Major Accidents* (in French and German). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

Basler & Hofmann (1999). *Case Study of a Risk Study for a Chlorine-Based Cleansing Plant in a Public Swimming Pool* (in German). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

Carbura (1999). *Manual for the Safety of Large Mineral Oil Storage Facilities.* CARBURA and Swiss Agency for the Environment, Forests and Landscape (SAEFL), (revision 11), Zurich, Switzerland.

LPE (1983). *Law Relating to the Protection of the Environment. Bundesgesetz vom 7. Oktober 1983 über den Umweltschutz (USG).* SR 814.01, Berne, Switzerland.

OMA (1991). *Swiss Ordinance on Protection against Major Accidents* (Ordinance on Major Accidents, OMA), SR 814.012, (in English, French or German) February 27, 1991 (Updated July 1994), Berne, Switzerland.

SAEFL (1991). *Handbook I for the Ordinance on Major Accidents, OMA, Guidelines for Establishments with Substances, Products or Special Wastes* (in French or German), Swiss Agency for the Environment, Forests and Landscape, SAEFL, Berne, Switzerland.

SAEFL (1996a). *Umweltschutz*, monthly publication of the Swiss Agency for the Environment, Landscape and Forests, SAEFL, Nr. 3/96, March 1996 (in German), Berne, Switzerland.

SAEFL (1996b). *Case Study of a Risk Study for a LPG Storage Vessel, Ordinance on Major Accidents* (in French or German), Swiss Agency for the Environment, Forests and Landscape (SAEFL), Berne, Switzerland.

SAEFL (1996c). *Evaluation Criteria for the Ordinance on Major Accidents, OMA, Evaluation of the Extent of Damage, Evaluation of the Acceptability of Risk, Guidelines for Establishments with Substances, Products or Special Wastes* (in French or German), Swiss Agency for the Environment, Forests and Landscape (SAEFL), Berne, Switzerland.

SAEFL (1999). *Case Study of a Risk Study for an Ammonia-Based Cooling Process in a Public Ice Rink* (in French or German, draft edition). Basler & Hofmann Consulting Engineers, Forchstrasse 395, CH-8029 Zürich, Switzerland.

SNGC (1997). *Manual for the Safety of High Pressure Natural Gas Installations.* Swiss Natural Gas Company (revised edition), Zürich, Switzerland.