Probalistic Risk Analysis
of

a switching accident involving chlorine

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Limitations: This report was made during the instruction of the above mentioned course. The main purpose was to practise problem solving and the methodology in problem solving. This reports conclusions and calculations have not been object for a investigation of quality in the range that quality safety requires. Therefore the report must be used by a great carefulness. Whom that uses the results from this report, in any context, bear the responsibility on his or her own.

Keywords: Probabilistic risk analysis, Chlorine dispersion, Individual risk, Societal risk, Risk profile, event tree.

S y n o p s i s

In this report a switching accident involving chlorine has been evaluated by using a probabilistic risk assessment method.

The switching accident is one of these scenarios that have been made subject to a prior analysis in the report "Risk evaluation in Physical planning - Tretorn area, Helsingborg"

By carrying out a probabilistic risk analysis the distribution of various input to the gaussian dispersion model are taken into consideration.

The individual risk has been calculated to 1,2E-5 per year in a distance of 168 m from the spill and 9,7E-6 per year in a distance of 580 m from the spill. The individual risk level is on the limit of what can be accepted by society.

The societal risk has been calculated. The Societal risk level lays way beyond the level that can be accepted in ex. Holland. Measures to lower the consequences due to a accident involving chlorine could be taken.

The sensitivity analysis shows that the size of the dispersion mainly is guided by the size of the leak and the wind velocity - two factors beyond human's possibility to influence. Therefore the frequency for accidents are to be lower and there should be some changes to the area surrounding the railroad. Otherwise the transportation of hazardous goods should be prohibited to run through or nearby residential areas.

Preface

This report was made during the course "Risk Management 2" at the School of Fire Safety Engineering, Lund University in the period from September 1st 1998 to October the 5th 1998.

During the report som references are made by [number], where the number in side the brackets are the reference's number in list over references. In chapter 6 "References" the used literature is listed.

Lund 5th of October 1998

Jakob Andersen Henrik Bygbjerg

The limitations of this report are translated into Swedish as well as into Danish down below:

In Swedish:

"Följande rapport är framtagen i undervisningen. Det huvudsakliga syfte har varit träning i problemlösning och metodik. Rapportens slutsatser och beräkningsresultat har inte kvalitetsgranskats i den omfatning som krävs för kvalitetssäkring. Rapporten måste därför användas med stor försiktighet. Den som åberopar resultaten från rapporten i något sammanhang bär själv ansvaret."

In Danish

"Følgende rapport er udarbejdet gennem undervigningen. Det overordnede formål har været at opnå træning i problemløsning og metode. Rapportens konsklusioner og beregningsresultater har ikke været underkastet en kvalitetsgranskning i det omfang, der kræves for kvalitetssikring. Rapporten bør derfor anvendes med stor forsigtighed. Den som anvender resultater fra denne rapport bærer selv ansvaret."

Table of contents

1. Introduction

The present report has been drawn up as a part of the course “Risk Management II” at the School of Fire Protection Engineering, Lund University in the period from September 1st 1998 to October the 5th 1998. It is based upon a single event described in a prior report “Risk Evaluation in Physical Planning - Tretorn area, Helsingborg”, carried out by Bödvar Tomasson and the authors of this report.

1.1 Probabilistic risk analysis

The purpose of this report is to carry out a probabilistic risk analysis of a single event ex. a spill / an accident involving hazardous goods. Roughly a probabilistic risk analysis takes into consideration the variation in the factors that affect the consequences of an spill, ex. the variation in velocity of the wind. By carrying out an Monte Carlo simulation on the different input data, the consequences of a spill can be examined more accurate.

As a tool to carry out a Monte Carlo-simulation on the different input data the software @RISK has been used.

In order to carry out a probabilistic risk analysis the consequences should be described by an analytical equation. The inputs however should be described as a distribution or a constant. Inputs that can be described as approximately constants could be data concerning the toxic substance ex. the molecular weight, heat capacity etc. Inputs that should be described as a distribution are generally input that can not be unequivocal determined due to variation through time ex. the ambient temperature varies throughout the year. It is not possible to determine the size or contraction of the outlet hole but these can vary through some probable sizes and contractions of the outlet hole and should therefore be described as a distribution.

2. Dispersion of Chlorine

One scenario in the report "Risk Evaluation in Physical Planning - Tretorn area, Helsingborg" the consequences of a switching accident involving chlorine was adapted. This switching accident is made subject for analysis according to probabilistic risk analysis. The consequences was calculated by the software "Chemsplus" given fixed input data i.e. that only ex. a single wind velocity was used.

2.1 The scenario

During the switching of railroad wagons some accident occur and one or more wagons are derailed. In most cases no fatal accident will occur i.e. no dispersion of hazardous substances. In the prior report the probability for a chlorine wagon leaking as a result of a derailment during a switching accident. The following event tree can be drawn describing the above mentioned accident, please see Figure 2.1.

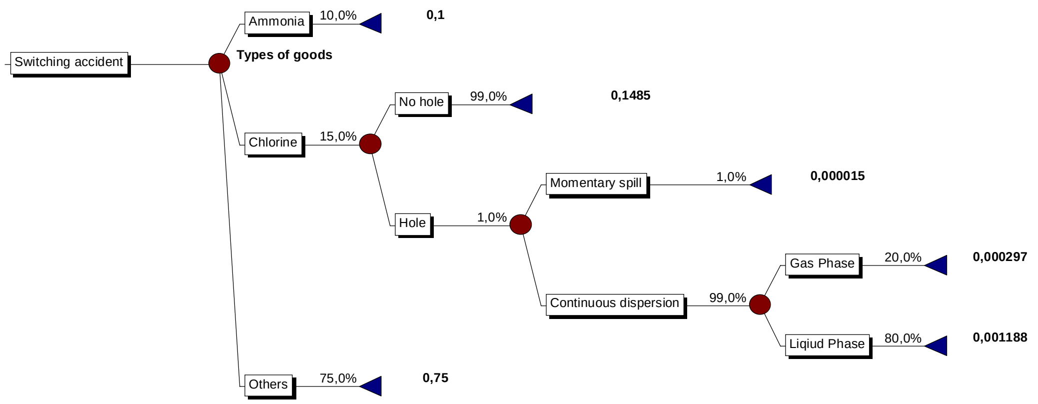

Figure 2.1: Event tree for a switching accident involving chlorine.

Only continuous dispersion is considered. Often are chlorine filled to a steel tank with a degree of filling at approximately 80% i.e. that approximately 80% of the tank is filled with condensed chlorine (liquid phase) leaving approximately 20% of the tank volume filled with mainly gaseous chlorine (gas phase). Railroad wagons have no relief-vales to prevent a build up of a unwanted overpressure inside the tank. Therefore railroad wagons are often filled to 80% leaving the 20% as a kind as "buffer-zone". The probability of getting a leak/hole in the liquid phase is therefore set to 80% resulting in 20% probability for a leak/hole in the gaseous phase.

The event tree gives a probability of 0,001188 for chlorine dispersion from the liquid phase respectively 0,000297 for chlorine dispersion from the gaseous phase due to one switching accident. The probability of having a switching accident per year is 0,197 according to /1/. This will result in probability of having a switching accident involving chlorine per year as listed in Table 2.1.

Dispersion	**[year^{-1}]**	**[year^{-1}]**
Gaseous phase	0,000297 · 0,197	5,85E-5
Liquid phase	0,001188 · 0,197	2,34E-4

Table 2.1: Probability of having a switching accident involving chlorine per year.

Under the assumption that the dispersion always will happen in a 15° angle down the wind the probability can be reduces by 1/24 due to the following calculation.

$$f_{i,d} = f_i \cdot \left(\frac{\Theta_i}{360°} \right) = f_i \cdot \left(\frac{15°}{360°} \right) = f_i \cdot \left(\frac{1}{24} \right) \tag{2.1}$$

Dispersion	**[year^{-1}]**	**[year^{-1}]**
Gaseous phase	0,0000585 · 1/24	2,44E-6
Liquid phase	0,0002340 · 1/24	9,75E-6

Table 2.2: Probability of dispersion of chlorine down the wind per year.

2.2 Limit value for exposure to chlorine

The limit value for exposure to chlorine has been chosen to 293 ppm. 293 ppm has been chosen upon the basis that this value is given as the limit value for 1 hour exposure in the "Handbook for accidents involving hazardous goods" used by Fire Officers in Denmark /3/. One hour exposure at this limit gives the Fire Brigade enough time to deal with the spill or to evacuate further areas if the situation should develop.

In order to decide at which distance people around the spill are to be considered being out of the danger-zone the 95% fraction. This means that "the safe distance" is the distance where the limit at 293 ppm is not exceed with a probability of 95%.

2.3 Assumptions

The dispersal can be calculated by the Gaussian-model, although chlorine in the gaseous phase is heavier than the ambient air **-** but when dilute down wind the gaseous chlorine can be considered as light gas.

In case of a spill of chlorine it is assumed that the turn-out force from the Fire Brigade will have the situation under control after approximately 20 minutes. Hereby not said that the leak/hole would be stop, but though controlled either by water mist or efforts to recondensate.

When having a dispersion from the liquid phase a part of the liquid will immediately turn into gaseous chlorine. It is assumed that an equal part will disperse in form of aerosol. The rest will build a pool of liquid chlorine.

The distributions describing the inputs are results from observing the variation concerning most likely value, maximum and minimum. Due to lack of proper information some of the distributions are based upon guesswork or fellow students' information. Only uniform and triangular distributions are used. All inputs are listed in Table 2.3.

Input		Distribution	min	occur	max	mean	units
Temperature (ground)	T_g	Triangular	263	283	303	**283**	K
Temperature (ambient air)	T_a	Triangular	263	283	303	**283**	K
Temperature (storage)	T_s	Triangular	263	283	303	**283**	K
Wind velocity	U	Triangular	1	3	15	**6,33**	m/s
Diameter of hole	D	Uniform	0,01		0,07	**0,04**	m
Contraction	C_d	Uniform	0,5		1	**0,75**	
Spill under control after x seconds	T_c	Constant				**1200**	sec
Atmospheric pressure	P_a	Constant				**1**	bar
Storage pressure	P_s	Triangular	7	8	9	**8**	bar
Amount of substance	W_s	Uniform	49,5		50,5	**50**	ton
Density of substance	ρ_s	Constant				**1468**	kg/m^3
Heat of evaporation of substance	H_s	Constant				**287**	kJ/kg
Boiling point of substance	T_b	Constant				**239**	K
Spec. heat capacity of substance	C_p	Constant				**0,946**	kJ/kg
Lat. heat capacity of substance	C_v	Constant				**0,698**	kJ/kg
Molecular weight of substance	M_s	Constant				**0,071**	kg/mol
Height of dispersion (gaseous)	h_g	Uniform	2,5		3,5	**3**	m
Height of dispersion (Liquid)	h_l	Uniform	0		2,5	**1,25**	m
Width of spill	W_s	Constant				**30**	m
Length of spill	L_s	Constant				**3**	m

Table 2.3: Inputs and distributions used in the probabilistic risk analysis.

2.4 Safe distance - dispersion due to leak in the liquid phase

The safe distance has been calculated by using the sampling type " Monte Carlo" and 10000 iterations. Several calculations had to be to done at various distances in order to determine the safe distance. By varying the distance the result of the calculations was that the safe distance should be at least 580 m in order to fulfil the criteria. The criteria set was that at the safe distance the concentration may not exceed the limit value in 95% of all cases.

When observing the safe distance the concentration of gaseous chlorine in the air will be distributed as shown in Figure 2.2.

An alternative approach to calculate the safe distance could be isolating the distance in the equation describing the gaussian model.

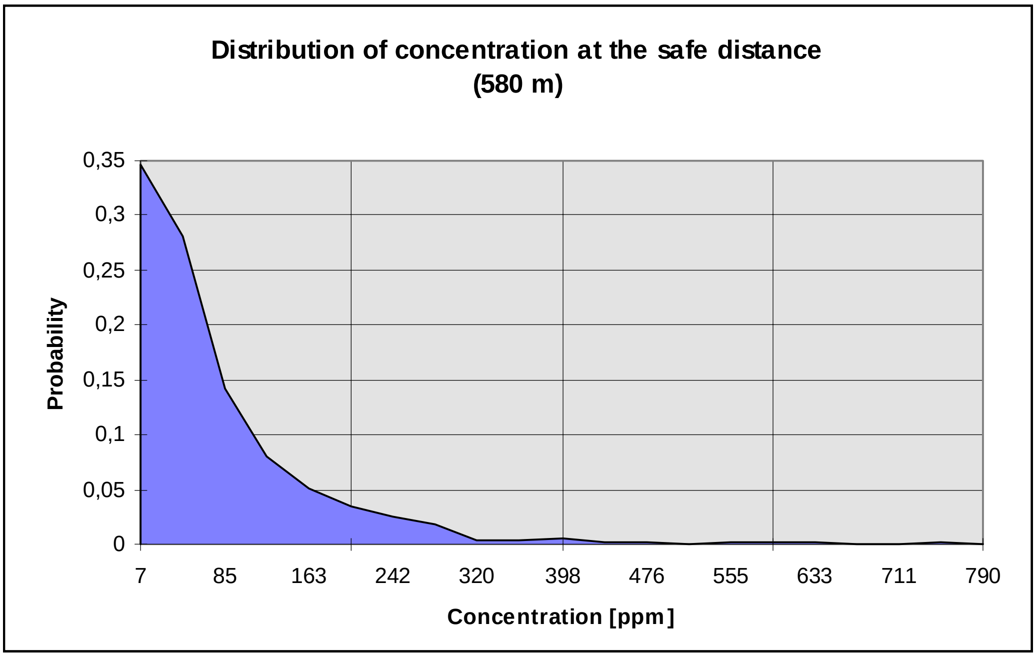

Figure 2.2: Distribution of concentration at the safe distance (580 m). Liquid Phase.

2.5 Safe distance - dispersion due to leak in the gas phase

The safe distance has been calculated by using the sampling type " Monte Carlo" and 10000 iterations. Several calculations had to be to done at various distances in order to determine the safe distance. By varying the distance the result of the calculations was that the safe distance should be at least 168 m in order to fulfil the criteria. The criteria set was that at the safe distance the concentration may not exceed the limit value in 95% of all cases.

When observing the safe distance the concentration of gaseous chlorine in the air will be distributed as shown in Figure 2.3.

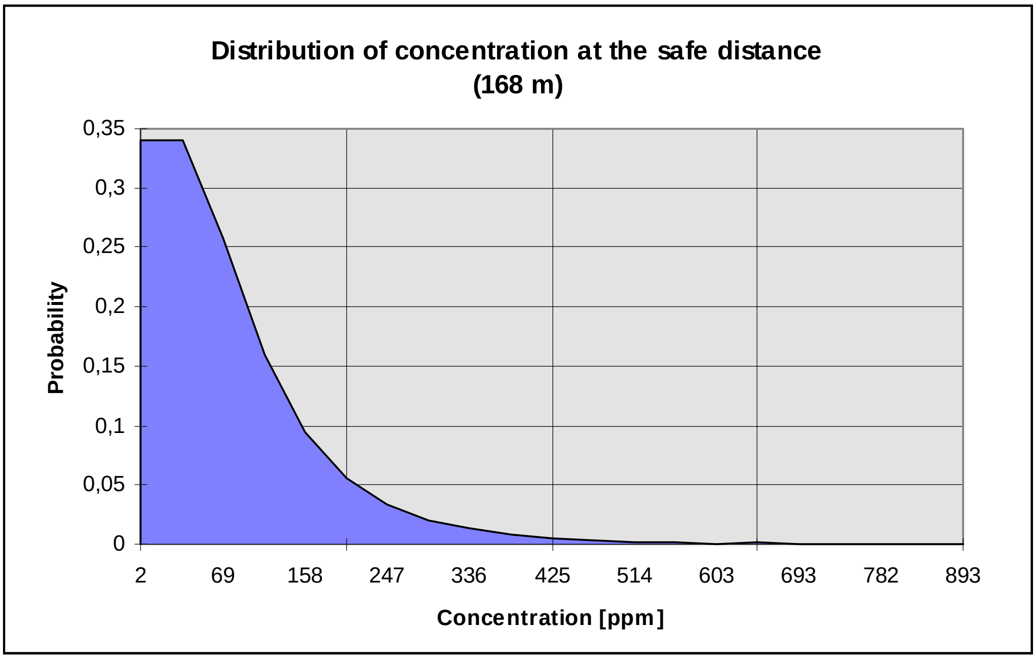

Figure 2.3: Distribution of concentration at the safe distance (168 m). Gaseous Phase.

2.5.1 Sensitivity

In order to discover which input influences the most on the dispersion, one could carry out a sensitivity analysis on the different input in relation to the gaussian dispersion model. The sensitivity analysis has been carried out by @RISK. The result of the sensitivity analysis is shown in Figure 2.4.

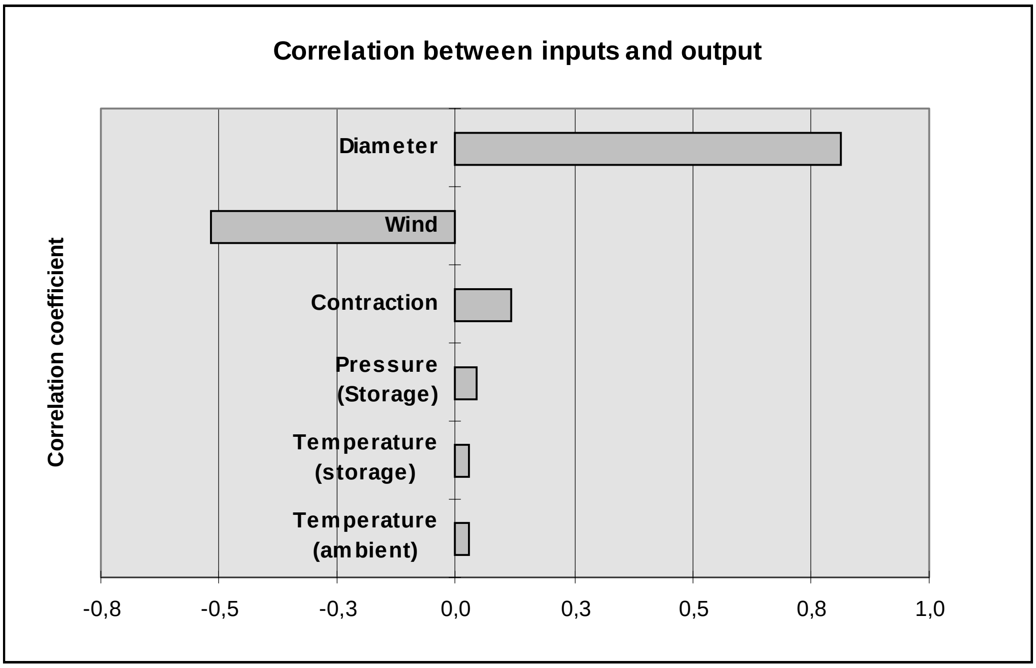

Figure 2.4: Correlation between inputs and output..

The results shown in Figure 2.4 concludes that the diameter of the hole influences the most on the dispersion. A positive correlation means that an increase will result in greater consequences, otherwise if an input is shown with negative correlation a decrease will result in greater consequences. In other words a larger hole will lead to a greater massflow and thereby greater concentration. A decrease in wind velocity will result in less dilution with ambient air resulting in a greater concentration.

It can be hard to do anything about the variation in leak size or wind velocity but some factors can be influences like the storage pressure. It will however have little influence on the final result according to Figure 2.4.

3. Risk analysis

According to the event tree, see Figure 2.1, a accident resulting in a hole in a train wagon loaded with chlorine could lead to two different type of leaks - a leak in the liquid phase or a leak in the gaseous phase. The probability are shown in Table 3.4.

Dispersion	**[year^{-1}]**	**Safe distance**
Gaseous phase	2,44E-6	168 m
Liquid phase	9,75E-6	580 m

Table 3.4: Probability of dispersion of chlorine down the wind per year.

In order to draw up risk profiles one must assume that residence within the safe distance in case of an accident will be fatal. Two types of risk profiles will be drawn up - an individual risk profile and a societal risk profile. Roughly the individual risk profile displays the risk (probability) for one person being exposed to a chlorine dispersion when residing in a certain distance from the switching area. The societal risk display the consequences in numbers of deaths due to a chlorine dispersion. The societal risk takes into consideration the population residing in the area of the switching area.

3.1 Individual risk

The individual risk profile has been drawn up on the basis of Table 3.4.

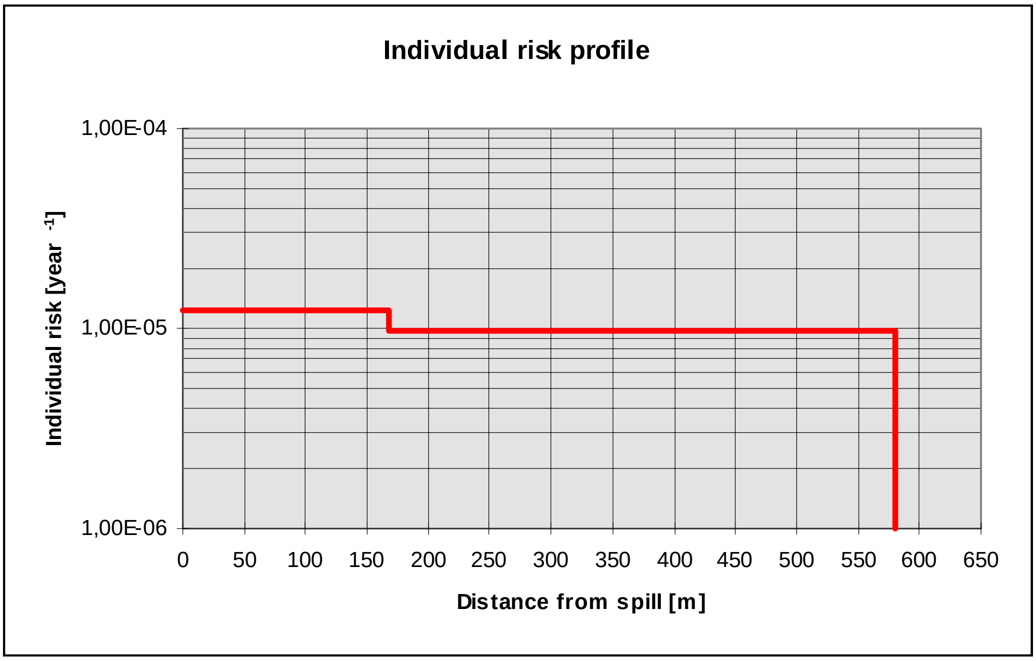

Figure 3.5: Individual risk profile.

The present risk level for individual risk is at the absolute limit of what can be accepted /2 p. 5-35/. Some countries gives 1E-4 as a maximal acceptable risk per year, but most countries gives 1E-5 or less as a maximal acceptable risk.

3.2 Societal risk

When drawing up the risk profile for societal risk the population of the different area surrounding the place for the accident shall be determined. Due to lack of information about the area no actual population density can be determined. Once again the population is based upon guesswork. By principle the event tree should be enlarged in order to take the probability of various wind directions into consideration. In this analysis we operate with 8 different wind directions, see Figure 3.7. If various wind directions were attached to various probabilities this had to be taken into consideration but due to lack of knowledge about these probabilities we assume that all probabilities are equal, see Figure 3.6.

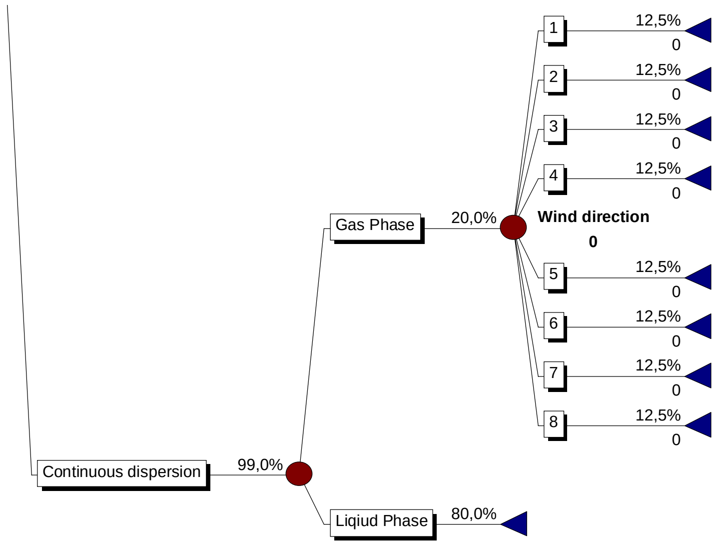

Figure 3.6: Event tree including the wind directions. Only displayed for leak in the gaseous phase.

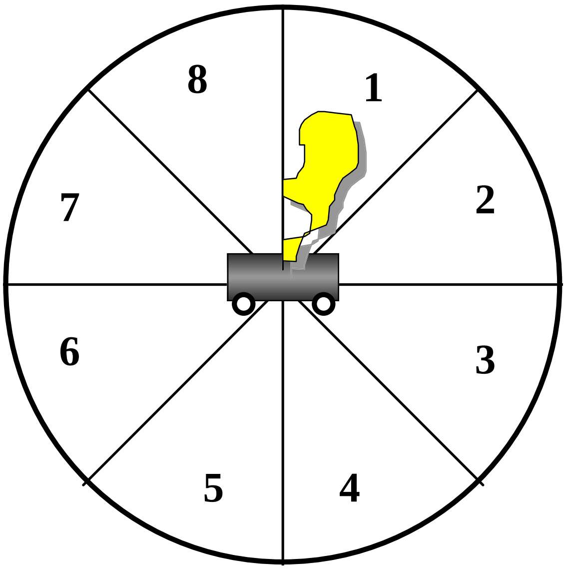

Figure 3.7: 8 different wind directions.

Due to lack of knowledge about the area the following data is assumed. Prior in this report it was assumed that the dispersion will happen under an angle of 15°. The wind directions are divided into 8 segments giving each an angle of 45°. Therefore the dispersion will only involve a third of wind direction segment.

It is assumed that there will be no residential or industrial areas within a radius of 200 m from the accident. Further it is assumed that industry and residential areas is located as described in table:

Wind direction	% industry	% residential
1	5	95
2	0	100
3	0	100
4	30	70
5	30	70
6	100	0
7	100	0
8	10	90

Figure 3.8: Assumed populations in different areas.

For residential areas the population has been assumed to be 10000 persons/km² and for industrial areas 2000 persons/km².

Leak	**Probability for leak**	**Wind direction**	**Probability for wind direction**	**Probability (total)**	**Fatal**
Gaseous Phase	5,85E-5	1	0,125	7,31E-6	No
		2	0,125	7,31E-6	No
		3	0,125	7,31E-6	No
		4	0,125	7,31E-6	No
		5	0,125	7,31E-6	No
		6	0,125	7,31E-6	No
		7	0,125	7,31E-6	No
		8	0,125	7,31E-6	No
Liquid Phase	2,34E-4	1	0,125	2,93E-5	Yes
		2	0,125	2,93E-5	No
		3	0,125	2,93E-5	Yes
		4	0,125	2,93E-5	Yes
		5	0,125	2,93E-5	Yes
		6	0,125	2,93E-5	No
		7	0,125	2,93E-5	Yes
		8	0,125	2,93E-5	Yes

Figure 3.9: Societal consequenses.

Wind direction	**Affected area [m²]**	**Affected industry [m²]**	**Affected residential [m²]**	**Number of deaths**
1	7000	350	6650	67
3	7000	0	7000	70
4	7000	2100	4900	53
5	7000	2100	4900	53
7	7000	7000	0	14
8	7000	700	6300	64

Figure 3.10: Number of deaths.

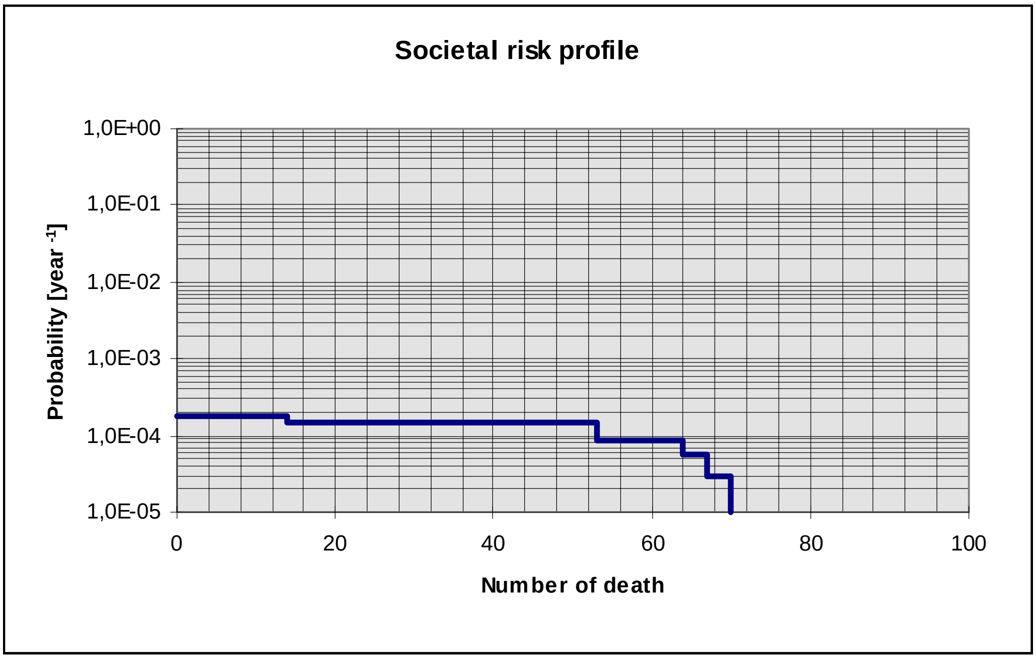

Figure 3.11: Societal risk profile.

4. Conclusion

In this present analysis the individual risk profile and the societal risk profile for an switching accident involving chlorine has been drawn. The Swedish regulations nor the Danish regulations do not give any guidelines on which risk level there should be accepted or not accepted. In order to use the risk profiles as a tool in physical planning these national risk levels needs to be established.

The risk profiles can in their present form be used to compare different measures that can be taken to improve the safety. One could also turn to foreign countries in order to get an idea of acceptable risk levels. The Dutch have a clear definition of what to accept or not. The Dutch maximal acceptable risk level is listed in Table 4.5.

	Individual risk	**Societal risk**
New constructions	1·E-6	0,01/N²
Present constructions	1·E-5	N.A.

Table 4.5: The Dutch's maximal acceptable risks.

If the Dutch's levels are compared to the risk profiles in this report the conclusion must be that the individual risk is on the limit of acceptable risk level. The societal risk lays way beyond the acceptable risk level and measures has to be taken, see Figure 4.1. The societal risk level can be lowered either be takes measure to prevent a switching accident or by relocating the rail area etc.

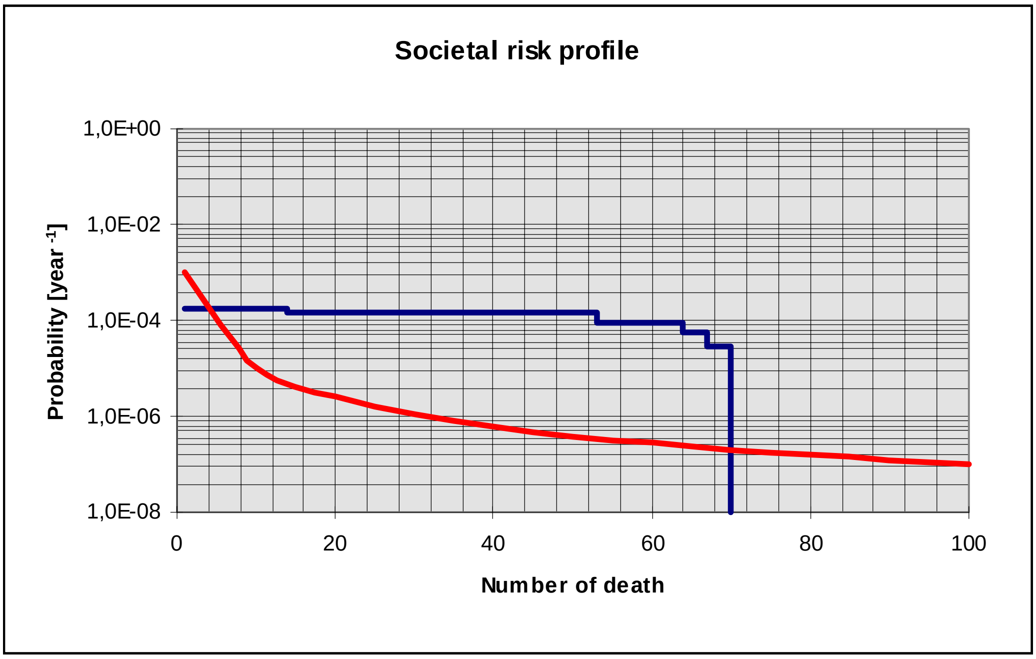

Figure 4.1: Comparison between Dutch acceptable risk level (red) and calculated societal risk level (blue).

5. References

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