Systematization of international knowledge concerning “worst-case scenario” approach. General guidelines for application of the approach in purposes of industrial safety.

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SYSTEMATIZATION OF INTERNATIONAL KNOWLEDGE CONCERNING “WORST-CASE SCENARIO” APPROACH.
GENERAL GUIDELINES FOR APPLICATION OF THE APPROACH IN PURPOSES OF INDUSTRIAL SAFETY.

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Abstract

The intention of this Masters thesis is to analyze the worst-case scenario approach and in doing so gather, summarize and analyze all available relevant information. The current project is limited to purely theoretical research. Due to a lack of order in information regarding this approach it has become very important to systematize information concerning worst-case scenarios.

A couple of interesting alternative approaches and opinions concerning content and usefulness of worst-case scenarios were found during the data collection phase. The ‘Likelier but less catastrophic’ scenario approach is one such example which has raised a number of new questions. Some unexpected difficulties have also arisen; for example, we have failed to find a single specific definition for what is considered to be a worst-case scenario.

Discussion within the scientific world centers on two competing approaches, qualitative and quantitative. Both can and should be applied for worst-case scenarios, however most contemporary researchers tend to overestimate the value of qualitative approaches. It is unclear which one suits our purposes, but it seems that both are needed for a thorough description of any scenario. This explains our introduction of a semi-quantitative approach.

One chapter of this thesis is dedicated to the study of safety legislation in countries all over the world, indicating that authorities in the United States appear to make the greatest effort to implement worst-case scenario approach in practice, while the legislation of European countries lacks clear definition of worst-case scenarios.

People need different types of information about the potential harm to their locales in case of serious accidents. The information should differ in quantity and content depending on the recipient. For example, technical details of scenarios are of little or no interest to the majority of the population. Moreover they can become a source of danger in case of misuse by terrorists. This is where the public’s “right to know” becomes secondary to safety and privacy requirements.

During work on this Masters thesis a large-scale accident in Buncefield took place. Reports of the investigation committee have become a valuable source of data, and a valuable addition to the Analysis of Safety (Seveso) Reports of three Swedish companies. These reports, as well as information from other sources, have served as a basis for a list of recommendations to companies preparing to analyze potential hazards.
Dedications


Det Svenska Institutet är en organisation som jag är mycket tacksam till. Det här arbetet och alla mina studier i Sverige skulle aldrig ha inträffat utan deras stöd.

Ett stort tack till alla!
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Introduction
We cannot imagine our life today without the consumer goods that surround us. These goods, each in their own way helping fulfill mankind’s needs, are generally the products of industry. This is why at present people must tolerate some risks, such as the risk of an accident at a manufacturing plant producing fertilizers, or at a filling station. Certainly no-one wants such events to happen. Because of this a large number of institutes, authorities and organizations work to reduce risk to within acceptable levels.

This aim can be promoted with the help of improved controls, often a source of major progress in terms of safety technologies. It frequently occurs that significant and tragic accidents become a catalyst for research, studies and legislative initiatives. The second half of the 20th century is a good example of this. Severe disasters at chemical plants in Seveso (Italy), Bhopal (India) and Basel (Switzerland) as well as a number of smaller accidents were followed by serious debates among politicians and in the international media. As a result of this, new laws, directives and protocols were written and approved.

The series of extreme accidents listed above has brought to life a new scientific approach, known as the ‘worst-case scenario’ approach, which this Masters thesis addresses. The term is used in the field of risk analysis and risk assessment. People now realize that such a scenario could occur elsewhere, even in their own neighborhood. They wish to know the worst case scenario that could happen and how to reduce its consequences, as do we.

Aims
This work aims to answer a number of questions. Several approaches to the definition of worst-case scenario exist within the scientific world. The first part of this thesis is a systematization of these definitions. The answers raise new questions which will be addressed in subsequent chapters.

It is not yet clear who the end-user of the information received from worst-case analysis might be. Is it a municipality giving authorization to build an installation? Is it a project engineer? Or is it a member of the public living in a potentially endangered area? A great depends on the person making this decision. All relevant stakeholders need appropriate information, but it should be tailored both in content and depth. That is something that people studying worst-case approach, should keep in mind at all times. It would be extremely useful to define the appropriate information required by every specific group of society.

There is a major issue today within the field of risk assessment regarding the creation of a common platform for people involved in risk analysis and authorities as representatives of the society. The quantitative results from an analysis generally offer little information to the public, which is why qualitative characteristics are required. They should be precise enough to satisfy scientific requirements, and at the same time clear enough for the public to comprehend and deal contend with. That is why the report contains comparative evaluation of quantitative and qualitative methodologies for evaluation of accident scenarios.

With this information in mind, the current study aims to answer the following questions:
1) What is ‘worst-case scenario’?
2) How is the approach used around the world?
3) Do the Seveso directives have any influence on worst-case scenario?
4) What is the best way to describe and evaluate worst-case scenarios?
5) How do companies use the approach in their safety reports?
6) What is the quantity and detail of information that should be provided to the public?
7) What advice could be given to those trying to implement the worst-case scenario approach?

Methodology
Our investigation is mainly based on two data sources, literature studies and websites. Internet searches take a higher priority as the topic of interest is of greater public and professional interest, and it is faster and easier to find new articles on the Internet than in reference books, which take longer for publication.

We analyze the so called Seveso Reports taken from three Swedish companies. Each was written in a different way by different authorities, which makes the reports more useful for our final goal: to write a list of recommendations for those preparing to apply worst-case scenario approach for specific facilities. We put the results of our “Seveso Reports” research into a comparative table and make analysis after that. In order to create a substantial basis for this guide, safety legislation from a number of countries all over the globe is reviewed in a subsequent chapter. The last chapter is a systematization and discussion of the knowledge from all the previous chapters. We make it in a form of step-by-step guidelines for industrial operators who want to use worst-case approach.

Delimitations
In order to focus our research and make it more detailed we placed certain restrictions on the field of our studies. This thesis is primarily focused on the application of worst-case scenario for liquefied natural gas (LNG) and oil storage. In regards to legislation, examples were taken from countries which proved to be amongst the global leaders of current safety regulations.
1. Definition of “the worst-case”

The end of the twentieth century has illustrated that the use of increased volumes of dangerous substances and the introduction of new technologies in various branches of industry presents a serious danger for people living in close proximity to industrial sites or networks transmitting hazardous products. Mankind has discovered or created a wide variety of synthetic chemicals, most of which are harmful to humans. Evidence indicates an increased number of accidents, injuries, and fatalities involving industrial personnel as well as civilians living outside facilities’ boundaries. ‘Worst-case scenario’ is a term recently added to the lexicon of scientists involved in the study of risk factors. This is connected to a growing interest within our society to the potential impact of accidents at nearby factories, pipelines, or gas-stations.

One immediate and significant problem is that no single, unified definition for the worst-case scenario approach exists within current literature. This may be due to the approach being relatively novel, but that is just one side of the coin. Here we conduct a literature study in order to discover the different meanings of the term “worst-case scenario”.

First of all “worst case scenario” has slightly different meanings depending on the area where it is mentioned. But it seems that the definition given by Peter M. Sandman reflects the general sense of the term: “worst case scenarios are high magnitude risks; they are the worst things that can happen. They are almost always low-probability – the worst that can happen does not happen very often. So they are mathematically equivalent but not “humanly” equivalent to alternative scenarios that are not so bad but a good deal more likely.” Doctor Sandman is a famous scientist in the field of risk communication, who also works as an adviser (consultant) for companies and governments in the United States, Europe and Australia. If rephrased and simplified, the worst case scenario is a sequence of events, actions, or accidents for a certain place (site) and time that causes the worst outcome. People are generally more concerned of such scenarios, even though alternative scenarios that are not so bad are more likely.

It is currently impossible to find a purely mathematical definition of worst-case scenario, as scenarios vary too much from case to case and from site to site. It is enormously difficult or almost impossible to create a single mathematical basis to describe the approach. But such a description exists for ‘worst-case release’. Let us judge this as a specific type of worst-case scenario. One can say that worst-case release corresponds to worst-case scenario concerning runoff of dangerous substances: “the current proposal by the USEPA (supplemental rule, March 1995) defines the worst case release as a release that fully depletes any hazardous material inventory in ten minutes.” Although some may regard this definition as very precise, it actually is not. This approach is often criticized for oversimplification, as the suggested time of 10 minutes may be appropriate for one case and absolutely inappropriate for another. Much depends on the type of substance and overall volume. This kind of example is very good because it shows us a current trend in the scientific world to narrow the field where a particular worst-case (or some other) definition is to be applied. On the other hand, this example proves that it is still extremely difficult to create a reliable definition and numerical basis, even within a very specific field.

When being used for emergency planning and indication of vulnerable zones around a facility, worst-case scenario presumes the instantaneous release of the entire amount of chemical substance stored at the site and assumes the failure of all safety and mitigation systems. The North American Environment Protection Association has a similar view of the problem. In the United States obligatory Risk Management Plans (RMP) must include worst-case accident estimations. In this case, worst-case scenario would entail complete and devastating failure and that no safety equipment works except for passive measures such as drains, dikes and basins. The weather conditions assumed should be the worst possible. There was a considerable discussion
about what should be considered as the amount of substance released in the worst case. On March 13, 1995 the definition was changed from “all the regulated substance in the process is instantaneously released and all mitigation systems fail to minimize the consequences of the release” to “... the release of the largest quantity of a regulated substance, resulting from a vessel or process piping failure”. It is not easy to determine how useful the results received are when this definition is applied. But it is clear that this approach is rather simple and can be applied across all major activities.

From these examples, it can be seen that in the majority of cases there is a trend towards simplifying definitions. Their purpose is to make these definitions clear to all and avoid situations where it may be difficult to apply. The worst-case scenario entails that the worst possible event happens at every stage of an accident.

In the introduction to “Algorithms for Worth-Case Design and Applications to Risk Management” the worst-case scenario is said not to be of an Armageddon-type. It is seen more as a range of scenarios which are quiet often rival to one another. Worst-case optimal decisions are said to provide guaranteed optimal performance for a system. The decision statement rises and answers a question if it is necessary to determine the very worst case and provide measures to avoid it. A single scenario is neither representative nor sufficient. In order to foresee and avoid the consequences of as many accidents as possible, a group of scenarios should be developed. That is why another approach called “likelier-but-less-catastrophic scenario” is of interest to us. It is often used in conjunction with the worst-case scenario term. According to its name this type of scenario differs from the worst-case scenario in two dimensions: it is less catastrophic or has a lower magnitude, and the likelihood of its occurrence is higher. Likelier-but-less-catastrophic scenarios are generally more representative in comparison to worst-case scenario as they are more likely to take place. However this does not mean that worst-case scenario is useless or that likelier-but-less-catastrophic scenario is a better approach. They are different, but valuable approaches. However, our literature study has not given a precise answer to the question as to where the border lies between these two distinct scenarios.
2. Modern problems of risk analysis and worst-case scenario as an approach to solve some of them

2.1 Qualitative versus quantitative approach

Nowadays people within the field of risk analysis and management speak about two kinds of approaches: either a qualitative or quantitative approach can be used to describe the likelihood of negative health effects or other adverse effects of accidents. The type of approach we choose in each particular situation depends on a number of factors, such as availability and reliability of information, complexity of the case, and availability of time resources for the assessment. Quantitative assessments deal with risks expressed as mathematical statements of chance of illness or death after exposure to a specific hazard. Its role is the representation of the cumulative probabilities of certain events occurring and the uncertainty associated with those events. Qualitative risk assessments use verbal descriptors of risk and severity instead of numerical information. It is very common for the aggregation of expert opinions to be substituted for calculations used in a quantitative approach.⁴ Some 10 years ago the importance of quantitative parameters was considered much higher in comparison to qualitative ones however the situation is changing from year to year. One contemporary scientist was recently quoted as saying: “I use the standard definition of probability times consequences… but we don’t use so much to present risk figures, because I don’t think it is possible to give the quantitative estimates for the likelihood of different scenarios, …it is almost impossible to give a quantitative, meaningful likelihood for most of the cases… we don’t speak very much about risk… I think that nowadays in safety assessment and the safety case, the meaning of numbers is going down, and down, and down, and it’s more about argumentation and how you present your system and how the system behaves, and then we do some calculations, but … they are not so important as they used to be, say 15 years ago”.⁵ This means, that a balance between qualitative and quantitative parameters is yet to be achieved. One may easily argue that there is insufficient proof to say that a qualitative approach is more valuable than quantitative and visa versa.

Quantitative: The quantitative approach is often associated with such terms as Quantitative Risk Assessment and Analysis (QRA). Quantitative or probabilistic risk analysis is not one, but a number of methodologies that provide numerical estimates of the level of risk. This approach is extremely useful because quantitative representation of risk in terms of the consequences and likelihood of the occurrence gives a manager an important tool to create a basis for his decisions. Results received from QRA enable the manager to answer questions such as:

1) Which events are most likely to happen?
2) Are risk reduction measures necessary?
3) What modifications/redundancy measures are most effective?
4) How does the risk compare to quantified risk acceptance criteria?⁶

Unfortunately this approach has a number of disadvantages, which include:

1) No accurate probability database may exist (which is crucial for calculations);
2) Probability is usually unique for each individual case;
3) Expected loss is hard to establish;
4) 'Expected' is not easy to accept; and
5) The approach has limited use.

Let us recount two articles by D.A. Carter and I.L. Hirst; “‘Worst case’ methodology for the initial assessment of societal risk from proposed major accident installations”⁷ and “A worst-case methodology for obtaining a rough but rapid indication of the societal risk from a major accident hazard installation”.⁸ The two scientists are famous for their work in close co-operation with Major Hazards Assessment Unit of the Health and Safety Executive. These articles reveal some uncertainties which can arise when working with worst-case technique. They also serve as simple and clear examples of the application of the quantitative approach. The authors are
focused on two particular cases: release of a toxic substance from a reservoir, and gas explosion at an installation. These two cases represent two different situations in terms of direction of impact. The gas explosion has an omni-directional impact and is almost equal in all directions, while the impact vector of a toxic substance’s release is unidirectional in most instances and depends mainly on weather conditions. As such the two cases require different calculations however it is quantified risk assessment that lies at the background of both. When it comes to individual risks a set of contour maps usually serves as a basis for the process. They depict defined levels of individual risk in chances per million (cpm) per year for a hypothetical house resident to be exposed to a harmful (or worse) dose of the agent. But if we talk about societal risk, then it is often represented by the relationship between the number of fatalities (N), and frequency (f) at which precisely N fatalities are predicted to occur. The articles describe, with the aid of mathematical operations, a way to apply QRA for the definition of a worst case scenario. The Major Hazards Assessment Unit (MHAU) of the Health and Safety Executive (HSE), with one of its main tasks being the assessment of off-site risks from large chemical warehouses, utilizes a quantitative approach.

**Qualitative:** More and more weight is being given to estimated consequences, while placing lower emphasis on estimated frequencies, in the majority of European countries. Similarly, less weight is being given to numerical estimates; some countries tend to disregard numerical estimates of frequencies almost completely. For example, the British Advisory Committee on Major Hazards announced in its First Report "… hazards should be minimized", while a quote from the Advisory Committee on Major Hazards’ (ACMH) Third Report states that "if the possible harm from an incident is high, the risk that the incident might actually happen should be made very low indeed". It is notable that these guidelines provide no figures, and these quotes serve as evidence of growing interest in the qualitative characteristics of accidents. It is interesting that even a quantitative approach places a higher importance on aftermath effects over mathematical frequencies.4

As has already been mentioned, the qualitative approach has much more to do with worst-case scenario than the quantitative approach. The most complicated side of the quantitative method is determination of likelihoods, which are often either unknown or uncertain. This gives a perfect opportunity to use the qualitative approach. It does not place emphasis on likelihoods to the extent that quantitative methods do. Probabilities are often roughly estimated, described in verbal terms or even completely disregarded. Consequences are most often quantified verbally without mention of figures. A perfect example of such a method is shown in Appendix 1. This kind of chart is used by competent authorities in several Member States. If we compare various “qualitative tables” applied in different countries for different purposes, we will see that they often differ in depth and level of detail. This is due in part to national regulations, traditions and existing practices. However there is also another reason; problems can occur as the qualitative approach relies heavily on the private judgments of experts. Project managers sometimes make risk estimates based on similar projects that have been previously completed. If individual managers make their judgment based only on risks they remember, it can cause inaccurate estimation.

Here are some general characteristics of qualitative approach:

1) It is widely used;
2) Estimated potential loss/impact used;
3) Probability database is not required; and
4) Risk 'level' is often produced.9
A qualitative approach requires less time and human resources, but when a facility faces a need for a safety report they usually choose the quantitative method. Why? Here are the drawbacks of qualitative techniques:

1) They are less accurate;
2) They are commonly based on private judgments; and
3) They are not convenient for benchmarking.

It is difficult nowadays to use a purely qualitative or quantitative method. Scientists usually try to combine the two techniques in order to overcome the drawbacks that exist when the methods are used separately. As a result ‘semi-’ approaches come into existence. They combine the flexibility of qualitative techniques with the accuracy of quantitative approaches. For example, it is a common practice now to substitute quantitative likelihoods with qualitative. In Appendix 3 one can see a link between qualitative and quantitative description: most European establishments use values proposed by relevant Dutch authorities for the purpose of substituting quantity-to-quality. The table is an interpretation of the Dutch approach, which has been used in Norway to assess the risks related to the operation of hydrogen filling stations\(^{10}\), and this technique is now a common practice in today’s world. Another example of quantity-to-quality classifications comes from the NASA Safety Manual\(^{11}\) (USA):

1) Likely to occur immediately. \((X > 10^{1})\)
2) Probably will occur in time. \((10^{-1}\geq X > 10^{-2})\)
3) May occur in time. \((10^{-2}\geq X > 10^{-3})\)
4) Unlikely to occur. \((10^{-3}\geq X > 10^{-6})\)
5) Improbable to occur. \((10^{-6}\geq X)\)

Both probabilities and consequences should be adequately defined. They should preferably have the same number of grades and be based on quantitative parameters. A big advantage of the chart from Appendix III is that it satisfies another requirement: it specifies damage done to people, environment and material. As one can see, different countries have their own view of semi-quantitative techniques. They may evaluate frequencies and consequences differently. Their view usually depends on the level of development, availability of material and scientific resources, and occasionally on culture.

2.2 Dimensions of damage

The scheme shown in Appendix 1 also reveals a complicated structure of harmful effects; it includes human beings, environment and property as objects that may be affected. Unfortunately this shows only one dimension of the situation. A second dimension deals with time axes. This dimension influences the next two items of interest, short-term consequences and long term consequences. On one hand, this subdivision simplifies the process of damage calculations and analysis. But a problem arises when we introduce time axes. The majority of environmental systems are very complex, so even if we can calculate the majority of short-term losses, the long-term influence would be still uncertain. In order to continue further quantitative assessment, some homogeneous units are needed. There were several attempts to convert all forms of loss into monetary value. And although some of the cases succeeded (for example, a group of Swedish scientists has tried to convert death and injuries caused by traffic accidents into monetary units with the aim of calculating reasonable investments into road safety), serious difficulties were encountered both with environmental and personal damage. A number of studies have attempted to convert environmental damage effects to a homogenous unit. The best known example is when environmental damage caused by an accident is expressed in units of loss of particular animal species if the environmental impact was directed onto its population.

Another approach towards estimation of environmental impact is based on the following viewpoints: the scale of the impact, severity of the impact, probability of occurrence, duration of
occurrence and difficulty/cost of restoration. This method for summarizing and describing environmental impact is used in the United States and is primarily based on simplified calculations, but in the final analysis impacts are evaluated qualitatively by means of substituting calculated figures with verbal terms. The range of impact is divided into classes of negligible, low, moderate and large. This approach also requires an area of impact to be specified and described in detail, as magnitude may differ depending on the location of the incident. Due to their importance when evaluating impacts, parameters that require explicit definition include air quality, water quality, soil quality and ecology.

Researchers encounter a lot of difficulties when trying to assess the environmental impact of industrial accidents. These difficulties include:

1) A long list of possible environmental receptors (both flora and fauna), and a lack of knowledge about how they are affected by particular chemicals;
2) A large quantity of possible transmission pathways such as soil, ground water, surface water, and air;
3) Limited understanding of the mechanisms as to how certain substances move, disperse, react, and transform in the environment; and
4) Insufficient data concerning environmental aspects of accidents in the past.

As such, competent authorities most commonly use techniques where all damages are calculated independently, and qualitative or semi-quantitative approaches are usually used for this purpose. It is rare that long-term effects are specified and described in detail. The greatest attention is always paid to potential harm to humans. There is an example of this approach in Appendix 3.

Despite the serious difficulties entailed in their assessment, more and more attention is being given to long-term effects. Yet there is no single system or approach which is used by all nations, and it is doubtful that such a system can or will be developed in the foreseeable future. The mechanism of long-term effects seems to be too complex and sophisticated to be accurately described by a mathematic or verbal model.

2.3 Acceptability limits
Despite the growing interest in the qualitative approach, the value of probabilistic or quantitative approaches is too high to ignore. Responsible organizations perform a great deal of work using probabilities in their attempts to estimate figures and describe potential for accidents that would be accepted both by industry and the general public.

Society in general seems more accepting of the possibility of one death per year, than the possibility of ten deaths at once in a ten year span. While the end result is the same, there is a difference in the public perception. This provides support for the assertion that a likelier-but-less-catastrophic scenario is more acceptable to the public than a worst-case scenario. However this does not mean that likelier-but-less-catastrophic scenarios are acceptable. Disregarding probability, society is hardly accepting of any accident involving at least one death. It is the task of scientists to determine the highest reasonable accident probability acceptable both for society (in terms of a profit/number of deaths ratio) and industry in terms of the cost-effectiveness of financial resources spent on safety.

The first problem for scientists to solve is to set an upper limit for scenarios that are beyond the realm of probability. Their task is to determine a specific probability barrier so that accidents which have a catastrophic aftermath but too low a probability of occurrence are excluded from the analysis. There are a number of indications that can help direct us to scenarios that could still be disastrous but more likely to occur. Nowadays, the term ‘credible accident’ exists. A credible accident is defined as “an accident that is within the realm of possibility (i.e., probability
higher than \(1 \cdot 10^{-6}/\text{yr}\) and has a propensity to cause significant damage (at least one fatality).\(^{14}\) Today’s practices indicate that it is wrong to apply the same probabilities to different facilities, so for especially hazardous activities and establishments the probability limit is often raised with the aim of revealing and avoiding more undesirable events, even if they are extremely unlikely.

Credible accidents are related to ‘acceptable’ accidents in some way. If industry states that a worst-case accident is unlikely to happen but is credible, then the public will want the company to provide mitigation measures and install protective equipment to avoid the accident or its consequences, so that risk becomes negligible. But a serious barrier exists there. It often costs huge and unreasonable of money to meet the criteria set by the public. This is the point where the term ALARP (as low as reasonably possible) becomes applicable. The ALARP band is defined by levels of individual fatality risk, where individual risk is the probability that an individual will experience an adverse effect. The upper tolerability limit for members of the public is a fatality risk of \(10^{-3}\), while \(10^{-6}\) per year is broadly judged as an acceptable level. However these limits can vary between countries, depending on their economical and technical development. Here is a technique that is commonly used to define whether risk meets ALARP criteria: individual risk levels are estimated for a facility and a cost-benefit analysis is run, to estimate what further risk reduction is costing per each life saved by the introduction of an additional measure.\(^{15}\) The price of the fatality prevention is then compared to the value of one man’s life as appraised by society. Some may argue that this is a questionable technique, but it works efficiently and has been found to produce good results. ALARP is a criterion approved by scientists that works as a form of agreement or compromise between industry and the public.

The next risk acceptability criteria we examine are taken from Italian research\(^{16}\), and are derived from the Dutch approach to risk evaluation. These figures are based on the Netherlands’ experience within the field of safety. It is a normal European practice as acceptable societal risk criteria are not standardized by EU Member states. Societal risk is the average risk in terms of the number of fatalities within a group of people exposed to an accident scenario, and is usually presented in the form of an F-N Curve.\(^{17}\) In the table presented below, one can see F/N ratios representing F/N limit curves established in the Netherlands, where F – frequency, P – cumulative frequency per year and N – number of fatalities.

<table>
<thead>
<tr>
<th>Evaluation of the risk</th>
<th>Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable risk</td>
<td>(P &lt; \frac{10^{-5}}{N^2})</td>
<td>No need for detailed studies. Check that risk maintains at this level.</td>
</tr>
<tr>
<td>Tolerability region A</td>
<td>(\frac{10^{-5}}{N^2} &lt; P &lt; \frac{10^{-4}}{N^2})</td>
<td>Tolerable risk if cost of reduction would exceed the improvements gained</td>
</tr>
<tr>
<td>Tolerability region B</td>
<td>(\frac{10^{-4}}{N^2} &lt; P &lt; \frac{10^{-3}}{N^2})</td>
<td>Tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion to the improvement gained</td>
</tr>
<tr>
<td>Unacceptable risk</td>
<td>(P &gt; \frac{10^{-3}}{N^2})</td>
<td>Risk intolerable: risk cannot be justified even in extraordinary circumstances</td>
</tr>
</tbody>
</table>
Acceptable risk levels will fall over time with the development of new safety techniques and equipment, and an increase in value of humans’ lives within society. As such, there is no doubt that companies will soon have to cope with new and more difficult tasks concerning safety. Even now, some companies have begun to make such changes and preparations.
3. International legislation review and comparison

It is of interest to see how interpretation of worst-case scenario and implementation of this scientific approach differs from country to country. Any differences found should be reflected in legislation and safety regulations in the countries examined.

So the next task for us is to find quotations containing the term “worst-case approach” in safety laws and regulations of countries all over the world. Although the term is widely used in scientific and near-scientific literature, its usage in legislative acts appears to be limited.

Before examining legislation dealing with LNG terminals’ safety, it is important to know that there are 40 operating LNG import terminals across 15 countries (as to January 2005), 24 of which are situated in Japan. Safety legislation and regulations governing risk assessment in countries with LNG terminals is quite similar across nations due to close cooperation in the field and the small number of terminal owners. However we will attempt to find differences in approaches used in different countries, and analyze several branches including, but not restricted to, LNG handling.

3.1 Non-European Countries

USA

The rapidly growing interest in risk estimations at potentially dangerous industrial sites in the United States is due in part to the accidental release of methyl-isocyanate during a large scale accident at the Union Carbide (American company) plant in Bhopal, India (December, 1984). Worst-case accident scenarios became an obligatory factor for inclusion into risk management plans for American companies in 1990, according to the Clean Air Act Amendments (CAAA).

It is the Clean Air Act that regulates risk management planning at sites handling hazardous chemicals. It demands owners and operators of all facilities covered by legislation to create special Environmental Protection Agency (EPA) Risk Management Plans, while every Risk Management Plan is demanded to include worst-case scenarios for the offsite consequences, together with prevention plans and damage mitigation contingencies. This process includes the evaluation of the potential threat of sudden, large releases of chemical substances. There was considerable discussion about criteria for the choice of enterprises that must perform worst-case analyses. In some states special “look-up” tables, which help to determine if the facility must comply with the regulation, were proposed. Currently 77 toxic substances and 63 flammable gases and volatile flammable liquids are listed by the EPA as requiring companies involved in their storage or processing to have an RMP.

Threshold amounts for each chemical, which have specific data requirements, are also defined by the EPA. Each of the covered chemicals has a corresponding acute toxicity concentration (ATC), measured in parts per million. There is a connection between the duration of a release and a chosen concentration criterion; for releases which last less than one hour, concentration criteria should be calculated as ATC divided by the release duration. For those lasting longer than an hour, concentration is taken as equal to ATC.

There are several key factors which determine potential off-site impact: relationship between the distance release point and the closest property line, the cloud length compared to the established concentration criteria, and a measurement of five times the concentration criteria. In cases where the cloud length to the concentration criteria in the downwind direction is higher than the distance to the closest property line, it is assumed that potential for offsite impact exists.
Sometimes a state-of-the-art review is required, with decisions based on the results of dispersion modeling, and an evaluation of risk reduction measures usually incorporated.

When the possibility of off-site impact exists, required actions are dependent on the actual concentration level expected. State-of-the-art reviews are not required when expected concentration levels are less than the set criteria. When the level is between the concentration criteria and five times the concentration criteria, then it is the probability of the release scenario that determines a need to perform a state-of-the-art review. The other criterion is border likelihood, equal to $10^{-4}$. If the probability is higher than this likelihood, a review is required. Whenever the off-site concentration of the substance is greater than five times the concentration criteria, a review is required regardless of the probability of occurrence. The statute requires the inclusion of three components into risk management plans:

1) A hazard assessment to assess the potential effects of an accidental release, including potential exposures to affected populations, a previous release history of the past 5 years, and evaluation of a worst case release, according to the proposed definition of the one;
2) A program for prevention of accidental releases. It should include precautions, maintenance, monitoring, and employee training; and
3) A response program to protect human health and the environment in case of a release, including measures to inform the public and local agencies, emergency health care and working personnel training.

The hazard assessment is expected to include:
1) A determination of the worst-case release scenario;
2) Identification of more likely, but still significant, accidental releases;
3) Analysis of the off-site consequences of the worst-case release scenario and other more likely significant accidental release scenarios; and
4) A five-year history of accidental releases.

While the off-site consequence analysis for the worst-case and more likely significant accidental release scenarios shall include:
1) The rate and quantity of substance emitted to the air, and the duration of the incident;
2) Identification of the distance in all directions where exposure to the substance or damage to off-site property or the environment may occur;
3) Description of populations within these distances that could be exposed to release; and
4) Assessment of environmental damage that could be expected within the distances, including consideration of sensitive ecosystems, migration routes, vulnerable natural areas, and critical habitats for threatened or endangered species.

This kind of hazard assessment is expected to be performed once every five years or more frequently if changes in equipment or process occur. Facilities are also forced to provide the relevant authorities with the following information explaining how off-site consequences for each scenario were determined:
1) Estimated quantity, rate, and duration of substances released;
2) Meteorological data used;
3) The concentration used to determine the level of exposure, and the data used to determine that concentration;
4) Calculations for determination of the distances downwind to acute toxicity concentration; and
5) Data used for estimation of the populations exposed or area damaged.

As one can see the process requires a great deal of data. The final results and conclusions are dependent on many parameters, some of which are not known for certain, requiring the use of
estimations and assumptions. If a worst-case scenario is primarily based on assumptions, its usefulness in certain cases may be questionable. That is why a worst-case scenario approach should never be the only basis for emergency planning. In the United States, worst-case scenarios are used simultaneously with likelier (but less catastrophic) scenarios. For example, LNG project developers perform analysis using computer models to estimate both flammable vapor cloud and thermal radiation exclusion zones. The exclusion zone analyses focus on the most severe plausible accident, but a worst-case scenario accident is also considered. Worst-case scenarios are regarded as an important source of data for emergency response planning as well as justification to enforce stricter accident prevention controls and more efficient safety technology.

Another legislative act we have found using the term “worst case scenario” is called the Levin-Thompson bill of 1997. It deals mainly with the off-site impacts of industrial accidents and proclaims that the real likelihood of a worst-case exposure scenario must be estimated. However “the most plausible estimates of risks must be favored over risks deliberately biased conservatively”\textsuperscript{32}. This is a very useful remark, but in admonishing the use of worst case scenarios the bill does not compare favourably to the aforementioned legislative act.

In Europe, Mexico, and Canada, project applicants are required to conduct a safety risk assessment according to prescribed methodologies, and submit their results to the permitting agency for review. United States regulations do not prescribe methodologies for formal risk assessments, although risk is evaluated both by the regulating authority and the project applicant.

**Canada**

There are many similarities between the safety legislation of the United States and Canada. But instead of worst-case scenarios, Canadian regulations require predictions to be done on worst-case but still credible incident scenarios. According to regulations, the prediction of vapor clouds is to be based on defined worst-case credible incidents. The quantity of LNG that could be released from one cargo tank is to be used the basis for evaluation. Calculations related to vapor clouds are rather complex, which is why the risk of fatalities can acceptably be calculated in terms of exposed persons per unit time in order to simplify evaluation. A number of measures for risk mitigation are listed in legislation as examples of good practices.\textsuperscript{17}

**Mexico**

Mexican legislation adopts most of the safety regulations of the United States, including the definition and usage of worst-case scenarios.

**Korea**

Terms of worst case scenario and alternative case scenario can be met in documents published by such organizations as KISCO (Korean Industrial Safety Corporation) and Labour Department. Definitions of these terms repeat the ones proposed by EPA in the United States. Korean scientists widely use GIS for estimation of accident consequences in their researches, which is also widely practiced both in the USA and EU.\textsuperscript{33}

3.2 **European Union States: Seveso Directives**

Before starting the review and analysis of specific real-life cases such as the Seveso (Safety) Reports, we will try to gather information about the origins of the Seveso Directives, their content and their current application.

The term “worst-case scenario” and the Seveso Directives are closely connected to each other in one way. The term has become widely used after a big-scale accident in Italy when a toxic cloud containing TCDD (2,3,7,8-tetrachlorodibenzo-\textit{p}-dioxin), regarded as amongst the most toxic of man-made chemicals, was released into the air. The dioxin cloud contaminated a densely
populated area of about six square kilometers lying downwind from the site. This accident has also served as the originating event for the development of so-called Seveso Directives. That is why we have a right to think that the Directives should definitely use worst-case scenario as one of the approaches to deal with industrial risks. And that is the reason why we are paying high attention to the Seveso Directives in the thesis work.

The event became widely known as the Seveso disaster, named after a neighboring municipality which suffered more than any other. One crisis of the Seveso disaster was the gradual acknowledgment of its scale while the population was exposed. The accident in Seveso was followed by discussions in the international mass media as well as scientific and political circles. Even people outside of Italy experienced heightened concern about industrial risks and the need for stricter laws and regulations for installations and the handling of hazardous chemicals. In these respects Seveso highly resembled Bhopal (1984) and Chernobyl (1986). All three accidents are now regarded as international symbols of industrial disaster.

Another well known consequence of the events in Seveso was the way in which it resonated around the world, giving impulse to the creation of the European Community's Seveso Directive. The Seveso Directive (Directive 82/501/EEC) was adopted by the Council of Ministers of the European Communities in June 1982. An important part of the directive is an acknowledgment of the public’s ‘need to know’, which is not as strong as the ‘right to know’ currently applied in the United States. It is the authorities’ right to decide if people have to know about hazards that threaten them and the safety measures taken to avoid them.

The European Seveso Directive was intended to fulfill the following goals:
1) To deprive unscrupulous industrial operators of competitive advantages that might come from exploiting differences among varied national regulations;
2) To add a powerful and valuable tool to the regulatory process;
3) To improve and ensure protection against hazards; and
4) To ensure harmonization of safety regulations in all European countries.

It is impossible to implement an EC directive in all member states immediately after its adoption however the states must build the directive into their national legislation within a specified time period. Such a requirement allows effective implementation with respect to different juridical and administrative aspects and traditions of individual nations.

Whereas implementation of the Seveso Directive gave way to various similar safety-related and environment protection directives, where more attention and resources were afforded to the issue of industrial safety, one may say that Seveso Directive met its goals. On the 9th of December 1996, a new so-called Seveso II Directive was adopted. The need for the new directive was explained as follows:
1) Seveso I Directive was only the first step in the harmonization process;
2) Seveso I Directive should be revised and supplemented in order to ensure high level of protection; and
3) The scope of the directive should be broadened and the level of information available to the public and responsible authorities should be raised.

A proposal to renew the old Directive came from several countries, and was very well received.

However, none of the two Seveso Directives mention the “worst-case scenario” term in any context. There are just two paragraphs in both directives which may be considered as a link to the concept:
1) “… the arrangements made to ensure that the technical means necessary for the safe operation of plant and to deal with any malfunctions that arise are available at all times.”

2) “… a reference to the external emergency plan drawn up to cope with any off-site effects from an accident.”

The two quotes are taken from sections describing what information should be published by companies (facilities). They demand that industrial sites must be able to cope with any undesirable events or accidents (which definitely include worst-case scenarios) and their consequences.

### 3.3 Seveso Guidelines

Following adoption and implementation of the Seveso Directives a number of guidelines explaining certain parts of the directives in more detail have been published:

2) Guidelines on a Major Accident Prevention Policy and Safety Management System;
3) Explanations and Guidelines on harmonized criteria for dispensations;
4) Guidance on Land-use Planning (new in 2006);
5) General Guidance for the content of information to the public; and
6) Guidance on Inspections.

Moreover, a number of answers to frequently asked questions agreed upon by the CCA are published on the MAHB (Major-Accident Hazards Bureau) Website. These guidance documents and F.A.Q. have no legal standing however they provide valuable guidance to industry and supervisory authorities. It is also important to note that the documents represent the unanimous view of all member states.

The guidelines interpreting the safety report in detail were written with the aim of providing a single template for the writing of safety reports by the relevant authorities of member states and companies. The document does not mention “worst-case scenario” at any point, but it is worthwhile to analyze the guidance. We will use quotations and remarks from the chapter offering advice and guidance to companies in regards to safety reports.

Guidance on land use and planning gives us a chance to understand what “worst-case scenario” is in the opinion of those who have taken part in the adoption and implementation of the Seveso Directives. The guidelines also help us understand how the worst-case scenario approach may be used in order to reach the aims of the directives.

In the guidance for planning two approaches, risk-based and consequence-based, are described. The risk based approach, also known as probabilistic, is not very useful for our purposes. It is based both on evaluation of the severity of consequences and estimation of their likelihood. Such terms as ‘Probabilistic Risk Assessment’ (PRA), ‘Probabilistic Safety Analysis’ (PSA) and ‘Quantified Risk Assessment’ (QRA) are used in conjunction with ‘risk based approach’. It is very explicit in terms of the calculation of frequencies and as such requires a great deal of time and resources. There has been some criticism leveled at the approach due to uncertainties associated with the frequencies assigned to particular initiating events.

The second approach, the consequences based approach”, is also regarded as deterministic. An important feature of this method is that it does not estimate the likelihood of accidents, caring only about the after-effects. When using this method we avoid uncertainties related to the quantification of frequencies. It is this approach which is used to define worst-case scenarios.
There is a belief that measures sufficient for the protection from the worst sequence of events exist, serving as justification for the availability of protective measures for less serious accidents. However, one problem with this statement is that several cases are known when accidents widely believed to be the worst ever were shown to result in not so extended consequences in comparison to those initially believed to be less severe. It is doubtful that one can determine worst-case scenarios without deep and detailed analysis of a system. The guidelines also say that safety policy has to provide measures on both low ‘frequency-severe consequence’ accidents as well as more frequent ones. These guidelines provide us with useful concepts regarding how to deal with the drawbacks of the worst-case scenario approach.

3.4 Seveso Practices
There are two levels of legislation governing the Chemical Industry of Europe, national and European. For example, the Seveso II Directive is a legal instrument that has been adopted in all the 15 member states and is being developed in the 10 new member states. The Directive describes in detail requirements for lower (medium hazard) and upper (high hazard) tier facilities. These requirements are extensive and range from establishment of a Safety Management System, Major Accident Prevention Policy and Emergency Planning to a Safety Report for upper tier establishments, listing all process hazards and how they are controlled. There is a special committee (the Committee of Competent Authorities) in the European Union which aims to promote the implementation of the Seveso II Directive. This committee also works in researching and developing regulations on the prevention of major-accident hazards. The committee consists of relevant authorities of the member states, and has a representative of the European Commission as its chairman.

Every single member state is allowed to add its individual requirements to those from the Seveso II Directive. These individual approaches are usually determined by various factors such as local legal frameworks, traditional enforcement and inspection systems, national standards and national custom and practice. Variations can be found in the way that risk assessment must be performed. A number of states work with worst-case scenarios using deterministic approaches, while others deal with Quantitative Risk Assessment.

Let us find out how some of European Union countries tackle the problem of industrial safety with the help of worst-case scenario approach. We have chosen these particular states because they seem to be proactive in the field of our interest.

UK
A state organization exists within the UK that is responsible for environmental protection and dealing with risk assessment, known as the Department for Environment, Food, and Rural Affairs (DEFRA). These functions belonged to the Department of the Environment, Transport and the Regions (DETR) before reorganization. In the United Kingdom the term ‘worst-case scenario’ does not seem to be widely used, and although one can find some links to worst-case scenario usage, the approach is not a cornerstone of hazard assessment as it is in the United States.

Their ‘Guidelines for Environmental Risk Assessment and Management’, state that in many instances useful information can be obtained from monitoring data, or based on ‘worst-case’ or ‘reasonable worst-case’ scenario estimates. The guidelines also state that worst-case scenario estimates can be used as one source on information to build an evaluation system for score assignment. Initial or preliminary assessment of risks can be performed with the help of reasonable worst-case approach, as it helps to reveal if deeper and more sophisticated assessment is required. Worst-case assumptions are taken if there is a need to deal with uncertainties in probabilities. These applications of worst-case scenarios are described and used by DEFRA. As
time goes on, more and more weight is being given to worst-case scenarios as a planning instrument in combination with GIS.

**Belgium**
There is a special guide for the identification and evaluation of major hazards in Belgium, published by the Administration of Labour Safety. The guidelines are written in accordance to the Seveso Directive and Belgian regulations concerning risk evaluation.

An interesting feature of worst-case scenario use in Belgium is that its main purpose is to analyze the efficiency of safety measures, but not provide a scale of consequences as it is in the United States, Canada, and other nations. To summarize the methodology in several sentences, it should definitely be mentioned that absolutely no attention is given to probabilities, while existing safety systems are excluded from calculations. After the evaluation of potential consequences the scenario serves as a measure of effort which should be undertaken to install safety measures to prevent such scenarios. Usually it is easier to identify the most improbable scenarios, which worst-case scenarios generally are, in comparison to more realistic cases. But the measures needed for improving safety against worst-case scenarios has been shown to be more useful in improving safety than more realistic scenarios. In other words, measures sufficient to cope with the greater evil should be capable of dealing with smaller ones.

**Netherlands**
After the accident in Enschede (Netherlands), the nation’s government decided to upgrade the policy in the field of external safety, and included the establishment of a special register known as the ‘Register of High-Risk Situations Involving Dangerous Substances’. It is focused on external safety problems of sites where dangerous substances are present. It is also related to the transportation of such substances, either through pipelines or ordinary transport. According to Dutch safety policy, the term ‘risk’ is associated with both the probability and effects of an event and is a combination of the two factors. Two kinds of risk are distinguished: location-based risk, and societal risk. Location-based risk is the probability of individual fatality in a particular place, in any given year, as a result of an accident involving dangerous substances. Societal risk is the probability of a major accident involving many fatalities. Quantitative risk analysis, if required, should be performed on the basis of the maximum volume of dangerous substance present at the site. As such, it can be seen that the usage and application of worst-case scenarios in Dutch regulations is strongly related to the American approach.

In an article about social risk by VROM (the Netherlands Ministry of Housing, Spatial Planning and the Environment), worst-case scenario is not mentioned directly. At the same time the article describes a specific method for risk identification: the development of an effect-based indicator, such as a maximum number of dead or injured, or a maximum cost of remediation, which may also be regarded as a worst-case scenario approach.

Some industrial sites and facilities have specified safety distances which help avoid domino effects and extra damage in case of accident. According to Dutch legislation these distances are supposed to be calculated on the basis of worst-case scenario estimates.

**Finland**
In the report on the application of the Seveso Directive in the EU member states, Finland is reported to be a country where risk assessments include scenarios for both typical and worst-case accidents. In 1999 Finland was said to be one of the leading countries in the implementation of the directive. A new decree (the so-called Decree on Industrial Chemicals), which included lots of legislative changes as required by the Seveso II Directive, came into force the same year. A number of changes occurred in the regulation of land use, construction, rescue services and
safety at work. Due to their achievements in the field, the Safety Technology Authority of Finland was chosen as the most competent national authority.  

On 8th September 2004 the latest report, covering the period 2000-2002, was approved by the Commission. It is the first report where the progress of the implementation of the Seveso II Directive within the member states is discussed. Here are some conclusions from the report:
  
1) The 15 Member States have fulfilled their legal obligation pursuant to Article 19.4 of Directive 96/82/EC and have provided the Commission with a three yearly report.

2) Following complaints from individuals or organizations, the Commission has opened a number of cases. The majority of these cases are related to land use planning.

3) The accidents in Enschede and Toulouse prove the need for more work on land use planning. A special technical working group has been set up with a view to draw up guidelines defining a technical database with risk data and risk scenarios by 31 December 2006, which is to be used for assessing the compatibility between Seveso establishments and residential and other sensitive areas.

4) The 10 new Member States will make contributions to the next report.

Conclusion about legislation
The worst-case scenario approach exists in the safety regulations of many countries. However the approach takes on a number of forms and use of the technique may differ in methodology and final aim from case to case. However it appears that two main aims exist: one is to evaluate the efficiency of mitigation equipment (as in Belgium), while the second is to perform analyses of safety distances or exclusion zones (as in the United States). In both cases existing safety devices are excluded from the evaluation, meaning that in a worst-case scenario it is assumed these devices will not function when an accident occurs.

The goals for new regulations using the term ‘worst-case scenario’ were to compel industry to understand and take responsibility for potential hazards present within their facilities. Another aim was to assist in the upgrade of old facilities as well as to assist construction of new facilities with prevention and mitigation of potential hazards in mind. Implementation of these new regulations is closely connected with the realization of the public’s ‘right to know’ and the development of dialog between industry and communities. In some countries worst-case scenario analysis has become an obligatory requirement as a part of general hazard assessments at potentially hazardous industrial sites.

One of the most important conclusions from this review of legislation is that the worst-case scenario approach is never used as a completely independent tool of analysis or source of information. In the legislation of the United States, Canada and Mexico the method is used in conjunction with other techniques: ‘likelier-but-less-catastrophic’ scenarios, or ‘most credible’ scenarios. The reasons behind this usage can be explained in two ways: either the worst-case scenario approach lacks a stable scientific basis, or is judged to be insufficient when used separately.
4. Cases
According to our project plan we have decided to investigate several Seveso (Safety) Reports (safety-related documents) written for Swedish companies. Companies are required to present and describe in detail all potential hazards, prove that existing risks are acceptable and all reasonable safety measures are taken. No law exists in Sweden demanding worst-case scenarios to be included into safety reports. The Seveso II Directive was implemented in Sweden during the second half of 1999. This directive did not cost a great deal for the country and its companies in terms of changes because the majority of Swedish safety legislation and regulations were already in compliance with the Directive at the time.

In 2002, over 300 facilities in Sweden were covered by the Seveso legislation, including upper tier and lower tier establishments. All had to provide the following information together with appropriate safety reports:
1) Internal emergency plans;
2) External emergency plans; and
3) Domino effects.

The aim of this chapter is to select and analyze a number of Seveso Reports. The idea here is to attempt to find similarities and differences between the ways which companies understand their obligations concerning the depth of content of Seveso Reports if a worst-case scenario approach is used. It is also of interest to compare Seveso Reports of companies working in the same or similar fields. The chosen installations/companies should be as typical and representative as possible. The criteria for their selection are as follows:
1) They should be of the same size, preferably of medium size; and
2) They should belong to similar fields, as reports from companies representing different fields can be too dissimilar for comparison.

4.1 Fortum Gas Station Seveso Report
This assessment was performed by Scandpower by means of specialized software package called “Trace”. The technique applied by Scandpower for risk analysis is semi-quantitative in nature, but is not novel. International experience is widely utilised. The frequencies and identification of consequences identification was derived from the classification originating from the Norwegian oil and gas industry. European standard EN 1473 plays a major role, as Fortum Gas Station was built according to standards of this document. Another foreign standard mentioned in the Safety Report and acting as a foundation for the project in general is American NFPA standard (National Fire Protection Association) 59A. Finally, special control should be undertaken at the station according to Swedish law 1988:868 regarding flammable and explosive substances.

During the first stage, the area of the prospective gas station is subdivided into a number of smaller zones. This is done for simplification of calculations and for better understanding of processes. Frequencies and consequences are calculated for each separate zone. According to these calculations the frequency and consequences are rated separately on a scale of 0 to 5. All data is finally collated on a single table so that each zone’s number, corresponding frequency and consequences are displayed. Risk is evaluated on the basis of those last two factors. The results of this analysis are presented in a manner that is clear for all to read. But although it is obvious an accident with risk factor of 5 is less desirable in comparison to the one with risk value of 4, it is can be difficult for a layperson to understand and interpret the types of risk associated with each value, and whether such values are acceptable.
This is why further analyses are required. All judgments concerning probabilities and consequences of different scenarios are performed on the basis of earlier analyses, documentation, information acquired, and Scandpower’s experience data. However, the general criterion for acceptability or unacceptability of risk is based on the policy of ‘no raised risk on the other side of the fence’. In other words:
- The warmth value in the case of accident is not higher than 1.5 kW/m² for a ‘third’ party; and
- No gas clouds with concentration higher than ½ LEL (lower explosive limit), which corresponds to 2.5% of natural gas in the air.

One questionable point of this policy is that it does not seem to pay attention to the safety of people working within the facility, and refers only to those ‘outside the fence’.

If we speak about a worst-case scenario, then probabilities are of lower importance. It is quite likely for that reason that quite a significant portion of the Seveso Report is devoted to consequences. Potential accident scenarios are developed for every single piece of the industrial chain, beginning with a tanker ship up to a truck cistern filling station. One example of the type of information which can be obtained from this report is that the worst consequences can be caused by delayed fire after the leakage from the sections 1L1/1L2 as well as big jet fire in sections 7G and 8G. These scenarios can cause critical consequences: one or several deaths inside the Energihamnen area. Some sections may be responsible for a number of probable accidents.

Although consequence assessment for every separate scenario is done irrespective of the probability, it is valuable to know the probability of each scenario. It is especially important when the likelier-but-less-catastrophic scenario approach is taken into consideration instead of the worst-case technique, which is why rough estimates of likelihoods are also provided in the report. For example, the highest chances of small and medium leakages are in the areas 6L1-6L8, while large leakages are most possible in areas 2L1 and 2L2 and also in sections 3L1 and 3L2.

So if we compare consequences to probabilities one can see where critical or serious consequences are most likely. This helps determine the areas and processes at greatest risk and apply necessary safety measures. In this example there is one zone where consequences could have greatest magnitude while the likelihood is also high.

<table>
<thead>
<tr>
<th>Consequences</th>
<th>Probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical consequences</td>
<td>1L1/1L2, 7G, 8G</td>
</tr>
<tr>
<td>Serious consequences</td>
<td>1L1/1L2, 2L1/2L2, 3L1/3L2, 3G1/3G2, 4L1/4L2, 5L1/5L2, 6L1-6L8, 6G1-6G8, 7G, 8G, 9G1/9G2, 10G, 11G1/11G2, 12G1/12G2</td>
</tr>
</tbody>
</table>

*the coincided area names in the two columns are marked.

In order to make data processing convenient the results are presented in the form of matrices. To calculate risk, columns with consequences and probabilities are multiplied with one other. If we compare and analyze the two columns, zone 7G appears to be a sector where an accident could cause critical consequences. At the same time we can see that probability of occurrence is rather high as well. So an accident that may occur in this zone corresponds to a likelier-but-less-catastrophic scenario. However the Report unexpectedly suggests that the highest risk area is
1L1/1L2 because the highest volume of gas passes this zone per unit of time. The report conclusion disregards the fact of lower probability of incident in 1L1/1L2 compared to sector 7G. This disregard, if remaining unexplained, may initiate questions from the public and produce mistrust. However the Safety Report is very well structured and has an extensive numerical basis.

4.2 Statoil Oil Terminal Seveso Report
Oil terminals are similar to gas stations in many ways. All oil storage sites in Sweden are built in a similar fashion, simplifying risk analysis. In order to focus on on-site activities, the transportation stage is usually excluded from risk analysis.

As it is proclaimed at the very beginning of the Statoil Oil Terminal Seveso Report, one of the cornerstones of Svenska Statoil AB’s safety policy is their goal of no harm or injury to people and the environment from the company’s facilities. Their second suggested aim is for no accidents to take place at all. Due to the difficulty of meeting this aim, the goal for protection is stated as an avoidance of all accidents or their limitation to minor incidents. Risk analyses of all operations at the terminal are run every 5 years in normal conditions or soon after every significant reconstruction. When defining risks the same level of attention is paid to probabilities and consequences. The work process is divided into five logical phases for the purpose of better and easier analysis:

1) Emptying of a tanker;
2) Pumping from a tanker (shore part);
3) Storage;
4) Pumping within the storage; and
5) Pumping to trucks.

By this stage this safety report is similar to that of the Fortum Gas Station, where the site area was divided into zones according to their role in the overall process. However, further analysis differs somewhat.

Leakages are judged to be the likeliest accidents at the station. This type of event can occur at almost any part of activities’ chain of the terminal, which is why a substantial part of the report is devoted to their description. Leakages are divided into 4 categories, depending on their scale. They are:

1) Small leakage;
2) Leakage;
3) Medium leakage; and
4) Big leakage.

Each type of leakage can occur only in a specific place or process. For example, leakage of more then 100m³ can be caused by a breach of a major tank onshore or on a tanker. When all the probable accidents are divided into these four classes, only those with the highest probability are taken for further analysis, which differs from the Fortum Gas Station report. However, some accidents with low probability of occurrence are also taken into account due to their high magnitude consequences or for other reasons. Every scenario is analyzed under two conditions:

1) If fire is involved; and
2) If fire is not involved.

Although oil is not an environmentally-neutral substance, it is clear that the worst possible scenarios involve fire. As a result of risk analysis 3 scenarios have been chosen as most dangerous for the Statoil Oil Terminal. They are:

1) Spill during car-tanker’s filling;
2) Spill at a pump; and
3) Overfilling of tanks.

It appears that these three scenarios are listed in their order of likelihood, from most to least likely. Further analysis involves the use of a risk matrix for risks evaluation. In what should be considered a positive step, it takes into account and specifies consequences potentially harmful to people, environment and private property. Probabilities in the matrix are graded from those with small likelihood to very probable ones in five stages. Consequences are rated from small to catastrophic in five stages as well. It is likely that this is done because a square matrix is easier to process and comprehend in comparison to an irregular one. All events are evaluated within the risk matrix. The system also uses three grades for the appraisal of safety measures taken to avoid a specific accident: ‘Ok’, ‘Improvements required’, and ‘Improvements required immediately’.

Another interesting and practical feature of the report is that a number of the most common and efficient prevention measures for the most probable scenarios are listed right after the definition of initiation events, scenarios, and consequences. The public would almost certainly appreciate such information. But the size of many reports does not allow such information to be included to their full extent, so this initiative is unlikely to become common practice.

4.3 Preem Oil Terminal Seveso Report

A primary aim stated in Preem’s Safety Policy is that the workplace should be safe for personnel. The policy is quoted as saying: “No accidents or undesirable events of sudden or unforeseeable nature, which could cause any damage to people, environment and private property, should happen.” Factors such as thunderstorms and storms are considered as serious sources of danger in the report. Landslides and sabotage are other accident-originating events taken into consideration.

There is another special feature in this report; it is clear that neighboring companies and their activities present a certain level of danger to Preem Oil Terminal. Unlike any safety reports from other facilities, Preem (Sweco) bears this fact in mind when preparing their safety report.

All companies around the terminal’s borders (OKQ8, Norsk Hydro, Univar, and Shell amongst others) handle flammable substances. Under certain accidental circumstances and weather conditions, fire from Preem Oil Terminal can reach the territory of all their aforementioned neighbors and vice versa. There are also some offices located in close proximity to the terminal, and people working there are at risk of being affected by fire originating from the terminal. Populated areas are far enough away not to be affected by fire, but some of them are at risk of being inundated with smoke in the instance of a serious accident.

Another interesting fact about Preem’s safety policy is that it is integrated into the quality system of the company. Currently risk analysis is performed every fifth year or due to reconstruction (substantial changes) at the terminal, a common practice within this branch of industry.

There are three critical stages in the industrial chain of the facility from a safety perspective, as defined by Sweco (the company responsible for this risk analysis):
1) Transaction from tanker-ships to cisterns. It is said that either pipe breach or overfilling can occur as well as fire;
2) Risk for explosion in conjunction with fire risk as a consequence of cisterns’ warming through the domino effect for fuel storage; and
3) Oil pumping to car tankers.
All three situations can be responsible for serious chemical accidents, but as judged by experts the most risky process inside the terminal is the filling of car cisterns. Environmental risk of spillage is excluded from the list because the filling station area is equipped with an advanced drainage system. We can conclude that personal injuries are of the highest concern when threat to environment does not exist. Accidents with the potential to cause serious harm to people and the environment are only possible when less dangerous or serious accidents such as overfilling or pipe breach occur in combination with fire. These events may be followed by warming, meaning that danger for fire in cisterns may increase. This is an example of a domino effect. The estimated probability for the sequence of events is said to be less than $1 \times 10^{-3}$, which is regarded by Sweco in the report to be low.

One measure taken to prevent occurrence of worst-case events is the construction of a reservoir which can gather and hold the entire volume of oil contained in the biggest cistern, plus 10% of all other cisterns’ volume (¾ of the total volume of oil stored). This reservoir is of the same volume as those usually built in the United States, which shows that Preem has utilised international experience when building the site. Such facts are worth mentioning in reports made available to the public.

Preem (Sweco) uses a technique borrowed from the Swedish Petrol Institute and Swedish Oil Ports’ Forum to calculate risks. This technique is built on quantitative risk analysis methods. Two groups of accidents are outlined: very likely but less serious, and serious but less likely. The likeliest but least serious accident is overfilling of a tanker truck. As stated in the report the likeliest accidents can only cause very limited damage to people and environment, but for some reason is still considered to be the most risky of all.

Risk analyses have been performed on all substances stored at the terminal with the exception of ethanol, which is handled by another operator while being stored. So Preem and the other company share their responsibilities in this way: Preem is responsible for pipes and cisterns where ethanol is stored while the other company answers for accident risks which can appear during pumping and filling. This decision appears to be questionable because it is not a common practice to have two responsible companies ‘under one roof’, and the border area of the two safety systems can potentially be a weak point of the whole system. The safety report of the other company should be presented together with the Preem Oil Terminal Seveso Report, otherwise there should be a united safety report for the both facilities.

A separate chapter of the Preem Seveso Report is dedicated to domino effects. It is a duty of the company to consider this issue because its activities are among those regulated by the Seveso II directive. A number of potentially dangerous objects related to the distribution or handling of flammable substances are situated within the surroundings of the terminal. The occurrence of a domino effect is dependent on wind speed and direction. A domino effect is considered to be the worst-case scenario because the probability of occurrence is lower then for a more typical accident. In order for a domino effect to occur, a number of circumstances must usually coincide. The reason for its consideration is that it can affect people not only within the terminal, but in neighboring areas as well. Domino accidents usually cause more damage in comparison to ordinary ones as they effectively consist of a number of single accidents.

A factor which is impossible to predict and influence in order to improve security is the possibility of terrorist attack. A directive from 2004 raises questions regarding safety improvements on tanker ships and in harbors and ports in terms of defense against terrorist attack. In this particular case the area of the terminal is protected from the land side but it is absolutely open from the water. Preem acknowledges this fact however there are not many things that can be done to improve safety in this regard. Terrorist attacks do not happen often in the
world, especially in Sweden. The actions of terrorists are difficult to predict so it is impossible to evaluate the probability of such an attack. But concerning magnitude, such attacks usually have a goal of maximum impact and resonance, so terrorists attempt to induce a worst-case scenario.

Information is communicated by Preem to people living in potentially endangered areas in a very special way which makes it worth mentioning. Information about accidents that may occur and contingency instructions are corresponded via post in conjunction with local newspapers. Furthermore, Preem and the other companies acting in the area organize special meetings from time to time with the primary aim of supplying residents with useful information regarding safety issues.

Preem/Sweco’s safety report appears to be the most innovative among the three reports. Creators of the report come to similar conclusions concerning the highest-risk events for the facility as the researchers at the two previously discussed sites. Preem Oil Terminal Seveso Report is extensive in depth and detail. It is current and up-to-date in regards to the modern global context, especially when trying to determine probabilities of terrorist attack. The company is also very proactive in their attempts to use new methods for the distribution of safety related information to interested parties.

### 4.4 Buncefield incident

During the course of this thesis being conducted, a serious incident at a site regulated by the Seveso II Directive occurred in the United Kingdom. It has been decided that a literature study of this incident would be useful.

The accident at Buncefield at the end of 2005 was large in scale and it is of significant interest as it happened at an oil storage depot belonging to our field of interest. There are still no final results from the investigation commission explaining the reasons and initiating events of incident, however one can see the damage done to buildings and individuals. Little information is available regarding environmental impact, and environmental impact has been judged to be of equal importance to damage to people. There were several explosions; the initial explosion was of massive in proportion and was followed by a large fire which engulfed more than 20 large fuel tanks over the area of the facility. Forty-three people were injured in the incident, but none seriously. Surprisingly (and fortunately), there were no fatalities. Significant damage occurred to both commercial and residential properties in the vicinity and a large area around the site forced the evacuation of about 2000 people on the advice of emergency services. The fire burned for several days, destroying most of the site and emitting large clouds of black smoke into the atmosphere, dispersing over southern England and beyond. Large quantities of foam and water were used to control the fire, bringing with it the risk of contaminating water courses and ground water. Subsequent research has shown that no significant damage has been done to ground water.

Three Investigation Progress Reports are available now for public use (as of 07.06.06). In order to view the whole picture of what is currently known about the incident, the third report should be read in conjunction with its predecessors. The first progress report, published on the 21st February, described the incident and emergency response. It pointed at the area where fuel had most likely originated from (at the north west of the site) and described some known details about the nature of the explosions and fire. The second progress report was published on 11th of April. This report was focused primarily on the environmental impact of the incident. It also set out measures required to monitor possible pollution levels.

Let us look at the incident as a case regulated by the Seveso II Directive. One of the goals of the Seveso II Directive implementation is to ensure companies and authorities share their
experiences concerning accidents. According to the directive, detailed reports must be prepared in case of any events listed in the directive. Concerning the Buncefield accident this has already been done, however there are still many unknowns that remain.

The source of spill is known, but not the source of ignition. It is impossible to make any definitive and effective recommendations to ensure and improve safety in future at this or similar depots at the situation when only partial information is available. However some conclusions are now known. The incident has been shown to be a consequence of equipment failure, occurring during the filling of one of the tanks. This operation is widely regarded as the weakest part of the chain, as mentioned in the two Seveso Reports of the aforementioned Swedish companies handling petrol. Several levels of control and warning did not show that the tank was full and motor spirit had been leaking over the floating roof of the cistern. This was dispersed into small droplets and evaporated on the way down to the earth. After being mixed with air it has formed a dense flammable cloud up to 2 meters deep which, following the topography, has covered a large proportion of the site. The explosion at the facility occurred as a consequence of an undefined source of ignition. Several likely sources of fire or spark are discussed. A primary one may have been located on site, with another in the Northgate car park.

Companies spend huge sums of money on safety equipment designed to protect people and environment from potential hazard or, ideally, avoid it. The incident at Buncefield is a good example of how things can go wrong unnecessarily. The likelihood of such a failure of an alarm system is very low, but has occurred. This case proves that at such a potentially dangerous facility, all safety systems should be duplicated and that every small detail has the potential to play a significant role. The database of incidents of that type and scale is rather poor, which is why further analysis of the case should be performed and conclusions should be drawn in order to facilitate effective counter-measures to avoid such undesirable events in the future.

4.5 Summary

All three Swedish facilities seem to provide sufficient proof of ensuring the safety of neighboring industrial sites as well as people in nearby communities. The reports are consistent and extensive, but despite sharing many similarities, they still differ to a high degree. When compared to each other, each report has its advantages as well as shortcomings:

<table>
<thead>
<tr>
<th>Report</th>
<th>Fortum Gas Station</th>
<th>Statoi Oil Terminal</th>
<th>Preem Oil Terminal</th>
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<tbody>
<tr>
<td>Advantages</td>
<td>1) Clearly defined acceptability criteria; 2) Good and extensive mapping.</td>
<td>1) Very well structured report; 2) Prevention measures are listed after definitions of most probable scenarios.</td>
<td>1) Well developed quantitative approach used as well as qualitative; 2) Well described domino effects; 3) High attention to means of information communication; 4) Policy cares about both on-site personnel and residents of surrounding areas.</td>
</tr>
<tr>
<td>Shortcomings</td>
<td>1) Some inconsistency in risk evaluation (unexpected results); 2) Simple but not very well detailed grading</td>
<td>1) It is unclear how scenarios are chosen for further analysis according to their likelihood.</td>
<td>1) Poor explanation of reasons why two companies operate at the same site and yet divide their safety</td>
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None of these reports is ideal, and after the comparison it appears possible that each could be improved.

In the reports it is emphasized that the highest risk is related to the movement of flammable substances both within and outside the facilities. This occurs due to large volumes of oil and fuels passing through a limited pipe diameter, and is a logical conclusion. Although tanker overfilling is one of the scenarios named among the most dangerous in the safety report by Statoil because of its high potential magnitude, not due to its probability, the accident at Buncefield oil storage depot has proven that catastrophic scenarios can still occur, regardless of their low probability. Moreover, catastrophic scenarios tend to occur for reasons that are usually unexpected. It is likely that one of the chains in the facility alarm system had been out of function, playing a major role in the incident. It is concerning to note that alarm systems do not seem to be given a great deal of attention in the Swedish companies’ Seveso reports. Another common feature of the reports is companies’ concern about the possibility of acts of terror. It is almost impossible to estimate their likelihood and suggest efficient measures to decrease related risks. Improvement of the external and internal security systems sounds like a positive initiative but is too general. This is an area where more work and research is still to be done.
5. Discussion

5.1 Technical recommendations
Based on the findings reported in previous chapters, we shall suggest a list of general rules for use by industrial operators. This list will include recommendations concerning the application of a worst-case scenario and conclusions and proposals concerning required content of safety reports.

The safety policy of any facility should begin with the formulation of a primary directive. ‘No increased risk outside the fence’ is a good example of such a directive, taken from the Seveso Report of a Swedish company previously described in a case study. It is strong, compelling, and meets the desires and expectations of the public.

Is it worthwhile to incorporate worst-case scenarios into safety reports? What else should a high quality safety report contain? Is making offsite consequence analysis results available for every citizen a reasonable practice?

First of all, worst-case offsite consequence analysis should be performed. Even taking into account all of its drawbacks, the technique is too valuable to be disregarded. It provides a perfect basis for rescue plans and comparisons of safety equipment effectiveness. In comparison to quantitative approaches, worst-case scenario analysis as a qualitative (or semi-qualitative) approach offers greater information into the potential hazards for an industrial site if read by a non-professional. One drawback of this method however, is that it describes the worst possible consequences, which can often be frightening. No-one wishes for a catastrophic event or accident to occur, which is why people often respond negatively if they understand the potential consequences of an accident even though such an occurrence may be extremely unlikely. In an attempt to allay such fears, safety reports must contain a substantial amount of information explaining what has been done to improve safety and the benefits for the public. A very important goal of any safety report is to help the public appraise risks (for example with the help of comparisons) and provide appropriate cases for use as comparators.

From our findings we have derived a series of summarized, technical recommendations, provided below:

1) When performing worst-case scenario analyses, mitigation measures should be excluded from the examination process much as they are in offsite consequence analyses in the United States. This enables us to perform efficiency calculations and measure reductions in hazard levels when new safety equipment and mitigation measures are implemented in the future. It is very important to add new equipment and measures individually, as this helps avoid loss of data and confounding of comparisons; sometimes the introduction of new mitigation measures actually create dangerous scenarios which had not been previously considered. Efficiency analysis of safety devices and mitigation measures requires checking how effectively they reduce levels of potential harm, risk radiuses, etc. Active (e.g. relief valves, alarms) and passive (e.g. dikes, walls) devices should be examined separately as the functionality of passive measures is not related to probability of effectiveness, while every active device possesses a certain level of reliability. This also allows us to make conclusions regarding the quality of the entire safety and mitigation system in comparison to those of similar sites. A worst-case offsite consequence approach can determine whether construction (for a new plant) or further operation (for an existing plant) is tolerable in terms of overall safety. For example, mitigation measures can be incorporated into the system individually with their effectiveness calculated as the ratio:
From this ratio one can create a list of safety measures, ordered by their increase in the efficiency of the overall system. With a certain level of generalization the results of the calculations may be applied to similar industrial sites or means of transport, which may simplify and unify the process.

2) The main comparative ratios for overall safety analyses should be estimated from the point of view of a worst-case release (scenario):
   a) The furthest distance a cloud of a substance could travel with a concentration higher than \( \frac{1}{2} \text{ LEL} \) (lower explosive limit);
   b) The distance from the site fence to the nearest reservoir (in the case of LNG terminals) is to be taken into account for estimation of offsite worst-case consequences;
   c) The most dangerous way in which a substance can spill is to be taken as the basis for the calculations; and
   d) The direction and the speed of the wind are assumed to occur in such a way that they enable the worst type of dispersion to happen.

3) The first level of examination should not include any quantitative probabilistic analysis. This analysis should be a simple comparison of preliminarily estimated hazard magnitude level for a specific plant with pass/not pass (acceptable/not acceptable) criteria. This procedure provides an opportunity to define the necessary depth of analysis for each facility, depending on the category to which a site belongs (ranging from safe to dangerous).

4) The next step is to find out less catastrophic, but likelier, scenarios. At this stage probabilistic analysis is added to consequential analysis. It is important to consider a number of potential scenarios; the larger the set of scenarios, the better it is. Sometimes it appears that less catastrophic but likelier scenarios are more dangerous than worst-case scenarios.

5) A very important issue to remember is that any type of numerical appraisal should be avoided wherever possible. Numerical values should be substituted by qualitative scales, which should be kept as straightforward as possible. For example, probability of occurrence could be evaluated with several grades ranging from very low (almost impossible) to high (rather probable), with grades based on calculated numerical values. In cases involving probabilities, each grade should be limited by two border values, maximum and minimum (rate of occurrence per n and m unit of time respectively). This substitution allows for the simplification of the evaluation and is more easily understood by non-specialists.

6) Depending on its location, potential consequences may vary for a plant or place of occurrence (e.g. for a road accident), while the potential hazard is an absolute value that may describe an outcome, such as an area polluted or damaged. Thus, any damage done to people and the environment is as dependent on the location as the type of plant. This can be a problem if we wish to use a particular type of plant as a basis for comparison. A new and very important requirement arises: surrounding areas should be described with a level of detail proportional to the severity of the potential consequences. A good description of surrounding territories, maps of proper scale, and development plans are helpful from two perspectives: firstly, as has already been mentioned, magnitude of an
accident depends to a high degree on the topography, population density, climate and other related issues, which is why a report on worst-case analysis should include a detailed description of surroundings; secondly, it is possible that processes and activities occurring outside the fence (either natural or man-made) may be a source of hazard to the establishment.

7) This can serve as a guideline for the risk assessment of an industrial site based on a worst-case scenario; procedures must be changed significantly to ensure an acceptable level of safety for personnel working within the boundaries of the facility. The differences entailed in handling toxic, flammable and explosive substances should be taken into account from the very beginning of the assessment, with numerical and qualitative parameters adjusted accordingly. Risk analysis for transportation is usually more difficult to calculate than for static objects. As soon as transportation has more than a single dimension (i.e. changing geographical position), it often becomes a more complex system than production chains.

If the aforementioned recommendations are collated, we are provided with the following key points:

**Model**
1) Assume the worst possible combination of events occurs.
2) Avoid probabilistic analysis.
3) Assume all safety equipment is disabled.

**Parameters to define**
1) Potential damage to:
   a) Human beings;
   b) Environment; and
   c) Real estate (financial).
2) Ability to withstand accident effects:
   a) Human beings; and
   b) Environment.
3) Availability and effectiveness of recovery and mitigation measures.

**Appraisal**
1) Each parameter is to be characterized with a qualitative grade;
2) The numerical quantity of grades is equivalent for each parameter (making it easier to save and process data in matrix form); and
3) All qualitative grades should correspond to a numerical parameter so that appraisal can be independent and consistent, regardless of the assessor.

5.2 Application
As a continuation of the discussion, one could conclude that the worst-case approach is not a constant. Its definition and application may vary from country to country, and from guideline to guideline. However it seems possible to divide methods of application into three groups.

In “Guidance on the Preparation of a Safety Report to Meet the Requirements of Council Directive 96/82/EC (Seveso II)”, it is stated that preliminary hazard analysis should cover all sources of danger within an establishment and clarify the potential impact of an accident on human beings, society and the environment. This preliminary assessment acts as a foundation for subsequent analyses, allowing conclusions to be made concerning depth and level of detail of the primary assessment phase. A simplified version of worst-case scenario approach is well suited
for this purpose, and is usually qualitative and does not require serious probability calculations. The worst-case approach is also well suited because it shows the maximum hazard potential of an establishment and serves as the perfect background for further risk assessment. One suggestion is that preliminary worst-case assessments should be made obligatory for all types of facility or transportation companies that handle dangerous substances, regardless of the volumes involved.

The second way the worst-case scenario approach could be applied is in conjunction with a likelier-but-less-catastrophic scenario approach, as they complement one another very well. On one hand, the worst-case scenario approach lacks a probabilistic basis and often has little to do with scenarios which contain plausible risk of occurrence. On the other hand, the likelier-but-less-catastrophic scenario approach is statistically undefined, with no upper and lower probability limits mentioned within existing literature. Sometimes, more probable accident scenarios differ from the worst-case to the extent that mitigation measures proposed for the first type of scenarios may not be sufficient to handle the second type, leaving the environment and public unprotected against a catastrophic sequence of events. However if the two techniques are used together they can produce superior results.

The third application of the worst-case approach is for the purposes of planning land use, as the widths of safety belts can be calculated on the basis of worst-case scenarios estimations.

The worst-case scenario approach is also widely used as a tool to deal with uncertainties for two main reasons: if the plant is ready for the worst possible scenario, then it is likely it will be able to cope with less devastating scenarios; and secondly, the approach avoids unnecessary complexity due to its qualitative basis.

5.3 Implementation
The EPA in the United States has printed over 5000 pages of guidelines describing the process of risk assessment. Some argue that the procedure has become too inflexible due to the detail of the regulations, often leading to overestimation or underestimation of potential consequences. However, America has made the most significant contributions in the field of implementing the worst-case approach into law and legislation. As such, European safety research and national safety regulations are often founded on the experience and knowledge base of the EPA.

The situation in Europe is currently quite controversial. Despite great interest in the worst-case approach it is not widely implemented in national safety regulations. Top-level official European institutions are working on the creation of guidelines for the implementation of the worst-case approach at all levels of law and regulation. The aim of these guidelines is to define the worst-case in terms of chemical reactions, traffic accidents, releases, spills, and other significant incidents; this study was in its active phase as of the end of 2005. A disproportionate coverage of questions related to the worst-case approach serves as evidence of this. For example, one can find a very extended and detailed description for worst-case chemical reactions in particular branches of industry, however few rules exist determining the worst-case scenario for traffic accidents or explosions. The Seveso Directives' implementation has been quite successful in the EU, and the main focus now is on implementing the directives in new EU member nations.

The Netherlands is a country known for its’ focus on safety questions and progressive research into the field of risk management. Within one of the most recent studies a proposal was made to use three new terms in addition to individual and societal risk. The new terms are ‘self-rescue’ (ability of people in the region to save themselves), ‘controllability’ (ability of emergency services to react) and ‘consequences’ (analysis of the scenarios in terms of damage, fatalities and injuries). The Netherlands is often taken held up as a positive example in regards to safety
regulations. Unsurprisingly, the majority of research is related to flood risks, but the results can be easily employed for other scenarios.

In Austria, a special working group (Austrian Permanent Seveso Working Group) was founded to accelerate the implementation of Seveso Directives. The decision was made to use both a deterministic and “worst-case” scenario approach. Availability and quality of data is a crucial point for probabilistic approaches, but according to expert opinion current databases are unreliable due to their insufficient volume and short timeframes. The accidents of the past have shown that a worst-case scenario can never be completely excluded from estimates, which is why it seems more appropriate to err on the side of safety when conducting deliberate and long-term planning. What these cases also illustrate is that it is never sufficient to analyze only one or two scenarios. In order to obtain meaningful and reliable results, an extended case-by-case estimation may be appropriate or necessary for specific situations. Detailed guidance is available explaining how safety distances should be calculated for the estimation of off-site consequences and domino effects in order to comply with the Seveso II Directive.

5.4 Communication of the results to the public and stakeholders

“Risks which are not undertaken by choice are perceived to be more threatening than those that the individual undertakes willingly.”

The so-called ‘right to know’ was first mentioned in directive 82/501/EEC (known as the Seveso directive), and was supported by a number of guidelines in the Seveso II directive. In an annex to the directive, a list of details from safety reports that should be available to public was presented. A barrier to the full implementation of this directive is that the guidelines do not have the power of law, and some statements from the guidelines could be interpreted in several ways. Consequently, the depth of the directives’ implementation varies among European states. Member states shall ensure that information on safety measures and the correct procedures to adopt in the case of an accident is supplied in an appropriate manner. People who are likely to be affected by an accident originating at a notified industrial site should receive appropriate information, without having to request it. This information should be repeated and updated at regular time intervals or after significant changes which could have decreased safety levels, and then be made publicly available. Such information shall contain details that are listed in Annex VII (Article 8 of Directive 88/610/EEC, amending Directive 82/501/EEC). However the quantity and quality of information communicated to the public between EU member nations also varies.

There are two dimensions to the problem of communicating risk assessment results to the public. First of all, the danger of terrorist acts is a real possibility in the modern world. Responsible authorities are afraid of possible misuse of detailed information. Details on worst-case scenarios published in the mass media or on the Internet provide a perfect opportunity for criminals and terrorists to achieve their goals. So what volume and content of information should be available for public access? These issues are widely discussed and debated in the media. People want to know as much as possible about potential hazards, and citizens may mistrust their government and industrial operators if they do not provide a substantial description of their activities and related hazards. Society needs sufficient information to be prepared to withstand undesired consequences of accidents. The Seveso I Directive suggests that only limited information should be communicated to people: “An important element of the framework of controls for the major accident hazards of certain industrial activities established by Directive 82/501 EEC1 is the provision of information on safety measures and on the correct behavior to adopt in the case of a major accident to persons (including the public) liable to be affected by such an accident.” Guidelines are written to provide scientists with rules that assist them in including only
information which is really helpful to people, and exclude information that could be a source of hazard if misused by terrorists. This topic became a major concern at the end of the 20th and beginning of the 21st century.

Worst-case scenarios are special cases in terms of their communication to the public, as expected consequences are usually extremely serious and frightening. Society becomes uneasy when being informed about the potential for catastrophic events in their neighborhood. Citizens pay little attention to fact that such events have minute likelihoods; it is only potential harm and consequences that are of importance to them.

To convince people of the truthfulness of their safety reports operators should list all potentially hazardous events, disregarding the probabilities and seriousness of these consequences. The description of these hazardous events should be followed by a detailed explanation of the measures taken and reasons why they could not cause a disaster that would physically impact upon public safety. Assertions used by various agencies in their safety reports to reassure people of their safety include:

1) The feared event is physically impossible;
2) Dangerous consequences of the event will not affect any crowded or populated areas;
3) The event is slow enough to ensure that the population can be evacuate or kept from harm; and
4) The likelihood of the event is so small that that it is almost completely impossible.

But nowadays a simple description of probable accidents, their likelihoods and their consequences is not enough. People want to know more to feel they are protected, and wish to take part in decision-making processes. Reliable arguments and information are required to fulfill these needs. The reaction of citizens to safety reports is a fascinating field of research. It is under increasing research by communication, psychological, and social scientists. Psychological factors play a major role in people's attitude to risks. Individual researchers and institutes are tackling the problem by trying to find common rules that could help operators describe their activities and corresponding risks to an audience in a satisfactory manner. A number of such assurances appear to diminish concerns, but these are insufficient when people want information such as:

1) What individuals can do to reduce their exposure;
2) What industry and government are/are not doing to reduce the risk;
3) The benefits as well as the risks of the substance/process of concern to that specific audience (not just society in general); and
4) The alternatives and their risks; what people can do to get involved in the decision-making process.

Information should be provided in order to help people evaluate the risks themselves. A very well known and useful way of communicating information is to compare the risk to other risks more familiar to the public. But the government and industrial operators should be aware of common mistakes such as comparing involuntary and voluntary risks, or trying to minimize the hazards of involuntary risks. Such mistakes have the potential to cause anger and outrage instead of understanding. Another factor limiting the value of comparisons is that risks tend to accumulate in people’s minds. Even if a newly introduced risk is low, this does not mean that it will be accepted by the public. As such, comparisons should be used with great care. Examples of good comparisons include:

1) Comparison to similar risks;
2) Comparison of risks with benefits;
3) Comparison to alternative substances/methods;
4) Comparison to natural background levels;
5) Comparison with a regulatory standard.\textsuperscript{43}

In the United States, the Federal Bureau of Investigations (FBI) has drawn the government’s attention to the dangers of international terrorism. The FBI suggests that free access to risk management plans and off-site consequence analyses, including worst-case scenarios, should be restricted. In response, ‘freedom of information’ activists argue that routine accidents are much more risky and likely when compared to the possibility of terrorist attack. Studies have been performed in order to determine any increase in risk level due to the availability of worst-case scenarios on the Internet. No major international incidents involving the use of industrial facilities as weapons are currently known, however specialist analysis has shown that risk levels double if offsite consequences are available via the Internet. As such, decisions have been made to restrict anonymous access and limit the extent and volume of information available.\textsuperscript{44}

Communication of the results is a very sensitive process that requires a great deal of expertise and aptitude in the field, as well as a high level of knowledge of both technical and social sciences. It should be kept in mind that the potential remains for information regarding worst-case scenarios to be misused by terrorists.

5.5 Conclusion

The term ‘worst-case scenario’ actually has only one general meaning – a scenario that facilitates consequences of the greatest and most devastating magnitude. Specific definitions exist for worst-case releases and worst-case reactions, which are variants of worst-case scenarios. But the application of the approach has been shown to vary. According to one application, the worst-case scenario is a tool to deal with uncertainties, and is related to a precautionary principle which assumes that the worst possible event is taken into account at every single chain of the scenario.\textsuperscript{45} Another application uses worst-case scenarios as a qualitative technique that aims to inform the public regarding the potential offsite consequences and safety/danger of the object or action in terms comprehensible to a specialist and an ordinary representative of the public alike. The third application of the worst-case approach is to examine safety equipment and mitigation measures. Associated mathematical calculations are usually approximate and uncomplicated, but may vary depending on case characteristics and the depth of analysis required. This simplification can as both an advantage and disadvantage of the worst-case approach:

- “In the past, when analyzing such accidents, a worst-case or single representative analysis has often been used. However, this may distort the analysis compared with a full evaluation. In addition, it is not always clear which case is worst or representative. Nevertheless, the advantages of such an approach are that it is relatively quick and easy and may be adequate.”

However:

- “The realistic analysis gives a much better representation of a major accident, as opposed to using a simple worst-case or representative analysis. This in turn gives a more accurate assessment of risk, thus enabling decisions to be taken with a higher degree of confidence.”\textsuperscript{46}

Some people consider measures taken against worst-case scenarios to be sufficient for the protection of neighboring areas in instances of less serious accidents. The problem here is that there is usually a very low level of probability associated with unwanted accidents of great magnitude. As such, investments into the reduction of risk related to catastrophic (worst-case) accidents are often unreasonable. When risk is considered as a factor of probability multiplied by magnitude, likelier but less catastrophic scenarios can often present greater risk (as a consequence of their higher probability) than worst-case scenarios. So often a worst-case scenario is not representative of potential scenarios, and the investments required to deal with
such a scenario will be uneconomical. However we may also encounter similar problems with a likelier-but-less-catastrophic accident approach. Both approaches can potentially produce scenarios unrepresentative of typical events that would require special safety measures. Thus it is unclear as to whether worst-case and likelier-but-less-catastrophic scenarios can act independently in assisting decision-making for the installation of safety devices and mitigation measures.

The worst-case accident method has already been implemented in the safety regulations of countries all over the world. The main areas of implementation are land-use planning and the creation of emergency strategies. The Seveso Directives in Europe and the Clean Air Act in the United States provide the cornerstones of industrial safety regulations around the globe. While there is no direct link to the worst-case approach in either of the two abovementioned documents, risk management plans in the United States and land-use planning guidance in the EU both incorporate worst-case analyses as an integral part of their structure.

All three case studies examined are based on Seveso (safety) Reports of three Swedish companies involved in the handling of flammable substances. Also included in the study is an incident that occurred in Buncefield (England) at a similar facility involved with the handling and storage of petrol. Although different approaches have been utilized by the operators, similar conclusions are made in each Seveso report regarding weak points, or points where incidents are most likely to occur, within the process chain.

Research involving worst-case scenarios generally aim to estimate offsite consequences and protect citizens of communities in close proximity to an industrial site. However no conclusions seem to have been reached regarding the application of worst-case scenarios to improve internal safety and limit the on-site consequences of a significant accident.

5.6. Results, questions still to be answered and topics for further research

In this work we have made an attempt to make a system of the information related to worst-case scenario approach. In the very beginning of the thesis we have asked a number of questions that we want to find answers for through research. We have managed to find a number of definitions for “worst-case scenario”. We have also looked at national and international regulations and laws that regulate industrial safety. It is important to admit that extent of available relevant information differs from country to country. That is why it is pretty difficult to make conclusions concerning use of worst-case scenario approach in some particular cases. International experience can be a valuable source of information. So we should probably pay more attention to the source in future research.

Although the simplified guidelines for the use of “worst-case scenario” approach have been proposed they do not answer all the questions. Branches of industry differ too much in terms of handled substances, chemical processes and production chains. This makes creation of a single, detailed document useful for all facilities practically impossible. A document, which explains application of worst-case approach for, say, gas filling station would be almost inapplicable in case of oil transportation. Thus every single brunch of industry needs special guidelines that would regulate worst-case scenario analysis.

Another area which seems to be very interesting and prospective for further investigations is communications of the results to the public. It could be interesting both for scientists dealing with social issues and for those working with risks.
Semi-quantitative approach is relatively new in cases where it is applied for risk evaluation. There are different visions of how it should be utilized for the purpose. Moreover the relative proportions of quantitative and qualitative aspects are still under scrutiny. Development of semi-quantitative approach use for purposes of industrial safety, and risk evaluation in particular, is on the agenda nowadays; and research related to this topic looks to be interesting.

Recently, a petroleum pipeline connecting Belarus and Russia ruptured, causing many tons of diesel fuel to flow into the Baltic Sea via the Dvina River. The accident has been proclaimed a catastrophe for the Baltic region. This is a “perfect” example of a worst-case event. It proves the fact that the magnitude of worst-case accidents often makes them regional, international problems affecting several nations.

The European Union is growing and its borders are steadily moving towards the East. Most of post-soviet countries have not paying enough attention to the safety issues in recent years due to their struggling economies following the fall of the Soviet Union. It is commonplace for pieces of legislation and regulations concerning safety to be out of date. For this reason research in the field of application of new approaches, such as worst-case scenario, in the countries of Eastern Europe with the aim to improve industrial safety issues has very high priority and could be of interest for us as well.
List of Abbreviations

ACMH – Advisory Committee on Major Hazards
ALARP – as low as reasonably possible
ATC – acute toxicity concentration
CAAA – Clean Air Act Amendments
CCA – Committee of Competent Authorities
DEFRA – Department for Environment, Food, and Rural Affairs
DETR – Department of the Environment, Transport and the Regions
EPA – Environmental Protection Agency
FAQ – frequently asked questions
FBI – Federal Bureau of Investigations
GIS – geographic informational system
HSE – Health and Safety Executive
KISCO – Korean Industrial Safety Corporation
LEL – lower explosive limit
LNG – liquefied natural gas
MAHB – Major Accident Hazards Bureau
MHAU – Major Hazards Assessment Unit
NASA – National Aerospace Agency
NFPA – National Fire Protection Association
PRA – probabilistic risk assessment
PSA – probabilistic safety analysis
QRA – quantified risk assessment
RMP – risk management plan
TCDD – 2,3,7,8-tetrachlorodibenzo-p-dioxin
TCP – 2,4,5-trichlorophenol
USEPA – United States Environmental Protection Agency
VROM – the Netherlands Ministry of Housing, Spatial Planning and the Environment
Reference list:

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Appendix I

Estimation of risk from consideration of magnitude, consequences and probabilities

<table>
<thead>
<tr>
<th>Increasing acceptability</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Severe</td>
</tr>
<tr>
<td>Probability</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>high</td>
</tr>
<tr>
<td>Medium</td>
<td>high</td>
</tr>
<tr>
<td>Low</td>
<td>high/medium</td>
</tr>
</tbody>
</table>

Here is a table, provided in the guidelines for risk assessment. It is supposed to provide a consistent basis for decision-making, though user should be aware of oversimplification.

Appendix II

Substitution quantitative frequencies with qualitative (for Norwegian filling stations)

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Definition</th>
<th>Frequency of event occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IMPROBABLE</td>
<td>Possible, but may not be heard of, or maybe experienced world wide.</td>
<td>About once per 1000 years or less</td>
</tr>
<tr>
<td>B</td>
<td>REMOTE</td>
<td>Unlikely to occur during lifetime/operation of one filling station</td>
<td>About once per 100 years</td>
</tr>
<tr>
<td>C</td>
<td>OCCASIONAL</td>
<td>Likely to occur during lifetime/operation of one filling station</td>
<td>About once per 10 years</td>
</tr>
<tr>
<td>D</td>
<td>PROBABLY</td>
<td>May occur several times at the filling station</td>
<td>About once per year</td>
</tr>
<tr>
<td>E</td>
<td>FREQUENT</td>
<td>Will occur frequently at the filling station</td>
<td>About 10 times per year or more.</td>
</tr>
</tbody>
</table>
### Appendix III

**Semi-quantitative evaluation of accident severity at a filling station**

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>People</strong></td>
<td><strong>Environment</strong></td>
</tr>
<tr>
<td>1</td>
<td>CATASTROPHIC</td>
<td>Several fatalities</td>
</tr>
<tr>
<td>2</td>
<td>SEVERE LOSS</td>
<td>One fatality</td>
</tr>
<tr>
<td>3</td>
<td>MAJOR DAMAGE</td>
<td>Permanent disability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prolonged hospital treatment</td>
</tr>
<tr>
<td>4</td>
<td>DAMAGE</td>
<td>Medical treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lost time injury</td>
</tr>
<tr>
<td>5</td>
<td>MINOR DAMAGE</td>
<td>Minor injury</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amoynance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disturbance</td>
</tr>
</tbody>
</table>