Risk acceptance criteria in the Landbased Process Industry: Evaluation and Comparison of different Practises

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Abstract

The article gives an introduction to the concepts of risk, risk acceptance, and risk acceptance criteria, and presents some of the principles for criteria setting in the landbased process industry. The main focus is the process industry that is covered by the Seveso II directive. This directive applies to facilities that store or handle certain types and amounts of dangerous substances. Proper land use planning is an important premise for balancing landbased industry with other kinds of land use. In addition, it is necessary to demonstrate that the risk imposed on the workers and the public is sufficiently low. This article compares the practises for risk acceptance with landbased industry in the UK and the Netherlands. Even if the countries share common challenges with process industry near densely populated areas, it is shown in this article that they have taken quite different approaches.

Keywords: Risk acceptance criteria, land use planning, ALARP, ALARA, risk metrics.

1 Introduction

Risk is part of our daily lives. Just being alive is a risk itself. Our willingness to accept risk is not an absolute quantity. We are often willing to accept more risk if we see some *benefits* from the activity. Biking to work may seem like an hazardous activity for some, while others think that this is a fair risk to stay in a physical good condition.

Being able to control the activity gives a feeling of lower risk, and therefore a greater willingness to accept more. Being the car driver often feels safer than

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being the passenger. Devastating consequences of accidents may have the opposite effect. The fear of terror may be one such example. Even if such events are rare in Europe and that many terrorists are caught before they are able to perform their attacks, the airports invest a lot in security checks to reduce the risk as much as possible.

All these three perspective to risk willingness are important to consider when setting risk criteria for activities in the society. Without risk criteria that reflect the public view of acceptable risk, there may be large disputes and potential law suits in relationship with new developments and accident investigations. One recent example is related to the location of a new liquified natural gas plant in Risavika near Stavanger in Norway. People living in nearby residential area feel that this plant will expose them to unacceptable risk. They cannot understand why the risk analyses come out with the opposite conclusion, particularly in light of the increased ship transportation with LNG in and out the harbour and with a new ferry terminal located close to the new plant [54, 53, 44]. The Norwegian practise for having the developer to set the risk acceptance criteria without any active national governing on land use planning has been questioned.

The objective of this article is to (1) give an introduction to the concepts of risk, risk acceptance, and risk acceptance criteria, (2) to present some of the principles used to set risk acceptance criteria, and (3) to evaluate their application in the landbased process industry.

Countries with more dense populations face even more potential conflicts between industrial developments and other land uses like residential areas, schools, hospitals, and roads. Here, it is important with a more active national and regional policy on risk acceptance to ensure proper land use planning.

The focus of this article is therefore directed to countries that seem to have taken several actions to balance development of industries with other land use. Countries that are often mentioned in this respect are the UK, the Netherlands, Canada, and Australia. The scope of this article is narrowed down to the UK and the Netherlands.

Landbased process industry covers a broad spectrum of industries, that uses physical, mechanical and/or chemical means to extract raw material and to transport and transform them into other products (Wikipedia). To indicate the span, we may use food industry, furniture industry, and petroleum refineries as examples.

The main focus of this article is landbased process industry that is covered by the Seveso II directive [18, 15] on control of major accidents. The Seveso directive applies to industrial facilities where dangerous substances are present in quantities that are exceeding the thresholds in the directive. Landbased industry that falls into this category are e.g., refineries, chemical plants, liquified natural gas (LNG) plants, and facilities that store chemicals and petroleum products.

2 Overall model for risk acceptance

Introducing a landbased process industry in an area raises a number of challenges, both for the plant developer or owner, the public, and for the local authorities. The plant developer or owner must adhere to laws and regulations that concern the safety of workers and on the potential risk that the plant may have on the vicinity, like the public members and the environment.

While to plant owners attention is on risk imposed by a particular plant, the authorities must consider the risk of the plant with other sources of risk in the area and determine if the overall risk is acceptable. Sometimes, the plant is introduced in a deserted area. Then it is not the risk of personnel that is the main concern, but rather the environmental impacts. If the plant is to be introduced into a populated area, for example a new hydrogen refueling station being introduced in a city, the personnel risk as well as environment and material/financial assets would need to be considered, the latter from being a potential consequence of the “domino-effect’ from an accident.

There are many examples were a landbased industry used to be located far away from populated areas, but where new developments and residential areas have expanded into these areas. A process industry that has been in a community for ‘ages’ without any major accident may reduce the awareness to its presence in the planning of new developments in the area. But accidents like the explosions in a fireworks warehouse in Enchede in 2000, the huge explosion at the fertilized factory in Toulouse in 2001, and the fire in the fuel depot in Buncefield in 2005, are all reminders of the opposite.

A decision on whether a new landbased industry can be localized in an area, or if an existing facility has become in conflict with nearby developments, should be based on the results from laws and regulations, risk analyses, prior experience with similar plants, and other sources of decision support, like expert and public opinions. Such a decision process may be illustrated as in Fig. 1 using a structured analysis and design technique (SADT).

With SADT terminology, see e.g., in [42], we look at functions, their inputs, outputs, controls, and mechanisms (resources). The *function* ‘Determine whether or not, and under which conditions, a landbased process facility has acceptable risk. Depending on the national laws and practises, this may a function performed by the national authorities or at a local level. The *outputs*, or the outcome, of the function is then one out of the following decisions: Acceptable, acceptable with conditions, or not acceptable. To perform a function, we have

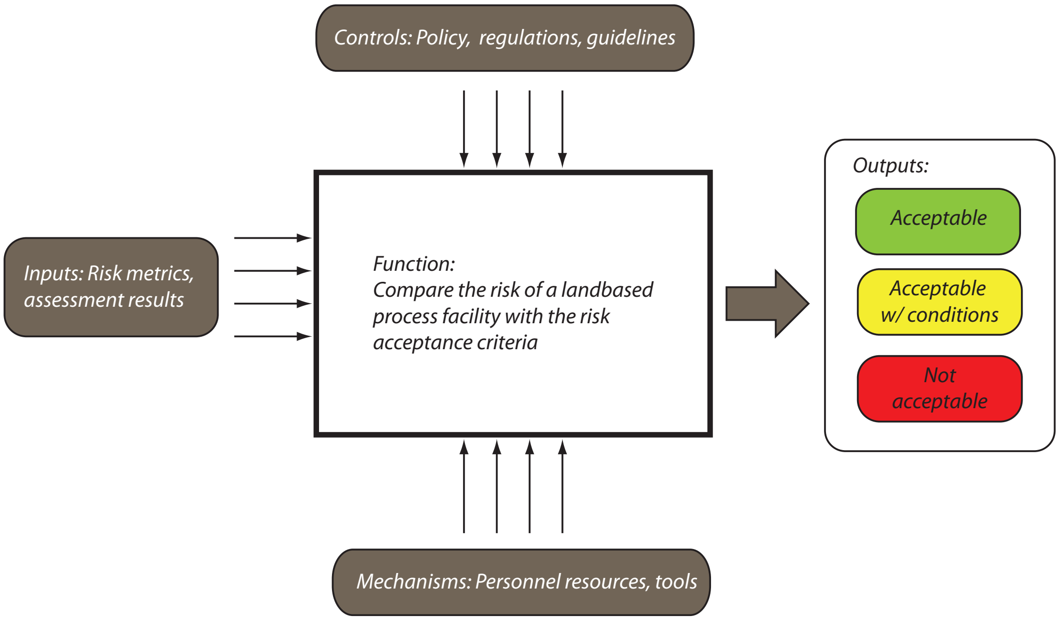

Fig. 1. An overall model for risk acceptance

to consider the associated inputs, controlling factors, and mechanism, which in this context are as follows:

Inputs: Inputs represent the information that we need for the particular plant in questions, like the results results from quantitative risk analyses (QRAs) with a number of risk metrics presented. Not only personnel risk should be considered, and it may therefore be relevant to ask for results from other analyses, such as environmental impact assessments.

Controls: The controls are the rules, policies, and requirements that restrict our freedom in making decision, to ensure that national and local interests are taken into account.

Important controls for a landbased process industry that are focused in this article is Seveso II directive, and its national implementations.

Regarding environment impact, it is necessary to adhere to the EU directive for environmental impact assessments [15] and integrated pollution prevention and control [16] and the national requirements that build on these directives. Regarding pollution prevention and control, there are also guidelines available from the international organizations like the International Association for Impact Assessment (IAIA).

Mechanisms The mechanisms are the resources and tools that are required to make proper decisions from the inputs and controls. This means that the decision process requires people with the right competence and which represent authority views.

In addition, it is necessary to have some public involvement. Many regulations require that new hazards and risks are presented to the public, so that their concerns are considered. Trying to 'force through' a decision without adequate involvement of *all* relevant parties can postpone a new development, or become the start of a long-term conflict between the public and the industry. The LNG plant in Risavika is one example where this may turn out to be the case.

The model in Fig 1 may be a useful tool for giving an overall structure and overview of elements that must be considered to determine if a landbased process industry represent acceptable risk to the workers and the vicinity. This article will not look into all these factors, but focus on specific topics such as risk acceptance metrics, risk acceptance criteria, and some practises on their application for the process industry. As part of the discussing on risk acceptance criteria, we present some of the national practises on how to set criteria and how to follow them up.

3 Risk, risk acceptance, and risk acceptance criteria

4 Risk and risk acceptance

To understand the concepts of risk acceptance and risk acceptance criteria, it may be useful to start by defining what we mean by risk. Risk is a frequently used term, but in different contexts it may have different meanings. Sometimes risk is used with a rather positive meaning, focusing on the "upsides" of we want to achieve: I take the risk of buying stocks, in the expectation that I may earn more than putting them in the savings account. In other situations, we use risk in a more negative context, focusing on what we would like to avoid: I don't want take the risk of biking on slippery ice.

Formally, we may define risk by asking the following three questions [33]: What can go wrong, how likely is it to happen, and if it does happen, what are the consequences. In other words, risk is a term that considers both the frequency and consequences. The level of risk (R) is determined by multiplying the probabilities and consequences from each potential outcome of an undesired or hazardous event:

$$\mathrm{R} = \sum_{\text{All outcomes}} \mathrm{p}_i \cdot \mathrm{c}_i \tag{1}$$

where i denotes an outcome, p_i is the probability of having this outcome, and c_i is the consequence, for example in terms of the number of fatalities.

Risk acceptance may be defined as “the willingness to live with a risk so as to secure certain benefits and in the confidence that it is properly controlled” [31]. This definition outlines that risk is about balancing two different options, achieving something (benefits) and potentially loosing something (human fatality or injury, financially, damage to environment).

In relationship with a landbased process industry, the question of proper balance should include:

- At the overall level: The benefits, e.g., new jobs and income to the community, versus the added risk to the plant workers, people living and working in the vicinity, and the environment.
- At the detailed level: The benefits of introducing a risk reducing measure at the plant (i.e., in terms of less probability of causing damage) versus the costs of introducing the measure.

When we discuss what is acceptable or not, we also need to address the term ‘tolerability’ [31, 30, 41]. Acceptability and tolerability have slightly different meaning, but their distinction is not always clear [35, 30]. One interpretation is illustration in Fig. 2. Here, tolerability is defined as the risk *that we can live with or adapt to*, taking into account that we are aware of the risk and that we have implemented certain measures to control it. What we consider as tolerable may not be single level, but rather a region where we are able to balance, not necessarily by saying that they should be equal, the benefits of taking a risk with the potential losses of hazardous events.

Acceptability is often used to express conformity that may take to states: Either it conforms, or it does not. In the context of acceptability, this means that we may distinguish between a risk that is acceptable or *not* acceptable.

In some cases, an acceptance may also be given with some restrictions, e.g., the risk is acceptable provided that some risk reducing measures are implemented. In this case, we have a risk that may be defined as tolerable.

Related to the discussion of tolerability and acceptability, we may ask: Acceptable or tolerable to whom? A useful approach here is to distinguish between different types of vulnerable ‘objects’, like:

- Workers (1. person)
- Personnel that temporarily visit the facility (2. person)
- People living in the vicinity (3. person)
- Unborn life/future generations (4. person)
- Environment

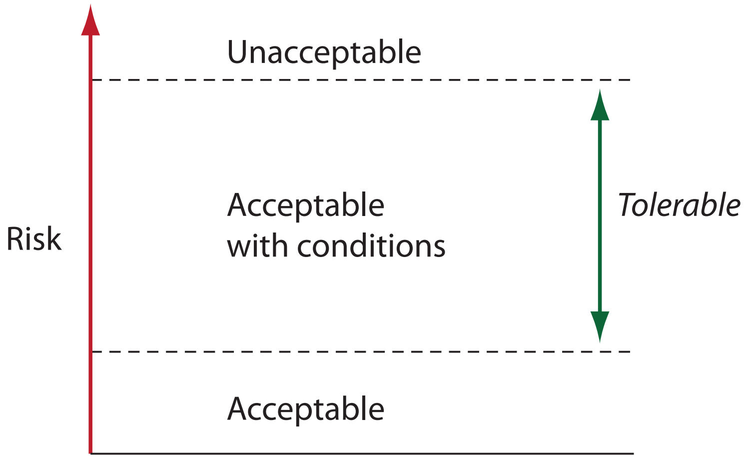

Fig. 2. One approach to distinguish between tolerable and acceptable

- Material and financial assets, both at the plant and in the vicinity
- Things (buildings, etc) of National heritage

The laws and guidelines on control of major accidents and on land use planning give risk acceptance criteria for 1., 2. and 3. person, the environment, and in some cases material and financial assets. Laws and guidelines on environmental impact may give criteria that take local and global carrying capacity of air, soil, and water into account.

5 Risk acceptance criteria

A risk acceptance criteria may be defined as criteria used as basis for decision about acceptable risk [40], here highlighting the main objective of having a criteria: Being an aid for making decisions.

Another definition is proposed by ISO/IEC guide 73 [32], here giving considerations to important elements of criteria setting:

> *The terms of reference by which the significance of risk is assessed.*
> *Risk criteria can include associated costs and benefits, legal and statutory requirements, socio-economic and environmental aspects, the concerns of the stakeholders, priorities and other inputs to the assessment.*

There are several ways of classifying risk acceptance criteria, each representing a useful perspective for understanding what a risk criteria is about. Personnel risk, may for example be further split into risk of fatality and risk of injury, see e.g., in [29, 13].

Another approach is to classify risk acceptance criteria according to the principle on how the criteria are set [30, 41]:

- **Equity-based:** All individuals have unconditional (and equal) rights to certain level of protection.

  In practise, a limit is set that represents the maximum level of risk above which no individual risk can be exposed. A critique that is sometimes raised for this approach is that is encourage a too mush conservatism in the risk estimates, causing undue alarm and despondency among the public [30].
- **Utility-based:** The incremental benefit of the measures to prevent the risk of injury or detriment is compared to the cost of the measures.

  There should be some disproportion between the costs and the benefits for NOT implementing the measure, where the disproportion should be large when the risk is large (so-called 'gross-proportion') and lower when the risk is lower. A critique against this criterion principle is that the one-sided focus on cost-benefit may cause other important considerations, such as ethics, to be ignored [30].
- **Technology-based:** Employing 'state of the art' control measures (technological, managerial, organizational) to control risk gives a satisfactory level of risk prevention.

  The main critique towards this principle is that it ignores a reasonable balance between costs and benefits. It may for example disfavour new safe, but less expensive products, that more people can afford as long as there are expensive but slightly more safe products on the market that just a few will buy.

The technology principle is used with integrated pollution prevention and control, where guidance on "best available technology" have been developed for various products and applications. As we will see later, the 'as low as reasonably practicable' (ALARP) incorporates all three principles [30].

Classification of risk acceptance criteria may also consider the way the criteria have been developed, as for example in [19], where it is distinguished between:

- Professional judgments, where technical experts' advices
- Boot strapping, where historical precedents are used as basis
- Formal analysis, where theory-based procedures, models, and calculations are used as basis

A very common approach is to differentiate between risk acceptance criteria for individual and societal risk [30, 31, 41]. The individual risk relates to the risk that we as individuals see, while the societal risk concerns the group risk, or the occurrence of multiple fatalities due to a single event. Both risk measures are relevant for landbased process industry, both for considering risk exposure at and from the plant and for the purpose of land use planning of nearby developments.

Regarding the individual risk, the literature does not always make clear the very important distinction between:

- Activity based individual risk: The average risk of death (or injury) of an individual due to his or hers activities.

  Many authorities and guidelines publish statistics on average individual risk for different age groups and for different types of activities, see e.g., in [30].
- Localized individual risk: The average risk of death (or injury) of an individual just from being at a particular location.

  The localized individual risk may sum up all risk exposure at the location, or reflect the exposure from a single hazardous event.

When this destination is not made one may end up comparing criteria or risk metrics that are based on quite different premises.

Both the activity based and localized individual risk may be split further into criteria that concern fatality risk, injury risk, and risk of property damage and accident propagation [41]. Different acceptance criteria may be defined for 1., 2., 3. and 4. person, taking into account their different degree of voluntariness, benefits, and degree of control. Regarding 3. person, this group is sometimes split into different vulnerability groups, for example those that stay in hospitals/schools/child-care and old age housing, those in residential places, those in retail centers and warehouses, and finally those in sporting complexes and active open space areas [41].

Criteria may be also reflect how individuals and property are affected by different consequences, for example explosion overpressure, heat radiation, and toxicity [41, 29]. This approach is often used with land use planning, to classify different zones around a landbased process facility.

Also for societal risk, we may consider environmental and property impact as well as fatality and injury risk. But different metrics will apply. The risk metrics are further discussed in Section 7.

6 Principles for setting risk acceptance criteria

The principles of equity based, utility based, and technology based principle for setting risk acceptance criteria have already been introduced. As is seen in the discussion to follow, Other principles may include one or more of these principles.

Some of the other frequently used principles for risk criteria which are relevant for the landbased process industry are shown in Table 1. It is indicated whether the principle applies to individual risk, to societal risk, or both. In this section gives a brief overview of these principles.

Table 1
Principles for risk acceptance setting

	Quantitative methods			(Semi) Qualitative methods	
	ALARP	MEM	GAMAB	Risk Matrix*	Pre caution
Individual risk	X	X		X	
Societal risk	X		(X)	X	(X)

6.1 ALARP

ALARP stands for 'as low as reasonably practicable'. This is an old principle, but was formalized for use with risk assessments by Health & Safety Executive (HSE), UK, through the report on the tolerability of risk (TOR) from nuclear power stations [31] and the Cullen report [11] that followed after the Piper Alpha accident in 1988.

The ALARP approach views risk acceptance in terms of different zones, the *Unacceptable region*, *Broadly acceptable region*, and the *Tolerable region*, as illustrated in Fig. 3.

In the unacceptable region, the risk is regarded as intolerable and is forbidden whatever the benefit might be. As such, we may consider the entrance into the unacceptable region as a equity based criterion.

Below the broadly acceptable region, the risk is so low that is considered insignificant and adequately controlled. The levels of risks characterizing this region are comparable with those that people regard as insignificant or trivial in their daily lives [30].

In the tolerable region, or the ALARP region, an activity is allowed to take place in order to secure benefits, in the expectation that:

- All hazards have been identified
- Nature and the level of risk is properly addressed, and the results are properly used to determine control measures
- Residual risks are not unduly high and kept as low as reasonably practicable (ALARP)
- Risks are periodically reviewed to ensure that they still meet the ALARP criteria

The HSE provides much guidance on how to determine what is 'reasonably practicable' risk reduction in the tolerable region, see e.g., in [30, 31, 24, 25]. There are two main approaches: One approach is to consider the costs of introducing a risk reducing measure with the benefit of averting a fatality, injury or environ-

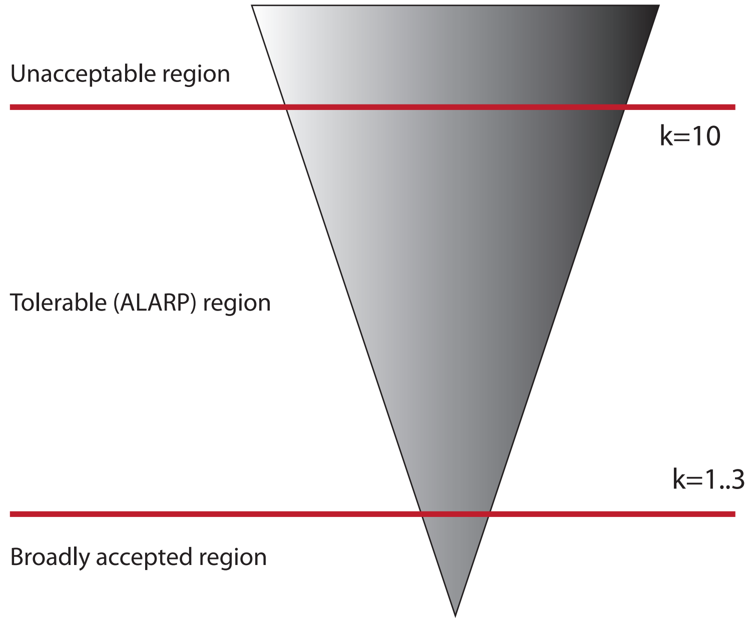

Fig. 3. ALARP principle

mental recovery. Such analyses are often called cost-benefit analyses, and may be considered as a utility based criterion. The other approach is to select 'state of the art' technology that for this type of risk reduction, in the expectation that it has previously been proved to be an adequate measure. In this case, we apply a technology-based criterion. Of the two approaches, the cost benefit analyses often get the most attion, and will be further described in the following.

The cost benefit analyses should have a disproportional balance costs and benefits [30]. The magnitude of disproportion should be influenced by the initial risk level. If the risk is high, meaning that it is within the upper zone of the tolerable region, it is expected that the plant owner spend more to reduce risk, than if the risk is lower, i.e. in the lower part of the tolerable region. The disproportional factor may be expressed by the following formula:

$$k = \frac{\text{Cost of measure}}{\text{Benefit from having reduced the risk}} \tag{2}$$

HSE suggests as a rule of thumb that the disproportional factor in the first case should be up to 10, and in the latter case down towards 3 (for workers) and 2 (for public) [30] and even 1 [25]. The triangle that is used in Fig 3 may be seen as a way to visualize the disproportional factor.

But what are included in the cost calculations, and how are the benefits quantified? Regarding the costs, it is first of all necessary to include the costs of introducing the measure, including material costs, installation costs, and any loss of production while the installation takes place. If the costs of installation is very high, it is expected that the costs may be shared by other activities that can take place during the same (shutdown period). Any additional costs, for example due to regular inspection and maintenance, should also be included. If the risk reducing measure may affect the production regularity or capacity negatively, these should also be reflected in the cost calculation. We may therefore give the following simplified equation for the cost (C):

$$C = C_I + C_M + C_{LP} \tag{3}$$

where C_I is the costs associated with installation (materials, labor, production loss during shutdown), C_M is the costs related to regular inspection and maintenance, and C_{LP} is the cost associated with reduced production capacity.

The benefits should quantify the value of averting fatalities, injuries, environmental recovery, and potential damage to material and financial assets and national heritage after an accident. An approach may be to first calculate the number of fatalities, injuries, and releases that may have a negative impact on the environment that are expected without the risk reducing measure and subtract the costs of fatalities, injuries, and environmental impact with the risk reducing measure in place. In some cases, there may be other (secondary) benefits, for example that a risk reduction measure leads to more efficient production. In this case, this cost may also be added.

We may therefore set up the following simplified equation for the benefits (B):

$$B = \Delta C_{VAF} + \Delta C_{VAI} + \Delta C_{VAE} + C_{Other} \tag{4}$$

where ΔC_{VAF} is the value of averting fatalities, ΔC_{VAI} is the value of averting injuries, ΔC_{VAE} is the value of averting environmental recovery, and C_{Other} is the value of any other benefits, such as increased production efficiency.

The quantification of benefits necessitates a value for a human life. This is not an easy task, as it includes ethical aspects and discussion about the value of a life. With injury, we also need to consider the cost of reduced quality of life. But even so, some values of a human life are suggested in the literature, for example £ 1 000 000 (2001 prices) which is proposed by HSE [30]. The value is determined based on what people seems to be willing to pay to secure small reductions in the risk of death in road traffic [22]. Higher values are recommended for death causes by cancer and radiation. In case the there is a potential for multiple fatality accidents, the plant owner may also be willing to pay a higher premium to avert fatalities to protect its public image and reputation [22, 30].

Discounting may be allowed to compare costs and benefits that occur in different time periods [24]. This may be straight forward with material costs, but may be controversial when considering the value of averting a fatality.

The criteria for what is unacceptable, tolerable, and broadly acceptable is most often used with individual risk, but it can also be defined for societal risk. In the UK, for example, it is considered unacceptable that any worker should face an individual risk of fatality of more than $1 \cdot 10^{-3}$ /year, whereas the limit for a member of the public is set one magnitude lower, $1 \cdot 10^{-4}$ /year, to reflect their lower voluntariness to the risk. On the other end of the scale, it is considered broadly acceptable that a worker has an individual risk of $1 \cdot 10^{-5}$ /year and for a public member $1 \cdot 10^{-6}$ /year. This corresponds to levels of risks which they are exposed to during other normal activities during a day.

6.2 ALARA

ALARA stands for 'as low as reasonably achievable', and is a principle that is similar to ALARP with one important distinction: The broadly acceptable region is not defined, because it is believed that all risks, as long as reasonable, should be reduced.

The principle was introduced by the International Commission on Radiological Protection (HSE homepage). A rationale for introducing this approach in this context may have been the difficulty of setting broadly acceptable quantities for radiations, which effects may not be known until many years later and for future generations.

The principle is also used by the Netherlands for the landbased industry, and also mentioned by the Canadian guideline on risk assessment and criteria setting [10]. As with ALARP, they need to adhere to good practise principles for cost-benefit analyses, similarly to what the practise that recommended by HSE.

6.3 MEM and GAMAB

MEM and GAMAB are two criteria setting principles that are frequently used in transportation, and in particular for railway (EN 50126). While MEM is used in Germany, GAMAB is used in France.

MEM stands for Minimum Endogenous Mortality, that is the estimated inherent mortality that is associated with a population of humans. The principle for criteria setting with MEM is that a new systems should not lead to a significant increase in the risk that is estimated for a group of population with the lowest endogenous mortality.

GEMAB stands for Globalement Au Moins Aussi Bon and is formulated as follows: A new guided transport system must offer a level of risk globally at least as good as the one offered by any equivalent system. The principle therefore share some characteristics with the technology-based criterion.

A drawback with this criterion is that it may inhibit new technologies that could have lead to reduced risk to personnel. For illustration, we may consider a knife. Cutting with knife is always and option to automatic bread cutters. If an automatic and rather expensive bread cutter is introduced to the market, it will inhibit others from introducing, at a later point in time, an automatic bread cutter that is cheaper than the expensive one as long as it is less safe than the expensive one. Regardless of the fact that this cheap bread cutter is safer than the knife.

The GEMAB principle has been adopted by the integrated pollution and protection control directive [16], and several guidelines are published on what to consider as 'best available technology' within the various industry sectors and application areas.

6.4 Risk matrix

A risk matrix is a table where each cell corresponds to a combination of probabilities and consequences of an hazardous event. The criteria is reflected by colors, indicating unacceptable combinations of probabilities and consequences, tolerable consequences, and broadly acceptable consequences.

The risk of each hazardous event may be located in the cell according to the most probable combination of probability and consequence. The way the risks appear in the table may form the basis for risk ranking, indicating which hazardous events that have the most (and possibly unacceptable) risk, tolerable risk, and broadly acceptable risk.

The probabilities and consequences may be purely qualitative, for example with probabilities that are either frequent, probable, occasional, remote, or very unlikely and consequences that are either minor, major, critical, and catastrophic. Another approach is to translate these categories of probabilities and consequences into quantitative values, for example that frequent means once every month or more often, and that a catastrophic consequence involve more than 100 fatalities. In this case, we may say that the risk matrix is a semi-qualitative way of criteria setting and risk ranking.

In France, a particular risk matrix has been developed for use with authorization of landbased process industry [17]. An operator who want to build and operate a plant must first obtain a permit called Prefect Authorization. With the application, it is necessary to submit a safety report which identifies the hazardous events and quantifies their risk. The authorities will use a risk matrix to determine if the risks imposed are too high to get authorized, if the risks are at a level where authorization can be given once all risk controlling measures have been put in place, or if the risks are so low that the authorization may be given.

6.5 Precautionary principle

The precautionary principle was originally formulated in the context of (global) environmental protection, for example, by the United Nations Conference on the Environment and Development (UNCED) in 1992, saying that:

> *...where there are threats of serious or irreversible environmental damage, lack of full scientific certainty shall not be used as a reason for postponing cost effective measures to prevent degradation.*

The European Community (EC) Treaty Article 174 says that the the EU environmental law should be based on the precautionary principle. However, the EIA directive does not mention the principle, except a reference to the mentioned treaty [12].

With the somewhat unclear implementation of the precautionary principle, EU has published a communication letter on what situations the precautionary principle should be selected and what type of analyses that are necessary in this case. Several articles, guidelines, and books discuss the use of this principle on environmental issues as well as in a broader context, see e.g., [38, 14, 34, 12].

So far, the precautionary principle is not mentioned in the Seveso II directive. But national authorities, like e.g., HSE, give guidance on when to “evoke” the principle and in what way current methods for risk assessments are inherently precautionary [30].

7 Risk metrics and risk criteria

A large number of risk metrics are used, both to measure risk and to set risk criteria, and some of these are shown in Table 2. The purpose of this section is to describe the meaning and application of these metrics. Formulas are not presented, and here it is referred to other literature such [39, 2, 8].

Table 2
Risk metrics for landbased process industry

Risk metric	Explanation
Average individual risk:	
- Individual risk per annum (IRPA)	Probability that an individual shall suffer a fatal accident during a year (probability of having a fatal accident/year*person)
- Localized individual risk per annum (LIRA)	The probability that an individual will suffer a fatal accident at a particular location (probability of having a fatal accident/year*person)
- Injury	a) May be a weighted factor of IRPA and LIRA (with the so-called 'injury criterion')[13, 29]
	or b) alternative, as various tolerability limits from heat radiation (kW/m), explosion overpressure (kPa), or toxicity (concentration) [41]
Comments:	
- LIRA may be shown as risk contours on maps	
- In the UK and Australia, LIRA is used to express the	
probability of receiving a dangerous dose or worse	
- A dangerous dose leads to severe distress, and in some cases (1%) to death [30]	
Societal risk:	
- Fatal accident rate (FAR)	The expected number of fatalities per 100 million hours ('1000 work lives')
- Potential loss of life (PLL)	The expected number of fatalities within a population or within an area during a specified period of time (e.g., a year)
- f-N curve	The frequency of exactly N fatalities
- F-N curve	The frequency of at least N fatalities)
Environmental risk	Qualitative consequence tables, see e.g., [41]

7.1 Individual risk

A frequently used measure for activity based individual risk is the individual risk per annum (IRPA). Regarding the localized individual risk, it should be noted that there are many different notations for the same type of metric. In this paper, we therefore use the notation localized individual risk per annum (LIRA) to be make sure that it is distinguished from the activity based measures.

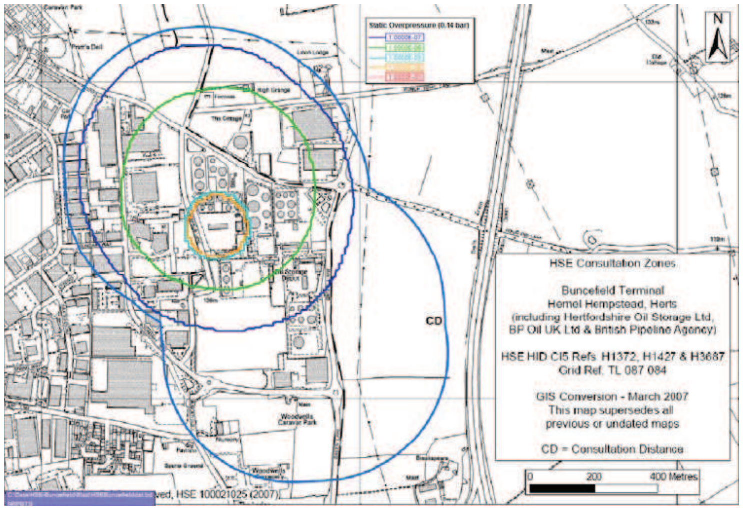

Fig. 4. Risk contours for localized individual risk (from [6])

For some type of accidents, for example where the public may be exposed to toxic gas clouds, it may be just as important to assess the risk of injury as to determine the risk of fatalities. Injuries may reduce the quality of life and have long term effects, even on the next generations. Two approaches for injury metrics are shown in Table 2:

- 'Injury criterion': Here, potential injuries are classified as either minor or major, and a corresponding weight factor is used to set the acceptance criteria relative to the criteria that are set for fatality risk. The approach is further explained in HSE [29] and [13].
- Indirect measures: Limits of tolerances for dangerous doses of heat radiation, explosion overpressure, and toxicity that may lead to personnel injuries are provided [41].

In the communication of individual risk with the public, for example in land use planning, the localized individual risk is often plotted as risk contours on maps. One such example is shown in Fig. 4. Here, the individual risk values are split into zones (or contours), ranging from the limit of tolerability to what is considered as negligible risk.

7.2 Societal risk

The most frequently used metrics for social risk are fatal accident rate (FAR), potential loss of life (PLL), and f-N and/or F-N curves.

FAR is defined as the number of expected (or observed) fatalities per 100 million *exposed* work hours. The risk metric is easy to understand, but may in some cases give a slightly wrong (and unfair) indication of risk. The FAR is often calculated

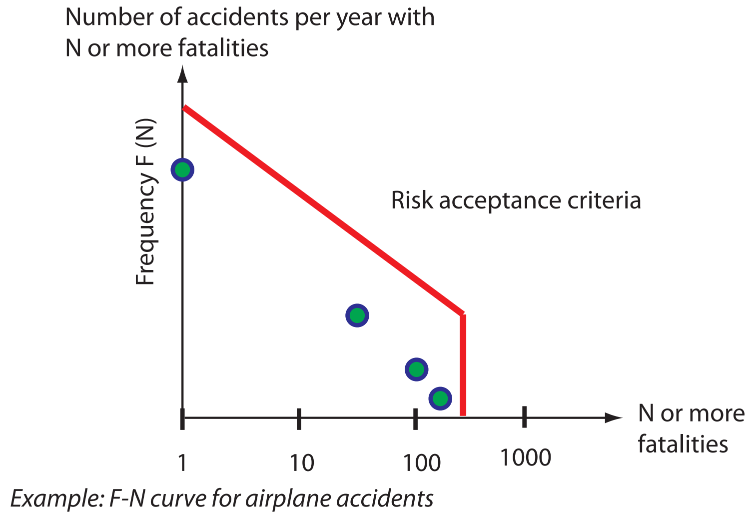

Fig. 5. Example of an FN-curve

for a company or a plant as a total, which means that a common FAR is given even if some workers (e.g., maintenance personnel, field operators) are exposed to higher risk, when exposed, than others (e.g., engineers working in office).

PLL is the expected (or observed) number of fatalities within a population or in a particular location during a specified period of time, usually a year. When calculating the PLL, the exposure time is not considered. To determine a PLL we simply count the number of fatalities during the time period, for example the number of people dying in car crashes, without considering how much time car drivers spend on car driving.

It is possible to convert PLL to IRPA by dividing PLL with the number of personnel that are exposed to the risk, i.e., the number of car drivers if we use the example above.

Many national authorities and guidelines provide societal risk acceptance criteria as plots in f-N curves or F-N curves. One example is shown in Fig. 5. The f-N curve is used to show the frequency of having exactly N fatalities, while the F-N curve gives frequency of having N or more fatalities. Both metrics are used to address different outcomes of a single event. In Fig. 5, it is demonstrated how the number of (hypothetical) accidents that lead to N or more facilities could be plotted against the frequency of how often they occur. We may expect that the frequency of accidents with one or more fatality is high compared to accidents with higher number of fatalities, as the first type of accidents include the accidents with small single engine planes. The hypothetical acceptance criteria is indicated in the plot, showing that airplane accidents with more than five hundred fatalities are not acceptable (or realistic).

The f-N and F-N curves are often plotted with logarithmic scale on both axes to make the curve linear. This may easily be shown by taking the logarithm of

(1) considering $\sum_{\text{All outcomes}} p_i$ equal $\Pr(N \geq n)$ or F(N) and $\sum c_i$ used with the meaning 'N or more fatalities':

$$\log R = \log F(N) + \log C \tag{5}$$

or

$$\log F(N) = \log R - \log C \tag{6}$$

The different countries may often suggest a criteria for a certain outcome. HSE suggests, for example, that the society is willing to tolerate a major accident with 50 or more fatalities one time every 5000 years. Based on this information, it is possible to plot a point in an F-N curve. Equation (6) indicates a slope of -1 on the logarithmic scale. This information may be used to construct the F-N curve for the acceptance criteria of societal risk that is shown in Fig. 5 (marked 'HSE').

Having a slope of -1 is often referred to as having no risk aversion [43, 56, 55]. This means that a large fatality accident is not weighted more than a smaller fatality accident. Another way to characterize this situation is that there is no aversion implemented [43, 56, 55].

The Netherlands have selected a slightly different approach, and included risk aversion in their criteria of societal risk. Here, they introduce an aversion factor k, so that $R = F(N) \cdot C^k$. Taking the logarithm on both sides gives:

$$\log F(N) = \log R - k \cdot \log C \tag{7}$$

In their criteria, the Netherlands uses $k = 2$. The resulting curve for the risk acceptance criteria is shown in Fig. 5 (marked 'VROM'). In the same figure, it is shown two additional curves, one for the risk acceptance criteria in Hong Kong and one for Danmark. As seen, the VROM criteria represent the strictest one, and Hong Kong does not accept any accidents with 1000 or more fatalities.

Both curves are drawn with logarithmic scale on both axes, so that the curves in the plot may be (close to) linear.

8 Evaluation and comparison of practises

This section gives a brief review of some of the current practises with risk acceptance criteria, using the UK and the Netherlands as examples.

Table 3
Overview of UK laws

Control with major accident laws	Notification of Installation Handling Hazardous Substances Regulations(NIHHS) (1982) with amendment in 2002 [46]
	Control with Major Accidents Regulation (COMAH) [50] with amendments [47]
Land use planning laws	Planning (Hazardous substances) Act 1990 [48]
	Planning (Hazardous Substances) Regulations (1992) [49], as emended by The Planning (Control of Major-Accident Hazards) Regulations 1999 [51]
Environmental impact	Should consult The Environment Agency

8.1 *Laws and authorities*

In the UK, the Seveso II directive is implemented through the following laws, acts, and regulations, see table 3. These form the basis for control with risk at the a plant, from the plant on the vicinity, and in relationship with other land use in the area.

Land use planning sets premises for new and existing landbased process industry. Land use planning controls have been a feature of the UK's strategy for managing major hazards for over 30 years. This originated largely from the Flixborough incident in 1974 in which a chemical plant exploded resulting in 28 deaths [26]. Improvements have been made to the laws and regulations after more recent accidents, for example after the Buncefield accident [6].

In the UK, it is the local planning agencies that make decisions regarding new developments [6]. Such developments may be to introduce a new landbased process industry to an area or plan for new developments around an existing industry.

Even if the local planning agencies have the authorities, they should consult the HSE for developments within the consultancy distance [6]. For this purpose, HSE has developed a guideline, the so-called PADHI guideline [23]. In addition to the guideline, the HSE is responsible for providing the local authorities with updated zone maps for the area around a landbased process facility. HSE split the surrounding area into three zones, the inner zone which starts at the fence of the process facility, the middle zone, and the outer zone. The outer border of the outer zone denotes the consultancy distance [6]. How the zones are constructed and used for land use planning are further described in Section X.

Even with laws and guidelines in place, the local authorities face several challenges related to land use planning [26]. One one side is the public and developers in the vicinity of a landbased industry, who would like to use the land for new residential, transportation, and commercial purposes, like new houses, new roads, and new retail centers. On the other side is the local authorities that need to balance such demands with laws, HSE advices, and HSE guidelines. Even if the public is concerned with their safety, it is not always easy for them to see the potential danger in a plant that has been in their vicinity years .

8.1.1 The Netherlands

The development of a policy for setting quantitative criteria for the tolerability of risk originated in the beginning of the 1980s, when it became clear that the use of liquified petroleum gases (LPG) would increase considerably [5]. Further development of acceptance criteria has of course been influenced by the Seveso Directive and lessons learned from major accidents in the landbased process industry, for example the Enschede accident in the Netherlands in 2000.

The Seveso II directive is implemented through [4]:

- Dutch Major Hazards Decree (BRZO) which focuses on the management of hazardous installations.
- Dutch Public Safety Decree (BEVI) which focuses on the regulations of land-uses around hazardous installations, i.e., the external safety regulation.

In short, the BRZO requires the applicant, i.e., plant owner or developer, to submit a safety report to the the permitting authorities. Permitting authorities also govern the land use planning. The safety report includes a quantitative risk analysis (QRA) with metrics for individual risk and societal risk [6, 4]. The permitting authorities use this information and the requirements in BRZO and BEVI as basis for their decision making. Regarding individual risk, the criteria are so-called legally binding, while the criteria for societal risk are considered to have an advisory role.

In the Netherlands, it is distinguished between three levels of permitting authorities [4, 17], the national level, the provincial level, and the municipal level. All three permitting authorities have their own independent planning power, but all decisions must respect the Dutch Spatial Planning Act.

What authority that would be relevant for a new installation under the Seveso II directive, depends on it's the major accident potential. Installations of national interest, such as nuclear power plants, is governed at the national level, with the Ministry of Housing, Spatial Planning and the Environment (VROM) as the competent body.

Other industry facilities are split into two groups, top-tier and lower-tier. Top-tier facilities are the ones that handle one or more of the ten ten carcinogenic substances, for which the Seveso II directive has specified very low quantitative thresholds [36]. Any landbased process industry of this category have the provincial competence as the permitting authority. For low-tier facilities, meaning other industry facilities that are under the Seveso II directive, including LPG storage, have the municipal competence as permitting authority.

8.2 *Risk acceptance criteria*

8.2.1 *The UK*

Getting a clear understanding of the most recent criteria in the UK is a cumbersome exercise. There are a large number of documents, e.g., [29, 31, 30, 21, 6, 1, 23, 26, 28] that present in some cases similar, but in other cases, slightly different criteria. Based on the literature review, we may split the criteria into two categories: The criteria that are used to control risk at and from the plant, and criteria that are used for land use planning.

Criteria for reducing risk at and from the plant: All facilities with dangerous substances must demonstrate, by risk assessments, that they meet the individual risk acceptance criteria set for workers and public members. In addition, it is necessary to demonstrate that the plant meets the risk acceptance criteria for societal risk for major accidents.

Regarding the individual risk, it is the activity based individual risk that is calculated. However, only activities occurring at the plant that may have an effect on the individual, either the worker or the public member, are taken into account. Since different workers and different public members have different living conditions, risk exposure, and health condition, the calculations are based on hypothetical (representative) persons: One calculation is done for a hypothetical person that represents a worker and one for a member of the public. A further description of the assumptions that are made for a hypothetical person is found in [20, 30].

The individual activity based risk criteria, which is a localized risk metrics, are found in [29, 31, 30] and summarized in Fig. 6. From the figure we see that:

- A activity based individual risk above $1 \cdot 10^{-3}$ per year is unacceptable, while it is considered broadly acceptable when this risk is below $1 \cdot 10^{-5}$ per year.
- For the public, the criteria is a magnitude lower, which means that a localized individual risk above $1 \cdot 10^{-4}$ per year in not acceptable but broadly acceptable if below $1 \cdot 10^{-6}$ per year.

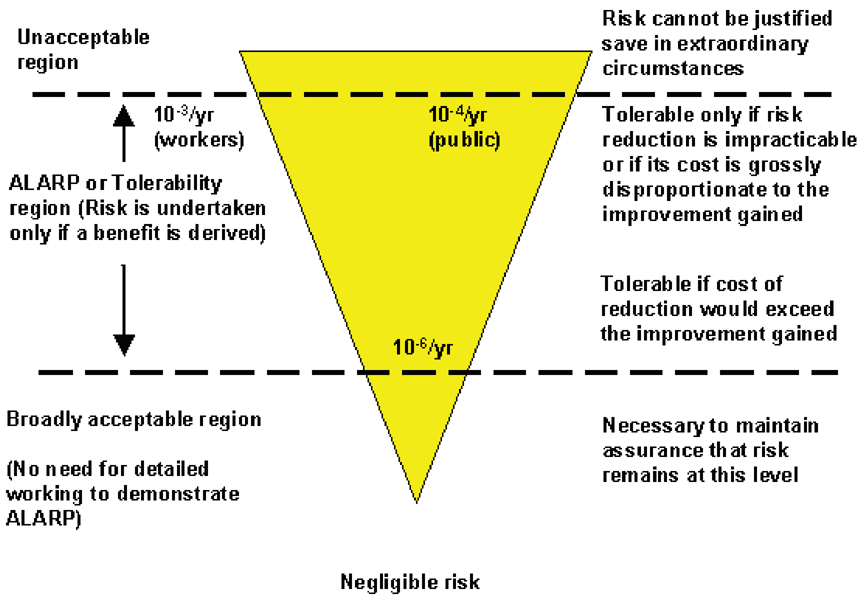

Fig. 6. Individual risk of fatality (from [27])

In the ALARP zone, which for workers would be between $1 \cdot 10^{-3}$ per year and $1 \cdot 10^{-5}$ per year and for the public $1 \cdot 10^{-4}$ per year and $1 \cdot 10^{-6}$ per year, require risk reduction according to the criteria described in Section 6.1. Risk contours are often used to visualize the criteria and the specific results from the risk analysis.

According to the so-called R2P2 report [30], the criteria for societal risk were based on an examination of the levels that society was prepared to tolerate from a major accident affecting the population surrounding the industrial installations at Canvey Island on the Thames. Reports on the risk from the installations at Canvey Island were discussed in Parliament, and (after improvements) the risk was deemed by Ministers to be just tolerable. Based on these studies, HSE made the following recommendations:

- Societal risk criteria for the limit of tolerability, for accidents where there is some choice whether to accept the hazard or not: The risk of an accident causing the death of 50 people or more in a single event should be regarded as intolerable if the frequency is estimated to be more than one in five thousand per annum , or $(2 \cdot 10^{-4}$ per year.
- The F-N curve is constructed using the assumption of no risk aversion (slope of -1 on the logarithmic scale).

The resulting F-N curve is further described in Section X.

Criteria for land use planning: A different set of criteria applies to land use planning [30, 17, 6, 4, 17, 9]. The result of having applied the criteria is a zone

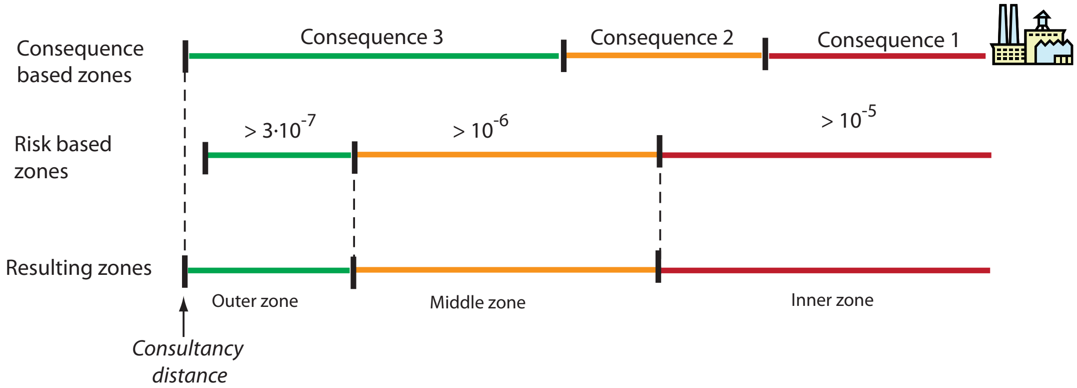

Fig. 7. Zone map construction in the UK)

map, indicating three zones with different recommendations of land use: The inner zone, which is closed to the plant and starts at just outside the fence, the middle zone, and the outer zone. The distances between each zone are based on a combination of a consequence approach and a risk based approach. The consequence based approach suggest the zone distances based on two sets of three consequence categories, one set considering the effect of explosion overpressure and one set considering the effect of heat radiation. The two approaches may end up with different zone distances, and in this case the zone map is constructed using the longest distances obtained for each zone.

When toxic release may be experienced, it is necessary to also perform a risk based determination of the zones. Again, the distances obtained for the zones are compared the distances obtained with the consequence based approach, and the most conservative ones selected. The approach is illustrated in Fig. 7.

At the outer edge of the outer zone is the consultant distance. This is the the furthest distance at which HSE wishes to be consulted about developments near hazardous installations/major accident pipelines. Within the consultant distance, the HSE undertakes an assessment of the hazards and risks from the installation and produces an updated map with three contours representing defined levels of harm or risk which any individual at that contour would be subject to.

Recent communications from HSE, it is mentioned that the inner zone can be split into two parts, a proximity zone and the (remaining part of) inner zone [26], but this approach does not seem to be fully implemented yet.

For the risk based approach for toxic releases, it is the localized individual risk (i.e., probability) of receiving a dangerous dose or worse that is calculated and used as basis for setting the zone distances. The zone distances are selected to reflect that the probability of receiving a dangerous dose of worse within the:

- Inner zone: $> 1 \cdot 10^{-4}$ or more [6] (alternatively, $> 1 \cdot 10^{-4}$ or more [26]) per year
- Middle zone:$> 1 \cdot 10^{-6}$ per year

Level of sensitivity	Development in inner zone	Development in middle zone	Development in outer zone
1	DAA	DAA	DAA
2	AA	DAA	DAA
3	AA	AA	DAA
4	AA	AA	AA

Sensitivity level 1	*Example*	Factories
Sensitivity level 2	*Example*	Houses
Sensitivity level 3	*Example*	Vulnerable members of society eg primary schools, old people's homes
Sensitivity level 4	*Example*	Football ground/large hospital

DAA means Do not Advise Against the development
AA means Advise Against the development

Fig. 8. Decision matrix for land use planning

- Outer zone: $> 3 \cdot 10^{-7}$ per year

Here, a dangerous doze is defined as a doze that leads to severe distress, need for medical treatment, and in some cases (about 1%) to death [28].

When the zone map is updated, the local authorities will make their advice in accordance with the PADHI guideline. This guideline uses a decision matrix, which is shown in Fig. 8. Based on the level of sensitivity for the new development, which may be from 1 to 4, and the zone in question, the decision matrix will propose either one of the two advices: 'Advice against" or "do not advice against" (the development). The local authorities will often, but are not obliged, follow these advices.

Until recently, HSE has made their land use decision guidance based on calculations of individual risk. But HSE acknowledges that societal risk should be considered [26]. For this purpose, they have started to use what is referred to as area risk integral (RI), sometimes also denoted $\mathrm{ARI}_{\mathrm{COMAH}}$, which is defined as [7]:

$$\mathrm{RI} = \sum_{\mathrm{All\ N}} F(N) \cdot N \tag{8}$$

How the $\mathrm{ARI}_{\mathrm{COMAH}}$ relates to different individual risk metrics are shown in [27].However, at this point it is not evident that this metric has been widely adopted.

8.2.2 The Netherlands

The Netherlands is perhaps the most densely populated European country, and it is evident that proper land use planning is important to avoid conflicts between residential areas and various types of landbased process industry, also in-

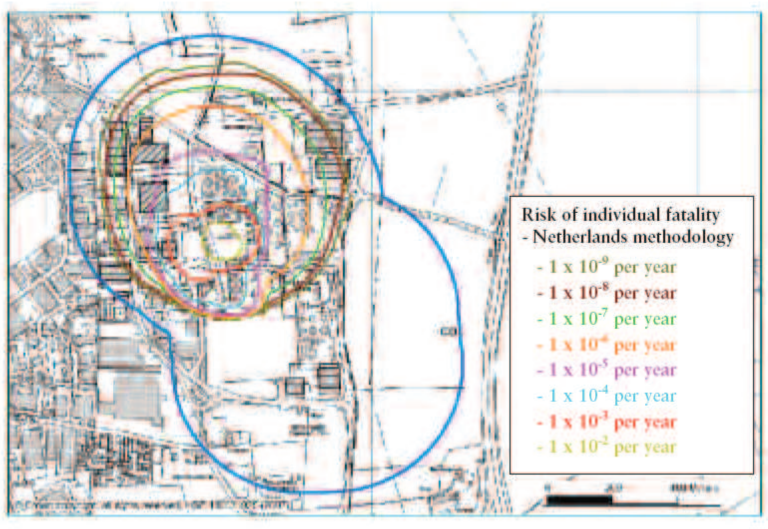

Fig. 9. (Localized) individual risk contours (from [6])

cluding small scale plants such as natural gases and hydrogen refueling stations.

It is required to submit a detailed quantitative analysis (QRA) with an application for a a new landbased process facility, or for a modification of an existing plant. The handling of the application follow the levels of authorities described in Section 8.1.

The Netherlands use both (localized) individual and societal risk acceptance criteria for land use planning. They are presented in 'The Purple book' [45], and also by Deutch laws (BEVI,BRZO) [17]. While the individual risk criteria are considered as legally binding thresholds, the societal risk criteria represent targets (advisory) [16]. (I have not identified other criteria that applies to the risk from and at the plant).

The principle for risk reduction shall follow the ALARP principle. This principle did in 1993 replace the ALARP principle [5].

The current risk control policy may be summarized as follows [9, 4, 6]:

- Both individual and societal risk shall be quantified
- Regarding individual risk, the criteria concerns localized individual risk due to a single risk source (e.g., from a plant)
- As part of the criteria setting it is distinguished between:
  · Vulnerable objects, that accounts for hospitals, schools, and residential areas.
    For these objects, LIRA $< 1 \cdot 10^{-6}$/year.
  · Less vulnerable objects, that includes industrial zones, office buildings, or recreational facilities. For these objects, LIRA $< 1 \cdot 10^{-5}$/year.
    From 2010, the criteria will be LIRA $< 1 \cdot 10^{-6}$/year for existing as well as

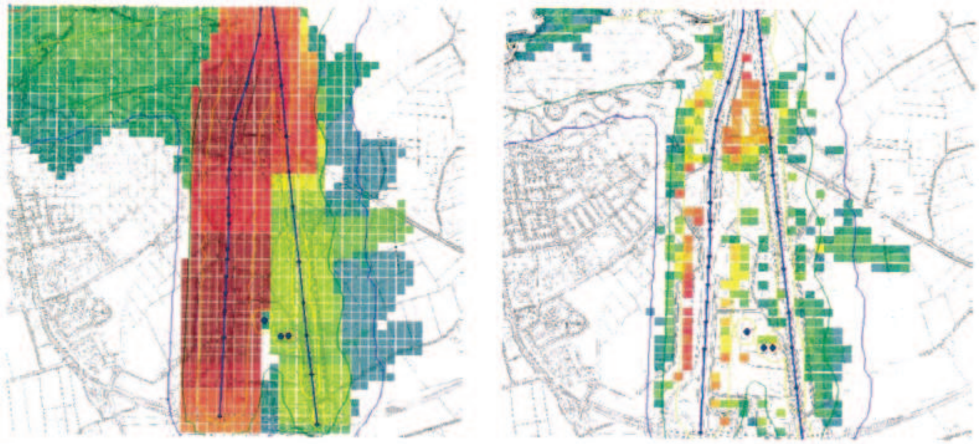

Fig. 10. Societal risk map as used in the Netherlands (from [52])

new installations.

- Regarding societal risk, the acceptance criteria is plotted in an F-N curve based on the equation:

$$1 - F(N) < \frac{10^{-3}}{N^2} \tag{9}$$

for $x > 10$ fatalities. This means that the frequency of having 10 or more fatalities should be less than $< 1 \cdot 10^{-5}$/year, for 100 fatalities less than $< 1 \cdot 10^{-7}$/year and so on.

The F(N) curve therefore implements a risk aversion factor of 2 (slope -2).

For communication with the public, the Netherlands make two kinds of risk plots; Risk contours for localized individual risk which is shown in Fig. 9 and risk maps which is shown in Fig. 10. It should be noted that the risk maps may be presented in many different ways, see e.g., in [52].

Risk maps have been introduced as an easy-to-read approach to societal risk [37, 4], as a means to improve the communication of risk with the public and decision makers in the follow-up of accident of Enschede [3]. The main objective is to indicate areas that are close to the acceptance criteria (red on the map), and those that represent lower risk, starting with orange, to yellow, green, and finally blue. Further information on how the risk maps are constructed, is found in [52].

The initial intention was to have them available for the public through the internet. However, questions were raised if the 'citizens right to know' was to be valued higher than the potential threats of having such information open to everyone. So, the result is that the risk maps may be obtained by following certain procedures.

A point to note, is that the Netherlands insist on the use of the same methodology for making risk calculations, for example by using the SAFETI software [9, 6], to ensure that the results are derived with the same premises as basis.

No specific criteria for acceptance criteria for environmental impact have been identified, the need to perform such studies are addressed in BRZO and the Environmental Management Act. The environmental effects of any major accident on air, water, and soil must be included in the analyses [17].

8.3 Summarizing the different practises

An overview of how the UK and the Netherlands approach criteria setting, authority in land use planning, and risk communication is presented in Table 4.

9 Conclusions and final remarks

This paper has described and discussed principles for risk acceptance criteria, and compared their application in the UK and the Netherlands. Based on the results, we find that different practises are used even if the countries adhere to common set of directives, such as the Seveso II directive. It seems like the practises that have evolved over many years are adhered to, and that new updates in European laws and directives do not really change their main course.

At this point in time, it is difficult to determine which approach that is the best. And perhaps it is not possible to make such conclusions, as they are used under different premises in laws, authorities, culture, and experience.

At first glance, it may seem that the approach for criteria setting is more clearly defined in the Netherlands. One reason is that the criteria of individual risk is stated in the law, and that the advice on societal risk is always traced back to the 'purple book'. In the UK, there are numerous documents that discuss risk acceptance criteria, and several versions of the requirements are published through reports, guidelines, communication letters and so on at the HSE home page. For a reader, it is a cumbersome process to identify the criteria that are the most recent and widely applied criteria.

An advantage with the approach in the UK is the openness in communication with the public. Almost all research reports, communications, guidance, and laws are freely available on the internet. Many of the documents do not only give requirements, but also discuss their underlying rationale and objectives. In this way, the documents can be used for educational purposes and raise the general level of competence among risk consultants, analysts, and researchers.

Table 4
Comparison of practises in the UK and the Netherlands

Topic of comparison	Comparison
Authorities	In the UK, it is the local authorities that make decisions regarding land use, regardless of type of new development. In the Netherlands, new developments under the Seveso directive follows a multi-level authority, where some land use is handled at the national level (VROM), and other decisions at the provincial or the municipal level.
Criteria setting	The UK mainly uses individual risk as criteria for land use planning, while the Netherlands use both societal and individual risk. The Netherlands consider the individual risk criteria as legally binding, while the UK does not. Neither countries have legal binding on the societal risk In the UK, criteria are listed in several documents (guidelines, so-called public communications, miscellaneous papers, reviews, information pages at www.hse.com), and it is not always easy to understand what is the most recent ones. In the Netherlands, it is usually referenced to the same source, the Purple book (CPR 18E). The Dutch requirement is stricter than the UK on societal risk, and implements, unlike the UK, risk aversion. UK defines levels of negligible risk and broadly acceptable risk, while the Netherlands do not define such lower limits. For land use planning, HSE uses a combination of a consequence based and risk based approach. The Netherlands use a risk based approach, and consider risk of fatality of individuals. HSE seems to provide more guidance on the practical use of the criteria than the Netherlands, for example on how to use cost-benefit analyses.
Risk assessments	Both countries authorities update the risk zones for land use planning purposes. In the UK, it is the HSE that performs the quantitative risk analysis based on key properties of the plant in question, for example the type and amount of dangerous substances, while in the Netherlands it is expected that the plant owner perform and include such analyses in their application for new facilities or for modifications of existing ones.
Risk communication	Risk contours are used in both countries to present individual risk. In the UK, a concept of inner, middle, and outer zone is used, while the Netherlands suggest drawing risk contours for individual risks from $1 \cdot 10^{-5}$ and each of the following three lower magnitudes. Societal risk is not used for land use planning in the UK (even if it is an ongoing discussion if they should do it), while the Netherlands compare the societal risk with the corresponding risk acceptance curve in F-N curves.

It could be interesting to complement this article with some missing pieces, e.g., to study and compare the practises of risk criteria setting for environmental impact, pollution prevention and control, and for consequences that may affect future generations.

In addition, it may be of interest to go even further and include compare other countries practises. Some comparisons have been done already and are presented in various literature sources. However, a comparison that takes the perspective of the process industry facility and identifies all types of criteria that would apply, seems to be missing.

In some countries, like in Norway, it is the developer that sets the risk acceptance criteria. This approach has been questioned, and an area of further work could be to perform a holistic comparison of consequences and benefits of this approach compared to some of the other countries.

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