Risk criteria in EU

V.M. Trbojevic
Risk Support Limited, London, U.K.

ABSTRACT: This paper focuses on risk criteria used in the EU for population living in vicinity of hazardous facilities. The criteria vary from fully risk-based and goal setting to the prescriptive consequence based criteria. In spite of the philosophical differences in the formulation of risk criteria, there is a single EU Directive (Seveso 2) on the control of major accident hazards involving chemicals which applies to every member state and clearly the level of safety across the EU should be very similar if not the same. Therefore the first aim of the paper was to minimise the differences between the variety of safety approaches across the EU in order to develop risk acceptance criteria with the potential to converge to a unified set. The second aim was to develop societal risk criteria completely consistent with the legally applied individual risk criteria.

1 INTRODUCTION

Approach to safety differs considerably across the EU. While on one side there is a basic recognition that "zero risk" is not attainable and that the real aim must always be to identify, control and reduce risk, on the other side, as a sharp contrast, there is still a belief that application of good practice embodied in design and other standards removes risk. Between the two extremes there are several variations, the simplest one being that as long as risk is lower that a prescribed threshold, it is acceptable, and even that the regulator can accept developments up to that prescribed limit. This situation is obviously reflected in the risk acceptance criteria and the safety legislation. This paper focuses risk criteria used in the EU for population living in vicinity of hazardous facilities, for which the following classification is proposed:

1 Risk based, goal setting criteria where safety goal is specified and not the means of achieving it (UK).
2 Prescriptive, risk based criteria where a prescribed maximum level of risk is used for risk control (The Netherlands, Hungary, Czech Republic) and some form of risk reduction may be specified but not necessarily implemented.
3 Prescriptive, consequence based criteria where the prescribed level of impact is used for control (France) or no risk is allowed outside the boundary of the facility (Germany).

In spite of the philosophical differences in the formulation of risk criteria, there is a single EU Directive (Seveso 2) on the control of major accident hazards involving chemicals which applies to every member state. The objective of the paper is to review and compare the above types of criteria, and if achievable, to propose a unified risk criteria.

2 REVIEW OF RISK AND IMPACT CRITERIA

2.1 *Individual Risk Criteria*

Individual risk is the frequency at which an individual may be expected to sustain a given level of harm from realisation of specified hazards Institution of Chemical Engineers, 1992.

The comparison of the risk criteria in use in the UK, The Netherlands, Hungary and Czech Republic is presented in Table 1. These four countries were chosen a) as representative of the first two risk based approaches, and b) to compare what from the safety perspective could be called the "old" and the "new" Europe. In addition, the recent information from the review of land use planning (LUP) in the UK, HSE 2004a, has also been included in Table 1.

It should also be noted that the basis on safety regulation in the UK is encapsulated in the Health and Safety at Work Act [3] which requires the duty holder to ensure and demonstrate that risk to employees, part time employed persons and the general public is As Low As Reasonably Practicable (ALARP). The Health and Safety Executive (HSE) publishes from time to time the risk levels it considers as intolerable or tolerable under certain circumstances and while these risk levels cover all industrial activities in the UK, the primary instrument for risk control is ALARP dynamics.

Table 1 Comparison of Individual Risk Criteria

IRPA	UK	The Netherlands	Hungary	Czech Republic
10^{-4}	Intolerable limit for members of the public			
10^{-5}	Risk has to be reduced to the level As Low As Reasonably Practicable (ALARP)	Limit for existing installations. ALARA principle applies	Upper limit	Limit for existing installations. Risk reduc tion must be carried out
3×10^{-6}	LUP limit of acceptability (converted from risk of dangerous dose of 3×10^{-7})			
10^{-6}	Broadly acceptable level of risk	Limit for the new installations and general limit after 2010. ALARA applies	Lower limit	Limit for the new installations
10^{-7}	Negligible level of risk			
10^{-8}		Negligible level of risk		

The situation in other countries is not very clear; for example in the Netherlands, two regions Rijmond and Schiphol are excluded from the new criteria (in force after 2010), while if there is a lower risk situation than the norms require, the Authorities can allow building up to the norm; the enforcement of ALARA is questionable.

It can be seen from *Table 1* that individual risk of 10^{-5} per year represents the upper limit in Europe for existing installations, while in the UK the intolerable limit is 10^{-4} but ALARP is strictly imposed, meaning that in reality the risk is well below the limit. The upper limit for individual risk for new installations in Czech Republic and in the Netherlands after 2010 is 10^{-6} per year. It should also be noted that the individual risk in the LUP guidelines in the UK, HSE 2004a, in terms of a dangerous dose of 3×10^{-7} per year can be converted to individual risk of death of 3×10^{-6} per year. The quoted value for the Netherlands (10^{-5} and 10^{-6}) represent so called location risk (risk contour), or the individual risk to a person who is permanently at the particular location. In addition, in the case of the Netherlands, the risk value corresponds to one establishment (facility), and the cumulative risks from several establishments are not taken into account.

The negligible risk levels specified in the UK as 10^{-7} per year and in the Netherlands as 10^{-8} per year are not questionable and it will be assumed that 10^{-8} value can be accepted across the EU for the time being.

2.2 *Impact Criteria*

The example of the consequence (impact) based criteria used in France, Salvi & Gaston 2004, is presented in Table 2. These criteria apply to the list of reference or predefined scenarios such as boiling liquid expanding vapour explosion (for liquefied combustible gases), unconfined vapour cloud explosion (for liquefied combustible gases), total instantaneous loss of containment (for liquefied, non-liquefied and toxic gases), instantaneous rupture of the largest pipeline leading to the highest mass flow (toxic gas installations), fire in the largest tank (for flammable liquids), etc.

Table 2 Impact Thresholds

	France		Germany
Effects	**Fatality Criteria (1%)**	**Criteria for Irrevesible Effects**	No risk to be imposed on people or the environment
Thermal radiation	5 kW/m2 if the exposure is more than 1 min, or	3 kW/m2 if the exposure is more than 1 min, or	
	Heat load of 1000 (kW/m2)4/3s in case of short exposure duration	Heat load of 600 (kW/m2)4/3s in case of short exposure duration	
Overpressure	140 mbar	50 mbar	
Toxic dose	Based on LC1% and exposure time (passage of the cloud)	Based on irreversible effects (first inuries) and exposure time (passage of the cloud)	

2.3 *Societal Risk Criteria*

Societal risk (SR) is the relationship between the frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards, Institution of Chemical Engineers 1992.

The origins of the societal risk criteria in the UK can be traced back to the late 1970s, Ball & Floyd 1998. The Advisory Committee on Major Hazards suggested in 1976 that a serious accident in a particular plant was unlikely to occur more often than once in 10,000 years, which could be regarded on the border of acceptability, ACMH 1976. This has often been taken as an anchor point for the FN curve where the chance of an accident involving 10 or more fatalities should not exceed 1 in 10,000 per year. In the second Canvey report, HSE 1981, it was suggested that an event with 1,500 fatalities and the frequency of 2×10^{-4} per year (2 in 10,000) could be judged as intolerable. The proposed slope of the FN curve was –1 (no risk aversion), based on historical record for the chemical industry. In the study, ACMH 1981, it was quoted as an upper maximum tolerable risk level a line of slope –1 through the point N = 500 and F = 2×10^{-4} per year. However, in HSE 2001, it is suggested that the risk of a single accident causing the death of 50 people or more with the frequency of 1 in 5,000 per annum can be considered as intolerable. The broadly acceptable level of risk is suggested as a line three decades lower than the upper tolerable line. This evolution of the upper tolerable level of risk over 20 years is presented in Figure 1, and clearly demonstrates the value of ALARP dynamics and the goal setting approach in reducing the upper level of tolerability of risk.

The quoted criteria are not systematically used in the UK, however HSE is using ARI_{COMAH} risk integral, HSE 2003, for evaluation of societal risk. This approach is based on the accident with the highest number of fatalities N_{max} and its frequency $f(N_{max})$, which are used to evaluate an approximate level of the Potential Loss of Life (PLL) or the fatal accident rate, using the risk aversion exponent of 1.4 (slope of –1.4). The explanation for the choice of this exponent seems to be that it matches the historical data.

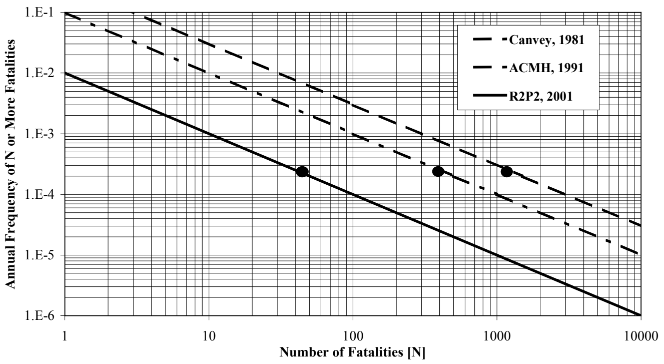

Figure 1 Evolution of the Upper Tolerable Level of Risk in the UK

It is also interesting to mention an alternative set of criteria based on the scaled risk integral or "injury criterion" has been proposed in 1989 by the HSE for land use planning (LUP), HSE 1989. The criteria are defined in terms of a dangerous dose of toxic gas, or heat, or explosion overpressure which gives the following effects a) severe distress to almost everyone, b) a substantial fraction requires medical attention, c) some people are seriously injured, requiring prolonged treatment, and d) highly susceptible people might be killed. The risk is then defined as the "risk of dangerous dose" or the risk of receiving a dangerous dose, or worse. The corresponding criteria are out of date but are summarised in Table 3 together with the current LUP methodology, HSE 2003. It should be noted that light shaded areas correspond to the new 2003 criteria, HSE 2003. The main difference is that in the current version there are three regions of risk zones (inner – nearest to the hazard site, middle and outer) for which HSE has not yet specified any numbers.

Regarding risk aversion, in the fundamental review of land use planning, HSE 2004a, there is the following quote "SR (societal risk) is concerned with measuring the likelihood of multiple fatality accidents and takes into account societal aversion", and the following example of historical data is given: "… the chance of killing 10 or more people in a fire in the UK is 1 chance per year. The chance of a railway accident killing or seriously injuring 100 or more people is 1 chance per 15 years". This would imply a slope of the FN line of –1.2.

Table 3 HSE's Land Use Planning Criteria

	Individual Risk of Dangerous Doze [Per Year] - 1989		
Category of development	**$> 10^{-5}$**	**Between 10^{-5} and 10^{-6}**	**Between 10^{-6} and 0.3 x 10^{-6}**
Sensitivity Level - 2003	**Inner Zone**	**Middle Zone**	**Outer Zone**
Housing developments providing for more than 25 people (Category A)	Assessment required Against development if > 25 people	Assessment required. Against development if > 75 people	Allow development
Level 1	**DAA**	**DAA**	**DAA**
Small workplaces, parking areas, etc. (Category B)	Allow development	Allow development	Allow development
Level 2	**AA**	**DAA**	**DAA**
Retail, community, leisure facilities, some workplaces, (Category C)	Assessment required. Against development if > 100 people	Assessment required. Against development if > 300 people	Allow development
Level 3	**AA**	**AA**	**DAA**
Highly vulnerable or very large facilities (Category D)	Against development	Assessment required. Against development if > 25 people	Specific assessment required
Level 4	**AA**	**AA**	**AA**
DAA	**Don't advise against development**		
AA	**Advise against development**		

In the Netherlands the Decree on Environmental Quality Requirements concerning external safety at Establishments (Staatscourant 22 February 2002, nr. 38) does not set the norm for SR, and "it has been decided, for now, to use societal risk values as non-legal orientation norms when assessing external safety". The values for orientation are the upper tolerable level as 10^{-3} / N^2 and the negligible level as 10^{-5} / N^2, in the FN space. This criterion has a slope of –2 and therefore incorporates risk aversion.

The upper tolerability criterion in the Czech Republic for the existing installations is the same as the "non legal" Dutch criterion (10^{-3} / N^2), while for the new installations it is more stringent, i.e. 10^{-4} /N^2. It seems that there are no societal risk criteria in use in Hungary.

The conversion of the old LUP criteria, HSE 1989, into FN criteria by interpreting location risk contour value as the probability of multiple fatalities is at least philosophically incorrect, but the results are interesting. By converting the location risk of dangerous dose that might kill highly susceptible people" of 10^{-5} to the location risk of death of general public of 10^{-6} (assuming that 10% of the general public are highly susceptible), the anchor points ($F=10^{-6}$, N=25 and $F=10^{-7}$, N=75) for the FN criteria can be obtained. It is interesting to note that the slope of the old UK LUP criteria is equal to –2.09, i.e. very similar to the slope in the Dutch and Czech criteria of –2.

In the absence on any other anchor points for the FN criterion, the risk matrix from the HSE guidance on ALARP demonstration in HSE 2004b, has been used to define the points $F=10^{-3}$ and $N=1$ and $F=10^{-6}$ and $N=100$ (implying the slope of –1.5).

It is far more difficult to convert the French criteria expressed as the minimum distance of the specified level of harm from the hazard source. The following approach is suggested – the assumption is made that the frequency of the predefined large consequence scenarios is 5 x 10^{-5} per year and that the probability of fatality at the boundary of the hazardous zone is 1% (i.e. 0.01); this defines the annual probability of death at that boundary of 5 x 10^{-7} (location risk contour).

It should be noted that the French criterion defines the safety distance (or the frequency of impact) regardless of the number of people living in the "safe" zone. Therefore, the second assumption is made that there would be no people living at the boundary i.e. in this case 5 x 10^{-7} contour, but that further away there could be some population, say at 10^{-7} contour. The French criterion is independent of the number of people exposed.

A comparison of the previously mentioned FN criteria is presented in Figure 2.

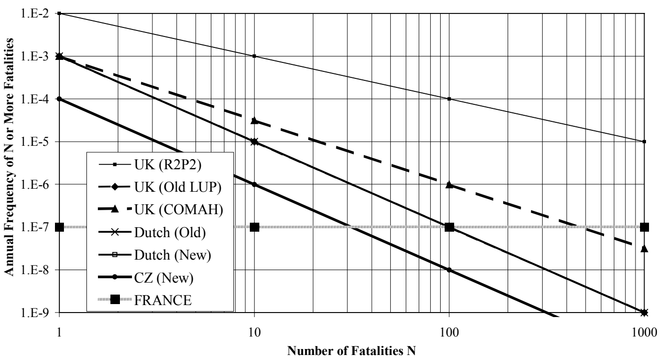

Figure 2 Comparison of FN Criteria

It is interesting to note that the UK (old LUP), and the old and new Dutch criteria practically coincide, while the Czech criterion for the new installations is a decade lower. The UK COMAH guidance, HSE 2004b, is not far off.

The French impact frequency criterion, not being risk based, will always deliver insufficient safety at large N, while it may also lead to unreasonable and uneconomical safety measures at lower N values. The situation will be worse by increasing the value of impact frequency.

The next objective is to link the societal risk criteria to individual risk criteria thus removing the following weaknesses:

1 There is no link to the "legally" quoted and used individual (or location) risk criteria, and
2 The size of the population FN criteria may be used for is undefined. It appears that the same criteria might be used for say 100 and 100,000 people.

3 LINKING SOCIETAL AND INDIVIDUAL RISK CRITERIA

The development of the societal risk criteria completely consistent with the individual risk is first proposed, Schofield 1993. This approach is based on a simple formula for PLL (potential loss of life) which is as follows:

$$N_{max} * IR = \Sigma f(N) * N$$

Where:
N_{max} is the number of exposed population
IR is the maximum tolerable individual risk
f(N) is the frequency of exactly N fatalities
N is the number of fatalities
β is a risk aversion factor which features in the risk criteria that incorporate risk aversion (i.e. in the definition of f(N)).

For a given cumulative frequency F(1), risk aversion factor and the maximum individual risk corresponding to the FN criteria presented in Figure 2, the number of exposed population (N_{max}) is calculated and shown in Table 4.

Table 4 Relationship between FN, IR and $\mathbf{N_{max}}$

Criterion	F(1)	Aversion Factor	IR	N_{max}
UK (R2P2)	1.E-2	1	1.00E-5	9,763
UK (Old LUP)	1.E-3	2	1.00E-5	163
UK (New LUP)	1.E-3	1.5	3.00E-6	847
Dutch (Old)	1.E-3	2	1.00E-5	163
Dutch (New)	1.E-3	2	1.00E-6	1,644
CZ (New)	1.E-4	2	1.00E-6	163

The above results clearly indicate the weaknesses of the quoted criteria which perhaps might be one of the reasons why the FN criteria are not officially used. On the other hand, in situations where the large offsite population is exposed to different levels of risk, intuitively it would seem that "risk averaging" as proposed by linking individual to societal criteria would not be politically acceptable. This type of argument can also be seen in the LUP criteria which (in the Netherlands and UK) either limit the number of people exposed to particular individual risk and/or specify upper limit for density of the population.

4 PROPOSED CRITERIA FOR EU

4.1 *Philosophical Basis*

It is assumed that there is an intolerable risk level which must not be exceeded and a negligible risk level which does not raise either individual or a public concern. These two levels encompass all other levels of risk in use in risk criteria across the EU, for example, the "upper and lower" limits, "broadly acceptable" limit, etc.

The region between these two limits can be called tolerability region. Within this tolerability region there is a risk level which is called here "target level" which is prescribed in some countries as either the upper level for new installations or target level to be used after 2010, etc. This target level is lower that the proposed intolerable level.

The doctrine of risk tolerability can now be developed along either of the two proposed principles:

1 The prescriptive approach preferred in Czech Republic, Germany and France, which is simpler to implement, requiring risk to be brought below the target level, and
2 The goal-setting principle preferred in the UK and partially the Netherlands which requires risk in the tolerable region to be reduced to a level which is as low as reasonably practicable (ALARP) or as low as reasonably achievable (ALARA).

Such a dual doctrine has the potential to be adopted across the EU. The countries where safety regulators lack the power or the know-how to impose a goal-setting approach could adopt the prescriptive approach. The progress by two approaches and the evolution of the best practice could be assessed say, every ten years, and the target boundary adjusted accordingly.

4.2 *Individual Risk Criteria*

These criteria are based on the following:

1 The upper or intolerable boundary for which the individual risk of 10^{-5} per year is proposed. This level of risk encompasses the criteria from other countries, except the UK where some older installations may not be able to comply. This could be avoided by delaying the date of introduction of this upper level of risk (e.g. until 2010).
2 The negligible risk level is set to 10^{-8} as this seems to be universally acceptable.
3 The "target level" is set at 10^{-6} per year as required by Dutch and Czech regulations.
4 Either of the two principles can be adopted in the tolerable risk region:
– The ALARP principle stating that risk is acceptable if as low as reasonably practicable (an acceleration factor in the higher risk region of the tolerability zone also applies meaning that more than nominally estimated should be spend on risk reduction than in the region of lower risk level), or
– The requirement that for all new installations the target level also applies as the upper limit (not necessarily excluding ALARP).

The proposed criterion for individual risk is presented in Figure 3.

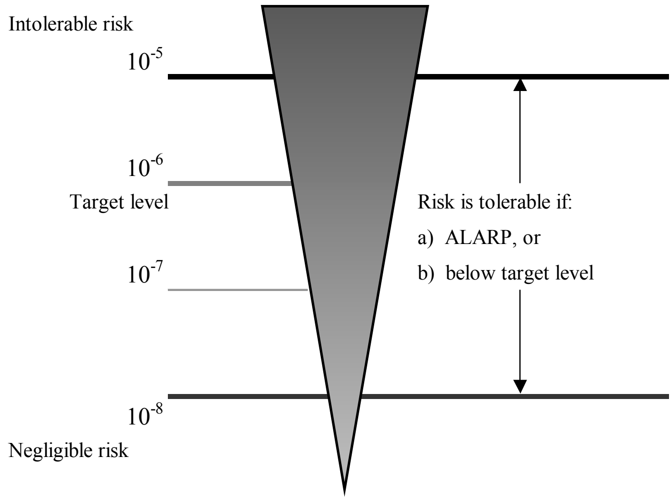

Figure 3 Proposed Individual Risk Criteria

4.3 *Societal Risk Criteria*

The societal risk criteria have the risk aversion built in and the slope of the FN line of –2 is adopted. This will be acceptable by the Netherlands and Czech Republic and perhaps by the UK as well. The argument for the UK for the risk aversion factor of 2 could be fortified by HSE's statement "that society is generally more concerned with one accident killing 10 people in one go, than 10 accidents killing one person each", HSE 2004a, and the precautionary principle. In fact it can be argued that risk criteria incorporating risk aversion are precautionary with respect to large consequence events. Large consequence events are inevitably associated with large uncertainties for which disproportionately more effort needs to be made to reduce the risks (principle of disproportion in the Tolerability of Risk Doctrine in the UK), which is, consequently, reflected in the proposed risk aversion factor.

The societal criteria presented here are based on several risk zones, for example, the inner (nearest to the hazard source), middle and outer zone for which the number of exposed people is given, as follows:

1 Goal-setting version - The intolerable limit of individual risk is defined and is the same for all zones. In addition, the population density, or the maximum number of people is defied for each zone. This can be achieved by specifying or limiting the potential loss of life for each zone. As the result there will be an upper tolerable boundary for each zone, as shown in Figure 4 for the maximum individual risk of 3 x 10^{-6} per annum and N_{max} equal to 10, 100 and 1,000 corresponding to the inner, middle and outer zones, respectively. Consequently, the FN curves will have to be calculated for each zone and compared against the corresponding criterion. The ALARP dynamics applies below the upper tolerable level of risk.

2 Prescriptive version – The target limit (lower than the upper tolerable) is defined along the same lines described in the previous point. The requirements for the FN curve is to be below the target boundary.

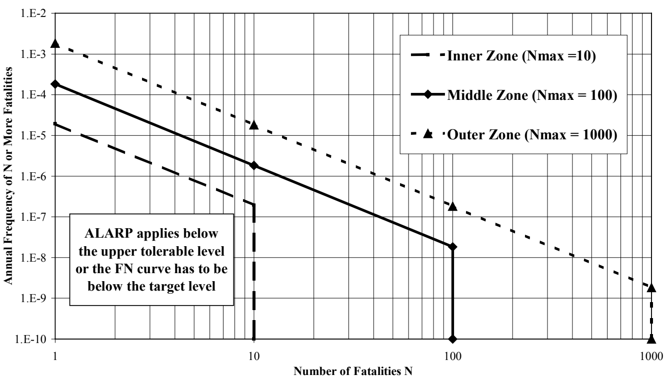

Figure 4 Proposed Societal Risk Criteria

The above criteria can be extended to include the negligible risk that would be compatible with the negligible level of individual risk.

5 CONCLUSION

It is shown in this paper that in spite of different approaches to risk control and management it is possible to develop risk criteria applicable across the EU. The original assumption that variety of risk criteria in use in the EU must deliver the similar levels of safety has been confirmed. The comparison between the criteria in actual use in different countries indicated considerable similarities with the exception of France and Germany where the trend seems to be in favour of converting to risk-based approach for safety regulation. This similarity facilitated the establishment of the tolerability limits and the tolerability region which encompasses all other risk criteria.

Risk management was then defined both along the goal-setting and prescriptive approaches in order for countries to choose according to their cultural and national preferences and to emphasise the convergence of the approaches.

The framework for societal risk criteria consistent with the (legally in use) individual risk criteria has also been confirmed. This approach has to be refined for situations where a large population lives in areas (or hazard zones) of varying risk level. An example of such criteria based on the same level of individual risk and the same level of expected fatalities across hazard zones has been presented as the first step.

6 ACKNOWLEDGEMENT

The work presented was performed within the EU - Project “Safety and Reliability of Industrial Products, Systems and Structures” (SAFERELNET), which has been funded by the European Commission under the contract number G1RT-CT2001-05051, http://www.mar.ist.utl.pt/saferelnet.

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