

# NUCLEAR RISK PERCEPTION, SAFETY GOALS AND SPECIFICATIONS

POPESCU GH. , GHERGHINESCU S. , VACARU M.

National Institute of R&D for Cryogenics and Isotopic Technologies

[popescu.gheorghe@icsi.ro](mailto:popescu.gheorghe@icsi.ro)

**Abstract:** In the nuclear installation design concepts like "tolerable", "acceptable" and "unacceptable" must be clearly defined, together with their characteristic levels (ALARP). These levels are affected by the specific risk perception of NPP (nuclear power plants) and other nuclear facilities, which leads to lower the importance of costs in choosing alternatives to reduce the risk of releasing radioactive substances into the environment. Thus for each nuclear installation project should be developed a plan to ensure security and reliability, which will include achievable goals and in accordance with the design theme, the design code to be used, the requirements of regulatory, licensing and control bodies: the National Commission for the Nuclear Activities Control and the The State Inspection of Boilers, Pressure Vessels and Hoisting for Nuclear Activities.

**Key-words:** design, risk, reliability, ALARP, risk management

## . INTRODUCTION

Risk is defined as the possibility that a hazard (a substance, a situation, ...) to produce damage in certain conditions. It's origin is in uncertainty; it is harmful, it's effects can not be removed once they are produced. Hazard is in every potential dangerous thing for people or the environment, like a fast car or pollution.

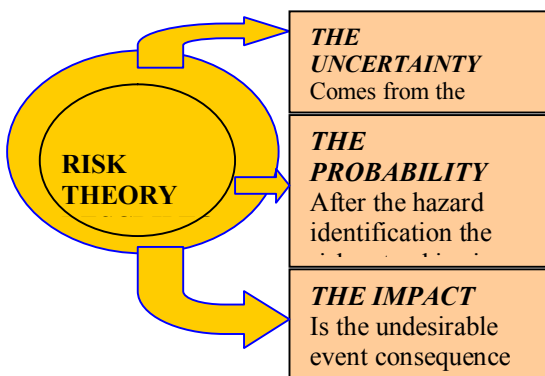


Fig. 1. Risk theory descriptors

The risk theory descriptors are the uncertainty, the likelihood and the impact (Figure 1):

a) The uncertainty (indeterminacy) comes from the absence or poor quality of information or due to failure of the decision maker's information system, which leads to ignorance about which of the identified event will occur, with what amplitude at what moment and with what effects; from here derives the risk. The concept of indeterminacy of the results is involved in all risk definitions. When told that the risk exists, then there is always at least two possible outcomes. Uncertainty can not be eliminated and brings a sense of doubt and ignorance in anticipation of events. Reducing the amount of uncertainty with respect to the probability of an adverse event or the magnitude of the consequences, it will not necessarily change the actual risk level, but will allow us to establish mitigation or safeguard measures.

b) The probability tell us in well-defined conditions, so on the basis of information input, to what extent is it possible to be produced a certain event. Probability, together with the impact, can define the risk for any event:

$$Risk = f(probability, impact) = Pf * Cfc \quad (1)$$

Pf = probability of failure

Cfc = cost of failure consequences

c) Impact (loss) is the undesirable event consequence and varies in the range: negligible, minor, moderate, serious and critical. Most of these losses can be divided into several main categories: - Loss of lives or health condition, is expressed as the number of dead and wounded - Environmental pollution and damage to the community, is expressed in quantities of toxic substances released into the environment - Financial losses, is expressed in monetary units - Damage to public confidence, which is of great interest in nuclear energy and have no unit of measurement. Knowing the likelihood and impact one can determine the amount of risk, which allows a quantitative assessment of the situation when one alternative involves "more risk " compared to other "less risky".

## 2. THE RELATIONSHIP BETWEEN THE MAGNITUDE OF THE RISK AND THE ACCEPTABILITY

### 2.1 Acceptable risk

If the risk is situated at a level low enough odds that the action to be adversely affected is minimal, so the risk

is acceptable. Acceptable risk is also known as allowable or tolerable and they are comparable to those encountered in everyday life. One can find them in safely activities and also in those who although may be risky are controlled so well that the risk was lowered very close to zero (e.g. It is estimated that drinking chlorinated water causes cancer and lead to death at a rate of 1 in 1 billion cases, which places it at an acceptable level).

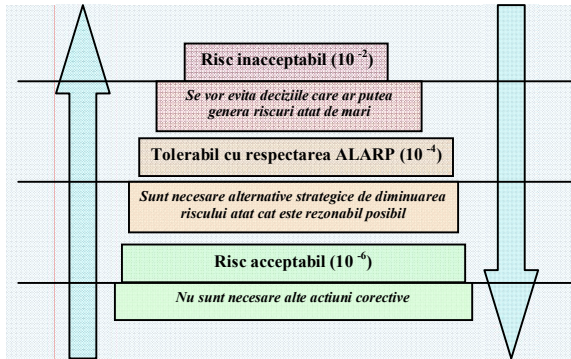


Fig. 2. The risk level and its acceptability

## 2.2 Tolerable risk

Above this level the acceptability decreases and risk mitigation strategy alternatives must be planned (Figure 2). Here are usually located those activities whose overall risk is acceptable in order to obtain certain benefits (eg working in a nuclear plant, fulfilling the work safety conditions) but only under the following conditions:

- The nature and level of risks are properly assessed and the results are used to determine appropriate control measures;
- Residual risks are not unduly high and are maintained at a level as low as reasonably practicable (ALARP), both for civil society and for groups or isolated individuals;
- The risks are reviewed periodically to verify the continued compliance with the ALARP principle. In nuclear facilities this condition is respected by conducting the Safety Report, which demonstrates the possibility of the holistic risk assessment for exposed civil society and the risk framing within the limits of acceptability. On this occasion we determine technology modifications that might require new nuclear risk reduction measures but also new knowledge gained on previously determined risks or new risk-reduction techniques appeared and or made available for the analyzed plant.

## 2.3 Unacceptable risk

At very high risk level we should avoid decisions that generate these risks, found unacceptable regardless of the nature of possible benefits to be obtained (e.g., working in toxic or radioactive environment, over the extent permitted by applicable law).

## 2.4 The acceptability of risk

Determination of acceptable risk faced in practice with a number of difficulties:

- First, it is necessary to mention for whom the risk is acceptable. For the same risk, acceptable risk level can be variable between countries, depending on a number of social, economic and cultural factors. As for French the red wine consumption is an acceptable risk but for the Muslim countries it is almost unacceptable. - In the same country, the level of acceptable risk change over time. After Sept. 11 the americans have become more sensitive to acts of terrorism than to hard attack.
- Acceptance of risk by the individual is subject to large variability. E-food health risk is very big for childrens but it decrease for adults. Also the acceptability is less for a passive risk (traveling by train) then for an active one (chosen by the individual, like smoking). Active risks are usually easier to accept than pasive risks, that no longer depend on the individual.

To determine the acceptability of a risk one should be taken into account more variables. ISO / IEC Guide 51 (safety aspects - Guidelines for their inclusion in standards in 1999) speak about the design and operating concept of risk mitigated to levels as low as reasonably achievable. Acceptable risk is the product of the search of an optimal balance between the ideal of absolute safety and factors such as cost effectiveness and societal conventions.

ALARA concept has its early beginning in the use of nuclear power and means to make all reasonable efforts to maintain exposure to ionizing radiation dose well below allowable limits, consistent with the purpose for which the plant is approved, taking into account existing technology, the benefits and costs concerned for the population health and safety in using the nuclear power in the public interest.

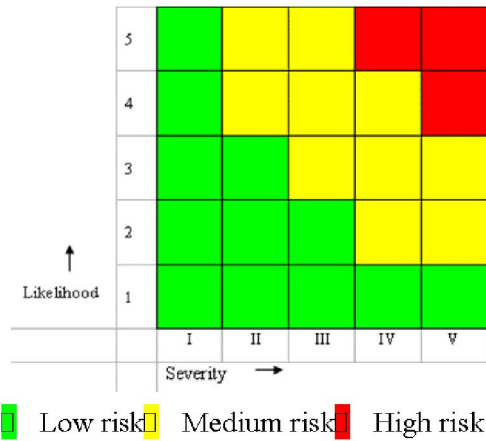
## 3. RISK ESTIMATION

On the difficulty of establishing acceptable risk levels one can add the difficulties to estimate in a quantitative manner the level of risk and therefore the choice is to use a quantitative or qualitative assessment of risk with their advantages and disadvantages of each. Risk assessment can be categorized by type as qualitative estimation, semi-quantitative estimation and quantitative estimation.

### 3.1 Qualitative risk assessment

Risk assessment techniques vary from simple qualitative approach to a detailed quantitative assessment. The latter are very expensive and time consuming. One solution is the qualitative risk matrix (Figure 3). This allows graphic representation of the combination of probability (frequency) and consequence (severity). It is mostly used in initial studies of chance (such as HAZOP) and preliminary risk assessments. While not providing such accurate results, qualitative

models for risk assessment are often preferred by professionals.



**Fig. 3 The risk matrix**

They are more accessible and offer some advantages as: a greater range of work with uncertainty, discretion and requires less time for carrying out.

Likelihood descriptions:

- 1- Very low
- 2- Low
- 3- Moderate
- 4- High
- 5- Very high

Severity descriptions:

- I Very low. Does not require medical care and do not affect the environment
- II Low. It may require first aid, a minor repair or routine cleaning
- III Moderate. Require medical treatment, compensation system, reporting of pollution
- IV High. Serious illness, destruction of property, environmental damage
- V-Very high. The disaster, one or more victims, the total system loss, lasting impact on the environment or public health

**3.2 The semi-quantitative representation of risk**

It is a risk assessment between the textual (qualitative) and the numerical (quantitative) evaluation, both regarding the effort required and the accuracy obtained. It works with numerical values and interpretation of results from qualitative considerations, presented as a matrix that takes into account the likelihood of producing threats and their impact.

One of the advantages would be that it does not require the same amount of data as the quantitative assessment, which makes it suitable for systems where we have little accurate data.

Predefined categories are used to classify risks located in a certain logical hierarchy, so that significant risks can be separated from the less important; also by comparing scores before and after the introduction of

major risk mitigation measures the safety engineer can determine the effectiveness of these measures.

This method uses non-technical description of the probability and severity of associated risk, such as “very low”, “low”, “medium”, “high”, “very high”. For this type of labeling to be unambiguous and useful safety engineer must make a list of clear definitions for each term used and scores assigned (Table 1).

For example, a ‘Low’ probability risk might be defined as an individual risk having between  $10^{-3}$  and  $10^{-4}$  probability of occurring in a year.

A five-point scale has generally proven to be the most popular in the risk community, sometimes with a sixth category representing zero for probability and impact, and a seventh ‘certain’ category for probability representing a probability of 1.

**Table 1. Example of a severity of consequence and likelihood scoring scheme**

Score	Severity	Severity of consequence
5	Catastrophic	leads to termination of the project
4	Critical	project cost increase > resources
3	Major	project cost increase > resources
2	Significant	project cost increase < resources
1	Negligible	minimal or no impact
Score	Likelihood	Likelihood of occurrence
5	Very high	occur for sure
4	High	occur frequently, about 1 in 10 projects
3	Medium	occur sometimes, about 1 in 100 projects
2	Low	rarely occur, about 1 in 1000 projects
1	Very low	almost never occur, 1 of 10 000 or more projects

All risks (e.g. the list of toxic gases that might be release in the working area) are plotted in one table, allowing for the easy identification of the most threatening risks as well as providing a general picture of the overall risk associated with the project (Table 2). The numbers in the table are indices for identified risks. Risks 20 and 25, for example, have high severity; risks 4, 6 and 8 have low severity. This model helps the prioritization of risks for any risk-reduction action. Clearly those risks that need most urgent action are high probability – high severity risks (red area), and those that need little attention are low probability – low severity (green area).

**3.3 Quantitative risk assessment and representation**

Assuming one equipment (non-repairable) which should work for a time  $t$ , but it breaks down before, the associated failure cost  $C$  consists of intervention cost to

block the propagation of undesirable effects that might result from defective equipment, its replacement cost and unrealized production cost.

For a number  $n$  of such equipments, we can say that some of them  $n'$  will fail before time. Knowing that only they produce losses one can say that total loss is:

$$Ct = n' \cdot C \tag{2}$$

and specific loss is:

$$C_s = \frac{n' \cdot C}{n} \tag{3}$$

**Table 2 Example of a Severity-Likelihood table for individual risks and their segregation into Low ['green'], Medium ['amber'] and High ['red']**

		LIKELIHOOD					
		Very Low	Low	Med	High	Very high	
SEVERITY	Catastroph				20	25	HIGH RISK
	Critical						
	Major		6	9			MEDIU M RISK
	Significant		4	6			
	Negligible						LOW RISK

If  $n$  is large enough we estimate the probability of failure for the equipment on the time interval  $0 - t$  as failure frequency:

$$\lim_{n \rightarrow \infty} \frac{n'}{n} = p \tag{4}$$

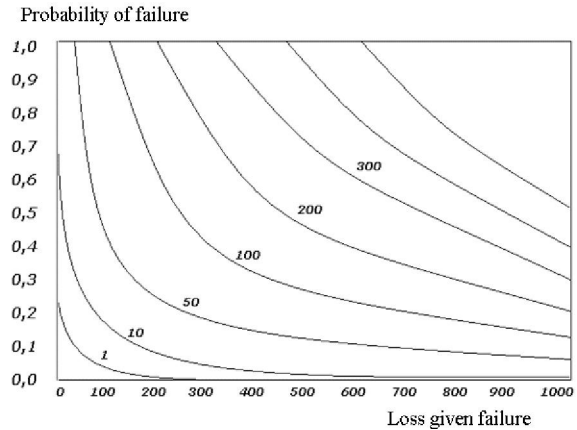
Since it is practically impossible to obtain an infinite number of trials,  $P$  is usually approximated by the

formula:

$$p \approx \frac{n'}{n} \tag{5}$$

and the risk expressed as expected loss from failure is:

$$R = p \cdot C \tag{6}$$



**Fig. 4. The constant levels of risk**

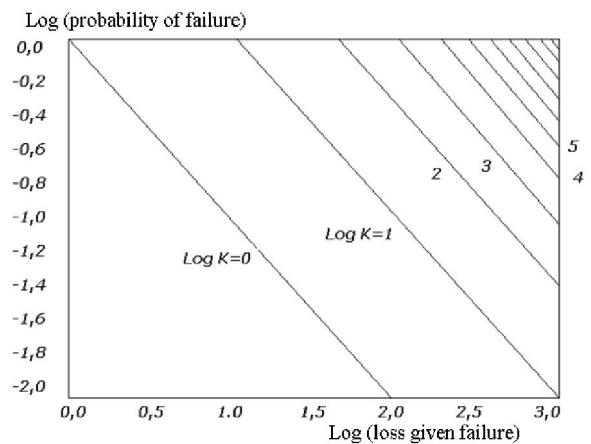
Risk is thus a representation of the expected amount of damage for a given period of time.

More generally the risk is the product of the uncertainty (frequency, probability) of an exposure to a loss due to an undesired initiating factor (hazard, failure, specific internal and external circumstances) and the value of loss (Figure 4).

If we take logarithm:

$$\log R = \log p + \log C \tag{7}$$

the graphical representation will be like in Figure 5:



**Fig. 5. Constant risk log K areas are delimited by straight parallel lines**

#### 4. CONCLUSIONS

Every time you talk about high-risk technologies the main question that arises is: "How safe has to be that technology to be considered safe enough and to be accepted?" Without giving a direct answer to this question regulatory agencies indicates instead a series of



requirements that must be met in the design, construction, operation and decommissioning of nuclear installations and other high-risk facilities in general.

In Romania the regulatory agencies with role in establishing and monitoring the nuclear security objectives are the National Commission for Nuclear Activities Control (CNCAN) and the State Inspection for Control of Boilers, Pressure Vessels and Hoisting Equipment in Nuclear Power (ISCIR Nuclear).

The main objectives of nuclear safety are:

1. Members of civil society should not bear additional risks to life and health due to nuclear accidents.
2. Additional life and health risk for the public while operating Nuclear Power Plants (NPP) should be less than or equal to that which would have resulted in the production of electricity by conventional methods. As an aside, it follows that if the nuclear option is considered to be the wrong choice then the good choice has already been correctly identified.

These objectives, while satisfying the public, are still difficult to quantify. In order to establish nuclear risk acceptability it should be clearly specified the thresholds of the incidence of additional risk brought about by using NPP compared with the sum of all the other risks that the Romanian population are routinely subjected to. In other words after setting the amount of total risk of death due to other accidents (domestic, driving, work, etc..) the additional risk of death of a person near a nuclear accident should not exceed x,x% of that value. As may be taken on the incidence of cancer - Under Romanian law, additional public irradiation is limited (outside the natural and medical) to less than a mSv/ year. It is lower than risk of traffic accidents and comparable to radiation due to ingestion of natural radionuclides - due to the proximity of a NPP in relation to all other sources of cancer identified in our country.

This way it would end speculation about the safety of NPP and would eliminate the bias that may arise in nuclear plants project analysis based on factors like cost, risk and benefit.

Figure 6 shows how the Intolerable, Tolerable and Acceptable regions might be defined. Thus for a single fatality (left hand axis) risks of  $10^{-5}$  to  $10^{-3}$  are regarded as ALARA. Above  $10^{-3}$  is unacceptable and below  $10^{-5}$  is acceptable. For 10 fatalities, however, the levels are 10 times more stringent.

For nuclear security to be measurable it must be prepared a security plan for each nuclear plant project, which will include:

- feasibility study to confirm the possibility of achieving the project target
- setting safety goals

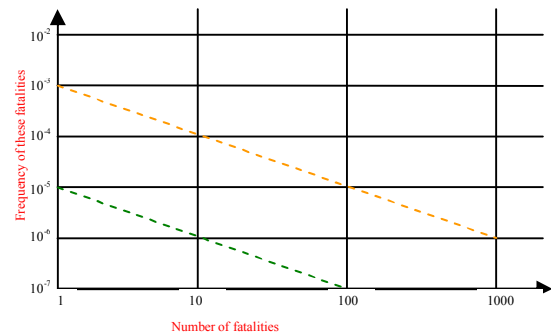


Fig. 6. ALARA zone

- specifications; with an indication of risk acceptability
- project review and stationary points; must be performed by a multidisciplinary team led by a independent person
- risk analysis; will be focused on special security systems - security systems are designed to bring into a safety state the controlled equipment
- pilot tests, which serve to verify the reliability estimates.

## REFERENCES:

- [1] Carabulea, A., s.a., Reingineria industrială a riscului energetic în concepția cercetărilor operaționale, Politehnica Press, 2006.
- [2] Gheorghiu, I. D., Reingineria Riscului, U.P.B., Bucuresti, 2007.
- [3] Carabulea, A., Managementul Sistemelor Energetice, U.P.B., Bucuresti, 2006.
- [4] Michael, T. Todinov, Risk-Based Reliability Analysis and Generic Principles for Risk Reduction, Elsevier, 2007.
- [5] Christian, Kirchsteiger, Risk Assessment and Management in the Context of the Seveso II Directive, Elsevier, Industrial Safety Series, Volume 6, 1998.
- [6] Aven, T., Risk Analysis: Assessing Uncertainties beyond Expected Values and, John Wiley & Sons, Ltd, 2008.