# RISK MANAGEMENT AND INDUSTRIAL ECOLOGY

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**Keywords:** ecology, safety risk, industry, management, accident (disaster), ecological hazard, emergency situation, ecological insurance.

## Contents



## Summary

This article contains a brief description of the present state of the problem of technical risk and ecological safety in the world. Examples of a number of the world's major industrial disasters are presented and the current trends in this sphere are described. Modern terms and concepts in the sphere of ecological safety and risk are presented, including the concept of acceptable risk and its analysis, and ecological risk management. The importance of introducing the ISO 14000 standards series of the International Standards Organization, oriented towards ecological management, is explained. The general algorithm of accident hazard for an industrial enterprise is presented. This contains a preliminary analysis of hazard factors, accident tree analysis, etc. The organization of the safety system for emergency situations in the technical sphere is considered, with the APELL system taken as an example. The important role of ecological insurance as an efficient market economic and legal mechanism in ecological risk management, is revealed. The important role played by the institutional environment, in the framework of which the ecological management is carried out, is also stressed. Perspectives for improving the efficiency of ecological risk management methods as a result of their transformation along the line of sustainable development, are clearly defined.

## 1. The ecological safety problem and technical risk.

The demographic explosion and the need to satisfy the growing material demands of people lead to expansion of the scale of economic activities and, in particular, industrial production; this in turn causes an increase in the anthropogenic burden on the environment. As a result, such problems as global pollution, global climate change, destruction of the ozone layer, and exhaustion natural resources become more important, and the number of technogenic disasters in industry grows. The prevailing trends in ecological hazard are not becoming weaker; on the contrary, they continue to grow, in the absence of any adequate reaction to the above mentioned problems on behalf of the world community. Development and effective use of modern methods of ecological risk management may play an important role in reducing ecological hazard in the sphere of industrial production.

Extremely high rates of development of the technogenic sphere in the second half of the twentieth century brought tremendous benefits but also tremendous dangers, which have no less impact on the life of communities. It is enough to say that in the world's technogenic complex there are about 1000 nuclear technology facilities for peaceful and military purpose, more than 50 000 items of nuclear ammunition, up to 80 000 tons of chemical weapons of mass destruction, and hundreds of thousands of tons of explosives and highly toxic substances. There is a huge range of civilian structures and facilities which present an emergency hazard, i.e. they have the potential to cause a major disaster. It is possible to distinguish nuclear and chemical facilities, major power generation plants, metallurgical and mining enterprises, major engineering constructions (bridges, dams, etc.), transport systems carrying large numbers of people and hazardous cargoes (land, sea, aerospace, etc.), and major oil and gas pipelines. Hazardous military facilities include those of aerospace, aircraft and missile systems, nuclear submarines, large cargo vessels, and the main depots of conventional and chemical weapons.

The modern technosphere is witnessing a massive increase in the of use of complex engineering systems and constructions in industry, increasing power capacity of equipment in industry, and increasing geographic concentration of such facilities. Saturation of industrial production with complex technical systems has reached such a level that the cost of a technical or human error becomes very high. And the use of efficient means of ensuring safety, such as multiple back-up systems for instance, is limited by economics and does not always provide the desired level of safety. Thus, due to the rapid development of industrial production and unpreparedness of modern society to ensure the necessary protection activity, the level of emergency hazard in the technogenic sphere continues to rise.

Statistical data proves that more than half (56%) of the world's large industrial disasters happened during the last two decades of the twentieth century. The scale of the disasters and their destructive impact are growing as well. This twenty year period saw about half (47%) of the overall number of human deaths from industrial accidents and about 40% of the industrial injuries in the whole of the twentieth century.

In USA, during the 30 year period (1950 to 1980) the number of emergency situations increased 2.6 times, the number of victims six times, and material damage eleven times. In the chemical industry, in which world output volume has grown tenfold over the last 35 years, the number of large disasters has steadily increased. From 1940 to 1970 the increase was three to four times; from 1971 to 1975 it was 15 times, and for 1975 to 1985 it was 30 times.

In recent decades large-scale technogenic disasters occurred in Russia, USA, Italy, India, Mexico and many other countries. These disasters took the lives of thousands of people and caused substantial damage to the environment; the economic losses and expenses for eliminating the consequences of the disasters are estimated at tens of billions of dollars. One example of such a large industrial disaster is the release of a chemical product, methyl isocyanate, from a plant at Bhopal (India, 1984); this resulted in death of more than 3000 people, 20 000 became invalids and disabled, and more than 200 000 people suffered from the effects of the toxic gas. In the same year there was an explosion of liquefied petroleum gas in Mexico city (Mexico), the result of which was the death of 650 people and more than 2000 people injured. And a disaster related to dioxin release which happened in 1976 in Seveso (Italy), may be considered a classical example. The results of the subsequent analysis of the causes of the disasters and recommendations were set out in "The Seveso Directive".

The most serious industrial accidents during the last twenty years happened at nuclear power stations (NPS). An emergency situation occurred at the "Three-Mile-Island" NPS (USA) in 1979 due to the partial melting of the active zone of the reactor. There was no large quantity of radioactive releases at that time but, nevertheless, the cost of the direct damage was estimated at one billion dollars, including the expenses for cleaning the radioactive pollution at the station.

In 1986 there was the Chernobyl disaster in USSR, when as a result of an explosion the protection around the nuclear reactor was damaged, leading to a massive release of radioactive substances, equivalent to the waste produced by a large nuclear explosion. The Chernobyl disaster resulted in death of 30 people, over 200 people were hospitalized and 115 000 people were evacuated (official figures produced in 1987). Analysis of the true scale of the Chernobyl tragedy, including estimation of all damage (social, economic and environmental), can hardly be made properly. To date hundreds of thousands of people still live in the polluted area. In this region there is a steady growth in the number of cancers, and in particular, growth of cases of thyroid cancer in children. Uncertainties about possible genetic consequences are of special concern. Unfortunately, the impact on the human body of relatively small doses of radiation over a long period of time can only be proved empirically. It is worth mentioning that the release of radioactive substances from the destroyed reactor continued for almost ten days and in that time the meteorological situation was changing. The zone of radioactive pollution, with density of one Ku/km$^2$ and higher, covered about 57 000 sq. km, or 1.6% of the European territory of Russia. Consequences of the Chernobyl disaster were registered in many European countries, Canada, Japan and the Philippines. For the first time ever there was a technogenic global scale disaster, the consequences of which will have impact on both present and future generations.

Natural calamities, like earthquakes, volcanic eruptions, tsunami, hurricanes, heavy rains and snowfalls, and large forest fires do more and more damage to modern society every year. This tendency results, above all, from the increase in the world population and its concentration in high density settlements due to the urbanization process. Over the last two decades natural calamities caused the death of almost three million people, and caused suffering of about 300 million people, according to United Nations statistics. Recognizing the special importance of this problem, which can be tackled only in a framework of active international cooperation, the UN General Assembly adopted a

Resolution in 1987 to hold under its auspices the period from 1990 to 2000 as the International Decade for Reducing and Preventing Damage from Natural Disasters.

It is worth mentioning that increase in the number and intensity of such catastrophic phenomena as hurricanes, tsunami, floods and droughts, may be related to global climate change. It is common knowledge that global warming is caused by the observed increase of greenhouse gas concentration (in particular, carbon dioxide) in the atmosphere, which in its turn is mainly a consequence of combustion of fossil hydrocarbon fuels, which constitute the main basis of the world's power system. Thus, even in disasters which seem to be only of natural origin, there is an anthropogenec component.

The data in Table 1 show the relative growth in the number of technogenic and natural disasters during recent years.

| | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 |
|---|---|---|---|---|---|---|---|
| Technical | 1.0 | 4.30 | 3.90 | 4.60 | 6.02 | 5.72 | 6.23 |
| Natural | 1.0 | 1.07 | 1.03 | 1.39 | 1.16 | 1.33 | 1.64 |

Table 1. Relative increase of technical and natural disasters from 1991 to 1997

The business world reacts ambiguously to the growing ecological hazards and the risk of technogenic disasters. Companies that directly take part in industrial production, and use and sell natural resources, have accumulated great experience in ensuring ecological safety; they have elaborated a concept of ecological efficiency based on the principle of improving economic indices of the company while reducing pollution and minimizing the use of natural resources. Financial companies dealing with shares, banking services and insurance, generally consider as their main objective the growth of income from investments, without taking into consideration possible ecological damage. However, considerable changes are also taking place in this sphere. Investors are starting to consider the impact of ecological costs and potential ecological commitments in the profitability of shares. Bankers try to minimize their risks when taking decisions on providing credit. They consider that companies with bad ecological parameters present high financial risks. Rating agencies that evaluate the creditability of companies and whole countries, are now taking ecological risks into consideration. Insurance companies incur serious financial losses from problems of ecological safety. According to some assessments, law suits against insurance companies for incurred damage from the spread of asbestos dust and hazardous wastes in USA amount to two trillion dollars. The insurance companies are also very much concerned about climatic change and related natural calamities, which may incur considerable damage to their future profitability. It should be noted that there are considerable difficulties in determining quantitative parameters of ecological risk, and this gives some companies an excuse for avoiding the strategy of ecological efficiency. In general one can conclude that the financial community starts to follow the above-mentioned strategy mostly for financial reasons.

## 2. The concept mechanism in the sphere of ecological safety and risk.

It is very important to define the concepts related to ecological hazard and safety. Despite the apparent simplicity of the meaning on everyday and intuition levels, as yet there is no generally acknowledged scientific consensus on the definition of safety (including ecological safety). It is possible to find in specialized literature no less than a dozen different definitions of these concepts. The reason for this situation is the complexity and internal contradiction of the basic concept of "safety", which may be adequately formulated and described only in the system unity with a corresponding mechanism which comes with this category. At the same time objective interpretation of the concept of "safety" is of interest not only for academic reasons; it has serious practical importance in formulating the tactics and strategy of safety management. On the whole, at present it is possible to speak only about an emerging spectrum of the basic concepts which to a greater or lesser degree defines the essence and contents of complex and multiple phenomena comprising scientific, technological, economic, social, psychological and other aspects.

It is common knowledge that any concept contains contents and volume, and an increase of the contents corresponds to decrease of the volume or the level of common characteristics of the concept. The concepts in the sphere of ecological safety are further defined according to the tendency of specifications and of making the used definitions more complete, while preserving, if possible, their main interpretation.

The concept of "hazard" as one of the most important characteristics of the system with a purpose orientation, is taken as basic and initial:

Hazard is defined as 'the possibility of occurrence of negative or catastrophic events'.

The term encompasses the philosophic category "possibility", the quantitative measure of which is probability. The use of such concepts as negative and catastrophic events in an implicit form testifies to the presence of target orientation. It should be mentioned that the universal purpose of self-organizing systems is their self-maintenance. To be more precise, a hazard of natural or technical origin is defined as the possibility of events or processes capable of injuring people, incurring material damage or having a destructive impact on the environment

Disaster is defined as 'uneven structural and functional changes in a system, leading to considerable disturbance of its functional regime or to system destruction'. Such changes may happen either as a result of short-term response of the system to smooth changes of actual parameters of its state, or under the influence of a strong external impact. For instance, a long-term "routine" pollution of a watercourse, even when it is not intensive, may lead to the destruction of the aquatic ecosystem. Catastrophic phenomena may occur in the event of a toxic release, i.e. a powerful one-time input of a toxic substances into a watercourse.

The term 'accident' is used in the technical sphere to describe cases of catastrophic events.

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Accident is defined as ‘a destructive release of the internal power resources of an industrial enterprise, when raw materials, intermediate products, the enterprise produce and the production wastes, as well as technological equipment, create harmful factors for the population, personnel, environment and the industrial enterprise itself”.

Risk (Ri) is defined as ‘an integral characteristic of hazard, defined by two main parameters: P – the probability of an accident, and U – the incurred damage in the event of an accident’.

As an additional characteristic of risk in a number of cases, we may take a complex of possible scenarios of accident development starting with an initial event up to a final catastrophic event (for instance, an explosion, fire, release of toxic waste, etc). This characteristic is important for elaborating preventive measures to minimize risks. The quantitative formula for risk is as follows:

$$Ri = P \cdot U \quad (1)$$

From (1) it follows that improbable accidents involving substantial damage, entail great risks.

Factors of ecological hazard (or risk) are defined as ‘anthropogenic and natural impacts, capable of making negative changes in the environment and people’s health’.

Many factors can initiate ecological hazard. For instance, environment pollution factors may be divided into material (gas and dust wastes into the atmosphere, toxic wastes into water basins, solid wastes, etc.) and energy factors (heat wastes, noise, ionizing radiation, etc.). These factors cause physical, chemical, or biological changes in the environment capable of injuring people or their health, or damaging flora and fauna and natural ecosystems.

When considering changes of parameters of the system state, it should be noted that the very variability of quantitative characteristics is limited to some extent. When these characteristics pass over a certain threshold, spasmodic transformation of the system takes place, according to the law of transition of quantitative changes into qualitative. The category “limit” is the border of quantitative changes, out of which the qualitative changes are taking place. Specification of the category of limit brings us to a concept of critical (threshold) deviation $\Delta_{cr.}$ of the actual parameters of the system from the stable (“normal”) state of the system. At the same time, presumably there is a maximum permissible deviation $\Delta_{max.per}$., below which the system will be able to function “normally”. For instance, maximum permissible concentration (MPC) of the polluting substance in any environment (air, water, soil, products) determines the border between the norm and ecological pathology. Thus, the sphere of “hazardous” states of the system is between the deviations $\Delta_{max.per}$. and $\Delta_{cr}$. Therefore, the hazard may be treated as the possibility of deviation of the current state of the system from the “normal” over and above the maximum permissible value ($\Delta_{max.per.}$).

The stochastic nature of hazard is revealed by the fact that there may be a very small but finite risk of realizing the critical deviation $\Delta_{cr.}$ (i.e. an accident); this shows the impossibility of achieving absolute safety. This is caused by the presence of accidental factors of initiating hazard which are uncontrollable. Consequently, it is impossible to create conditions for ensuring absolute safety. Thus, efforts at ensuring safety mean creating such conditions in the system that the impact of determined and accidental factors leading to hazardous situations, is limited, and as a result it reduces the hazard to a certain acceptable level. How small or big the possibility characterizing the acceptable level of hazard may be, is determined by optimizing the functions of usefulness and hazard, which means it depends on the cost of ensuring the necessary conditions for limiting the possibility and scales of the impact of risk factors. Accordingly, the concept of safety may be defined as follows:

Safety is defined as 'an acceptable level of hazard depending on the costs of limiting the hazard-initiating factors'.

Ecological safety is defined as 'a socially and economically acceptable level of ecological hazard'.

In other words, ecological safety is equated to an acceptable possibility of deviation of environmental condition and people's health from the norm. It is natural that the possibility of substantial deviations will be gradually reduced when more efficient means and ways of protection (involving certain expenditure), are used. It is important to note that the concept "ecological safety" characterizes its essence and has a rather general meaning. The meaning of this concept, given below, is more precise and appropriate to the reaction to the coming ecological disaster as well as focusing on the problems of protection from ecological consequences and hazards

Ecological safety is defined as 'the level of protectability of the vitally important interests of a person, society, state, or the world community from the consequences and hazards caused by negative changes (degradation) of the environment as a result of anthropogenec or natural effects, which is acceptable at a certain stage of social and economic development'.

'Acceptable level of protectability' means the maximum possible level of ecological safety which may be practically ensured by the state (or society) at a definite level of its social and economic development. It also means that the ALARA principle is followed (as low as reasonably achievable), according to which there should be reasonable optimization of costs for ensuring ecological safety, based on economic and social factors. This principle differs from the ALAPA principle (as low as practically achievable) when the lowering of hazard is limited mainly by the practically achieved level of development of the accident prevention measures. This leads to considerable increase in expenditure.

Objects of ecological safety are defined as 'social and ecological systems of different levels: global, national, regional, local, level of economic subject, individual level'.

A socio-ecosystem at the national level includes the population of the country (territory or habitat), that may, of course, be any country of the world. It is an integral system with diverses elements and subsystems (personality, state subjects, state management, environment components, biosphere ecosystems, industrial objects etc.) which are interconnected with interdependent flows of energy, substance, information (including, above all, management information). According to the principles of the system approach, the border of an organizational system is determined by the limits of the impact of internal management of the system itself, or, in other words, by the sphere of control of the person taking decisions. Protection of national interests and achievement of national goals in the modern world is impossible without ensuring protection of the vitally important interests of a person, state and society from any ecological hazards. Therefore, such a wide interpretation of a concept—the ecological safety of a state—seems quiet appropriate and necessary. It is clear that the methodology of ecological risk management elaborated mostly for economic enterprises, cannot be used directly at the national level, for which special fundamental research is needed. It is important to elaborate parameters of acceptable safety or acceptable risk for all the hierarchical levels of management. For the state management level it is necessary to define, among other parameters, a criterion determining the optimal average costs of ensuring ecological safety. A similar criterion should be determined for regional (state, district) levels as well as local levels. Clearly the international level of solving the problem of global ecological safety must be born in mind. It is common knowledge that fundamental research work in this sphere started in 1989 at the International Institute for Analysis of Applied Systems (in Austria) in the framework of a project on management of global safety and risks aimed at determining acceptable thresholds of risk, the violation of which would threaten global disaster for human civilization.

Sources of ecological hazard are defined as 'objects of industrial, domestic, military or other activity, containing hazardous factors or ecological risk'.

Examples of such objects are the enterprises in industry, the energy sector, transport, and agriculture as well as military complexes, dumping grounds, etc. These enterprises may produce both permanent waste and polluting toxic effluents and emissions, the probability of which is equal to one (1), and accidental stochastic wastes, for which the probability is less than one (1).

Ecological consequences (the results of actual events), are characterized at a definite moment by changes in the condition (degradation) of the environment. For instance, it is vitally important to carry out restoration works to restore the environment and to carry out treatment of ecologically dependent human diseases in areas subject to emergency ecological conditions.

Ecological hazards are defined as 'predicted consequences or potential scenarios of accident development which are the results of changes in environmental condition and which may bring damage to vitally important interests of a person, society, state or the world community'.

There are external and internal hazards related to the existing socio-ecosystem. External ecological hazards for the state include: negative events associated with cross-border movement of contaminating substances, in particular, acid rain, greenhouse gases leading to global warming, destruction of the ozone layer, and dissemination of toxic and radioactive wastes. Ecological hazards may also be divided according to degree of urgency, taking into account the time factor. Urgent hazards are scenarios of negative events which may be realized in the near future and which need the taking of urgent decisions. Potential hazards have a longer period of safety and, as a rule, need elaboration of strategic management solutions.

Ensuring ecological safety is a process of developing and realizing a system of management impact on the socio-ecosystem, aimed at minimizing ecological hazards and protection of ecological resources, up to an acceptable level of safety.

The process of protective reaction, or the cycle of ensuring ecological safety, contains two aspects of minimizing ecological risks: protection from ecological consequences and preventive protection from ecological hazards. In both cases the aim is to ensure an acceptable level of protection for the objects of ecological safety. Protection from ecological hazard means using a system of measures aimed at limiting the effect of ecological risk factors in order to reduce risks to the acceptable level. Prevention of ecological hazard involves a preventive system of measures aimed at minimizing the possibility of existence of potential and real factors of ecological risk so that they don't exceed the acceptable level.

Protectability of the objects of ecological safety is first of all determined by the fact that real parameters of environmental condition should not exceed maximum permissible concentrations ($\Delta < \Delta_{max.per.}$). Maximum permissible concentrations of actual parameters are determined for the quality of the environmental components (e.g. water, air, soil, foodstuffs) the security of human health (sanitary-hygienic norms), and the sustainability of natural ecosystems (maximum permissible norms of loading), with due regard to the sources of ecological hazard and the limits of impact of ecological risk factors. An important characteristic of the ecological safety of a socio-ecosystem is the ecological capacity of the territory, reflecting its potential for self-recovery. The level of deviation or discrepancy of actual parameters of the condition of the socio-ecosystem related to the corresponding norms, reflects the acuteness of ecological problems and may serve as a criterion for prioritization.

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