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Oksana Gennadyevna Feoktistova
Igor Konstantinovich Turkin
Dmitry Alexandrovich Zatuchny

Safety in Civil Aviation

Monitoring Management of Ecology

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Oksana Gennadyevna Feoktistova ·
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Oksana Gennadyevna Feoktistova
Moscow State Technical University of Civil Aviation
Moscow, Russia

Dmitry Alexandrovich Zatuchny
Moscow State Technical University of Civil Aviation
Moscow, Russia

Igor Konstantinovich Turkin
Moscow Aviation Institute
Moscow, Russia

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Contents

Abbreviations

AC	Aircraft
AE	Aviation equipment
AEDFAL	The average expected duration of the forthcoming active (healthy) life
ARP	Aircraft repair plant
ASLH	Approximately safe levels of harmfulness
ATM	Air traffic management
BNO	Biological need in oxygen
CA	Civil aviation
CD	Control of decision
CHO	Chemically hazardous objects
CNO	The chemical need in oxygen
ECM	An electronic and calculation machine
EQ	Ecology quality
EPF	Excessive pressure in the front
ES	An emergency situation
FAM	Fuel-air mixture
FAR	Federal aviation regulations
FATA MT RF	Federal Air Transport Agency of the Ministry of Transport of the Russian Federation
GTS	Geotechnical system
GVAM	Gas-vapor-air mixtures
HTS	Highly toxic substance
IAP	Index of atmospheric pollution
IC	Index of consistency
ICAO	International Civil Aviation Organization
IDC	Interdepartmental commission
IRP	Internal rate of profitability
ISO	International standardization organization
LC	Life cycle
MD	Making a decision

MGO	Main Geophysical Observatory, named after A.I. Voeykov
MIA	Ministry of internal affairs
MPC	The maximum permissible concentration
MPL	Maximum permissible level
MPCE	The maximum permissible coordinated emission
MPE	Maximum permissible emission of harmful substances
NPI	Net present income
NS	National standart
OSAF	Organizational support of aircraft flights
OTS	Organizational and technical system
OUN	Organization of United Nations
PMD	The person, making the decision
RC	Relation of consistency
RF	Russian Federation
RI	Random index
RIAAI	Rules for the investigation of aviation accidents and incidents with civil aircraft in the Russian Federation
RTM	Relative toxic mass
RSFSR	Russian Soviet Federal Socialistic Republic
SCF	Special cases in flight
SD	Synthetic detergents
SEQ	System of environmental quality
SES	Socio-economic system
SF	Safety of flight
SME	System of management of environmental
SMES	System of management of ecology safety
TC	Technical Committee
TCE	Temporarily coordinated emission
TIC	Territorial-industrial complex
TPE	Technically permissible emission
TS and R	Technical service and repair
TS and R AE	Technical service and repair of aviation equipment
USSPEES	Unified state system for the prevention and elimination of emergency situations
VARP	Vnukovo aircraft repair plant
YI	Yield index

Part I

Theoretical Foundations of Building of the System for Management of Ecology Safety in Civil Aviation

Chapter 1
Analysis of Compliance of the System for Management of Ecology Safety in Civil Aviation with Modern Requirements

1.1 Statement of the Problem and Task of Research

A specific feature of aviation as a type of transport is its direct impact on the troposphere from the perspective of the heights of the maximum concentration of ozone (20–30 km). Much attention to environmental protection is caused to a large extent by the correlation between the decrease in the integral (in height) amount of ozone and an increase in the density of harmful ultraviolet radiation from the Sun. According to the data of doctor of technical sciences A. L. Stasenko (Problems of Aviation Ecology «Energia», 1999, no. 7, p. 21–24), a local decrease in the ozone by 13% (caused by the intrusion of ozone-depleted air masses) led to an increase in the density of ultraviolet radiation by 23%. If the thickness of the ozone layer decreases by an average of 15%, the intensity of DNA-damaging radiation will increase by 47%. The jet spray of engines contains components (nitrogen oxides, hydroxyl, atomic oxygen, sulfur oxide, and others) that serve as catalysts for chemical reactions, that destroy ozone, for a long time.

In addition to the above, the aircraft has mechanical, thermal, electrical, electromagnetic, radiation, and other energy, and chemical and physical effects on the surrounding space. Such an abundance of objects and factors affecting nature makes it almost impossible to conduct natural experiments to assess and prevent aviation ecological hazards. In this regard, it is necessary to note the increasing role of mathematical modeling of the processes of interaction between aviation and ecological systems in order to predict subtle global negative changes in the safe ecological balance in a continuous mode.

The peculiarity of the aviation impact on the environment is its multiplicatively, as a result of direct and feedback: during maintenance, the aircraft not only «worsens» the external environment, but also loses its quality, including due to the influence of external factors.

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A feature of the natural ecological system is its homeostasis—the ability to self-regulate and self-repair the disturbed balance of the composition and properties of the natural environment.

Technical service and repair of aviation equipment (TS and R of AE) play an essential role in improving the efficiency of the system of management of ecology safety. This is due to the fact that the engineering and aviation support of flights maintains and restores the reliability of AE throughout the entire period of maintenance, reducing the rate of degradation of the system of the aircraft. But at the same time, it is necessary to take into account the fact that the production activity of enterprises, according to TS and R, is a certain factor of anthropogenic danger and should be among the predicted ones.

Conceptually, the task of the study is to study the conditions of interaction between the biosphere and the techno sphere, under which inequality is observed:

$$\begin{aligned}&\big(V_{\text{degradation of environmental from the impact of aircraft on it}}\\&-V_{\text{reducing of degradation impact on environmental of the aircraft in case of } TS \text{ and } R}\big)\\&+V_{\text{degradation impact on environmental of production } TS \text{ and } R}\leq V_{\text{ecology homeostasis}}\end{aligned}$$

It follows from the above that the task is of an integral nature and the subject of theory, which is understood as a system of generalized reliable knowledge about the subject of research. It describes, explains, and predicts the system functioning of a certain set of its constituent objects.

The principle of specialization, as a scientific method of studying reality, is that ecology is divided into separate problems, the solution of which develops its own special methods and experience. On the one hand, specialization increases the productivity of work, facilitates it, and accelerates the accumulation of experience. On the other hand, specialization leads to a divergence of methods. At the same time, the possibility and probability of solving problems increase, when they are formulated in a generalized form. It is obvious that the solution to improve the efficiency of management of the system of ecology safety in civil aviation on the basis of comprehensive monitoring of its condition is a complex problem and cannot be solved by specialization methods.

In general, this concept has been widely understood by scientists and practitioners, working in the area of ecology. In particular, in a number of works, efforts were made to generalize the known data from the standpoint of a higher degree of abstraction and a number of ecology laws and regularities were obtained [1–7].

The transition of civil aviation (CA) to the market conditions of the economy has introduced some fundamental points in economic activity. For example, sanctions for non-compliance with ecological requirements can ruin an enterprise; ecology «clean» products increase the rating of the company that produces them and increases its competitiveness; forecasting strategic marketing in the area of environmental protection ensures timely investments in the area of ecology, etc. These points require consideration of the aircraft repair industry as a system and, consequently, a systematic approach to its study.

The system has, first of all, integrity. The property of the whole is irreducible to the sum of the properties of its components, and is characterized by the dependence of each element on its place and functions in the system. As A. A. Bogdanov originally noted in the «Tautology-General Organizational Science», developed by him: «…an organism is a whole, that is greater than the sum of its parts». Previous attempts to somehow improve the system by typically command-and-control methods in the conditions of market mechanisms did not bring satisfactory results.

The reasons for this situation in the area of ecology (as a subject of science) are similar to the reasons, formulated by G. Clauss in his study of the interaction of cybernetics and philosophy. He notes that both the method and the theory ultimately follow from the subject of science. If the theory of a certain subject area is sufficiently developed, then the method and the theory uniquely correspond to each other in such a way that the method is based on the theory. The theory establishes what actually takes place, and the method describes how, on the basis of what really takes place, people's scientific or practical activities should proceed.

However, in the period of the formation of any science, this relationship between method and theory does not look like this. During this period, the method does not rely on any developed theory. But for this period, we can have a method of approaching things, even when the structure of these things and their exact way of behavior are not completely known. This method is cybernetic and is based on the input–output relationship. Here, special attention is paid not to the material and not to the special structures of the systems, but, first of all, to their behavior. Mathematics, mathematical modeling in this case, can well show the qualities of the subject, and not just its quantitative assessment.

With the cybernetic approach, the mathematical modeling of processes of management of ecology safety is formulated as a task of synthesizing a complex system: The input characteristics (monitoring results) and the desired output characteristics (empirical analysis of compliance with the requirements of ecology safety standards). It is required to form such a complex system, consisting of a certain number of subsystems that converts the input characteristics into output characteristics. The formed system will be a mathematical model of the system of management of ecology safety, based on integrated monitoring. In fact, it is a show of facts, things, and relations in the ecological area of knowledge in the form of a simpler, more visual material structure of this area. In another way, it is a mathematically displayed system of views, visions, ideas, actions, etc. aimed at interpreting such a phenomenon as the organization of ecology safe economic activity. This is (in essence) a theory, with which it is possible to solve the tasks, set to create a flexible and effective system of management of ecology safety.

The next task after that will be the structural optimization of the system. This task is methodological: the behavior of the system is determined not so much by the features of its individual elements, but by the properties of its structure. Therefore, the formation of a rational structure of the functional elements of the system of management of ecology safety is an important stage in the adaptation of enterprises to the conditions of a market economy.

A necessary condition for solving this problem is the formalization of the object of research. But there are many tasks of a creative nature for which the methods of formalization are unknown. These are tasks, related to the choice of the principles of construction and organization of an object, the synthesis of schemes and structures in conditions, when the choice of an option is made among an unlimited set of options. At the same time, the possibility of obtaining new, previously unknown solutions is not excluded. It is obvious that the purpose of the study belongs to this class of tasks.

Therefore, it is necessary to solve the problem, when a stochastic model of the state of the environment enters the «input» to the system of management of ecology safety, and a deterministic model of this environment should be obtained at the «output». This model is determined by the requirements of safety standards. It is necessary to determine the «black box» operators, corresponding to mathematical models of control actions to improve ecology safety. Then, by selecting the optimization parameters, determine which control process is optimal.

In this formulation of the research task, it is obvious that, first of all, it is necessary to conduct a critical analysis of international requirements (legislation) for systems of management of ecology safety. This follows from the fact that these requirements are the most abstract in terms of the degree of integral generalization of ecological requirements (global ecology, which comprehensively studies the impact of anthropogenic, space, geophysical, and other impacts on the biosphere).

1.2 International Requirements for Systems of Management of Ecology Safety

International requirements define the conceptual criteria of optimality of the system of management of ecology safety (SMES). These criteria are based on its ability to «sustainable, self-supporting development», which ensures that the needs of the present are met. At the same time, the ability of future generations to meet their needs is not rejected.

The implementation of this concept is a set of international ecological standards, primarily ISO 14000 standards, developed by the International Organization for Standardization (ISO). The standards of this series focus enterprises on the implementation of ecology management, and not on individual emission standards. Their use provides for compliance with certain procedures, the adoption of appropriate documents, and the creation of a system of responsibility for the ecology safety of production. They are designed to correct the national ecological standards.

The international standards ISO 9000:2000, ISO 9001:2000, and ISO 9004:2000 have Russian analogues NS R ISO 9000–2001, NS R ISO 9001–2001, and NS R ISO 9004–2001. ISO 9001:2000 contains the requirements for the organization of production, which are imposed on the system of production organization. If they are satisfied, the product quality is ensured automatically. Enterprises are classified according to the completeness of compliance with the ISO 9001:200 QMS.

The ISO 14000 system contains the following standards: ISO 14001—ecology management systems; ISO 14004—guidelines for the principles of creating and methods of using ecology management systems; ISO 14010—guidelines for ecology audit.

ISO 14011/1—guidelines for audit procedures; ISO 14012—guidelines for the qualification criteria of ecology auditors; ISO 14014—guidelines for determining the initial level of ecology efficiency of an enterprise; ISO 14020—principles of ecology labeling of products; ISO 14031—guidelines for assessing the ecology activity indicators of an enterprise (organization); ISO 14040—assessment of the ecology component at all stages of the product life cycle; ISO 14060—guidelines for taking into account ecology aspects in product standards.

In the Russian practice of using international standards of the ISO 14000 series, in 2000, a certificate of compliance of the system of management of environment (ecology management system) of the enterprise with the ISO 14001 standard (NS ISO 14001–98 in the official translation into Russian) was obtained.

ISO, analyzing the practice of implementing these standards in the practice of Russian enterprises, notes the formal nature of their compliance with certification requirements. This does not lead to an improvement in the results of ecology activities. In this regard, the ISO Technical Committee (TC 207) is revising the provisions and some requirements of the ISO 14001 standard in the direction of their greater concretization. In particular, the requirement for an open demonstration of real improvement in the results of ecology activities and regular environmental audits is clearly defined. The World Bank, the European Bank for Reconstruction and Development, and the European Investment Bank adhere to this position in their credit and investment policy.

As the main criteria for compliance with the requirements of ecology management systems with ISO standards, the following are defined: compliance of the company's ecology policy with the provisions of the standards; coverage of all main and auxiliary production facilities by the ecology management system; the number of ISO requirements that are not included in the system as contradicting the traditional features of the Russian enterprise; what features of the Russian enterprise were taken into account in addition to the ISO requirements; the specificity of the formulation of goals for preventing impacts on the environment and improving it; the presence of internal requirements for ecology aspects of activity; the presence of quantitative indicators (indicators) of ecology and others.

An indirect indicator of compliance is the presence of difficulties of the enterprise in providing information on the specified main criteria.

The international standards ISO 14000 series «System of Management of Environment» (SME) have developed universal regulatory procedures for evaluating corporate systems for compliance with ecology Russian and international legislation.

The system of management of the environment (ISO14004-98, 14,001–98) ensures the order and consistency of solutions by organizations to their ecology issues through the allocation of resources, the distribution of responsibilities, and the constant assessment of methods, procedures, and processes.

The system of management of the environment is important from the point of view of the organization’s ability to predict and meet its ecology targets, as well as to ensure continuous compliance with national and international requirements.

Management of the environment is an integral part of the overall system of administrative management of the organization. The development of the system of management of the environment is a constant and interrelated process.

The ISO 14000 series standards are based on the same principles as the earlier ISO 9000 series standards. This circumstance allows enterprises to use their ecology quality (EQ) systems, based on the 9000 series as the basis for creating SME. This makes it possible to facilitate the certification of enterprises that have a certificate of compliance with the requirements of ISO 9000 series standards, as well as joint certification for compliance with the requirements of ISO 9000 and ISO 14000 standards. At the same time, it should be borne in mind that the range of stakeholders in the case of ISO 14000 certification is wider than in the case of ISO 9000 certification. The reason for this is the fact that EQ considers the needs of only the consumer, and the creation of SME is caused by the need to protect the ecology interests of society as a whole. The integration of EQ into SME will make it possible and expedient in the future to conduct verification and certification of these systems simultaneously by the same accredited certification body for this activity. At the same time, it is necessary to have EQ certification experts and ecology auditors (experts) for SME certification in the body.

The enterprise’s SME, based on the requirements of ISO 1400, is part of the overall administrative management system, which includes organizational structure; responsibility planning; methods, procedures, processes, and resources necessary for the development, implementation, analysis, and support of ecology policy. The purpose of implementing SME at the enterprise is to protect the environment and prevent its pollution while saving a balance with socio-economic needs.

The problem of ensuring the safety of man, society, and the natural environment is a complex social problem [8]. For its correct solution, this problem requires not only identification and determination of quantitative characteristics of possible hazards, the formation of goals and corresponding safety criteria, but also taking into account the entire set of social laws of social development and laws, governing the action of society in conditions of various types of danger, and changes in preferences over time.

Indeed, within the framework of the concept of acceptable risk, for example, it is implicitly accepted that a person as a «consumer» of security always strives to achieve the highest possible level of security, i.e. to maximize the average expected duration of the upcoming active (healthy) life (AEDFAL). The expected duration of life is the number of years that a representative of a given generation will have to live on average, assuming that the mortality rate of representatives of a given generation during its transition from one age group to another will be equal to the current mortality rate in these age groups. It is obvious that the extension of the AEDFAL clearly indicates an increase in the level of security in society. However, a longer and healthier life represents only an increase in the potential opportunities for the implementation of the set social or individual goals, as well as more opportunities for the development of the abilities of each member of society. The realization of these opportunities is determined, on the one hand, by the level of development of social production and industrial relations and, accordingly, by the degree of satisfaction of the population's needs for natural, material, and spiritual goods at a given stage of economic development. On the other hand, it is determined by the degree of development of the needs of people themselves. In other words, AEDFAL will be a sufficiently adequate measure to measure the level of security, only if a longer life is accompanied by an increase in the well-being of society, i.e. an increase in real income per person, the level of education of society, and the satisfaction of other needs that characterize the quality of life. Thus, specific AEDFAL levels will provide necessary ideas about the state of protection of the individual and society, if the considered goal in the problem of ensuring security (the state of health and the quality of the natural environment) is used within the framework of a more general, strategic goal of the development of society, including improving the quality of life of the population.

Research, aimed at forming reliable and effective indicators of the level of safety of the population and the environment, should take into account their dependence on the whole set of goals and their corresponding indicators that determine the overall strategy of social development. The study of this dependence is carried out on the basis of structuring the goals of society's development and constructing their hierarchy [9].

The concept of sustainable (stable) development, which was the starting point not only for the Declaration on environment and sustainable development but also for another important document «Agenda for the XXI Century», is considered as a concept of the development of society. This document contains more than 100 programs in various fields and essentially represents the achievement of sustainable development. Articles 2–5 of this document raise the question of the characteristics of sustainability, the formation of sustainable development goals, and their structuring by constructing a hierarchy of these goals. A variant of the hierarchy of sustainable development goals, taking into account the goals of ensuring human security and the environment, is shown in Fig. 1.1.

The goal of the top level—«sustainable development»—is initial. The concept of «sustainable development» is an abbreviated record of the goal: «creating conditions that meet the needs of today without exposing of risk the ability of the environment to support life in the future, i.e. without the danger for future generations to meet their needs». For the first time, this goal was formulated in this form in 1987 in the report «Our Common Future», published by the OUN World Commission on environment and development (Brundtland Commission). However, it is not possible to directly measure the sustainability of development. As a result, the main goal of «sustainable development» is divided into two sub-goals: improving the quality of life and ensuring security.

Further, each of these two goals is divided into goals of the lower level, forming two branches in the hierarchy of goals. The goal of «ensuring safety» is divided into sub-goals «public health» and «quality of the natural environment». The goal of «improving the quality of life» is divided into sub-goals «economy», «education»,

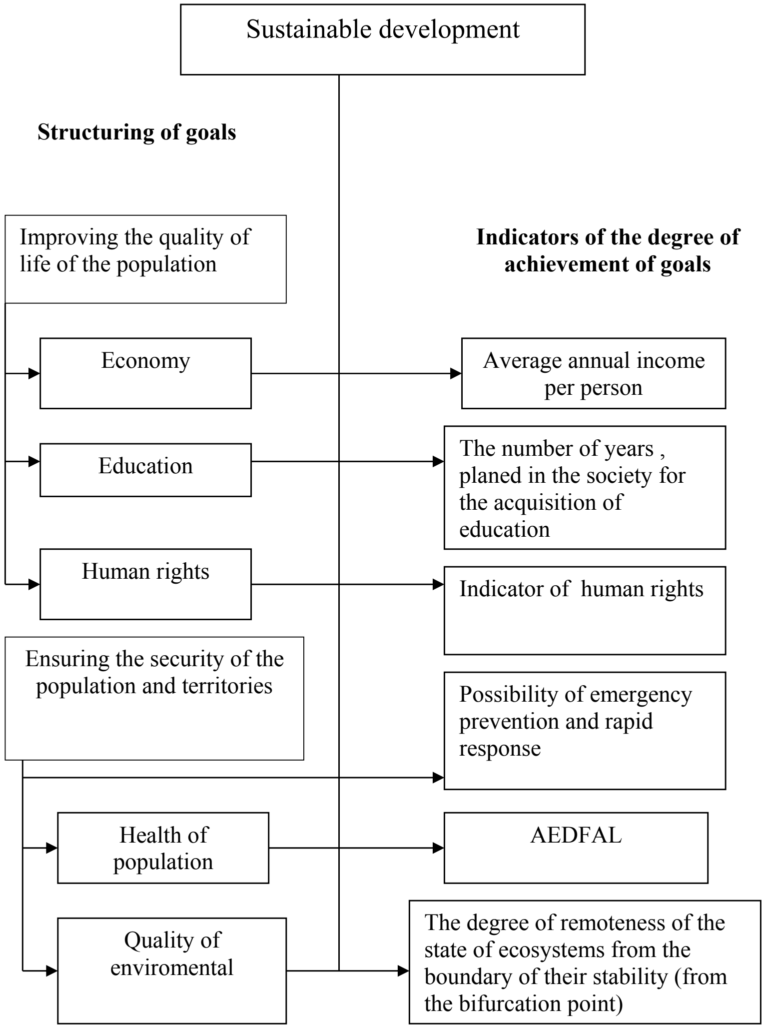

Fig. 1.1 The goals and indicators of sustainability of development

and «human rights». Thus, in such structuring, the main goals are the basis for setting lower level goals, since the fulfillment of the latter ones is a condition for achieving higher level goals. For goals, located at the lower levels of each branch of the goal hierarchy, it is much easier to set indicators and formulate criteria for achieving the goal for them. Criteria for achieving the goals of the lower level should be considered as a means of forming criteria for achieving the goals of the highest level of the hierarchy.

The goals of the lower level in the hierarchy of goals are relatively more specific and allow for a relatively simple choice of indicators that characterize the degree to which these goals are achieved. The AEDFAL and the degree of proximity of the state of ecosystems to the boundary of their stability (to the bifurcation point) act as indicators for assessing the degree of achievement of the goals «health» and «quality of the natural environment», respectively.

It is obvious that as an indicator of assessing the achievement of the goal of «ensuring the security of the population and territories», it is necessary to introduce the criterion «The possibility of preventing emergency situations and rapid intervention», which is directly related to this goal.

Structuring the goals allows us to specify the definition of the concept of stable development, introduced by the Brundtland Commission, and formulate it in a fairly formalized form. Based on this structuring, the definition of the term «stable development» is formulated as follows: stable development is development that provides conditions for improving the quality of life and security of a person and his environment (society and the natural environment).

A set of criteria—maximizing the economic well-being of a person, ensuring his rights, increasing the level of his education, characterizing the achievement of such a goal as the quality of human life—and the set of criteria—maximizing human life duration and not exceeding the limits of ecosystem stability, characterizing the degree of achievement of such a goal as ensuring human security and the environment—are quite complete from the point of view that they give a complete idea of the degree of achievement of the main goal—ensuring stable development.

Structuring of goals is a general rational approach to solving complex social problems that ensure the choice of desirable development paths among a variety of possible alternatives, based on the study of the structure of the system, goals, and conditions of its development. However, this is only the first stage on the way to solving this problem.

The next stage is the construction of a mathematical model of the system under study and the determination of control actions, the analysis with the help of the dynamic consequences of possible solutions, and the assessment of the sensitivity of the results to changes in the proposed model.

Comparing the trends toward an increase and decrease in AEDFAL as a result of the introduction of a particular technology or activity, designed to achieve one of the sub-goals of stable development—improving the quality of life—allows us to determine the degree of achievement of the second sub-goal of stable development—ensuring human and environmental safety.

The basis of the model for solving the problem of ensuring the safety of the population in such a territory is the following three blocks (or subsystems):

1. The «danger» block: natural (natural) and artificial (man-made) human habitats (i.e. the biosphere and techno sphere) that ensure the vital activity of the population of the territory and at the same time contain potential dangers to human health. The potential nature of the impact of the biosphere and techno sphere is determined by environmental and techno genic factors, respectively.
2. The «protection» block: safety systems (social and technical) that reduce the negative impact on humans of ecology technology factors, respectively. The

effectiveness of these systems determines the degree of human security from social and technology risks.

Social risk is understood as the risk of deterioration of the health of people from various social groups of the population due to insufficient levels of material benefits and employment, due to unsatisfactory quality of medical care, housing conditions, education, due to possible emergency situations (for example, epidemics, floods, droughts), etc. Techno genic risk is the risk of deterioration of the health of the population and the environment due to environmental pollution as a result of economic activities or accidents at industrial enterprises, etc.

3. The «security» block: the economy of a particular region or country as a whole, the level of development of which determines the effectiveness of security systems, and, accordingly, the levels of techno genic and social risks in this region.

In other words, it is assumed that the levels of each type of risk can be determined by the economic costs that are directed to the corresponding security systems.

The development of technology, aimed at improving the material standard of living of the population, simultaneously leads to the appearance of certain types of danger both for the health of the population and for the state of the human environment. To eliminate these types of techno genic hazards, it is necessary to spend a certain share of the material resources of society, which are always limited. Consequently, the costs of creating and maintenance of technical systems, that increase the safety of industry, divert funds from those areas in which goods are produced that increase the material standard of living of the population and the quality of life. The more the money is spent on technical security systems, the less there is left for the fight against diseases, and for the production of goods and services that make life more complete. At present, when the costs of ensuring safety in industry make up a significant share of the material resources of society, the problem of optimizing these costs becomes urgent.

Recently, AEDFAL has been widely used in the activities of the OUN in the development of a sustainable development program, which was initiated by the report «Our Common Future», prepared in 1987 by the OUN Commission on environment and development.

Currently, conceptual and methodological approaches to the creation of a national system of ecology safety are being developed at the state level.

The analysis of the requirements for systems of management of ecology safety has shown that the specified international legislation.

- is a fairly complete criteria system of the highest hierarchical level for a comparative analysis of the compliance of ecology safety management at lower levels for compliance with modern requirements;
- can be interpreted as a verbal model and serve as a basis for the further formalization of the conditions for the effectiveness of the system of management of ecology safety.

The task of further research, taking into account these criteria, is to construct a subsystem of the third level, which is part of the subsystem of the second level—requirements (legislation) for the systems of management of ecology safety in the Russian Federation, namely the analysis of compliance of the systems of management of ecology safety in the Russian Federation to modern international requirements.

1.3 Requirements for Systems of Management of Ecology Safety in the Russian Federation

The solution to the problem of increasing the efficiency of the system of management of ecology safety in civil aviation on the basis of comprehensive monitoring of its condition is associated with a critical analysis of the system, operating in CA, with systems of a higher hierarchical level. In turn, the correspondence of the subsystem to the higher level subsystem and the system itself assumes that there are no internal contradictions between them. A necessary and sufficient condition for this is the consistency and compliance of the system of management of ecology safety in the Russian Federation and international legislation. This section of the book is devoted to the answer to this question.

In the Constitution of the Russian Federation, article 42 states: «Everyone has the right to a favorable environment, reliable information about its condition and to compensation for damage, caused to his health or property, by an ecology offense».

Proceeding from the above, the state administration bodies are obliged to ensure compliance with this constitutional provision. It is natural to expect that in determining the priorities of its activities, the state authorities document the directions, related to ensuring the constitutional rights of Russian citizens to a favorable environment.

In the Concept of national security of the Russian Federation (as amended by the Decree of the President of the Russian Federation of March 10, 2000), national security is defined as «a system of views on ensuring the security of the individual, society, and the state in the Russian Federation from external and internal threats in all spheres of life» [10].

In the law «On Security», adopted by the Supreme Council of the Russian Federation on March 5, 1992, security is defined as «the status of protection of the vital interests of the individual, society, and the state from internal and external threats» [11], which in the substantial part is close to the above definition. However, it contains important clarifications, regarding the definition of «vital interests». They are understood as «a set of needs, the satisfaction of which reliably ensures the existence and opportunities for the progressive development of the individual, society and the state» [12].

In the first section of the Concept, when determining Russia's place in the world community, it is stated that economic, political, scientific, technical, ecological, and information factors play an increasingly important role in improving the mechanisms of multilateral management of international processes. The characteristic of national interests in the ecology sphere is limited to the statement that it is necessary to preserve and improve the environment.

The fourth section of the Concept provides a detailed description of ensuring the national security of Russia. Among the priority areas in the ecology sphere, the following are highlighted: rational use of natural resources, education of the ecological culture of the population; prevention of environmental pollution by increasing the degree of safety of technologies, related to the burial and disposal of toxic industrial and household waste materials, etc.

These priorities in the ecology sphere are not the result of serious analytical work, since they do not contain the main thing: there is no definition of the concept of ecological danger in general, and the elements that make it up are not identified, i.e. what it is necessary to develop a system of protective measures against is not defined. At the same time, the mechanisms by which this system of protective measures will be implemented are not indicated.

The priorities, indicated in the Concept of national security, are mainly the result of the lack of a competent policy in the area of environmental protection. There is no question of creating a state system of ecology security, not to mention the conceptual principles of its construction.

As the main objects of security in the Law «On Security», the following ones are considered: «the individual—his rights and freedoms; society—its material and spiritual values; the state—its constitutional system; sovereignty and territorial integrity» [13].

From this, and also based on the constitutional right of every citizen of our state to a favorable environment, it follows that we are also guaranteed ecology safety.

Article 2 of the Law «On Security» states: «The main subject of ensuring security is the State, which performs functions in this area through the legislative, executive and judicial authorities. The state, in accordance with the current legislation, ensures the safety of every citizen on the territory of the Russian Federation». At the same time, the main principles of ensuring security in accordance with Article 5 of the Law are legality; respect for the balance of vital interests of the individual, society, and the state; mutual responsibility of the individual, society, and the state to ensure security; integration with international security systems.

Further, Article 8 of the Law defines a security system, the main elements of which are «legislative, executive, and judicial authorities, state, public, and other organizations and associations, citizens, who take part in ensuring security in accordance with the law, as well as legislation regulating relations in the area of security».

Further, in Article 9, the Law defines the main functions of the security system, which include the identification and forecasting of internal and external threats to the vital interests of security facilities, implementation of a set of rapid and long-term measures to prevent and neutralize them, etc.

Therefore, the main functions of the security system are to identify, predict, and prevent internal and external threats to the vital interests of the individual, society, and the state.

Article 12 of the Law explains how security is ensured.

Article 13 of the Law «On Security» defines the status of the Security Council of the Russian Federation: «The Security Council of the Russian Federation is a constitutional body, that prepares decisions of the President of the Russian Federation in the area of security».

The Security Council of the Russian Federation considers issues of ecology and other types of security, public health protection, forecasting, preventing emergency situations and overcoming their consequences, and ensuring stability and law and order. Among the main tasks, facing the Security Council, is the improvement of the system of management of security.

As of today, 12 permanent Interdepartmental Commissions (IDC) have been created in the Security Council, including on ecology safety.

The Commission on ecology safety (Decree of the President of the Russian Federation no. 1603 of September 1, 2000, as amended on December 25, 2000) consists of heads of federal state authorities. Its powers allow us to create an effective system for forecasting and preventing the manifestation of ecological hazard factors.

However, this IDC does not include representatives of the Prosecutor General's Office, the Ministry of Transport, the media, and the public, without whose participation it is hardly possible to create an effective national system of ecology safety.

The documents, defining the structure, functions, and composition of the IDC on ecology safety, do not define ecology threats (ecological hazard factors) and, accordingly, the mechanisms for their prevention. So, it is assumed that these legislative gaps will be filled in the development of federal laws, concepts, and programs.

In the Federal Law «About environmental protection», the definition of ecology safety is given in the following form: «ecology safety is the state of protection of the natural environment and vital human interests from the possible negative impact of economic and other activities, natural and man-made emergencies and their consequences» [12]. In this definition, the natural environment and a person are referred to as security objects, while the Law «On Security» defines a person, society, and the state as security objects. In its meaning, the definition of ecology safety is close to the definition, adopted in the recommendation legislative act «About the principles of ecology safety in the Commonwealth States» [13]. In it, ecology safety is understood as «the status of protection of the individual, society, and the state from the consequences of anthropogenic impact, as well as natural disasters and catastrophes». Such a definition is unlikely to serve as a basis for the practical development of the system of ecology safety, since it is not clear from the above definition what the state of «security» is, how it is measured, and by what methods it is possible to achieve it.

At the same time, an important addition to the definition of ecology safety in the Law «About environmental protection» is the inclusion in the objects of protection not only of human interests but also of the natural environment. This shows the understanding of the need to preserve the quality of the natural environment. But the concept of «ecology safety» in terms of mechanisms and methods for ensuring ecology safety has not received legislative development in the text of the Law.

The «Ecology doctrine of the Russian Federation» (decree of the Government of the Russian Federation no. 1225-r of August 31, 2002) [14] states: «The strategic goal of the state policy in the area of ecology is to preserve natural systems, maintain their integrity and life-supporting functions for the sustainable development of society, improve the quality of life, improve the health of the population and the demographic situation, ensure the ecology safety of the country». The necessity of preserving biodiversity and ensuring a favorable environment is stated. But it does not specify on what principles the state system of ecology safety should be constructed.

The fourth section of the «Doctrine» highlights the state priorities: ensuring the ecology safety of potentially dangerous activities, rehabilitation of territories and water areas, affected by man-made environmental impacts; improving the quality of life, health and increasing the duration of life of the population by reducing the adverse impact of ecology factors and improving ecology indicators of the environment; identification and minimization of ecology risks to the natural environment and public health, associated with the occurrence of natural and man-made emergencies, including timely forecasting and identification of possible ecology threats, assessment of natural and man-made factors of possible emergencies with negative ecology consequences, development and implementation of measures to reduce the risk of emergencies with negative ecology consequences, training of the population in the rules of behavior, actions and methods of protection in emergency situations, and development and improvement of universal means of protecting the population and territories in the event of emergency situations with negative ecology consequences.

At the federal level, the development and implementation of the policy are entrusted to the Ministry of Natural Resources of the Russian Federation. His «Plan of actions for the implementation of the Ecology Doctrine for 2003–2005» approved on October 28, 2003, no. 961, defines the responsible ministries of the Russian Federation: the Ministry of Economic Development, the Ministry of Energy, the Ministry of Health, the Ministry of Finance, the Ministry of Transport, the Ministry of Agriculture, the Ministry of Emergency Situations, the Ministry of Foreign Affairs, and the Ministry of Defense. This list does not include the Ministry of Internal Affairs (which has ecology police units), the Prosecutor General's Office (which has the Environmental prosecutor's office), as well as the Ministry of Education of the Russian Federation (see Article 73 of the Federal Law «About environmental protection» no. 7 of 10.01.02) [12].

The ten sections of the Plan show the following issues: reduction of environmental pollution and resource conservation; ensuring safety in the implementation of potentially hazardous activities and in emergency situations; development of the system of state management of environmental protection and nature using; regulatory legal support and law enforcement; economic and financial mechanisms; environmental monitoring and information support; scientific support; ecology education; development of civil society as a condition for the implementation of state policy in the area of ecology; international cooperation.

The system of ecology safety cannot be created by simply summing up environmental protection measures and optimizing the anthropogenic load on the environment, implemented within individual ministries and departments.

Today, more than 30 ecology laws of direct effect have been adopted in Russia, but the results of their enforcement do not lead to an improvement in the quality of the environment.

To confirm this, we will cite excerpts from the State Report «About the state and protection of environment of the Russian Federation in 2002»: «The Index of atmospheric pollution (IAP), summing up the multiplicities of exceeding the average annual concentrations of several impurities, was more than 7 in 130 cities with a total population of 58.48 million people» [15]. Moreover, the number of such cities increased by 38% in the period from 1999 to 2002. During the same period, the number of cities with a high level of air pollution (IAP more than 14), in which more than 20 million people live, i.e. 1/7 of the population of Russia, increased by 59%. The deterioration of quality is also noted for other components of the environment: water resources, soils, forest plantations, bio resources, and the state of health of the population of Russia.

The State Report in part VII contains a section «Ecology Safety», which again states the need to adopt a number of ecology laws, as well as numerous examples of violations of current legislation.

The analysis of the above documents allows us to come to the following conclusions: at the national level, there is no understanding of what constitutes an ecology hazard. As a result, there is no effective concept of ecology safety and, moreover, the principles of its creation; the documents are declarative and instructional in nature and involve the development of a significant number of concretizing sub-laws.

In the existing structure of management of environmental protection and its anthropogenic impact on it, it is impossible to organize effective work not only to ensure ecology safety, but also in the area of environmental protection. Moreover, the activities of a specially authorized body in the area of environmental protection are in contradiction with the basic ecology law «About environmental protection». Article 65, p.5 of this Law says: «It is prohibited to combine the functions of state control in the area of environmental protection (State ecology control) and the functions of economic use of natural resources». The problems of ensuring ecology safety and environmental protection, as an element of it, cannot be regulated by law and enforcement within a separate ministry or department.

The Law «About environmental expertise», adopted in 1995 [16], fixes the principle: «Presumption of ecological danger of planned economic and other activities». Environmental expertise is required to conduct a comprehensive assessment of the «life cycle» of the produced impact on the environment. This requires a legally established: unambiguous definition of the scope and content of the concept of «environment»; identification of a complex of phenomena and processes that lead to environmental degradation and are environmental hazard factors from the entire variety of processes and phenomena, occurring in the world around a person and society itself; creation of mechanisms for neutralizing environmental hazard factors.

Currently, this is missing. There are only variable interpretations of these terms. Let’s list some of them.

The Federal Law «About environmental Protection» interprets ecology safety as «the state of protection of the natural environment and vital human interests from the possible negative impact of economic or other activities, natural and man-made emergencies, and their consequences» [12].

I. I. Mazur and O. I. Moldavanov interpret ecology security as a set of actions, states, and processes that directly or indirectly do not lead to vital damage (or threats of such damage), caused to the natural environment, individuals, and humanity; a set of states, phenomena, and actions that ensure ecology balance on the Earth and any of its regions at a level to which humanity is physically, socio-economically, technologically, and politically ready [17].

The following definition of ecology safety is given in the Conceptual and terminological dictionary «Civil Protection»: «Ecology safety is the state of protection of the vital interests of the individual, society, and the natural environment from threats, arising as a result of anthropogenic and natural impacts on it» [18].

Danilov-Danilyan [19] in the «Dictionary of terms and definitions» of the «Security of Russia» series gives the following definition of ecology safety: «Ecology safety is the probability of violation of the ecological balance of the environment; a state in which the threat of environmental impact factors has been created or is likely to occur, leading to changes in the environment or, as a result, to a change in the conditions of human existence and society; a situation in which undesirable events may occur, that cause deviations of the health status of the population and/or the state of the environment from their average value; deviations of certain parameters, signs, factors, characterizing the state of the environment from their established (optimal, permissible) values» [19].

Naumova [20] gives the following definition of ecology safety: «Ecology safety should be defined as the ability of the state to control, reduce and eliminate ecological hazards of various scales, identified and evaluated by scientific methods, to ensure the welfare of society and human health, political, economic and social stability».

In the work [21], ecology safety is represented as a system characteristic of the object of the socio- and ecosystem, defined as an acceptable level of danger, caused by the action of anthropogenic and (or) natural factors, i.e. an acceptable possibility of deviation of the current state of the socio- and ecosystem below the maximum permissible value.

The explanatory dictionary of the Russian language by Ozhegov [22] offers the following interpretation of security: «A state, in which there is no danger, there is protection from danger.»

Security is the most important need of a person, along with his need for food, water, clothing, housing, and information. This general scientific category acts as an integral form of expressing the viability and resilience of various objects of a particular world in domestic and foreign policy, defense, economy, ecology, social policy, people's health, computer science, technology, etc. although the threat of potential danger is a motivation for the development of mankind.

Based on the analyzed material, the authors propose the following concept of ecology safety: «Ecology safety is an appropriate mechanism, that ensures the prevention of the manifestation of hazard factors and their localization in case of their occurrence».

Ensuring security is achieved by conducting a unified state policy as a system of measures of an economic, political, organizational, and other nature that are adequate to threats to the vital interests of the individual, society, and the state. Security can be ensured by eliminating sources of danger and increasing security, which implies identification of hazards, risk assessment and forecasting of emergency situations; risk reduction and improvement of the effectiveness of protection of the population and territories; state regulation in the field of risk reduction and mitigation of the consequences of man-made accidents and natural disasters; development and improvement of emergency response forces and means.

The state policy in this area is based on the global concept of ensuring the security of current and future generations (the Concept of sustainable development, adopted at the OUN Conference in Rio de Janeiro) [23]. For its implementation, the Russian Federation has adopted the Concept of transition to a model of sustainable development [24] in the long term, providing a balanced solution to the tasks of socio- and economic development and preserving a favorable state of the environment and natural resource potential in order to meet the vital needs of current and future generations.

Based on the concept, a sustainable development strategy has been developed in the Russian Federation. This strategy is focused on ensuring a balanced solution to the problems of preserving a favorable environment and natural resource potential. It includes the conceptual foundations of sustainable development, proposals for the formation of external environmental and economic policy, proposals for determining long-term priorities for the development of the economy and environmental management, as well as social, scientific, technical, and regional development, taking into account the fact that the main factors, limiting the economic activity of society, lie in the development of the biosphere.

The «Concept of the transition of the Russian Federation to sustainable development» assumes that the mechanisms for developing and making decisions should be focused on the relevant priorities, as well as take into account the consequences of implementing decisions in the economic, social, and environmental spheres. In addition, the most complete assessment of costs, benefits, and risks should be provided and the following criteria should be met: no economic activity can be justified, if the benefit from it does not exceed the caused damage; environmental damage should be at as low a level as can reasonably be achieved, taking into account economic and social factors.

The concept of acceptable risk is the basis for rational planning of measures to ensure the safety of the current and future generations of people, taking into account social and economic factors. It is the basis of the concept of ensuring techno genic safety in Russia. Its application to the management of the security of various types of professional activities is discussed below. Acceptable risk levels should be established in the country legally.

In the work [25], socially acceptable criteria for the safety of special equipment objects are proposed for society as a whole and individuals. This criterion for society consists in the mathematical expectation of damage of no more than 1% of the public costs for the creation, maintenance, and destruction of special equipment objects.

This criterion for an individual from the population is the probability of death or serious injury no higher than household or from accidental damaging factors. This criterion for an individual from the staff is the probability of death or serious injury is not higher than for the least dangerous professions.

However, within the framework of the concept of acceptable risk, the growth of the level of living of all members of society can be significantly limited. The reason for this is the fact that its implementation does not take into account the benefits (public utility) of advanced technologies, which at first may be associated with an increased risk for those who implement them [25]. This leads to their rejection by the public, mainly because some people take risks, and others benefit from it.

1.4 The System of Management of Ecology Safety for Flight Operations, Technical Service, and Repair

In the previous sections, the main requirements for the systems of ecology safety, both international and Russian, were considered. To create an SME for CA, it is necessary to consider the impact of aviation on the environment, including on the basis of an analysis of aviation incidents.

The performance of flights of aircraft for various purposes is accompanied (in the area of their influence) by a deterioration in the ecology of the biosphere, an artificial change in the state of the environment, increased loads on the aircraft, crew, and passengers, as well as on people on the ground [26]. This is especially noticeable in the places of creation, study, research, application, and maintenance of aircraft.

The state and corporate secrecy of information in the aerospace industry is an obstacle to the formation of a unified and integral concept in the area of flight safety.

The flight of the aircraft is performed in the environment, which is a combination of components of the natural environment, natural and natural-anthropogenic objects, as well as anthropogenic objects. The environment (Fig. 1.2) includes an anthropogenic object—an object, created by a person to meet his social needs and does not have the properties of natural objects; the natural environment—a set of components of the natural environment, natural and natural-anthropogenic objects; components of the natural environment—earth, subsurface, soil, surface and underground water, atmospheric air, flora, fauna, and other organisms, as well as the ozone layer of the atmosphere and near-Earth outer space, which together provide favorable conditions for the existence of life on Earth; natural object—a natural ecological system, natural landscape, and their constituent elements that have preserved their natural properties; a natural-anthropogenic object is a natural object that has been changed as a result of economic and other activities, and (or) an object, created by a person, that has the properties of a natural object and has recreational and protective significance.

The performance of the flight depends on the state of the environment, which is characterized by physical, chemical, biological, and other indicators and (or) their totality [26].

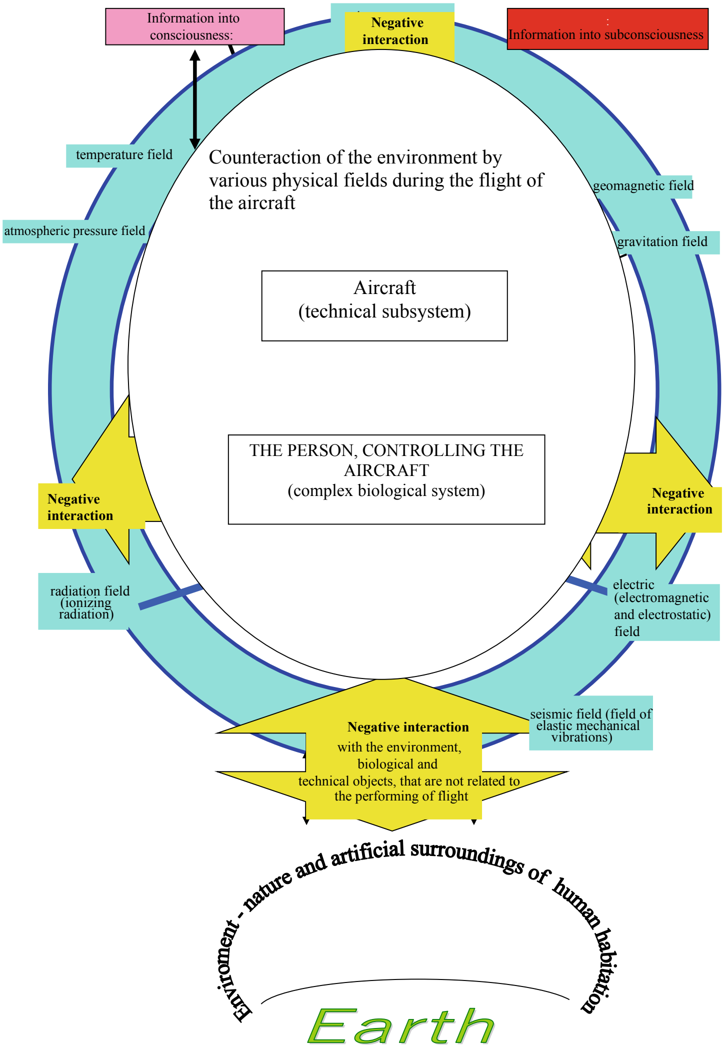

Fig. 1.2 Interaction of the aircraft and the environment

During the flight of the aircraft, there is a negative impact on the environment. The quality of the environment ensures the sustainable functioning of natural ecological systems, and natural and natural-anthropogenic objects, i.e. human habitation and its factors are affected. Among these factors: ecology factors (Federal Law no. 52 «About sanitary and epidemiological welfare of the population»)—biological (viral, bacterial, parasitic, and other), chemical, physical (noise, vibration, ultrasound, infrasound, thermal, ionizing, non-ionizing, and other radiation), social (food, water supply, living conditions, work, and recreation), and other environmental factors that have or may have an impact on a person and (or) on the health of future generations;

a favorable environment (Federal Law of January 10, 2002 no. 7-FL «About environmental protection»)—the environment, the quality of which ensures the sustainable functioning of natural ecological systems, natural and natural-anthropogenic objects; negative impact on the environment (no. 7-FL «About environmental protection»)—the impact of economic and other activities, the consequences of which lead to negative changes in the quality of the environment; human habitat (Federal Law of March 30, 1999 N52-FL «About sanitary and epidemiological welfare of the population» (as amended on December 30, 2001, and January 10, June 30, 2003))—a set of objects, phenomena, and environmental factors (natural and artificial) that determines the conditions of human life; aircraft (a complex technical system), performing a flight in the environment and interacting directly with it, is exposed to the negative effects of external factors, such as mechanical, climatic, biological, radiation, electromagnetic, special environments, and thermal. In turn, aircraft also negatively affect these physical fields.

The state of the aircraft at each point of the flight trajectory (the bifurcation point of a small aircraft system) is determined by an acceptable level of risk, in which there is no unacceptable probability of deterioration of the performance of the airframe structure, propulsion systems, systems, and aggregates; dangerous changes in the chemical and (or) physical state of the environment, materials, liquids, and gases inside the aircraft; manifestations of ergonomics deficiencies; deterioration of the condition of: passengers (including an attempt to commit illegal actions by them), additional equipment, cargo (explosion or fire hazard), biological systems (environmental contamination, etc.), weapons, etc.

An acceptable level of the aircraft's condition at the time of interaction with the environment is established, according to the air legislation, at the stages of its development, creation, maintenance, and disposal.

The condition of the aircraft is also influenced by internal factors—the processes of aging and wear. Aging processes occur continuously both during operation and during storage and transportation of products. Wear is manifested during maintenance and depends on the influence of external factors, on the maintenance modes, and operation of products. The probability of the influence of internal factors increases with the increase in the duration of maintenance and in case of violation of operating modes. According to the time and nature of the impact, the modes of maintenance and operation of products can be continuous, cyclic, one-time, repeatedly intermittent, and random.

The effects of factors on the materials of products are manifested by adsorption (surface absorption of some substances by others), diffusion, chemical, corrosion, and radiation mechanisms. The physical and chemical processes, occurring in this case, lead to changes in the values of parameters and characteristics of materials and products. Physical and chemical processes in structural materials can occur in the volume and on the surface of products and are the result of the influence of external energy, which turns from one type to another.

The products are affected by the following types of energy: thermal, electrical, electromagnetic, mechanical, and chemical. The most common causes of equipment failures are thermal destruction, deformation and mechanical destruction, electrical destruction, electrochemical corrosion, radiation destruction, wear of products, and pollution of surfaces.

Vibration (vibrational) effects lead to cyclic fatigue of the material. Shock effects can cause damage due to the occurrence of strong, although short-term, overloads in the product material.

The occurrence of acoustic noise leads to the excitation of mechanical vibrations (vibration) of products. There may be cases when acoustic noise is caused by the vibration of objects and occurs inside the cases of various products. This phenomenon is called acoustic vibration.

Climatic effects are determined by weather conditions: temperature, solar radiation, atmospheric pressure, humidity, prevailing winds, precipitation, and others.

The radiation regime is characterized by the distribution of the radiation balance, which takes into account the arrival and consumption of energy from electromagnetic oscillations of solar radiation. The presence of a wide spectrum of solar energy radiation at the level of the Earth's surface leads, in particular, to photochemical processes of degradation of materials (plastics, paints, etc.). These processes lead to changes in the appearance of products, and deterioration of their electrical and mechanical characteristics.

The presence of circulation processes in the atmosphere (wind action) leads to the appearance of wind: horizontal and vertical. At the same time, turbulent flows occur, accompanied by the appearance of vortices that regularly break away from the surface of the product and lead to its fluctuations. Under the influence of wind and air flows, sand, dust (aerosol), moisture, ice crystals, and gases, contained in the air, can move. In addition to dust, the air contains smoke and industrial gases, the components of which are oxidized, turning into sulfurous and sulfuric acids. Under the influence of dust mixtures of various compositions, the values of electrical and mechanical parameters of products change. The impact of dust is mainly manifested in optical and rubbing structural elements. The occurrence of electric charges in various combinations of the dust mixture leads to the attraction of dust to stationary surfaces. The presence of dust affects the electrical strength of the products. All products, made of metal materials due to chemical or electrochemical interaction with the atmosphere, are exposed to corrosion—spontaneous destruction.

The corrosive aggressiveness of the atmosphere is determined by the content of corrosive agents in the air (for example, chlorides, sulfur dioxide, hydrogen sulfide, nitrogen oxides, and ammonia), as well as the moistening of the surface of metal products.

In the case of chemical corrosion, metal oxidation and reduction of the oxidizing component of the corrosive medium occur simultaneously. During electrochemical corrosion, the metal interacts with the electrolyte solution. In this case, ionization of metal atoms occurs and the oxidative component of the corrosive medium is reduced. There are quite a lot of types of corrosion. For example, fretting corrosion occurs when two surfaces vibrate relative to each other and the protective oxide film is destroyed in an oxidizing medium. Corrosion can be continuous and point (local).

There are a number of sequential physical processes that occur with water: evaporation, condensation (cloud formation), precipitation, as well as moisture transfer.

Water molecules are dipoles, which causes their corrosion activity. Water droplets in the fog are highly concentrated solutions of active substances. Water, penetrating into all cracks, gaps, and capillaries or being on the surface of structural elements of products, being held on its fine particles, interacts with the materials of these elements and, depending on the degree of this interaction, changes the values of mechanical and electrical parameters that characterize its suitability for use. Water has a chemical effect on structural materials, which also leads to a deterioration in the values of electrical and mechanical parameters of products.

The influence of the elevated and lowered temperatures and changes in temperature can lead to sudden or gradual failure, caused by changes in the electrophysical, physico-chemical, and mechanical properties of materials and elements.

Damage to products by organisms or their communities, causing a violation of their serviceable and functional state, is caused by biological influencing factors.

There are the following effects of biological factors: mechanical, chemical, and biological clogging.

The greatest amount of damage occurs under the influence of mold. Mold is a fungal formation that is widespread in nature. Up to 40,000 varieties of mold fungi are known. There are up to 400 varieties of penicillin alone. The optimal conditions for the development of most types of mold are high relative humidity (more than 85%), air immobility, and a temperature of 20–30 °C. These conditions occur in the tropical, subtropical, and even temperate zones. Mold spreads and multiplies by spores, the size of which does not exceed 10 microns. Reproduction is so fast that within a few days, a small fungal formation gives several million new spores. Spores together with organic dust easily move over long distances under the influence of wind. Wind and convection air movements contribute to the penetration of spores into the products. A characteristic feature of the growth of fungal formations (mold) is the creation of organic compounds from inorganic compounds (carbon dioxide, water) without the help of the light energy of the Sun, i.e. without photosynthesis. Fungal formations consist of mycelium. The nutrition of fungal formations occurs mainly due to the substances on which they are located. In the process of growth and development, the mold allocates waste products, consisting mainly of various types of acids. These allocations (called metabolites) cause corrosion of metals and decomposition of insulation materials. Damage can also be caused by other biological individuals: birds, rodents, termites, and others.

Radiation effects (ionizing radiation) on the AE are determined by the processes of interaction of particles (or quanta) of the radiation field with structural materials. The radiation is divided into directly ionizing radiation (streams of charged particles that interact with the electron shells of atoms and molecules of element materials, ionizing them) and indirectly ionizing radiation (when exposed to directly ionizing radiation with structural radiation, secondary ionizing radiation can be formed).

Under the influence of the listed main external and internal factors, changes in structural quality indicators occur, and damages (defects) appear. The most characteristic defects of the main elements of the AE design are.

1. Malfunctions of rolling bearings—corrosion of rolling elements; tight rotation due to lack of lubrication, dust, and dirt ingress; «crunch» during rotation due to deformation of the outer ring, when it is pressed into the socket and rolling; turning of the rings in the sockets and on the shaft due to weak fit and wear of the landing surface; coloring of the raceways and rolling surfaces; wear from contamination; formation of holes on the raceways due to the pulsating nature of the load; wear of the rolling bodies under the action of axial loads; destruction and malfunctions of the separator; loss of balls; loss and crumpling of washers; run colors; risks, nadirs, and metal covering.
2. Cranes, valves, and reducers—internal leakiness of cranes due to ridges, nadirs, corrosion on the mating surfaces of parts, gaps, increased compared to those allowed, and ovality and taper of spool pairs due to wear—erosive rounding (wear) on the cut-off edges of the belts. External and internal leakage of valves due to wear, shrinkage, or destruction of sealing parts. For air reducers is leakiness in the joints, violation of adjustment, wear and corrosion of parts.
3. Glazing defects, which arise from the impact of aerodynamic loads, excessive pressure, sudden temperature changes, precipitation, and ultraviolet rays. The main defects are a decrease in strength; cracking (silver); scratches, pins, nicks, deep cracks, peeling of the soft fastening tape, violation of the tightness of the cabins in the places of glass sealing, and turbidity; increased stresses in the glass.
4. Covering-loosening of rivets. External signs may be «smoking» of rivets-traces of burning and soot at the places of countersinking of the nest under the rivet; the formation of the corolla of the embedded head, skew.
5. Undulation or corrugation. It usually occurs within the «cage», formed by stringers, ribs, frames, and other power elements of the frame, due to the loss of stability of the sheathing sheet due to structural deformation.
6. Cracks, which most often occur in the places of attachment to the elements of the frame.
7. Dents, which are due to the ingress of foreign objects and improper maintenance of the aircraft.
8. Power elements of the airframe frame—partial or complete destruction of the shelves and ribs of the spar belts, destruction of the spar along the entire section, deformation of the belts and walls of the spars, partial or complete destruction of stringers, ribs, and frames. There may be cracks and nicks on the walls of stringers.
9. Helicopter rotor and tail rotor blades: on metal blades is a violation of the paint coating; holes and cracks on the skin, rib shelves, and tail stringer; peeling of the skin from the frame elements; damage to the shackles and fairings; on wooden tail rotor blades is a violation of the paint coating; peeling of the solid film coating; destruction of the shackles and their fastening parts: failures of the anti-icing system.
10. Parts and control units—on the parts and nodes of rigid wiring—violation of the protective coating and corrosion of rods, rockers, and brackets; cracks; risks, nicks, and dents; wear of the rod pipes under the guide rollers; weakening of

tubular rivets and their crumpling by adjustable rod tips; malfunctions of ball bearings, and other connection parts.

11. Cable control—creases, dents, and serifs; on the wires of the strands: corrosion, wear, and cable extraction; weakening of the cable sealing in the tips; coloring, dents, and deep wear of the edges and working grooves of the rollers; malfunctions of the ball bearings of the guide rollers.
12. Units of liquid—gas systems. Their characteristic malfunctions are external and internal leaks. External leakiness is characterized by the appearance of leaks through seals in joints, welded, and soldered seams; internal leakiness is characterized by the flow of the working substance from one cavity of the unit to another through faulty seals. Jamming and jamming of moving parts due to dust, corrosion, and other particles, entering the working gaps. Cracks, nicks, dents, risks, and corrosion of parts.
13. Pipes—leak compounds; destruction (cracking) pipes and fittings; dents, nicks, fading, and twisting; violation of protective coatings and corrosion.
14. Power cylinder—cracks on the parts and weld joints; external and internal leakage due to wear and stand-institution connector surfaces and sealing parts: deformation of the walls of the cylinders and rods; wear locks and springs; corrosion of parts, especially of the air cylinders. On the inner surface of the cylinders—risks, scratches, nadirs, and corrosion.
15. Take-off and landing devices—on the shock-absorbing struts of the front and rear legs of the landing gear: cracks in the welds and on the base metal; wear of the working surfaces of the rods, boxes, and cylinders; leaky seals due to damage and wear; corrosion. Chassis wheels—defects in the bodies (drums, ribs) of wheels, brake parts and assemblies, wear and damage to cameras and tires. There may be nicks and nadirs on the galtels and in the grooves. On the treadmills of roller bearing rings, there are cracks, nadirs, and colors of running. Brake pads—uneven wear, chipped.
16. Turbines of aircraft engines—overheating and destruction during operation, fatigue failure due to the formation of cracks; nicks; corrosion; plaque of solid combustion products; increase in the roughness of the surface of the blades. A feature of the destruction of the blades is their extraction with the formation of a neck, in the narrowest place in which a break occurs. Fatigue failure, mainly along the first groove of the tree lock and along the profile part of the pen. On the turbine shaft bushing, shaft slots, and the leading spline bushing, there is a riveting, metal covering, and nadir. The turbine body and the outer casing of the nozzle apparatus have shrinkage, warping, and cracks on the lintels of the bolt holes.
17. Aircraft engine compressors—there are scratches, nicks, dents, and surface roughness of erosive origin on the input part of the comp-spring. On the body parts—cracks, nicks on the walls, roughness of the inner polished surface, violations of the paint coating, staining of the talc coating of the labyrinth seal, development of guide blades in the holes for the trunnions, bending, and nadir on the landing surfaces of the bearing housing. There are nicks and cracks on the guide and straightening blades, corrosion on the steel blades, and riveting on

the trunnions. On the rotors—roughness, wear, nicks on the blades of the air intakes;roughness of the working surfaces, rivets, and workings of the blades of the impellers. On the rotors—nicks and nadirs of the trunnion threads, bearing fit changes, thread failure on the trunnions, nicks, and nadirs on the mazes. There are nicks and roughness on the shoulder blades, increase in tangential backlash, curvature, cracks, and metal stratification. On the ball and roller bearings—workings, discoloration, cracks, traces of overheating, and corrosion.

18. Thin-walled parts of the hot path—warping, cracks, abrasion of the landing surfaces, burning of the edges, local overheating (and burnouts) of the metal, destruction of protective coatings, and weakening of the attachment points.
19. Fuel equipment units—their defects are similar to self-flying units. On the nozzles—scratches, nicks, curvature, nozzle rupture, erosion, deposits, clogging, wear, and rivets.

The safety of aircraft flights is determined by state priorities. It includes the immediate safety of people on the ground when flying aircraft; the safety of the environment and personnel when providing, maintaining, and preparing the aircraft for flight; the safety of the environment when flying aircraft; the safety of the environment and personnel when providing and maintaining the flight process of the aircraft itself; the safety of passengers when flying on an aircraft; the safety of the crew when flying on an aircraft; safety of cargo transportation on an aircraft; safety of an aircraft in flight.

Flight performance by an aircraft (flight maintenance of an aircraft):

(1) it must be justified, predictable, and provided with the necessary (specified) degree of reliability, depending on the logical goal that the operator pursues (an acceptable level of threat and risk laid down in the air legislation);
(2) it may not pursue any logical goal, be unfounded, unpredictable, or unprovided by any reliability (unacceptable threat level, adventure, and absolute risk).

In the first case, the flight safety of the aircraft is determined by a logical goal. If the purpose of the flight is humane (for civil aviation, it is humane), then its safety is determined by the necessary degree of reliability (an acceptable level of threat and risk, conditional and sufficient security) of the interacting systems: the environment; aircraft; crew and passengers; ground services (training, support, and flight management).

The necessary safety of the flight of an aircraft can be achieved by sufficient reliability (an acceptable level of risk for the state, society, and individual) of each of the systems, interacting during flight maintenance (components of a small aviation system are the environment, the aircraft, and the person controlling the aircraft) at each point of the aircraft's location (the moment of instantaneous contact of the components of a small aviation system).

The main safety condition at the bifurcation point is the absence of contradictions between the contacting systems (the environment, the aircraft, and the person controlling the aircraft).

If the purpose of the flight is not humane, then its safety is determined by the established (assigned) mission of the flight and the resulting relative degree of reliability of the interacting systems on the trajectory of movement (hovering) of the aircraft (in place, in time, and in the local direction).

When performing a flight by an aircraft, events may occur that exceed the acceptable level of the state of the aviation system. Such events are called aviation events, which are divided into aviation accidents (catastrophes, crashes); aviation (serious aviation) incidents; and emergency accidents.

The aviation system should have the properties of self-regulation, in which state regulation in the field of flight safety becomes sufficient to exclude cases of exceeding an acceptable level of risk of the probability of unacceptable negative interaction of the components of the «small aviation system», when organizing, providing, preparing, performing, and managing flights in the «aviation system».

This can be achieved by highly professional provision of the Air legislation of the Russian Federation with uniform regulatory, legal, and organizational requirements, necessary resources, as well as timely preventive measures; independent of departmental interests, control, and supervision of the implementation of the Air legislation of the Russian Federation, compliance with international treaties in the Russian Federation, and the implementation of preventive measures in the area of flight safety.

The norms, rules, conditions, restrictions, and other requirements, contained in federal laws and regulatory legal acts of the Russian Federation, as well as regulatory technical documents, that are adopted in accordance with the established procedure by the relevant state bodies and are aimed at ensuring flight safety, being flight safety requirements (components of Air legislation), must comply with the state policy in the area of maintenance and development of aviation of the Russian Federation.

The successful implementation of the state policy in the area of ensuring the safety of aviation flights of the Russian Federation is impossible without the rapid collection and analytical processing of information, and the use of versatile and long-term information resources of the state about the dangers that arise during flights.

The federal executive authority in the area of environmental protection (the Ministry of Natural Resources of the Russian Federation or the Federal service for ecology and technological supervision), whose activities are managed by the Government of the Russian Federation, on the basis of and in compliance with the Constitution of the Russian Federation, federal constitutional laws, other federal laws and the powers, established by the Decree of the President of the Russian Federation in the area of ensuring the safety of aviation of the Russian Federation, adopts (issues) individual legal acts, regulating the activities of legal entities and individuals to ensure flight safety by meeting the requirements of technical regulations, standards, rules, and parameters for assessing the permissible negative techno genic impact on the environment and rapid analysis of its state.

The Ministry of Natural Resources of the Russian Federation developed proposals for approval by the Government of the Russian Federation in the field of adopting regulations, standards, and decisions on accreditation and certification of organizations (institutions). These organizations carry out their activities in the field of influence on the physical state of the environment, the creation of expert organizations and commissions to prepare requirements for assessing the physical state of the environment, permissible norms of influence on its state, as well as conditions and parameters for providing information about the physical state of the environment (air or near-Earth space) to aviation personnel.

In the interest of ensuring the safety of aviation flights of the Russian Federation, the Federal service for ecology and technological supervision organizes a unified state accounting. This unified state accounting includes permits (licenses) for the use of sources of negative techno genic influence on the physical state of the environment; stations for monitoring the physical state of the hydrosphere, lithosphere, atmosphere, and near-Earth outer space of the territory of the Russian Federation.

Also, the Federal service for hydrometeorology and environmental monitoring organizes a unified system for monitoring the dynamics of changes in the physical state of the airspace over the territory of the Russian Federation and the negative impact of natural and anthropogenic physical fields on it.

1.5 Compliance of the System of Management of Ecology Safety in Civil Aviation with International and Domestic Requirements

Currently, the Russian Federation has more than 30 Federal laws and 10 Presidential decrees, more than 50 Government resolutions, and 150 various orders and instructions of ministries and departments, including those left over from the USSR, regulating activities in the area of aviation. The number of federal rules, guidelines, instructions, and directives, acting in the area of aviation safety in Russia, is difficult to account for. The provisions of many of them were issued by ministries (their officials) that are not sufficiently competent in regulating aviation activities.

The analysis of aviation events has shown that one of the causes of aviation accidents is regulatory imperfection. In the same airspace, with the same degree of risk—for crews, passengers, and people, who are in the zone of (negative: existing or potential) influence of aircraft flying, according to uniform physical laws, there is an objective contradiction, a difference of interests.

The interests of the state, the subjects of the Russian Federation, municipalities, private capital, legal entities and individuals, and public organizations should be synergistic in ensuring the priorities of aviation security and the permissible degree of risk. This requires a unified state policy, general legislative provisions in the field of ensuring the safety of aviation flights of the Russian Federation, control, and supervision, ensuring the necessary and sufficient balance of interests for the state.

Currently, the Air legislation of the Russian Federation is based on the provisions of the Constitution; Federal Laws; Decrees and Orders of the President; Resolutions and Orders of the Government; Interstate Treaties (agreements), as well as other regulatory legal acts.

An analysis of the existing regulatory framework in CA showed that it does not fully comply with the current legislation of the Russian Federation. For example, Article 8 of the Air Code [27] establishes mandatory certification and attestation only in CA. In the first part of this article, it is emphasized that «legal entities, engaged in the technical service and repair of aviation equipment, airfields, aircraft, as well as legal entities, whose activities are directly related to ensuring the safety of aircraft flights are subject to mandatory certification». Article 8 does not extend the requirements for certification and attestation in state aviation, i.e. the content of this article artificially separates the complex of works on ensuring flight safety in civil aviation from similar activities in state aviation. According to CA, Chapter IV provides for «State control over activities in the field of civil aviation», according to which (Article 30) the rights and responsibilities of civil aviation inspectors are determined by the Government of the Russian Federation, and state control over activities in the area of CA is carried out by a specially authorized body in the field of CA. The Air Code does not provide for such an approach to state control and the mechanism of its implementation in state aviation.

The Air Code prescribes the introduction of a large number of sub-laws and Federal Aviation Regulations (FAR) (Articles 8–10, 29, 35–37, 48, 53, 66, 74, 84, 85, 87, and 109–114), of which only eight provide for rationing the activities of state aviation. Many issues, related to the activities of state aviation, are not closed in the Air Code and are reduced to general formulations such as «are established (implemented) by a specially authorized body in the area of defense».

Air legislation today is characterized by incomplete work on the preparation of a row of projects of Resolutions of the Government of the Russian Federation, related to the development and revision of more than half of the manuals, instructions, regulations, and decrees (which should be put into effect as Federal Aviation Regulations).

The analysis of the existing Federal Aviation Regulations revealed the absence of ecological requirements in most of them (Table 1.1) [28, 29].

There are currently no FARS regulating the issues of environmental protection from the impact of activities in the area of CA and regulating the system of ecology safety. Persons, responsible for ecology safety, have been appointed at the air enterprises. There are their job descriptions, which specify the duties: «…to monitor the state of the environment; to develop and plan measures to reduce and prevent environmental pollution; to organize the implementation of orders; to carry out ecology education, etc.»; responsibility for «violation of environmental legislation, non-compliance with norms, regulations, orders, etc. environmental protection documents». As a rule, the company has a list of documents on ecology safety. Of the 15 positions, only one is a branch document. The proposed document «Methodological guidance on the organization of the activities of aviation enterprises and civil aviation organizations in the area of environmental protection», dated November 18, 2003, cannot perform a system function, since it determines only persons responsible for compliance with ecological requirements for various types of activities and no more.

Table 1.1 Analysis of the existing federal aviation regulations

FAR Certification requirements for organizations, engaged in activity for organizational support of aircraft flights (OSAF) (FAR-141)	There are no requirements for ecology safety
FAR Certification procedures OSAF	There are no documents in the list of documents for the application, related to the ecology assessment of the activity
FAR Organizations for TS and R of AE (FAR-145)	There are no requirements for ecology safety
FAR Certification of airports. Procedures (FAR-151)	The list of airport activities does not include ensuring the safety of the environment
FAR Certification requirements for legal entities, engaged in airport activities for airfield support of aircraft flights	There are no requirements for ecology safety, including absence of assessment of the impact of air transport on the environment
FAR Radio engineering support of flights and aviation telecommunications. Certification requirements (FAR-173)	The impact of radio equipment on people and the environment is not considered
FAR Flights in the airspace of the Russian Federation (FAR-91)	Flight rules, actions in case of various failures are considered in detail, but there are no requirements for ecology safety
FAR Certification requirements for organizations that control the quality of aviation fuel, oils, lubricants, and special liquids, refueled in aircraft (FAR-159)	There are requirements for ensuring flight safety. There are no requirements for ecology safety
FAR Certification requirements for operators of commercial civil aviation. Certification procedures	«The operator ensures compliance with requirements of ecology safety and sanitary and epidemiological requirements The operator has the necessary regulations on ecology safety, develops and implements the organization and technical measures to comply with their requirements»
FAR Certification of ground-based aviation equipment	«The rules are developed, based on the state's obligations to minimize the risks of harm to the life, health of citizens, property of individuals and legal entities, and the environment, when using ground-based aviation equipment (GBAE), taking into account the compliance of aviation enterprises with the established operational requirements for GBAE» There are no indications of methods and means of ensuring ecology safety during the maintenance of the GBAE
FAR Regulations on the procedure for admission to maintenance of single samples of aircraft of aviation of general purpose	There are no requirements for ecology safety

(continued)

Table 1.1 (continued)

FAR A sample of the aircraft. Certification requirements and procedures	There are no requirements for ecology safety
FAR The operators of aviation of general purpose. Requirements to operator of aviation of general purpose, procedures for registration and control of activities of aviation of general purpose	There are no requirements for ecology safety
FAR Certification requirements for legal entities, engaged in airport activities, to provide services for passengers, cargo, and mails (FAR-148)	There are no requirements for ecology safety

All other documents are Federal laws, a Government decree, and orders of the State committee for ecology and the Ministry of Nature. These documents are valid in all sectors of the national economy and are not specified for aviation.

The positive trends in the issues of reforming the regulatory and legal framework in the area of aviation include the fact that, in accordance with the law «On technical regulation», it is planned to adopt general technical regulations «On ecology safety», as well as macro-industry regulations (proposed by the Ministry of Transport) «The conditions of delivery of AE and after-sales support for its safe operation», «Standards of airworthiness and ecology safety of civil aircrafts», etc. It is possible that these documents will help solve the issues of ecology safety in the branch.

The projects of Resolutions of the Government of the Russian Federation «About testimonies of CA aviation personnel», «Regulations on the peculiarities of working hours and rest time of CA aircraft crew members», FARs «Flight operations in civil aviation of the Russian Federation», and «Issuance of certificates to aviation personnel» have been prepared and sent to the Ministry of Transport of the Russian Federation for implementation.

Currently, the Concept of the project of Federal Law «About state regulation, control, and supervision in the area of aviation safety and the use of the airspace of the Russian Federation» has been submitted for consideration by the Government [30].

The Government of the Russian Federation, on the basis of and in compliance with the Constitution, Federal constitutional laws, this Federal Law, other federal laws, and the powers, established by the Decree of the President of the Russian Federation in the area of aviation safety of the Russian Federation, will adopt (issue) regulatory legal acts, regulating the functions of federal executive authorities in the area of flight safety in the independent implementation of legal regulation of activities in the area of development, design, manufacture, and production of aviation equipment, provision of state services by air transport of state, civil and experimental aviation, development of individual legal acts of health, social development, and environmental protection.

Based on the unified legal area of state policy, the regulatory legal regulation of relations in the area of aviation safety of the Russian Federation will be carried out (within the competence and powers, established by Federal Law) by federal state authorities, which are entrusted with the functions of independent legal regulation of activities in the area of defense, industry, transport and communications, environmental protection, education and science, health and social development, finance, and others.

Currently, the Federal law «About the state regulation, control, and supervision in the sphere of ensuring the safety of aviation and use of airspace» is prepared.

The purposes of the state regulation, control, and supervision in the sphere of ensuring the safety of aviation are giving priority to the preservation of life and health of people in the process of aviation activity; preventing damage from accidents, and dangers to the vital interests of the individual, society, and the state.

One of the goals of state regulation is to «prevent damage from aviation accidents that pose a danger to the vital interests of the individual, society, and the state». As a result of the incident, local ecology disasters arise, which pose a danger to society and the state. The Government of the Russian Federation and federal executive authorities that carry out state regulation in the area of flight safety do not assume the function of preventing ecology consequences as a result of aviation accidents.

The most important law «About technical regulation» regulates the relations arising during [31] development, adoption, application, and execution of mandatory requirements for products; processes of production, maintenance, storage, transportation, sale, and disposal; development, adoption, application, and execution on a voluntary basis of requirements for products, processes of production, maintenance, storage, transportation, sale and disposal, performance of works, or provision of services; conformity assessment.

Technical regulations are adopted in order to protect the life or health of citizens, the property of individuals or legal entities, state or municipal property; protect the environment, the life and health of animals and plants; prevent actions that mislead purchasers.

They also, taking into account the degree of risk of harm, establish the minimum necessary requirements that ensure radiation safety; biological, explosive, mechanical, fire, industrial, thermal, chemical, electrical, nuclear, and radiation safety; electromagnetic compatibility in terms of ensuring the safety of devices and equipment; unity of measurements.

The technical regulations contain requirements for the characteristics of products, processes of production, maintenance, storage, transportation, sale, and disposal, but they should not contain requirements for design and execution, except in cases where, due to the lack of requirements for design and execution, taking into account the degree of risk of harm, the achievement of the specified goals of the adoption of the technical regulations is not ensured.

The regulations, taking into account the degree of risk of harm, may contain special requirements for products, production processes, maintenance, storage, transportation, sale, and disposal; requirements for terminology, packaging, labels, and the rules for their application, ensuring the protection of certain categories of citizens (minors, pregnant women, nursing mothers, and disabled people).

Technical regulations also establish the minimum necessary veterinary-sanitary and phytosanitary measures for products, originating from individual countries and (or) places, including restrictions on the import, use, storage, transportation, implementation, and disposal, ensuring biological safety (regardless of the safety methods, used by the manufacturer).

In the Russian Federation, there are general technical regulations; special technical regulations.

The requirements of the general technical regulations are mandatory for application and compliance with all types of products, production processes, maintenance, storage, transportation, sale, and disposal.

General technical regulations are adopted on the following issues: safe maintenance and disposal of machinery and equipment; safe maintenance of buildings, structures, and the safe use of adjacent territories; fire safety; biological safety; electromagnetic compatibility; ecology safety; nuclear and radiation safety.

The requirements of the special technical regulations take into account the technological and other features of certain types of products, and processes of production, maintenance, storage, transportation, sale, and disposal.

Currently, the development of technical regulations is generated in the branch. These are such regulations as «About ensuring the safety of AE during its development, production, repair and testing», «About the requirements for ensuring the safe operation of AE and infrastructure, related with it», «Airworthiness standards and ecology safety of civil aircrafts», etc. A general technical regulation «About ecology safety» is also developed. However, it is not known when it will be developed and adopted.

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Chapter 2
Analysis of Work in the Area of Improving the Requirements to the System of Management of Ecology Safety

2.1 Determination of the Factors of Ecology Threats

To create a system of ecology safety in air transport, it is necessary to clearly understand the factors that cause ecologically dangerous situations. The formation of a system for the prevention and localization of negative impacts on the environment requires knowledge of the causes that cause the deterioration of its condition.

First of all, it is necessary to formulate the definition of «ecology threat». In the published sources, there are various definitions of this term that are identical to each other.

The explanatory dictionary of the Russian language by Ozhegov [1] interprets threat as «an opportunity, a threat of something very bad, some misfortune».

In [2], «threat is a consequence of the action of some negative factors on a certain object of influence. When the characteristics of the influencing factors do not correspond to the characteristics of the object of influence, the phenomenon of threat appears».

In the «Ecological encyclopedic dictionary», ecology threat is defined as a situation in the human environment. In this environment, under certain conditions, there may be dangerous factors that can lead to one of the following undesirable consequences for humans and the environment: deviation of human health from the average value, i.e. illness or even death of a person; deterioration of the human environment, caused by material or social damage and/or deterioration of the quality of the environment [3].

Both definitions of ecology threat speak about it, on the one hand, as a possibility or probability, and, on the other hand, as a state or situation. However, they do not specify the impacts that create dangerous ecology situations, deviations, and deterioration. In [4], the author offers his own definition: «ecology threat is a realized or possible (probable) ecology threat as a result of anthropogenic or natural influences, that causes human health disorders and/or environmental degradation».

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https://doi.org/10.1007/978-981-19-6207-3_2

The conceptual and terminological dictionary «Civil protection» contains the following definition: «ecology threat is a state, that threatens the vital interests of an individual, society, the natural environment as a result of anthropogenic and natural influences on it» [5].

Thus, the category «ecology threat» is considered as a threat to a person and his environment in the conditions of the increasing dependence of society on a rapidly changing environment under the increasing influence of society itself.

The study of ecology safety involves the analysis of ecology threats. This is due to the fact that, knowing the factors contributing to the destabilization of the socio-ecosystem, it is possible to prevent their negative impact. At the same time, the occurrence of a state of degradation of one of the components, that complement each other and exist, according to the law of optimal compliance of the state of the natural environment with the pace and nature of the development of society, formulated by E. V. Girusov [6], is not allowed.

The author proposes to define «ecological threat» as any change in the parameters of the functioning of natural, anthropogenic, and natural-anthropogenic systems, leading to a deterioration in the quality of the environment below the established standards.

In accordance with NS 15,467–79, «product quality is a set of product properties that determine its suitability to meet certain needs in accordance with its purpose». The international standard ISO-8402 defines quality as a complete set of characteristics of an object, related to its ability to meet established and expected needs.

Ecologically dangerous situations can arise not only from anthropogenic but also from natural processes and phenomena.

The first fairly complete taxonomy of threats was constructed by Marshall [7], while he considered only human threats (industrial threats in general and the dangers of chemical industries in particular) and did not touch threats to the environment.

Marshall proposed to classify the threats to humans as follows:

1. On the general effects of changes in environmental conditions.
2. According to the time of implementation («acute» and «chronic» threats: the action of the first manifests itself within an hour from the moment of the beginning of the implementation of the threat, and the action of the second after a month or more).
3. By the number of affected people.
4. Individual and group threats.
5. According to the level of risk.
6. According to the method of rendering the damaging effect.
7. Voluntary and compulsory threats.
8. By the source of the damage.
9. Threats of stationary and transport installations.
10. Concentrated and scattered dangers.

Other classifications of threats and related risks differ from each other in the degree of detail, the breadth of coverage, the goals of a specific study, etc.

Threats and risks, according to the scale of the manifestation, can be local, regional, and global [8, 9].

According to the objects of exposure, threats and risks can be divided into the following groups: threats and risks to human life and health [6, 9]; threats and risks to the environment [8, 10]; threats and risks to economic resources [11].

In the work [9] is proposed to introduce a new concept—the concept of social risk, which means the risk to the population of the region as a certain aggregate (society) that is in close relationships with the natural environment. Social risk is the highest category of group risk and includes not only professional risks and risks to public health, but also risks to the environment.

In [12], threats and risks are divided into three groups, according to their origin: natural, anthropogenic (or techno genic), and social.

The authors of the work [13] propose to classify on the basis of the internal nature of threats—sources of dangerous factors. «Factor» in [14] is qualified as the cause, the driving force of a process or phenomenon that determines its character or individual features, an essential circumstance in a process or phenomenon that causes the existence or occurrence of the latter in the environment. Accordingly, the numerous factors that are dangerous to humans and the environment are divided into four types:

- ecological (ecologically dangerous) factors—factors caused by natural causes (climatic conditions unfavorable for human life, animals, and plants; physical and chemical characteristics of the atmosphere, water, and soil; functional characteristics of ecosystems; natural disasters, etc.);
- socio-economic factors—factors caused by social, economic, and psychological reasons (insufficient level of nutrition, health care, education, and provision of material and spiritual goods; problems in public relations; weak development of social structures; economic crises, etc.);
- techno genic (or anthropogenic factors)—factors caused by the economic activity of people (excessive emissions and discharges into the environment of waste from economic activity in the conditions of the normal functioning of enterprises and in emergency situations, unjustified alienation of land for economic activity; excessive involvement of natural resources in the economic turnover, mistakes of management decisions, related to economic activity, etc.);
- military factors—factors caused by the activities of military units and the military-industrial complex (transportation of military materials and equipment; testing of weapons and their destruction; functioning of military facilities and the entire complex of military means in the event of military operations, etc.).

In [15], the author considers some classifications of factors.

Also, the classification of the factors of ecology threat is proposed by the authors in the works [2, 16, 17, 18, etc.]. For example, A. G. Shmal presents a classification of factors but does not distinguish conflict emergencies, and transport is not considered. Lapin V. L. and Akimov V. A. present a fairly complete classification, including the factors caused by the failure of equipment.

Figure 2.1 shows the proposed classification of factors of ecology threat and their brief characteristics.

Previously, when creating the systems of ecology safety, all factors of ecology threat were divided into two types: natural and anthropogenic (or techno genic).

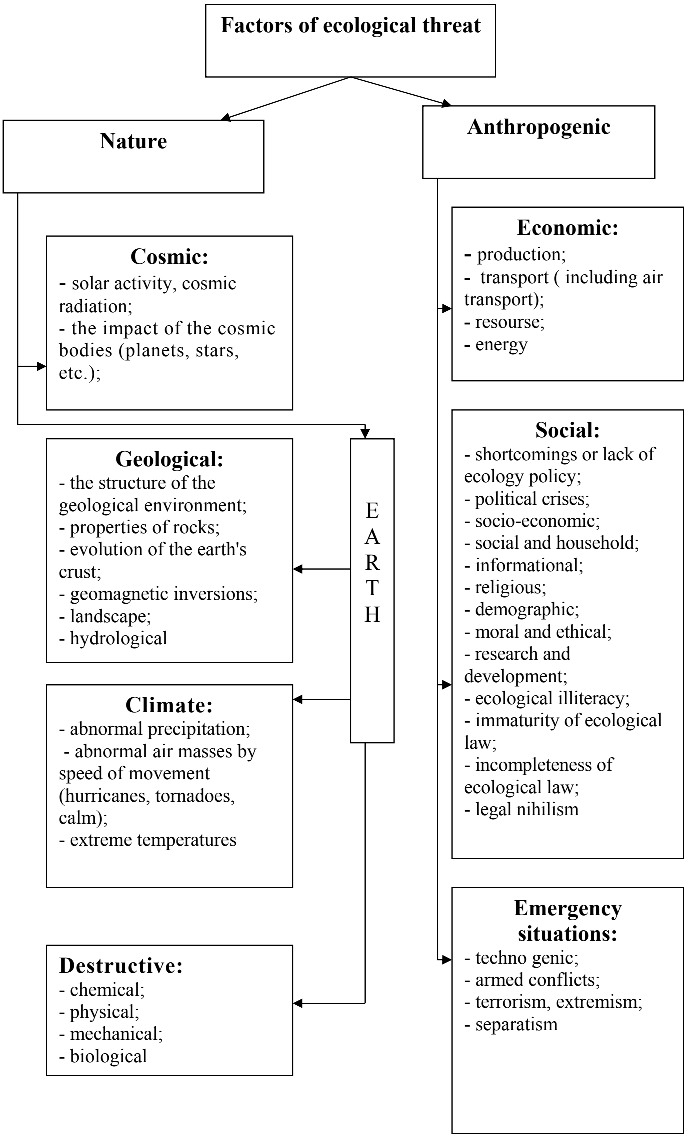

Fig. 2.1 Factors of ecological threat

Natural phenomena and processes, that can have a negative impact on natural and anthropogenic components of the environment, serve as the basis for allocating classes to the natural type. In the natural type, the following classes of factors of ecology threats are distinguished: cosmic, terrestrial, and unforeseen. There are three subclasses in the terrestrial class of factors: geological (including landscape-geographical), climatic, and destructive.

Geological factors are associated with processes occurring during the evolution of the Earth's crust: the movement of lithospheric plates, the development of geosynclinal belts, as well as under the influence of cosmic factors external to the Earth.

On the Earth's surface, the above processes manifest themselves in the form of earthquakes and volcanic eruptions.

Climatic factors of ecological threat include abnormal precipitation, abnormal speed of movement air masses (hurricanes, tornadoes, calm), and extreme temperatures.

The destructive class of factors of ecological threat includes: chemical, physical, mechanical, and biological factors, which are distinguished by the dominant process of disintegration of the substance. This class of factors is a manifestation of a fundamental process, taking place on Earth—a cycle that occurs in all components of the environment, including the biosphere (producer—consul—reducent).

Destruction as a factor of ecological threat is manifested, on the one hand, in the destruction of man-made objects, and on the other hand, it increases the xenobiotic nature of production. Everything, created by man, is either waste or deferred waste, since any human creation is destroyed over time, becoming obsolete morally and physically. Corrosion-resistant waste entering the environment does not collapse for a long time under the influence of natural factors, accumulates in huge quantities, and thereby pollutes the environment. On the other hand, the destruction of waste leads to the involvement of toxic substances in natural cycles, which have a toxic effect on the biosphere and return to humans through trophic cycles. The nomenclature of the generated waste is growing from year to year, and therefore more and more new substances are involved in the biotic cycle, which living things have not encountered in the course of their evolution and their impact on living things has not been studied to date.

There are three classes of factors of the anthropogenic type of ecological threat: economic, social, and emergency situations. The basis for the allocation of classes are the main aspects of human activity.

There are four types of factors in the economic class: production, transport, resource, and energy.

Production factors include everything, related to techno genic pollution of the environment by various industries, and the negative impact on the biosphere and humans. The main manifestation of this type of factor is the release of polluting substances into the atmospheric air, the discharge of pollutants with wastewater, etc.

Transport factors include pollution of the biosphere by various modes of transport. This is manifested in the release into the atmospheric air, soil pollution, destruction of ecosystems, and the creation of excess physical fields (noise, vibration, electromagnetic, radiation, etc.). The allocation of this factor is associated with the increasing impact of various types of transport, including aviation.

Any human activity is accompanied by the consumption of resources. Thoughtless consumption of resources leads to major ecological disasters. As a result of excessive agro technical loads, the quality of soils deteriorates, which leads to a decrease in yield, an increase in the processes of denudation, and decay. According to scientists, studying the biosphere, the withdrawal of bio resources should not exceed 10% of the biomass. Otherwise, irreversible processes of degradation of bio systems begin.

Energy factors of ecological threat affect the parameters of the state of the environment, on the one hand, as a type of production in the form of emissions of pollutants into the atmosphere (especially, when using coal and fuel oil as fuel), waste in the form of slags, spent nuclear fuel, and thermal pollution of reservoirs. On the other hand, the concentration of people in huge megacities and the concentration of production facilities in a limited area lead to a concentration of energy consumption and natural resources, which, according to some scientists, leads to irreversible degradation of the biosphere.

In addition, the energy factor of ecology threat is also manifested in the case of power supply failures to ensure the activities of techno sphere objects, which simply cannot maintain their structural and functional integrity without energy produced and supplied by humans.

In the social class of factors of ecological threat, the following types are distinguished: socio-economic, socio-household, informational, religious, demographic, moral and ethical, and ecological illiteracy. The same class includes issues related to politics and law, since they are related to the life of a person.

The scientific and research factor of ecology threat is caused by a person's desire to learn the unknown and create new things. At the same time, new substances are created by man, and new types of effects on objects of the biosphere are generated, which living things have not encountered in the course of their evolution. The threat lies in reactions that can cause new types of influences in the development of the living.

The legal type of threat is the main one, since it is the development of legal norms and rules that will minimize the likelihood of occurrence of the main factors of ecology threat. At the same time, we should not forget that legal norms are based on knowledge of the mechanisms that control factors of ecological threat. This requires, in turn, knowledge of the laws of the development of the natural environment and human society.

The incompleteness of ecological law is caused, on the one hand, by the absence of the above-mentioned ecological ideology, and on the other hand, by insufficient efforts of legislative bodies in the development of laws of environmental protection.

Emergencies are represented by the following types: techno genic, armed conflicts, terrorism, extremism, and separatism.

Military operations within the framework of one country, terrorism, and extremism are accompanied by the creation of dangerous ecological situations as a result of the capture of chemically dangerous industries, the violation of technological modes of their maintenance, and the destruction of transport infrastructure. Mining and explosion of ecologically dangerous industries are often carried out. The actions of terrorists are often directed against the civilian population (Israel, Chechnya, Ireland, Spain, etc.), which creates psychological tension in society, and causes fear and discomfort among people. Today, terrorism is considered as a global threat.

A significant danger is also hidden in ecological separatism, when individual states or social groups, for one reason or another, ignore decisions and norms, adopted by the international community or state legislation, aimed at preserving and restoring the environment.

It is also possible to distinguish another unforeseen class of anthropogenic factors of ecological threat. It can contain factors from any of the above classes, since it shows the degree of our ignorance.

In reality, living things are under the influence of the entire set of factors of ecological threat. Therefore, it is very important to study the integral indicators that characterize the state of the biosphere. First of all, this is biological diversity, which characterizes the stability of the biosphere as a whole.

For a person, an integral indicator is the state of health, the stability of the immune system, the absence of violations in hereditary information, etc. The whole complex of problems, concerning the influence of the environment on a person, is studied by medical ecology. The permissible anthropogenic impact on the environment as a whole is defined by some researchers as the maximum technological capacity of the territory, which is understood as the maximum permissible impact that does not lead to degradation of the environment [19].

2.2 Analysis of Work in the Area of Improving the Requirements to the System of Management of Ecology Safety in the Russian Federation

The system of ecology safety is based on the basic theoretical principles that determine the methodology of its construction. Such principles should be the general laws of ecology as a science. The fact is that the system of ecology safety is a mechanism for the practical implementation of the principles of management of impact on the environment.

In a generalized form, the principles that are the theoretical basis for creating the system of ecology safety are given in Table 2.1.

The systematic organization of the material world is the basis of all natural science knowledge. According to the law of consistency, any object is an object-system and any object-system belongs to at least one system of objects of the same kind. The object-system is a composition or unity, constructed on the relations r of the $\mathrm{R}_{\mathrm{environment}}$ set and the conditions z of the $\mathrm{Z}_{\mathrm{environment}}$ set that limit these relations. At the same time, in each object-system are distinguished [20] the primary elements that make them up; unity relations, which are connections between elements that bind

Table 2.1 The principles that are the theoretical basis for creating the system of ecology safety

Principle (law)	Definition	Consequence
Development of the system at the expense of the environment (N. F. Reimers)	Any system can develop only through the use of material, energy, and information capabilities of its environment	The system of ecology safety should prevent the negative consequences of the withdrawal of material, information, and energy resources from the environment, as well as the emission of the results of anthropogenic activities into the environment
System organization of the material world (Yu. A. Urmantsev)	Any object is an object of the system, and any object of the system belongs to at least one system of objects of the same kind	The system of ecology safety should be implemented at all levels of management This system should include all levels of the organization of the environment and its components
Internal dynamic equilibrium (N. F. Reimers)	Substance, energy, information, and dynamic qualities of individual natural systems and their hierarchies are so connected that any change in one of these indicators causes concomitant functional and structural quantitative and qualitative changes that preserve the total sum of the qualities of the systems	The system of ecology safety should assess all the consequences of disturbing impacts on the environment, caused by both natural and anthropogenic factors of ecology safety
Physical and chemical unity of living matter (V. I. Vernadsky)	All the living matter of the Earth is physico-chemically one	The system of ecology safety should assess the anthropogenic impact on living things along the entire chain of possible consequences
The Law of necessary regulation of human impact on the environment (A. G. Shmal)	The human impact on the natural and anthropogenic components of the environment should be consistent with the fundamental laws of the evolution of human society and environmental components	The system of ecology safety should ensure compliance with permissible anthropogenic impacts on the environment, established on the basis of knowledge of the fundamental laws of the evolution of human society and the environment

(continued)

Table 2.1 (continued)

Principle (law)	Definition	Consequence
The law of the necessity of forming of ecological worldview among the population of the planet (A. G. Shmal)	The harmonization of anthropogenic impact on the environment is possible only on the basis of the formation of ecological worldview, as a constituent element of universal culture among the overwhelming number of earthlings	The formation of an ecological worldview among the population of Russia is one of the main elements of ecology safety

them into a single whole (emergent or system-forming properties); conditions that limit unity relations, or the so-called laws of composition; the inevitable belonging of each object-system to at least one system of objects of the same kind.

Therefore, an object-system is a composition or unity of primary elements, constructed on relations (in the special case—interactions) and conditions, limiting these relations. A set of object-systems with common generic features form a system of objects of this kind, called the R-system. For it, there are two peculiar limits on the content of the constituent elements. The upper limit corresponds to the highest form of generality—an abstract system that encompasses all other concepts in the form of its constituent elements. The lower limit corresponds to a zero-system that does not contain any elements of this kind. Thus, a system series is formed: zero-system (0) → object system under study (i) → the system of objects → systems of given kind (R) → an abstract system (A).

Two consequences arise from the formulated principle of consistency, which must be taken into account, when creating the system of ecology safety. First, the system of ecology safety should be created at all levels of state and administrative management. Secondly, the system of ecology safety should include all levels of the organization of the environment and its components.

N. F. Reimers formulated the law of conservation in relation to ecology as the law of the development of a system at the expense of its environment—any system can develop only through the use of material, energy, and information capabilities of its environment [21]. Hence, it follows that the laws of the development of the environment are also manifested in the development of the system itself. In turn, the system also has an impact on the environment that is relevant due to the scale of human impact on the environment.

The anthropogenic impact on the environment is manifested in two types. The first is the withdrawal of natural resources, which leads to a violation of the integrity of environmental components. The second is the emission of the results of human activity into the environment, which causes disturbances and disturbances and violations in the components of the environment, and often the destruction of their integral organization, which, in turn, leads to the birth of new systems.

Therefore, there is an important consequence that must be taken into account when creating the system of ecology safety—this system should prevent the negative consequences of the removal of material, information, and energy resources from the environment, as well as the emission of the results of anthropogenic activities into the environment.

The system of ecology safety should predict and prevent the manifestation of all anthropogenic facts of ecology threats.

The principle (law) of internal dynamic equilibrium (Reimers N. F.)—matter, energy, information, and dynamic qualities of individual natural systems and their hierarchies are so connected that any change in one of these indicators causes concomitant functional-structural quantitative and qualitative changes that preserve the total sum of the material-energy, information, and dynamic qualities of the systems, where these changes occur or in their hierarchy.

It follows from the law that when studying the relationships in the «person-environment» system, it is important not only to establish the parameters of the impact on the environment (for example, the intensity and volume of emissions of pollutants), it is even more important to trace the «life» of this impact in various components of the environment. For this purpose, combinations with the effect of summation are identified, giving rise to new impacts (often more dangerous), and integral indicators of the ecological state of territories are developed (total pollution indicators, biological diversity, etc.).

The following consequence arises from the law—the system of ecology safety must assess all the consequences of disturbing impacts on the environment caused by both natural and anthropogenic factors of ecology threat.

The system of ecology safety evaluates not only the impact on a specific component of the environment but also the entire chain of disturbances caused in the environment. That is, it is necessary to evaluate the entire life cycle of the produced impact on the environment.

The principle (law) of the physico-chemical unity of living matter (V. I. Vernadsky)—all living matter of the Earth is physico-chemically unified.

This principle largely echoes the previous one. However, given the uniqueness of the living and the presence of a reasonable person in it, it seems necessary to highlight it. It follows from the discussed principle that the negative impact on one of the parts of a living substance cannot be indifferent to another part of it. Therefore, when analyzing the consequences of anthropogenic impact on the biosphere, one cannot limit oneself to a local assessment (directly on the impact area), but it is necessary to trace the entire chain of consequences of the impact. An important consequence arises from this law—the assessment of the anthropogenic impact on living things must be carried out along the entire chain of consequences of the produced impact.

This consequence also emphasizes the need to introduce the ISO 14040 standard «Assessment of life cycle» into the practice of managing the anthropogenic impact on the environment.

The law of necessary regulation of human impact on the environment—human impact on natural and anthropogenic components of the environment must be consistent with the fundamental laws of the evolution of human society and environmental components.

The need to coordinate human activity with the laws of the evolution of the surrounding world is due to the following reasons:

- According to the scale of the impact on the components of the environment, humanity at the present stage of its evolution has become the main geological force.
- The human impact on the environment is not consistent with the fundamental laws of the functioning and development of the environment and the human society itself, which leads to its destruction, degradation, and the creation of an environment dangerous for the person and the biota as a whole.
- A human, as the only representative of the living world with intelligence, is obliged to develop rules of behavior that allow preserving the evolution of the biosphere in the channel, where a human is its organic element, and not a factor in its and his destruction.

In order for the system of regulation of human activity to be effective, it is necessary to determine the range of phenomena, processes, and factors that the system of regulation should cover. At the same time, it is necessary to proceed from the main goal facing the general ecology—to coordinate the anthropogenic impact on the environment with the fundamental processes of the evolution of the human environment and the human society itself.

The system of ecology safety should be the mechanism that ensures compliance with the permissible parameters of anthropogenic impact on the environment, without causing catastrophic violations in the fundamental processes of the evolution of the environment and human society.

The following consequence arises from this law—the system of ecology safety must ensure compliance with permissible anthropogenic impacts on the environment, established on the basis of knowledge of the fundamental laws of the evolution of human society and the environment.

The creation of an effective system of regulation of anthropogenic impact on the environment is based on the competent definition of standards of impact on the environment, which is the task of the ecology of components of the environment. Compliance with the established standards is one of the main tasks of the system of ecology safety. The effectiveness of solving this problem is determined by the completeness of the establishment of subject-object relations in the system «subject of ecological control—object of impact on the environment—subject of ensuring of ecology safety».

2.3 Basic Principles of the System of Ecology Safety

The system of ecology safety by its purpose is a tool that should ensure the constitutional right of citizens of our country to a favorable environment. Therefore, the system of ecology safety should ensure, first of all, the prevention of the manifestation of any factors of ecology threat. This task can be solved only if the state administration bodies consider ecology safety as an element of national security [22].

In recent years, there have been no trends in Russia to improve the efficiency of managing the anthropogenic impact on the environment. Moreover, the reforms, carried out by the Government of the Russian Federation in the area of management of the quality of the environment and the anthropogenic impact on it, will not bring tangible results. Currently, there is an active discussion of philosophical, applied, and legal aspects of problems of ecology safety in scientific circles [23–25]. The problems of ecology safety are discussed in the works of Akimova T. A., Bogolyubov S. Yu., Israel Yu. A., Moiseev N. N., Muravykh A. I., Reimers N. F., Rybalsky N. G., Serov G. P., Haskin V. V., Yablokov A. V., etc. At the same time, the scientific community has not yet developed coordinated scientific and methodological approaches to solving this most urgent problem.

The most qualitative philosophical analysis of the problem of ecology safety from a systemic perspective was performed by Muravykh [26]. The system of ecological safety of territories, developed by the author, has an applied character, however, it is based on similar initial principles. We will give a brief illustration of the methodological approaches, adopted in this work, to the analysis and development of the system of ecology safety.

The existing global ecological contradiction is illustrated by A. I. Muravykh with the help of a system-dialectical model of the problem (Fig. 2.2.).

The current and target state of the «humanity-environment» system is characterized by a set of values of essential parameters P_1, P_2, … P_n. The target setting of the

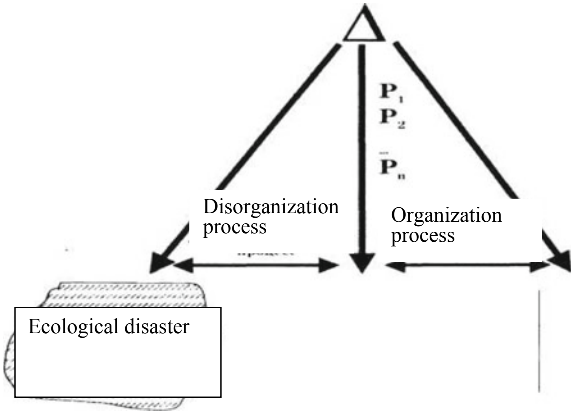

Fig. 2.2 System-dialectical model of the problem of ecology safety

system is to achieve an ecologically safe state that meets certain ecological standards and is characterized as a high degree of organization of the system. The degree of deviation of the current state of the system shows the severity of the problem of ecological safety.

From the diagram, shown in Fig. 2.2, follows that for the development of the system in the target direction, problem-solving actions should be taken. If they are not taken or are not effective enough, then the system will develop toward a disorganized process. In our case, this means a further deepening of the ecological crisis. At the same time, it should be borne in mind that the value of the deviation from the target state is not unlimited. When the deviation goes beyond a certain framework, a jump-like transformation of the system occurs, according to the law of the transition of quantitative changes to qualitative ones. Such a deviation is characterized as critical and means a state of ecological disaster.

The state of ecological safety is influenced by many factors in various combinations, some of which are unknown to us. Therefore, the transition from a safe state to a dangerous one has a probabilistic character and a fuzzy (blurred) zone of dangerous states, behind which there is a zone of guaranteed disaster.

A graphic illustration of the above is shown in Fig. 2.3. With minor deviations from the target state, the probability of the system going into a critical state (ecological disaster) is not great. With an increase in the degree of deviation before MD, there is a slight directional trend of increasing the probability of unfavorable development of the system. With deviations above the MD, the probability of an ecological disaster begins to increase sharply, and with the CD, the probability of an ecological disaster becomes a reliable event.

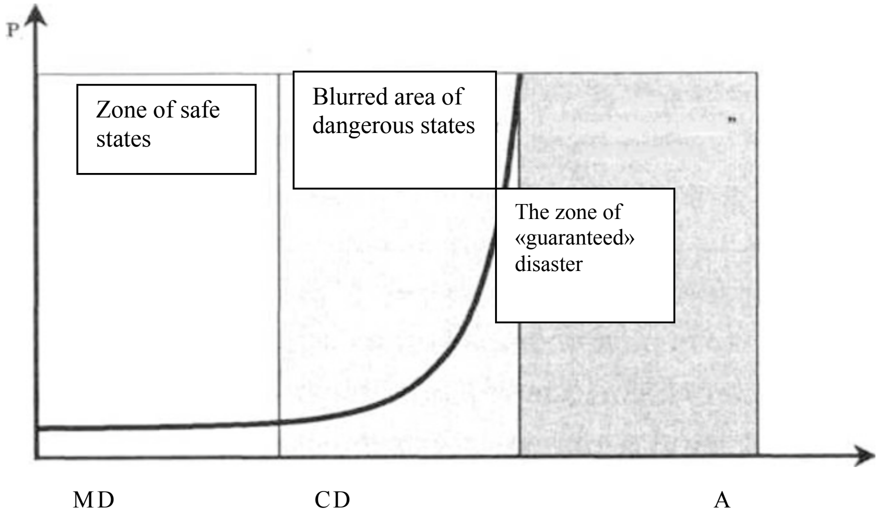

Fig. 2.3 The dependence of the probability (Pi) of the occurrence of an ecological disaster from the value of the deviation of the system from the target state (A)

It follows from this that ecological safety means the creation of such conditions in the «humanity-environment» system that guarantee the movement of the system to the target state, corresponding to ecological safety.

The environment is affected simultaneously by a huge number of anthropogenic and natural factors of ecological threat. The created system of ecological safety should ensure the prevention of the manifestation of factors of ecology threat, as well as a set of measures to minimize the consequences, if they are implemented.

It should be taken into account that the manifestation of most factors of ecological threat is of a probabilistic nature. This means that they manifest themselves in the case of a certain combination of cause-and-effect relationships that can be caused by both human activity and the evolution of components of the environment. In this case, the system of ecological safety should prevent the manifestation of factors of ecological threat with the greater the probability, the greater the possible threat.

Based on the above, we will formulate the definition of ecological safety as an acceptable level of the negative impact of natural and anthropogenic factors of ecological threat on the environment and the person himself.

The system of ecological safety is a constantly developing system that changes along with the deepening of knowledge about the laws of the development of the world around a person and human society. The state of ecological safety is determined by the scientifically based regulation of human activity.

As is known, the essence of management by safety and risk of techno genic impacts is to recognize, identify, and resolve problematic situations, related to ensuring techno genic safety, ecological safety, and risk in the conditions of accidents and catastrophes at these facilities. On its internal basis, it is a single functionally and organizationally structured process in which the systematic purposeful activities of state, and departmental and functional management bodies and structures are organically linked, including research, scientific and technical organizations, as well as management bodies of forces and means of monitoring, control, and eliminations of the consequences of emergency situations in case of techno genic accidents and catastrophes.

In the process of managing the safety and risk of techno genic impacts, three consecutive stages can be distinguished in accordance with their essence and functional meaning [27]:

- analysis of safety and risk, which provides for the identification and study of sources of threat, modeling processes of techno genic impact, and assessment of possible damage and risk levels;
- risk assessment, which consists in comparing calculated or actual risk.
- levels with scientifically based socially conscious, so-called acceptable risk levels;
- development and adoption of regulatory legal acts and management decisions on measures to reduce techno genic threat, establishing, maintaining, and restoring an acceptable level of safety and risk for humans and objects of the environment.

The management of techno genic safety and risk is associated with the activation of certain social and economic mechanisms, therefore it is based on the theory and practice of managing socio-economic systems. The position of this theory, in relation to emergency situations, has been developed in the works of a number of Russian scientists: For example, in the work of B. N. Porfiriev «Management in emergency situations: problems of theory and practice».

Based on the analysis of these works, it is possible to express the following considerations.

When forming a model of the process of management of safety and risk under techno genic impacts, the authors [27] believe that it is necessary to proceed from the main directions of efforts to ensure the protection and safety of humans and objects of the environment, undertaken at various levels. At the same time, it is necessary to observe the principle of continuity of these efforts during the transition from one level to another, as well as the own interests of each of the levels of the management system.

The security and risk management system, including its federal, regional, and local levels, is considered as a complex hierarchical structure. The management of this system should be carried out on the basis of the synthesis of the principles of control theory, the theory of non-antagonistic games, and the information theory of hierarchical systems. In hierarchical systems, the tasks of centralized and decentralized management are usually considered when the interests of lower level management structures are taken into account. At the same time, it is taken into account that independent actions of management subsystems, pursuing their goals, can to a certain degree reduce the effectiveness of solving tasks by the center.

Risk management strategies are understood as the main directions of efforts to achieve an acceptable level of security in all its aspects, subordinated to the idea of ensuring a high standard of living for a person.

The set of actions for the formation of strategies, management of their implementation, providing for a reasonable transition to alternative strategies, taking into account the views, formulated in the work of Burdakov N. I. et al., can be called the strategic management of security and risk. The sphere of strategic management mainly includes the upper echelons of power management and other structures, through which the selection and implementation of organizational, technical, economic, and regulatory mechanisms for regulating the level of security and risk are provided. In the hierarchical structure of the system of management of security and risk, strategic management is inherent at the federal and regional levels of this system.

At the federal level, the management of techno genic safety and risk should be focused on solving long-term tasks, forming target settings and strategies of management, and creating the necessary legislative and regulatory framework.

At the regional level, covering the territory of the republic (several republics) within the Russian Federation, the territory (several territories), and a number of regions, in addition to solving these tasks, it is advisable to provide for the adaptation of security and risk management strategies, adopted in the state, to the conditions of the region, the formation of spatially distributed databases and knowledge bases in the subject area under consideration; solving practical tasks for the implementation of the current strategy, analysis, and assessment of security and risk indicators at the regional level; organization, management, and coordination of actions to protect the population and personnel of techno genic dangerous objects, as well as to eliminate the consequences of accidents and reduce risk levels to acceptable levels.

At the local level (in republics, territories, regions, cities, and districts), safety and risk management focuses on solving practical tasks, related to the organization of comprehensive monitoring and implementation of all types of control over the sources of techno genic impacts, identifying, evaluating, and predicting the development of the situation in the conditions of the normal, routine functioning of dangerous objects and in emergency cases, developing and making management decisions to normalize the situation and protect the population and personnel of objects, ensuring the safety of people and the environment, reducing risk levels, and eliminating the consequences of accidents. It also provides for carrying out research, design and survey, and other works to develop and justify the optimal options for the placement of the production base, and directions of socio-economic development, based on the criteria for ensuring safety and acceptable levels of risk in techno genic impacts; licensing and certification of objects and territories that are dangerous in techno genic terms; creation and development of distributed databases and knowledge bases that meet the tasks of information and intellectual support for the process of preparing and making control decisions. In addition, at the local level, training is being conducted for headquarters, as well as regular and non-regular units and formations of various departments and objects, involved in solving tasks to ensure the protection and safety of personnel of the object, the population, and the environment.

In [27], it is proposed to construct the management of security and risk in the Russian Federation on the basis of a Unified state system for the prevention and elimination of emergency situations, based on the information base of the state integrated monitoring and control, organized on the territory of the Federation and techno genic dangerous objects.

Based on modern views on the management process in extreme conditions, a set of well-organized management bodies that solve problems of analysis, safety, and risk assessment, and the development of adequate management decisions should be considered as a complex hierarchical system. The management of such systems is carried out, using the methods of general management theory, the theory of non-antagonistic games, and the information theory of hierarchical systems.

Table 2.2 shows the tasks of analysis, assessment, and reduction of risk that are solved at various levels of management.

In the work [28], the authors propose a system for managing ecological safety of the organizational and technical system «Polygon».

The organizational and technical system (OTS) «Polygon» is a complex object that occupies a significant space, marked (or conditionally marked) on Earth, on water, in the atmosphere, and in space [28].

This is an object in which a number of technological processes are implemented, mainly of an industrial, transport nature, large energy exposures are used, and various chemical compounds are processed (in particular, burned).

The second group includes factors that can manifest themselves randomly; their implementation is complex and multidimensional. But in general, these are those

Table 2.2 Tasks for the analysis, assessment, and reduction of risk, solved at various levels of management

Tasks to be solved for the analysis and assessment of security and risk at various levels of management

At industrial and other dangerous objects, in departments and organizations	**In the subjects of the Federation**	**On federal level**
Analysis and evaluation (a) techno genic risk: – the probabilities of the occurrence and development of accidents and catastrophes, and the formation of damaging factors; – the mathematical expectation of damage (loss of life, destruction, material losses, etc.) caused by the impact of damaging factors (b) natural risk: – the probability of occurrence and development of natural threats and natural disasters; – mathematical expectation of damage (c) ecological risk: – probabilities of occurrence and mathematical expectation of the volume of ecological consequences in case of accidents, catastrophes and dangerous natural phenomena, deterioration of health and negative changes in the living conditions of people, violations of natural processes, shifts in ecological balances, etc.	1. Analysis and complex assessment of risk, construction and mapping of fields of potential threats for territories and districts 2. Development of a system of adequate measures and actions for the prevention and elimination of emergency situations, for reducing the levels of risk, their occurrence and, mitigating the consequences	1. Development and implementation of a strategy for reducing risks and mitigating the consequences of techno genic, natural, and ecological emergencies 2. Development, regulatory, and legal justification and implementation of state control and regulation of levels of risk in the case: – expert examination of projects of potentially dangerous objects; – declaring the safety of industrial objects; – licensing of maintenance activities of objects; – state supervision of the technical safety of objects; – insurance of risk; – creating a system of financial and material resources

Scientific justification and establishment of acceptable levels of risk, taking into account international experience, socio-economic, and other factors

factors whose composition and patterns of formation are mainly known and can be described by statistical, probabilistic methods.

The latter group, apparently, should include factors with more complex effects, the dynamics of disturbances, and the consequences of which can be very significant over time. These are the factors that are currently difficult to quantify and predict. Factors that can manifest (accumulate) and can be decisive for a long-term multidimensional interaction under the action of poorly predictable generating disturbances.

The entire sum of the techno genic impacts and interactions of OTS «Polygon» can be divided into three groups. The first group consists of those factors that are sufficiently studied and can be quantified: For example, land pollution by aircraft structural elements, thrown off in flight.

It is important to identify the third group of factors when studying ecological problems. With this approach, in the case of solving project tasks, the principle of emergence (threat) is implemented, which is a consequence of the dialectical approach to cognition.

The issues of forecasting the ecological state of OTS «Polygon» are directly related to the solution of the problem of management of ecological safety at the polygon, since it is mainly about the anthropogenic impact on the habitat. Before considering the methods of ecological forecasting, it is necessary to consider the task of managing the ecological safety of a missile polygon.

The position and goals of the analysis of ecological safety may be different: (1) assessment of the state of the natural environment on the territory of the polygon; (2) forecasting and management of the ecological safety of the «Polygon» and the surrounding territories. It is obvious that data on the dynamics of the natural environment of the polygon are necessary for forecasting and making management decisions. The necessary studies are carried out by the services of ecological safety of the polygon (territories).

The management of ensuring the ecological safety of the OTS «Polygon» is associated with the determination of the parameters of equipment and technologies used to perform work to ensure ecological safety at the polygon. At the same time, it is required that the management of their functioning during the elimination of the consequences of adverse techno genic impacts, such as to ensure the required level of ecological safety and that the costs of performing such work, are minimal. Formally, such a problem can be written as follows:

$$-C^{6}\left(\prod^{6}, \mathrm{Tx}^{6}, \varphi^{6}(t), \beta(t)\right) \rightarrow \min$$

$$prob.\left(\mathrm{K}^{2}\left(\Pi^{б}, \mathrm{Tx}^{б}, \varphi^{б}(\mathrm{t})\right) \in \mathrm{K}^{2\mathrm{giv}}\left(\mathrm{t}_{\mathrm{lim}}\right)\right) \geq \mathrm{P}^{\mathrm{giv}}$$

$$\prod, \mathrm{Tx}_{\mathrm{maint}}, \varphi(t) - \mathrm{giv.},$$

$$\prod^{6}, \mathrm{Tx}^{6}, \varphi^{6}(t) \in G^{6}(t_{\mathrm{lim}}) \tag{2.1}$$

$$t \in \mathrm{T}^{\mathrm{giv}},$$

where C^6 (.)—the total cost of performing work to ensure the ecological safety of the polygon in the planned time.

These costs include the costs of monitoring, forecasting of characteristics, the development of special equipment, the maintenance of the latter in the planned period (may be and modernization).

$\prod^6$, Tx^6, φ^6(t)—parameters of technical means, parameters of implemented technologies, and a generalized control function of special equipment that is used when performing work to ensure ecological safety.

$\beta(\mathrm{t_{lim}})$—vector of defining parameters—coefficients of the model of cost; $\prod$, $\mathrm{Tx_{maint}}$, φ(t)—parameters of rocket and space technology, parameters of the implemented technologies of maintenance and control of the functioning of rocket and space technology that has a negative impact on the environment; $\mathrm{P^{giv}}$ —a given level of probability of ecologically safe operation of the equipment; $\mathrm{T^{giv}}$—the specified time interval; Gб ($\mathrm{t_{lim}}$)—acceptable range of possible values $\prod^6$, Tx^6, φ^6(t) $\prod^6$, Tx^6, φ^6(t), which is determined by scientific and technological progress, the time of the project implementation.

The condition of ecologically safe operation can have an integral character (i.e. to determine the total impact), and can also be recorded separately for different types of impact, for certain stages of work, and for possible emergency situations. When forming the corresponding dependencies, a predictive analysis of the processes of the impact of technology on the environment is carried out. Statistical methods of forecasting, methods of expert assessments, as well as modeling methods are used.

In general, the formulation and solution of such a task mean an active approach to the management of ecological safety in the event of a techno genic impact on the natural environment.

At present, it is increasingly obvious that the occurrence and aggravation of ecological problems are associated with human activities. In this regard, the issues of management of ecological safety are increasingly relevant. The issues of management are raised at the local, regional, state, and global levels. The organization and implementation of effective management is a vital and important scientific and practical task.

2.4 Analysis of the Existing System of Management of Ecological Safety in Civil Aviation

Currently, the system of ecological safety in civil aviation is at the stage of formation. Therefore, we will analyze the work of the department responsible for this direction. In the Federal Air Transport Agency of the Ministry of Transport of the Russian Federation (FATA MT RF), there is neither a department for work in the area of ecological safety nor a person responsible for this work.

At enterprises, as a rule, there is a person responsible for ecological safety, although sometimes the same person is also responsible for labor protection at the enterprise. At large air enterprises, a department of «Protection of environment» can exist.

The company issues a standard document «Ecological policy of the air company», the main principles of which in the area of protection of the environment are.

- effective functioning of the system of ecological management as a guarantee of continuous reduction of the negative impact of economic and other activities on the environment;
- compliance with the requirements of legislative, regulatory, and technical documents in the area of protection of the environment, and established standards of permissible impact on the environment;
- a scientifically based combination of ecological, economic, and social interests of a person, an air company, and society in order to ensure sustainable development and a favorable environment;
- high-quality implementation of industrial ecological control, improvement of technological processes to reduce the amount of generated production and consumption waste, reduce the amount of pollutants, discharged from wastewater, waste, and released into the atmosphere;
- effective industrial ecological control, reliable indicators of the effectiveness of environmental protection activities of the enterprise;
- reliable accounting and reporting about the actual ecological indicators of the economic and other activities of the enterprise;
- implementation of the following principles in practice: environmental pollution is easier to prevent than to eliminate; environmental protection is the business of every employee of the airline;
- training of air company employees in the area of environmental protection and ecological safety, improving their ecological culture in order to understand their responsibility for the consequences of negative impacts on the environment;
- providing the authorities and the public with complete quantitative and qualitative information about the impact of the production and other activities of the air company on the environment.

By the order of the General Director of the air company is appointed the person responsible for ecological safety of the air company.

The company also has a job description for the person responsible for ecological safety.

«The main task of the person, responsible for ecological safety, is to comply with the requirements of the Constitution of the Russian Federation, the Law of the Russian Federation «About protection of environment», other environmental legislative and regulatory documents of the Russian Federation to reduce the negative impact of the air company's economic activities on the environment and on ecological safety.

The objects of activity of the person responsible for ecological safety are.

- equipment, vehicles (including aircraft) of the air company, and technological processes, related to the formation of industrial waste, emissions into the atmosphere, discharges into water bodies and to the soil, polluting or adversely affecting the surrounding environment;
- security equipment (trapping, neutralizing devices, treatment facilities, monitoring devices, etc.).

The activities of the person, responsible for environmental safety, should be aimed at.

- reduction of atmospheric pollution from the emission of harmful substances from engines (including on aircraft), as well as emissions from stationary sources;
- prevention of contamination of water bodies and soil with petroleum products;
- prevention of environmental pollution by industrial waste, reduction of waste generation, and organization of their collection;
- compliance with technological and ecological requirements for technological processes;
- reducing the level of aircraft noise, electromagnetic, radiation, and other radiation;
- reducing the cost of natural resources (fuel, water, etc.).

The instructions of the person, responsible for ecological safety and protection of the environment are mandatory for all services of the air company».

The list of documents on ecological safety and sanitary and epidemiological requirements, available at the enterprise, is given below.

- The Constitution of the Russian Federation, art. 41, 42, 71, 72, 114, extract;
- Federal law from 10 January 2002 y. N7-FL «About protection of the environment». Adopted by the State Duma on December 20, 2001. Approved by the Federation Council on December 26, 2001, art. 30, 32, 32, 34, 35, 39, 65, 77, extract;
- Federal law from 30 March 1999 y. N52-FL. «About the sanitary and epidemiological welfare of the population» (with changes from 30 December 2001 y., 10 January, 30 June 2003 y.). Adopted by the State Duma on March 12, 1999. Approved by the Federation Council on March 17, 1999, extract;
- Federal law from 19 July 1997 y. N109-FL. «About the safe handling with pesticides and agrochemicals» (with changes from 10 January 2003 y.). Adopted by the State Duma on June 24, 1997 year, extract;

- The Code of administrative offences of the Russian Federation from 30 December 2001y. N195-FL (current version). Adopted by the State Duma on December 20, 2001. Approved by the Federation Council on December 26, 2001. Chapters 8, 12, 23, 28, extract;
- Resolution of the Government of the Russian Federation of October 29, 2002 y. No 777. «About the list of objects subject to Federal state ecological control», extract;
- Decree of the Government of the Russian Federation No. 613 from August 21, 2000 «About urgent measures to prevent and eliminate emergency spills of oil and petroleum products» (as amended on April 15, 2002), extract;
- Rules for the implementation of state ecological control by officials of the Ministry of Protection of Environment and Natural Resources of the Russian Federation and its Territorial Bodies (approved by the Ministry of Nature of the Russian Federation on April 17, 1996), extract;
- Order of the State committee for the ecology of the Russian Federation No. 372 of May 16, 2000, «About approval of the Regulations on the assessment of the impact of planned economic and other activities on the environment in the Russian Federation», extract;
- Order of the Ministry of Health of the Russian Federation of July 17, 2002, No. 228. «About the procedure for carrying out control measures in the implementation of state sanitary and epidemiological supervision», extract;
- Resolution of the Plenum of the Supreme Court of the Russian Federation of November 5, 1998, No. 14 «About the practice of applying by courts of legislation on liability for environmental offenses», extract;
- Resolution of the Plenum of the Supreme Arbitration Court of the Russian Federation of October 21, 1993, No. 22 «About some issues of practical application of the Law of the RSFSR» and «About protection of the environment» (as amended on April 10, 2000), extract;
- Federal aviation regulations «Certification requirements for commercial civil aviation operators and Certification procedures» (approved by the order of the Ministry of Transport of the Russian Federation, dated February 4, 2003, No. 11), Article 38, extract;
- «Methodological guide for the organization of the activities of aviation enterprises and civil aviation organizations in the area of protection of the environment», dated November 18, 2003;
- «Branch rules for labor protection when working with special liquids in CA organizations», approved by order of the Minister of Transport of the Russian Federation No. 27 of March 20, 2003.

The head of the air company approves a plan of organizational and technical measures to comply with the requirements of the regulatory acts of the Russian Federation on environmental safety. It may include.

«The exclusion of the release into the flight of aircraft, whose content of pollutants in emissions or the noise level, produced by them during operation, exceeds the standards, established by the state standards of the Russian Federation; exclusion of the operation of motor vehicles exceeding the standards for the content of pollutants in emissions or noise level standards; ensuring safe conditions for the environment and methods of collection, use, neutralization, transportation, storage, and disposal of production and consumption waste, including radioactive waste; exclusion of the discharge of production and consumption waste, including radioactive waste, into surface and underground water bodies, into catchment areas, into the subsoil, and onto the soil; exclusion of the placement of dangerous waste and radioactive waste in the territories, adjacent to urban and rural settlements, in forest parks, resorts, health-improving, recreational zones, on animal migration routes, near spawning grounds, and in other places, where danger to the environment, natural ecological systems, and human health may be created; exclusion of the disposal of dangerous waste and radioactive waste in the catchment areas of underground water bodies, used as water supply sources, for the extraction of valuable mineral resources; exclusion of the import of dangerous waste and radioactive waste into the Russian Federation for the purpose of their disposal and neutralization; exclusion of the facts of concealment, intentional distortion, or untimely communication of complete and reliable information about the state of the environment and natural resources, about the sources of pollution of the environment and natural resources, or other harmful effects on the environment and natural resources, and about the radiation situation, by persons, who are obliged to report such information».

In 2003, in order to provide methodological assistance, air companies were offered a «Methodological guide for organizing the activities of aviation enterprises and civil aviation organizations in the area of protection of the environment». On the basis of this manual, the ecological policy of the enterprise is described and an order «About the organization of the system of ecological management and the implementation of industrial ecological control» is issued. This order appoints persons, who are responsible for fulfilling (ensuring) ecological requirements.

For example:

«1. To assign the organization of the activities of the air company in the area of protection of the environment and industrial ecological control to………, by appointing him the deputy for protection of the environment.
2. To assign the responsibility for the implementation of industrial ecological control, coordination of the activities of all departments of the enterprise in the area of protection of the environment, implementation of ecological policy at the enterprise to……….., by appointing him the head of the ecological service.
3. The responsibility for compliance with the requirements of environmental legislation, measures for the protection of the environment, compliance with ecological standards of permissible impact on the environment, and requirements for the maintenance of technological and environmental protection equipment should be assigned to.

Factory shop # 1—the head of factory shop …….,
Factory shop # 2 —the deputy of the head of factory shop …….,
Transport factory shop—the head of the factory shop ……………,
Repair and mechanical section—chief mechanic ………….,

Electromechanical section—chief power engineer …………,
Warehouse management—the head of the warehouse management ……………….

4. By their order, the heads of departments and services should appoint specific performers and persons responsible for the implementation of individual measures to protect the environment and ensure ecological safety.
5. By their order, the heads of departments and services should appoint responsible persons for maintaining environmental protection equipment (dust and gas treatment plants, sewage treatment plants) in a technically proper condition and carrying out environmental protection measures.
6. The responsibility for the timely repair of dust and gas cleaning equipment, ventilation systems, and treatment facilities should be assigned to the chief mechanic…………….
7. The responsibility for the organization of the collection, storage, disposal, and removal of production and consumption waste should be assigned to the deputy director for economic affairs…………….
8. The responsibility for ensuring ecological safety during storage, disposal, export of production, and consumption waste from the territory of the enterprise should be assigned to the head of the economic part,………… etc.».

As we can see from the given example, there is nothing but the appointment of responsible persons in this order.

The manual suggests creating a system of management of the environment for the air company.

«Ecological management includes the following stages: planning of work, determination of the contractor, appointment of the head of work and the controlling person, material and technical support of work, organization of interaction of employees involved in the work, among themselves and with other groups (divisions), and verification of the work during their implementation and upon completion».

That is, management means the appointment of performers and verifiers and nothing else.

As is known, the essence of management of safety of techno genic impacts is to recognize, identify, and resolve problematic situations, related to ensuring ecological safety and risk at these objects.

In the process of managing the safety and risk of techno genic impacts, in accordance with its essence and functional meaning, three successive stages can be distinguished:

analysis of safety and risk, which provides for the identification and study of dangerous sources, modeling of techno genic impact processes, and assessment of possible damage and risk levels.

risk assessment, which consists of comparing calculated or actual risk levels with scientifically based socially conscious, so-called acceptable risk levels.

development and adoption of regulatory legal acts and management decisions on measures to reduce techno genic threats, establish, maintain, and restore an acceptable level of safety and risk for humans and objects of the environment.

This is not included in the recommended methodological guide. Air companies use this method only for writing orders and policies.

From the above analysis, it can be seen that the system of ecological safety at air enterprises does not fully exist.

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Chapter 3
Theoretical Studies of Ways to Improve the Efficiency of the System of Management of Ecology Safety in Civil Aviation

3.1 Development of a Mathematical Model of System Management for Ecological Safety in Civil Aviation

3.1.1 Mathematical Model of System Management for Ecological Safety

The ecological consequences of economic activity, and as a result, techno genic impacts on the environment, are expressed in the contamination of its components with various kinds of harmful substances, changes in the course of cyclic biogeochemical and other natural processes in nature. The identification and analysis of the current ecological situation, when assessing these consequences, is carried out.

The ecological situation is understood as a set of conditions and factors of abiotic and biotic nature formed due to the internal variability of natural systems and anthropogenic impact on ecosystems and natural-territorial complexes. These conditions and factors are characterized by quantitative values of certain parameters, with the help of which it is possible to assess the impact of the ecological situation on the health and vital activity of people, the state of ecosystems, natural-territorial complexes, and other objects of the biosphere.

These parameters include the levels of geophysical fields, including the fields of ingredients, that pollute the environment, the dosage of temperature and humidity factors, birth rates, population growth and mortality, and the rate of natural population increase.

Mathematical modeling is designed to promote a deeper understanding of the nature of the phenomenon in order to obtain information about the real world as a result. This information stimulates the development of new scientific problems and methods of their solution and also serves as a basis for decision-making when implementing specific projects.

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Implementation of strategies for creating the system of ecological safety in order to create a flexible monitoring and management structure primarily depends on the effectiveness of its functional structures. This is explained by the fundamental nature of the tasks to be solved at the management stage.

The environmental safety service has at its disposal technical and economic information in the form of annotations, guidance materials, reference books, standards, norms, descriptions of inventions and patents, research results, and other data, available at the beginning of the receipt of the development task.

The service of ecological safety has at its disposal technical and economic information in the form of annotations, guidance materials, reference books, standards, norms, descriptions of inventions and patents, research results, and other data, available at the beginning of the receipt of the development task.

The result is a technical and economic justification that allows you to start the process of creating a system. The information, obtained at the same time through feedback channels, allows you to specify individual subsystems and work out the effectiveness of connections between them. This stage would be much shorter if experiments with a mathematical model of the ecological system were carried out instead of full-scale testing. The full-scale stages of working out methods are effective, but time-consuming, complex, and associated with high costs of money and time. Analytical methods are economical and fast, because they are based on the use of computer technology, but their implementation requires mathematical modeling of real processes.

Modeling is based on isomorphism (structural or functional similarity) of different systems. It allows you to reproduce and study complex systems in mathematical or physical models. By changing the parameters of the model, the ecologist receives data, similar to those, that would take place in reality, if real conditions change. Thus, many variants of the model are tested, each of which represents a certain combination of factors, and from this set, the optimal or close to optimal option is selected under given real conditions.

A characteristic feature of mathematical modeling is that, when studying any ecological process by this method, it is necessary, first of all, to build its mathematical description or a mathematical model of the process under study. The presence of a mathematical description of the original process allows you to reasonably choose the appropriate control process. A mathematical model of a real process is a certain mathematical object, corresponding to a given physical process, if there are relations, that express real physical connections in the form of mathematical dependencies.

This is a set of relations of formulas, equations, inequalities, logical conditions, operators, and other expressions, that connect the characteristics of the process with the parameters of the corresponding system, initial information, and initial conditions.

The current level of development of ecological monitoring and management requires a systematic approach, in which all objects and phenomena, associated with the preservation and restoration of production and transport systems lost during the operation are considered in a complex as a single system in which the process of managing the environmental protection system is implemented. Its components are the processes of monitoring and managing the complex state of the ecology. Optimization of these processes at all hierarchical levels contributes to improving the quality of the ecology.

The improvement of ecological management processes is organically interconnected with the improvement of the entire ecology of the system. The development of optimal management decisions in the course of preparation for its creation of production is possible only with the complex modeling of all elements of the system and the relationships between them on the basis of a single system of mathematical modeling. This requirement is met by a hierarchical system of mathematical modeling of objects at various levels of abstraction.

To simulate the specified recovery process, a model, that displays the system connection of elements, is used. The processes, occurring in the ecological system, are modeled as the process of changing its elements under the influence of various factors.

Changes in the system can affect any of its properties and relationships.

The peculiarity of the processes of management of ecological systems does not allow using the basic principle of modeling newly developed systems of management—the method of analogies.

The multifactorial nature of the management processes of ecological systems, associated with the variety of factors involved in it, as well as with a wide range of their physico-chemical properties, requires the use of various principles of management organization, different in their essence.

Let there be a certain set of homeostasis processes that ensure the restoration of the properties of the ecological system. Restoration, in this case, means taking measures and implementing targeted actions for the course of natural homeostasis; stimulating the processes of homeostasis; carrying out artificial measures to eliminate the consequences of ecological disasters. Then, formally, there will be a mapping of the original set to the final one. Due to the equivalence of the sets, there is a one-to-one correspondence between them. Each element is an image, when displaying some and, moreover, a single element.

The physical content of the display corresponds to the type and characteristics of the process, which changes the properties of the restored ecological system to a given (better than the original) level. If no one process provides the possibility of such a recovery, there is no display. The type of display is objectively selected, based on the discrepancy between the parameters, characterizing the properties of the same name, taken into account in the sets, and determined, respectively, by the conditions of ecological safety, based on the results of environmental monitoring.

The development of such a system should provide for the selection of the most effective management processes and their rational sequence. To do this, the entire process should be represented as a set of sequential processes, each of which affects the individual properties of the ecological system. Such a description of the structure of the properties of an ecological system allows us to strictly define the requirements for dependencies, developed for its formalization as part of systems of ecological restoration processes. At the same time, it is possible to combine heterogeneous recovery processes, based on different principles of their implementation, into a single process.

The above theoretical provisions are implemented in a mathematical model of the management system and restoration of the ecological system. It uses the apparatus of abstract algebra—theory of sets [1].

The ecology of the system can be considered qualitative (satisfying our needs), if all the elements, included in it, are qualitative—air, water, soil, and so on, and they interact qualitatively with each other (for example, they do not form aggressive environments). All the elements, included in the product, are characterized by qualimetric quality indicators $\mathrm{a_i}$ [2, 3]

$$a_1, a_2, \ldots, a_i, \ldots, a_n.$$

Combining ∩ of the final set of n qualimetric indicators of quality can be considered as a model of an element of an ecological system in terms of the algebra of sets. The capacity of this set will be the number of individual indicators, specified in various documentation (for example, sanitary norms and rules):

$$\mathrm{A} = \bigcup_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{a_i}. \tag{3.1}$$

Here A—set, that is, the combining of nth the number of indicators of quality $\mathrm{a_i}$, each of which $\mathrm{a_i} \in \mathrm{A}$ and forms an empty set $\mathrm{a_i} \cap \mathrm{a_j} \rightarrow \emptyset'$, when intersecting with any indicator of quality with an individual variable $\mathrm{i} \neq \mathrm{j}$.

With this methodological approach, there is no need to model the individual properties of the components of an ecological system differently from the expression $\mathrm{a_i}$ (3.1), since its quality is usually determined by the quality of the components of the system and their interactions.

In the process of industrial and transport maintenance, $\mathrm{a_i}$ is affected by various maintenance factors $\mathrm{b_j}$, which change the individual indicators of quality by the value $\delta\mathrm{a_i}$

$$A/\Delta A = \bigcup_{i=1}^{n} (a_i/\delta a_i). \tag{3.2}$$

The complex (integral) impact of maintenance factors on an element of the ecological system itself will be their combination

$$B = \bigcup_{j=1}^{m} b_j. \tag{3.3}$$

The change $\delta\mathrm{a_i}$ is a function (display) f maintenance factors and the time of their action on an element of the ecosystem

$$f : \left(\bigcup_{j=1}^{m} b_j, \tau \right) \to \bigcup_{i=1}^{n} a_i \bigg/ \delta a_i. \tag{3.4}$$

Taking into account (3.4), the expression (3.2) is written as

$$(\mathrm{A}/\Delta\mathrm{A}) = \bigcup_{i=1}^{n} f : \left(\bigcup_{j=1}^{m} b_j, \tau \right). \tag{3.5}$$

To ensure the safe maintenance of an industrial or transport component, the administrative documentation sets the maximum deviations of the parameters

$$(\mathrm{A}\ /\Delta\mathrm{A}) = \bigcup_{i=1}^{n} (a_i/\delta a_i \ \mathrm{max}). \tag{3.6}$$

The condition for the possibility of safe maintenance for reasons of requirements of ecological safety and taking into account (3.5) and (3.6) will be

$$(A/\Delta A \ \mathrm{max}) \succ \bigcup_{i=1}^{n} f : \left(\bigcup_{j=1}^{m} b_j, \tau \right). \tag{3.7}$$

Verification of the condition (3.7) in real time is carried out during the ecological monitoring work

$$(\mathrm{A}/\Delta\mathrm{A}\ \mathrm{max}) > (\mathrm{A}/\Delta\mathrm{A}). \tag{3.8}$$

If condition (3.8) is not met, the maintenance of the industrial (transport) system must be terminated, according to the actual condition, and further work is required to identify risk factors and restore its safe operability. From the standpoint of modeling in terms of the theory of sets, this process does not differ in any way from the expression (3.2). However, if in the process of ecological monitoring, they focus on determining the current parameters (3.5), then in the process of identifying risk factors are determined fixed values, that do not satisfy the condition (3.8).

The purpose of identifying risk factors is to find those characteristics of the system, that require restoration, as well as the values of the discrepancy between these characteristics and the characteristics of the established favorable ecological environment for the development of the restoration process, its parameters, and modes

$$\bigcup_{i=1}^{n} (\delta a_i) = \left(\bigcup_{i=1}^{n} (a_i/\delta a_i) \right) \bigg/ \left(\bigcup_{i=1}^{n} (a_i) \right). \tag{3.9}$$

Ecological safety standards set the limit characteristics of the output of the system parameters from the originally set ones

$$\bigcup_{i=1}^{n}(\delta a_i)\max\max. \tag{3.10}$$

Exceeding them entails the adoption of emergency measures, up to the termination of the maintenance of the system. If the characteristics of deviations from the norms do not exceed the limit characteristics, then measures are taken to restore the parameters, lost during maintenance.

The condition of termination of maintenance of the system

$$\bigcup_{i=1}^{n}(\delta a_i)\geq\bigcup_{i=1}^{n}(\delta a_i)\max\max. \tag{3.11}$$

The condition for restoring system parameters

$$\bigcup_{i=1}^{n}(\delta a_i)\max\geq\bigcup_{i=1}^{n}(\delta a_i). \tag{3.12}$$

By analogy with (3.9), the system parameters, that meet the requirements of the shelf life standards (do not require restoration), are recorded

$$\bigcap_{i=1}^{n}(\delta a_i)=\left(\bigcap_{i=1}^{n}(a_i/\delta a_i)\right)\Big/\left(\bigcap_{i=1}^{n}a_i\right). \tag{3.13}$$

The process of restoring the ecological safety of an object should carry out an unambiguous transformation of the characteristics of a «dangerous» object (3.2) into the characteristics (image) of an «ecologically safe» (3.1), which in terms of the algebra of sets can be modeled by displaying these sets

$$\Phi:\left(\bigcup_{i=1}^{n}(a_i/\delta a_i)\right)\rightarrow\left(\bigcup_{i=1}^{n}\left(a_i/\delta^{*}a_i\right)\right). \tag{3.14}$$

By the rules of algebra of sets, (3.14) are transformed

$$\Phi:\left(\bigcup_{i=1}^{n}(\delta a_i)\right)\rightarrow\left(\bigcup_{i=1}^{n}\left(\delta^{*}a_i\right)\right). \tag{3.15}$$

The expression (3.15) means that as a result of the adoption of «restoration» measures, Φ, obtained as a result of maintenance of the deviations of individual indicators of quality ($\delta\ a_i$) are not completely eliminated, but only up to a certain value ($\delta^*\ a_i$), such that the condition (3.7) is fulfilled.

When developing the system of ecological safety, it is necessary to strive for ($\delta^*\ a_i$) → min. In ideal: $\lim(\delta^* a_i) = \emptyset$.

The process of restoring the characteristics of an element of an ecological system is a combination of various types of processes, operations, modes, and so on. From this arsenal, specific processes are selected for the restoration of specific elements and the elimination of specific ecological inconsistencies. This combining can be modeled

$$\Phi = \bigcup_{i=1}^{c} \varphi_i. \tag{3.16}$$

The expression (3.15), taking into account (3.16), can be written as

$$\left(\bigcup_{i=1}^{c} \varphi_i\right) : \left(\bigcup_{i=1}^{n} (\delta a_i)_i\right) \rightarrow \left(\bigcup_{i=1}^{n} \delta^* a_i\right). \tag{3.17}$$

The real complete process of restoring the ecological system consists of a set of management actions, operations that consistently bring the system to the initial level of ecological safety, thereby restoring the quality lost during maintenance. Therefore, the expression (3.16) can be written as

$$\Phi = \varphi_1 \cdot \varphi_2 \cdot \ldots \cdot \varphi_i \cdot \ldots \cdot \varphi_{c-1} \cdot \varphi_c. \tag{3.18}$$

If the expression (3.16) models management decisions and their structure (a set of documented measures of influence on the system), then (3.18) models the dynamics of the impact of these measures on real inconsistencies, in a real recovery process

$$\begin{gathered}
(\varphi_1 \cdot \varphi_2 \cdot \ldots \cdot \varphi_{\mathrm{i}} \cdot \ldots \cdot \varphi_{\mathrm{c}-1} \cdot \varphi_{\mathrm{c}}) : (\delta \mathrm{a}_1) \rightarrow \left(\delta^* \mathrm{a}_1\right) \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
(\varphi_1 \cdot \varphi_2 \cdot \ldots \cdot \varphi_{\mathrm{i}} \cdot \ldots \cdot \varphi_{\mathrm{c}-1} \cdot = \varphi_{\mathrm{c}}) : (\delta \mathrm{a}_{\mathrm{i}}) \rightarrow \left(\delta^* \mathrm{a}_{\mathrm{i}}\right) \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
(\varphi_1 \cdot \varphi_2 \cdot \ldots \cdot \varphi_i \cdot \ldots \cdot \varphi_{\mathrm{c}-1} \cdot \varphi_{\mathrm{c}}) : (\delta \mathrm{a}_{\mathrm{n}}) \rightarrow \left(\delta^* \mathrm{a}_{\mathrm{n}}\right).
\end{gathered} \tag{3.19}$$

The system (3.19) does not mean, that by consistently applying the entire arsenal of restoration measures to each indicator of quality, that has gone out of the norm, we will get a complete restoration of the quality of the system as a whole, because some of these impacts cannot fundamentally restore the specific lost ecological quality:

$$\varphi_{\mathrm{j}} : \left(\delta \mathrm{a}_{\mathrm{y}}\right) \rightarrow \emptyset.$$

Therefore, the task of the ecological monitoring system and the management system for restoring its quality is always reduced to choosing a consistent set of specific restoration actions from the arsenal of available science and technology that fundamentally lead to the goal (3.17).

As result, for each δ, $\mathrm{a_i}$ must be identified a strictly individual product of displays, that meets the requirements of ecological safety

$$(\varphi_{\mathrm{i}} \times \ldots \times \varphi \mathrm{j}) : (\delta \mathrm{a_i}) \rightarrow \left(\delta^{*} \mathrm{a_i}\right) \tag{3.20}$$

The set Φ in (3.16) is a subset of the set of the entire arsenal of restoration processes, known to science −Ω, the capacity of this set c is equal to the number of these famous processes

$$\Omega = \bigcup_{i=1}^{c} \omega_j. \tag{3.21}$$

Due to the fact that the science that develops restoration processes, methods, and means of their implementation, equipment, and so on, does not stand still, but is in development, the capacity of c in the expression (3.21) is a function of time, and as a rule, increases, although cases of loss of such processes are quite possible. Therefore

$$\Omega(t) = \bigcup_{i=1}^{c(t)} \omega_j. \tag{3.22}$$

As indicated above, restoration measures (3.8) are included in (3.22)

$$\Phi \subset \Omega; \tag{3.23}$$

$$\left(\Phi = \bigcup_{i=1}^{c} \varphi_i\right) \subset \left(\Omega(t) = \bigcup_{i=1}^{c(t)} \omega_j\right). \tag{3.24}$$

The limiting state of the restoration process of the ecological system (3.20) will be a situation when all the individual indicators of the quality of the system components and their connections will be exactly equal to the indicators of the same system at the time of the start of maintenance of the natural polygon

$$\left(\varphi_{\mathrm{i}} \mathrm{X} \ldots \mathrm{X} \varphi_{\mathrm{j}}\right) : (\delta \mathrm{a_i}) \rightarrow \emptyset \tag{3.25}$$

The expression (3.14), taking into account (3.20), can be converted as

$$\left(\varphi_{\mathrm{i}} \mathrm{X} \ldots \mathrm{x} \varphi_{\mathrm{j}}\right) : (\mathrm{a_i} \backslash \delta \mathrm{a_i}) \rightarrow \quad (\mathrm{a_i} / \delta \mathrm{a_i}) \tag{3.26}$$

At the same time

$$\delta^{*}\ \mathrm{ai}\ << \delta a_i \tag{3.27}$$

$$\delta * a\mathrm{ai} \leq \delta \mathrm{a_i}\ \mathrm{max} \tag{3.28}$$

Here, (δ $\mathrm{a_i}$ max) is the component of the set (3.29)

$$\delta a_i\ \max \subset \bigcup_{i=1}^{n} \delta a_i\ \max\,. \tag{3.29}$$

As it is known, according to the legislation, the designed systems of management of ecology of systems should regulate the unambiguous correspondence of the right and left parts of the expression (3.28). But the capacity of the set of recovery processes bank (3.29) is currently so large that it is possible to implement alternative methods of restoring systems, each of which will meet the conditions (3.27) and (3.28).

$$\int \begin{array}{ll} \left(\varphi_{\mathrm{i}} \cdot \ldots \cdot \varphi_{\mathrm{j}}\right) : (\delta \mathrm{a_i}) \rightarrow (\delta^{*} \mathrm{a_i}) & 1 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots & \\ \left(\varphi_{\mathrm{i}} \cdot \ldots \cdot \varphi_{\mathrm{j}}\right) : (\delta \mathrm{a_i}) \rightarrow (\delta^{*} \mathrm{a_i}) & \mathrm{y} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots & \\ \left(\varphi_{\mathrm{i}} \cdot \ldots \cdot \varphi_{\mathrm{j}}\right) : (\delta \mathrm{a_i}) \rightarrow (\delta^{*} \mathrm{a_i}) & \mathrm{d.} \end{array} \tag{3.30}$$

The system (3.30) formally allows one to carry out the optimal choice of the recovery process, according to some selected criteria or according to the Pareto principle.

In Fig. 3.1, the iconographic model of the system of management of ecological safety is presented.

3.1.2 The Model of the Production System of Aircraft Repair

The set of Φ requires the study of the possibilities of their analytical interpretation. This is shown by the example of the development of a mathematical model of production system of the TS and R of aviation equipment.

The system of mathematical structural modeling, necessary for the implementation of formalized algorithms for the synthesis of a technological process, should adequately show the simulated production system, as well as meet all the basic requirements for mathematical models (accuracy, efficiency, versatility, development) [4].

The production system of repair is modeled at the following levels: set-theoretic, logical, and quantitative [5].

At the same time, the following main properties of the production system are modeled:

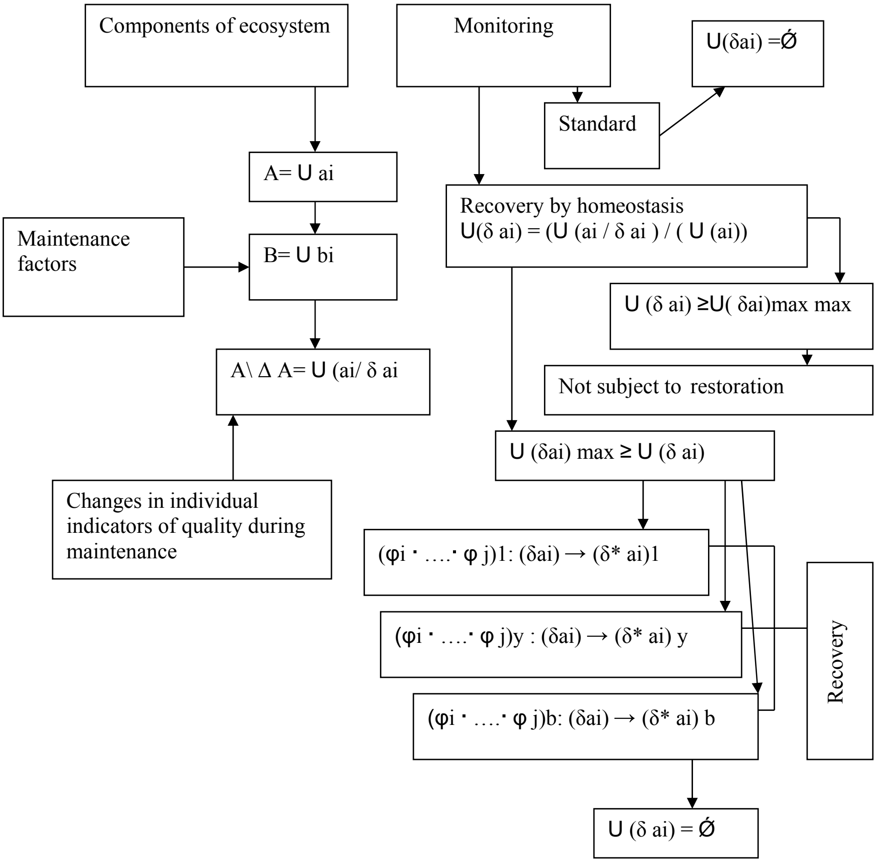


Fig. 3.1 Iconographic model of the system of management of ecological safety

- belonging of an element of the production system to a certain set of elements, that make up a set-theoretic model of the production system;
- adjacency relations of the elements of the production system;
- relations of the order of the elements of the production system;
- relations of hierarchical subordination of the elements of the production system.

The analysis of the process of technological preparation of the AE repair process shows that it reflects the interaction in time and space of three main sets of elements of the production system of restoration:

1 object of production A (A_2);
2 subject of production H;
3 technology system P.

All these sets have a different nature. In the process of technological design, they are combined as part of the description of the technological process—«technologies».

The basis for this combination is a unified space of properties F, consisting of a set of individual properties $\{F_1, F_2, \ldots, F_n\}$, having such a feature, that the properties of each of the elements of the production system A, A_2, H, P, namely, F(A), $F(A_2)$, F(H), F(P), are part of a unified space of properties F

$$\begin{gathered} \mathrm{F} = (\mathrm{F(A)}, \mathrm{F(A_2)}, \mathrm{F(H)}, \mathrm{F(P)}) \forall \mathrm{F(A)}, \mathrm{F(A_2)}, \mathrm{F(H)}, \mathrm{F(P)} \\ (\mathrm{F(A)}, \mathrm{F(A_2)}, \mathrm{F(H)}, \mathrm{F(P)} \subseteq \mathrm{F}). \end{gathered} \tag{3.31}$$

Binary relations between elements of sets A, A_2, H, P, and F are modeled as Cartesian products A × F, $A_2 \times F$, H × F, P × F and can be represented by a set of adjacency matrices of the form

$$||\mathrm{C_{ij}}|| = [\mathrm{T} \times \mathrm{T}] = \begin{array}{c c} \begin{array}{cccc} \tau_1 & \tau_2 & \ldots & \tau_n \end{array} & \\ \begin{bmatrix} C_{11} & C_{12} & \ldots & C_{1n} \\ C_{21} & C_{22} & \ldots & C_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ C_{n1} & C_{n2} & \ldots & C_{nn} \end{bmatrix} & \begin{array}{c} \tau_1 \\ \tau_2 \\ \ldots \\ \tau_n. \end{array} \end{array} \tag{3.32}$$

The sets A and H are homogeneous in their structure, and the set P consists of a subset of technological operators T, a subset of means of technological equipment N, production resources R, and ecological constraints (internal O and external L)

$$\mathrm{T} \subseteq \mathrm{P}; \mathrm{S} \subseteq \mathrm{P}; \mathrm{R} \subseteq \mathrm{P}; \mathrm{O} \subseteq \mathrm{P}; \mathrm{L} \subseteq \mathrm{P}.$$

The set-theoretic model of the production system also includes a set of parametric models of X. A correspondence can be established between the set X and the set F in the form of an adjacency relation, described as a Cartesian product F × X or as an adjacency matrix of the form (3.32).

Consequently, the adjacency relation on the set-theoretic model of the production system is established in the form of Cartesian products

$$\begin{gathered} (\mathrm{A} \times \mathrm{F}, \mathrm{A_2} \times \mathrm{F}, \mathrm{H} \times \mathrm{F}, \mathrm{T} \times \mathrm{F}, \mathrm{S} \times \mathrm{F}, \mathrm{R} \times \mathrm{F}, \mathrm{O} \times \mathrm{F}, \mathrm{L} \times \mathrm{F}, \mathrm{A} \times \mathrm{X}, \mathrm{H} \times \mathrm{X}, \\ \mathrm{T} \times \mathrm{X}, \mathrm{S} \times \mathrm{X}, \mathrm{R} \times \mathrm{X}, \mathrm{O} \times \mathrm{X}, \mathrm{L} \times \mathrm{X}, \mathrm{F} \times \mathrm{X}) \end{gathered} \tag{3.33}$$

where $\{T, S, R, O, L\} \subseteq P$.

Thus, a complete set-theoretic model of a production system is a combination of sets

$$\mathrm{A} \cup \mathrm{H} \cup \mathrm{P} \cup \mathrm{X} \cup \mathrm{F} \tag{3.34}$$

The basis of the technological process is made up of technological operators, that form an ordered set

$$T_i = ({}_1t_i, {}_2t_i, \ldots, {}_kt_i) \tag{3.35}$$

The set of technological operators T_i is a subset of the set of all technological operators T, which, in turn, is the most important subset of the set of elements of the technological system P

$$T_i \subseteq T \subseteq P \tag{3.36}$$

The elements of the set T are not equal, that is, they form a hierarchy: the technological process consists of operations; operations, in turn, consist of transitions, etc.

The hierarchical structure of T can be represented as a graph-tree, each fragment of which can have the following form:

$$T_1^x = \{t_1, t_2, \ldots, t_n\}. \tag{3.37}$$

where x—level of a hierarchy, i— number of element T on x level of a hierarchy,

n—the number of elements at the lower level of the hierarchy.

The relation of the set T and F is established in the form of a Cartesian product T × F and is modeled by an adjacency matrix of the form (3.32).

The presented system models the set T at the set-theoretic level.

Similarly, other elements of the set P are modeled: the set of elements of the technological system S, resources R, and ecological constraints O and L, as well as sets A, A2, and H.

At the same time, the physical meaning of structural models changes.

For the set A:

- adjacency relationships show the physical relationship of the elements of aircraft;
- the relations of order show the sequence of disassembly and assembly of AE elements during the repair process;
- hierarchical subordination relationships show the entry of structural elements into the composition of elements of a higher level of hierarchy.

For the set H:

- adjacency and order relations have no practical meaning;
- relations of hierarchical subordination model the belonging of performers to a particular production site.

For the set S:

- adjacency relations define standard sets of means of technological equipment;
- relations of order have no practical meaning;
- relations of hierarchical subordination determine the specific composition of the equipment, interconnected according to the hierarchical principle.

For the set R, O, and L, the relations of adjacency, order, and hierarchical subordination have no physical meaning.

In addition to the relation of the elements of the structural mathematical model (A, H, P) through a unified space of properties F, direct connections between the sets A, H, and R are also established and modeled. When developing technological processes, models of the connection of the elements of the production system of the following form are also used:

$$[\mathrm{T} \times \mathrm{H}], [\mathrm{T} \times \mathrm{S}], [\mathrm{T} \times \mathrm{R}], [\mathrm{S} \times \mathrm{H}], [\mathrm{S} \times \mathrm{R}], [\mathrm{H} \times \mathrm{O}], [\mathrm{T} \times \mathrm{L}], [\mathrm{S} \times \mathrm{L}]. \quad (3.38)$$

Model [T × H] shows the ability to perform technological operators by individual performers.

Model [T × S] shows the need for means of technological equipment for the performance of individual technological operators.

Model [S × H] shows the possibility of using the means of technological equipment by individual performers.

Models [T × R] and [S × R] show the need for resource support, related to the performance of individual technological operators or with the use of various technological equipment.

Model [H × O] shows the connection of the contractor with the requirements of labor safety.

Models [T × L] and [S × L] show the relationship between technological operators and technological equipment with the requirements of ecological safety.

The described model is shown in Fig. 3.2.

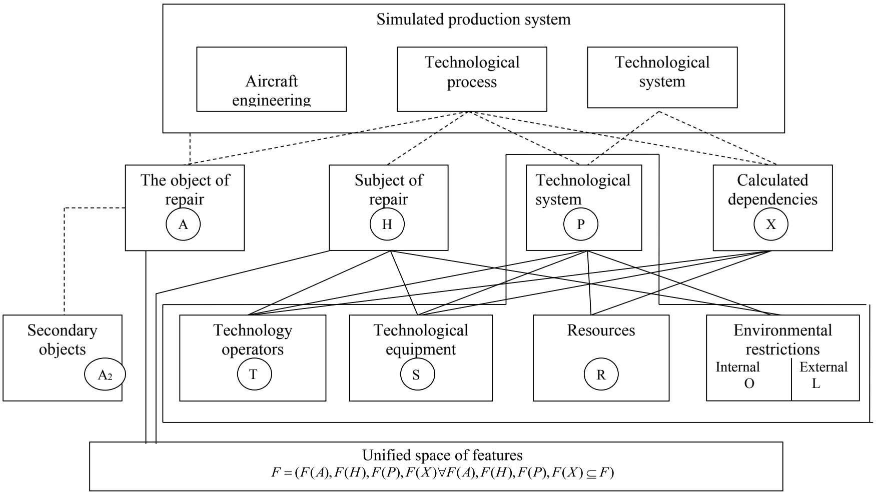


Fig. 3.2 The model of the aircraft repair production system, taking into account environmental requirements

This system of mathematical modeling is used to determine the necessary composition of the restored properties of the damaged product, to determine the composition and sequence of technological operators, to select the means of technological equipment, to determine performers, to select calculation dependencies, and to calculate the parameters of the technological process. It is an integral part of the production system of civil aviation. As you can see, there are constraints in the model of production system in accordance with the requirements of ecological safety.

The algorithm for the synthesis of the technological process of repair of AE consists of four stages:

(1) comparative analysis of the repair with the reference model and determination of the properties of the repair object, that require restoration;
(2) definition of a set of technological operators of a production system, that implement a set of properties of the object that require restoration;
(3) ordering of the set of selected technological operators and determining the set of ordered sets of technological operators, sufficient to restore the repair object;
(4) determination of the composition of technological equipment, performers, resources, and quantitative models for calculating the parameters of the technological process.

Let’s consider the stages of the synthesis of the technological process of restoration in more detail.

The first stage.

The repaired object A has many properties, which are denoted as $F^-(A)$, and the restored (reference) object—$F^-(A)$. Then the set of properties of the object that needs to be restored during the repair process ($F^+(A)$) is determined by the set-theoretical operation of addition

$$F^+(A) = F^-(A) \backslash F^{\circ}(A) \tag{3.39}$$

If we imagine sets $F^-(A)$, $F^+(A)$, $F^{\circ}(A)$ in the form of ordered discrete sequences, transformed into the form of Boolean vectors, i.e. in the form of $F^-(A) = \left(1 - 0\ 1\ 1 \ldots 0\ 1\ 0\right)$, then the transformation (3.39) can be implemented on the ECM as a Boolean operation of logical multiplication of vectors

$$F^+(A) =^- F^-(A) \cap F^{\circ}(A) \tag{3.40}$$

where ${}^-F^-(A)$—the result of the inversion (logical negation) of the vector $F^-(A)$.

In the case, if the object is not subject to restoration, then $F^+(A_2)$—recyclable object—is formed.

The algorithm for obtaining a vector $F^+(A)$, consisting of K elements, is shown in Fig. 3.3.

The second stage.

To perform the second stage, it is necessary to make a sequential comparison of the Boolean vector $F^+(A)$ with vector strings of a boolean matrix [TxF].

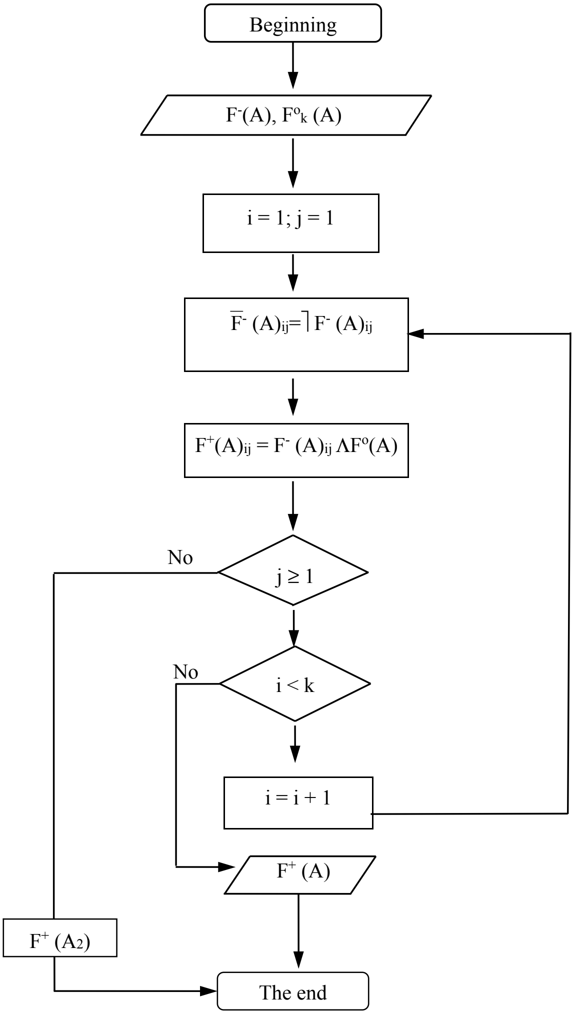


Fig. 3.3 Algorithm for obtaining the vector of the restored properties of the repair object

If ith element of vectors $F^+(A)_i$ and $F(\tau_j)_i$ (where $F(\tau_j)_i$—ith element of jth vector string) of matrix [T × F] coincide, then τ_j implements the property of the repair object and jth the technological operator is included in the set of technological operators $T^+(A)$, implementing properties $F^+(A)$.

The algorithm for selecting elements of the set $T^+(A)$ is shown in Fig. 3.4.

The third stage.

The ordering of the elements of the set $T^+(A)$ is performed using a structural model of the order of the form [T × T]. The sequence of ordering is as follows:

The subsets $T^+(A) \subseteq T^+(A)^*$, implementing the full composition of the elements of vector $F^+(A)$, is collected from set $T^+(A)$.

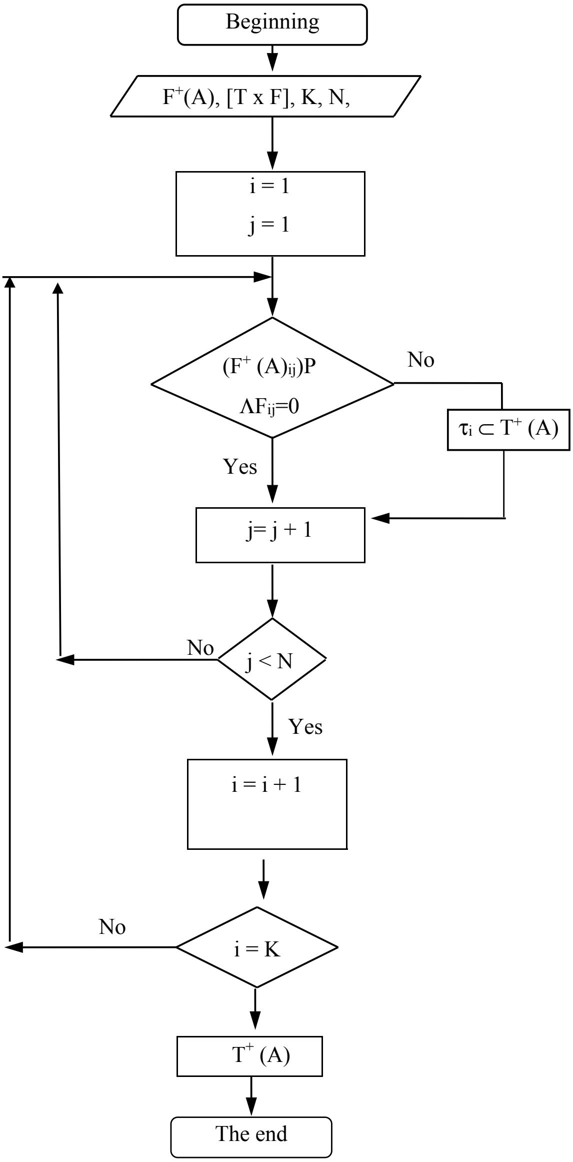


Fig. 3.4 The algorithm for determining the technological operators that implement the recoverable properties of the repair object

This operation is performed on the basis of a sequential comparison of the properties of F(T) of all possible subsets of $T^+(A)$ with the vector $F^+(A)$. At the same time, those subsets of $T^+(A)$ that are less than F + (A) in capacity are discarded (here $T(A)^+_p$, $p = \bar{1}, \bar{C}$ is p-th combination of technological operators, which is part of the set $T^+(A)$, where C is the capacity of a set of all subsets of set $T^+(A)$).

The set of selected subsets is denoted by $T + (A)^*$. Then the elements of the sets $T^+(A)^*_i$ are ordered.

The essence of the ordering algorithm is as follows:

From the structural mathematical model of adjacency of technological operators, elements adjacent to the components of the set $T^+(A)^*_i$ are selected.

The capacity of set $T^+(A)^*_i$ may increase at the same time. Each pair of adjacent elements is ordered, based on a structural mathematical model of order (precedence-sequence), then every two pairs of elements are ordered, etc. The result is a set of ordered sets (chains) of technological operators. The chains are checked for the condition of the complete implementation of the set $F^+(A)$, and if necessary, they are supplemented by other chains or technological operators that are part of the set $T^+(A)^*_i$, but they do not have the conditions of preceding-following.

If further expansion of the chain is impossible, and the properties, included in the set $F^+(A)$, are not fully implemented, then the resulting sequence of technological operators is discarded. Technological operators, that do not meet the ecological conditions are also discarded.

As a result, a set of ordered sequences of technological operators T^+, implementing the full composition of the restored properties of the repair object $F^+(A)$ will be obtained (Fig. 3.5).

The fourth stage.

At this stage, for each technological operator of each ordered sequence of technological operators, included in the set T^+, the composition of the elements of the production system, for which the adjacency relation is established in the structural mathematical models of adjacency $[T \times S]$ and $[T \times X]$, is determined.

The algorithm for selecting the composition of the tools of technological system (technological equipment and resources), performers, and quantitative models coincides with the algorithm shown in Fig. 3.3.

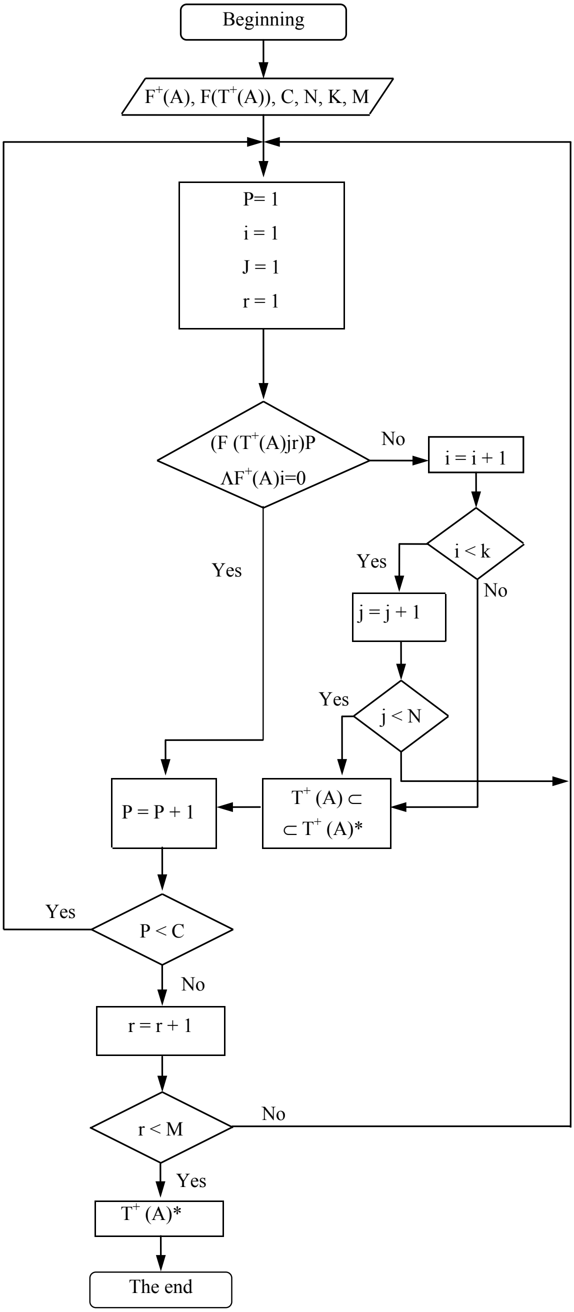
3.2 Approximate Analysis of the Directions of Improving the Efficiency of System Management for Ecological Safety in Civil Aviation

For the successful functioning of the system of ecological safety, an integral part of which is the disaster prevention system at CA enterprises, it is necessary to conduct an expert assessment of the probability of an emergency situation [6].

Currently, all measures to improve the work of the branch and correct errors are carried out, based on the results of the investigation of aviation accidents (incidents). The analysis of emergency situations is an information base for the manifestation of aviation situations.

The author suggests carrying out these measures, based on the results of assessing the probability (risk) of an event or factors, leading to a special situation. Warning of these events will help us to reduce the number of accidents and incidents.

Fig. 3.5 An algorithm for determining subsets of technological operators that implement the full composition of the restored properties of the repair object



To do this, let's return to the function of the dependence of the probability (P_i) of the occurrence of an ecological disaster from the value of the deviation of the system from the target state (A) (Fig. 2.3. clause 2.3.).

We will be interested in the blurred area of dangerous states, which is located between the zone of safe states and the zone of «guaranteed» disaster. Within this area, the probability of a disaster or incident approaches one.

The rules for the investigation of aviation accidents and incidents with civil aircraft in the Russian Federation provide a list of events that are subject to investigation in maintenance. When comparing this list and investigation reports by year, we select the main events for which we assess the probability of an aviation accident (incident):

1 The human factor (60–78% of air accidents, up to 20% of incidents):
   - violation of the flight rules by the aircraft crews;
   - violation of flight rules in case of aircraft failure;
   - errors of the aircraft crew and violation of the ATM personnel activities;
   - shortcomings in the work of the flight crew.

2 Failure of aviation equipment in the flight:
   - destruction/damage of the airframe;
   - failure/malfunction of aircraft systems;
   - failure/malfunction of the engine;
   - failures, related to violation of the rules of technical maintenance of the AE.

3 Disadvantages in ground providing of flights.
4 Active influences of environment and other causes:
   - meteorological impact;
   - violation of the norms of aircraft loading and alignment rules;
   - refueling of aircraft with substandard fuels and lubricants and aviation liquids;
   - aviation security;
   - ornithological impact.

Let's use the data from the analysis of aviation events and group the events into the corresponding areas of manifestation. We will also establish cause-and-effect relationships and the possibility of their manifestation. To do this, we will use the linguistic variables of the theory of fuzzy sets, constructed on the basis of a survey of experts. Let's group the events into the corresponding areas of manifestation (Table 3.1).

Based on the available data, we will make a reference model for the development of an emergency situation (Fig. 3.2).

In general, the reference model of the development of an emergency situation, applicable to calculations, looks like this (Table 3.2).

The analysis of air accidents shows that their main cause (up to 80%) is the «human factor».

In general, the interaction of the «pilot–aircraft» system is a classic example of a conflict situation, in which the pilot does not always have all the data, necessary

Table 3.1 Grouping of the events into the corresponding areas of manifestation

## Aviation event	Aviation event (Ki)	Area of manifestation, consequence (A1, A2,.. Ak)	The list of incidents (failures), the reason (a1, a2, …..aj)	The possibility of a manifestation of cause-and-effect relationship
K1	Aviation event (accident, disaster)	A11. Complete destruction of the airframe	a111. Metal fatigue a112. Routine maintenance (repair) was performed poorly a113. Collision in air with another aircraft a114. Violation of the rules of flight performance by aircraft crews: – rough landing; – rolling out, etc	1. Almost unbelievable 2. Extremely unlikely 3. Extremely unlikely 4. Unlikely
		A12. Failure of engine	a121. Metal fatigue a122. Routine maintenance (repair) was performed poorly a123. Collision in air with birds a124. Refueling with substandard fuels and lubricants a125. Crew error	1. Extremely unlikely 2. Extremely unlikely 3. Extremely unlikely 4. Extremely unlikely 5. Extremely unlikely
		A13. Failure of aircraft systems	a131. Routine maintenance (repair) was performed poorly a132. Collision in air with birds. a133. Refueling with substandard fuels and lubricants a134. Crew error	1. Extremely unlikely 2. Extremely unlikely 3. Extremely unlikely 4. Extremely unlikely
		A14. Violation of maintenance restrictions	a141. By mass a142. By centering a143. Spontaneous discharge of cargo	1. Unlikely 2. Unlikely 3. Unlikely

(continued)

Table 3.1 (continued)

## Aviation event	Aviation event (Ki)	Area of manifestation, consequence (A1, A2,.. Ak)	The list of incidents (failures), the reason (a1, a2, …..aj)	The possibility of a manifestation of cause-and-effect relationship
		A15. Meteorological impact	a151. Errors and violations of the weather service personnel a152. Errors and violations of the crew	1. Extremely unlikely 2. Unlikely
K2	Aviation incidents	A21. Partial destruction/damage of the airframe	a211. Metal fatigue a212. Routine maintenance (repair) was performed poorly a213. Collision in air with birds. a214. Violation of the rules of flight performance by aircraft crews	1. Extremely unlikely 2. Extremely unlikely 3. Unlikely 4. Unlikely
		A22. Failure of engine	a221. Metal fatigue a222. Routine maintenance (repair) was performed poorly a223. Collision in air with birds. a224. Refueling with substandard fuels a225. Error and violation of the crew A226. False alarm operation	1. Unlikely 2. Unlikely 3. Unlikely 4. Unlikely 5. Extremely unlikely 6. Moderately likely
		A23. Failure/malfunction of aircraft systems	a231. Routine maintenance (repair) was performed poorly a232. Collision in air with birds. a233. Refueling with substandard fuels and lubricants a234. Error and violation of the crew	1. Unlikely 2. Unlikely 3. Unlikely 4. Unlikely

(continued)

Table 3.1 (continued)

## Aviation event	Aviation event (Ki)	Area of manifestation, consequence (A1, A2,.. Ak)	The list of incidents (failures), the reason (a1, a2, …..aj)	The possibility of a manifestation of cause-and-effect relationship
		A24. Violation of maintenance restrictions	A241. By mass A242. By centering A243. Spontaneous discharge of cargo	1. Unlikely 2. Unlikely 3. Unlikely
		A25. Meteorological impact	a251. Errors and violations of the weather service personnel a252. Error and violation of the crew	1. Extremely unlikely 2. Unlikely
		A26. Failures, related to violation of the rules of technical maintenance of AE	a261. Error and violation of the crew a262. Error of ground services a263. Other	1. Unlikely 2. Unlikely 3. Unlikely
K3	Emergency incident	A31. Death of a person	a311. Intentional or careless action of the victim a312. Penetration into areas, closed to access a313. Adverse impact on the environment after an emergency landing outside the airfield a314. Contact with the aircraft or its element or gas-air jet	1. Extremely unlikely 2. Extremely unlikely 3. Extremely unlikely 4. Extremely unlikely
		A32. Damage of aircraft	a321. Natural disaster a322. Violation of the storage rules	1. Unlikely 2. Unlikely
		A33. An act of unlawful interference	a331. Aircraft hijacking a332. Attempt of hijacking a333. False message about a planted explosive device	1. Unlikely 2. Unlikely 3. Unlikely

Table 3.2 The reference model of the development of an emergency situation

Air accidents area of manifestation	Emergency incident Ꝁ$_1$	Incident Ꝁ$_2$	Disaster Ꝁ$_3$
Human factor			
A1	a11 + a12; a13; a15; a12 + a14; … ai + aj	A11 + A12; A13; A11 + A14; A12 + A14; A15 + A12 … AI + AJ	A11 + A12; A13; A12 + A14 … AI + AJ
….			
Ak			
Equipment failure and/or aircraft damage			
A1	a11 + a12; a13; a15; a12 + a14; … ai + aj	A11 + A12; A13; A11 + A14; A12 + A14; A15 + A12 … AI + AJ	A11 + A12; A13; A12 + A14 … AI + AJ
….			
Ak			

to make an optimal decision. There is a situation, that is characterized by: (a) the actions of the pilot; (b) the process, taking place in the aircraft, for a number of reasons beyond the control of the pilot. Thus, the components of the system do not always know, how the opposite side will behave.

Such situations, when it is necessary to make a decision in conditions of uncertainty, in order to recognize the current situation, are usually called game situations, and the decision-making process-conflict resolution is called a game. In game theory, a game-theoretic approach is used to solve problems of this type [7, 8].

We will consider the recognition problem as an antagonistic game of $\boldsymbol{\Gamma}_{\mathbf{p}}$ with Nature. By player II, we will understand the person making the decision (PMD), and by player I the nature. The strategies of the PMD are the algorithms of recognition $\mathbf{e_q}$, the set of which is $\{\mathbf{e_q}\}$.

Nature strategies are a set of information descriptions of objects **{S (U)}**. The situation in the game of $\boldsymbol{\Gamma}_{\mathbf{p}}$ is formed as a result of choosing each of the players with their own particular strategy. Let's denote the situation in the game of $\boldsymbol{\Gamma}_{\mathbf{p}}$ by $\boldsymbol{c} = \left\{\mathbf{S}(\mathbf{U}), \mathbf{e_q}\right\}$. Among the $\{\mathbf{e_q}\}$strategies, there are strategies for compiling standard **So** information and, in addition, So(−{**S**(ĸ)}. The winning function H is defined, given on a set of situations c(−Ꝁ).

Thus, the game-theoretic model of the problem of assessing flight accidents is called the set

$$\Gamma_p = \left\langle\{\mathrm{S(U)}\}, \left\{\mathrm{e_q}\right\}.\mathrm{H}\right\rangle. \tag{3.41}$$

We associate the function H with the functional for evaluating the quality of the recognition algorithm V (eq).

Let's put

$$\mathrm{H(c)} = \mathrm{H}\big(\mathrm{S(U)} \cdot \mathrm{e_q}\big) = \mathrm{H}_{\mathrm{s(q)}}\big(\mathrm{e_q}\big) = 1 - \mathrm{V}\big(\mathrm{e_q}\big)\mathrm{s(q)}. \tag{3.42}$$

The optimal behavior of players in the game $\boldsymbol{\Gamma}_{\mathbf{p}}$ is considered to be their behavior, in which the following is performed:

$$\max_{\{\mathrm{S(U)}\},\{\mathrm{eq}\}}\min \mathrm{H}\big(\mathrm{S(U)} \cdot \mathrm{e_q}\big) = \min_{\{\mathrm{eq}\},\{\mathrm{S(U)}\}}\max \mathrm{H}\big(\mathrm{S(U)} \cdot \mathrm{e_q}\big). \tag{3.43}$$

The strategies of nature consist of the fact that it gives the person (PMD) the most diverse information about objects and processes of the real world. The ways of providing this information are very diverse and it is natural to assume that the number of these ways is infinite. The ways of providing information are closely related and actually represent trees of concepts defined on $\{\mathrm{W}\}$.

The use of the game-theoretic method for assessing incidents is primarily due to the fact that the development of the situation is characterized not by a set of exact laws, but only in the form of regularities. At the same time, specific events are a manifestation of the main tendency-rules, allowing for various kinds of deviations.

Secondly, such events could be described by probabilistic and statistical methods, but the hypothesis about the nature of the distribution function imposes very strict restrictions on the processed information. But in the case of analyzing and predicting a flight accident, strict mathematical methods are unacceptable.

And, thirdly, in practice, specific events, being a manifestation of general tendencies, are subject to the action of many heterogeneous factors that lead to a great variety. It is impossible to take into account all such factors, moments, and causes of their occurrence and consequences for the object under study.

The application of the method of game-theoretic analysis of conflict situations is given in [9].

Construction of a universal scale.

When analyzing flight accidents, we are faced with situations, when the same technical malfunction of the aircraft leads to different results. In this regard, we are forced to use other linguistic variables of fuzzy set theory instead of strict probabilistic variables. That is, we say that, when one of the engines fails, plane crashes «sometimes» occur, and when two engines fail, plane crashes «quite often» or «almost always» occur. Linguistic variables «sometimes», «quite often», «almost always», and others are the essence of the theory of fuzzy sets [10]. Linguistic variables are described by the membership function, which, along with the distribution function of statistical data on air accidents, are used to construct a universal scale.

In control models, the set of linguistic variables and the set of practically used values of these variables are finite, so you can use the methods of the theory of expert assessments to construct membership functions [11]. In our study, we are interested in constructing a universal scale for describing the frequency of phenomena and processes. For a qualitative description of events in natural language, such words and phrases as «almost never», «rarely», «often», and «almost always» are used. These words are used by the expert (the person making the decision—PMD) to assess his subjective probabilities, with which he describes the frequency of certain

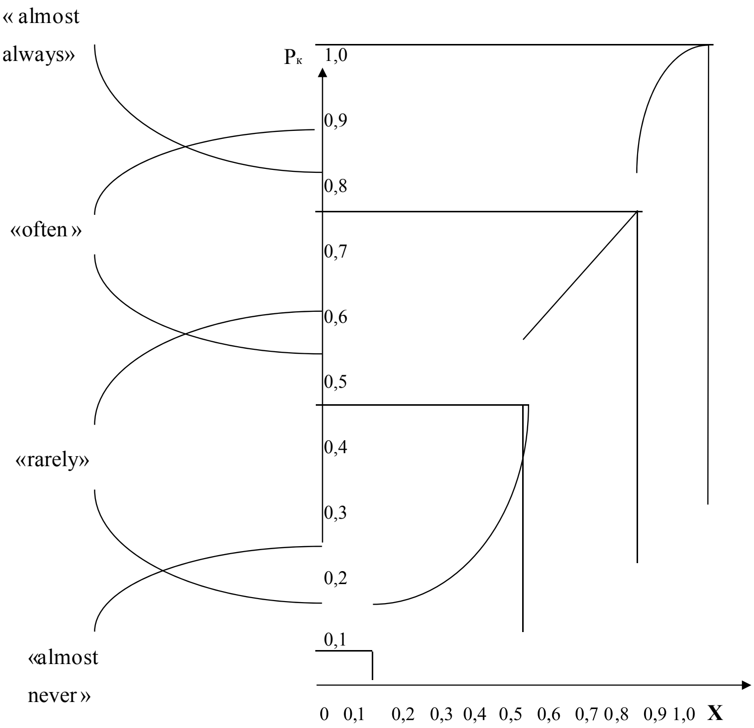


Fig. 3.6 Universal scale

events. The universal scale is constructed on the segment {0, 1} and is a series of mutually intersecting bell-shaped curves, corresponding to the scaled frequency estimates (Fig. 3.6).

The transition from the scale of relative frequencies of the occurrence of the observed event to frequency estimates, called quantifiers, and vice versa is carried out, using the display function $S : X \to \{0, 1\}$.. So, in our case, the frequency quantifier «rarely» corresponds to the relative frequency of 0.3, and the relative frequency of 0.65 corresponds to the frequency quantifier «often».

The advantage of using universal scales, when determining the situation at the control object and issuing control actions is their independence from changes in control conditions. Changing the control conditions causes only an adjustment of the display function S, with the help of which direct and reverse transitions from the subject scale to the universal one are carried out.

The universal scale practically coincides with the probability distribution function of the occurrence of events, based on statistical data (Fig. 3.7).

The process of managing the ecological safety of aircraft flights can be represented as a solution to a multi-criteria problem [10].

Aircraft flights are always at risk. There are two aspects of risk:

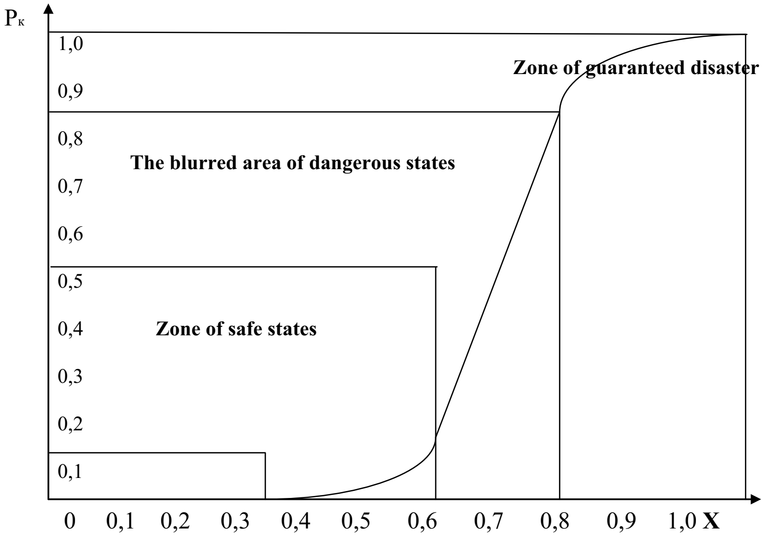


Fig. 3.7. The distribution function of statistical data on air crashes

1 The probability, that certain accidents will occur.
2 Ecological damage, caused by these accidents, if they occur.

We often assume that «risk reduction» can always be achieved by reducing the probability of an accident. However, we should not forget about the possible consequences when we try to reduce the risk. In other words, in the case of risk, when there is a one-in-a-million chance, the consequences of a small plane crash can lead to catastrophic consequences in a locality with a large population. This is intuitively assessed as a much greater risk, if an airbus crash occurs, for example, in the desert.

For this purpose, we use a three-dimensional usefulness function, based on such criteria as «human victims», «damage to property», and «damage to the environment». The first of the criteria can have a range of possible values from 0 to 1200, the second ranges from 0 to 10 million dollars, the third criterion is measured by a subjective indicator, using a discrete scale, consisting of 10 points (gradations) given in Table 3.3.

Table 3.3 The impact of air crash on the environment

1	No consequences
2	Residual surface accumulation of substances, that can be removed, for example, fuel from tanks
3	Sustained damage to the leaves without their falling off (the appearance of spots, discoloration), but the foliage remains edible for wild animals
4	Sustained damage to the leaves (leaf fall), but new leaves grow the next year
5	The foliage remains poisonous to animals (an indirect cause of the death of some animals as a result of eating it)
6	Animals become easier prey for predators due to the direct action of chemicals and the resulting physical weakening
7	The death of most small animals
8	Short-term (for one season) leaf fall and migration of those animals, that feed on vegetation. It is possible to restore the forest
9	The death of foliage and the migration of animals
10	Complete devastation of the entire area and the impossibility of future restoration of vegetation and the return of animals

Note This scale is suitable for both terrestrial and aquatic conditions

3.3 Structural Optimization of the System of Management of Ecology Safety in Civil Aviation

3.3.1 Threat and Risk Assessment at Enterprises

The development of transport, industry, and energy leads to an increase in the probability (risk) of emergency situations, that can cause significant damage to people, the environment, and industrial facilities themselves [11]. Very often, probable events become reliable, this is shown by the examples of specific accidents in V. Marshall's work «The main dangers of chemical production» [12].

By the beginning of the 70th year, a sufficient number of methods of risk assessment for technical systems had been developed. This was caused by the need to ensure the safe operation of industrial facilities, as well as to ensure the safety of people and the environment. At the same time, some groups of researchers considered the terms «risk» and «threat» as synonyms, other groups of researchers tried to give them a very specific meaning, but were mutually inconsistent.

V. Marshall noted the existence of discrepancies in the conceptual definitions of «danger» and «risk» both in the scientific terminology and in the terminology of insurance companies in his work [13]. In the same place, he stressed the need to introduce precise definitions of these concepts, which is mandatory in scientific research. In [14], he gave the following definitions of danger and risk:

«danger is a situation (natural or in the techno sphere), in which there may be phenomena or processes, that can affect people, cause material damage, and have a destructive effect on the human environment; risk is the frequency of the implementation of dangers; risk can be defined as the frequency (dimension-inverse time) or the probability of occurrence of event B, when event A occurs (a dimensionless value, that takes values in the range from 0 to 1).»

These definitions (with various additions and clarifications) are accepted as basic in the modern scientific and methodological literature on risks [15–19]. For example, in the «Methodological guidelines», approved by the State technical supervision of Russia [15], «danger» is defined as «a source of potential damage, harm or a situation with the possibility of causing damage», and «risk» (or «degree of risk») is defined as «a combination of the frequency (or probability) and the consequences of a certain dangerous event».

In the reference dictionary [16], the term «danger» is understood as a situation in the human environment in which, under certain conditions (of a random or deterministic nature), undesirable events, phenomena or processes (dangerous factors) may occur, the impact of which on humans and the environment may lead to the following consequences:

- deterioration of a person's health, his illness or even death;
- deterioration of the human environment, caused by material or social damage (violation of the process of normal economic activity, loss of a particular type of property, etc.) and (or) deterioration of the quality of the natural environment.

In the work [20], «risk» is defined as «a measure for the quantitative measurement of danger, which is a vector (i.e. multicomponent) value, measured, for example, using statistical data or calculated, using simulation models, that include quantitative indicators:

- damage, caused by the impact of a dangerous factor;
- the probability (frequency) of the occurrence of the considered dangerous factor;
- uncertainty in the values of damage and probability.»

Probably, the last two definitions are the most capacious and complete in content. Thus, the authors of the work [21] use them in the framework of setting the task of creating a new scientific discipline—the theory of security, the approaches to the formation of which should be based on the concept of sustainable development.

V. Marshall defined two types of risks, directly related to the impact of dangers on a person—the definition of «individual risk» and the definition of «social risk» [14]:

«individual risk—the risk (frequency of occurrence) affecting the impact of a certain type, arising in the implementation of certain dangers in a certain point in space (in which individual may be located); characterizes the distribution of risk, social risk—the dependence of risk (frequency of occurrence) of events, consisting of the defeat of a certain number of people, exposed to the damaging effects of a certain type in implementations of certain dangers, from this number of people; characterizes the scale of catastrophic of danger».

In addition, the scientific literature uses the concepts of collective and potential territorial risk, which may have some specifics, depending on the area of application. We will give them, for example, according to the Methodological guidelines [17]:

«collective risk is the expected number of fatally injured as a result of possible accidents for a certain period of time; potential territorial risk is the spatial distribution of the frequency of the implementation of a negative impact of a certain level.»

The reason for the intensive development of risk science is, apparently, the process of changing the concept of «absolute security» (or «zero risk») to the concept of «acceptable risk», that has been taking place in recent decades.

The fundamental purpose of the concept of «absolute security» [22–26] is to create such technical security systems and take such organizational measures that allow eliminating (as far as possible at this level) any danger to humans and the environment, that may potentially be inherent in a particular object or type of economic activity. This policy is based on the following main provisions:

1 if a person is protected, then the environment is also protected, because a person is considered as an object of the biosphere, the most sensitive to dangers;
2 the impact of techno genic dangerous factors on the human body, caused by environmental pollution with harmful substances has a threshold character, i.e. the «effect» of the impact of harmful substances is manifested only at concentrations, exceeding certain maximum permissible values;
3 the functioning of technical and technological systems is strictly determined, therefore, emergency situations at industrial and transport facilities can be almost completely eliminated by using appropriate organizational and technical safety measures.

According to these provisions, the main forces and means of carrying out the «absolute safety» policies were directed to the study of physical, chemical and biological effects caused by the impact of dangerous techno genic factors on humans and the environment; the development of standards for maximum permissible concentrations and levels; monitoring of techno genic sources of danger and associated dangerous techno genic and ecological factors; the development and implementation of engineering and technical means of safety and control [14, 27–30], etc.

In the case of crisis and emergency situations, the principle of «to react and correct» was used: taking all possible measures to eliminate undesirable situations and reducing their consequences «to zero»; analyzing the causes of what happened, and tightening security and control measures on this basis.

The practical application of the concept of «absolute safety» has made it possible to achieve a high level of human and environmental safety in the conditions of the routine operation of dangerous industrial and transport facilities, to reduce the overall accident rate on them. An extensive knowledge base on the environment, the interaction of the biosphere and the techno sphere, the impact of various techno genic dangerous factors on humans and the environment, and monitoring systems for the state of the environment were created.

In 70th year, the process of realizing that the concept of «absolute safety» does not correspond to the new realities of economic activity and the scale of the impact of this activity on the environment and humans began:

- the growth of industrial production and its impact on the environment have reached unprecedented proportions [22, 31];
- in order to improve economic indicators, there has been a significant increase in the unit capacity of enterprises and, accordingly, a significant complication of technical and technological systems, and the functioning of such systems is subject to probabilistic laws, and emergency situations in such systems cannot be excluded in principle;
- despite the general decrease in accidents, the damage from accidents, accompanied by explosions, fires, and leakage of toxic substances has significantly increased;
- the biosphere's self-purification capabilities were close to exhaustion [32–34].
- it turned out to be almost impossible to determine the maximum or optimal costs for the development and improvement of security systems, especially since the security systems themselves are sources of new dangers [35], etc.

As a result, the concept of «absolute security» is gradually replaced by the concept of «acceptable risk» [25, 26, 36–39].

The concept of «acceptable risk» is based on the idea that a person, a group of people or society as a whole is ready to take a certain risk from the impact of dangerous techno genic factors in order to meet their needs. This risk is called an «acceptable risk» [35, 40].

The «acceptable risk» policy is based on the following approaches [20]:

1 the formation of a qualitatively new goal of safety—from the goal of the «absolute safety» policy, which focused on improving technical systems, to the goal, focused on improving the health of each person, society as a whole, and improving the quality of the environment;
2 development of methods for quantitative assessment of dangerous factors based on the methodology of risk study;
3 development of methods for quantitative assessment of safety, based on indicators of human health and environmental quality;
4 development of methods for determining an acceptable balance between risks and benefits from a particular activity based on an assessment of social preferences, economic opportunities, and environmental constraints of the latter, i.e. methods for determining «acceptable risk»;
5 reorientation of the safety control system—from control, focused mainly on dangerous factors to control the impact of these factors on humans and the environment (while maintaining, of course, control over dangerous factors).

Therefore, the main goal of the «acceptable risk» policy is to improve the health of each person and society as a whole, and to improve the quality of the natural environment.

The safety criteria are no longer indicators of the reliability and efficiency of technical systems themselves, but indicators, that determine the state of public health and the quality of the environment. Approaches, based on the principle of «to react and correct», on which the management system is constructed in «absolute security», are replaced by approaches, based on the principle of «to foresee and warn» in the policy of «acceptable risk» [20].

The concept of «acceptable risk» is associated with the concepts of «negligible», «maximum permissible», and «excessive» risk levels. The authors [20] give the following definitions of the concepts of «negligible» and «maximum permissible» risk levels:

- «negligible level of risk—the level of individual risk, caused by economic activity, which is negligible for an individual, since, for example, it is within the fluctuation of the natural (background) level of risk; such a level of risk is outside the sphere of interests of the regulatory body (the regulatory body is an authority, vested with official authority, dealing with public safety, environmental protection);
- the maximum permissible level of risk is the level of individual risk, caused by economic activity, which should not be exceeded, regardless of the economic and social benefits of such activity for society as a whole; it should be so low that its presence does not cause for individual worry.»

The level of excessive risk characterizes excessive danger [17]: «excessive danger is the discrepancy between the habitat of humans, plants, and animals to their innate and acquired properties, leading to an excess of the level of acceptable safety.» The level of individual risk, exceeding the maximum permissible is considered excessive, and any practical activity that leads to the fact that an individual is forced to live in conditions of excessive risk is unacceptable [19].

Schematically, the ratio of the levels of negligible, acceptable, maximum permissible, and excessive risk is shown in Fig. 3.8.

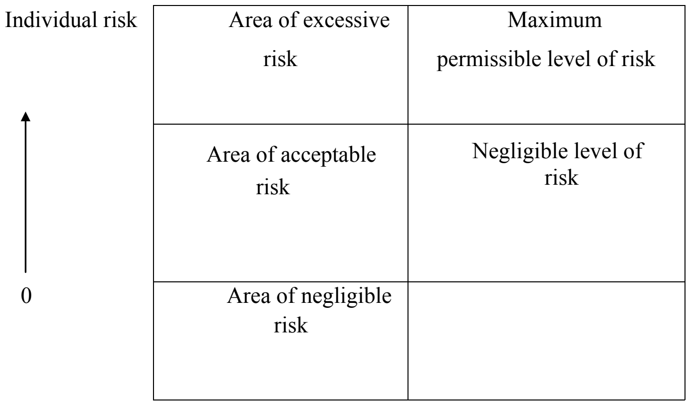


Fig. 3.8 Classification of individual risk

It follows from the above definitions of risk that, in the general case, the mathematical expression for calculating it should be the product of two quantities: the probability (frequency) of a dangerous or undesirable event and the damage that may be caused as a result of the implementation of such an event, taking into account the uncertainties in determining both quantities. The risk value can be either a dimensionless value (although «dimensionlessness» may imply the existence of dimensions such as person/person, rub./rub., etc.), or have a dimension (inverse time, monetary calculation, etc.).

The parameters, included in certain formulas for calculating risks, can be determined in various ways, including using well-known forecasting methods:

- statistical processing of data on undesirable events in the past and extrapolation of the results into the future, assuming that the conditions, for which the risk was determined, remained in the future,
- expert assessment;
- modeling of processes or phenomena based on empirical or theoretical concepts; in this case, it is possible «to play» of different options of the flow of processes or phenomena with different initial data and varying control variables; «the specialist by risk» in this case is limited only by the properties of the used model.

When we talk about risks, we are talking about the future: we are interested in the probability of occurrence of undesirable processes or phenomena in the future, and the likely ways of their development.

Thus, it can be concluded that the risk assessments, in their essence, are predictive assessments.

In addition, the above implies the fact that principally different dangers in their nature, when they are quantified in the form of risks, can be brought to a comparable form, which will allow:

- to determine the amount of the total (total) risk from the impact of various factors,
- to identify the most significant dangerous factors;
- determine the probable damage both by individual factors and by their entire combination,
- to optimize the costs of reducing the levels of risks from various dangerous factors in conditions of limited resources.

3.3.2 The Management of Safety and Risk at the Level of Organizational and Technical Systems (Civil Aviation)

The essence of the management of safety and risk of techno genic impacts on dangerous objects is to recognize, identify, and resolve problematic situations related to ensuring safety and risk in the conditions of accidents and catastrophes. On its internal basis, it is a single functionally and organizationally structured process, in which the systematic purposeful activities of the state, departmental and functional management bodies and structures, including research, scientific and technical organizations, as well as management bodies of forces and means of monitoring, control, and elimination of emergency situations in techno genic accidents and catastrophes, are organically linked.

Analysis and assessment of accident risk include several stages, starting from the identification of possible dangers and ending with the calculation of risk levels and their comparison with criteria.

The analysis of possible dangerous events and emergency situations includes consideration of all situations associated with a deviation from the routine functioning of the object and the occurrence of particular damage. The purpose of this analysis is to identify the sequence of events that finally lead to accidents, to develop scenarios for the occurrence and development of accidents, and to assess the probability of their occurrence.

The analysis of possible dangerous events and emergency situations in full, as a rule, is carried out at the stage of preventive risk assessment and risk management. In other cases, taking into account specific data on the occurrence, nature of the accident, and its development, it can be carried out with certain reductions.

At the stage of preventive assessment, the content, scope, and methods of the carried out analysis may also be different depending on the purposes of the assessment, and the required degree of detail. For example, if a risk assessment is carried out to develop recommendations for choosing the location of a dangerous object, when only data from its preliminary design is available about the object, it is not possible to use methods based on the analysis of event and failure trees, as well as other methods of detailed research.

Further, at the stage of designing the object, it becomes possible to assess the maintenance risk.

According to the established world practice, there is a fairly large number of methods for identifying dangerous events and analyzing the development of emergency situations. The used methods [41–44] can be represented by three groups:

- the first is comparative methods, which include methods, based on routine inspections, audits of safety levels, relative separation of potentially dangerous processes, conditions and materials into categories of «penalty», «creditable», etc.;
- the second is the so-called basic methods including investigation of the risk of maintenance by regular inspection of the object in order to identify possible deviations from the standards; analysis of the failure states of equipment, devices and their consequences, in particular, the system's reactions to failures; evaluation of the results of unexpected events according to the «what if?» scheme, etc.;
- the third is methods, based on the development, construction, and analysis of logical diagrams: event trees, cause-and-effect relationships, and the reliability of the human factor.

The methods that give the best results include the method of analyzing failure trees, the method of analyzing the event tree, and the method of analyzing cause-and-effect relationships, combining the two previous methods. When implementing these methods, all possible ways of developing emergency processes are considered. The first method is based on the analysis of reliability and system failures. At the same time, great importance is attached to the construction of a failure tree that would show all possible overlaps of failures and the consequences that arise in this case. The failure tree defines the structure and sequence of probabilistic calculations for assessing the risk of the occurrence of possible accidents.

In the method of event tree analysis, the events that finally lead to an accident are considered, and the predominant sequence of these events is highlighted. The initial event is taken as the starting point of the event tree. The list of initial events that can cause the development of emergency processes is established during the design of the object and is contained in the technical documentation. Then, a logical search is carried out for various ways of developing the accident (branches of the event tree) and its possible consequences. It is not easy to construct an event tree that would take into account all possible situations, especially for complex technical systems (such as an aircraft). This is due to the variety of equipment, systems, and devices used, a large number of possible ways of developing accidents. Therefore, when constructing a tree of events and conducting analysis, they follow the path of excluding events that does not make a significant contribution to the probability of the consequences, being realized or are practically impossible due to the contradiction of certain physical laws. Using the event tree, a calculation scheme is constructed to assess the probability of possible emergency situations.

Currently, the method of assessing the probability of occurrence of emergency situations, based on the analysis of cause-and-effect relationships, has been quite widely developed. This method also provides for the construction of a calculation diagram that links failures and dangerous events into cause-and-effect chains. Some specific recommendations on the design of cause-and-effect diagrams, the ratio of failure elements, and dangerous events in their chains have not yet been formulated.

Very useful recommendations for the practical use of cause-and-effect analysis are contained in the works of I. A. Ryabinin and his teachers [43, 44]. The method, developed in these works, is called logical-probabilistic. It is based on the analysis of the function of danger (safety) of the system and the tree of the dangerous (safe) state. The analysis is provided with the help of mathematical logical-probabilistic models, implemented on ECM.

Along with the above methods, on the basis of which it is possible to determine a quantitative measure of the risk of emergency situations, other methods also deserve attention. Among them, in particular, is a method called «examination of the risk of maintenance». The term «risk», used here, does not have the strict meaning that was discussed above. Here, we mean risk as a synonym for danger.

When analyzing all the methods discussed above, it is suggested to use a certain database of failures of various types of equipment and systems. This data is usually presented in two ways—in dependence on the nature of the equipment and the mode of its use. For constantly used equipment, operating in both constant and discrete

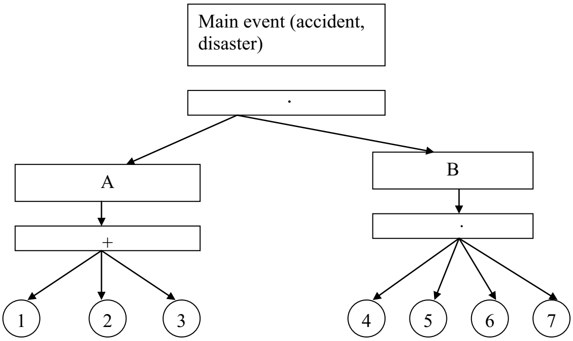


Fig. 3.9 Diagram of «accident tree»

modes, failure data is given in the form of failure rate; for components of equipment or systems, that are not used constantly, but are activated when necessary, for example, some security systems, signaling devices—in the form of a probability of failure to a requirement.

Usually, for conducting research on the safety of techno genically dangerous objects and risk assessment calculations, models of dangerous sources, and diagrams of trees of accidents and events—the results of an accident (catastrophe) are developed, taking into account all possible variants of their occurrence and development.

The first stage of modeling the sources of danger of techno genic origin is a formalized representation of possible ways of occurrence and development of emergency processes.

At the same time, in the diagram «incident tree», shown in Fig. 3.9, usually a single main event is included, which is connected by specific logical conditions with intermediate and initial presuppositions that caused its appearance in the combination [45].

The « + » sign on the diagram indicates the logical condition of summation «OR», the «•» sign indicates the logical condition of multiplication «AND».

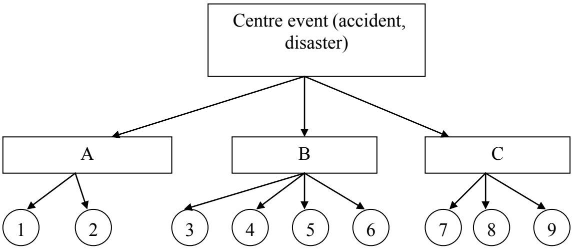
An accident or a disaster is usually considered as the main event. The branches of the incident tree are the prerequisites and their causal chains, the leaves are the initial events, further detailing of which is not advisable, i.e. failures, personnel errors, adverse external influences.

The diagram «failure tree» in its appearance does not differ much from the diagram «accident tree»: possible failures of technical systems (nodes) are analyzed at each stage, as well as the human factor of these failures and their probability are estimated. Finally, the probability of the occurrence of the main event, i.e. an accident or disaster, is determined.

Diagrams for complex systems, which are usually sources of techno genic danger, as a rule, have a multi-stage and highly branched character.

The model-diagram «tree of events—consequences of an accident, disaster, etc.», or simply «tree of events» is also a graph, i.e. a system of points (in this case rectangles), denoting events that are connected by communication lines. However, the

Fig. 3.10. Diagram (event tree-accident outcomes)



analysis of this diagram is conducted from the central event, which usually represents an accident, crash, etc. to the chains of events, that are its consequences.

In this case, the graph expresses all possible outcomes of the accident (disasters). As branches of the tree, there are possible scenarios for the development of an accident and causing damage to environmental objects, people, material, and natural resources [45]. These scenarios differ in the circumstances that arise during an accident and the conditions for the impact of damaging factors on objects. The diagram is shown in Fig. 3.10.

The diagram «tree of events—outcomes of an accident (disaster)» is essentially a stochastic graph, according to which estimates of the probability of events at each branch are made. The sum of the probability of implementing the events of each branch is equal to one.

Diagram of incident tree and diagram of outcome tree are usually combined into one generalized diagram. In this case, the main event of the first diagram is a result of the realized prerequisites and events of the second level, leading to an accident (disaster), and the central event of the second diagram, the possible outcomes of which are arranged in certain chains, are combined and form the core of the diagram.

It should be noted that when analyzing the development of accidents and disasters, it is advisable to use Bayes formulas, widely known from the theory of probability. With their help, the a posteriori probabilities of the implementation of possible hypotheses of the occurrence and development of an emergency process can be determined.

The probability of occurrence and development of an accident in accordance with H_s hypothesis is determined by the formula:

$$P(H_s!A) = \frac{P(H_s)(A!H_s)}{\sum_{k=1}^{n} P(H_k)P(A!H_k)}, \tag{3.44}$$

where $P(H_S|A)$—the desired a posteriori, conditional probability; A—random event of an accident occurrence; $P(H_s)$, $P(H_K)$—a priori probabilities of the implementation of scenarios (hypotheses) H_s and H_K; $P(A|H_s)$, $P(A|H_k)$—a priori probabilities of accident occurrence by scenarios (hypotheses) H_s and H_K.

If the number of scenarios for the occurrence and development of an accident (hypotheses), taken into account, is equal to n, then

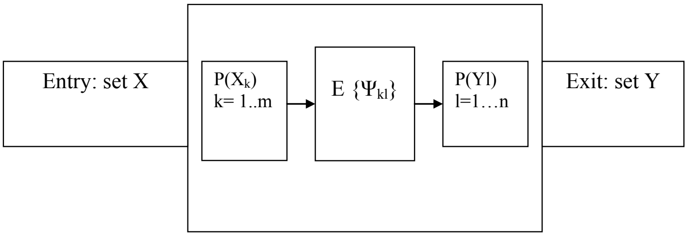


Fig. 3.11 The model of a material system as a dynamic one

$$\sum_{k=1}^{n} P(H_k) = 1; \tag{3.45}$$

$$\sum_{s=1}^{n} P(H_s!A) = 1 \tag{3.46}$$

The model of Belov [38, 42] of the «man–machine–environment» system, which in the most general form shows the structure and connections inherent in socio-economic and organizational-technical systems, is of interest.

For modeling the functioning of technogenically dangerous objects that can be classified as organizational and technical systems, the dynamic model of the material system, described by P. G. Belov, is also acceptable. This kind of model, presented in Fig. 3.11, provides wider opportunities for conducting research, than using the above—mentioned «man—machine–environment» model, which has a general character.

In this model, a certain set of input elements (data of impacts on the system) $\mathrm{X} = \sum_{\mathrm{k}=1}^{\mathrm{m}} \mathrm{X}_{\mathrm{k}}$ is generally received at the input of the system, and a set of output elements (the results of the functioning of the system) $Y = \sum_{l=1}^{n} Y_l$ is formed at the output of the system.

The system is characterized by the operator E{Ψ}, performing the necessary transformations of the input elements of set X into the output elements of set Y.

The transformations occur with a certain effectiveness Ψ, depending on the features of the input elements and the nature of the performed transformations. For example, X_{κ} is converted to Y_{l} with effectiveness Ψ_{kl}. The core of the model, providing the transformation, gives the result in the form of a matrix {Ψ} from elements Ψ_{kl}, showing the effectiveness of each of the individual transformations.

The processes of input elements, entering the system, and output elements, being generated by the system in real conditions, depend on a large number of random events and are of a statistical nature. Let’s denote the probability of receiving input elements by $\mathrm{P}(\mathrm{X}_{\mathrm{k}})$, and the conditional probability of generating output data as $\mathrm{P}(\mathrm{Y}_{\mathrm{l}}|\mathrm{X}_{\mathrm{k}})$.

Note, that we are talking about a conditional probability $\mathrm{P}(\mathrm{Y}_{\mathrm{l}} \mid \mathrm{X}_{\mathrm{k}})$, because production Y_{l} can be implemented if there is X_{k} at the entrance to the system. Taking into account the above considerations, the operator of a dynamic material system is expressed by the formula

$$E\{\Psi\} = \sum_{kl} \Psi_{kl} P\,(X_k) P(Y_l!X_k). \tag{3.47}$$

When n = m, the matrix {Ψ} is square. For n < m, it is assumed that individual input elements duplicate redundant input elements, and a row of values of Ψ_{kl} is a function of three arguments.

For its application to a particular system, it is important to correctly determine the physical meaning of the input and output elements, as well as the technology of data processing by the model core. For example, the input elements of the model of the system, which is a certain organizationally and functionally related set of production, technological, transport and other elements and structures, bodies of management, coordination, and control, can be:

- information about the reliability and survivability of the elements and structures of the system, the prerequisites for the occurrence of techno genic accidents and disasters, and the possibility of emergency situations;
- possible scenarios of occurrence, development, and outcomes of accidents and disasters;
- probabilistic characteristics of the development of accidents and disasters and mathematical expectation of damage;
- information about the state and degree of readiness of formations and groups of forces and means of civil protection;
- data on the availability of all types of resources for the prevention and elimination of emergency situations;
- potential and real threats and dangers to the population and territories in case of possible accidents and disasters;
- scenarios for the elimination of accidents and disasters, the promotion of forces, means, and delivery of material resources to the place of emergency rescue and other urgent work;
- standards and the predicted efficiency of performing the assigned tasks in management decisions, etc.

The output elements in this case are the most appropriate solutions for the

prevention and elimination of the consequences of accidents and disasters, measures and actions to protect the population and territories, adequate to the situation (input information about the situation), directions of the main efforts to stabilize the situation and reduce the risk, etc.

The considered dynamic model can be used for modeling not only ordinary organizational and technical systems, but also for the so-called systems of a polyergotechnical nature, characterized by the presence of heterogeneous organizational structures and a variety of engineering and technical systems and tools.

Such systems can include a system of integrated monitoring, a system for preventing and eliminating emergency situations, and other systems.

The input elements of the system of integrated monitoring and forecasting of emergency situations may include data from sources of primary information about techno genic sources and impacts, the state of the environment, sources of harmful effects on human health, etc. The output elements of such a system include:

- the results of the assessment and forecast of the development of the techno genic and ecological situation;
- data on the impact of this situation on human health;
- proposals for making management decisions on the protection of the population and territories, as well as the normalization of the techno genic and ecological situation, etc.

This system is distinguished not only by its structural complexity, but also by the ambiguity of management relations. In our opinion, it's functioning fully fits into the framework of the dynamic model.

However, in this case, the sets of input and output elements, as well as the core matrix of the model $\{\Psi\}$, acquire significant sizes. There are also difficulties in determining the operator for converting input elements into output elements.

Conceptual systems play an important role in security and risk management, along with material systems.

The conceptual systems in the area of security and risk management should include:

- the accepted concept and methodology for the analysis, assessment, and forecasting of techno genic, natural, and ecological risk factors of the population and territories;
- a system of strategies, as well as preventive and operational measures and actions for the prevention and elimination of emergency situations;
- a system of views, practical recommendations, and procedures for safety and risk management, ensuring mitigation of the consequences of accidents, disasters, and dangerous natural phenomena;
- a cooperative agreement between regions, subjects of the Federation, and other administrative and economic entities (socio-economic systems) for the protection of the population and territories from common sources of techno genic, natural and ecological dangers, as well as other documents of a scientific, methodological and regulatory nature, containing conceptual provisions on various aspects of ensuring civil protection.

Modeling here consists of structuring these concepts and methodologies, formalizing and morphologically describing their structural elements.

This modeling is aimed at presenting concepts and methodologies in a convenient form for analysis and practical use. When modeling, it is necessary to ensure that the model is adequate to concepts and methodologies and that it is possible to obtain new knowledge in the area of the issues and problems under study.

3.3.3 *Formalized Description of the Process of Management of Security and Risk*

Currently, the management process in almost all areas of activity is carried out on the basis of a systematic approach. In this sense, security and risk management are not an exception, and this is quite convincingly shown in [46].

In full accordance with the theory of complex systems, a number of complex organizational and technical systems can be distinguished in the subject area of security and risk management, which include various technical, engineering, organizational, and management structures.

A set-theoretic description of a complex organizational and technical system can be given in the form

$$\mathrm{S} =< \mathrm{A}, \mathrm{R}, \mathrm{Z}, \mathrm{Y}, \mathrm{F}, \Sigma >, \tag{3.48}$$

where A—set of elements of the system; R—relation on the set A, characterizing the relationship between the elements of the system ($\mathrm{R} \subset \mathrm{AxA}$); Z—set of the system inputs; Y—set of the system outputs; F—the set of functions, implemented by the elements of the set A; Σ—the emergence relation, defined on the sets A and F and putting the functions, implemented by them, in accordance with the elements of the system.

Here, elements are understood as material objects, involved in the transformation of resources into a result.

Note that from the point of view of evaluating the effectiveness of security and risk management, it is advisable to choose as elements any organizational and technical element of the system or a set of such elements.

In the subject area of security and risk management, certain types of actions can be identified to perform certain tasks called «operations» in the theory of operations research.

Operations are usually understood as a set of consecutive coordinated actions, aimed at achieving a certain goal. These types of actions or, in other words, operations are: terminal, developing, and calendar-developing.

Terminal operations should be understood as those that are completed by achieving the goal in a finite time interval.

Developing operations, which can otherwise be called continuous, are characterized by the fact that, in the process of their implementation, a higher goal is formed compared to the previous one, that is, a continuous process of achieving and correcting the goal is carried out.

In calendar-developing operations, the goal is periodically repeated.

The goal of the operation is considered achieved, if the result, corresponding to this goal, is obtained. In many cases, the result can be expressed by the level of achieved risk (the probability of an occurrence of a negative phenomenon or the mathematical expectation of damage).

No matter how the desired result of the operation is expressed, no matter what physical meaning is given to it, it can be obtained by converting certain resources. Resources here are understood as forces and means, including various kinds of material objects, energy, finance, etc.

As examples of terminal operations, can be called actions to normalize the techno genic situation, formed during accidents at explosive, fire, chemical and radiation dangerous objects, when the parameters of this situation are previously identified. If such actions for one or another reason begin with a situation that is not fully clarified, or with an environment that changes unpredictably, operations to normalize it are of a developing continuous nature.

The number of calendar-developing operations in the area of civil security should include the preparation of the population, formations, forces, and means for actions in emergency situations.

Operations in the area of security and risk management also differ by the type of resources. On this basis, they can be attributed to material and technical, financial, information, etc.

Since almost all these operations are carried out with the participation of people and with the use of energy resources, then according to the accepted classification, they can also be called human and energy in a certain sense.

Any operation carried out in the area of security and risk management, that is, actions to perform certain tasks, can be described on the basis of a set-theoretic approach in the form of a set of elements (O)

$$\mathrm{O} =< \mathrm{R}_1, \mathrm{R}_2, \mathrm{F}_0, \Theta, \mathrm{T} >, \tag{3.49}$$

where R_1—resources; R_2—results; F_0 —ratio $\mathrm{R}_1/\mathrm{R}_2$, putting the result in accordance with the spent resources ($\mathrm{F}_0 \subset \mathrm{R}_1 \times \mathrm{R}_2$); Θ—conditions for conducting of operation; T—the time of execution (duration) of the operation.

When managing security and risk, it is advisable to divide resources into two parts: active resources, i.e. directly converted into a result, and passive resources, used to create a system and maintain it in a state that ensures conducting of operations.

The results of an operation to achieve a goal with a certain amount of resources depend on a number of factors: the chosen method of performing the tasks being solved to achieve the goal, the adopted algorithm for controlling the process of the influence of external conditions on the conducting of operation, etc.

The conditions for carrying out any actions to perform tasks (operations) in the area of security and risk management have a direct or indirect impact on the resource consumption, the result, and the time of its achievement, as well as on the operation execution process itself, that is, on the type of Fo relationship.

Therefore, the expression (3.47) can be represented as

$$\mathrm{O} =< \mathrm{R}_1(\theta), \mathrm{R}_2(\theta), \mathrm{F}_\mathrm{O}(\theta), \mathrm{T}(\theta) > . \tag{3.50}$$

The latter expression can be somewhat transformed if we take into account the dynamics of the conducting of operation and the degree of achievement of the result, as well as the properties of resources, which are characterized over time by a certain set of phase coordinates.

In this case, the resources of the R_i operation can be formally described by a vector

$$X(t) =< x_1(t), x_2(t), \ldots, x_n(t) >, \tag{3.51}$$

and the result of the R_i operation can be formally described by a vector

$$Y(t) =< y_1(t), y_2(t), \ldots, Y_n(t) > . \tag{3.52}$$

The components of the vectors characterize the individual properties of the resources and the result, respectively.

Taking into account the entered views

$$O =< X(\theta, t), Y(\theta, t), F0(\theta, t), T(\theta, t) > . \tag{3.53}$$

This conditional description of the operation shows the dynamics of any targeted measures and actions to ensure safety and risk at all levels, i.e. the dynamics of management.

3.3.4 Assessment of the Emergency Situation in Civil Aviation

We apply the method of assessing the probability of emergency situations, based on the analysis of cause-and-effect relationships for the analysis of emergency situations on aircraft.

In the event tree analysis method, the events, that finally lead to an accident are considered, and the predominant sequence of these events is highlighted. The initial event is taken as the starting point of the event tree. The list of initial events, that can cause the development of emergency processes is established during the design of the object. Then a logical search is carried out for various ways of developing the accident (branches of the event tree) and its possible consequences. Using the event tree, a calculation scheme is built to assess the probability of possible emergency situations.

In Fig. 3.12, the diagram «tree of failures (incidents)» is presented, which includes one main event, associated with specific logical conditions with intermediate and initial prerequisites that caused its appearance in the combination.

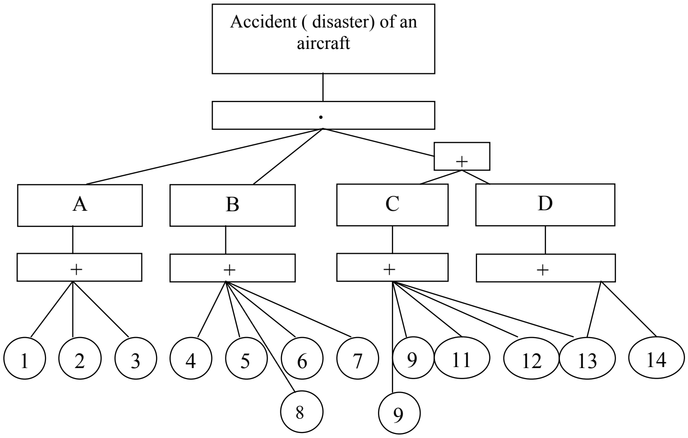


Fig. 3.12 Diagram of «tree of failures (incidents)» of an aircraft

An accident or a disaster of an aircraft is considered as the main event. The branches of the incident tree are the prerequisites and their causal chains, the leaves are the initial events, i.e. failures, personnel errors, and adverse external influences.

In this model, the main event (an accident or a disaster of an aircraft) was the result of the simultaneous imposition of the following prerequisites: A—the presence of an aircraft; B—the presence of people; C—the implementation of the flight; D—maintenance on the ground. In turn, event A can be affected by: 1—the failure of aircraft equipment (airframe, engine, etc.); 2—refueling with substandard fuel; 3—violation of the norms of loading the aircraft. For event B: 4—poor training of the crew; 5—poor health (illness); 6—psychological incompatibility of the crew; 7—family problems; 8—mistakes of the management staff. For event C: 9—violation of flight rules; 10—ornithological support; 11—violation of the activities of ATM personnel; 12—weather conditions. And for event D: 13—errors of technical personnel; 14—aviation safety.

The model-diagram «tree of events—consequences of an accident, disaster, etc.» or simply «tree of events» is also a graph. However, the analysis of this diagram is conducted from the central event, which usually represents an accident, disaster, etc. to the chains of events, which are its consequences. For an aviation accident (disaster), it looks like this (Fig. 3.13).

An emergency situation may develop with the preservation of the aircraft (A) or without saving (B). If the aircraft is preserved, fuel can be drained (C), in turn, the fuel has an adverse effect on the soil (1), flora and fauna (2), water (3), and air (4). If the development of events goes along path B, then the destruction of the aircraft in the air (D), an explosion (E), and a fire (F) may occur. The destruction of the aircraft (D) and an explosion (E) lead to the scattering of fragments of the aircraft (G), fuel spill (H), and loss of life (I). A fire (F) also causes a fuel spill and loss of life. Fragments of aircraft affect the soil, flora, and fauna, and fuel pollutes the soil, water, and air, and destroys the flora and fauna.

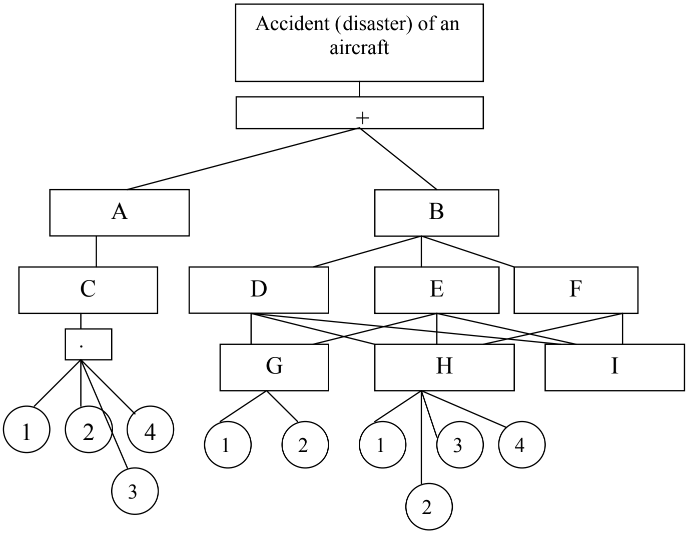


Fig. 3.13 Model-diagram «tree of events—consequences of an accident, disaster, etc.»

3.4 Development of a Method for Ranking Tasks in the System of Management of Ecology Safety in Civil Aviation

Decision-making is important to the perception of risk. This perception, which has not been fully investigated, seems paradoxical. In essence, it shows our culture and our attitude to ourselves and to the world. The paradoxical nature of the situation is illustrated by the data presented in Table 3.4 [47]. In which, technology is understood as a way to do something.

The first column of Table 3.4. shows technologies and types of activities. The last column on the right shows the annual mortality rates. According to it, smoking, alcohol consumption, and accidents on road transport are leading by a large margin. If we literally follow the criterion of maximizing life span, then the main efforts of society should be directed mainly to the elimination of these ills.

Other columns of this table are also of interest, showing, how the company treats risk. At the same time, nuclear energy, the mortality rate from which is very low, in the opinion of students and businessmen comes out in the first place in terms of the degree of danger, and alcohol consumption is shifting to the sixth and seventh. Previously, this state of affairs was associated with the imperfection of the picture of the world formed during education, with prejudices, with the mass media, «showing reality in a crooked mirror».

However, there is another point of view. Perhaps subjective risk assessment algorithms are much more complex and effective than they seem at first glance. And before introducing formalized, «artificial» rules for risk assessment, it is useful to

Table 3.4 Results of ranking the degree of risk

Technology and type of activity	Groupe				
	1	2	3	4	5
Nuclear power engineering Ground transport Firearms	1	1	8	20	100
Ground transport	2	5	3	1	50,000
Firearms	3	2	1	4	17,000
Smoking	4	3	4	2	150,000
Riding on a motorcycle	5	6	2	6	3000
Alcohol consumption	6	7	5	3	100,000
Private aviation	7	15	11	12	1300
Work in the police	8	8	7	17	160
Pesticides	9	4	15	8	
Surgery	10	11	9	5	2800
Working as a firefighter	11	10	6	18	195
Large structures	12	14	13	13	1100
Hunting	13	18	10	23	800
Aerosol cans	14	13	23	26	
Mountaineering	15	22	12	29	30
Bike riding	16	24	14	15	1000
Commercial aviation	17	16	18	16	130
Electrical energy	18	19	19	9	14,000
Swimming in reservoirs	19	30	17	10	3000
Contraceptives	20	9	22	11	150
Alpine skiing	21	25	16	30	18
X- ray (medicine) ray (medicine)	22	17	24	7	2300
Football (injuries)	23	26	21	27	23
Railways	24	23	20	19	1950
Food preservatives	25	12	28	14	
Food dyes	26	20	30	21	
Motor cars	27	28	28	28	24
Antibiotics	28	21	26	24	
Home equipment	29	27	26	22	200
Vaccination	30	29	27	25	10

understand the «natural» ones. In fact, alcoholism is localized in time (within one human life) and in social space (it is usually associated with one person and his relatives). There is a large arsenal of preventive and curative measures for him. It is largely related to the choice of lifestyle by the person himself. The reverse situation is taking place with nuclear energy. The consequences of the decisions, which are already made, will have to be dealt with by distant descendants, local actions in this area can affect many, and not much depends on the choice of one person here. In addition, this technology is relatively new, many acute problems have not been solved in it, and the long-term consequences of its use are not obvious. Therefore, there is a logic in the intuitively high assessment of its danger in comparison with other risks.

Geometric mean for groups, rank 1 corresponds to the most dangerous technology, 1—businessmen, 2—students, 3—club members, 4—experts, 5—annual mortality.

If we turn not to the simplest one-dimensional ranking, when the risk is characterized by a single number, but to the «risk plane», used by a number of experts (see Fig. 3.14), then the intuitive preferences of students and businessmen will no longer seem so strange and not adequate to the real situation. Indeed, new risks and effective measures to counteract, which have not yet been found, should be given a much higher priority. In practice, this is how it happens. The research, conducted by the well-known specialist in mathematical psychology V. Y. Krylov confirms this conclusion. On the basis of appropriate techniques, it is possible to determine what the geometry of subjective spaces is, and how many variables a person actually compares in order to find out, how much one event is more dangerous than another. It turned out that the subjective space, associated with the category «risk» is really two-dimensional. In this case, usually, one variable characterizes the objective threat, and the other is the degree of human involvement in the creation or prevention of a dangerous situation. Obviously, this correlates with the «invisibility» and «uncontrollability» of the threats shown in Fig. 3.14.

There are two fundamentally different approaches to decision-making, concerning the safety of the techno genic sphere and protection from natural disasters. We can say that the first approach comes «from the person» and the second approach «from the essence of the problem».

In the first approach, we believe that experts or decision makers have a good idea of how to act in various specific cases. And the task is to extract this knowledge, using formal methods and computer systems, correctly posing questions to them and discussing various model situations, clear of internal contradictions, and on this basis, construct decisive rules and evaluate possible options for action. When implementing a row of large technological projects, related to high dangerous objects, with the need to coordinate the interests of many parties, such procedures have proved to be very effective. They are especially necessary if we intend to approach each object and the taken decision individually. This is a tactic rather than a strategy for the management of risk.

With the second approach, we form general principles, applied to many heterogeneous objects, relevant norms, and methods, and then fix them in legislative acts. This approach is simpler, more general, and more visual than the first one, but less flexible and specific. Apparently, when analyzing risk management, it will be necessary to solve an important methodological question—when should the first approach be preferred, and when should the second approach be preferred?

Of course, many things, related to the management of risk, are quite obvious and do not require the use of formal methods and scientific analysis. For example,

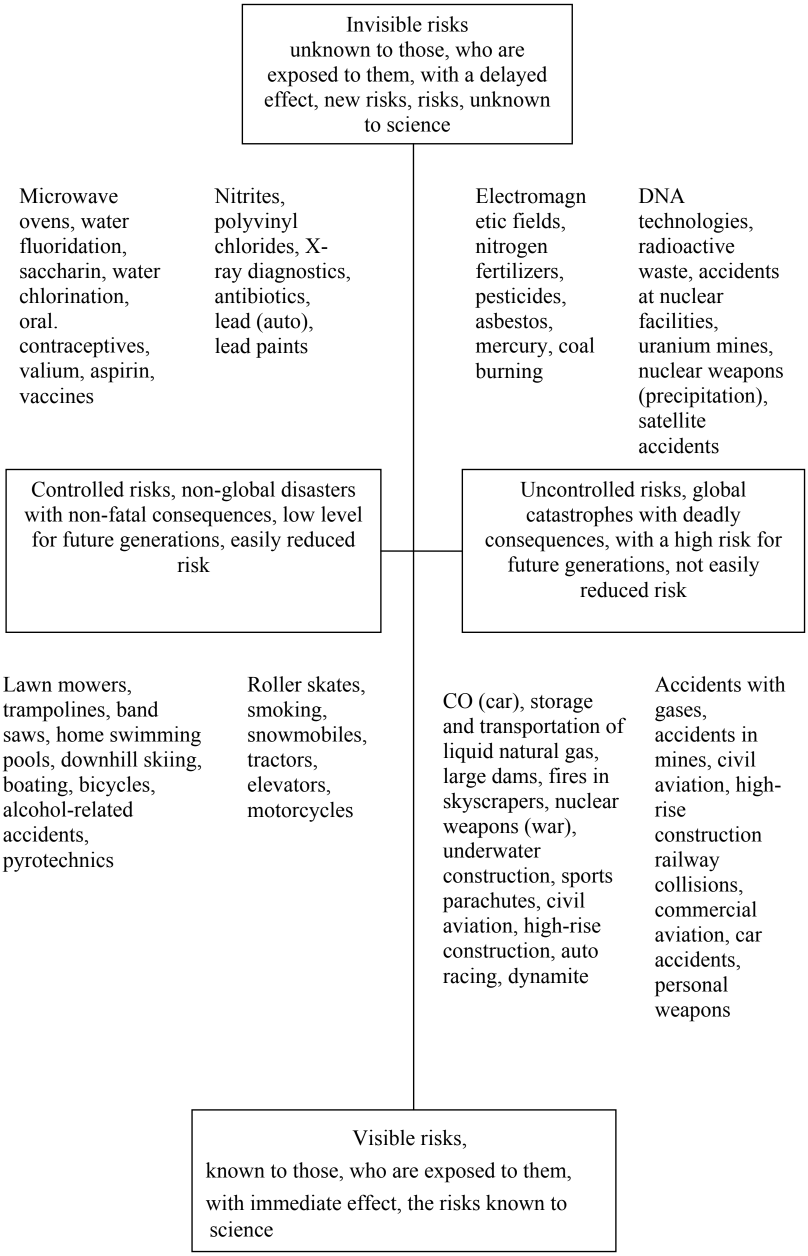


Fig. 3.14 Representation of threats in a two-dimensional risk space

both practice and textbooks convince, that controlling or inspection bodies cannot be legally or actually subordinate to those services and departments, that they are called to control. Otherwise, the effectiveness of the activities of the relevant structures, and with them, security, will fall. For example, the Higher Attestation Committee cannot be subordinate to the Ministry of education, etc. The implementation of many other provisions of this kind is not a matter of science, but of practice.

For the first time, the idea of the equation of existence, described in [48], was developed for technological systems in [49], and for the processes of maintenance and repair of aircraft equipment in [50], which proves the universality of the idea of the equation itself.

By analogy, the equation of the existence (state) of the system of management of ecological safety (environment) for civil aviation enterprises can be written as [51]

$$\Theta \quad = \nu_1 + \nu_2 + \ldots + \nu_i + \ldots + \nu_N = \sum \nu_i \text{ (от } i = 1 \text{ до } N), \tag{3.54}$$

where Θ generalized qualimetric indicator of environment state; ν_i—the component of the state indicator; N—capacity of the set of individual variables i.

If we divide the right and left sides of the Eq. (3.54) by Θ, we have

$$1 = \sum \xi_i (\text{from } i = 1 \text{ to } N) \tag{3.55}$$

where $\xi_i = (\upsilon_i/\Theta)$—the relative component of the state indicator.

Each ξ_i is a function of series factors: (a, b, c, ...)

$$\xi_1 = f(a_f, b_f, c_f, \ldots), \xi_2 = \varphi\left(a_\varphi, b_\varphi, c_\varphi, \ldots\right), \ldots \xi_N = \psi\left(a_\psi, b_\psi, c_\psi, \ldots\right), \tag{3.56}$$

then equation (3.55) is written in the form

$$1 = f(a_f, b_f, c_f, \ldots) + \varphi\left(a_{\varphi,\varphi}, c_\varphi, \ldots\right) + \ldots + \psi\left(a_\psi, b_\psi, c_\psi, \ldots\right). \tag{3.57}$$

The components of functional dependencies (3.56) and Eqs. (3.57) must comply with the System of International ecological management standards ISO-14000 and their domestic analogues NS ISO 1400–98 14,031–2001.

Drawing up the equation of state of the system of management of ecological safety (environment) in the form of a qualimetric sum (3.55) is possible only partially, since a number of requirements for this system are statements regarding the statement Θ:

«The developed system of control meets the requirements of ISO-14000». The truth of the latter is determined only through logical operations

$$1 = \xi_1 \& \xi_2 \& \ldots \& \xi_i \& \ldots \& \xi_{N-1} \& \xi_N, \tag{3.58}$$

where $\xi_i = 1$—evidence of the truth of the statement (it can be defined, among other things, as an expert assessment); and conjunction; $\Theta = 1$ (compliance with the requirements of ISO-14000), in the case $\vee\, \xi_i = 1$.

In accordance with [52], the following statements can be distinguished that correspond to the conditions of the logical operation (3.58):

$\xi_1 = 1$—the company has a documented policy in the area of environmental protection;

$\xi_2 = 1$—the policy shows the main purposes of the enterprise in environmental protection activities;

$\xi_3 = 1$—the policy is approved by the board of directors or other supreme administrative management body;

$\xi_4 = 1$—it is possible to correct this policy;

$\xi_5 = 1$—the goals and tasks of the ecological policy are formulated;

$\xi_6 = 1$—the environmental policy provides the direction of activity in the area of ecological monitoring, the use of appropriate technologies in management practice;

$\xi_7 = 1$—the ecological policy supports the activity for continuous improvement of ecological characteristics, ecological monitoring, and compliance with regulatory requirements;

$\xi_8 = 1$—the company's management ensures the performance of regulatory and other requirements in the area of environmental protection. The ecological policy of civil aviation enterprises (CA) should show the following main aspects:

$\xi_9 = 1$—it has the goals and directions of activity of the CA enterprise;

$\xi_{10} = 1$—it complies with regulatory and guidance documents on environmental protection, laws, other by-laws, norms, and rules, for which the company is responsible;

$\xi_{11} = 1$—it contains requirements for the system of management of ecological safety, including the requirements of interested parties (related to environmental protection activities);

$\xi_{12} = 1$—it is aimed at preventing environmental pollution, reducing the amount of waste, spending raw materials and material resources, as well as preventing accidental environmental pollution (pollution as a result of aviation accidents, disasters, emergency fuel discharge, etc.);

$\xi_{13} = 1$—it is consistent with other aspects of administrative policy, for example, in the area of ensuring the quality of services (for example, the transportation of passengers and cargo), health and safety;

$\xi_{14} = 1$—it promotes ecological education and personnel training (advanced training of enterprise managers on environmental protection issues);

$\xi_{15} = 1$—it promotes the exchange of experience in environmental protection;

$\xi_{16} = 1$—it reduces waste and saves resources;

$\xi_{17} = 1$—it reduces or eliminates emissions (discharges) of pollutants into the environment;

$\xi_{18} = 1$—it allows you to design aircraft with minimal impact on the environment during production, maintenance, and disposal;

$\xi_{19} = 1$—it provides management of the level of impact on the environment of the feedstock;

$\xi_{20} = 1$—it affects the improvement of ecological awareness among the company's employees and the public.

For a specific type of enterprise activity, the power of a set of propositional variables can change both in the direction of increasing and decreasing.

The assessment of the mechanism for achieving the goals and tasks of ecological policy is more progressive when analyzing the results evaluated in measurable (qualimetric) indicators of ecological compatibility, according to the expression (3.57), since it is possible to compare their values with regulatory requirements and determine the dynamics of events by comparing with the indicators of the previous period, for example.

$f(a_f, b_f, c_f, \ldots)$—the amount of emitted harmful gases;

$\varphi(a_\varphi, b_\varphi, \quad c_\varphi, \ldots)$—the amount of solid waste, produced per unit of production;

$\psi(a_\psi, b_{\psi,} c_\psi, \ldots)$—efficiency of use of raw materials and energy.

Promising measured parameters can be the number of accidents (disasters), associated with impact on the environment; the level of waste disposal; mileage of vehicles per unit of production; the amount of released gaseous pollutants; investments in environmental protection; ensuring the system of management of ecological safety with material resources; personnel support; training and advanced training of environmental protection specialists and enterprise personnel; personal responsibility for the performance of ecological requirements.

As measured, expert assessments (self-assessments) can also be used on developed legislative and regulatory acts; standards, rules, and regulations; documents showing the ecological aspects of the enterprise's activities, its products, and services that have a significant impact on the environment; the existing practice and procedure for implementing management of environment at the enterprise, as well as an assessment of the characteristics of monitoring of environmental components.

The further direction of work on improving the system of management of ecological safety (environment) should be the definition of the functional terms of the Eq. (3.58), for example.

$f(a_f, b_f, c_f, \ldots)$; $\varphi(a_\varphi, b_\varphi, \quad c_\varphi, \ldots)$;..., $\psi(a_\psi, b_\psi, c_\psi, \ldots)$ et al.

It follows from Eq. (3.58) that if, as a result of the taken measures, the argument a_f changes by the value δa_f, then f will change to δ f.

Then

$$F_1 = f - \delta f = f\{(a_f - \delta a_f), b_f, c_f, \ldots\}. \tag{3.59}$$

By analogy with (3.59), the expression (3.54) will take the form

$$(\Theta - \delta v_1) = (v_1 - \delta v_1) + v_2 + \cdots + v_i + \cdots + v_N. \tag{3.60}$$

Dividing similarly (3.57) the right and left sides of the Eq. (3.60) by the value $(\Theta - \delta v_1)$, we will get

$$1 = f\{(a_f - \delta a_f), b_f, c_f, \ldots\} + \varphi_1 + \cdots + \psi_1. \tag{3.61}$$

As can be seen from the comparison of Eqs. (3.57) and (3.61), a change in one of the components of Eq. (3.57) as a result of measures, taken to improve the ecological situation by the value of $\delta\nu_1$ changes the proportion of other components. Consequently, the problem («bottleneck») of increasing ecological safety is shifting toward other components.

Thus, the equation of the state of the system of ecological safety:

- shows the effectiveness of the activities, carried out at the enterprise;
- indicates the location of the next «bottleneck», that needs to be «expanded» by focusing the necessary investments at this stage of work;
- allows you to carry out strategic marketing and plan a long-term investment policy of the enterprise to ensure ecological safety;
- can be an integral part of monitoring ecological safety at enterprises.

3.5 Methods of Expertise in the Management of Systems of Ecological Safety at Aviation Enterprises

The purpose of managing systems of ecological safety is to ensure the required level of environmental quality. The practical function of the system of quality management is to tell the administration when it is necessary to intervene in the technological process and in which part of the organizational system this intervention should be carried out.

Measurement system of a quality can be defined as a set of indicators, their mathematical models and measurement methods, that provide a quantitative determination of the level of quality.

A systematic approach to the creation and analysis of systems convinces that formalized models are not enough to describe modern tasks. We also need informal descriptions that establish the compliance of the characteristics and parameters of the systems with the initial requirements, in which almost the main place is occupied by qualitative features.

In response to the need for practice, a new methodology of system analysis has emerged as an alternative to the established tradition. Its meaning is the combination of mathematical and informal methods of analysis, strict formalized methods with experiments, heuristic techniques, and expert judgments.

The essence of expertise as a scientific method is the rational organization of conducting the experts analysis of the problem with the quantitative assessment of judgments and processing of the results. The generalized opinion of the expert group is accepted as a solution to the problem. The whole variety of tasks, solved by experts, is reduced to two types: system analysis of the design solution and parametric analysis [53].

The research and evaluation of the quality of the system are carried out in two main directions. The first direction is to assess the quality of the system's project proposal and compare alternative options in order to choose the best one. The second direction of quality assessment is system certification.

The tasks of expertise related to measuring the quality of project proposals, their comparative evaluation, and making a decision on choosing the best project proposal are important, since they are solved at the project stage.

An important point, that determines the quality of the expertise itself is the formation of a system of criteria on the basis of which assessment of the quality of competitive project proposals of the system under study is evaluated. The quality of the expertise also depends on the chosen methods of expert assessment, the form of the expert survey, and the method of processing the survey results. Finally, the quality of the expertise is determined by the composition of the group of experts and their professionalism.

The most general requirement for the system of criteria indicators, obviously, is that the quality assessment is inherently complex and systematic. It is advisable to represent such a system in the form of a hierarchy, at the top of which there is a generalizing indicator of the quality of the product. The second level is formed by complex indicators.

The formation of a system of criteria indicators by which project proposals are compared is an informal task. It can be solved by an expert method. Based on expert assessments of the importance of certain indicators of the quality of the technical system, it is concluded that it is advisable to include them in the system of criteria for evaluating alternative project proposals.

The target quality shows the main purpose of the system for which the object in question is created. This component of quality is usually called target (or functional) efficiency. It is a relationship between the properties of the projected object and the result of its functioning. The variety of target tasks and different application conditions make it difficult to use a single meter to assess the target quality of various technical systems.

In relation to the ecological system, the target purpose is the effectiveness of this system.

The quality of the service of performance of the target task shows the providing side of performance of the main target function, i.e. the fitness of the object to fulfill the target purpose. Obviously, the same target task can be performed with different levels of security, reliability, etc.

Service quality is associated with many system parameters. For each type of system, the list of parameters is different.

In our case, these can be the following parameters: the enterprise has a documented policy in the area of environmental protection; the policy shows the main goals of the enterprise in environmental protection activities; the possibility of correcting this policy is provided; the goals and tasks of the ecological policy are formulated; the ecological policy gives the direction of activities in the area of ecological monitoring, the use of appropriate technologies in the practice of management; the ecological policy supports activities for continuous improvement of ecological characteristics, for ecological monitoring and compliance with regulatory requirements, etc.

The conducting of expertise includes several stages: selection and formation of an expert group; conducting a survey; processing and analysis of the survey results.

The stage of selection and formation of an expert group is one of the most important and responsible in conducting an expert examination. The success of the expertise largely depends on the quality of the selection of experts.

The selection of the quantitative and qualitative composition of experts is based on the analysis of the breadth of the problem, the reliability of the results of the expertise, the personal characteristics of experts, and the cost of resources for conducting the expertise.

For quantitative assessment of the degree of competence, the competence coefficient (authority coefficient) is used. The assessment of the competence coefficient can be made before the conducting of expertise on the basis of self-assessment or mutual assessment by other experts, and after the expertise on the basis of processing its results.

There are several approaches to determine the coefficient of expert competence. The simplest method is to evaluate the relative coefficients of competence, based on the results of specialists' statements about the composition of the expert group. The essence of the method is as follows. A number of specialists are invited to make a judgment on the inclusion of persons in the expert group to solve a certain problem. Based on the results of the survey, a matrix Z is compiled, the elements of which are the variable z

$$z_{ij} = \begin{cases} 1, & \text{if } j-\text{th expert call } i-\text{th expert}; \\ 0, & \text{if } j-\text{th expert did not call } i-\text{th expert}. \end{cases} \tag{3.62}$$

According to the matrix data, competence coefficients are calculated as the relative weights of experts by the formula

$$\mu_i = \frac{\sum_{j=1}^{n} z_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} z_{ij}} \quad (i = 1, 2, ..., n), \tag{3.63}$$

where μ_i—competence coefficient of ith expert; n—number of experts (the dimension of the matrix Z).

The competence coefficients are normalized so that their sum is equal to one.

The reliability of the expert's estimates is quantified using the formula

$$\mu_i = \frac{N_i}{N} \quad (i = 1, 2, ..., n), \tag{3.64}$$

where N_i—the number of cases, when ith the expert gave a decision, the acceptability of which was confirmed by practice;

N—the total number of cases of participation of the i-th expert in solving the problem;

n—number of experts in the group.

The method of expert assessment is a method of measuring the characteristics of the importance, reliability, and preference of the analyzed objects. There are a number of methods of expert assessment that differ in the ways of decomposition of the problem and the principles of measuring (evaluating) the properties of technical systems. The choice of a specific method is determined by the purposes of the expertise, the essence of the problem being solved, the completeness and reliability of the information, and the time and cost of conducting the expertise. The classical methods of expert evaluation are ranking, pair comparison, direct evaluation, and sequential comparison.

Pair comparison is a procedure for determining the preference of objects when comparing all possible pairs. When comparing a pair of objects (if the degree of superiority of one object over another is not taken into account), only relations of strict order or equivalence are possible. In this case, the paired comparison, as well as the ranking, is a measurement on an ordinal scale.

The numerical representation of m objects, that are in strict-order relations or equivalence, in the method of paired comparisons has the form

$$c_{ij} = \begin{cases} 2, & \text{if } i-\text{th object is preferrable, than } j-\text{th object} \\ 1, & \text{if } i-\text{th object is equivalent to } j-\text{th object} \\ 0, & \text{if } j-\text{th object is preferrable, than } i-\text{th object} \end{cases} \quad (i, j = 1, 2, ..., m)\,. \tag{3.65}$$

Another possible numerical representation of the relations of a set of objects in a paired comparison is a numerical representation in the scale of relations, which allows evaluating objects, taking into account the degree of preference of one object over another

$$c_{ij} = \begin{cases} \alpha, & \text{if } i-\text{th object is preferrable, than } j-\text{th object} \\ 1, & \text{if } i-\text{th object is equivalent to } j-\text{th object} \\ 1/\alpha, & \text{if } j-\text{th object is preferrable, than } i-\text{th object} \end{cases} \quad (i, j = 1, 2, ..., m)\,, \tag{3.66}$$

where $\alpha = 1, 2, \ldots, \alpha^*$. The integer parameter α^* represents the upper limit of the measurement scale.

Expert assessments c_{ij} form a matrix of paired comparisons. Note that the comparison in all possible pairs does not yet give a complete ordering of objects, and therefore, the choice of the best object. Therefore, the task of ranking objects, based on the results of the paired comparison remains relevant.

An expert survey is a hearing and recording in a meaningful or quantitative form of expert opinions on the problem being solved. The main forms of the survey are: questionnaire, interviewing, Delphi method, brainstorming, and discussion [54, 55].

After conducting a survey of a group of experts, the results are processed and analyzed. The initial information for processing the results is numerical data, expressing the preferences of experts and a meaningful justification of these preferences. The purpose of processing is to obtain generalized data and new information, contained in a hidden form in expert assessments. A solution to the problem is formed based on the results of processing.

Giving a comparative assessment of the method of paired comparison with other classical methods of expert assessments (ranking, direct evaluation, and sequential comparison), it should be noted that this method, based on a pair comparison of objects by individual characteristics, has one, but a very important advantage. This advantage lies in the fact that the method allows for expert evaluation of a large number of objects by a large number of features.

The logical development of the pair comparison method was the method of hierarchy analysis, which is currently one of the most powerful and effective methods of expertise and decision-making [56, 57]. The method of hierarchy analysis, proposed by Thomas Saati, combines the idea of the paired comparison of objects with an analytical approach to the formation of an evaluation solution. The analytical approach, based on the algebraic theory of matrices, allows you to construct an ordered series of objects based on the results of paired comparisons by one or a set of hierarchically related indicators (comparison features) and thereby determine the best object.

The hierarchy analysis method is a systematic procedure for the hierarchical representation of the elements that determine the essence of any task. The method consists of decomposing the problem into increasingly simple components and further processing the sequence of judgments of the decision maker (expert) by paired comparisons. As a result, the relative degree (intensity) of the interaction of elements in the hierarchy can be expressed. These judgments are then expressed numerically.

The application of the method of hierarchy analysis to solving the problem of expertise and quality assessment of the system's project proposals includes three main stages:

1 a hierarchical representation of the expertise task, in which the lower level of the hierarchy is represented by alternatives (project proposals of the technical system), the upper-by the goal (quality assessment of the technical system), the intermediate—by single and complex quality indicators, according to which the project proposals of the technical system are compared;
2 conducting paired comparisons to determine the quantitative assessment of the degree of influence of elements of each level of the hierarchy (alternatives, criteria) on each element of the neighboring upper level of the hierarchy (criterion, goal);
3 obtaining priorities that characterize quantitatively the degree of influence of alternatives (evaluated project proposals of the technical system) through criteria (a system of individual and complex indicators of the quality of the technical system) with the goal of evaluating the quality of the system.

In the most elementary form, the hierarchy is constructed from the top (goals from the point of view of management), through intermediate levels (criteria on which subsequent levels depend) to the lowest level, which is usually a list of alternatives.

Table 3.5 Table of the importance of the elements of the expertise task in relation to their common characteristic (goal, criterion)

Goal (criterion)	A_1	A_2	…	A_n
A_1	a_{11}	a_{12}	…	a_{1n}
A_2	a_{21}	a_{22}	…	a_{2n}
…	…	…	…	…
A_n	$a_{\mathrm{n}1}$	$a_{\mathrm{n}2}$	…	a_{nn}

In the task under consideration, the expertise of the ecological system is aimed at a comparative assessment of solutions from the standpoint of the quality of the system. The goal occupies the top level in the hierarchical representation of the expertise task (further hierarchies). The lower level of the hierarchy—the level of alternatives is represented by a set of evaluated enterprises. The intermediate levels of the hierarchy are occupied by complex and individual indicators of the quality of the system.

The formation of a system of criteria by which project proposals are compared is an informal task. It can be solved by an expert method. Based on expert assessments of the importance of certain indicators of the quality of the technical system, it is concluded that it is advisable to include them in the system of criteria for evaluating alternative project proposals.

After the hierarchical reproduction of the expertise task, the question arises: how to set the priorities of the criteria (indicators) and evaluate each of the alternative design solutions, according to the criteria?

In the method of hierarchy analysis, the elements of the expertise task (A_1, A_2, …, A_n) are compared in pairs with respect to their impact («weight») on a common characteristic for them (goal, criterion), Table 3.5.

Quantitative judgments about pairs of elements (A_i, A_j) are presented by a matrix **A** of size $n \times n$. Components of matrix a_{ij} are determined by the next rules:

Rule 1. If $a_{ij} = \alpha, a_{ji} = 1/\alpha, \alpha \neq 0$.

Rule 2. If the judgments are such, that A_i has the same with A_j relative importance, then $a_{ij} = a_{ji} = 1$.

Rule 3. Components $a_{ii} = 1$ for all i.

Thus, matrix A, which is called the matrix of paired comparisons, has the form

$$\mathbf{A} = \begin{bmatrix} 1 & a_{12} & \ldots\ a_{1n} \\ 1/a_{12} & 1 & \ldots\ a_{2n} \\ \ldots & \ldots & \ldots\ \ldots \\ 1/a_{1n} & 1/a_{2n} & \ldots\ \ 1 \end{bmatrix}. \tag{3.67}$$

After obtaining quantitative judgments about pairs (A_i, A_j) and their representations in numerical terms through a_{ij} the task is reduced, that to correspond the set of numerical weights w_1, w_2, …, w_n, which would show the fixed judgments to the elements A_1, A_2, …, A_n. In this case, the matrix will have the form

$$\mathbf{A} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}. \tag{3.68}$$

The matrix **A** is inversely symmetric because $a_{ij} = 1/a_{ji}$. If our judgments are perfect in all comparisons, then $a_{ik} = a_{ij}a_{jk}$ for all *i*, *j*, *k* and matrix **A** is called by consistent.

An obvious case for a consistent matrix is when comparisons are based on accurate measurements, i.e. the weights w_1, w_2, …, w_n are known. Then $a_{ij} = w_i/w_j$ $(i,\ j = 1, 2, \ldots, n)$ and consequently

$$\begin{aligned} a_{ij}a_{jk} &= \frac{w_i}{w_j} \cdot \frac{w_j}{w_k} = \frac{w_i}{w_k} = a_{ik}\,; \\ a_{ji} &= w_j \big/ w_i = \frac{1}{w_i \big/ w_j} = 1 \big/ a_{ij}\,. \end{aligned} \tag{3.69}$$

In this ideal case, when paired comparisons are based on accurate estimates, the own values and vectors are determined from the matrix equation

$$\mathbf{Aw} = n\mathbf{w}\,. \tag{3.70}$$

In matrix theory, this formula means that **w**—the own vector of matrix **A** with the own value, which is equal to *n*, and others own values are zeros.

If w_1, w_2, …, w_n are not known in advance, then paired comparisons of elements are made, using subjective judgments of experts, numerically evaluated on a certain scale. In this case, the subjective assessments of experts a_{ij} will deviate from the «ideal» relationship w_i/w_j. Therefore, Eq. (3.70) will no longer hold.

It can be shown [57] that in the case of subjective estimates, instead of Eq. (3.70), we will have the following equation for determining our own values

$$\mathbf{Aw} = \lambda_{\max}\mathbf{w}\,, \tag{3.71}$$

where $\lambda_{\max}$—the largest own value of an inconsistent matrix **A**;

w—the own vector, corresponding to the own value.

At the same time, the numerical weights w_i, w_j will be linked by the ratio

$$w_i = \frac{1}{\lambda_{\max}} \sum_{j=1}^{n} a_{ij} w_j, \quad (i = 1,\ 2,\ \ldots,\ n) \tag{3.72}$$

Since it is desirable to have a normalized value, we replace **w** with $\left(1 \big/ \alpha\right)\mathbf{w}$, where $\alpha = \sum_{i=1}^{n} w_i$. This ensures the uniqueness of the solution, as well as the fact that $\sum_{i=1}^{n} (1/\alpha) w_i = 1$.

A scale has been developed for conducting subjective paired comparisons (Table 3.7). Before presenting the scale, it should be noted that by convention the relative importance of the left elements of Table 3.6 is compared with the elements at the top. Therefore, if the element on the left is more important than the element at the top, then a positive integer (from 1 to 9) is entered in the cell; otherwise, the inverse number (fraction). The relative importance of any element, compared to itself, is 1; therefore, the diagonal of the matrix contains only units. Finally, the symmetric cells of Table 3.5 are filled with inverse values.

Table 3.6 The scale of relative importance

Intensity of relative importance	Determination	Explanation
1	Equal importance	Equal contribution of two criteria (alternatives) to the goal (criterion)
3	Moderate superiority of one over the other	Experience and judgments give an easy superiority to one criterion (alternative) over another criterion (alternative)
5	Significant or strong superiority	Experience and judgments give a strong superiority to one criterion (alternative) over another criterion (alternative)
7	Significant superiority	One criterion (alternative) is given such a strong superiority, that it becomes practically significant
9	Very strong superiority	The evidence of the superiority of one criterion (alternative) over another is confirmed most strongly
2, 4, 6, 8	Intermediate solutions between two neighboring judgments	It is used in a compromise case
The inverse values of the reduced numbers	If, when comparing one criterion (alternative) with another, one of the specified numbers is obtained, then when comparing the second criterion (alternative) with the first, we get the inverse value	

Table 3.7 Random index, depending on the size of the matrix of paired comparisons

Size of matrix *n*	1	2	3	4	5	6	7	8	9	10	11	12
Mean RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,54

Why the scale, presented in Table 3.6, was chosen for conducting subjective pair comparisons.

The answer to this question is based on two provisions. On the one hand, the scale should make it possible to catch the difference in the opinions of experts, when conducting paired comparisons. In accordance with this, the scale should have as many gradations as possible. On the other hand, the number of scale gradations is limited by the number of objects compared with each other. It is known from the practice of expertise that no more than 7 ± 2 objects can be compared at the same time [57]. When comparing this number of objects, the expert is still quite confident in all the gradations of his judgments. This position determines the upper limit of the scale.

Since there are small changes in the elements a_{ij} of inconsistent matrix **A** cause a small change $\lambda_{\max}$, deviation of the latter from n (the largest own value in the case of a consistent matrix) is a measure of consistency. It allows you to assess the proximity of the resulting scale to the main scale of relations. As the index of consistency (IC) is accepted

$$(\lambda_{\max} - n)/(n - 1). \tag{3.73}$$

Index of consistency of a generated randomly inversely symmetric matrix on a scale from 1 to 9 with the corresponding inverse values of the elements, we call random index (RI). Parameter RI depends from size n of matrix of pair comparisons and is determined from Table 3.7.

Relation IC to mean RI for the matrix of the same order is called the relation of consistency (RC).

Matrix of paired comparisons is considered acceptably consistent if the condition

$$\mathrm{RC} \leq 0,1. \tag{3.74}$$

is met.

Conducting paired comparisons and drawing up a matrix of paired comparisons, based on them, begins with comparing the relative importance of criteria at the second level of the hierarchy in relation to the overall goal that makes up the first level of the hierarchy. Next, a group of paired comparison matrices is constructed to compare the relative importance of the second-level criteria. Similar matrix groups should be constructed for a paired comparison of each criterion of the next level of the hierarchy (if it exists) relative to the criteria at the current level of the hierarchy. At the last level of the hierarchy, matrices of paired comparisons are constructed to compare the relative importance of alternatives to each of the criteria of the penultimate level of the hierarchy.

The elements of the matrices of paired comparisons are determined on the basis of expert assessments in accordance with the scale are presented in Table 3.3. When conducting paired comparisons, the importance of a particular criterion (alternative option) and the degree of its impact on the overall goal (criterion) are taken into account. In this way, the matrices of paired comparisons are filled in to compare the importance of the hierarchy elements in relation to criteria (goals), that do not have a quantitative expression. In case when there are numerical values of indicators-criteria, the elements of the matrix of paired comparisons are filled based on the reduction of numerical data to a scale of relative importance (Table 3.6).

The purpose of constructing each matrix of paired comparisons **A** is getting the vector of priority **X**, components which $X_1, X_2, \ldots, X_n$ express the relative influence of the set of elements of task on the element (criterion) of the level, adjacent from above. To determine the vector of priority, it is necessary to calculate the own vectors of the matrix, and then normalize the result to one. The vector of priority, obtained in this way, is called the local vector of priority. It must be found for each matrix of paired comparisons.

After constructing the matrices of paired comparisons and determining local priorities, the priorities are synthesized. Priorities are synthesized starting from the second level down. Local priorities are multiplied by the priority of the corresponding criterion at the higher level and are summed for each element in accordance with the criteria affected by this element (each element of the second level is multiplied by one, i.e. by the weight of the single goal of the highest level). This gives the composite (generalized) or global priority of that element, which is then used to weigh the local priorities of the elements, compared with respect to it as a criterion and located a level below. The procedure continues to the lowest level.

For a three-level hierarchy, in accordance with the method under consideration, it is necessary to construct one matrix of paired comparisons to compare the relative importance of criteria in relation to the goal (Table 3.8) and a group of paired comparison matrices to compare the relative importance of a set of alternatives in relation to each of the N criteria (Table 3.9).

The vectors of priority, determined from the matrices of paired comparisons (Table 3.8, 3.9) are local priorities. To determine the generalized priorities (and in the special case of a three-level hierarchy, they are at the same time global priorities), a priority table is constructed (Table 3.10).

Generalized (global) priorities X^A, X^B, X^C, … are calculated by the formula

$$X^* = \left(X_1^* \cdot X_1\right) + \left(X_2^* \cdot X_2\right) + \cdots + \left(X_N^* \cdot X_N\right), \tag{3.75}$$

Table 3.8 A matrix of paired comparisons for comparing the importance of criteria in relation to the goal

Goal	Criterion				Vector of priority
	1	2	…	**N**	
Criterion 1	1	a_{12}	…	a_{1N}	X_1
Criterion 2	$1/a_{12}$	1	…	a_{2N}	X_2
…	…	…	…	…	…
Criterion N	$1/a_{1N}$	$1/a_{2N}$	…	1	X_N
$\lambda_{\max} =$ **RC** =					

Table 3.9 A matrix of paired comparisons for comparing the importance of alternatives with respect to the i-th criterion

Criterion I ($i = 1, 2, \ldots, N$)	Alternative				Vector of priority
	A	B	C	…	
Alternative A	1	$a^i{}_{AB}$	$a^i{}_{AC}$	…	$X^A{}_i$
Alternative B	$1/a^i{}_{AB}$	1	$a^i{}_{BC}$	…	$X^B{}_i$
Alternative C	$1/a^i{}_{AC}$	$1/a^i{}_{BC}$	1	…	$X^C{}_i$
…	…	…	…	…	…
$\lambda_{\max} =$ **RC** =					

Table 3.10 Table of priority of hierarchy

Alternative	Vector of local priority from Table 3.8				Vector of priority
	X_1	X_2	…	X_N	
A	$X^A{}_1$	$X^A{}_2$	…	$X^A{}_N$	X^A
B	$X^B{}_1$	$X^B{}_2$	…	$X^B{}_N$	X^B
C	$X^C{}_1$	$X^C{}_2$	…	$X^C{}_N$	X^C
…	…	…	…	…	…

where, as sign *, letters A, B, C, ….are understood.

The vector of global priorities shows the relative weight of each of the alternatives (at the lowest level of the hierarchy) in relation to the goal (at the highest level of the hierarchy). Therefore, by comparing the components of the vector of global priority quantitatively, it is possible to choose the best alternative, that best meets the set goal.

After determining the global priorities, you should evaluate the consistency of the entire hierarchy. The consistency of the entire hierarchy can be found by multiplying each consistency index by the priority of the corresponding criterion and then summing the obtained numbers. The result is then divided into an expression of the same type, but with a random index of consistency, corresponding to the size of each priority-weighted matrix. An index of consistency value of 0.1 or less is acceptable. Otherwise, the quality of judgments should be improved, perhaps by revising the way in which questions are asked and judgments are made, when conducting paired comparisons. If this does not help to improve consistency, then the task should probably be structured more precisely. A return to stage 1 (hierarchical representation of the expertise task) will be required, although only «questionable» parts of the hierarchy may require revision.

To conduct an expertise of existing ecological systems at enterprises, a developed software and methodological complex consisting of the EXPERT management program and 10 software modules were used. The modules are written in the C++ and FORTRAN programming languages.

The following criteria were selected:

Criteria 1—the company has a documented policy in the area of ecological protection;

Criterion 2—the possibility of correction of this policy is provided;

Criterion 3—ecological policy supports the continuous improvement of ecological performance, ecological monitoring, and compliance with regulatory requirements;

Criterion 4—the company's management ensures compliance with regulatory and other requirements in the area of environmental protection.

The ecological policy of civil aviation enterprises (CA) should show the following main aspects:

Criterion 5—complies with regulatory and guidance documents on environmental protection, laws, other by-laws, norms, and rules for which the company is responsible;

Criterion 6—is aimed at preventing environmental pollution, reducing the amount of waste, spending on raw materials and material resources, as well as preventing accidental environmental pollution (pollution as a result of aviation accidents, accidents, disasters, emergency fuel discharge, etc.);

Criterion 7—is consistent with other aspects of administrative policy, for example, in the area of ensuring the quality of services (for example, the transportation of passengers and cargo), health and safety;

Criterion 8—reduces the amount of waste and saves resources;

Criterion 9—reduces or eliminates emissions (discharges) of pollutants into the environment;

Criterion 10—allows you to design aircraft with minimal impact on the environment during production, maintenance, and disposal.

If the criteria are ranked without the method of hierarchy analysis, then the vector of global priority, using the vector of priority of criteria, is calculated by using the following formula:

$$\mathrm{X}_{\mathrm{i}}^{(1)*}\mathrm{Y}_1 + \mathrm{X}_{\mathrm{i}}^{(2)*}\mathrm{Y}_2 + \cdots + \mathrm{X}_{\mathrm{i(k)}}\mathrm{Y}_{\mathrm{k}} = Z_i. \tag{3.76}$$

Based on the results of calculations (the value of the vector of global priorities), it is possible to assess, how the system of ecological safety functions at the enterprise. The head of the enterprise, which has the lowest indicators, should correct the management of the system of ecological safety.

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Part II

Comprehensive Monitoring of the System for Management of Ecology Safety in Civil Aviation

Chapter 4
Development of Analytical Methods for Solving Problems of Management for Ecology Safety in Civil Aviation at the Stages of the Life Cycle of an Aircraft Product

4.1 Analysis of Existing Methods for Assessing the Ecology Consequences of Emergency Situations

The ecological consequences of any economic activity and the inevitable technogenic impacts on the environment are expressed in the contamination of its components with various kinds of harmful substances, changes in the cyclic biogeochemical and other natural processes, occurring in nature.

According to a number of experts [1], the loads that arise during the daily operation of facilities in normal operating conditions are most easily regulated and normalized. The most poorly predictable impact on environment occurs during technogenic accidents and disasters, in particular, the ecological consequences of aviation accidents. Such an impact is characterized by high loads, accompanied by deharmonization of natural processes, shifts in ecological balance, which requires the development of effective methods for analyzing and evaluating the consequences of technogenic emergency situations.

The damage, caused by emergency situations, is of a diverse nature, so there is no doubt, that it is necessary to use a wide range of specific and diverse indicators to measure it. Assessments of the consequences of emergency situations are carried out by specialists of different specialties, each of which uses a specific conceptual apparatus, a system of measurements and assessments [2].

Currently, work is underway to create a mechanism for assessing damage from emergency situations.

The section «Assessment of damage» has been introduced into the system of standards «Safety in emergency situation (ES)» and two fundamental standards for assessment of damage have been developed [3, 4].

Ecological damage is one of the components of damage from emergency situations. The structure of environmental damage, taking into account the negative changes in the environment, that occur during emergency situations, can be presented in the following form (Fig. 4.1).

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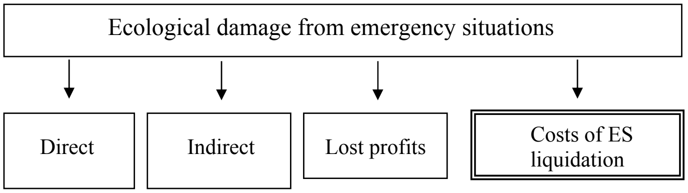

Fig. 4.1 The structure of ecological damage in emergency situations

Direct ecological damage is caused by pollution of the atmosphere, water, destruction of soil cover, destruction of plants and animals, destruction of ecosystems under the direct impact of damaging factors of emergency situations.

Indirect ecological damage is a consequence of direct damage is of a long-term nature and is associated with long-term consequences (for example, deterioration of the quality characteristics of natural environments, violation of the climatic balance, etc.) or is formed as a result of a sequential layering of secondary consequences. For example, a fire at an industrial facility can cause the destruction of containers with toxic substances in a nearby chemical warehouse, followed by contamination of the territory and reservoirs, which leads to a decrease in the bio-productivity of terrestrial and aquatic ecosystems, etc. In terms of scale, indirect damage may exceed direct damage, and in terms of structure, it repeats it.

The loss of lost profits is expressed in the loss of profit from the use of natural objects, polluted or destroyed as a result of emergency situations, and the diversion of financial, material, and labor resources from environmental protection activities to investigate, rescue, and eliminate the consequences of emergency situations.

The sum of the costs for the elimination of emergency situations consists of the funds, spent on the restoration of destroyed ecosystems.

The assessment of the ecological consequences of emergency situations is a complex methodological and practical task and can be presented in the form of methodological principles [5].

The final goal of identifying the ecological consequences of anthropogenic activities is to assess the human condition. Therefore, the methodology should take into account, first of all, the principle of humanism, which requires, that human health, not only physical, but also mental and social, be considered as the main indicator of damage.

The principle of ecosystems implies taking into account the synergetic effect of processes, occurring in the environment, since the negative consequences of technogenic emergency situations can be transmitted through natural environments, nullifying or complementing each other, creating new ecological threats.

The principle of subjectivity implies taking into account all factors, affecting on the environment in emergency situations, since at each stage of the functioning of a technical system from its creation to disposal, an emergency or catastrophic situation is possible, which differs in its subject. The objects of the impact of anthropogenic emergency factors are various components of the environment and natural environments.

The principle of the dynamics of the ecological state assumes that ecological assessments of the state of environmental components are based on a comparison of the results, obtained with the initial (background) states, which are determined by the standards. During the evaluation procedure, it is not allowed to revise the standards or change them, since they are a characteristic of the initial state of the object under study. The regulatory framework is a necessary condition for the functioning of the methodology for assessing the ecological consequences of anthropogenic activities. The standards regulate the ecologically permissible loads, which should not exceed the mechanisms of compensation and self-regulation of natural processes, occurring in the natural environment of ecosystems. The negative impact of these loads should not go beyond the ecological reserve. Such an assessment can be provided, if there is complete, reliable, comparable, and timely information about the dynamics of environmental characteristics, i.e. fixed changes, deviations, etc. At the same time, in the methods of assessing of the ecological consequences of emergency situations, it is assumed that special standards are used, which contain ultra-permissible values. The values of these standards require clear restrictions, since they cannot be fatal to humans or destructive to other components of nature.

To date, the sources of information on emissions and discharges of substances by specific users and at the same time an instrument for operational management of harmful effects are departmental systems for control of impact on environment. They are organizationally and methodologically unrelated to each other, and as a result, the comparability of the data, received from them, is difficult, when conducting a comprehensive analysis of the state of the environment. The system of rapid detection, analysis of the causes, and forecast of the consequences of emergency situations related to accidental pollution of the natural environment is currently only being formed. The formed system should be constructed and function according to a specially developed methodology and have its own organizational structure. It can be based on a Unified state system of ecological monitoring and a Unified state system for the prevention and elimination of emergency situations (USSPEES), one of the main activities of which is «ensuring the protection of … the environment…» [6].

Departmental systems should become the main tool for obtaining primary data about the impact on the environment in extreme situations. Currently, there is no such system in civil aviation. To solve a comprehensive assessment of the impact of emergency situations on the environment, an appropriate regulatory and methodological framework is needed within individual branches and departments.

Currently, a potential has been created in the field of methodology for assessing the impacts on environment of technogenic accidents and catastrophes. There are models and computational methods for numerical modeling of the processes of propagation of various substances in the atmosphere and aquatic environments. There are assessments of the behavior in ecosystems of various classes of pollutants, the accumulation of their impact on public health.

When considering the ecological consequences of technogenic emergency situations, can be used methods, using numerical, probabilistic, expert, statistical, and combined methods [7].

Two types of numerical methods are used to assess the consequences of anthropogenic emergencies. The first group of numerical methods is based on the modeling of physical and chemical phenomena and processes, that lead to emergency situations. Such methods are intended for evaluating the parameters of processes, that are used in methods for assessing the consequences of accidents at various facilities or with different types of consequences. Some of these methods are used to predict the concentrations of pollutants in atmospheric air or water bodies, to determine the fields of pollutants. The second group of numerical methods is used to predict the levels of environmental pollution: air, water, vegetation, soil, etc. and to obtain long-term forecasts (for several months), as well as to predict the long-term consequences of pollution and the accumulation of negative impacts by individual components of the ecosystem. The analysis of the possibilities of using methods and regulatory documents for predicting the consequences of technogenic accidents and ensuring the safety of industrial objects is given in [8].

The «Methodology for predictive assessment of pollution of open water sources with disaster chemically hazardous substances in emergency situations» provides operational calculations for determining the main characteristics of pollution of watercourses and reservoirs during disaster discharges of hazardous chemicals into them [9]. The paper uses differential and normative methodological approaches.

The «Methodology for assessing damage from accidents on main oil pipelines» presents a procedure for a comprehensive assessment of ecological damage from emergency situations, using numerical methods of regulation [10]. The methodology contains the calculation of the total volume (mass) of oil, spilled during the accident, the masses, that polluted the components of the environment, the calculation of the areas of contaminated land and water bodies, as well as the calculation of damage for pollution in the cost form.

The «Methodology for assessing the consequences of chemical accidents» allows us to determine the amount of hazardous chemicals, released into the atmosphere during various accidents; the spatial and temporal field of concentrations of these substances in the atmosphere; the size of the territories of chemical contamination, as well as social consequences (human damage) [11]. This work is based on numerical methods and takes into account differential (object) and normative methodological approaches.

Probabilistic methods are based on the use of mathematical models that link the prerequisites for emergency situations with the possibility of their manifestation (for example, probabilistic analysis of the safety of nuclear reactors). The consequences of emergency situations are predicted from the analysis of the consequences of already existing emergency situations. The area of the probabilistic method is limited, since it does not allow an objective assessment of the consequences of relatively rare emergency situations.

In the work of L. D. Barinova and L. E. Karaseva, some approaches to the assessment of ecological and related social damage from disasters at transport objects, using probabilistic methods, are considered. The analysis of the contribution of the transport complex, including transport disasters, to the technogenic load on the habitat is carried out. The authors propose a methodology for creating specific mathematical models for predicting the results of impact of toxicants on people [12].

The analysis of the impact of an emergency situation (on the example of a chemical accident) through the elements of the abiotic environment on a person, using probabilistic methods, is considered by V. M. Kolodkin. Specifying the type of emergency impact, the author considers atmospheric air as an element of the abiotic environment, and climatic characteristics (air temperature, wind speed and direction, precipitation, etc.) as the conditions of impact [13].

Statistical methods are based on the collection and processing of data about the impact of various factors on the elements of the object of assessment. The limitation of these methods is that the conditions of their use cannot differ from the conditions in which they were constructed, and a large array of information is required for processing. However, statistical methods are developing rapidly due to the creation of information and measurement systems with real-time data processing.

Statistical methods are used to quickly predict the ecological consequences of environmental pollution as a result of emergency situations. A. F. Egorov and co-authors, analyzing the use of statistical models for predicting atmospheric air pollution, note that the predictive abilities of statistical models are largely determined by the completeness of the initial sample and the comparability of the observation period with the forecasting period [14].

In the absence of sufficient volume of statistical information on failures and accidents at industrial objects and the severity of their consequences, expert methods are used. Their meaning is to survey the opinions of specialists, who have experience in scientific research on this problem and practical work in this field of activity. The results are processed, using special methods (expert assessments, ranking). A forecast, based on expert methods, requires significantly less initial data to obtain the required estimates, which is an undoubted advantage of this approach. But the algorithms of expert forecasts do not take into account the entire complex of properties of the object and its environment, which affect the level of disaster danger. Also, the predicted generalized hazard indicator is not directly related to the amount of damage from environmental pollution.

Most of the methods for assessing the consequences of accidents at technogenic hazard objects provide indirect estimates of ecological consequences, i.e. data (mass or volume of a toxic substance spread, etc.), which are not direct indicators of environmental damage, but serve as the starting point for further calculations. Such methods, as a rule, use combined methods, which are the most common and are based on a combination of several methods.

A quantitative assessment of the impact of technogenic loads, arising from accidents and catastrophes, on the structure of communities of living organisms and landscapes is given in the monograph by A. A. Bykov and N. V. Murzin, which is referred to by Vladimirov and Izmalkov [1]. The authors propose to make an assessment, using a dimensionless energy parameter pE, which is determined by the amount of energy, utilized by the community, and is based on the generalization of the results of a large number of nature studies and characterizes the degree of chemical or radioactive pollution of the environment. The monograph uses statistical, probabilistic and numerical methods, and differentiated (object) approach.

«The Methodology for predicting the scale of infection with highly toxic substances in accidents (destructions) at chemical hazardous objects and transport» [15] combines numerical and statistical methods. It is designed to assess the ecological consequences of air pollution. The method allows you to quickly predict the scale of infection and the duration of the damaging effect of toxic substances; it takes into account differential (branch) and regulatory approaches.

In the «Methodology for assessing the consequences of emergency explosions of fuel–air mixtures» [16] and «Methodology for assessing the consequences of accidents at fire and explosive objects» [17], combined methods (a combination of numerical and probabilistic) were used. This combination allows us to calculate the social consequences and physico-chemical parameters of an emergency situation.

A simplified version of the methodology [17] can be considered the «Express methodology for predicting the consequences of explosive phenomena at industrial objects», designed to assess possible injuries to the personnel of the object and the population during the destruction of buildings and structures, located both on the territory of the object and in industrial zones, using numerical methods [18].

In the work «Assessment of the consequences of emergency situations», some methodological approaches to the assessment of indirect ecological damage, caused by cascade effects, are considered [19]. The paper says that the chain of considered cycles in the cascade of indirect losses can be infinite, and the question arises about the reasonable limits of its consideration. Damage to the natural environment is interrelated with damage to economic sectors. The authors believe that the calculation of the total damage is a multi-level, cumbersome, and incompletely solved task.

A fairly detailed assessment of indirect damage is presented by Y. V. Podrezov. It provides methodological recommendations for assessing the total damage (including ecological damage) from the impact of a forest fire. The concept of «emergency forest fire situation», introduced by him, means, that the cause of an emergency situation can be both natural and anthropogenic [20]. Depending on the specific emergency situation, it is planned to use numerical, probabilistic, statistical, and expert methods for assessing ecological damage and their combinations. In addition to the differential methodological approach, the market approach is used in the work.

The issues of methodology for assessing the ecological consequences of technogenic emergency situations are considered in a number of works [21–23]. Most often, these studies are of a branch-specific nature (an branch-specific methodological approach). The assessment of environmental damage is based on legally established standards (normative approach).

G. I. Turkina considers an emergency situation, related to the overflow of a tank with petroleum products in the seaport, and according to the data on the volume of spilled petroleum products, suggests assessing the economic damage of ecological consequences for all variants of the event. At the same time, it is assumed to use both the method of expert assessments, as well as numerical and probabilistic ones [24].

A. V. Averkiev, on the basis of regulatory documents, offers a methodology for constructing zones of potential territorial risk of damage to the population in accidents with chemically hazardous objects (CHO) [25].

V. V. Karpova offers a methodological apparatus for assessing ecological damage to the environment in oil pipeline accidents, which is constructed on the basis of the methodology [10] and assumes, that these assessments are also carried out within settlements and in the process of eliminating emergency situations [26].

This analysis has shown that most of the existing methods from the standpoint of assessing the ecological consequences of anthropogenic impacts allow us to determine intermediate results (the area of the spill or the area of the spread of a cloud of harmful substances, the duration of its damaging effect, the concentration in the air or water environment, etc.). According to these data, it is then possible to determine the real ecological damage, expressed in natural or cost indicators.

4.2 Features of the Analysis of the Ecology Consequences of an Emergency Situation in Air Transport

The NS ISO 14040–99 standard defines the life cycle as «successive and interrelated stages of the production system from the acquisition of raw materials or the development of natural resources to the disposal of products» [27, 28].

Taking into account a number of proposals, we will consider the life cycle (LC) for an air company (Fig. 4.2).

At each stage of the life cycle, energy resources, structural, construction, and operational materials are consumed; technological processes are accompanied by emissions of harmful substances, that can be accumulated in the components of the biosphere.

The stage of creation includes the extraction and processing of raw materials, the production of structural and construction materials, that make up the transport object, consumable operational materials, necessary for its operation.

The stage of production includes the manufacture of components, parts, assembly of transport objects, construction of engineering structures.

The stage of maintenance (use) includes the performance of transport functions during the standard service life of the vehicle or the maintenance of a transport infrastructure object. In our opinion, at this stage it is necessary to take into account the environmental impacts, arising from emergency events at air transport objects (Block ES).

The stage of repair provides for carrying out maintenance, repair of the transport object with the restoration or replacement of parts, assemblies, aggregates, that have exhausted their resource.

The stage of disposal of the transport object provides for the disassembly and processing of parts and assemblies, unsuitable for restoration, waste disposal.

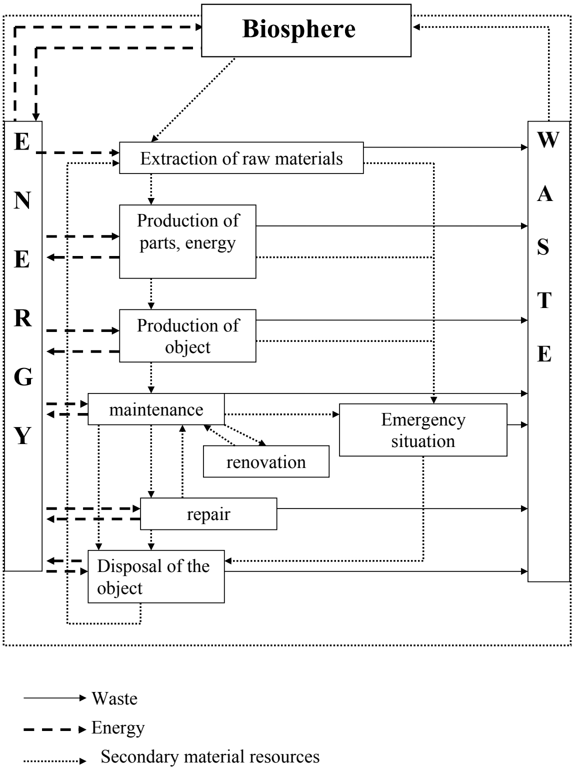

Fig. 4.2 Life cycle of Avia company

The stage of renovation provides for the repeated use of structural, construction, and maintenance materials at previous stages of the life cycle of transport objects or in other areas of activity.

The level of ecological safety of aviation equipment and its main factors of adverse impact on environment—noise and emissions of pollutants by aircraft engines—is regulated by domestic standards and federal aviation regulations, which are largely analogs of international standards (Annex 16 to the Convention on international civil aviation [28, 30]). The tightening of standards is considered by the International Civil Aviation Organization as an important condition for the creation and introduction into the practice of civil aviation of highly economical aircraft of new generation, that are fully compatible with the increased requirements of environmental protection. The revision of domestic standards occurs with a great delay, and their implementation by the aviation industry due to economic difficulties in the country occurs only, when developing new models of aviation equipment, while the types of aircraft and aircraft engines in maintenance, as a rule, are not subjected to the necessary modernization. As a result, the majority of the fleet of domestic aircraft and aircraft engines, currently in maintenance, do not meet modern requirements in terms of aircraft noise and emissions of pollutants. Due to the specific features of the impact of aviation on the environment, when evaluating the activities of aviation enterprises, in addition to the general rules of industrial ecology, special « Requirements of ecological safety for the maintenance, repair and testing of aircraft and aircraft engines at civil aviation enterprises. Atmospheric air and aviation noise» [29] apply, compliance with which is controlled in the process of state ecological control. However, the implementation of the «Requirements…» by aviation enterprises, for various reasons, is very slow. Also, the existing regulatory and methodological acts and the established practice of state regulation of environmental protection activities of enterprises, which have proven themselves well for industrial enterprises with a predominant emission of harmful substances from stationary sources, are ineffective or not at all effective for aviation enterprises, especially airports, due to the prevailing level and distance of the impact of the main adverse factors, such as aircraft noise, the spread of impurities of harmful substances from aircraft engines and electromagnetic radiation from air traffic control devices.

The assessment of the impact on environment of aircraft is carried out, using numerical methods, according to the «Methodology for calculating emissions of pollutants into the atmosphere by engines of the main types of civil aviation aircraft» [30], «The methodology for control of atmospheric air pollution in the vicinity of the airport» [31] and «The recommended method for calculating noise contours around airports» [32]. The data, presented in [32], developed and approved in the late 80 years–early 90 years, need to be revised and refined. Their main disadvantage is the lack of market approaches, that take into account the lost profit in the structure of ecological damage. The differentiated approach is limited to the assessment of the impact on the atmosphere.

To increase the level of ecological safety in the activities of aviation enterprises, special measures have been developed and are being developed—from increasing the requirements for state ecological control, developing special regulatory and methodological acts, suitable for effective ecological regulation, to introducing additional control during certification and licensing of the activities of aviation enterprises by the Federal air transport agency of the Ministry of transport of Russian Federation (FATA MT RF).

State ecological control at aviation enterprises has features, that consist in a clear regulation of ecological requirements for aviation enterprises and making a decision on the implementation of these requirements on the basis of evidence-based documentation, which excludes arbitrary interpretation by regulatory authorities of methods and approaches in assessing the ecological consequences of aviation activities.

It should be noted that the Rules for the investigation of aviation accidents and incidents with civil aircraft in the Russian Federation (RIAAI) [35]—the main document, regulating the procedure for investigating emergency situations in air transport, does not contain information, regarding the assessment of the impact of air transport on the environment. There is no such information in the ICAO documents, operating on the territory of Russia.

Therefore, the development of a methodological base for the assessment of ecological consequences, arising from aviation accidents, is an urgent scientific and practical task.

4.3 Methodology for Assessing Ecology Safety in Civil Aviation

It is necessary to develop a criterion that allows you to compare different technological processes with each other and assess their impact on the environment.

In the work [33], the justification of this criterion is proposed.

The maximum permissible concentration (MPC) of a substance characterizes its toxicity. The more toxic the substance, the lower the MPC.

You can compare different substances, and therefore sources of emissions into the environment, using the index of relative toxicity:

$$\mathrm{I_0 = MPC_{pat}/MPC_i,} \tag{4.1}$$

where $\mathrm{MPC_{pat}}$—the maximum permissible concentration of a conditional substance (component) for water bodies, taken as *pattern*, mg/dm^3;

$\mathrm{MPC_i}$—maximum permissible concentration of the compared i-th substance (component) for water bodies, mg/dm^3.

The toxicity of the source of contamination for the i-th component will be equal to

$$\mathrm{T_i = C_i * I_0 = C_i * MPC_{pat}/MPC_i,} \tag{4.2}$$

where $\mathrm{C_i}$—the concentration of the ith component in the drains.

Then the total toxicity of the source for n components is equal to

$$\mathrm{T} = \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{T_i}. \tag{4.3}$$

The value of T shows how many times it is necessary to dilute the drain, so that it ceases to be harmful, i.e. the condition $\mathrm{T} \le 1$ will be reached. If the concentrations of pollutants and the relative toxicity indices are known for the source of the drain volume, it is possible to determine the value of the relative toxic mass, discharged from the source into the water body

$$\mathrm{m_i = T_i * V;} \tag{4.4}$$

$$\mathrm{m_n = T * V_n.} \tag{4.5}$$

where V—volume of the drain.

As a general characteristic of environmental pollution, we will take a unit of relative toxic mass (RTM), which will characterize the amount of a conditional (reference) pollutant in the object under consideration. For example, characterizing the presence of pollutants in a wastewater storage tank with a volume of 1 m^3, containing carbon disulfide (MPC cs2 = 1 mg/dm^3) with a concentration of Ccs_2 = 1000 mg/dm^3, we obtain that the full storage tank contains 1 kg of relative toxic mass (kg t.m.).

The impact on the environment of a polluting substance is in different aggregate states and present in different natural environments on the basis of a known system of equations (dependencies)

$$\mathrm{lqMPC}_{\mathrm{a.a.}} = 2 + 0.86\mathrm{lqMPC}_{\mathrm{a.w.a.}} \tag{4.6}$$

$$\mathrm{lqMPC}_{\mathrm{w.}} = 0.61\mathrm{lqMPC}_{\mathrm{a.w.a.}} - 1, \tag{4.7}$$

where $\mathrm{MPC}_{\mathrm{a.a.}}$, $\mathrm{MPC}_{\mathrm{a.w.a.}}$, $\mathrm{MPC}_{\mathrm{w.}}$—maximum permissible concentrations of the ith component in atmospheric air, in the air of the working area and in water bodies; mg/m^3, mg/m^3, mg/dm^3 accordingly, with certain assumptions, is reduced by O. G. Vorobyov to the following unified (general) form:

$$\mathrm{MPC}_{\mathrm{a.a.}} = 0.256\mathrm{MPC}_{\mathrm{w.}}^{1.41.} \tag{4.8}$$

Substituting the values of the pattern value $\mathrm{MPC}_{\mathrm{w}} = 1$ into Eq. (4.8), we obtain the value of the pattern value $\mathrm{MPC}_{\mathrm{a.a.}} = 0.256$, reduced to water.

Thus, there is a relationship between MPC for water bodies and MPC for atmospheric air.

The impact of solid waste on the environment is primarily associated with the dissolution and leaching of their soluble components. Therefore, for solid waste, it is sufficient to determine the concentration of water-soluble components and use MPC for water bodies.

Using the concept of RTM allows you to compare various sources of emissions and discharges of solid, gaseous, and liquid substances, that pollute all natural areas, compare different technological processes with each other and choose the most ecologically best one.

Considering that for discharges into water reservoirs $I_0 = 1/\ \mathrm{MPC}_{\mathrm{w.}}$, emissions into the atmosphere $I_0 = 0.256/\ \text{ПДК}_{\text{a.a.}}$, waste, sent to lithosphere $I_0 = 1/\ \text{ПДК}_{\text{lit}}$ (taking into account the solubility coefficient of solid waste), the results of the impact of all types of waste can be recalculated for adequate pollution of water bodies, using the reporting of enterprises in the field of environmental protection.

This approach allows you to express emissions, discharges, and waste from the technological processes maintenance and repair of aircraft (AC), using a common RTM unit. Therefore, it can be used to solve problems of management of ecological safety at CA enterprises.

The health status of the population is assessed by a set of criteria and indicators of environmental pollution: atmospheric air, water, and soil [34, 35].

The main medical and demographic indicators include morbidity, child mortality, medical and hygienic disorders, specific and oncological diseases, associated with environmental pollution.

Medical and demographic indicators for ecologically unfavorable territories are compared with similar indicators in control (background) territories in the same climatic and geographical zones. As such control (background) territories, settlements or individual parts of them are accepted, where the most favorable values of medical and demographic indicators are recorded [36].

These indicators are determined: separately for the urban and rural population for several (three or more) territories with a favorable ecological (sanitary and hygienic) situation. The average value of several minimum indicators is taken as a control (background) value [37–41]. It is unacceptable to use only the average indicators for the republic or region as control values. Preference should be given to indicators, calculated over 10 years and (or) their dynamics over this period. An exception can be made only for relatively rare diseases, as well as specific diseases and other health disorders, that are related to environmental factors of anthropogenic origin. It is also allowed to use data on the territory for previous years as control figures for comparison with their value at the time of the conducting an expert examination [41–44].

It is also allowed to use data on the territory for previous years as control figures for comparison with their value at the time of the conducting an expert examination.

When preparing materials on medical and demographic indicators, it is mandatory to submit a complete primary material, on the basis of which the question of assigning the territory to zones of environmental disadvantage is raised.

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Chapter 5
Development of Comprehensive Monitoring of the Sustainability of the System for Management of Ecology Safety in Civil Aviation

5.1 Development of a System for Monitoring the Anthropogenic Danger of the Techno Genic Sphere in the Mode of Real Time

5.1.1 Main Processes, Leading to Accidental Emissions

Reimers N. F. defined the release as a short-term or for a certain time (hour, day) entry of any pollutants into the environment. In the reference dictionary [1], emissions are understood as waste, generated as a result of anthropogenic activities, the entry of which into the environment is an integral part of techno genesis. Summarizing the definitions, we can say that emissions are any pollutants, including harmful substances, that enter in the environment as a result of normal («regular») operation of industrial enterprises, vehicles, and as a result of incidents, accidents, and disasters [2].

Depending on the aggregate state, emissions are divided into gaseous, liquid, and solid, as well as vaporous and gas-dust. Depending on the amount of pollutants, entering in the environment per unit of time, emissions are divided into mass or salvo (for example, during accidents) and non-mass (for example, during the «regular» operation of industrial enterprises). If possible, the emissions are divided into two groups: organized and unorganized.

Organized (or coordinated) emissions of harmful substances into the atmosphere, water bodies, and soil are carried out, using special devices: pipes, flares, treatment facilities, etc. For organized emissions, the standards MPCE—the maximum permissible coordinated emission, TCE—temporarily coordinated emission, TPE—technically permissible emission, and some others are established.

Unorganized emissions include, for example, leaks through fineness in equipment, fittings, pipelines, evaporation of products from tanks and storage facilities, spills, and salvo emissions in emergency situations.

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The main processes that lead to accidental emissions of harmful substances at chemical plants, warehouses of dangerous substances, during their transportation, include explosions and fires. These processes are often interrelated, and in themselves serve as sources of dangerous damaging factors, the implementation of which can lead to an increase in the total damage from an accident due to the initiation of secondary processes (fires and explosions, emissions of harmful substances).

An explosion is a short-term process of rapid transformation of a substance with the release of a large amount of energy in a small volume. These transformations occur as a result of a chemical (condensed, liquid, and gaseous explosives) or nuclear reaction. Explosive processes also include processes caused by physical causes: the destruction of compressed gas tanks, steam boilers, as well as powerful electrical discharges. The main result of the explosion is a shock wave that propagates some distance from the source of the explosion [3, 4].

At work, explosions can occur due to non-compliance with the technological modes of production processes, untimely repair or replacement of faulty or worn-out equipment, violation of the rules for conducting gas welding and open flame work, non-compliance with the rules for working with electrical installations, due to malfunction of lightning protection systems, smoking in prohibited places, etc. The most common cause of explosions is a spark, including as a result of the accumulation of static electricity.

In case of emergency explosions, the main damaging factors include a shock wave, thermal radiation, and a fragmentation field. The damaging effect can be amplified, when secondary explosions are excited—when objects with energy carriers fire and explode under the influence of the primary explosion (the so-called «domino effect»).

The most important characteristics of a shock wave, that determine the effect of its impact on various objects and a person, include excessive pressure in the front (EPF) and high-speed pressure. Other important characteristics of the shock wave are the duration of the compression phase and the unit impulse.

Theoretical approaches to determining the characteristics of a shock wave, as well as calculation formulas, obtained on their basis, are described in the works [5–7].

In practical calculations, simpler formulas are usually used, given, for example, in [3–5].

The most reliable data on possible destruction of buildings under the influence of a shock wave is obtained as a result of their dynamic calculation. It is also possible to use approximate engineering methods for calculating equivalent static loads [7–10].

The results of theoretical calculations, using experimental data, and the results of statistical processing of data on real events are often presented in the form of graphs, diagrams, and tables. They can be used in practice to assess the consequences of the impact of explosive loads on various objects and people [8, 11, 12].

Explosions of gas–vapor-air mixtures (GVAM) form a special class of volumetric explosions [11, 13–15]. Explosions of GVAM can take place both in closed spaces (in gas tanks, tanks, tanks for storage and transportation of explosive and fire—hazardous substances; as a result of leaks of combustible gases in buildings, mines, etc.), and in open spaces (as a result of the destruction of gas pipelines, the spill of liquefied combustible gas, etc.).

The fire of the GVAM cloud occurs, when there is a source of fire. In this case, the transition of the subsonic deflagration mode with an accelerating flame to a supersonic detonation mode is possible [16]. The transition to the detonation mode is facilitated by various obstacles in the path of flame propagation that cause turbulence (buildings, terrain irregularities, etc.).

Fragments are formed during the explosion of ammunition, and during the emergency destruction of the shells of vessels, boilers, and containers, aircraft are under high internal pressure.

The fragmentation field refers to the area of space in which fragments fly from the explosion site to the fall to the surface of the earth. When there are certain objects (obstacles) in the fragmentation field, it is possible that fragments will collide with these objects.

The damaging effect of fragments depends on their ability to penetrate or destroy an obstacle and, therefore, is associated with the determination of such parameters as the mass and speed of fragments (kinetic energy), their shape (or cross-sectional area), and the physical properties of the material of fragments and obstacles. The formula for determining the change in the velocity of fragments with distance is given in [17]. In [165], formulas are given for calculating the depth of penetration of fragments into obstacles, depending on the mass, speed and shape of the fragments, and the properties of the obstacle material. In [18], a formula is derived for determining the number of fragments during the destruction of a cylindrical shell, as well as formulas for calculating the average mass of fragments and their cross-sectional area.

The damaging effect of fragments on a person, with a 50% probability of causing severe injuries, can be estimated by the maximum impact velocity V_{50} (m/s), according to the empirical dependence, given in [8].

Accidents, related to explosions, are often accompanied by fires. The causes of fires are usually the same as those of explosions. In this case, an explosion can be the cause or consequence of a fire, and vice versa, a fire can be the cause or consequence of an explosion [7].

A fire is an uncontrolled process, accompanied by the destruction of material values and creating a danger to human life [19].

A fire is a complex physico-chemical process that includes, in addition to chemical reactions of combustion, the phenomena of mass and heat exchange (the release and distribution of combustion products, gas exchange, and thermal radiation) and develops in time and space. Burning is a complex physical and chemical process. The definition phenomenon in a fire is the process of burning substances and materials. Only the elimination of burning can lead to the termination of mass and heat exchange (they are called general fire phenomena), which are characteristic of any fire, regardless of its size and place of occurrence. In case of a fire, the burning process is not controlled by a person for a sufficiently long period of time, which can lead to significant material losses [2, 20, 21].

General fire phenomena can lead to particular phenomena, such as explosions, deformations, and collapse of technological installations and building structures, boiling or release of petroleum products from tanks, etc. [21].

The main dangerous factors of fire damage are (NS 12.1.004–85, according to 11,141): elevated temperature and thermal radiation, open fire and sparks; smoke and toxic combustion products; low oxygen concentration; falling parts of collapsing structures and structures; the possibility of explosion of explosive objects, that have fallen into the fire zone.

Fires and explosions cause significant material damage, often cause serious injuries and loss of life.

In Russia, there is an annual increase in fire damage, and the number of people, who die in fires, annually exceeds 12 thousand. The greatest damage from fires and explosions is noted in the energy sector, as well as at oil and gas production and oil refining facilities.

Some objects of civil aviation and the Armed Forces of the Russian Federation pose a certain fire hazard. There are a large number of objects in their infrastructure, in case of accidents and disasters, processes and phenomena that are dangerous for humans and the environment occur, and factors of techno genic and ecological risks are formed.

First of all, such facilities include warehouses of aviation fuel and rocket fuel components, arsenals, and warehouses, where ammunition and explosives are stored. These objects have certain features, which, for example, at stationary airfield warehouses of fuel and lubricants are characterized by the following factors [22]: a significant and uneven consumption of aviation fuel, which significantly depends on the type of aircraft, the tasks, being solved, and meteorological conditions; the necessity of using high-purity fuel in the interests of flight safety; limited time to prepare aircraft for repeat departure; the use of a wide range of oils, lubricants, and special liquids and, as a rule, in large quantities.

Warehouses of fuel and other flammable substances, no matter, what department they belong to, pose a potential danger to the population and territories.

The danger is compounded by the fact that fires in warehouses, as well as refueling points, are often accompanied by explosions. In case of fires in high-temperature zones, along with burning, there is an intense evaporation of hydrocarbon fuels with the formation of vapor-air (steam-gas) clouds, usually called fuel–air mixture (FAM), rapid combustion of which is often accompanied by a detonation explosion. Explosions occur mainly in closed volumes, for example, in tanks at sufficiently high pressures. It should be noted that when oil products are burned in the tank, not only their explosions occur but also the boiling and release of oil products, accompanied by a rapid burning of the foamed mass occur.

The danger of this group of objects lies primarily in the possibility of fires, which is why they are called fire-hazardous.

Accidents at the objects under consideration can be caused by several reasons. The most likely of them are the destruction of tanks and storage facilities with petroleum products and other flammable substances, pipelines, and structural units that ensure the transportation of the latter. For aircraft, this may be caused by aging of materials and equipment, as well as violation of the rules of their maintenance [23–26].

This reason is of particular concern, given that by now in Russia, potentially dangerous facilities and production facilities are characterized by a significant reduction of the project resource. Significant equipment wear is observed everywhere.

It is also impossible to exclude explosions of storage facilities, warehouses, and arsenals as a result of terrorist acts.

In some cases, fires may cause boiling and release, for example, of petroleum products from tanks, and under certain conditions, explosions may occur.

In this case, the explosion is a chemical explosion, since, unlike the so-called physical explosion, it is accompanied by chemical transformations with the release of heat and burning products.

The cause of boiling and release of petroleum products during fires in fuel warehouses is, as a rule, the presence of water in these products. In this case, there is a rapid burning of the foamed mass, a sharp increase in temperature (up to 1500 °C) and the size of the flame, the release of petroleum products from the tanks. It is noted that thousands of tons of petroleum products can be thrown out at a distance of eight or more tank diameters. In this case, the burning area can be equal to several thousand square meters.

When considering the damaging factors of accidents at fire-hazardous facilities, it is necessary to distinguish two main options [2]:

1. A fire in the storage of petroleum products and flammable liquids without the release or with the release of products from the containers.
2. A fire with an explosion of the fuel-air mixture.

Fires without explosions

In such fires, three zones can be distinguished: burning, thermal impact, and smoke.

In the burning zone, the processes of thermal decomposition and evaporation of, for example, petroleum products occur in the volume of the diffusion flame torch. The boundary of the burning zone is the surface of the burning product and a thin luminous surface layer of the flame, where the oxidation reaction occurs. Intensity of burning is determined not by the rate of the oxidation reaction itself, but by the rate of oxygen supply from the surrounding space to the burning zone.

The zone of thermal interaction is adjacent to the boundary of the burning zone. In this part of the space, heat transfer processes occur, which cause the formation of one of the most important damaging factors in a fire—the irradiation of people and environmental objects with thermal radiation.

Most of the heat is transferred by convection. For example, when gasoline is burned in a tank, the convective heat transfer decreases by 57–62% [27].

Heat transfer by radiation is most typical for outdoor fires. Powerful heat radiation occurs, when burning of flammable liquids in tanks with the formation of an external flame. In this case, from 30 to 40% of the heat can be transmitted over considerable distances.

In internal fires, heat transfer occurs mainly by thermal conductivity. In case of fires of flammable liquids in tanks, heat is transferred in this way to the lower layers of these liquids. At the same time, conditions are created for their boiling and release.

The zone of smoke in case of fires of petroleum products and other types of liquid fuel is adjacent to the burning zone. The boundaries of the smoke zone are considered to be isolines with a concentration of the aerodisperse phase of smoke of 10 kg/m^3, visibility of objects of 6–12 m, and an oxygen concentration of at least 16% [27].

The process of fire development at the objects under consideration can be characterized by a number of physical and geometric parameters that must be taken into account, when assessing its danger to people and the environment.

The characteristics and parameters of fires include the type of fire (in a closed or open volume); the fire load, i.e. the amount of thermal energy, that can be released during the burning of petroleum products or other fuels, contained in an disaster object; the intensity of heat release, i.e. the amount of thermal energy, released per unit of time and depending on the amount of incoming air; the mass rate of product burnout (determined by the intensity of evaporation in the burning zone); burning area; fire area; fire front; linear rate of burning propagation; the period of fire development.

Methods for determining the quantitative values of the above parameters are covered in sufficient detail in the special literature [28–30].

The damaging factors include irradiation of people and environmental objects with high-intensity thermal radiation from the burning zone; impact on people and environmental objects by a high-temperature field, formed in the zones of propagation and absorption of thermal radiation by the environment, convective movement of hot burning products, heat transfer by thermal conductivity; air pollution with toxic burning products and depletion of oxygen to levels below the threshold in the zones of thermal interaction and smoke.

There are formulas, obtained, taking into account some assumptions for the average conditions of burning of petroleum products and the propagation of thermal radiation from the burning zone, and recommended for practical use in predicting the possible consequences of fires [31]:

$$\begin{aligned} I_0 &= 0,8 \cdot I_{st} \cdot e^{-0,33\mathrm{R}}, \\ R &= 33 \cdot \ln\left(0,8 \frac{I_{st}}{I_p}\right), \end{aligned} \tag{5.1}$$

where $\mathrm{I_{st}}$—the intensity of thermal radiation from the surface of the torch from burning spills, kVt/m^2, $\mathrm{I_p}$—permissible radiation intensity, kVT/m^2.

Using the formula (5.1), it is possible to determine the distance, at which the radiation intensity will be equal to the permissible value.

The value of the heat flow from the burning zone, required for calculations, can be selected from Table 5.1 [31].

With a known value of the radiation intensity at a certain distance from the burning zone, it is possible to assess the damage, caused to human health.

The index of the dose of thermal radiation depends on the intensity and time of radiation. For the considered type of fire (without explosion), the value of the dose index i_p is recommended [3] to be determined by the formula:

Table 5.1 The intensity of thermal radiation on the surface of the torch from burning spills

Combustible substance	Heat flow, кVT/m^2
Gasoline	130
Diesel fuel	130
Kerosene	90
Oil	80
Fuel oil	60
Methanol	35
Hexane	165

$$i_p = 60 \cdot I_0^{\frac{4}{3}} \tag{5.2}$$

At certain thermal impulses, burns of exposed and protected areas of the skin occur. There are usually four degrees of burns [7, 13].

Under the influence of intense thermal radiation, burning and ignition of combustible materials occurs.

Fires with an explosion of a fuel–air mixture

In most cases, two-phase diffusive burning occurs during fires, in which no explosions occur in open volumes. However, in the case of foaming and release of petroleum products during fires in tanks and other storage facilities, as well as during emergency opening of storage facilities, heated during a fire, release and intensive evaporation of hydrocarbon fuels into a closed space, fuel–air mixtures are formed, in which conditions for homogeneous exothermic combustion reactions can be created.

In real conditions, as a rule, there is turbulence of the movement of gas-air masses, curvature and increase of the flame front. At the same time, the speed of its propagation increases significantly. When the flame propagation speed reaches tens and hundreds of meters per second, explosive or deflagration burning occurs. Shock waves with a maximum pressure of 20–100 kPa are generated. During explosive burning, burning products can be heated to a temperature equal to 1500–3000 °C, and the pressure in closed systems can increase to 0.6–0.9 MPa. Burning reaction duration before the formation of the deflagration (explosive combustion) mode is approximately: for vapors of hydrocarbon fuels 0.2–0.3 s, for gases −0.1 s [3].

Under certain conditions, deflagration burning transforms into a detonation process, in which the flame propagation velocity exceeds the sound propagation velocity and reaches 1000–5000 m/s [3]. In this case, a shock wave occurs. In the front of this wave, the density, pressure and temperature of the fuel–air mixture sharply increase. At a certain moment, when these parameters of the mixture increase, a detonation explosion occurs.

The value of the total energy potential can be used to determine the mass m (kg) of a vapor–gas cloud [32]:

$$\mathrm{M} = \mathrm{E}/4,6 \cdot 10^4 \tag{5.3}$$

The main damaging factors, that occur during deflagration (explosive) burning and detonation explosion of the fuel–air mixture are.

- air shock wave;
- thermal radiation from the zone of explosive burning (zone of detonation explosion);
- the scattering of fragments (fragments of aircrafts, structures), if the explosion occurs in a tank or other closed volume.

The shock wave is characterized mainly by the magnitude of the excess pressure in its front, the nature of the amplitude, the duration of the positive and negative phases.

When predicting the impact of the damaging factors of the considered explosive phenomena, as a rule, a priori developed graphs, tables and methods are used.

It is impossible to reduce the estimation of the scattering of fragments (fragments of collapsing structures) to the solution of a typical problem [33].

As a rule, when a cylindrical tank breaks, two fragments of equal mass are formed.

The damaging factors in the explosions of these substances usually include shock waves and the scattering of fragments, fragments of structures, structures, etc. accompanied by their impact on the environment.

In a ground explosion, as in an air explosion, a shock wave with a vertical front, propagating from the epicenter is primarily considered. In addition, a rather complex wave pattern of seismic waves is taken into account. This is done mainly in the interests of assessing the degree of damage to underground structures and objects.

During underground explosions of condensed explosives and ammunition, an air shock wave, «induced» by the movement of the ground first appears on the surface, and then there is an exit or breakthrough of gases. In case of underground explosions at shallow depths, only a wave from the gas outlet is observed, and in case of explosions at great depths, only a «induced» wave is observed.

The analysis of the literature sources [3, 7, 34], where the characteristics and description of explosions of condensed explosives are given, shows, that the main parameters of an air shock wave, that must be taken into account, when assessing its impact on people and environmental objects, should include.

- excessive pressure in the wave front;
- duration of the compression phase (the air shock wave in its development at

the point of impact passes through two phases: the compression phase, often called positive, and the discharge phase, called negative);

- local impulse of the compression phase;
- high-speed pressure.

The listed parameters are determined by a number of mathematical dependencies.

5.1.2 Distribution of Harmful Substances in the Environment

Harmful substances, released into the environment, are subjected to various reactions: they enter into chemical reactions (both harmless and dangerous compounds can be formed), are exposed by transformation (radionuclides decay along the radioactive chain), migrate in water flows, soil, atmosphere, accumulate in soil, roots, leaves and stems of plants, in bottom sediments, etc. Harmful substances enter the body of farm animals with atmospheric air, water, and feed plants.

Harmful substances enter the human body directly in three ways: inhalation (into the lungs with inhaled air—gaseous, aerosol, adsorbed on dust particles), oral (into the mouth and digestive organs—with drinking water, animal and vegetable food, etc.), skin-resorptive (through the skin surface—when bathing, etc.). A person is exposed to internal radiation, when radionuclides enter the body, external—in the presence of radioactive substances in environmental components.

In the works of Egorov et al. [35–37] synthesizes and studies a model of the spread of a radioactive pollutant in the ecosystem of a cooling reservoir of a nuclear power plant. When constructing the model, the authors proceed from the population level of consideration, believing, that a population is a kind of unit of ecological scaling and the ideas about the transfer of radionuclides from one population to another and the accumulation of radionuclides in each population. This makes possible not only to determine the effect of exposure to radionuclides on each population, but also on the person in contact with this population.

The theory, modeling, practical techniques, related to the problem of groundwater pollution are described in detail in [38].

The paper [39] describes methods for calculating individual radiation doses along food chains, while using various models and methods: a model of local activity, methods of system analysis; the method of accumulation coefficients. Using the methods of system analysis, the following models are constructed, for example, a migration model for agricultural plants; a model of metabolism in the body of farm animals. Using the method of accumulation coefficients, the following chains were studied: vegetable, meat and milk chains in the air path of contamination, vegetable, meat and milk chains in the root path of contamination; meat and milk chains in the intake of radionuclides at the watering of farm animals.

From the point of view of emergency management, the processes of spreading harmful substances in the surface layer of the atmosphere are of particular interest. This is due to the fact that, firstly, harmful substances in the air have a direct damaging effect on the human body, primarily inhalation; secondly, emergency emissions are usually very short-term (minutes, hours, less often days), and thirdly, the spread of harmful substances in the atmosphere depends on meteorological conditions, many parameters of which (for example, wind speed and direction) are random. Atmospheric diffusion models are used to predict the spread of harmful substances in the atmospheric air.

Mathematical modeling of atmospheric diffusion develops in two main directions: on the basis of solving differential equations of the theory of turbulent diffusion and on the basis of statistical theory, the final result of which is the Gaussian distribution of the impurity in the release cloud. There are also models, that use approaches from both directions.

The first theory of the diffusion of impurities in atmospheric air was created by G. Taylor (1915) and V. Schmidt (1917) [40]. The equation of turbulent diffusion, proposed by them, actually expresses the law of conservation of mass and is based on the assumption, that the processes of molecular and turbulent diffusion are similar, i.e. the proportionality of the impurity flow to the gradient of its concentration in the air:

$$\frac{\partial c}{\partial t} + u \cdot \frac{\partial c}{\partial x} = \frac{\partial}{\partial x}\left(K_x \cdot \frac{\partial c}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \cdot \frac{\partial c}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \cdot \frac{\partial c}{\partial z}\right), \tag{5.4}$$

where c–mass concentration of the impurity; t–time, x, y, z–the system of rectangular coordinates (the x–axis in the direction of wind, the z–axis is vertical); u–the speed of wind; K_x, K_y, Kz–the coefficients of turbulent diffusion along the x, y, and z axes, respectively.

The solution, obtained by O. Roberts in 1923 y. for a stationary point source with coordinates (0, 0, h) at constant coefficients of turbulent diffusion and constant wind speed, showed, that the axial concentration of the impurity varies depending on the distance, according to the law $c \sim x^{-1}$. However, the first experimental studies revealed serious discrepancies with the decision of O. Roberts. According to these studies, the concentration changed, according to the law $c \sim x^{-1,8'}$. The reason for such discrepancies is the qualitative difference between turbulent diffusion and molecular diffusion. In particular, the coefficients of turbulent diffusion are not constant values, but depend on the size of the impurity cloud, since at each moment of time the cloud scattering is determined mainly by vortex flows, comparable with the cloud in magnitude.

To obtain equations, that satisfactorily correspond with experimental data, the coefficient of turbulent diffusion was presented in the form of functional dependencies [41, 42].

In 1963 y., the solution of the equation of turbulent diffusion for a point source, located above the earth at an altitude of H, was obtained at the Main Geophysical Observatory, named after A. I. Voeykov (MGO, named after A. I. Voeykov of the State Committee for Hydrometeorology) under the authority Berlyand [43]. For the surface impurity concentration, taking into account the averaging time, this solution has the form

$$C_{x,y,0} = \frac{M}{(1+m) \cdot k_1 \cdot \varphi_0 \cdot x^2 \cdot \sqrt{2 \cdot \pi}} \cdot \exp\left[-\frac{u_1 \cdot n^{1+m}}{k_1 \cdot (1+m)^2 \cdot x} - \frac{y^2}{2 \cdot \varphi_0^2 \cdot x^2}\right], \tag{5.5}$$

where M—power of ejection; $\varkappa_{1,}\ u_{1}$—the values of the turbulent diffusion coefficient and the wind speed at a single altitude; φ_0—dispersion of wind direction; m and n are coefficients, m = n • (2–n).

Another variant of the numerical solution of the turbulent diffusion equation, obtained in MGO, named after A. I. Voeykov, has the following form [44]:

$$G = \left[\frac{0,94 \cdot \varphi \cdot Q}{\lambda^{3/2} \cdot u \cdot D} \cdot \exp\left(-\frac{1,8 \cdot \gamma^2}{\lambda \cdot G^2}\right)\right]^{1/2}, \tag{5.6}$$

where φ—the parameter, determined by the ratio u and G, is proportional to the value $G^{1/2}$; Q—the amount of matter, transferred to the primary (secondary) cloud; λ—a constant, that depends on the degree of vertical stability of the air; u—the speed of wind; D—threshold toxodose of a highly toxic substance (HTS); γ—width of zone.

In 1932 y., O. G. Satton published a paper [45], in which the theory of impurity scattering was presented, based on the statistical theory of turbulence. Using G. Taylor's theorem about the behavior of a particle in an isotropic turbulent flow and assuming, that the distribution of impurity concentration in the cloud obeys the Gauss normal distribution law, Setton obtained the following solution for a stationary point source:

$$\mathrm{C_{x,y,z}} = \frac{\mathrm{M}}{\pi \cdot \mathrm{u} \cdot \mathrm{x}^{2-\mathrm{n}} \cdot \mathrm{k_y} \cdot \mathrm{k_z}} \cdot \exp\left[-\left(\frac{\mathrm{y}^2}{\mathrm{k_y^2} \cdot \mathrm{x}^{2-\mathrm{n}}} + \frac{\mathrm{z}^2}{\mathrm{k_z^2} \cdot \mathrm{x}^{2-\mathrm{n}}}\right)\right], \tag{5.7}$$

where M—power of ejection; u—the speed of wind; $\mathrm{k_y}$, $\mathrm{k_z}$—«virtual diffusion coefficients» in the direction of the coordinate axes; n is a number from 0 to 1, determined by the wind speed profile.

Ideas of O. Setton was developed by many scientists: F. Paskwill [46, 47], P. Andreev [48], L. Khaykina [49] and others.

Most models, using the representation of the Gaussian distribution of impurities in atmospheric air, are based on the equation for a stationary point source [6, 10]:

$$\begin{aligned} C_{x,y,z} = {} & \frac{M}{2 \cdot \pi \cdot \sigma_y \cdot \sigma_z \cdot u} \cdot \exp\left(-\frac{y^2}{2 \cdot \sigma_y^2}\right) \\ & \cdot \left\{\exp\left[-\frac{(z-h)^2}{2 \cdot \sigma_z^2}\right] + \exp\left[-\frac{(z+h)^2}{2 \cdot \sigma_z^2}\right]\right\}, \end{aligned} \tag{5.8}$$

where σ_y and σ_z—horizontal and vertical dispersion of the impurity distribution.

For calculations of σ_y and σ_z, relations $\sigma_\mathrm{y} = \mathrm{A} \cdot \mathrm{x}^\mathrm{a}$; $\sigma_\mathrm{z} = \mathrm{B} \cdot \mathrm{x}$ are used, where A, a, B, b—the coefficients, depending on the conditions of impurity scattering and roughness of the earth's surface (determined experimentally).

The formula (5.8), of course, is not a direct solution to the equation of turbulent diffusion, but it is qualitatively agree with it, i.e. it will give results, close to those, that could be obtained with an exact solution of Eq. (5.4). The formula (5.8) coincides with the Setton formula (5.7) for

$$\sigma = \mathrm{K}/2 \cdot \mathrm{x}^{1\mathrm{n}/2} \tag{5.9}$$

D. L. Laichtman used the ideas of both the statistical theory and the theory of turbulent diffusion, when constructing the atmospheric scattering model. In 1963 y., he proposed to describe horizontal vertical scattering by different equations: horizontal—by the Gauss equation, and vertical—by the semi-empirical equation of turbulent diffusion [41].

It should be noted, that the gas-aerosol mixture, ejected through the pipe, has a certain speed and, due to the temperature difference between the mixture and the surrounding air, some buoyancy. As a result, in the absence of wind, the ejection jet at the outlet of the pipe continues to move vertically upwards for some time. When the directional movement, set by the pipe, stops and the actual process of diffusion scattering begins, a fictitious source of emission appears in real conditions, raised above the pipe to a certain height h.

The problems of air flow around various objects were studied in the works of Elterman [50], Strizhenov [51], Samsonov [52], Titov et al. [40] and others.

In practical calculations, the conditions of impurity scattering (meteorological conditions) are distributed, according to the categories of atmospheric stability, and the classification is carried out on the basis of certain specific atmospheric diffusion formulas, as a result of which the classification systems and calculation formulas are not always compatible.

There are several systems of classification of meteorological conditions: Lampoon [46], Lampoon-Gifford [53], Turner [54] etc.

The classification of weather conditions, according to Packwill, has become the most widespread. This classification use six categories of atmospheric stability: A—extremely unstable; B—moderately unstable; C—slightly (weakly) unstable; D - neutral; E—slightly (weakly) stable; F-moderately stable. Sometimes the seventh category—G is used to characterize strong stability, but this is rarely done due to the lack of sufficient data on the scattering of impurities under these conditions. The stability categories are determined in several ways: by wind speed and insolation (during the day) or cloud cover (at night); by the vertical temperature gradient in the air layer of 10–60 m; by wind speed and the vertical temperature gradient in the layer of 20–120 m, etc.

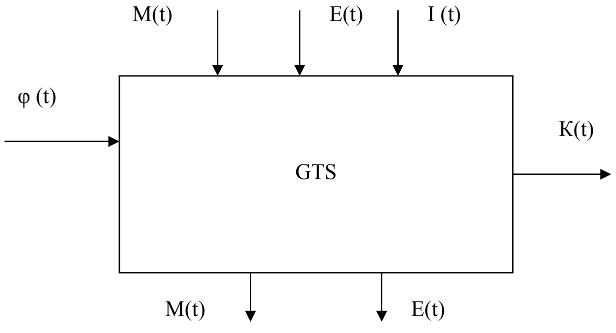
In Russian Federation, a classification system, consisting of three categories of stability: inversion, isothermy and convection, is usually used,. They are determined by the wind speed, time of day, clouds, the presence of snow cover [55, 56].

Specific models of atmospheric diffusion in different countries are the basis for regulatory documents, that are used in the practical activities of relevant institutions and organizations. The normative document «Methods for calculating the spread of radioactive substances in the environment and doses of the population radiation» [57], developed on the basis of the recommendations of the International Atomic Energy Agency is based on approaches, based on both Gaussian models (the Pasqwille-Gifford model) and approaches, based on semi-empirical equations of turbulent diffusion. The method is based on the solution of the turbulent diffusion equation, obtained in MGO, named after A. I. Voeykov (formula 5.6) [58, 59].

5.2 Development of a System for Monitoring the Delayed Anthropogenic Hazard of the Technogenic Sphere

The natural environment, that exchanges matter, energy, and information with the technical system is included in the composition of complex geotechnical complexes [60, 61]. Having adopted the system approach as the basis for the study of the geotechnical system (GTS), we note, that when supplementing it with a mathematical model of the system, we should already talk about system analysis. One of the most difficult tasks of the methods of system analysis consists [62–64] in the organic combination of formal mathematical models with the material, obtained by traditional research methods. In such conditions, conditions have been created at the intersection of sciences for the transformation of system analysis into a fundamental scientific direction, that needs its own concepts. At the same time, the methods of system analysis acquire not only general theoretical, but also a very special applied value.

When studying GTS (Fig. 5.1), it is necessary to note [65] several features, inherent in systems in general and ecological ones in particular:



K(t) – vector of output characteristics; φ (t) – the vector - function of controlling the functioning and development of a technical system at various stages; M(t) , E(t), I (t) - mass, energy and information, consumed in the process of functioning and allocation

Fig. 5.1 The model of the geotechnical system

- common features, since there is nothing in the system, that is missing in its subsystems;
- complexity, due to the variety of elements and connections between them, as well as the degree of intensity of these connections;
- the peculiarity of the position of the system under study as a subsystem within a larger system;
- reliability, which characterizes the probability of course of internal processes and keep its properties over time;
- sustainability to external disturbing influences.

In the system analysis, the main attention is focused on identifying the method of connecting the components, subsystems and elements of the object as a whole, on determining the functions of each element as a whole, on studying the dynamics of the development of the object and the conditions of its functioning, on developing forecasts of the state of the system as a basis for its subsequent optimization. That is, GTS should be considered as dynamic systems, that have a certain set of common structural and functional properties, have a hierarchical organization, developing in time and space, which are based on information interaction between elements within the system and with external systems with an important role of feedback.

Any anthropogenic impact can be considered as external, aimed at changing not only the properties of GTS components, reaction rates, but also at changing its structural parameters [66].

The development of the theory of rational nature using requires considering a single natural-industrial complex with modified (or changing) natural connections, techno genic geochemical anomalies, which are the result of adaptive activity of the system, in turn, adapting the environment [63, 67, 68].

The study of the regularities of the formation and evolution of GTS in time and space allows us to reveal a complex mechanism of internal connections between techno genic loads, changes in the geochemical background and ecological consequences, that manifest themselves in nature. The latter is especially important, because it allows you to predict the possibility of critical situations in nature and equips the researcher with a tool for regulating of techno genic loads already at the design stage.

Any enterprise, including transport, involves raw materials and natural resources in the sphere of production and directs waste from production processes to the environment. Natural and techno genic substances and energies contribute to the redistribution of waste due to the processes of migration, transformation and accumulation.

We consider the environment, affected by technological waste, on the example of processes, used at CA enterprises, and formed a single geotechnical system with it (CA enterprise) [69, 70].

GTS have a clearly defined hierarchical structure, determined by the size and specifics of the system-forming object—the core. It can be formed by a free-standing boiler house, an industrial (transport) enterprise, an industrial (transport) node, and, finally, a set of interconnected nodes, forming a single territorial-industrial complex (TIC).

Zones of increased degradation of the natural environment are often observed inside large GTS, due not only to the intensity of the anthropogenic load from individual powerful sources of industrial waste, but also to the mutual overlap of fields, generated by several relatively low-power sources. This circumstance requires the formulation of special studies of the structure, intensity and composition of material and energy centrifugal flows in the GTS and the techno genic geochemical fields, formed by them.

The nature of the propagation of waste components in the environment is described by the migration function F:

$$\mathrm{F} = \mathrm{d}/\mathrm{d}\tau\,\mathrm{grad}(\mathrm{M},\mathrm{E}) = \mathrm{d}^2(\mathrm{M},\mathrm{E})/\mathrm{dL}\,\mathrm{d}\tau, \tag{5.10}$$

where F—migration function; M, E—mass and energy of the substance of production waste, propagating in the environment; L—the distance, at which the action of the substance manifests itself over time τ.

If the value F characterizes the direct connection of the enterprise with the environment, then the feedback is the reaction of the environment, aimed at reducing the techno genic impact due to natural energy b of the mass of the components of the environment. In the case of equality of the values of direct and negative feedback, the GTS are in a state of dynamic equilibrium, i.e. the environment withstands techno genic load and is relatively resistant to it.

Purposeful optimization of the GTS system requires identifying the strength of the interaction of the enterprise with the environment. A non-stationary material (and energy) field is observed in the zone of influence of the enterprise. The field is characterized by a gradient, associated with the surfaces of level, on which the field strength has a constant value: m(x, y, z) = const. To determine the conditions for normalization and optimization of interaction in GTS, let's consider a simplified model of the field, generated in the system.

The mass M, concentrated at a point with known coordinates (a, b, c), can be considered as a mass, distributed in space with a density of

$$\mathrm{g(x,y,z)} = \mathrm{M}\cdot\delta(\mathrm{x}-\mathrm{a})\cdot\delta(\mathrm{y}-\mathrm{b})\cdot\delta(\mathrm{z}-\mathrm{c}), \tag{5.11}$$

where δ—the Dirac function (the derivative of the Heaviside function).

Consider the problem of the field strength with radius R, created by a point charge q_1. The flow of the vector field E¯ of intensity through the surface F is equal to:

$$\int_F \overline{\mathrm{E}}\mathrm{dF} = \int_F \frac{\mathrm{q_i}}{\mathrm{r}^2}\mathrm{dF} = \frac{\mathrm{q_i}}{\mathrm{r}^2}\int_F dF = \frac{\mathrm{q_i}}{\mathrm{r}^2}4\pi r^2 = 4\pi\mathrm{q_i} \tag{5.12}$$

where E¯-vector of of intensity.

Let the field be created by several charges. By analogy with the Gauss theorem

$$4\pi \mathrm{q}_1 + 4\pi \mathrm{q}_2 + \cdots + 4\pi \mathrm{q}_n = 4\pi \sum_{i=1}^{n} \mathrm{q}_1 = 4\pi \mathrm{q}, \tag{5.13}$$

where $\mathrm{q} = \mathrm{q}_1 + \mathrm{q}_2 + \cdots + \mathrm{q}_\mathrm{n}$.

We will consider production in GTS as a point source of techno genic matter and energy $\sum_{\mathrm{i}=1}^{\mathrm{n}_1} (\mathrm{M}_\mathrm{i}, \mathrm{E}_\mathrm{i})^\mathrm{T}$, which interacts with some (any) point of the environment at a distance L during the time SYMBOL 116 \f "Symbol". At the point under consideration, $\sum_{\mathrm{j}=1}^{\mathrm{n}_1} \left(\mathrm{M}_\mathrm{j}, \mathrm{E}_\mathrm{j}\right)^\mathrm{T}$ natural substances and energy from j components of the natural environment are concentrated.

The momentum J of the interaction force of two sources (production and the point under consideration), by analogy with Coulon law, can be represented by the expression:

$$\mathrm{J} = \frac{4\pi \sum_{\mathrm{i}=1}^{\mathrm{n}_1} (\mathrm{M}_\mathrm{i}, \mathrm{E}_\mathrm{i})^\mathrm{T} \cdot \sum_{\mathrm{j}=1}^{\mathrm{n}_2} \left(\mathrm{M}_\mathrm{j}, \mathrm{E}_\mathrm{j}\right)^\mathrm{n}}{4\pi \mathrm{L}^2}, \tag{5.14}$$

where L—the distance from the production to the point under consideration.

Elementary acts of mass-energy transfer can be expressed by the formulas:

- for the techno genic component:

$$\sum_{\mathrm{i}=1}^{\mathrm{n}_1} (\mathrm{M}_\mathrm{i}, \mathrm{E}_\mathrm{i})^\mathrm{T} = \sum_{\mathrm{i}=1}^{\mathrm{n}_1} (\mathrm{K}^\mathrm{T} \cdot \Delta^\mathrm{T} \cdot \mathrm{F}^\mathrm{T}), \tag{5.15}$$

- for the nature component:

$$\sum_{\mathrm{j}=1}^{\mathrm{n}_2} \left(\mathrm{M}_\mathrm{j}, \mathrm{E}_\mathrm{j}\right)^\mathrm{n} = \sum_{\mathrm{j}=1}^{\mathrm{n}_2} (\mathrm{K}^\mathrm{n} \cdot \Delta^\mathrm{n} \cdot \mathrm{F}^\mathrm{n}). \tag{5.16}$$

where $\mathrm{K}^\mathrm{T}, \mathrm{K}^\mathrm{n}$—mass-energy transfer coefficients for techno genic and natural substances;

$\Delta^\mathrm{T}, \Delta^\mathrm{n}$ driving forces of processes;

$\mathrm{F}^\mathrm{T} = \mathrm{F}^\mathrm{n} - \mathrm{F}$—contact area in the process of mass-energy transfer.

Optimization of the interaction of techno genic and natural components in the case $\tau = \mathrm{const}$ can be achieved as follows:

$$\mathrm{opt}\{\mathrm{J}\} \Rightarrow \frac{\min\left\{\mathrm{K}^\mathrm{T} \cdot \mathrm{K}^\mathrm{n} \cdot \Delta^\mathrm{T} \cdot \Delta^\mathrm{n} \cdot \mathrm{F}^2\right\}}{\max\left\{\mathrm{L}^2\right\}} \tag{5.17}$$

We substitute the expressions (5.15) and (5.16) in (5.14) and analyze the main optimization conditions

$$J = \frac{K^T \cdot K^n \cdot \Delta^T \cdot \Delta^n \cdot F^2}{L^2} \tag{5.18}$$

Minimization of the interaction force pulse in the system (GTS) is achieved, thus, by reducing the mass, concentration, temperature of production waste, as well as by reducing the contact area of technological objects with the environment, possibly more complete isolation of production processes from the active components of the medium (water, air). This determines the strategy and tactics of developing low-waste and resource-saving technologies, implemented in GTS.

The basis for the construction of the enterprise—environment system is a schematic diagram of the circulation of matter and energy in nature. This scheme includes processes, occurring both in the biosphere as a whole and in its constituent parts. The processes of movement of matter and energy between the components of the environment are mutually reversible: each flow corresponds to a certain feedback—the reaction of the environment. Quantitatively, these flows are not equal, which causes migration processes.

We will determine the criterion of ecological friendliness of processes or a general assessment of ecological efficiency (K,%), based on the equation:

$$M_1 + M_2 = M_3 + M_4, \tag{5.19}$$

where M_1 and M_2—the mass of imported and local raw materials, as well as auxiliary materials; M_3—mass of finished products; M_4—mass of waste from technological processes.

We transform the Eq. (5.19):

$$M_4 = M_1 + M_2 - M_3 \tag{5.20}$$

Then

$$K = \frac{M_1 + M_2 - M_3}{M_1 + M_2} = \frac{M_4}{M_1 + M_2} = \frac{M_4}{M_3 + M_4}. \tag{5.21}$$

It follows from the formula (5.21), that the criterion K generally shows the level of production only in the form of a value, opposed to the technological output of products from a unit of raw materials. This criterion does not allow us to make a specific ecological (and economic) assessment of the impact of the technological process on the environment in order to develop specific measures to achieve the condition $K \rightarrow 0$, i.e. to ecologically friendly production.

Continuing the transformation of Eq. (5.21), we obtain:

$$K \cdot (M_3 + M_4) = M_4; \tag{5.22}$$

$$M_4 \cdot (1 - K) = KM_3 \tag{5.23}$$

A quantitative assessment of the ecological safety of various processes, taking into account the composition and local amount of waste in relation to the manufactured products, can be presented as:

$$K = \sum_{i=1}^{n} q_{li} \frac{C_{li}}{MPC_{li}} + \sum_{i=1}^{n} q_{si} \frac{C_{si}}{MPC_{si}} + \sum_{i=1}^{n} q_{gi} \frac{C_{gi}}{MPC_{gi}} \tag{5.24}$$

where q_{li}, q_{gi}, q_{si}—local masses of the ith toxic component in liquid, gaseous and solid waste;

C $_{li}$, C_{si}, C_{gi}—concentration ith component in liquid, gaseous and solid waste, mg/m^3;

MPC_{li} and MPC $_{gi}$—maximum permissible concentrations i-th component in the water of fishing reservoirs and in the air of populated places, mg/ m^3.

To assess the toxicity of solid waste, it is proposed to use MPC_l, since during the storage of these wastes, they are dissolved in precipitation, sewage water and groundwater.

Local mass of ith component in the liquid waste of a single source is determined as follows:

$$q_{li} = 2,4 \cdot 10^{-5} \frac{C_{li} \cdot V_t}{Q_a}, \tag{5.25}$$

where V—volume of liquid waste per unit of time, m^3/h; t—number of working days per year; Qa—the actual volume of commercial products, t / year.

The local mass of the i-th component in gaseous waste is equal to

$$q_{gi} = \frac{10^{-6} \cdot C_{gi} \cdot V_g}{Q_a}, \tag{5.26}$$

where V_g—volume of gaseous emissions from a single source, m^3/h.

The local mass of the ith component, emitted with gaseous waste by all single sources is determined by summing q_{gi}, taking into account the working time:

$$\sum_{i=1}^{n} q_{gi} = 2 \cdot 10^{-2} \frac{\sum_{i=1}^{n} q_{gi} \cdot t}{Q_a}, \tag{5.27}$$

The average concentration of the ith component in the gaseous waste is calculated by the equation

$$C_{\mathrm{gi}} = \frac{\sum C_i V_g}{\sum V_{\mathrm{t}}}, \tag{5.28}$$

where $\sum V_t$—total volume of emissions, m^3/h.

The local mass of the ith component in solid waste is determined by the formula

$$q_{\mathrm{si}} = \frac{V_{\mathrm{s}} C_{\mathrm{si}}}{\mathrm{Q_a} \cdot 100}, \tag{5.29}$$

where V_s—volume of solid waste, t/year.

The results of the analysis of the ecological efficiency criterion showed, that K has ecological significance, since its value depends on the amount and toxicity of waste, that determines the impact of the technological process on the environment, and therefore, it can be used to compare traditional technological processes with each other and with promising processes.

To calculate the criterion, the following data are required: the volume of manufactured products; the volume of liquid waste; the concentrations of toxic components in liquid waste; the volume of gaseous emissions; the average concentrations of components in gaseous emissions; the mass of solid waste; the chemical composition of solid waste.

Further development of the described approach to the assessment of ecological safety of various processes is possible after finding a way to compare production waste of any aggregate state with each other, regardless of which natural sphere they are sent to. It is possible to develop such a method by solving the following tasks:

- definition of clear relationships between the enterprise and the environment;
- measuring the results of their interaction;
- economic assessment of ecological damage to the environment.

5.3 Improving the Decision-Making Function, Based on Monitoring Data to Ensure the Sustainability of the System for Ecology Safety

Currently, there are quite a large number of security definitions (see earlier). It is known, that safety is understood as a state of a particular system, in which there are no dangers, the saving and reliability of this state is ensured. Thus, this term is interpreted in the dictionary of V. I. Dal and in the academic Dictionary of the Russian language. There is also such a definition of security—«the absence of threats to acquired values».

In real life, there have always been, there are and will always be dangers of a very different nature, and therefore the risk of occurrence and impact on humans and the environment of various kinds of negative phenomena and processes, including accidents and disasters.

Safety and risk management of organizational and technical systems (which include air companies) should be organized, on the one hand, from the point of view of ensuring the protection of the population, territories and environmental objects, i.e. objects of security, on the other, from the point of view of ensuring such functioning, in which the probability of accidents and disasters does not exceed acceptable values, and the mathematical expectation of damage is minimal.

When it comes to the state of protection of people and other objects of security, the organizational and technical system, that is a source of danger, in our opinion, should be included in the complex, that unites all the objects of the socio-economic system, that occupies a higher hierarchical position. With this approach, it is possible to take into account the contribution, made to ensuring safety due to the external links of the considered dangerous object with other subsystems and other structures of the socio-economic system. These external relations can be expressed in the form of bodies and structures, created within the socio-economic system, that ensure the protection of the population and territories, funds of material and financial support for the elimination of the consequences of accidents and disasters and the restoration of the functioning of objects in the event of emergency situations, insurance funds, etc.

For each object, its contribution to the integral level of risk for the population, territories and the environment is determined. When evaluating each contribution, the features of hazards and threats, inherent in specific objects, are taken into account, as well as methods for determining their quantitative measure.

Therefore, the issues of safety and risk management for the population, territories and environmental objects in the event of accidents and disasters at hazardous facilities, that are part of certain socio-economic systems, should be considered at several hierarchical levels. The lowest level here is a techno genically dangerous object (an air company), and then several steps in the management process belong to socio-economic systems of various levels: from local to federal ones. Each of the levels in the management process carries a certain functional load.

An important role in ensuring security belongs to the management structures of socio-economic systems.

The ultimate goal of safety and risk management at all hierarchical levels of socio-economic systems is seen in improving the quality of life of people and the quality of the natural environment as a guarantee for creating conditions, that ensure meeting the needs of today, without exposing to risk the ability of the environment to support life in the future, i.e. without putting in danger the ability of future generations to meet needs.

Achieving this goal can be possible only, if certain principles are observed, which must be followed in management activities to reduce risk and ensure safety. These principles have a meaning of the necessary interrelated conditions, that are imposed on the content of the justifications, when preparing decisions on measures of risk reduction.

The main principles can be attributed to:

- the principle of justification of management activities, carried out at a particular level of socio-economic systems, and optimization of the ratio of benefits and damages from this activity;
- the principle of optimizing of measures for safety and protection, ensuring a full-blooded and active life of people in a state of complete physical, mental and social well-being and the maximum possible value of the average expected the duration of the upcoming life;
- the principle of ensuring the necessary level of safety and risk for any person and for society as a whole, taking into account the entire cumulative spectrum of existing dangers in a given socio-economic system or region;
- the principle of the ecological imperative, which consists in the need to make management decisions to ensure safety within the strict limits of techno genic impact on ecosystems and natural-territorial complexes.

A group of Russian scientists (N. A. Makhutov and others) proposed the following conditions, that should be followed, when managing risk [71]:

- practical activities, in which individual members of society (individuals) are exposed to excessive risk, cannot be justified, even if it is beneficial for society as a whole;
- members of the society voluntarily give consent to the presence in their lives of a certain, not exceeding an excessive level of risk, of one or another activity, the implementation of which is required to meet their material and spiritual needs;
- all possible measures should be taken to protect each member of the society from excessive risk. The costs of these measures (relocation of people, creation of protective barriers, as well as monetary compensation, etc.) should be included in the total amount of expenses for the implementation of this type of economic and other activities and, thus, taken into account, when assessing the usefulness of this activity for society as a whole. It is assumed, that, when choosing specific measures of protection against excessive risk, it is mandatory to take into account the opinion of the individual, who needs such protection.

The concept of excessive risk, which is used in theory of security is directly related to its maximum permissible level for an individual.

Any activity, associated with risk, the values of which lie in the area of excessive risk for the individual, is unacceptable, even if it is beneficial for society as a whole.

Economic and other activities with a level of risk, that lies within its acceptable values, should be constantly monitored by the relevant supervisory authorities.

As it is known, the acceptable level of risk for a particular economic and other activity is determined mainly on the basis of scientifically based socio-economic, moral and psychological considerations and criteria. At the same time, the above-mentioned principles are taken into account, guided by which decisions on risk management are made.

Of all the types of risks, arising from techno genic loads on the environment, usually the main attention is focused on the risk to human health and vital activity. At the same time, individual, collective and social risks are considered.

Individual risk, as a rule, is expressed by the probability of lesions of people, that entail deterioration of health, including various diseases. First of all, we mean fatal diseases, that is, the death of people. Most often, the probability of a fatal injury (death) of one person for a certain period of time, for example, for a year, is determined.

The concept of collective (group) risk was introduced to assess the risk of certain categories of the population, for example, personnel of radiation-hazardous facilities, as well as the general population of a particular region, country, and even the entire Earth.

Social risk, as well as collective risk, is estimated by the number of people, who may be exposed to this or that damage from the impact of risk factors.

The views on the calculation of levels of social risk, showed in the works of other authors [72–74], suffer from ambiguity. Based on the analysis of these views, it is possible to express the following considerations on the content and order of calculations.

When assessing the social risk for a single event N, first of all, it is necessary to calculate the average number of people, exposed to the type of damage under consideration, using the formula:

$$\mathrm{N} = \mathrm{R}_2(\tau)\mathrm{R}_3(\tau)\sum_{i=1}^{k}\mathrm{P}_{0\mathrm{i}}(\tau)\mathrm{n}_\mathrm{i}(\tau) \tag{5.30}$$

where R_2—the probability of forming loads of a certain level; R_3—the probability, that the loads will cause the damage under consideration; P_{qi}—the probability, that a group of people with the same conditions will be in the place, where the negative impact is manifested; τ—estimated time point; n_i—number of people in the group; k—the number of settlement groups.

Summation is performed for all groups of people, characterized by the same conditions on average. The average loads for each load group are taken into account.

Next, the probability of a dangerous event is determined by a logical-probabilistic or other method. The resulting value is interpreted as the probability, that a certain number of people, no less than N, may be affected by damage:

$$\mathrm{R}(\mathrm{n} > \mathrm{N}) = \mathrm{R}_1, \tag{5.31}$$

where $\mathrm{R}(\mathrm{n} > \mathrm{N})$—the numerical value of the social risk in the considered dangerous event (disaster, accident); R_1—the probability of occurring of a dangerous event.

In the case, when determining the level of social risk, it is advisable to take into account a number of events, developing under different scenarios and entailing the type of damage under consideration, calculations should be made, according to the above scheme for each event. Then, after analyzing the obtained results, it is necessary to justify the socially significant damage, which is expressed by the number N. Next, you should rank all dangerous events, select those, for which n > N, sum up the probabilities of their occurrence for these events and thus find:

$$R(n\rangle N) = \sum_{i=1}^{m} R_{1i}, \tag{5.32}$$

where m—the number of events, taken into account, when calculating social risk.

Calculations of the level of social risk can be carried out in another way, if we introduce into consideration a certain random variable q, which includes all the parameters of a stochastic nature, from which the number of people, exposed to damage, depends, including the variability of wind direction and wind speed and other meteorological factors. Under this condition, the values R_2 and R_3 will acquire a slightly different content and value. Taking into account the above comments:

$$R(n > N) = n(\tau)R_1R_2(\tau)R_3(\tau)\int_{N}^{\infty} f(q)dq, \tag{5.33}$$

where f(q)—the density of distribution of a random variable q.

As noted earlier, a quantitative measure of risk can be expressed in terms of the mathematical expectation of damage. In this case, the amount of social risk can be determined by the formula:

$$R_{M0} = R_1^n \cdot Y^m \tag{5.34}$$

where Y—the amount of damage; n and m—indicators, that show the attitude of society to various values of probabilities and damages.

In the case, when all possible scenarios of accidents are taken into account, when assessing the risk, the formula takes the form:

$$R_{M0} = \sum_{i=1}^{k} R_{1i}^{n} \cdot Y_{i}^{m}, \tag{5.35}$$

where R_{1i}—probability of realization of the i-th scenario of the accident development;

Y_i—the amount of damage in the ith scenario of the accident development.

When justifying the level of acceptable risk, it is necessary to base on the reasonability of ensuring the maximum possible security and to strive to ensure, that the negative impact of risk factors is as low as it can be achieved by technical and organizational measures, taking into account economic and social factors.

The limits are the levels of dose and their corresponding risk levels, which should not be exceeded under any circumstances.

In emergency cases, the levels of doses of negative impact and risk are significantly influenced by the stochastic nature of many factors of the accident development, as well as the parameters of the meteorological situation, that determine the laws of the distribution of substances in the environment. The actual values of the risk levels can be estimated only with certain, sometimes quite large, errors. In this regard, along with the risk limit, another value is used, in the case of coincidence with which the calculated value of risk for emergency conditions with a certain guaranteed probability would not exceed the limit. This value is called the conditional limit of risk.

With a known law of distribution of density of probability of a random risk value, depending on the change in the accident factors, the conditional limit of risk can be easily found. However, the specified distribution law is unknown. There is no data on this in the publications. In this regard, along with the risk limit, a certain value of the risk level is set, called the risk goal. The meaning of this value practically coincides with the concept, introduced above—the conditional limit of risk. The determination of the value of the risk goal is provided mainly on the basis of experimental data and intuition by the method of expert assessments.

As already noted, the level of the maximum risk should not be exceeded under any circumstances. Exceeding the risk goal is allowed. At the same time, a risk, exceeding the risk goal, is considered acceptable, if it is as small as it is achievable.

The calculation and establishment of risk limits and goals is usually carried out for certain categories of personnel of hazardous facilities and the population.

Based on the provisions of the general theory of management of complex systems, management of civil security should be considered within the framework of a certain socio-economic system (SES), which unites the population, economic objects, infrastructure, territories, as well as management structures with stable internal connections.

With this in mind, management of civil security is understood as the function of the specified SES, aimed at saving a given level of security of the population, territories, economic facilities and infrastructure under techno genic, ecological and military impacts, as well as ensuring the regulation of the security level of the system and its transfer to a new state with higher safety indicators [75].

The determining factor in SES safety management and the criterion for evaluating its effectiveness is the achievement and maintenance of safety and risk at the necessary, socially and economically acceptable level.

In the process of managing this type of security, two levels and two hierarchically related components should be distinguished.

The first level includes management activities of an analytical, scientific-prognostic and organizational nature. Its result is primarily the definition of strategies of safety and risk management for SES at various levels under external, for example, techno genic impacts, as well as the organization and mechanism of their implementation, taking into account social, economic and other factors.

The second level of the management process concerns organizational and technical systems. The basic elements of the system of management of security at this level are the functional contour and information technology, methods and means of preparing and making managerial decisions, as well as the methodological apparatus of risk analysis and assessment, taking into account social, economic and other aspects.

The essence of management of safety and risk of techno genic impacts is to recognize, identify and resolve problematic situations, related to ensuring safety and risk, especially in the conditions of accidents and disasters at the objects under consideration. On its internal basis, it is a single functionally and organizationally structured process, in which the systematic purposeful activities of state, departmental and functional management bodies and structures, including research, scientific and technical organizations, as well as management bodies of forces and means of monitoring, control and liquidation of techno genic emergency situations are organically linked.

In the process of managing the safety and risk of techno genic impacts, in accordance with its essence and functional meaning, three consecutive stages can be distinguished:

- analysis of safety and risk, which provides for the identification and study of hazard sources, modeling of processes of techno genic impact, assessment of possible damage and risk levels;
- risk assessment, which consists of comparing calculated or actual risk levels with scientifically based, socially conscious, so-called acceptable risk levels;
- development and adoption of regulatory legal acts and management decisions on measures, that ensure the reduction of techno genic hazards, the establishment, maintenance and restoration of an acceptable level of safety and risk for humans and environmental objects.

The management of techno genic safety and risk is associated with the activation of certain social and economic mechanisms, therefore it is based on the theory and practice of managing of socio-economic systems.

When forming a model of process of management of the safety and risk in the event of techno genic impacts, it is necessary to base on the main efforts to ensure the protection and safety of humans and environmental objects, undertaken at various levels. At the same time, it is necessary to observe the principle of continuity of these efforts during the transition from one level to another, as well as the own interests of each of the levels of the management system.

Three strategies of management in emergency situations are usually considered [75–79], the name and meaning of which in relation to the type of management under consideration can be formulated as follows:

- strategy for preventing the causes of techno genic accidents and disasters and ensuring the normal, regulation functioning objects, which are hazardous in techno genic relation;

- a strategy for localizing accidents (disasters) and preventing the formation of a dangerous techno genic situation, when the cause of an accident (disaster) cannot be eliminated for technological, economic, social or other reasons and a chain reaction of events, leading to an accident or disaster;
- a strategy for the maximum possible prevention or mitigation of the effects of techno genic factors on people and the environment and the elimination of the consequences of an accident or disaster in the shortest time.

The first strategy is preventive in nature. The management of security and risk, that follows from this strategy can be called preventive. It is carried out as planned and includes a number of activities.

The other two strategies of management of safety and risk are implemented in the order of rapid response to the occurrence and development of accidents and disasters. In this sense, they can be called strategies of operational management of security and risk.

Operational management of security and risk, regardless of whether it is aimed at the implementation of the second or third strategy, includes:

- identification, assessment and forecasting of the development of an emergency situation, the formation of factors of techno genic impact on humans and the environment;
- organization and implementation of emergency technological control, including monitoring and control of emissions of harmful substances, as well as localization of emergency processes and emissions of these substances;
- development and adoption of management decisions on localization of accidents (disasters), prevention of the formation of dangerous factors of techno genic impact, and in the event of an accident (disaster) — prevention or maximum possible mitigation of the impact of these factors on humans and the environment, as well as elimination of consequences and compensation for caused damage;
- bringing tasks to the special services, forces and means, as well as units of emergency facilities and other structures, involved in the implementation of taken decisions, informing the population and the public about the emergency situation and the measures, taken to ensure safety;
- management and coordination of actions of state and departmental structures at all levels, to localize and prevent the development of accidents and disasters, to minimize the caused damage and eliminate the consequences in accordance with the adopted management decisions and interaction plans.

The set of actions for the formation of strategies, management of their implementation, providing for a reasonable transition to alternative strategies, taking into account the views, formulated in the work of Burdakov et al. [80], can be called strategic management of security and risk.

The management of civil security is a necessary condition for the normal functioning of the socio-economic system at any level: federal, regional, territorial, local and object. The more effective this management is, the higher the system's ability to implement intentions and plans for socio-economic development.

As in many other cases, management of security may involve individual and group decisions. At the same time, the organizational structure of the management system takes into account a clear distribution of tasks and powers for decision-making between persons or groups of persons, representing certain structures of the socio-economic system under consideration.

Within the framework of the structure of the system of management of security, it is advisable to implement the joint use of two principles: unity of command, based on the unity of authority and responsibility, and distributed responsibilities, which ensures coordination and consultation, as well as creates conditions for eliminating inevitable disagreements and even conflicts.

Information about the state of objects of management should show all three elements of the triad «security»: the vital interests of the individual, society, and the state; threats and dangers; measures and actions to ensure security and finally quantify characterize the level of danger (security) of facilities and resource capabilities to save this level or increase security.

The core of information about the state of objects of management should be considered the main parameters of the state of the SES under consideration in terms of civil security: the vital interests of the individual, society, and the state in the natural and techno sphere areas; the threats and dangers currently existing; the measures and actions, taken to ensure security. Together, this information should give an idea about the level of danger (safety), taking into account the measures and actions, taken to ensure it.

A quantitative measure can be the level of risk or the mathematical expectation of damage. The level of risk in this case is a generalized indicator of the degree of danger. In principle, it can be defined both for individual structural elements of the control object and for the object as a whole.

At the same time, the manifestation of danger can be expressed in a variety of ways. For the population, the danger is expressed in the possibility of causing fatal injuries and loss of life, for economic objects—in the possibility of accidents and disasters, for territories—in a significant negative change in environmental objects, deterioration of conditions and reduced opportunities for life support of the population, etc.

In all cases, a quantitative measure of the danger can be determined in the form of the probability of its occurrence or the mathematical expectation of the caused damage.

Information about the state of the external environment includes: transboundary or trans-regional techno genic impacts; unforeseen, unexpected natural hazardous phenomena; climatic impacts; the impact of the destroyed ozone layer on the environment, etc.

Part of the information, related to external threats and hazards, as well as measures and actions to ensure security, is taken into account in the information about the state of objects of management. The parameter shows only the information, that is not amenable to this accounting and is used as a separate information package, when preparing and making decisions. As a quantitative measure of information about the external environment, probable values should also be used: the probability of occurrence of hazards and the mathematical expectation of damage.

In our opinion, a management decision should be made in two stages: the first is the adoption of a conceptual decision, that determines, based on the situation, the goal of management and security levels (risk levels), as well as a strategy of risk management for the main management objects; the second is the adoption of an organizational decision on measures and actions, aimed at implementing the conceptual decision.

The conceptual decision is made on the basis of socio-economic, scientific and technical analysis, the state and main directions of regulation and improving the level of security, assessment of resource capabilities and legislative aspects. For its preparation, not only the relevant management bodies are involved, but also are involved the experts in the main areas of the comprehensive system analysis.

The management decision, taken at the second stage, should also determine the tasks, the composition of the involved forces and means, the mechanism for implementing measures and actions to save the population, territories and economic objects in the new conditions, at the established level of security, or to increase the level of security of certain management objects, as well as the organization of management, interaction, preparation for solving tasks and control of execution.

The development of an organizational solution is based on the management goal, developed in the conceptual solution, established for the objects of management of the risk levels, as well as for the chosen strategy of risk management. For the study of processes of management of security, the nature of the functional dependence of command information from information about the state of control objects and the external environment is important. This functional dependence in general form can be expressed by the following formula:

$$\mathrm{u_c}(\mathrm{t}+\tau) = P\left[\sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{u_{si}}(\mathrm{t}) + \mathrm{u_{ee}}(\mathrm{t})\right], \tag{5.36}$$

where $\mathrm{u_c}$—command information; t—the time point, to which information about the state of control objects and the external environment refers;

τ—the time of processing information, received by the management body, assessing the situation and developing a management decision;

P–a function, that describes the process of processing, evaluating information and developing a management decision;

n—the number of management objects; $\mathrm{u_{si}}$—information about the state of the ith control object; $\mathrm{u_{ee}}$—information about the state of the external environment.

At the stage of making a conceptual decision, the physical meaning and the quantitative measure of command information and information about the state of management objects and the environment are defined as the level of risk.

The specific type of the P function can be clarified only on the basis of a large, fairly representative number of calculations, according to the accepted information processing scheme, assessment of the situation (analysis and risk assessment) and decision-making, construction of graphical dependencies, based on calculated data and their approximation by analytical expressions. In the process of these calculations, various options for resource consumption at the hierarchical level of the system under study are taken into account.

Functional dependencies of the type (5.36) show only the relationship of information flows in the cyclic process of management of civil security. In the practical solution of management tasks, as a rule, it is necessary to determine the necessary expenditure of resources to save at a certain level or increase the level of security of certain objects, as well as to optimize material and other costs, taking into account socio-economic factors.

The volume of resources of any kind and their consumption should be expressed in terms of probabilistic characteristics of risk levels. This is not an easy task, since it is not always possible to determine with sufficient accuracy the correspondence between the consumption of resources and the amount, by which the level of risk is reduced and the degree of security of the control object is increased.

The P function can be estimated, based on the developed scheme of movement and redistribution of toxic substance masses in the geotechnical system (GTS) (Fig. 5.2) [69, 81].

The whole scheme is described by the following equations:

$$\begin{aligned}
\mathrm{m(S)} &= \mathrm{1S + 2S + 3S + 4S - S1 - S2 - S3 - S4} \\
&\quad \mathrm{+GS - SG + LS - SL - SA + AS}, \\
\mathrm{m(G)} &= \mathrm{1G + 2G + 3G + 4G - G1 - G2 - G3 - G4} \\
&\quad \mathrm{+SG - GS + LG - GL + AG - GA}, \\
\mathrm{m(L)} &= \mathrm{1L + 2L + 3L + 4L - L2 + GL - LG} \\
&\quad \mathrm{+SL - LS + AL - LA}, \\
\mathrm{m(A)} &= \mathrm{1A + 2A + 3A + 4A - A1 - A2 - A3 - A4} \\
&\quad \mathrm{+UA - AU + GA - AG + SA - AS + LA - AL}, \\
\mathrm{m(B)} &= \mathrm{1U - U1 + AU - UA},
\end{aligned} \tag{5.37}$$

where m(S), m(G), m(L), m(A), m(U)—the masses of toxic components in subsystems of surface and ground waters, the lithosphere, the lower near-earth layers and the upper layers of the atmosphere;

SG, SL, SA—pollutants, coming from surface reservoirs into ground waters, the lithosphere and the lower layers of the atmosphere;

GS, GL, GA—pollutants, coming from groundwater into surface waters, the lithosphere and the lower layers of the atmosphere;

LS, LG, LA—pollutants, coming from the lithosphere into surface waters, ground waters and the lower layers of the atmosphere;

AS, AG, AL, AU—pollutants, coming from the lower near-Earth layers of the atmosphere into surface waters, ground waters, the lithosphere and the upper layers of the atmosphere.

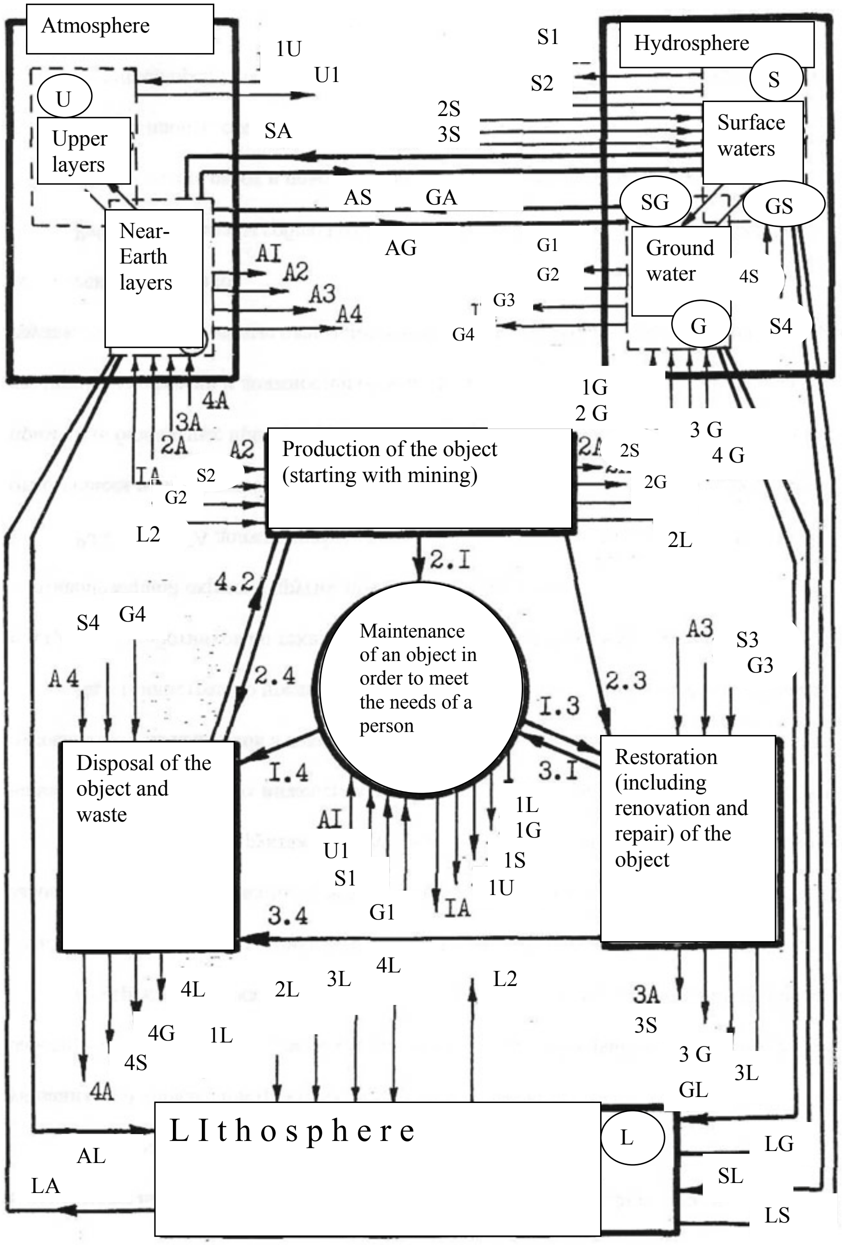


Fig. 5.2 The scheme of movement and redistribution of toxic substance masss in the GTS

UA—pollutants, coming from the upper layers of the atmosphere into the near-Earth layers of the atmosphere.

4.2—objects, coming into production after recycling;

2.1, 2.3, 2.4—objects, that come into maintenance, restoration and disposal after production;

3.1, 3.4—objects, that come into maintenance and waste disposal after restoration;

1.3—objects, received after maintenance, for restoration.

Experimentally, it is possible to determine only a part of the flows, directly related to the production and maintenance unit. This makes it difficult to solve Eq. (5.37).

For each pair of exchange flows between natural spheres, we determine the distribution coefficients:

$$\begin{aligned} &\mathrm{K_{LS} = LS/SL;\ K_{GS} = GS/SG;\ K_{LG} = LG/GL;}\\ &\mathrm{K_{AG} = AG/GA;\ K_{AL} = AL/LA;}\\ &\mathrm{K_{AS} = AS/SA;\ K_{AU} = AU/UA.}\end{aligned} \tag{5.38}$$

Substituting the coefficients into the equation, we obtain the nature of the distribution of pollutants between natural environments over time τ.

$$\begin{aligned} \mathrm{dm(S)/d}\tau &= \mathrm{1S + 2S + 3S + 4S - S1 - S2 - S3 - S4}\\ &\quad \mathrm{+GS(1 - 1/K_{GS}) + LS(1 - 1/K_{LS}) + AS(1 - 1/K_{AS}),}\\ \mathrm{dm(G)/d}\tau &= \mathrm{1G + 2G + 3G + 4G - G1 - G2 - G3 - G4}\\ &\quad \mathrm{+AG(1 - 1/K_{AG}) + LG(1 - 1/K_{LG}) - GS(1 - 1/K_{GS}),}\\ \mathrm{dm(L)/d}\tau &= \mathrm{1L + 2L + 3L + 4L - L2}\\ &\quad \mathrm{+AL(1 - 1/K_{AL}) - LS(1 - 1/K_{LS}) - LG(1 - 1/K_{LG}),}\\ \mathrm{dm(A)/d}\tau &= \mathrm{1A + 2A + 3A + 4A - A1 - A2 - A3 - A4}\\ &\quad \mathrm{-AS(1 - 1/K_{AS}) - AG(1 - 1/K_{AG})}\\ &\quad \mathrm{-AL(1 - 1/K_{AL}) - AU(1 - 1/K_{AU}),}\\ \mathrm{dm(U)/d}\tau &= \mathrm{1U - U1 + AU(1 - 1/K_{AU}).}\end{aligned} \tag{5.39}$$

Consequently, the maximum increase in the mass of waste falls on surface drain, that is, industrial waste, no matter, what environment it is directed to. They will necessarily contribute to the pollution of water bodies. Therefore, it is advisable to carry out all calculations in relation to the hydrosphere, for condition, that all pollutants are reduced to equivalent water pollution.

5.4 Development of Methodological Recommendations for the Creation of the System for Ecology Safety in the Organizational Structures of Civil Aviation

5.4.1 Management Bodies of the System for Ecology Safety in Civil Aviation

To ensure the effective functioning of the ecological safety system in civil aviation, it is necessary to determine the management bodies and the structure of this system.

In Fig. 5.3 the author presents the relations of the levels of the organization of the ecological safety system of the CA.

The management of the ecological safety system has two levels. At the first level, the existing ecological safety system is directly managed in a certain sense as a technological process. At the second level, there should be a body, that works on the continuous improvement of both the system itself and its management. Moreover, the latter should be outside the control of a functioning ecological safety system, since the development of methods for improving the ecological safety system (development strategy), as well as the identification of new ecological hazard factors, cannot be inside the existing management system.

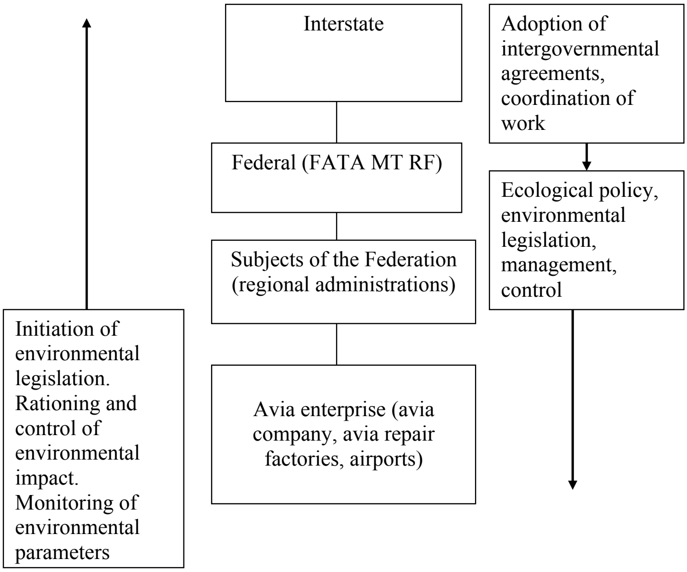


Fig. 5.3 The levels of the system for ecological safety in CA

The ecological safety system should ensure both the prevention of the manifestation of all types of ecological hazard factors, the classification of which is given earlier, and a set of measures to minimize and eliminate the consequences of their manifestation.

Therefore, the top level of management of the ecological safety system should be the National council for ecological safety, which, in turn, consists of permanent commissions, in accordance with the components, allocated in the structure of the environment. At the same time, the National council for ecological safety is created not as a federal agency in the structure of the Government of the Russian Federation, but directly subordinate to the President of the Russian Federation, since the environment belongs to the entire population of the Earth. Therefore, the main state official, elected to this post by the majority of Russian citizens, should bear responsibility for its state.

The National council for ecological safety solves the following four main tasks:

(1) forecasting of ecological hazard factors, arising during the evolution of the components of the environment and human society;
((2) development of mechanisms, technologies, methods for preventing the manifestation of factors of ecological hazards;
(3) development of mechanisms, technologies and methods for eliminating the consequences of the manifestation of factors of ecological hazards;
(4) assessment of the effectiveness of the current ecological safety system and development of recommendations for its improvement.

The following commissions are allocated in the composition of the Council: according to the biosphere, atmosphere, hydrosphere, lithosphere, techno sphere, ergo sphere, information sphere, socio sphere.

The creation of the National council for ecological safety does not require the adoption of additional legislative acts, since its creation can be carried out on the basis of the law of the Russian Federation «About Safety» [82], which defines the status of the Security Council, its functions, as well as the status of Interdepartmental commissions of the Security Council [82].

This approach to the formation of the National council for ecological Security and to the formation of the composition of the commissions is quite well consistent with the Regulations on the scientific council under the Security Council of the Russian Federation (approved by Presidential Decree No. 1317 of September 29, 1999).

Ensuring the ecological safety of individual components of the environment is developed within the framework of separate commissions. The basis of each commission should be made up of permanent members, who are authoritative experts in the field of the commission's profile.

Within the framework of permanent commissions, committees may be established on certain most urgent issues within the competence of the commission.

The purpose of the commissions is to forecast of ecological hazard factors and develop recommendations for improving the elements of the ecological safety system in relation to environmental components, that are within the competence of the relevant commission.

The recommendations, developed by the committees on improving the ecological safety system are approved by the relevant commissions and submitted for approval to the National council for ecological safety.

At the second level of the ecological safety system, on the one hand, there are all control services for compliance with the norms and rules of ecological safety by the subjects of economic and other activities. On the other hand, there are forces and means of practical ensuring the ecologically safe functioning of economic and other subjects.

Control services include all state supervisory services, both federal and federal subjects, as well as supervisory services of local self-government bodies. More correctly, it is necessary to have a single state body, that would coordinate the supervision of compliance with ecological safety standards and rules.

In the structure of the Russian Government, the «Federal service for supervision in the field of ecology and nature management» is being created (this service is being created within the Ministry of natural resources) and a number of other supervisory services, that will carry out, among other things, supervision of compliance with ecological safety standards. Such services, in our opinion, include the Federal service for supervision in the field of health and social development, the Federal service for nuclear supervision, the Federal service for technical regulation and metrology, the Federal service for technological supervision, the Federal service for veterinary and phytosanitary supervision, the Federal service for hydrometeorology, the Federal service for supervision in the field of communications, the Federal customs service, and the Ministry of transport.

Within the framework of FATA MT RF, it is necessary to create a department for compliance with ecological safety standards in air transport.

At the same time, it should be borne in mind, that the effective functioning of the ecological safety system is possible only, if Russia has a specially authorized body in the field of environmental protection, that coordinates all environmental activities in country and at the international level.

Such a body, in our opinion, should be the federal agency for environmental protection, or, using the current structure of the Government of the Russian Federation, a special federal service for supervision in the field of ecology.

The effectiveness of the functioning of the ecological safety system will be determined by the establishment of competent subject-object relations in the system: the subject of ecological control-the object of impact on environment—the subject of ensuring ecological safety (Fig. 5.4).

The subject of ecological control means all specially authorized bodies in the field of ecological control. These include the Federal service for supervision in the field of ecology and nature use, as well as the Federal service for supervision in the field of health and social development, the Federal service for hydrometeorology, the Federal service for nuclear supervision, the Federal service for technical regulation and metrology, the Federal service for technological supervision, the Federal service for veterinary and phytosanitary supervision, the Federal service for supervision in the field of communications, the Federal customs service, and also the Ministry of transport.

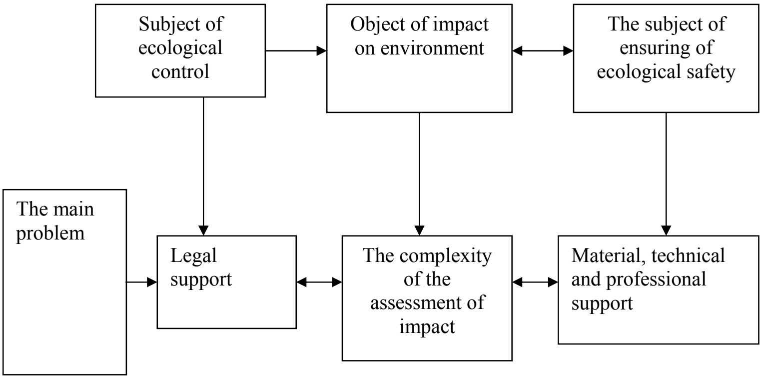


Fig. 5.4 Subject-object relations in the ecological safety system

In addition, it is necessary to create an ecological control service in the Federal Air Transport Agency and in regional departments.

Subject-object relations, that ensure ecological safety can be established, if three main conditions are met:

(1) full and noncontradictory legal support for the activities of ecological control services at all levels of state power and management in the branch;
(2) the complexity of assessing the impact of an object (air company) on the environment, both by type of impact and by assessing the consequences of the impacts on the environment (assessment of the life cycle of impacts);
(3) sufficient material, technical and professional level of ensuring the subjects of ensuring ecological safety.

The completeness and noncontradictory of the legal support for the activities of ecological control bodies lies, on the one hand, in the development of legal acts, covering all components of the environment. On the other hand, there is a clear separation of the objects of control among the subjects of ecological control at various levels of state power and management bodies in the branch. And, on the third hand, there is a need for consistency and noncontradictory of environmental laws, which excludes duplication and discrepancy of legal norms in various legal acts.

Let us conclude, that the existing legislation does not correspond to the structure of the environment in its modern sense. Environmental legislation has historically emerged as necessary to ensure the safety of individual components of the environment. This refers to the natural components of the environment that have been actively used by humans for a long time. These include atmosphere, hydrosphere, soil sphere, lithosphere and biosphere, for which relevant legal acts, government resolutions have been adopted and a set of NS and other regulatory documents has been developed. These laws were developed without realizing, that they are legal acts, that ensure the protection of individual components of the environment, that make up a single whole—the environment. There are inconsistencies, noncontradictory and incompleteness between them.

In relation to the ergo sphere (physical fields), there is still no understanding as something general. Currently, a set of documents, regulating the impact on environment of ionizing sources has been most fully developed. The sanitary norms and rules regulate, mainly for humans, acoustic, electromagnetic effects, and illumination standards. In relation to buildings and structures, standards for vibration exposure have been developed. However, there is currently no legal document, defining the general principles of regulating the impact on environment of physical fields. This is due to a lack of understanding, that the entire set of physical fields forms the ergo sphere, which has a fundamental influence on both the evolution of living things and other components of the environment [80, 83].

Both at the international and state levels, there are international agreements, charters and legislative acts on certain elements of the anthropogenic components of the techno sphere, the socio sphere and the information sphere.

A number of legislative acts have been adopted to regulate individual components of the techno sphere: the Agreement on industrial safety at hazardous production facilities, the laws «About the basics of technical regulation in the Russian Federation», «About industrial safety of hazardous production facilities, «About the safety of hydraulic structures», «About the safe handling of pesticides and agrochemicals», etc.

There are a number of documents, regulating its functioning in the information sphere. These include the Okinawa Charter of the global information society; the Resolution of the interparliamentary Assembly of the member states of the Commonwealth of Independent States «About the organization of the work of the Interparliamentary information and reference service» (St. Petersburg, May 23, 1993); the Doctrine of information security of the Russian Federation (dated 26.02.2000; federal laws «About participation in international information exchange», «About information, informatization and information protection», Patent Law, «About mass media».

Let’s move on to the analysis of the complexity of the assessment of the object of environmental impact. First, we will determine all types of environmental impact of the object under consideration, i.e. the air company. Secondly, we will assess the consequences of the impacts on the environment. On this basis, the permissible environmental impact of the object of assessment is determined, i.e. ecological rationing is carried out. At the same time, we will understand ecological rationing as a much more complex task, than rationing the emissions of pollutants into the atmospheric air, the discharge of pollutants into surface water bodies and the disposal of production and consumption waste. As a rule, a separate enterprise acts as an object of rationing, while they often form entire agglomerations, which are defined as industrial zones, industrial nodes. Therefore, it seems appropriate to develop a methodology for maintaining a register (cadastre) of environmental impact objects, based on the development of principles for their allocation as a whole (for example, a common sanitary protection zone) and assessing the socio-economic consequences of the impacts that they produce.

The next element of subject-object relations in the system of ecological safety are the subjects of ensuring of ecological safety. Taking into account the allocated levels of the organization of the ecological safety system (Fig. 5.3), the ecological services of air enterprises act as these subjects. These subjects must ensure the ecologically safe operation of enterprises. The effectiveness of their work depends on the level of material and technical and professional support, which today is clearly insufficient both in material, technical, and professional relations.

At the level of the subject of the federation and the federal level, FATA MT RF and regional departments act as subjects of ensuring ecological safety. Unfortunately, these agencies only investigate the causes of emergency situations, but they are not engaged in forecasting and warning.

To prevent the entire complex of ecological hazard factors, it is necessary to create a forecast center. This center can be located in the structure of FATA MT RF and coordinate all activities in the field of environmental protection in air transport. Taking into account the identified ecological hazard factors, the optimal subject-object relations are also determined in the system «subject of ecological control—object of impact on environment—subject of ensuring of ecological safety».

Summing up the analysis of the management bodies of the ecological safety system, we note that at the top level there is the National council for ecological Safety, which ensures the identification of ecological hazard factors and the development of mechanisms for their prevention and elimination of the consequences of their manifestation. The task of the national council also includes the establishment of optimal subject-object relations in the system «subject of ecological control—object of impact on environment—subject of ensuring of ecological safety». The task of the national council also includes the establishment of optimal subject-object relations in the system «subject of ecological control-object of impact on environment—subject of ensuring of ecological safety». At the second level, there is a specially authorized body in the field of environmental protection that coordinates all activities in the field of environmental protection in the branch and the effectiveness of established relations in the system «subject of ecological control—object of impact on environment—subject of ensuring of ecological safety».

5.4.2 Structure of the System for Ecology Safety

In the practical implementation of the ecological safety system, it is important to organize it hierarchically, on the one hand, in accordance with the levels of organization of environmental components, on the other hand, in accordance with the levels of organization of state and administrative management. Only in this case, the ecological safety system will work effectively.

From the standpoint of a systematic approach, the ecological safety system should have a multi—level character—from the source of impact on environment to the national one. The system-forming basis for the allocation of levels of the ecological safety system should be the administrative division within one state.

Based on this approach, the authors suggests the following scheme of ecological safety (Fig. 5.5) [84, 85]

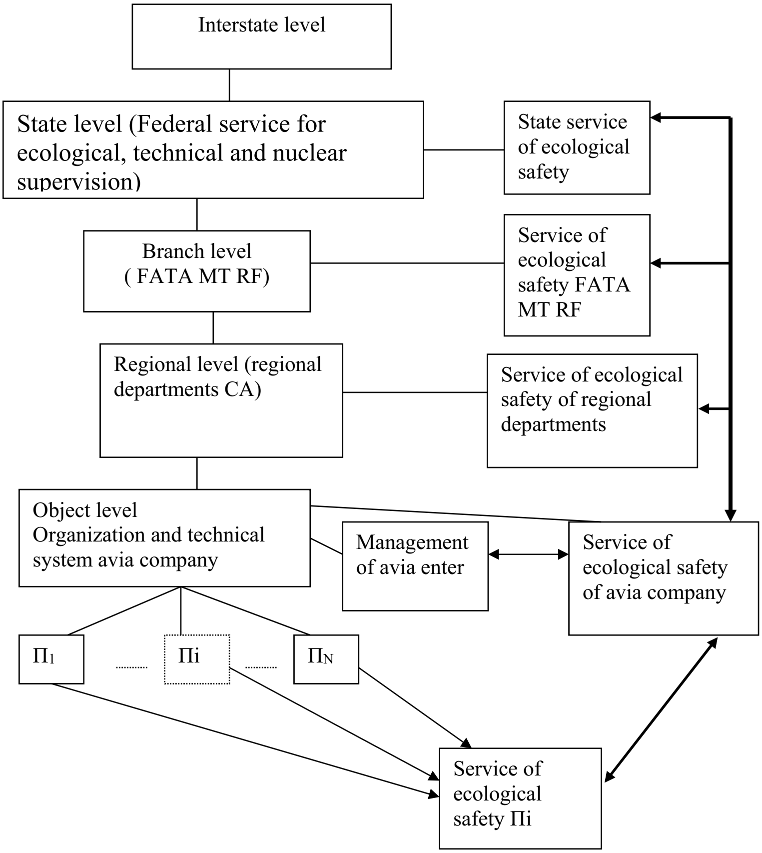


Fig. 5.5 Scheme of ecological safety CA

Management decisions, made at the level of the subjects of the federation (regional administrations, FATA MT RF) and at the national level, as a rule, do not have in mind a specific source of impact on environment. The main thing at these levels of ecological safety is the development of ecological legislation and the development of measures to implement the concept of sustainable development. The level of the subject of the federation and the federal level of the ecological safety system, on the one hand, should initiate the development of conceptual foundations of ecological safety, on the other—the adoption of national programs in the form of ecological policy.

The interstate level ensures the adoption and implementation of regional programs (cross-border transport, preservation of unique landscapes, creation of specially protected natural territories, basin programs for water bodies, etc.). In addition, programs are coordinated to regulate certain types of impacts on environment, inherent only to individual states (for example, nuclear technologies, genetic engineering, space exploration, production and destruction of chemical and biological weapons).

The administrative division requires compliance with a number of conditions, when creating ecological safety systems:

(1) development and implementation of integration programs both within a specific level of the ecological security system, and on the inter-level elements of the ecological security system, due to the discrepancy between the administrative boundaries and the boundaries of the natural components of the environment;
(2) a fundamental change in the provisions on specially authorized bodies in the field of environmental protection in plans of coordinating of clear, mandatory procedures for the exchange of ecological information not only between individual specially authorized territorial state bodies, but also between various departments;
(3) when creating an ecological safety system, industrialized regions and states should bear greater responsibility, since, on the one hand, they have greater financial, scientific, technological and material capabilities for this, on the other hand, they have a greater impact on the environment.

The practical implementation of the ecological safety system at any level of the organization is possible only with the joint efforts of state administration bodies (federal and subjects of federation), the direct participation of specially authorized bodies in the field of environmental protection, as well as with the use of the scientific and technical potential of enterprises, the media and the entire population.

It is possible to distinguish the main tasks of the ecological safety service at the industry level (FATA MT RF):

1. Analysis and generalization of territory monitoring, determination of forecasting the dynamics of relations, assessment of the impact on environment of safety indicators of external factors and factors, associated with specific impacts.
2. Effective management of ecological safety and analysis of generalized data for monitoring the state of the natural environment with the existing technological base, generalization of experience, development of recommendations
3. Development of scientific methods and technologies for solving ecological safety problems. Development of the program and management of modernization with the development of the technological base of the ecological safety service.
4. Assessment of the ecological consequences of aviation accidents.
5. Analysis of the dynamics of the reliability of stored semi-poisonous and toxic waste, development of technical and technological measures.
6. Recommendations for effective management of disposal, recycling, destruction.

At each level of the organization, the ecological safety system functionally consists of three standard modules that logically complement each other and only in their unity make up the system itself. These are integrated ecological assessment of the territory, ecological monitoring and management decisions (ecological policy).

Table 5.2. provides a description of the functions of the elements of the ecological safety system in a general form.

A comprehensive ecological assessment of a territory is the identification and assessment of quantitative and qualitative parameters of a complex of ecological hazard factors that can potentially manifest themselves in the assessed territory.

The manifestation of ecological hazard factors should be recorded and evaluated, if possible, quantitatively. The results of the assessment of the manifestation of ecological hazard factors are issued in the form of a set of maps, databases, and cadastres.

At the same time, it should be borne in mind that both the manifestation of ecological hazard factors and their scale, on the one hand, are determined by the properties of ecological components in the assessed territory, on the other hand, by the types and scale of anthropogenic impact on the environment. Therefore, in the course of a comprehensive ecological assessment of the territory, its resistance to the manifestation of both anthropogenic and natural environmental hazard factors is assessed.

Table 5.2 Characteristics of the functions of the elements of the ecological safety system

Element of the ecological safety system	The function of the element of the ecological safety system
Comprehensive ecological assessment of the territory	Determination and assessment of the complex of ecological hazard factors, that manifest themselves in this territory
	Zoning of the territory, according to the resistance to the manifestation of ecological hazard factors
	Preparation and maintenance of the register of impact on environment
	Preparation and maintenance of the register of nature resources
	Determination of the structure of anthropogenic load
	Preparation and maintenance of the register of «polluted» areas
Ecological monitoring	Rationing of impacts on environment
	Control of sources of impact on environment
	Quality control of environmental component
Management decisions	Formation of ecological policy
	Prevention of the manifestation of anthropogenic factors of ecological danger
	Minimization the consequences of the manifestation of ecological hazard factors
	Development and improvement of environmental legislation and methods of forming an ecological worldview

Since the stability of ecological components depends on the type of produced anthropogenic impacts, it is important to fully assess the existing environmental impact. For this purpose, a register of sources of anthropogenic impact on the environment is being created, which assesses the types and extent of impact on environmental components, as well as the consequences of this impact in space and time (assessment of the life cycle of the produced impact).

It is advisable to classify the anthropogenic impact by different types.

The main types of impact are material (consumption of natural resources and the release of production and consumption waste), physical, chemical, biological and informational.

The register of objects of impact on environment is developed on the basis of the methodology of ecological risk with their division, according to the degree of danger into objects of the federal, subject of the Federation and municipal levels. At the same time, it should be borne in mind that not only individual enterprises are considered as an object of influence but also their agglomerations, united by a common sanitary protection zone.

Preparation and maintenance of the register of natural resources of the territory in the form of databases and a set of maps show the characteristics of the natural resources of the territory and the zoning of the assessed territory, according to the natural properties of environmental components. The assessment of natural resources is made in the form of registers. The approximate list of natural registers is as follows: land, water (surface reservoirs and underground waters), forest, mineral resources, specially protected natural territories, animal and plant worlds. It is used to assess their reserves and quality, as well as to develop master plans for the socio-economic development of territories.

The assessed territory is zoned, both from the point of view of resistance to anthropogenic impact, and from the point of view of its «contamination» as a result of anthropogenic impact. The first serves as a basis for making decisions on the prospective development of the territory, the second—for developing measures to restore the quality of environmental components.

The definition of the structure of the anthropogenic load consists in the characteristic of the existing spatial relations of the objects of the techno sphere, the intensity and scale of the anthropogenic impact on the natural components of the environment. Anthropogenic impact requires regulation. To do this, it is necessary to divide all human activities. The main types of activity are the following: transport, industry, agriculture, extraction of natural resources (forestry, mining, extraction of biological resources), artificial reservoirs and water intakes, housing and communal services, etc.

This make easier the maintenance of databases, the typification of impacts for various technological processes, the development of specific indicators of impact on environment and the normalization of these impacts.

The compilation of the register of polluted territories is necessary for the development of measures for their restoration, which can be reduced to the reduction or complete prohibition of certain types of anthropogenic impact. If necessary, environmental disaster zones are allocated, for which cardinal measures for their conservation and restoration are being developed.

Knowledge of the natural properties of environmental components, the peculiarities of anthropogenic load and its impact on the quality and the state of the environment serve as the basis for the development of the second part of the ecological safety system—ecological monitoring.

Ecological monitoring is understood as a subsystem of regular monitoring, analysis and forecasting of parameters of the state of environmental components and sources of impact on environment.

According to the intended purpose, ecological monitoring is divided into two types:

(1) monitoring of the sources of impact on environment;
(2) monitoring of the state of the environment.

The objects of environmental monitoring are all components of the environment, both natural (atmosphere, hydrosphere, soil, lithosphere, ergo sphere, biosphere (including humans and pathogenicity of the habitat), and anthropogenic (techno sphere, socio sphere and information sphere). The subjects of ecological monitoring are specially authorized bodies in the field of environmental protection. Today, for each component of the environment (the object of monitoring), several state specially authorized bodies act as a subject of monitoring [86, 87].

Currently, environmental authorities are regularly undergoing reformations.

The reorganizations, carried out by the Russian government, lead to the loss of qualified personnel and the arrival of absolutely incompetent people in the field of anthropogenic impact management, starting from the Ministry of natural resources of the Russian Federation to state inspectors on the ground. Most importantly, in the course of the reform, the understanding, that a special agency should be engaged in managing the anthropogenic impact on the environment, has been lost.

This agency should exercise state control and coordinate all environmental protection activities in the country, as well as solve one of the main problems—to develop a mechanism for integrating all interdepartmental information in the field of anthropogenic impact on the environment, since only on this basis can an effective system for managing anthropogenic impact be developed.

It is advisable to conduct ecological monitoring in three stages.

The first stage is the development and regular monitoring of regulatory ecological documentation of enterprises that use natural resources (i.e. enterprises, whose activities are accompanied by an impact on the environment). The purpose of this stage is to establish standards for impact on environment. All types of anthropogenic impact and in relation to all components of the environment are subject to rationing. This task is solved within the framework of creating a register of sources of impact on environment. Information about all objects and types of impacts that affect the environment is concentrated in a computer database, which is constantly updated and corrected.

At the second stage, a system of collecting, processing and systematizing information on the parameters of the state of individual components of the environment, available to various state regulatory bodies (environmental services, foresters, hunting specialists, fish protection, land committees, agrochemical services, water protection services, etc.) is organized.

At the third stage, on the basis of a comprehensive ecological assessment of the territory and systematization of information, obtained at the first two stages of creating an ecological monitoring subsystem, a network and a mode of regular field observations of the parameters of the state of environmental components and sources of environmental impact are justified. This makes it possible to establish operational control over the impact of techno sphere objects on the environment and the compliance of the quality of environmental components with established standards, as well as to determine trends in changing the quality parameters of environmental components.

The final stage of the ecological safety system of the CA is an ecological policy in the form of a subsystem of management decisions that are made by the relevant controlling and managing state and administrative bodies to optimize the anthropogenic load on the environment, improve and restore the habitat of the population.

Management decisions are based on environmental legislation and are the driving force of the ecological safety system of the territory, since they represent problem—solving actions in the «humanity-environment» system.

In any territory, where an ecological safety system is being created, management decisions should be developed for each class of factors that represent an ecological hazard.

Anthropogenic factors of ecological danger are completely dependent on the person and therefore the reduction of the probability of their manifestation depends on a well-developed system of management decisions. The basis of the development of such a system is a retrospective analysis and forecast. The retrospective analysis allows to identify the causes of the manifestation of ecologically hazardous factors and on this basis to develop management decisions that minimize the likelihood of their occurrence.

The forecast consists in the development of predictive models of the likely manifestation of a specific ecological hazard factor, taking into account the properties of environmental components in a given territory. At the same time, the development of predictive models should be based on the methodology for assessing the life cycle of the anthropogenic impact on the environment. This means not only assessing the consequences of a specific anthropogenic impact, but also the consequences that it can cause due to the summation effect, as well as by initiating new types of impacts, often more powerful and dangerous, than the initial impact.

The whole complex of management decisions, implemented at a particular enterprise in the branch, represents the main directions of ecological policy, carried out by specially authorized bodies in the field of environmental protection, legislative and executive authorities. The formation of ecological policy is based on the following main provisions:

- The presence of a strategy for the socio-economic development of the state and specific air companies.
- Taking into account the results of a comprehensive ecological assessment in the development of the anthropogenic infrastructure of the territory.
- Rationing of anthropogenic impact on the environment, taking into account its sustainability.
- Regular monitoring of the parameters of the impact of techno sphere objects on environmental components and the quality parameters of environmental components.
- Creation of a favorable socio-ecological environment for the population.
- Ensuring the sustainability of the biosphere on the basis of saving and restoring the biodiversity of the surrounding animal and plant worlds.
- Formation of an ecological worldview.

Each of these items is implemented in the form of a specific program. The list of programs depends on the natural features of the territory, the formed structure of the anthropogenic load and the level of the ecological safety system. Nevertheless, it is possible to select a list of programs that form the basis of ecological policy. First of all, this is a General plan for the development of the territory, taking into account data on the assessment of the stability of natural components of the environment to anthropogenic load and its structure, as well as taking into account recommendations for optimizing the anthropogenic load on environmental components and the allocation of specially protected natural territories. The development of the territory's infrastructure should be designed, taking into account the existing anthropogenic load on the environment. Comprehensive registers of natural resources and zoning of the territory for resistance to various types of anthropogenic impact are the basis for the approval of land allotments, ecological expertise of projects, development of assessments of impact on environment, ecological insurance and ecological audit.

In order to develop targeted measures to normalize the anthropogenic impact on the environment, a «Program for optimizing of the anthropogenic load on the environment» is being developed.

The basis for the development of measures for the implementation of this program is the data for determining the extent of the impact of anthropogenic load on the environment. The main directions in this program are measures to reduce the anthropogenic impact on the environment, which consists in reducing the volume of emissions of pollutants into the atmospheric air from aircraft, discharges of pollutants into water bodies, reducing the amount of waste generation and measures for their disposal, reducing noise, thermal pollution, etc.

The solution of environmental problems cannot be solved only by administrative and economic methods. In the strategic plan, the most important program is the program for the formation of the ecological worldview of the population.

The importance of this program requires the executive and legislative authorities, departments of education to pay priority attention to the problem of ecological education and upbringing of the population. The most effective is the creation of a system of continuous ecological education and upbringing.

A program should be developed to educate the entire population of Russian Federation, using printed and electronic mass media.

An important role in creating an ecological safety system is played by financial support of budgets of various levels, the use of payments for impact on environment to finance environmental programs and economic encouragement for environmental protection activities of enterprises.

Payments for negative impact on environment should play an important role in this. However, this mechanism works only, if the basic standards of payment for impact on environment will show the real damage, caused to the environment. Payments for impact on environment, especially for excess, will be significant in the indicators of economic activity of enterprises, which will encourage enterprises to implement environmental protection measures.

With limited total costs for ensuring ecological safety, financial policy is of fundamental importance. The relevant decisions are influenced by the forecast of changes in the amount of allocated funds, as well as factors, such as the overall state and rate of increase of harmful waste, the availability of new effective developments of recycling technologies, etc.

The structure of the system for ensuring of ecological safety during the technical service and repair of aviation equipment (TS and R AE) (generally includes (Fig. 5.6):

- subsystem of management of functioning and development;
- a subsystem of technological and technical means of providing of ecological safety and special means of protection;
- subsystems that supply the necessary materials, energy resources, personnel and information.

The required resources are supplied by the State. The insufficient level of relevant revenues directly affects the efficiency of the function of the system.

The effectiveness of the ecological safety system depends on, how well the technical and technological base is developed. With a given financial and resource

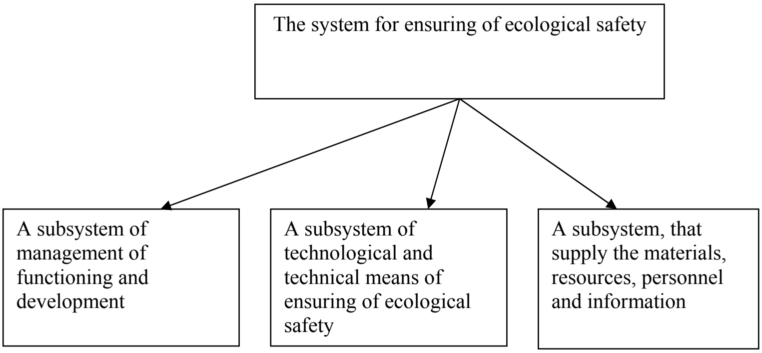


Fig. 5.6 The structure of the system for ensuring of ecological safety

support, the management of the system is reduced to a rational distribution of the allocated funds to maximize the level of ecological safety.

If the level of ecological safety is given, then the task of effective ecological safety management can be written as follows: with a given composition and parameters of the used technologies, the state of ecological safety and the forecast of the dynamics of the latter in the planned period, find the types and parameters of equipment and technology for ensuring ecological safety, such as, to meet the requirements of ecological safety (the level of ecological safety should not be lower than the limit) and that the average total costs for the implementation of such protection technologies are minimal.

It should be emphasized that with multi-level management of ensuring of ecological safety in TS and R AE, the following problems are presented: 1-search for effective ecological safety management at each level of decision-making with existing limitations of funds and resources; 2-complex linking of management decisions at each level to ensure the necessary overall efficiency.

If there is a lack of funds, allocated for solving the problem of ecological safety, the level of total efficiency of ensuring of ecological safety may be lower than the permissible value. Therefore, it is necessary to talk about the redistribution of efforts to reduce the decline in the safety indicator, to keep the most dangerous indicators of ecological safety at the necessary level.

5.4.3 Economic Mechanism of Management of the System for Ecology Safety

The system of the economic mechanism for managing the system of economic security should consist of various economic regulators: compensatory, restrictive, incentive, stimulating.

One of the most important elements in the economic management mechanism is the payment for the use of natural resources, because it is a form of implementation of economic relations between the owner of natural resources and their user.

A certain fee is charged for the release/discharge of pollutants and the use of natural resources in the Russian Federation. In accordance with the current economic mechanism, all enterprises that can potentially negatively affect the environment through emissions and discharges into air and water, waste, etc. are required to pay a fee for this as a necessary condition for obtaining a permit/license.

Payments for environmental pollution are a specific form of compensation for damage, caused by enterprises in the course of production activities.

The creation of market relations in the ecological sphere involves the formation of a market for pollution units, allowing enterprises to buy, sell, trade or redistribute rights to pollution. This is based on the initial distribution of permits for pollution, which are then provided to firms.

Economic damage from environmental pollution is understood as actual and possible losses of the national economy, associated with environmental pollution, including direct and indirect impacts, as well as additional costs for eliminating the negative consequences of pollution. Ecological and economic assessment of damage to the natural environment consists in determining the actual and possible (preventable) material and financial losses and losses from deterioration as a result of anthropogenic impact of qualitative and quantitative parameters of the natural environment as a whole and its individual ecological and resource components (water resources, land resources, plant and animal resources).

There are two methodological approaches to determining the economic damage, caused as a result of pollution: an indirect (aggregated) and a recipient approach (based on a direct account).

There are a number of methods for identifying the impact of pollution on recipients for quantitative assessment of the natural damage from pollution, the use of which is the basis for determining the amount of damage from the impact of pollution on recipients:

- control area;
- analytical dependencies;
- combined one.

The result of comparing the indicators of the control and polluted areas is a change in the state of a particular recipient (for example, a decrease in the productivity of biological resources of this territory):

$$\Delta Y = |Y(C) - Y(P)|, \tag{5.40}$$

where ΔY—indicator of changes of the recipient's state; Y(P)—its condition in a polluted area; Y(K)—its condition in a control area.

Analytical methods for determining damage are usually used in the cases, where there are difficulties in applying the control area method. The method of analytical dependencies is associated with the need to collect and process a large array of source information. The accuracy of the analytical method is directly proportional to the volume of the processed statistical array. Methodically, the analytical determination of damage is based on specific or average estimates of influencing factors and indicators of the recipients state.

The combined method is based on a combination of control area methods and analytical dependencies and is used in cases, when neither of the two methods can be clearly and completely implemented for all components of economic damage.

The economic aspects of the functioning of the economic security system include the assessment of damages that arise as a result of possible deterioration of the quality of the natural environment due to pollution as a result of techno genic impact, caused by imperfection of the used technologies, accidents, etc. In addition to direct and indirect losses from deterioration of environmental quality, additional costs for compensation and elimination of the consequences of this deterioration are usually also included in the damage.

Assessing the amount of damage, caused by environmental degradation, caused by a natural disaster, a techno genic accident or the constant flow of a pollutant into a particular area of the environment is one of the most difficult problems. This is due to the fact that the level of damage (especially its cost form) depends not only on the specifics of the object, the nature of its vital activity, but also on the method of presentation and method of calculating losses, which, in turn, are often regulated by legal relations.

The calculation of damage and losses is carried out on the basis of the current regulatory and methodological documentation, cadastral assessment of natural resources, as well as taxes for calculating the amount of recovery for damage to objects of the animal and plant world.

In the conditions of a market economy, it is recommended to compare any investment projects and choose the most effective one, using the «cost—benefit» analysis and «cost—effectiveness» analysis approaches. Among the main indicators for analyzing the effect, the following are distinguished: net present value, yield index, internal rate of and payback period (T_{pb}).

In practice, it is considered that a project deserves attention, if its yield index (YI) is not less than 1.3 and the internal rate of profitability (IRP) is greater than the loan rate by 8–10 points or at least 15–20%.

For the «cost—effectiveness» analysis, an indicator of the overall cost effectiveness is used. Using these generally accepted indicators, it is possible to assess the overall effectiveness of investment in environmental measures. In this case, the formula for calculating economic results (R_t) changes, they will consist of three components—the amount of reduction in the fee for emissions ($p \cdot Y$, where p is the payment rate; Y_t is the amount of emission reduction) plus earning from the sale of disposed waste ($\Delta P'_t(Y_t)$) and minus the reduction in profit in the main production due to the implementation of the event ($\Delta P''_t(Y_t)$) [88]:

$$R_t = p \cdot Y_t + \Delta P_t'(Y_t) - \Delta P_t'(Y_t). \tag{5.41}$$

In addition, the bank interest for the case of several sources of financing is determined, according to the expression:

$E = aE_a + bE_b$, where a, b—shares of investments, received from different investors; E_a, E_b—the norms (rates) of interest on the invested capital for different investors.

The given general approach to determining the economic efficiency of production investments for ecological measures has two significant disadvantages. Firstly, none of the considered general efficiency criteria gives an answer to the question of what is considered of a condition for sufficient effectiveness of the implementation of ecological measures. Here it is necessary to take into account that, unlike contributions to the main production, ecological investments, as a rule, do not have commercial purposes. And, secondly, in a market economy, unlike a planned one, several market entities that have their own interests and pursue their own goals, can participate in the investment of ecological programs. According to the diversity of interests of the participants of the investment project, several modifications of the investment efficiency criterion can be given.

If we consider the absolute economic efficiency of investments in ecological measures from the position of the state, then among the characteristics we can distinguish the following indicators: net present income (or net discounted income (NDI)), YI and IRP. The option with the maximum values of these indicators will be considered as the most effective.

From the point of view of individual enterprises, it is necessary to take into account possible forms of financial assistance for the implementation of ecological measures from the nature protection authorities (investments, benefits). The types of support that have become widespread in foreign countries, can be considered as financial assistance.

1. Direct and indirect subsidies are investment subsidies that cover part of the costs of repair, reconstruction, new construction of environmental protection equipment, and maintenance costs. There are several types of subsidies: grants as a form of unpaid financial assistance for the implementation of measures to significantly reduce pollution of national or regional significance; «soft» loans as targeted low-interest loans to enterprises for the implementation of environmental protection measures; subsidies for the payment of interest to simplify of the implementation of loans.
2. Provision of an accelerated depreciation mode for environmental protection equipment.
3. Preferential rates for indirect taxes on the sale of ecological equipment or its exemption from tax.
4. Tax benefits for income from environmental protection programs of private enterprises.
5. Exemption of enterprises from payments for environmental pollution for some time in the case of implementation of environmental protection programs.
6. Preferential tariffs for companies for wastewater cleaning at municipal wastewater cleaning plants.

Then the cost formula takes on a slightly different form:

$3_t = \alpha' \bullet C_t + \alpha'' K_t$, where K_t, C_t—capital investments and annual costs per year t; α', a''—the share of investments and expenses for the implementation of environmental measures without subsidies and other financial benefits that the enterprise can count on.

A condition for the rationality of environmental protection activities for an enterprise can be considered its economic break-even. Taking into account the state methods of nature protection management, ecological programs of enterprises, as a rule, do not pursue commercial goals, that is, making a profit, when solving ecological problems, is not an end in itself. At the same time, if the break-even condition is not met, it makes no sense to implement ecological programs.

Break-even will be achieved, if NDI > 0 or YI > 1. Then the criterion of the effectiveness of investment of environmental programs for the enterprise will be calculated according to the formula:

$$E^e = \frac{\sum_{t=0}^{T} R_t \cdot (1+E)^{-t}}{\sum_{t=0}^{T} (\alpha' \cdot C_t + \alpha'' \cdot K_t) \cdot (1+E)^{-t}} \rightarrow \max, \left(E^e \geq 1\right), \tag{5.42}$$

Ecological investments also affect the interests of another possible investor—the nature protection authorities. Based on the goals of the organization of ecological funds, the environmental policy itself, its economic mechanisms, it can be concluded that from the point of view of this investor, the priority direction of financing is activities that bring ecological and social effects. In contrast to the goals of aircraft repair enterprises, for which the economic results of measures are primarily important, the main criterion for the effectiveness of the investment mechanism of ecological policy is to obtain maximum ecological results at minimum economic costs. Therefore, it is necessary to distribute limited financial resources, taking into account the indicators of ecological and economic efficiency of various types of environmental protection measures, carried out at different enterprises of the region.

Therefore, the criterion of economic efficiency of investments of nature protection bodies in environmental programs of enterprises can be written in the following form:

$$\begin{aligned} E_{np}^e &= \frac{\sum_{t=0}^{T} R_t}{\sum_{t=0}^{T} [(1-\alpha') \cdot C_t + (1-\alpha'') \cdot K_t] \cdot (1+E)^{-t}} \\ &= \frac{\sum_{t=0}^{T} \sum_i p_i \cdot Y_{it} \cdot (1+E)^{-t}}{\sum_{t=0}^{T} [(1-\alpha') \cdot C_t + (1-\alpha'') \cdot K_t] \cdot (1+E)^{-t}} \rightarrow \max \end{aligned} \tag{5.43}$$

where i = 1,2, …., n—the number of pollutants, whose emissions have been reduced as a result of the implementation of an ecological measure; (1 -α′), (1–a″)—the share of investment benefits and operating expenses benefits that can be provided by the state to stimulate the environmental activities of the enterprise.

In this formula, the result of ecological investments of nature protection authorities in the form of assistance to enterprises in the amount of (1-a′), (1-a″) will be a reduction in environmental pollution (Y_{it}), and efficiency in cost form is determined by the maximum result per unit of costs.

In order to form a real financial policy in the ecological sphere, in addition to the conditions, specified in the formula (5.43), it is also necessary to take into account the peculiarities of the ecological state of the area, where the enterprise is located. To do this, it is necessary to enter the coefficient of intensity of the ecological situation (κ_i^{ies}) for each ingredient of the release, discharge, waste into the formula (5.43). This coefficient can be defined as the ratio of the actual concentration of the ingredient in the zone of influence of the object to its maximum permissible concentration:

$$k_i^{ies} = \frac{C_i}{MPC_i} \tag{5.44}$$

where C$_i$—the average annual concentration of the ith pollutant; MPC$_i$-the average daily maximum permissible concentration of this substance.

The coefficient shows, how many times the actual concentration of the ith substance differs from the maximum permissible standard.

Accordingly, the final version of the ecological and economic indicator of the effectiveness of state financing of ecological programs of enterprises has the form:

$$E_{np}^{e/e} = \frac{\sum_{t=0}^{T} \sum_{i} k_i^{ies} \cdot p_i \cdot Y_{it} \cdot (1+E)^{-t}}{\sum_{t=0}^{T} ((1-\alpha') \cdot C_t + (1-\alpha'') \cdot K_t) \cdot (1+E)^{-t}} \to \max \tag{5.45}$$

As can be seen from the formula, the greater the coefficient of intensity of the ecological situation in the area of the enterprise's location, the higher the efficiency of reducing its impact on the environment. Therefore, the greater the effect will be achieved at lower financial costs, the more effective the financial mechanism of ecological policy.

The formula (5.45) characterizes the effectiveness of the use of ecological funds for the implementation of various ecological measures at enterprises. To apply it, it is first necessary to determine, according to condition (5.42), the break-even of measures, choose a sufficient form of support from the nature protection authorities and determine the share of investment or maintenance benefits that must be implemented through ecological funds. If they have the appropriate capabilities and funds, then according to the condition (5.45), a list of ecological measures is determined, the investment of which must be carried out first, or the conditions, under which the support from the funds will allow the implementation of the measures, are determined. The process of calculating the effectiveness of the use of public funds to support ecological measures, as well as the effectiveness of ecological policy, is a procedure, using informal operations. The sequence of individual stages of the procedure is shown below.

Nature protection authorities, in relation to activities, that do not need support, can take either a passive position (i.e. this is the business of the enterprise itself), or an active one and monitor the process of their implementation from the point of view of their own goals, stimulating it, if necessary, by providing financial assistance or benefits.

An active position is preferable, since it allows you to actively influence the implementation of ecological programs. When determining preferences from the point of view of the interests of nature protection bodies, as opposed to the priorities of enterprises, it is necessary to enter the coefficient of intensity of the ecological situation (2.44) in the formula (5.42):

$$E^{enp} = \frac{\sum_{t=0}^{T} \left(\sum_i k_i^{ies} \cdot p_i \cdot Y_{it} + \Delta P_t' - \Delta P_t''\right) \cdot (1+E)^{-t}}{\sum_{t=0}^{T} (\alpha' \cdot K_t + \alpha'' \cdot C_t) \cdot (1+E)^{-t}} \to \max \tag{5.46}$$

The ecological and economic efficiency, obtained by this formula, allows the nature protection authorities to rank activities that do not need support by priority from the position of their own interests. For the selection and evaluation of ecological investment projects for support through the republican environmental funds, it is necessary [88]:

I. To analyze the project, taking into account all the indicators and their interrelation, as well as the interests of the participants.

II. Make decisions for investment and support.
An enterprise makes a decision to invest in ecological projects, based on its system of priorities and, above all, on the condition of its economic break-even, and in the case of new construction of an industrial facility—on the compliance of decisions with existing legislative norms. A significant incentive for the implementation of measures can be the possible support from the nature protection authorities, which decide to support ecological projects, based on their system of priorities, as well as on the limited capabilities of ecological funds [89–91].

III Carry out the selection of investment projects.
The prerequisites for selection are

- the company is able to implement the project, if with or without support, it is able to ensure its economic break-even, or if its implementation meets the above priorities of investors;
- the state can provide investors with direct or indirect support in the form of direct investments and a number of benefits, if this corresponds to its interests.

Variants of situations, when selecting projects:

- projects, focused on the implementation of federal ecological priorities, the support of which is possible with the involvement of federal ecological funds;
- projects, designed to implement regional priorities;
- initiative projects outside the framework of priority areas.

Based on the primacy of federal priorities over regional and regional ones over initiative projects, decisions are made on the structure of the distribution of funds [92].

When forming investment programs, the quality criterion is the completeness of achieving the goal by the activities that are included in the program. Previously, projects should be accepted, taking into account the requirements of federal programs, criteria for economic efficiency, the amount of necessary support and existing resources for this, ecological and economic criteria for the effectiveness of the use of support funds, etc.

At the preliminary stage of selection [93, 94]:

- the structure of priority areas is determined, which is understood as a systematic analysis of the problems of their implementation, identification of components and assessment of the possibility of solving them within the available means. Such methods as expert-analytical are used.

– Preliminary implementation programs are formed as a whole, an estimate of the upper limit of possible costs is given, which will serve as a guide, when evaluating projects.

  The final order of project selection is as follows [95, 96]:

  1 Preliminary procedures:

    - making a list of priority areas, based on federal and regional programs;
    - formation of programs for the implementation of priorities.

      The list of ecological measures is compiled, taking into account applications to the nature protection authorities from enterprises for the provision of benefits, which indicate the amount of the necessary benefits, the amount of investment for the implementation of the event, reducing the impact on the environment, including by type of pollution, the duration of the implementation of measures, the service life of the ecological funds of the event, etc. and taking into account possible ecological measures, identified by expert means.

  2 Selection of projects and verification of compliance with priority areas.

  3 Calculation of indicators of economic effect. The criterion of efficiency and sufficiency in the implementation of measures from the point of view of the enterprise is the condition of their economic break-even. Based on this condition and applications for benefits, the required amount of state support for ecological measures is calculated.

  4 The degree of reduction of the permissible level of efficiency, when increasing the priority rank of measures, is determined in each specific case, according to the recommendations of experts. Projects, that implement the priorities of the highest rank, can also be accepted with a negative rate of income. However, in this case, preference is given to a project with maximum efficiency with mandatory support from the highest-ranking ecological funds or appropriate legislative support for the possibility of price increases for the products of enterprises in this industry.

The nature protection authorities determine the total quota of funds, allocated for the provision of benefits, based on the planned amounts of payments and the needs for financing territorial ecological programs, the formation of reserves of the fund, etc. [97].

The declared measures are arranged in descending order of the indicator of the ecological and economic efficiency of the use of the provided funds of the fund.

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Chapter 6
Forecasting the Functioning of the System of Management of Ecology Safety in Civil Aviation on the Basis of Comprehensive Monitoring of Its Condition at the Stages of the Life Cycle of an Aircraft Product

6.1 Development of the Entropy Concept of Formalization of Tasks at the Main Stages of the Life Cycle of an Aircraft Product

Considering the concept of safety, it is impossible not to dwell on some views regarding the nature of accidents of technogenically dangerous objects, in particular, on the energy-entropy concept of accidents, considered in the work of Belov [1].

From its essence, two important provisions follow, within the framework of certain assumptions, that do not contradict the laws of thermodynamics.

1. It comes down to the fact that when carrying out any production activity, related to energy production, energy processing, or energy consumption, the value of such an important thermodynamic parameter of state as entropy decreases in the system. The fact is that at facilities, engaged in this kind of activity, the ordering of energy flows, the concentration of energy of one kind or another in certain structural production nodes is provided for. A certain topography of energy potentials is formed.
2. The state of the system (in our case, a technogenically dangerous object), characterizing by a small amount of entropy from the thermodynamic point of view, is nonequilibrium. At the same time, there is an objective possibility of the system transition to a less ordered state, accompanied by an emergency release of energy.

Entropy is a quantitative measure of the disorder of a particular system.

In the process of establishing an equilibrium state in an isolated system, the disorder of the system monotonically increases, until it reaches the maximum value, corresponding to equilibrium. The maximum value of the entropy of the system indicates a large disorder in it. Real organizational and technical systems are not isolated, but open. The possibility of using thermodynamic functions, in particular entropy, for the analysis of their state can be justified by the following arguments.

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In open systems, ordered subsystems can be formed, which, from a thermodynamic point of view, are dissipative structures, that feed on energy from external systems. At the same time, the total value of entropy in the aggregate of systems tends to a maximum, i.e. the second law of thermodynamics is being implemented [2].

If a stable ordering of a new quality with a low entropy value occurs in a system, then the total increase in the entropy of the aggregate of interacting structures significantly exceeds the above-mentioned decrease in entropy in a separate subsystem [2].

This means, that the creation of an ordered structure, such as any industrial and other technogenic object, is associated with very high costs to ensure the former stability of a higher-order system.

Ordered structures react to external influences with greater sensitivity, than equilibrium thermodynamic systems, and change their properties. The necessary and sufficient conditions for the existence of ordered systems are [2]:

(1) the presence of sources that supply matter and energy with low entropy;
(2) the possibility of getting rid of waste with high entropy.

The most important source with a low entropy value, i.e. high-quality energy, is solar radiation. It ensures the vital activity of the biosphere, the course of various nonequilibrium processes, including photosynthesis and other biochemical reactions.

It should be noted that there is an objectively existing possibility, due to the laws of nature, of their exit from the state of maintained dynamic equilibrium under the influence of external influences or as a result of a significant change in operating parameters. The transition of the system to a more stable state will occur with an emergency release of energy.

Therefore, the nature of the occurrence of accidents at energy-equipped facilities has a certain connection with the behavior of one of the important thermodynamic functions of the state-entropy. This circumstance should be taken into account, when creating and developing the entire system of measures and actions to ensure technogenic safety. Any technical product is a system and, like any system, is a set of objects (assembly units, parts) with a set of connections (connections) between them. During operation and interaction with the environment, the system changes its initial state—it is damaged. The accumulation of damage leads to a malfunction, when it does not meet at least one of the requirements of the regulatory and technical documentation. The accumulation or growth of malfunctions can cause a failure—a malfunction.

The concept of entropy, widely known from thermophysics, has acquired at the present time a much greater depth and corresponds to the rank of the concept of qualimetry of the organization of the system [3].

Synergetics (the theory of self-organizing structures, the doctrine about the self-organization of complex systems) expands the concept of «entropy» from the usual thermophysical quantity that characterizes the thermal state of a body to a conceptual one: entropy is a measure of the internal disorder of a system.

Based on this definition, the second principle of thermodynamics acquires the meaning of a universal generally recognized universal law: for all processes, occurring in a closed system, entropy either increases or remains constant. It increases, if the processes are irreversible. It remains constant, if the processes are reversible.

The entropy of the closed system remains constant, and the entropy of open system increases to the maximum value—the greatest disorder, the lowest degree of organization.

Technical structures actively interact with the environment and, therefore, are open systems, that have integrity properties, since a change in one part of the system causes a change in other parts. The maintenance process takes place in conditions of progressive isolation: changes lead to a gradual transition from integrity to summativeness [4].

The concept of entropy can be considered at all stages of the life cycle of an aircraft product. We will consider it at the stage of aircraft equipment (AE) repair [5, 6].

Malfunctions are detected and eliminated in the conditions of maintenance of the AE and major repairs at specialized repair plants in the process of restoring operability. The terms «repair» and «restoration» are often incorrectly used as synonyms. To restore the AE means to bring its properties, lost during maintenance, into a state, that meets the requirements of the technical conditions for its delivery. The repair of AE is a complex of organizational, technical, and economic measures to prevent or eliminate malfunctions and damages in order to preserve or restore its operability. This formulation combines repair activities, both during the operation of aircraft, and at repair plants.

The maintenance measures are aimed at maintaining the performance of the AE during the established resource. The measures, carried out during major repairs at specialized aircraft repair enterprises, are aimed at restoring all the characteristics of the AE, including resource and reliability. These fundamental differences from the standpoint of the entropy principle are shown in Fig. 6.1.

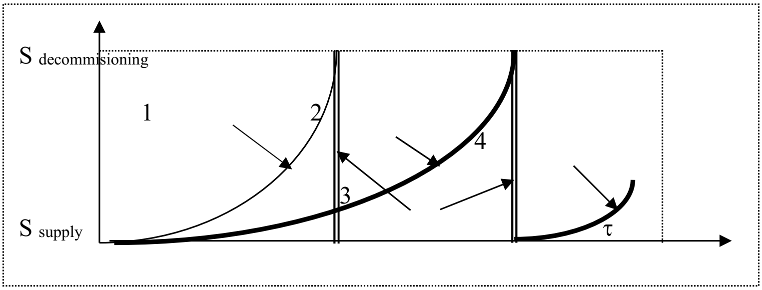


Fig. 6.1 The fundamental difference between measures in maintenance and at specialized aircraft repair enterprises: S supply and S decommissioning are the entropy of the aircraft (the degree of internal disorder, disorganization, degradation of the system; the measure of non-compliance of the system with qualimetric quality indicators; the degree of wear of the system, etc.), respectively, in the state of delivery and decommissioning after reaching a dangerous level; τ-maintenance time; 1-entropy growth in the absence of measures in maintenance; 2-entropy growth during measures in maintenance; 3-decrease of entropy during conducting measures at specialized aircraft repair enterprises; 4-increase of entropy during post-repair maintenance

At first glance, the decrease of the entropy of the AE structure in the process of major repairs contradicts the second principle of thermodynamics. And here (remembering the sentence of the doctor of technical sciences, professor V. P. Frolov, that «Repair is a health care system for machines»), an analogy with living organisms is appropriate [7, 8], which, despite their aging, and therefore an increase of entropy, are in a state of homeostasis, i.e. the ability of the organism to maintain the balance of its internal environment in conditions of a constantly changing environment. Homeostasis is always based on the «norm of reactions»—the range of fluctuations of the organism reactions to external influences without pathological deviations. One of the manifestations of adaptive reactions to the action of damaging environmental factors is a disease, which is known to be treated. In living organisms, during their growth and development, there may be an increase in order, which, it would seem, contradicts the second law of thermodynamics.

The organism is constantly doing work, it is growing, therefore, the total amount of free energy in it should increase, but free energy increases only in isolated systems. Within such a system, in its living part, that is, in an organism, free energy can increase, and entropy, respectively, decrease, but under the indispensable condition of its simultaneous increase in the inanimate part of the system.

The exponential function of entropy growth in Fig. 6.1. is caused by the multiplicativity of systems due to the fact that each maintenance damage can be considered as a discrete-sudden failure with an exponential function of the failure rate. On the other hand, the statistical meaning of entropy is expressed by the Boltzmann formula [9]:

$$\mathrm{S} = \mathrm{k} \ln \omega, \tag{6.1}$$

where k—constant of Boltzmann, ω—the statistical weight of the state, in which the system is located (the number of microscopic states, that implement it); the greater the ω, the greater the probability of the state. In nonequilibrium processes, the system goes to a more probabilistic state. Multiplicativity, as a fundamental property of large systems, consists in the fact that negative processes have the property of multiplication, not addition; destructive processes have a very pronounced tendency to self-flow and self-destruction of systems in the absence of proper controlling and regulating action on the part of the control object; positive trends do not have this ability. Therefore, in the process of «destruction» of the structure, there must come a moment (an inflection point), when the potential function turns into a logarithmic one and, in the limit, the entropy reaches its maximum. In accordance with the Le-Chatelier-Brown principle, a change in the parameters that brings the system out of equilibrium is accompanied by such changes, that tend to eliminate the disturbing changes in the parameters. The increase of the nonequilibrium factor to a certain threshold value leads to a qualitative change in the structure, properties, and behavior of the system [10].

Synergetics states, that nonequilibrium states are more highly organized, since in them the driving force of the process is not a minimum of free energy, as is typical for equilibrium processes, but a minimum of entropy production. From the point of view of synergetics, the goal of «maintenance measures», making curve 1 in Fig. 6.1 a flatter one, is just the minimum of entropy production. The Glensdorff-Prigogine theorem states: the state of any linear open system with time-independent boundary conditions always changes in the direction of decreasing entropy production, until the current equilibrium state is reached, at which entropy production is minimal. Moiseev called it «the principle of minimum energy dissipation».

The transition from curves 1 and 2 to line 3 in Fig. 6.1 corresponds to Klimontovich's S-theorem: at critical phase transitions through threshold values of control parameters, an abrupt decrease of entropy occurs with a decrease in its production. With the growth of the control parameter, the transformed entropy decreases, that is, the process of self-organization takes place.

Consequently, the functioning of complex systems (they mean any system, including structures) is accompanied by the costs of the quality, originally inherent in it. As this quality is consumed to perform the work, part of it becomes incapable to further work, so the system tends to fail and break down. Since entropy is a unit of measurement of randomness (the disorder of the system, the degree of its degradation, loss of quality), so the entropy principle shows: the greater the role of chance, the greater the entropy; as the structures wear out, fall into decay and deteriorate, the entropy increases. When the system becomes more organized and complex, the entropy decreases. Any system is prone to wear, to loss of order, to randomness.

No matter, how perfect the forms of TS are, no matter how minimal the increase of entropy during maintenance is, there will definitely come a time, corresponding to chaos theory, when an infinitely small uncertainty in the initial conditions can lead to huge uncertainty in predicting further behavior. This is absolutely unacceptable, according to the maintenance conditions for the state. And here there is necessarily not a technical, but an economic question—disposal or major repairs?

For some reason, the term «major repairs» causes a special rejection among the aviation community. But this is just an element of the classification of types of repairs.

At the present time, no repairs are planned, but the role of classification division continues to be relevant. This is due to the fact that Amendment No. 23 to Annex 6 adopted in 2000 by the International Civil Aviation Organization (ICAO) and Amendment No. 98 to Annex 8 of the Chicago Convention in 2001 defined the repair of AE as an integral part of maintenance, and an independent part. This happened because of the Aviation regulations Part 145. «Repair organizations» and the Guide 145.1. «The procedures for certification of repair organizations» of the Aviation Register of the Interstate Aviation Committee establishes a unified procedure for certification of repair organizations and requirements for the repair (modification) of aircraft and their components. When giving permission for repairs, in addition to the type of equipment, it is necessary to indicate to what extent the repair work is allowed.

During the «routine repair», malfunctions are eliminated by replacing damaged or worn parts. During the «average repair» the restoration of maintenance characteristics is performed by replacing worn or damaged parts with their adjustment and checking the technical condition of the remaining parts of the product with the elimination of detected malfunctions. «Major repair» consists of the complete disassembly of the

AE product, cleaning, defecation, replacement or restoration of all components of the product, assembly, and testing.

Independent aircraft modules, entering in the «repair by condition» are undergoing major repairs, and it can be stated, that aircraft as a whole, according to the sum of all modular repairs, is undergoing major repairs, but it is stretched over the maintenance time.

Only in the process of major repairs, it is possible to reduce entropy to a safe level by «opening» the design system in the process of disassembly and cleaning, and information and energy saturation of subsystems and connections of the system in the technological processes of restoration and assembly.

The ecological policy of both the state as a whole and its constituent economic entities is to protect the environment and prevent its pollution, while maintaining a balance with socio-economic needs. When considering these issues, the geochemical ecological principle is often forgotten, according to which the use of structural materials in technological processes should not disrupt the distribution, dispersion, concentration, and migration of chemical elements in the earth's crust and the earth's interior. Violation of this law causes an accelerated growth of the total entropy. During major repairs, the share of the initial involved chemical elements is an insignificant percentage, compared to the process of manufacturing a new product. The ecological «harmfulness» from pollution is determined by the scale of technological processes and production. During major repairs, this scale is much lower. Therefore, in the strategic planning of ecological policy, it is necessary, in addition to taking into account the factors of increasing ecological danger from the maintenance of morally and physically outdated aviation equipment, to take into account the specified geochemical principle.

6.2 Forecasting of Anthropogenic Hazard Processes at the Stages of the Life Cycle of an Aircraft Product

The impact on environment by transport objects, which are aircraft, occurs at all stages of their life cycles, starting from the extraction of raw materials, its processing (obtaining materials), manufacturing, maintenance, repair and restoration, renovation and disposal of the object, its components and parts.

The ecological balance of a vehicle is a combination of all types of negative impact of an object on the environment during the implementation of the life cycle. The ecological balance is represented in the form of flow processes of energy and substance exchange, expressed as the sum of the volumes of consumption of materials, emissions of harmful substances, energy consumption at each stage of the life cycle of a single vehicle or structure.

The environment of airport areas is a complex ecological system, the state of which changes under the influence of natural and technogenic impacts. The forecast of the spatial–temporal dynamics of the state of such a system and its analysis are necessary to determine the directions for eliminating or preventing negative external influences, i.e. for managing its ecological safety.

The normal ecological situation is associated with the structure of the biosphere and its vital activity, that has developed in this territory or, more precisely, the biogeocenosis. An imbalance, introduced into the ecological system due to any impact, in a normal system, according to the principles of existence, stimulates processes in it, that tends to return the system to its original state.

However, with a sufficiently powerful impact, according to [11], the system can lose stability and go into a non-stationary state. Today, it seems that this paradigm is the key one for determining the state of the ecological system. In addition, it should be understood that from the point of view of a systematic approach to ecological problems, the entire earth's biosphere should be considered as a system, and the consideration of regional ecological problems should be carried out from the point of view of global ecology.

A person allows himself to interfere with the cycles of the circulation of matter and energy in the biosphere, thereby breaking or disrupting the cycles, that nature has created. And despite the fact, that the margin of safety in nature was quite large, according to estimates [11], the crisis stage of the biosphere as a whole has already arrived and humanity has very little time to come to its senses and begin activities to return the biosphere to an equilibrium state.

To date, the assessment of the ecological situation is based primarily on sanitary and hygienic criteria and indicators. The concept of acceptable risk is more correct. The main advantage of the approach to assessing the sanitary and hygienic condition from the standpoint of the risk concept is to reduce many normative indicators to one—the risk value, which allows you to compare the effects of various factors by nature.

At the present time, we do not have sufficient and reliable data to conduct appropriate assessments. It is necessary to assess the ecological state by such methods, that would not contradict the basic ecological principles and would allow making quantitative assessments of the situation as a whole.

The criteria are the most significant indicators of the state of the natural environment, economic and social conditions. In each of these areas, many indicators can be used (Table 6.1) [12].

However, the number of criteria must meet the requirements of objectivity and economy. Objectivity increases with an increase in the number of criteria only up to a certain limit, after which it begins to decrease due to the noise, created by insignificant indicators. The discrepancy between the criteria is primarily related to the degree of generalization of information, and integral criteria are given more weight. However, working with a small number of generalized indicators can lead to a loss of objectivity in the process of transmitting information. Therefore, the combination of generalized and partial indicators should be considered optimal.

1. Air pollution of territories, intended for construction
   The degree of atmospheric air pollution is determined by the multiplicity of MPC excess, taking into account the hazard class, the summation of the biological

Table 6.1 Criteria and indicators of the state of ecosystems

Criteria	Indicators
Well-being	statistical norm; the empirical norm; theoretical norm; expert norm-biotic index F. Woodiwissa
System criteria	landscape—the relation between the changed and undisturbed; ecosystem—the laws of changes in the species diversity of the spectrum of life forms: an integral indicator of the violation of the cenotic climax: $dK(P/B \cdot M/B \cdot B/B/\mathrm{H})^{0,25}$; **c p** Shannon diversity index: $\mathrm{H} = -\Sigma \mathrm{n/N}\ \log_2(\mathrm{n/N})$; coefficient of reserve: $\mathrm{K_{mi}} = \mathrm{Qaccept.}/\mathrm{Q_{cr.}}$
Energy	energy capacity per unit area of the country, reduced to the global average; anthropogenic pressure «energy demographic index» (EDI); balanced nature using: the comparison of the production and natural potentials of the ecological system with the value of the technological capacity of the territory $\Sigma \Pi_\mathrm{i}(R, t) \le H(R, t)F$
Assessment of state of health	total morbidity rate; immune status; perinatal pathology
Sanitary and hygienic indicators	maximum permissible concentrations (MPC); approximately safe levels of harmfulness (ASLH): noise; vibration; ultrasound; temperature fluctuations
Atmosphere	maximum-one-time MPC; maximum permissible emission of harmful substances (MPE); the multiplicity of exceeding the MPC—K; the index of atmospheric pollution (IAP) of air pollution-visibility; levels of air pollution by various substances to sulfur dioxide pollution (M. A. Pinigin) $\mathrm{I_i} = (\mathrm{Q_{cpi}}\ /\mathrm{MPC})_{\mathrm{Ci}}$, where Q—the average concentration of ith substance

(continued)

Table 6.1 (continued)

Criteria	Indicators
Surface and underground water	MPC of substances; threshold concentration for organoleptic properties; threshold concentration for the general sanitary regime; inactive (subthreshold) concentration; BNO—biological need in oxygen; CNO—the chemical need in oxygen
Soil	MPC—maximum permissible amounts (in comparison with the background natural level) of the category: I—acceptable, II—moderately dangerous, III—highly dangerous, IV—extremely dangerous; the total indicator of soil contamination by a complex of metals L_c; Category: valid < 16, moderately dangerous 16–32, dangerous 32–128, extremely dangerous > 128
The risk of technogenic pollution of the environment	–

effect of air pollution, and the frequency of MPC excess. In accordance with the current MPC, the actual maximum single and average daily concentrations for the last few years, but not less than two years, are used to assess the degree of air pollution.

The measurement results are processed and presented separately for each selected point, substance, and year of observation. At least a pre-selected number of observations should be taken into account for each substance.

Assessment of atmospheric pollution by maximum single concentrations.

By statistical processing of the material, the C_{95} concentration value is calculated, at which the repeatability of the concentration values will be lower or equal to this concentration in 95% of cases. When the atmosphere is polluted with several substances, that have the effect of summing up the biological action, the concentration of $C_{95\mathrm{lim}}$, reduced to one of the summing substances, is calculated.

Assessment of the degree of atmospheric air pollution by average daily concentrations.

To assess the degree of contamination, the average daily samples obtained by continuous aspiration for 24 h or intermittent aspiration at least four times a day at regular intervals are used. All concentrations from the selected average daily samples are analyzed.

2. Impact of air pollution on environment

   The main indicators of atmospheric air pollution that characterize the impact on the natural environment (vegetation, soil, surface, and underground water) are critical loads and critical levels of pollutants. They are understood as the maximum values of precipitation or, accordingly, concentrations of pollutants in the atmospheric air, which do not lead to noticeable changes in the structure and function of ecological systems.

3. Criteria for pollution of the water objects
   Concentrations of priority toxic pollutants, as well as generally accepted physical and chemical characteristics: pH, BNOfull, CNO, dissolved oxygen, biological characteristics are selected as the main indicators for assessing the state of surface and underground waters.

   The contamination of underground water (not used as drinking water) in places of economic activity is estimated by the area of contamination. At the same time, if the area of contamination is 0.5 sq.km or less, the situation is considered satisfactory. With large areas of contamination, the situation is considered unfavorable.
4. Criteria for soil contamination
   In the assessment of the ecological state of soils, the main indicators of the degree of ecological disadvantage are chemical pollution. In this particular case, the most significant are the area of contaminated land and concentrations of chemicals.

   For the selected impact factors, data on the «impact-effect» dependencies are collected and evaluated, in terms of completeness and compliance with the requirements. The simplest and least time-consuming approaches and models are used, which, however, allow us to obtain results, that can be clearly interpolated and allow for comparisons and estimates. At this stage, the risk factors, associated with various factors, are considered and compared, and the possibilities of their combined impact are evaluated.

There is a close relationship between the level of risk and the dose load, created by substances, that pollute water, food and air and other factors, the so-called «impact-effect» relationship. You can use the indicator of the multiplicity of exceeding the normatively permissible pollution of the habitat. The indicator of the multiplicity of exceeding the normative permissible pollution of the human habitat of the K_p is estimated by the reduced sum of the multiplicities of exceeding the normative limits of total air pollution K1, water K2, and food K3 by the chemicals and radionuclides. The assessment of the concentrations of pollutants is carried out, using calculations, based on physical and mathematical models or by experimental means. The values of «acceptable risk» are established on the basis of.

- expert assessments;
- comparison of the obtained levels with the «background risk levels» for a given territory and/or territories with similar natural condition;
- balancing the interests of local authorities and institutions, whose activities lead to technogenic impacts.

At the same stage, it is possible to establish the amount of fees for emissions and discharges, assess material damage due to technogenic activities, and develop recommendations to reduce the levels of pollution and risk.

Figure 6.2 shows a general scheme for assessing the risk of adverse consequences for public health and ecological risk from technogenic pollution of the natural environment [12]. Based on this scheme, it is possible to distinguish various types of information, necessary for complex risk assessments. The most important characteristic of an industrial or transport facility, from the point of view of ecological risk, is the probability of an accidental release of harmful substances and the volume of emissions. For more detailed studies, it is necessary to know the probability distribution of accidents of various types and the probability of emissions of various volumes and types in such accidents.

The next step in conducting assessments of risk is to model the spread of chemicals after release. If we are talking about the safety of the population, it is enough to limit ourselves to modeling the transport of substances in the atmosphere, which requires meteorological characteristics of this area. When assessing ecological risk (including due to long-term effects on the population), it is necessary to take into account the processes of transformation of a chemical into other compounds, its transfer, accumulation, and destruction in other environments (water, soil). At this stage of modeling, in addition to weather conditions, characteristics of soil, vegetation, surface, and underground waters are required.

At the final stage of the assessment, when the spatial and temporal parameters of possible pollution have already been obtained, the impact of the release on the ecological system is analyzed.

This analysis is carried out on the basis of known or specially obtained ecological and toxicological information about the ways of pollutants, entering in various parts of the ecological system (rations, coefficients of the «environment-ration» transition) and about the sensitivity of various organisms and populations to the considered pollutants.

Due to the diversity of living organisms, the main attention should be paid to the most sensitive species, as well as to the assessment of the accumulation of harmful substances by animals and plants, used by humans for food. Such studies require characteristics of the ecological system in the area of possible pollution, information about the organization of water supply and data on the share rations of the population, living in a dangerous region. Since, along with individual risk, group risk (the probability of hitting several people) is important, the number and distribution of the population in the studied region can be attributed to the necessary characteristics.

The activities of civil aviation cause an adverse impact on the environment, causing pollution of the atmosphere, soils, and reservoirs. At the stage of aircraft maintenance, there is a chemical impact on the atmosphere, which includes emissions of harmful substances by aircraft engines and their impact on the ozone layer, and a physical impact, which includes aircraft noise, sound shock, and electromagnetic radiation from ground-based Air Traffic Management systems.

Reducing aircraft noise is the most important problem of modern civil aviation. Significant progress in the field of aircraft engine construction and applied aviation acoustics has recently made it possible to significantly reduce the noise of new aircraft, equipped with turbojet engines with a high degree of double-circuit. However, the problem of reducing the irritating effect of aviation noise for a number

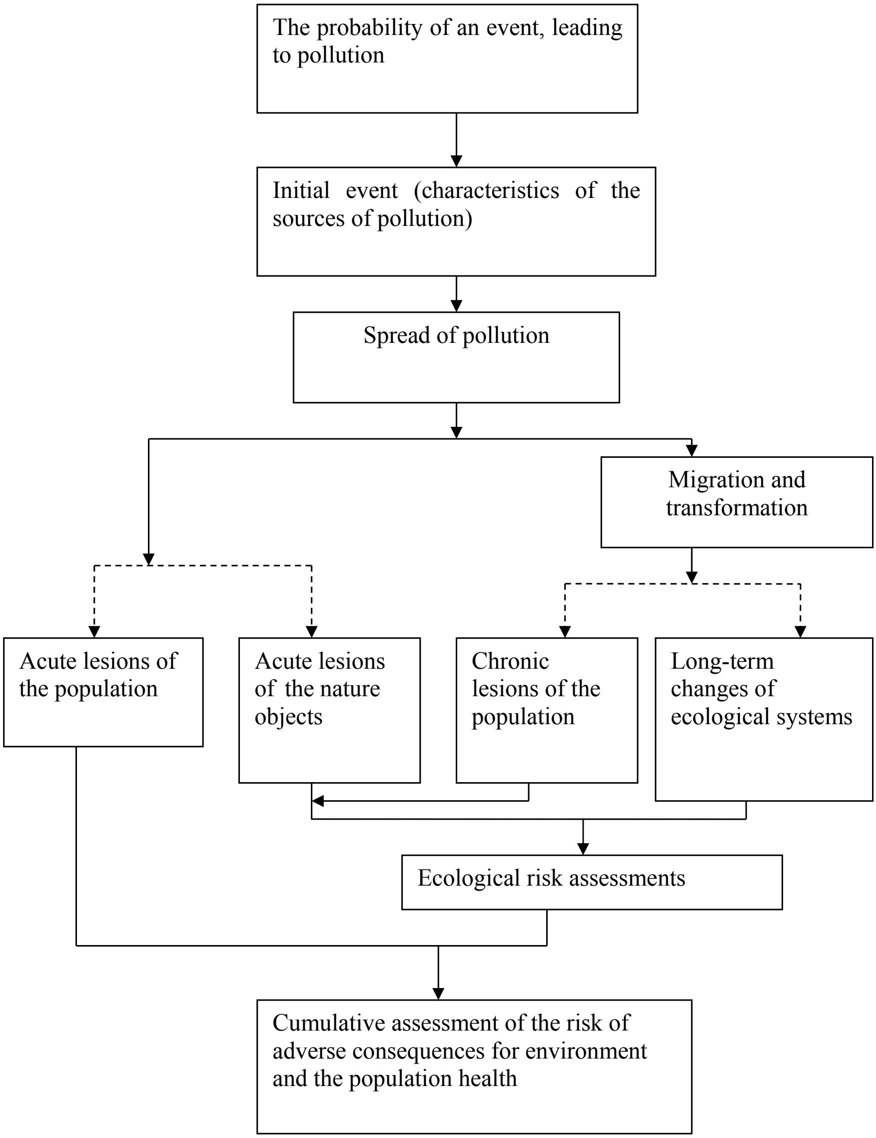


Fig. 6.2 The stages of ecological risk assessment in case of technogenic environmental pollution

of reasons, among which the main ones are the maintenance of noisier aircraft of older types and the approach of residential development to existing airports, remains quite acute.

Aviation noise has an adverse impact on the population, living near the airport, technical personnel, servicing aircraft equipment, employees and visitors of the airport, air passengers.

Recently, a number of new international (ICAO) and national regulatory requirements have been developed that regulate the noise of aircraft of various categories and classes. Creating an aircraft, that meets these requirements, is a rather complex technical task. Now such a level of development of the aircraft industry has been reached, in which an attempt to further reduce noise, associated with stricter noise standards can lead to a noticeable deterioration of the flight and technical characteristics of the aircraft. Thus, the developed methods of combating with aircraft noise, typical for the modern level of aircraft construction and aviation acoustics, cause losses, that can reach unacceptable values with a noise reduction of 5–8 EPNdB during takeoff and 3–6 EPNdB during landing, compared to the regulatory requirements of the ICAO standard [13].

Therefore, taking into account the insignificant progress in the field of reducing the noise of aircraft engines for new subsonic aircraft in the future, it is necessary to study and consider the possibility of using other measures, that are no less radical.

The most effective is an integrated approach to solving the problem of aircraft noise, in which it is possible to achieve a significant reduction in the irritating effect of noise in a shorter time and at a lower cost [14].

An integrated approach provides for reducing noise in the source not only by creating less noisy aircraft. It also includes the following activities:

(a) special piloting techniques during take-off and landing (take-off with the implementation of a steep trajectory in combination with throttling of engines and regulated turns);
(b) rational organization of air traffic (preferred runway noise, «minimum noise» routes, the use of aircraft of less noisy types, especially at night, the optimal ratio between the intensity of day and night flights, etc.);
((c) implementation of construction and planning measures, that take into account the restriction of residential development in areas with increased noise near airports;
(d) introduction of a noise restriction system in settlements near airports and monitoring of their compliance.

The optimal combination and systematic implementation of such complex measures will allow us to achieve the final goal of protecting the population from the adverse effects of aircraft CA noise most quickly and at a lower cost.

The severity of the noise problem is largely determined by the unacceptably close location of the existing residential development, as well as the continuing approach of the boundaries of urban development to airports [15].

Domestic and foreign experience shows that the restriction of development near airports is one of the most effective means of reducing the irritating effects of noise. For this purpose, NS 22,283–76 was developed and put into effect in Russian Federation, regulating the permissible noise levels in residential buildings near airports.

The solution of the problem of reducing the emission of harmful substances by aircraft engines also has a pronounced complex character. Research works are carried out on the following issues: creation of perfect engine designs and used fuels; regulation of emission characteristics and their control; development of a model for calculating atmospheric pollution in the airport area, which should be continuously improved on the basis of extensive laboratory and field studies of the formation and spread of harmful substances in the atmosphere, taking into account the prevailing meteorological factors [16].

The issues of systematic control over changes in the concentration of substances are also of great importance. The results of their generalization over a long period are important information for assessing the actual state of affairs, related to compliance with the established restrictions, and for improving the calculation model.

The atmosphere of the airport is also polluted by special vehicles, operated on the territory of the airport [17–19].

The exhaust gases of cars contain carbon monoxide (fuel combustion products), nitrogen oxides (mainly nitrogen oxide and nitrogen), aldehydes (formaldehyde, acrolein, etc.), hydrocarbons (methane, ethylene, benzene, acetylene, toluene, xylene, etc.), complex hydrocarbons (pyrene, benz(a)pyrene), soot, hydrogen sulfide (in the case of using fuel, containing sulfur, lead and its compounds (when using anti-knock additives), etc.

The amount of harmful substances, emitted by internal combustion engines, can be determined by the volume of burned gasoline and diesel fuel or by the number of cars, taking into account their average daily mileage and the basic fuel consumption standards, established for average conditions of operating.

When restoring the aircraft's operability, work is carried out that involves contamination of atmospheric air, water and soil with harmful substances, the consumption of structural, operational materials and energy resources: cleaning and washing, lifting and transport, disassembly and assembly, mechanical, battery, paint, etc. These processes are determined by the frequency of routine maintenance, the level of reliability of the structure, the range of used equipment, the consumption of materials and tools for repair and maintenance needs. In Table 6.2, the range of harmful substances, released at some production sites, is given.

Table 6.2 The range of harmful substances, released at some production sites

The site	Released harmful substances
Washes	Toluene, ethyl acetate, acetone, ethyl, and isobutyl alcohol
Battery-powered	Sulfuric acid vapors, sulfur dioxide, lead compounds, aerosols
Mechanical	Dust, aerosols
Testing of aircraft engines	Nitrogen dioxide, soot, sulfur dioxide, carbon monoxide, marginal hydrocarbons
Paint	Paint aerosols, toluene, xylene, solvent, chlorobenzene, dichloroethane, alcohols, inhibitors of organic and inorganic fillers, film-forming substances
Vibration strengthening	Dust (suspended substances)

The following substances are released into the atmosphere at the aircraft repair plant (ARP): nitrogen dioxide, acetone, gasoline, butyl acetate, vanadium pentoxide, suspended substances, benzene, hydrogen fluoride, hydrogen chloride, hydrogen cyanide, dichloroethane, potassium carbonate, nitric acid, sulfuric acid, xylene, methylene chloride, nickel (soluble salts), metal dust (aluminum oxide), soot, sulfur dioxide, lead, isobutyl alcohol, ethyl alcohol, trichloroethylene, toluene diisocyanate, toluene, hydrocarbons, carbon oxide, cyclohexanone, zinc oxide, ethyl acetate, acetylene, kerosene, phosphoric acid, mineral oil, caustic soda, abrasive dust, wood dust, fiberglass dust, hexavalent chromium.

There is an intensive contamination of water resources (wastewater) with suspended substances and petroleum products with weak emulsification as a result of cleaning and degreasing the surfaces of parts and components of vehicles, using alkaline and acid solutions, synthetic detergents (SD), turpentine, fats, formaldehyde. The greatest amount of pollution of water resources is associated with the washing of aircraft, as well as units and parts during repair.

Waste solutions of detergents contain petroleum products and suspensions up to 5 g/l, surfactants—up to 0.1 g/l and alkaline electrolytes up to 20 g/l, i.e. the concentration of harmful impurities in these solutions is 40–90 thousand times exceeds the sanitary standards.

To restore the parts and give the working surfaces the specified physical and chemical properties, galvanic processes are used, in particular, electrolytic methods of precipitation of chromium, iron, zinc, copper, cadmium in sulfuric acid solutions on the surface of the parts. Therefore, wastewater contains acids, alkalis, chromium compounds, copper, nickel, zinc, and cadmium salts.

Toxic substances during the coloring of products are released in the processes of degreasing surfaces with organic solvents, during the preparation of paint and varnish materials, their application to the surface of the product and drying of coatings. About 4% of the volume of consumed paint and varnish materials ends up in water.

Repair production is accompanied by the release of harmful substances that pollute the water environment. Washing works are a source of sewage pollution due to the use of alkaline and acidic solutions, synthetic detergents, formaldehyde.

One of the processes, widely used in aircraft repair production, is soldering. The method of modeling the technological process, physico-chemical, and production features represent a number of conditions, each of which indicates the possibility or impossibility of using soldering to restore a specific damage to the part. The advantage of such a «tested» model structure is that the chain of conditions can constantly increase as our knowledge about the process is replenished, it can include deterministic and stochastic submodels, as the experience of modeling the processes of surfacing, spraying and others shows, it is universal in terms of use for the needs of computer-aided design.

The calculation algorithm for this model includes the conditions for the process: temperature; interaction of flux and oxide film; wettability and spreadability; constructive acceptability; thermal balance; metallurgical interaction of solder and soldered material; strength; endurance; plasticity; corrosion resistance; aging; durability; reliability, in total, 140 operators [20].

Taking into account the developed methodology of integrated ecological assessment of technological processes, the algorithm for calculating the conditions for the possibility of recovery by soldering is presented in Fig. 6.3.

6.3 Economic Efficiency of Environmental Protection Measures

Ecological support measures should be economically justified, using the results of calculations of the economic efficiency of the carried out measures.

If the level of ecological safety is known (based on regulatory documents), then effective management of safety can be written as follows: with a given composition and parameters of the used technologies, states of ecological safety, find the types and parameters of equipment and technologies, that ensure the quality of the environment is not lower than the limit, while the costs should be minimal.

The objective function looks like this

$$\begin{aligned} \mathrm{W_q(D_m)} &\rightarrow \mathrm{W_k^{giv.}}, \\ \mathrm{C(D_m)} &\rightarrow \min, \end{aligned} \tag{6.2}$$

where

W_q	the quality of the environment, determined by regulatory documents;
$C\ (D_m)$	the costs of implementing a management decision.

The economic assessment of the effectiveness of the proposed measures is carried out on the example of a comparative assessment of the costs of additional equipment and their payback period. The measures that are proposed to be used are the use of treatment facilities, that bring the environmental quality indicators to the specified ones. As an example, we will carry out the economic efficiency of the activities, carried out at the Vnukovo aircraft repair plant (VARP). To reduce emissions from the mechanical section (where processing is carried out in sandblasting chambers), it is proposed to use systems of the «Cyclone» type.

The main indicators for comparative economic assessment, according to the recommendations of the methodological guidelines [21], are.

- capital investments, including the cost of materials, the cost of manufacturing a protective fence, the cost of accessories and equipment;
- current maintenance expenses, which include the cost of materials for technological purposes; energy costs; salaries of production workers (basic and additional); deductions for social needs; expenses for the saving and maintenance of equipment.

A common indicator of the economic efficiency of measures is the net present income (NPI), which characterizes not only the value of the discounted flow of

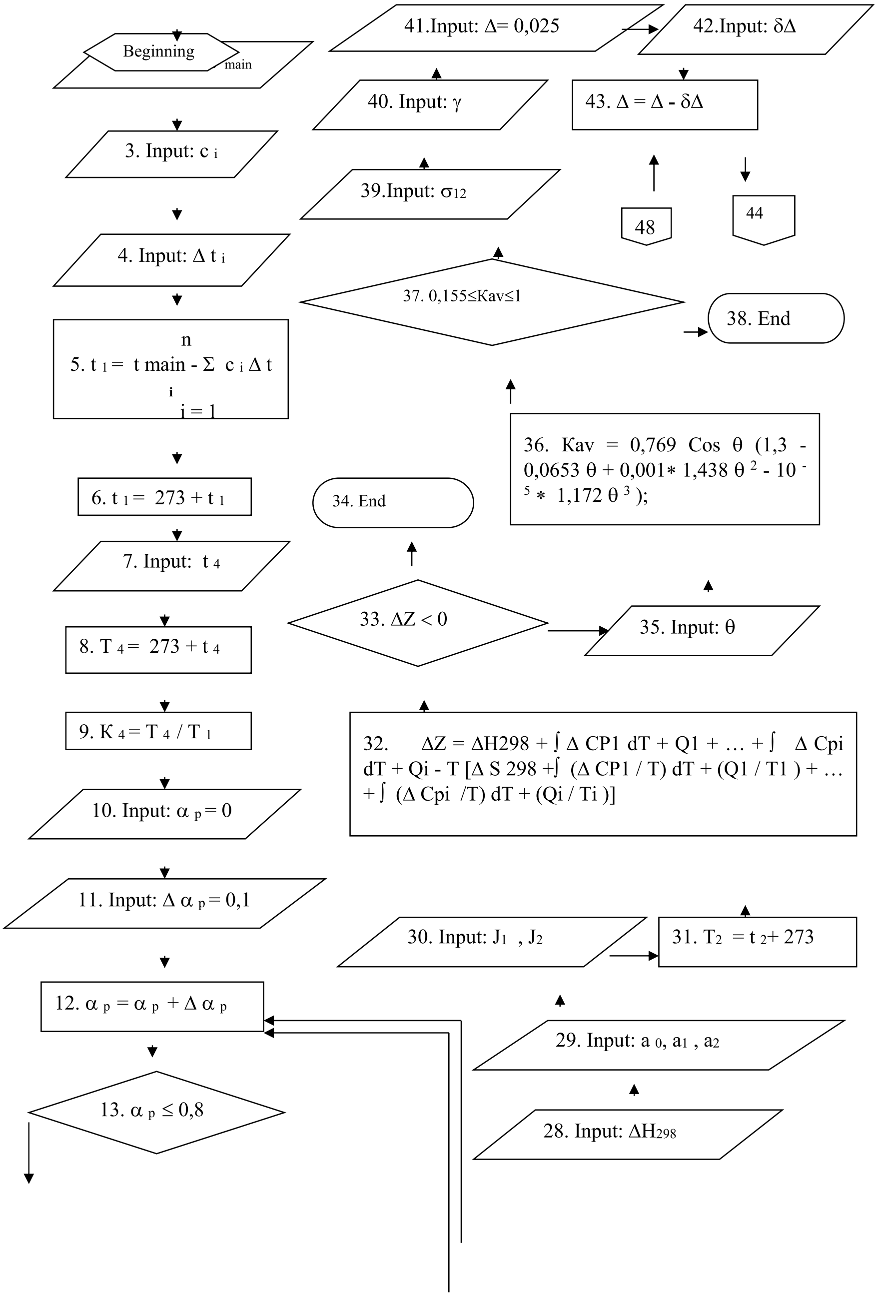


Fig. 6.3 Algorithm for calculating the conditions for the possibility of recovery by soldering, with an assessment of ecological pollution

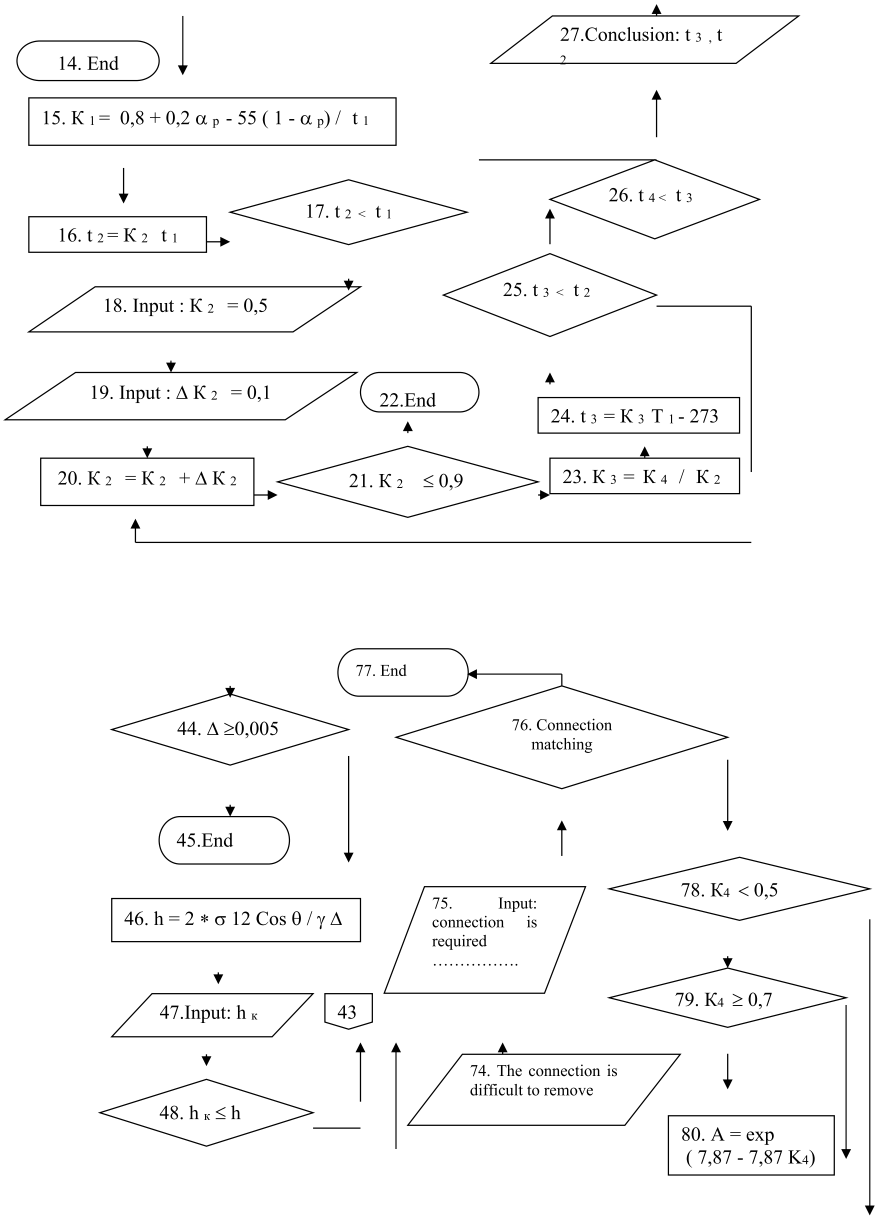
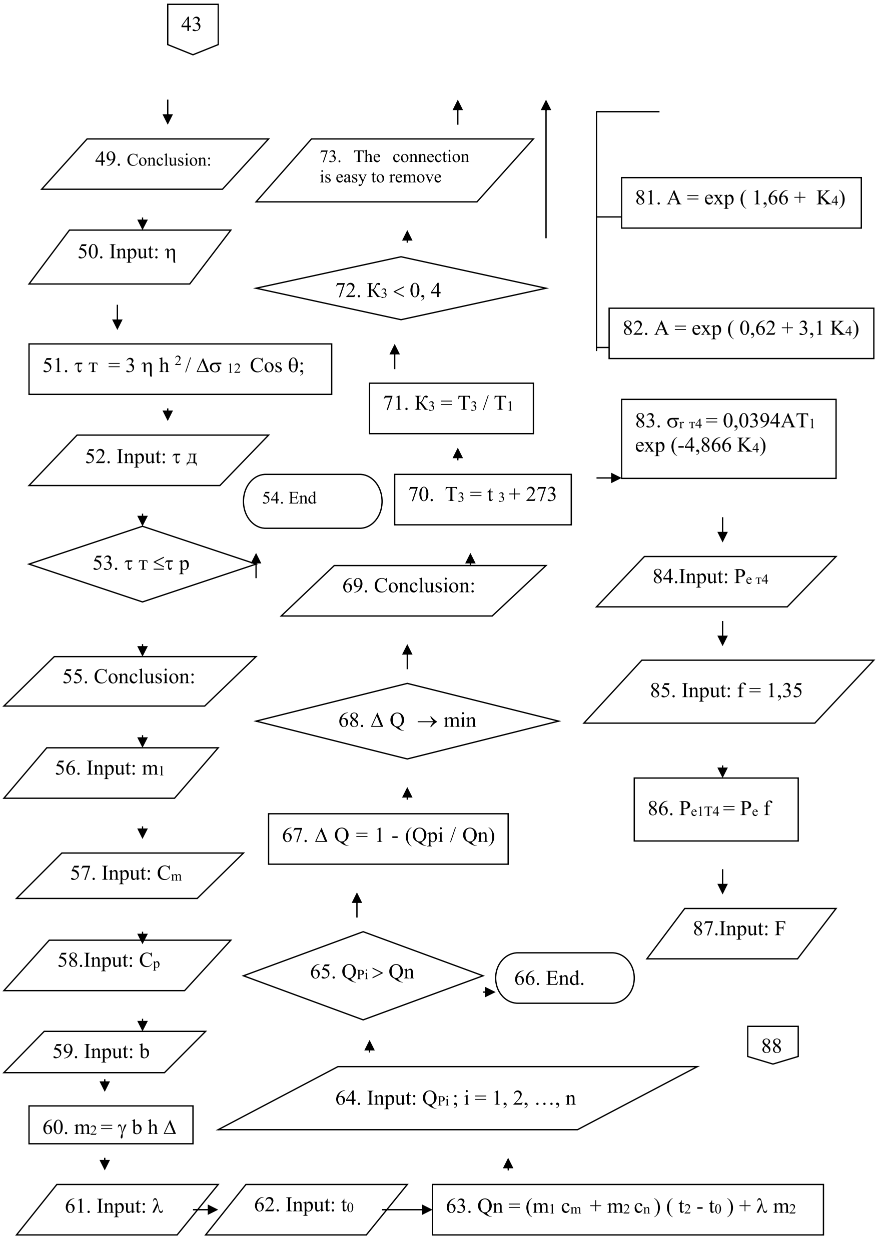


Fig. 6.3 (continued)



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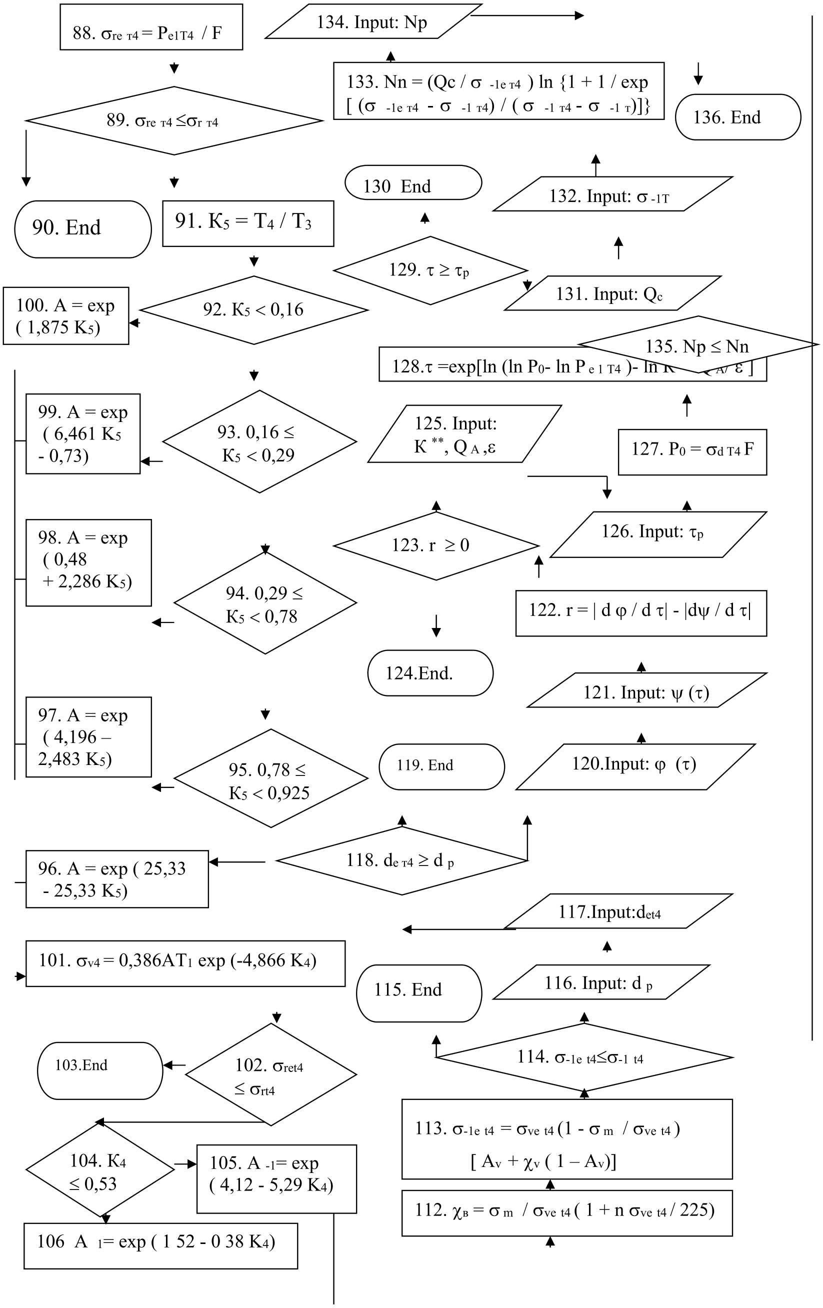

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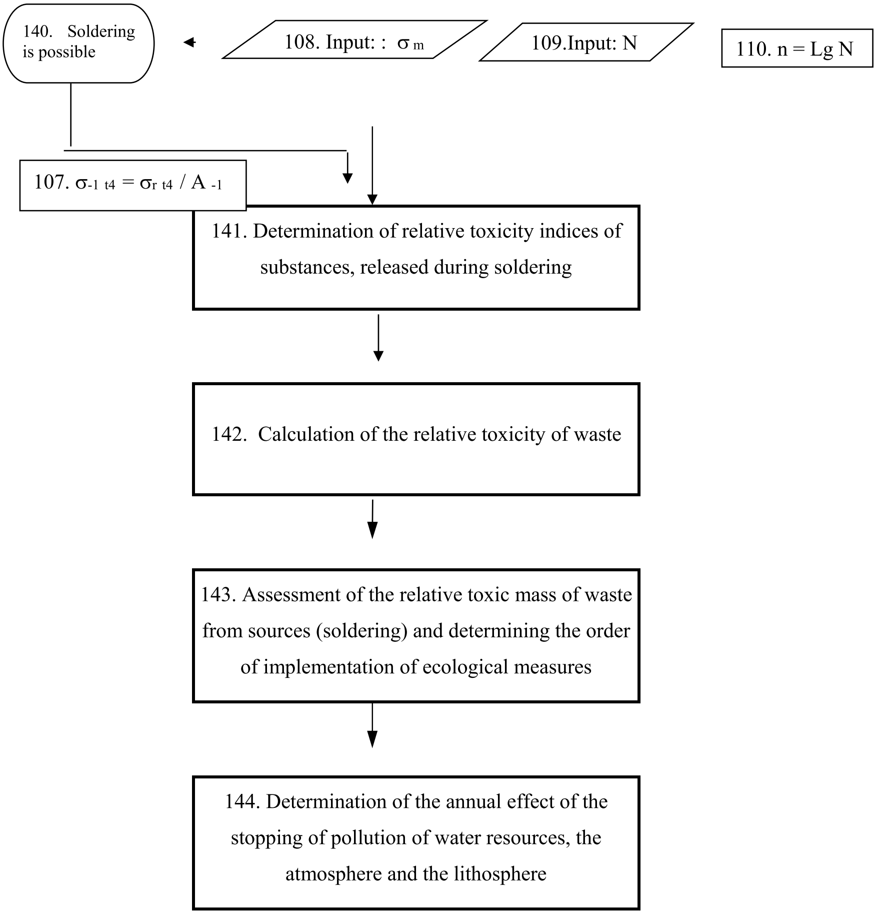

Fig. 6.3 (continued)

payments, aimed at repaying one-time capital investments, but also determines the payback period of one-time costs for modification:

$$\Delta \mathrm{NPI} = -\Sigma \mathrm{C} + \frac{\mathrm{Pn}}{(1+\mathrm{R})^{\mathrm{t}}},$$

where

P_n net profit,
R coefficient of discount (R = 0,1);
t number of years.

The ΔNPI is reduced to the moment, when it is equal to zero. This moment will be the payback period for additional capital investments.

Additional capital (one-time) costs (ΔC) are determined, as a rule, at the full cost of carrying out the work, taking into account the level of profitability (Cp) and tax for added cost (C_{TAC}):

$$\sum \Delta C = C_{mod} = \left(C_{mod} \cdot C_p \cdot C_{TAC}\right),$$

where C_{mod}—capital (one-time) costs for conducting of modification; C_{mod}—full cost of work on modifications; C_p—coefficient of profitability; C_{TAC}—tax for added cost.

The total cost of work can be determined by the following formula:

$$C_{mod} = C_M + C_{FP} + C_{SP} + C_{sal.}{}^{main} + C_{ded} + C_{el} + C_{ot},$$

where

C_M; C_{SP}; CFP	costs, respectively, for basic materials, spare parts, finished products;
$C_{sal.}{}^{main}$	salary of the main production workers;
C_{ded}	deductions for social needs;
C_{el}	electricity costs;
C_{ot}	other expenses, determined as a percentage of other items.

Total capital investments include $C_{tot.}$—cost of materials; C_{inst}—nstallation costs:

$$\sum C = C_{tot} + C_{inst} = 69\ 828 + 34914 = 104742\ \text{rub.}$$

The labor intensity of the installation: Tpeop.hour.installation = 48 h X 2 peop. = 96peop.hour.

The material costs of paying for the installation work are due to the costs of basic and additional salaries for workers, deductions for social needs:

$$\begin{aligned} \text{Csal} &= \text{Tpeop.h.} \cdot \text{Cwr.(hour)} \cdot \text{Cbr} \cdot \text{Cded} \\ &= 96\text{peop.h.} \cdot 140 \cdot 1,2 \cdot 1,26 = 20321\text{rub.}, \end{aligned}$$

where Cwr.(hour)—hourly wage rate for this category of workers; Cbr—bonus rate (20%); Cded—the coefficient, characterizing deductions for social needs (26%).

The total additional capital investments will be

$$\begin{aligned} \sum C &= \text{Cmod.} \cdot \text{Cp} \cdot C_{TAC} \\ &= (104742 + 20321) \cdot 1_2 07 \cdot 1,18 = 157904\text{rub.} \end{aligned}$$

The additional balance profit from the proposed modifications is formed at the expense of the prevented damage:

$$Y_{prev.} = Y_{without\ cleaning} - Y_{with\ cleaning}$$

In shop 17, there are two sandblasting chambers and a section with polishing machines. Let’s estimate the fee for the emissions of suspended substances from these sites.

$$\begin{aligned}&\text{Camera 1 :}5,31\text{t/y}\cdot 13,7\cdot 1,9\cdot 1,2\cdot 1,4 = 191,8\text{rub/y}\\&\text{Camera 2 :}9,29\text{t/y}\cdot 13,7\cdot 1,9\cdot 1,2\cdot 1,4 = 406\text{rub/y}\\&\text{Polishing: }0,155\text{t/y}\cdot 13,7\cdot 1,9\cdot 1,2\cdot 1,4 = 6,8\text{rub/y}\end{aligned}$$

$$y_{\text{without cleaning}} = 191,8 + 406 + 6,8 = 604,6\text{rub/y}$$

The systems of the «Cyclone» type are cleaned with an efficiency of 82%, therefore 12 t/y is thrown out, which is 490 rub/y.

$$y_{\text{prev.}} = 604,6 - 490 = 198,6\text{rub/y}$$

It is also necessary to take into account the damage, associated with special working conditions.

Total industrial damage from vocational diseases:

$$Y_{\text{voc. dis}} = Y_{\text{company}} + Y_{\text{med. organiz.}}$$

The damage to the company consists of:

(1) the cost of training a new employee to replace the victim: the number of days ·by the cost of one day of training = 30 · 300 = 9000 rub;
(2) additional payments of the salary difference, when transferring the victim to a temporary job: 3000 rub/month;
(3) severance payments, when transferring to disability: 5000 rub/month.

$$Y_{\text{company}} = (9000 + 3000 + 5000)\cdot 12 = 204\ 000\text{rub/y}$$

The damage to a medical organization consists of

(1) payment of sick list: 7000 rub/month;
(2) payment of the cost of treatment in the hospital: 10,000 rub;
(3) payment of the cost of medicaments: 5000 rub.

$$\begin{aligned}y_{\text{med. organiz}} &= (7000 + 10000 + 5000)\cdot 12 = 264\ 000\text{rub/y}\\Y_{\text{voc, dis.}} &= y_{\text{company}} + y_{\text{med. organiz.}} = 204\ 000 + 264\ 000\\&= 468\ 000\ \text{rub/y. (per person).}\end{aligned}$$

Savings from the cost for diseases.

Without the use of cleaning, 20 per/y are sick (that is 468 000 rub/y); with the use of cleaning, 10 per/y are sick (that is 234 000 rub/y).

The savings, when using cleaning are 234 000 rub/y.

$$\Delta \sum \mathrm{P_{bal}} = \sum \mathrm{y} = \mathrm{y_{prev.}} + \mathrm{y_{by\ dis.}} = 198,6\,\mathrm{rub} + 234\ 000\,\mathrm{rub} = 234\ 198,6\,\mathrm{rub}$$

Additional net profit

$$\begin{aligned}\Delta \sum \mathrm{P_n} &= \Delta \sum \mathrm{P_{bal}} - \mathrm{IT} + \mathrm{A_{year}} \\ &= 234\ 198,6 - (234\ 198,6 \cdot 0,24) + (104\ 742 \cdot 0,1) \\ &= 188\ 465,1\ \mathrm{rub.},\end{aligned}$$

where IT—income tax

Let's move on to calculating the net reduced income and the payback period of the costs for modification:

$$1\mathrm{yearNPI} = -157\ 904 + 188465,1/1,1 = 13427,9\ \mathrm{rub}$$

It follows from the presented calculations that the payback period for the installation of cleaning systems will be 1 year.

A graphical representation of the payback period of one-time costs is shown in Fig. 6.4.

The use of additional environmental protection equipment for cleaning emissions from sites is the most used measure.

The set of economic instruments for compliance with ecological safety includes [22]:

(1) payments for nature using (resource payments and payments for environmental pollution);
(2) financial and credit instruments (methods of preferential crediting of environmental measures, loans, subsidies, mode of accelerated depreciation of environmental equipment, ecological and resource taxes, etc.);
(3) market instruments (market prices for natural resources, voluntary environmental agreements, etc.).

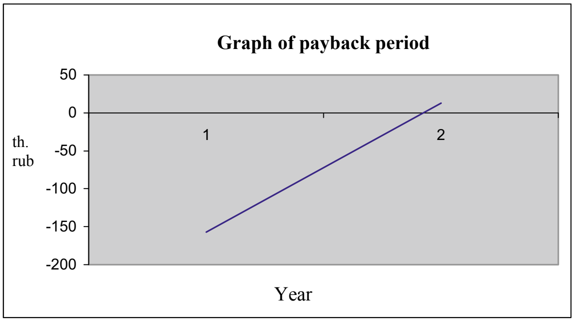

Fig. 6.4 Graph of payback period

When using environmental protection equipment, the emissions of pollutants are reduced. Consequently, payments for environmental pollution are also reduced. You can also use the accelerated depreciation mode of environmental protection equipment, which is not currently used at companies.

6.4 Forecasting the Role of Psychophysiological Factors in the System of Ecology Safety

According to the results of the investigation, more and more reasons for aviation incidents are attributed to the «human factor». Where the reasons are attributed to «special cases in flight» (SCF), for example, the failure of aircraft technical systems, most often, the actions of the crews in these cases are provided for in the flight operation manuals.

The activity of a pilot is a process, carried out by him to achieve the goals, set for the pilot-aircraft system, and consists of an ordered set of actions.

Actions can be not only practical, but also related to the search and perception of information (through visual, auditory, and other analyzers), memorizing and perceiving the necessary information in memory mechanisms, performing mental procedures (processing and analyzing information, etc.).

There are automated actions (for example, for a repeatedly repeated known signal) and non-automated ones. The latter are divided into reproductive (performed in accordance with a well-known program) and productive (not defined in advance and formed as a result of intellectual activity). An example of an automated action is changing the speed mode by reducing the engine speed, increasing the pitch angle, releasing the brake flap (on military aircraft). The reproductive effect is manifested, when parrying a failure, where the algorithm is strictly defined. A productive action takes place in those cases, when it is necessary to analyze the incoming information and make a decision, based on it, defining a goal and an algorithm for achieving it, which was not previously known [23].

The activity of the pilot, despite its external integrity, has a pronounced combined character and consists of separate fragments. This means that the piloting of the aircraft is provided by the implementation of not one, but several activities, each of which has its own subject and is aimed at achieving a specific independent goal.

Effective and safe flight performance is achieved by the implementation of four independent activities by the pilot, the subjects of which are.

- ensuring the movement of aircraft in flight (aircraft control);
- providing a given spatial position of the aircraft relative to the gravity vector, the x, y, z axes and the Earth's surface (pilotage orientation);
- providing the specified location of the aircraft relative to celestial and significant ground landmarks (navigation orientation);
- collision prevention with out-of-cab objects (conducting caution).

It is necessary to consider the mental regulation of the pilot's activity. Mental education as an image of flight is one of the terms, often used in the professional flight lexicon.

The image of flight is a complex mental formation, that combines images, that regulate the performance of combined tasks by the pilot. The information content of the image is represented by instrumental (from devices) and non-instrumental (out-of-the-cabin environment, efforts on the controls, noise, vibration, acceleration, etc.) signals. The formation of the image of flight is carried out in the process of professional training and preparation. At any moment, not the entire image of flight, as an integrative formation, is involved in the regulation of the pilot's activity, but only its part, determined by the performed task, conditions, and means. This part is named in an operational way. The essence of mental regulation consists in the fact that the pilot compares the current parameters of one of the tasks with regulating it one an operational way, containing information about a given state, and on the basis of this makes a decision, that is implemented in the form of control actions. The information, received after this by feedback, indicates, that the desired result has been achieved or not achieved.

Depending on, what information is used, there are three levels in the regulation of the pilot's actions:

Level 1—sensations and perceptions;
Level 2—views;
Level 3—speech-thinking.

The level of sensations and perceptions is characterized by the fact, that the actions of the pilot are regulated on the basis of directly perceived information. For example, the pilot saw, that a roll, appeared involuntarily during the horizontal flight mode, and immediately parried it.

At the level of representations, the regulation of actions is carried out not on the basis of directly perceived information, but on the basis of images of those objects and phenomena, that were affected in the past. So, thanks to the previously accumulated professional experience, the pilot has fixed in memory the idea of the dynamics of the flight, all changes in the route or the complex of performed aerobatics, and regulates his activities, based on this idea.

At the speech-thinking level, actions are regulated due to a generalized and indirect show of reality. This level provides the formation of action goals, decision-making criteria, forecasting the development of the situation, etc. Its role is especially great, when parrying emergency flight situations, when the maximum realization of the pilot's intellectual potential is required.

Identification of the level of regulation of the error, made by the pilot, during the investigation of an aviation accident (incident) significantly facilitates the search for the main cause of the incident.

A special place in the regulation of the pilot's activity, when controlling the aircraft, is occupied by non-instrumental information and the «feeling of the aircraft», formed on its basis. The latter is defined as the ability of the pilot to predict the state of the aircraft and the dynamics of its spatial movement on the basis of the most informative non-instrumental signals, received by the pilot from the moment of impact on the controls.

Activity, as a process, when performing any task, consists of several stages: receiving information; processing information; making a decision; implementing a decision; monitoring the implementation of a decision.

In the interests of the investigation of aviation accidents and incidents, it should be borne in mind, that the reception of information, including out-of-cabin information, may be difficult and even distorted for both objective and subjective reasons. Due to the ergonomic imperfection of the instrument equipment, errors may occur, when reading information, and unfavorable external conditions contribute to the creation of various kinds of visual illusions. If the pilot's performance is impaired (fatigue, illness, illusion, etc.), the reception of information often suffers, which is manifested, as a rule, in the delay of perception or the omission of important signals.

The holistic view of the state of the problem being solved, that has developed after the perception of information, is compared with the given one and the need for its preservation or change is determined. With good information support, this stage of activity is extremely fleeting (curtailed), but with uncertainty, contradiction of the perceived information, the duration of its processing increases significantly. At the same time, thought processes are actively involved, which not only help to process the existing information, but also regulate the search for new information. It becomes obvious, that, when assessing the reliability of the pilot's actions, it is important to conduct a full-fledged analysis of all the information, available to him.

At the decision-making stage, the pilot forms the goal of the action and chooses ways to achieve it. Of course, in ordinary situations, involving an unambiguous solution, the pilot does not experience any difficulties. And the situation is completely different, when it is difficult to choose a goal and (or) a method of action in conditions of time shortage, and the price of an error is exceptionally high. It is clear that this stage in the pilot's activity should be subjected to particularly close attention, when investigating aviation accidents and incidents.

As a rule, the implementation of the decision is carried out in the form of motor acts (control actions) or speech messages. In the process of training on the simulator and performing real flights, the control movements are brought to automatism. And, nevertheless, they can be erroneous. The reason for this kind of error can be hidden both in violations of the need-motivational area, and in deviations, made at previous stages of activity (when perceiving information, etc.). This should be taken into account, when investigating aviation accidents and incidents.

At the stage of monitoring the implementation of the decision, when information about the results of the control action is received, the pilot is convinced, that the goal has been achieved or not achieved and has the opportunity to identify the made error.

The identification of the above stages is important in the investigation of aviation accidents and incidents to understand the significance of the psychophysiological nature of the made error.

The most complex character of the combined activity of the pilot becomes, when the SCF occurs, or rather from the moment of perception of the first abnormal signal. This signal, whatever its nature (visual, auditory, tactile, etc.), primarily has a psychogenic effect on the pilot. The strength of this impact, all other things being equal, will largely depend on the mental readiness of the pilot. The higher the mental readiness, the lower the level of psychogenic impact, and therefore, the reliability indicators of the pilot's actions in the current conditions will be better, and vice versa.

Mental readiness includes two components:

1. psychophysiological stability, which is determined by the state of the organism's systems and their ability to resist the unfavorable effects of SCF factors;
2. mental stability, due to the peculiarities of the psychological qualities of the pilot's personality and his professional training. This includes increased motivation and an attitude to a favorable outcome, a sense of duty, the ability to urgently update knowledge and operational thinking, professional readiness for actions in SCF.

In addition, mental readiness depends on external factors: the volume and completeness of information about what happened, the ergonomic characteristics of the cabin equipment, the time reserve, the availability of information about the effectiveness of their actions, the severity of violations of the stereotype of actions [24].

The perception of the first abnormal signal includes two types of reactions:

1. adaptive-protective (ensure the mobilization of additional resources of the organism to parry the SCF, that has arisen);
2. complex intellectual actions (aimed at identification SCF, decision-making, and its implementation).

After the perception of the first abnormal signal, the pilot, along with the aircraft piloting contour, forms a second clearly defined contour—the SCF warning, which further complicates the already combined activity. The pilot is forced now to constantly switch his attention from piloting the aircraft to actions to prevent SCF. But since piloting an aircraft includes four independent tasks, when an SCF occurs, the pilot's reserve capabilities for combining all tasks are limited and, depending on the conditions, he refuses some of them (for example, conducting caution, navigational orientation).

The activity in the SCF parry circuit includes five stages:

1. SCF detection;
2. situational assessment of the current situation;
3. SCF identification;
4. making a decision;
5. implementation of the adopted decision and its control.

SCF detection begins from the moment, when the first abnormal signal is perceived. This is a signal, indicating, that the actual flight parameters (in-cabin conditions) do not correspond to the specified ones. It is from perception, and not from the appearance of an abnormal signal, that the pilot is included in the SCF parry circuit. The fact is that the first abnormal signal, that appeared, should be perceived by the pilot. However, the distance between the appearance and perception of the signal (on a time scale) can be quite large, and it is determined primarily by such a characteristic of the signal itself as activity.

In the interests of investigating aviation accidents (incidents), it is important to note, that the pilot's reaction to the first abnormal signal (and most often it is aimed at restoring the spatial position of the aircraft) is not evidence, that he understood the situation (recognized the failure) and performs actions to parry it. The first reaction is precisely the reaction to the first abnormal signal, which is usually based on a late reflex (i.e. the torso leans to the right—the hand automatically gives the steering wheel to the left, etc.), and the pilot has yet to identify a special situation on board the aircraft.

After receiving the first abnormal signal, the pilot does not immediately begin to identify the SCF, but first performs a situational assessment. Its purpose is to make a strategic decision, based on the operational perception of information about the situation, that has arisen, the conditions and circumstances in which the aircraft is located, and the peculiarities of its behavior, choosing one of the alternatives:

1. Immediately stop the flight without recognizing the situation (on aircraft, where there is a catapult—leave it).
2. Continue the flight, identify the situation, and parry it.
3. Continue the flight without determining the SCF, only parrying its manifestations. Only after performing a situational assessment and choosing an activity strategy with SCF identification, the pilot begins this process.

SCF identification is a complex process, usually expanded in time. The psychological content of this process depends on the level of professional training of the pilot, which determines the method of identification. Two main methods are selected in the experiments:

1. The pilot actively searches in random order for all signals, indicating the development of SCF, and thanks to their perception, forms a holistic view of what happened and identifies the SCF.
2. The pilot, based on his professional experience, actualizes in his mind the image-standard of the most likely SCF, associated with the first abnormal signal, and, based on it, perform purposefully, without searching (and this is important to emphasize), the perception of other signs, confirming the suggested special situation. If these signs are not detected, the image-standard of another SCF is updated and the necessary information is collected in accordance with it. When the situation is uncertain, after the perception of the first abnormal signal, experienced pilots, when identifying the SCF, first of all assume, and therefore form an image-standard of the situation, that has the least reserve time (this is the period from the moment of the occurrence of the SCF to its unfavorable completion). If the SCF is not recognized, then the image-standard of another SCF with a large backup time is updated.

Actualization of the image-standard and active purposeful perception of significant features, based on it, is the most effective way to identify SCF. At the same time, it is impossible to completely exclude the option of an active, but in a random order, search for SCF signs. This option turns out to be the only one, when there is an SCF on board the aircraft, that is not described in the flight-methodical documents, and therefore, has not been previously studied and the pilot has not formed an image-standard of it.

It is impossible not to mention another method of identifying SCF, which is among the unproductive ones, but is found in aviation practice. It consists in identifying the SCF by one first non-standard signal. This happens in cases, when, due to the imperfection of the used training methodology, the pilot has formed a rigid connection between a specific signal and an equally specific SCF. Therefore, having received the signal, the pilot immediately «recognizes» the SCF. The signal, as if involuntarily (without activity on the part of the pilot), «pulls» the image of a specific SCF from the memory mechanisms. There is a passive identification. Sometimes this method brings a positive result. But, considering, that even such instrumental signals as the lighting of the emergency display are not specific, since the alternative to true activation is false (if the display system itself fails), it becomes clear, that this method of SCF identification is unproductive. Pilots, who connect the first abnormal signal about the occurrence of a special situation with only one of them, and do not know, that this signal may be a manifestation of other SCFs, certainly make errors in identifying failures.

The knowledge of the flight crew about possible emergency situations, when a specific emergency signal is received, is accumulated, as they gain experience in flight work.

Pilots with different levels of professional training are able to see from 1 to 4 special situations behind each emergency signal. Moreover, if pilots with a flight of up to 1000 h associate with a specific emergency signal, as a rule, 1–2 special situations, then pilots with a flight of more than 2000 h—2–4 situations.

With experience, the attitude to instrumental information about SCF also changes. If inexperienced pilots perceive the inclusion of any failure display unambiguously as a signal about the occurrence of a specific SCF, then experienced pilots do not exclude an alternative option—its false triggering.

Therefore, the pilot's ignorance of all the most probable SCFs, when the first emergency signal is received, is one of the psychological reasons for their low professional reliability.

Another equally important psychological reason for reducing the professional reliability of the pilot in the SCF is the use of ineffective identification methods (by the first abnormal signal or by actively, but randomly searching for other signs of SCF).

The core of the SCF image-standard is the system reference signal. It represents the spatio-temporal structure of individual signals in such a combination of them that is specific to a given specific SCF and provides its identification.

The pilot's ignorance of the spatio-temporal structure of the signals of the most probable SCF and the lack of formation of the system reference signal as the core of the image-standard of each SCF is another psychological reason for reducing the professional reliability of the pilot in emergency situations.

An important role in the identification of failures is assigned to the logical thinking of the pilot, which is based on the knowledge of certain patterns in the development of special situations and the connections between them.

Poorly developed logical thinking is another psychological reason for the lack of professional reliability of a pilot in the SCF.

There is an important dependence for practice: a high attitude to failure (waiting for failure) with insufficient professional training does not ensure the reliability of the pilot's actions in special situations.

It is revealed that one of the reasons for the low efficiency of detecting failures of the air horizon, the flight navigation device and some others is the lack of formation of the pilot's algorithm of activity, including the comparison of the readings of the main and backup devices. In this case, the pilot does not have the opportunity to detect in a timely, that one of the devices gives false information, which means that it has failed.

The next stage in the SCF warning is the decision-making, which includes the formation of the action goal and determining the way to achieve it, taking into account the conditions and circumstances of the flight. It is clear that the purpose of the action may include not only parrying the SCF, but also an emergency landing, leaving the aircraft (on which the means of saving the crew are provided). Of course, after the completion of the complex stage of SCF identification, making a decision seems easier, but errors are also possible on it.

The implementation of the made decision and its control is the final stage of the pilot's activity in the SCF. With complex algorithms for preventing one or another SCF, it is possible to make errors, that aggravate the situation, turning it into an emergency or catastrophic.

Conclusions on incidents, attributed to the «human factor», as a rule, demonstrate the apraxia of crew members in the event of special cases in flight. Such a violation of purposeful action with the preservation of its elementary movements is a violation of the highest mental function of the organism, and neurology refers it to focal lesions of the cerebral cortex or the conducting pathways [25, 26]. But a sudden morphological pathology of the nervous system in the described case is unlikely.

Psychophysiology introduces a reason for the loss of skills of complex purposeful actions, developed in the process of individual experience, the appearance of sudden, irresistible fear, confusion, that is, panic [27].

In an ordinary situation, arbitrarily performing any action, a person does not think about which muscle should be turned on at the right moment, does not keep in conscious memory the working scheme of the sequence of the motor act. Habitual movements are made imperceptibly for attention, the change of some muscle contractions by others is automated. These motor automatisms contribute to the most economical expenditure of muscle energy in the process of performing movements. A new, unfamiliar motor act is always more wasteful energetically than the usual, automated one [28].

This praxis—the ability to perform sequential complexes of movements and perform purposeful actions, according to a developed plan, including performing complex motor acts, is achieved in the process of professional training. The mechanism, necessary for learning, is memory. With its help, past experience is accumulated, which can become a source of adaptive behavior changes.

In turn, learning, that is, a set of processes, that ensure the acquisition of individual memory, causing adaptive behavior modification, is divided into two types [29]:

1. habituation—weakening of behavioral reactions with repeated presentation of the stimulus (extinction of the unconditional orientation reflex);
2. sensitization—strengthening of the reflex reaction under the influence of a strong or damaging extraneous stimulus.

Sensitization is the result of activation of the modulating system of the brain, which occurs on a strong side stimulus. The strengthening of the reflex is caused by a change in the functional state of the organism.

Now the preparation for the flights is carried out on simulators. Previously, training sessions were held on real equipment. During the flight task, the instructor could consistently close the curtains in the pilot's cabin, turn off the engine and even two engines. The crews were mentally ready for this. They landed «blindly», using instruments, started the engines in the air, vented the screws in manual mode, provided the correct roll, pitch, yaw under conditions of changing moments of reactive force, and much more.

If the skills of real flight are mastered enough quickly, then the correct actions in emergency situations are learned and consolidated, in the worst case, as a result of bitter experience, and at best—through purposeful training.

What is the difference between real and simulator testing of special flight conditions? The fact that the real danger of flight is lost. Implicitly, the sensually trained person knows, that having «crashed» on the simulator, he will remain alive and, as they say, «retake the simulator». As a result, incorrect motivation is laid in the subcortical areas of the brain. And the most terrible thing is that it is laid at the level of the subconscious. As a result, sensitization learning changes its sign. It becomes a negative learning—habituation.

The brain can not only respond adequately to external irritation, but also actively make plans for its behavior. The doctrine of the «model of the necessary future» allows us to talk about «getting ahead of reality». It is these features, that have formed aviation and space psychology as independent scientific disciplines. What is good for astronauts, can be bad for pilots. The psychological laws of flight activity in special flight conditions are based on the principle of secondary automatism, that is, an action, implemented without the direct participation of consciousness and formed in life by sensitization learning. In the process of an incident in the air, there is no time for thinking. For astronauts, the rescue processes in emergency situations during the period of the Earth's gravitational field influence (launch, orbit entry, descent, landing) are automated. In orbit, in a state of weightlessness, as a rule, there is time to realize the situation (often with the help of the Flight control center) and make a conscious logical decision to get out of this situation.

When planning crew training under special flight conditions, it is necessary to develop, maintain and consolidate the correct psychophysiological actions, remember, that conditioned reflexes arise during individual development and accumulation of new skills. The development of new time connections depends on changing environmental conditions.

By constantly improving the skills of air navigation, unconditional reflexes are formed. Reflex motor reactions are unconditional and occur in response to instrument, light, sound, and other irritations. It has to do with not only to simple reflex motor reactions, but also to complex reactions in the form of a series of consecutive purposeful movements.

Unconditional reflexes can change under the influence of illness, as a result of emotions (a special type of mental processes), that express a person's experience of his attitude to the world around him and to himself, performing the functions of a connection between reality and need. The resulting emergency situation causes strong and relatively short-term emotional experiences, accompanied by pronounced motor and visceral manifestations. These effects arise in response to a situation, that has already actually occurred. Moreover, their action can have a twofold nature—physical and social. Physical is a subconscious fear of biological factors, affecting the physical existence of a person.

But they can also have a social nature, for example, the fear of punishment for incorrectly committed actions to prevent an emergency situation.

The role of emotions (including effects) in aviation life has not yet been sufficiently realized. Especially their reflective function is a generalized assessment of events at the subconscious level and interaction with the subconscious as a stereotype of automated behavior—various automated skills.

Emotions cover the entire organism and represent an almost instantaneous and integral assessment of behavior as a whole, which allows us to determine the usefulness and harmfulness of factors, acting on a person, even before the localization of the harmful action is determined. The reflective function calls the prompting function.

What is the correct and most effective way to form this function, that encourages the pilot to take preventive actions?

It is important to realize that there is no «human factor». There are errors in learning [30]. And, most likely, aviation psychophysiology should give its weighty word in this matter, which can be studied, for example, within the framework of ecological psychophysiology.

Ecological psychophysiology is engaged in the study of the psychophysiological mechanisms of the impact on a person of ecologically harmful factors, that violate mental activity and human behavior.

Its field includes, among other things: the creation of a system of psychophysiological monitoring of functional states and mental functions of a person, taking into account the norms of permissible deviations in mental health; the development of measures for the prevention and correction of psychophysiological disorders, caused by ecological factors; clarification of the role of various individual properties, that both strengthen the protective functions of the organism and make it vulnerable to harmful environmental factors.

The most typical manifestations of mental deviations, associated with ecological factors are expressed in violations of cognitive processes, a decrease in intellectual potential, changes in the emotional and volitional area, the development of non-optimal functional states, deterioration of a person's well-being and mood, the appearance of neuropsychic tension, stress.

For example, it suggests using a completely isolated and identified neuron. A neuron is a nerve cell, consisting of a body and appendages, extending from it. Neurons conduct nerve impulses from receptors to the central nervous system (sensory neuron), from the central nervous system to the executive organs (motor neuron), connect several other nerve cells (insertion neurons). They are used as a highly sensitive biological system to identify the level of environmental pollution.

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