Substantiation of the Choice of the Optimal Variant of Measures for Organizing and Ensuring the Protection of Critical Information Infrastructure Facilities When Exposed to Destructive Electromagnetic Radiation Based on Itoss Technology

Dvilyanskiy A. A, Eremenko V.T, Averchenkov V. I, Averchenkov A.V, Lozbinev F. Yu, Rytov M.YU.

Abstract— Ensuring the safety of the critical information infrastructure (CII) from destructive impacts, including electromagnetic, is currently an important state task, since even a short-term failure of the life support systems of the state and society will inevitably lead to a functional collapse. The consequences of which may be irreversible. Electromagnetic safety of KII facilities implies conducting research within the framework of developing methods to counter various threats, including their protection from destructive electromagnetic radiation (DER) [1, 2].

I. INTRODUCTION

Increasing the level of protection of objects of the CII from DER (hereinafter referred to as objects from radiation) should be considered as a set of measures to create a system of protection of objects containing a set of technical means (TM) and protection methods that prevent the functional and catastrophic destruction of computer equipment objects in the conditions of exposure to powerful electromagnetic radiation. and uncontrolled dissemination of information in terms of access to it through technical channels of information leakage through SEMR.

Building a system to protect objects from radiation is an iterative sequence: setting tasks – exploring options for implementing them — making a decision. In this regard, there is a need for a comprehensive solution to this problem.

Structural optimization of the protection system (PS) of the facilities of the CII consists in forming such a protection system scheme that will determine the main functional parts of the system necessary to ensure an extreme value of the system optimality indicator with the financial resources allocated for its creation.

An indicator of the optimality of the PS arising from its functional purpose is the level of reliability of the protection of X-ray objects provided by the system, and the criterion of efficiency is the required probability of solving the problem of protecting information at a fixed time (interval) of time [3].

The mathematical formulation of the problem of structural optimization of PS is:

$$\left.\begin{aligned} &\overline{G}\left(D_{\overline{G}}, M_{0\overline{G}}, F_{\overline{G}}\right) \in \arg\max R_з; \\ &M_0 \in M_B, C \in C_{\max}, R_з \geq R_н. \end{aligned}\right\}$$

In expression (1), the following notation is used: $\overline{G}$ - the efficiency vector of the NN objects of the CII corresponding to the functional purpose of the protection system; $D_{\overline{G}}$ - the structure of the NW as a whole, given by the composition of the functional subsystems; $M_{0\overline{G}}$ - the structure of the subsystem of monitoring the electromagnetic environment and protection against DER, as well as localization (elimination) of leakage channels of protected information, defined by the optimal variant of the composition of TEPI; $F_{\overline{G}}$ - the goal function of controlling the properties of the above subsystem [3,4].

To implement the concept of increasing the level of protection, it is proposed to use the ITOSS (Intellectual Technology of Optimization and Stabilization of Systems) technology, which involves developing and applying fundamentally new approaches to technical solutions for protecting objects from radiation, taking into account that functioning of the disparate non-equilibrium components of the system either compete with each other or form new compounds that stabilize each other. The stabilizing subsystems, in turn, are focused on fundamentally new functions arising from a set of randomly possible ones, and form stable modes that subordinate other subsystems to themselves. As a result, a new stable system structure is formed, using the existing protection technologies more rationally, while simultaneously searching for combinations of existing technologies and then finding their optimal trajectory in order to achieve the maximum or maximum effect of their application, and in conditions of limited

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resources, with high demands on the protection parameters This becomes quite relevant and leads to a decrease in the economic costs of its creation [4].

Taking into account the analysis, let us highlight the following: with the help of an evolutionary choice, it is necessary to select the most efficient technologies, which together will contribute to the creation of a system for protecting facilities and their TM with economic effect [5,6].

Obtaining the necessary protection technology for objects is conveniently represented in the form of a graph shown in Figure 1.

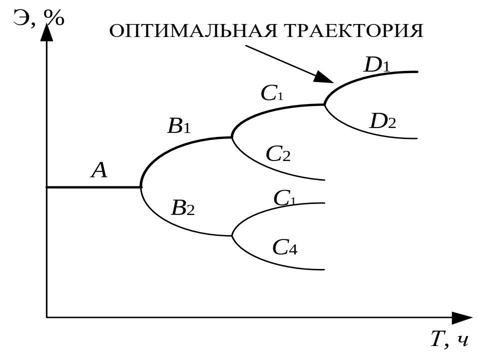

Fig. 1. The process of choosing the optimal trajectory of the formation of technology to protect objects CII

Let us assume that the source technologies of protection A, B, C are available at the facility. To obtain an effective protection technology, it is necessary either to develop or acquire the missing D, G technologies on the market and then invest funds to adapt and harmonize a variety of source technologies on the considered object [7].

When constructing the scheme (Fig. 2), we give each edge of the graph a weight — the cost of the corresponding technology, and a loop — we will add the weight of the cost of implementation (adaptation) at the corresponding object.

On the graph, the resulting technology will be denoted by E and, in accordance with set theory, it can be defined as follows:

$$E = A \cup B \cup C \cup D \cup G. \quad (2)$$

For the development of this technology additional financial investments are needed, so as a result, we are moving from E to technology H, which in general can include both the acquisition and development of new technologies.

To this end, it is necessary to conduct periodic monitoring of the technology being developed to identify its subcomponents that are applicable in other systems of similar purpose (Fig. 3).

The process of forming the necessary technology to protect objects from radiation, which is characterized by a set of certain properties, can be represented as a structural diagram consisting of a chain of consecutive links. Each property is created as it passes through a link of a certain cycle of the technological process and can only appear at the final stages.

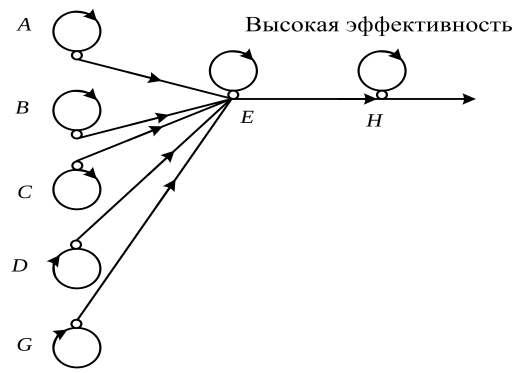

Fig. 2. Graph characterizing the development of new technologies.

***HIGH EFFICIENCY**

In principle, it can be assumed that each link in the technological chain has an impact on the qualitative characteristics of the parameter, which can be estimated using the experiment planning method [4, 7].

We believe that at the end point Z (Fig. 3) a technology should be created, the use of which will make it possible to obtain, with a certain probability, an PE that satisfies the requirements for the protection of objects from radiation.

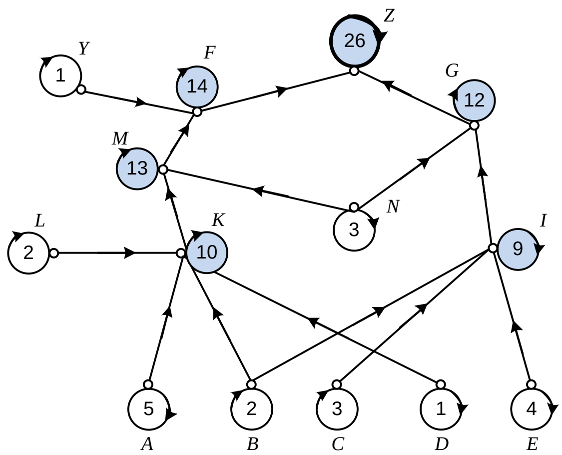

Fig. 2. Graph of creation of new technologies.

At the initial stage, there are initial technologies A, B, C, D (a certain technology is assigned to each vertex). Instead of drawing several edges between the same vertices, A and K, you can draw only one edge, assign multiplicity indicating how many times this edge should be counted. Each non-isolated vertex of the graph has one or more edges, for which A serves as an end. All these edges are called incident vertex A. The weight of such edges is denoted by and is called the degree of vertex A, and there are n ways to reach vertex Z.

Stages of development of technology to protect objects from radiation

Such technology can be developed by organizations that have a different set of technologies, which, moving along the graph to point Z, either develop the missing ones or buy technologies from manufacturing firms. Each edge is assigned a weight - the cost of technology. In our case, there are two manufacturers (competitors): the first has many technologies: A, B, C, D, the second - only E. Next, the following operations are carried out with sets of technologies: union (addition) of sets, intersection of sets, addition of sets, inclusion of one sets to another, etc. There are two ways: $\left(A,B,D \to K \to M \to F \to Z\right)$ and $\left(E,B,C \to I \to G \to Z\right)$, at the same time, many technologies are acquired: in the first case - L, N and Y, in the second - N, and technologies are developed at the vertices K, M, F and Z - in the first case; I, G, Z - in the second. For a formalized description, it does not matter how many edges (technologies) are drawn between one or another vertex. Such relations in the general case can be obtained. If one takes into account mutual influences, they can have a more complex form and should be considered using fuzzy logic methods.

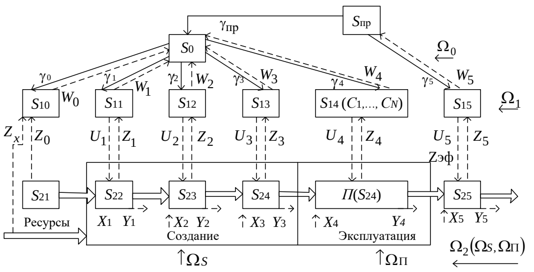

Fig. 4. Considering the heritability of properties in the mathematical description of product life cycle management

The feasibility of choosing the path of developing a new technology is determined primarily by efficiency. Of the n paths should be selected, having the lowest cost, provided that the parameters of the product or new technology are the same. In practice, it is necessary to choose a compromise solution in order to best meet the criteria: scientific and technical level of quality, reliability and cost, risk, competitiveness, etc.

Accounting for the heritability of properties in the mathematical description of product life cycle management processes is based on a three-level hierarchical representation scheme of a complex quality management system (Fig. 4), ensures that heredity is taken into account in the evolutionary development of technologies, including innovation, and allows the development of basic technologies to protect objects from radiation economic costs in creating new technologies to protect against destructive impacts, which ultimately will lead to increased efficiency proposed protection system [4-7].

The quality of the functioning of the PS objects from radiation is largely determined by the choice of optimal options (methods and methods) of protection based on the availability of financial (budget) funds allocated to achieve the chosen goal of protection [8-10].

The approach to optimizing such a system by enumerating all its options under tight time constraints is not feasible due to the large dimension of the task, which, when developing protection measures, is usually reduced by some heuristics, and the effectiveness of protection is calculated by the criterion of minimum attracted forces and means.

Indicators of optimality of the PS, taking into account its functional purpose, are the level of reliability provided by the PS of objects under destructive radiation conditions, and the effectiveness criterion is the required probability of solving the problem of protecting objects in a fixed time interval. The protection system performs the function of complete or partial prevention of exposure to the protected object. The main characteristic of the protection system is the probability of preventing damage caused to the X object in the specified conditions.

Let us denote $\overline{D}_C$ the total damage prevented by EPI, and prevented damage due to the implementation of measures to protect through $\overline{D}_{RS}$. We formulate in general terms the task of synthesizing facilities to protect objects from radiation: it is necessary to choose such an option to protect objects of infocommunication systems, which minimizes the damage D_C caused by minimum financial cost of its creation. The task of minimizing damage is replaced by an equivalent task of maximizing preventable damage $\overline{D}_C$ from the effects of threats D_C at acceptable costs allocated to the protection system Exp_{adm} with a fixed vector of distribution of the means of destruction $\overrightarrow{Df}$.

Prevented damage in general is determined by the following dependency:

$$\overline{D}_C = F\left(p_{D_{ij}}; D_C; P_{D_C\text{пред}}\right),$$

and prevented damage due to the implementation of protection measures - dependency

$$\overline{D}_{RS}\underset{Exp_{\text{adm}} \to \min}{} = F\left(p_{D_{ij}}; D_C; P_{D_C\text{пред}}\right) \to \max. \quad (4)$$

Damage can be determined in absolute terms: economic losses due to catastrophic failures of the elements of objects (CE), time costs and the amount of information destroyed or “spoiled”, etc.

It is very difficult to estimate the damage in practice, especially in the early stages of designing GIS, therefore it is advisable to use relative damage, which represents the degree of danger of electromagnetic radiation for objects, instead of absolute damage. The degree of danger can be determined by an expert in the

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assumption that the threat of the use of destructive effects on the object constitute a complete group of events:

$$0 \le D_C \le 1; \sum_{\forall ij=1}^{n} D_{ij} = 1. \quad (5)$$

The task of synthesizing and building a system to protect objects from radiation is to find the optimal variant when searching for equilibrium in mixed strategies used in game theory [8-10], for which the following notation is used: mixed i $(i=1,...,m)$ player strategy p_i in the final non-coalition game, i.e. complete a set of probabilities of applying its pure strategies, forming a complete group of events:

$$p_i = \{p_{i1}, p_{i2}, ..., p_{i,m_i}\}, \quad \sum_{j=1}^{n} p_{ij} = 1, \quad p_{ij} \ge 0, \quad j = 1,...,n_i. \quad (6)$$

The strategy p_i will present the possibility of achieving a maximum of prevented damage $\overline{D}_{RS_i}$. The set of mixed strategies S_i of player i is a simplex $\sum_{m_i}$, , and the mixed strategy $\mathrm{e}_j \in S_i$ of the player i corresponds to its j pure strategy.

Accordingly, the mixed strategy q_j of the player j $(j=1,...,n)$ in the final non-cooperative game is the full set of probabilities of using his pure strategies:

$$q_j = \{q_{j1}, q_{j2}, ..., q_{j,n_i}\}, \quad \sum_{i=1}^{n} q_{ji} = 1, \quad q_{ji} \ge 0, \quad i = 1,...,m_j \quad (7)$$

and, also, represents the possibility of achieving the minimum expenditure of permissible financial resources $Exp_{\mathrm{adm}j}$ necessary for the construction of PE facilities of CII.

The solution in such a situation, according to von Neumann's theorem, is called a pair of mixed strategies $\left(p^{\mathrm{opt}}, q^{\mathrm{opt}}\right)$ that forms the saddle point of a function $\Pr_A(p,q)$, i.e . [8-10]:

$$\Pr_A\left(p, q^{\mathrm{opt}}\right) \le E_A\left(p^{\mathrm{opt}}, q^{\mathrm{opt}}\right) \le \Pr_A\left(p^{\mathrm{opt}}, q\right), \ p \in \sum_m, \quad q \in \sum_n, \quad (8)$$

Where

$p^{\mathrm{opt}} \in \arg \max\limits_{p \in \sum_m} \min\limits_{1 \le j \le n} E_A(p,q)$, $q^{\mathrm{opt}} \in \arg \min\limits_{q \in \sum_n} \max\limits_{1 \le j \le m} \Pr_A(p,q)$ - optimal mixed strategies, like solving a matrix game in mixed strategies [8-10].

However, the most difficult issue in assessing prevented damage is determining the likelihood of prevented damage under the impact of an electronic attack $\overline{P}_{D_C \text{пред}}$ in the design of EPI. Assuming that this probability is determined by how fully taken into account the qualitative and quantitative requirements for the system of protection of the objects of CII in their design, i.e.

$$\overline{P}_{D_C \text{пред}} = f_i\left(x_{i1}, \ldots, x_{ij}, \ldots, x_{im}\right), \quad (9)$$

where x_{ij} - the degree of fulfillment of the i-th requirements for EPI to eliminate the j-th external influence, $i = \overline{1,m}; \ j = \overline{1,n}.$

where $P_{D_C \text{пред}}(0) = 0$ is the probability of preventing PS attack (impact consequences) in case of non-compliance with the protection requirements; $\frac{\partial P_{D_C \text{пред}}}{\partial x_{ij}} = \gamma_{ij}^{\mathrm{opt}}$ - the value characterizing the degree of influence of the i-th requirement on the likelihood of the system preventing the attack from an attack (the importance of meeting the i-th requirement to prevent exposure to electromagnetic radiation of objects). Obviously for $i = \overline{1,n}$ that $0 \le \gamma_{ij}^{\mathrm{opt}} \le 1; \sum_{j=1}^{m} \gamma_{ij}^{\mathrm{opt}} = 1$.

After substitution of the corresponding values in expression (10) we get:

$$\overline{P}_{D_C \text{пред}} = \sum_{i=1}^{m}\sum_{j=1}^{n} \gamma_{ij}^{\mathrm{opt}} \cdot \overline{x_{ij}} + \sum_{i}^{m}\sum_{j=1}^{n} \gamma_{ij}^{\mathrm{opt}} \cdot \mu\left(x_{ij}\right)^{\mathrm{opt}}. \quad (10)$$

Thus, the task of synthesizing PE objects of the CII is reduced to the optimal substantiation of the quantitative and qualitative requirements for the system at acceptable economic costs and takes the form:

$$\max \overline{P}_{D_C \text{пред}}\left(x_{ij}; i = \overline{1,n}; \ j = \overline{1,m}\right),$$

while limiting $Exp\left(x_{ij}\right) \le Exp_{\text{доп}}, i = \overline{1,m}; \ j = \overline{1,n}$,provided $\min Exp\left(x_{ij}; i = \overline{1,m}; \ j = \overline{1,n}\right)$

In the absence of information on threats, an indicator of the following form can be used to solve problem (26):

$$\overline{P}_{D_C \text{пред}} = \sum_{i=1}^{m}\sum_{j=1}^{n} \gamma_{ij}^{\mathrm{opt}} \cdot \overline{x_{ij}} + \sum_{i=1}^{m}\sum_{j=1}^{n} \gamma_{ij}^{\mathrm{opt}} \cdot \mu\left(x_{ij}\right)^{\mathrm{opt}}. \quad (12)$$

Evaluation of the economic gain from the introduction of scientific and technological solutions to improve the integrated protection of the objects of the CII from EMR, radiation and interference

In accordance with the formulation of the task to select the optimal variant of measures for organizing and ensuring the protection of objects from radiation, the main stages of its solution are:

- collection and processing of expert information on the characteristics of possible threats: the frequency of occurrence of ij threats and possible damage $D_{ij}\left(i = \overline{1,m}\right)$;

-collecting and processing expert information to determine the importance of fulfilling the i-th requirement

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to eliminate possible j-th threat and membership function $\mu(x_{ij})^{opt}, (i=\overline{1,n},\ j=\overline{1,m})$;

-estimation of the cost of the PE for a particular variant of its implementation, depending on the degree of fulfillment of the requirements $Exp(x_{ij}; i=\overline{1,n};\ j=\overline{1,m})$;

- development of a mathematical model and an algorithm for choosing a rational option for constructing a EPI (rational specification of requirements) in accordance with the statement of problem (8) as a linear programming problem (simplex method).

As a typical object of CII, potentially exposed to radiation, of different nature of origin, including destructive, let us take an automated control system (ACS) of one of the life support systems, which is located in the model task, designed without taking into account the possibility of such effects. In this connection, the PE at the facility does not satisfy the requirements for security, and there is a need for a number of activities aimed at its improvement.

The cost of the hardware complex located at the facility CII is 2,094,000 rubles. Thus, the damage from radiation exposure will amount to $D_C(Att_k) = 2\,094\,000$ RUB. We introduce qualification signs corresponding to protective measures, which are divided into the following types: external and internal decoration of the RPMP of the CII facility building, installation of modular shielding structures (MSS) of welded and modular type into the building, and multilayer shielding of the CE building; multilayer shielding of the CE case with a shielding factor that provides the required level of protection of the object from radiation. The shielding factor achieved during protective actions in accordance with the qualification criteria is $\eta_{E(H)} = 100-120$ dB: exterior and interior of the building of the subject of the CII object - taking into account the cost of materials (screening metallized protective nets AARONIA 2000+, SISALKRAFT), as well as costs associated with supporting the project for interior or exterior decoration of the presented object with an area of 420 m2 - 580,000 rubles); installation of all-welded and collapsible MSS for equipment placement (OOO “NTTs Faraday”, St. Petersburg) - 814,000 rubles; multilayer shielding of the corpus of electronic means, taking into account the cost of manufacturing and applying RPPKM - 3577 rubles / m2 (OOO NPP "Spetsoborudovanie", Izhevsk), respectively, the cost of screening CE as part of the ACS is 272,000 rubles.

Using the data obtained in order to solve the optimization problem in mixed strategies, the payment matrix was compiled using the Gauss-Jordan method:

Strategy of player «A»	**Strategy of player «B»** B_1	B_2	B_3	B_4	
A_1	0,272	0,814	2,094	0,58	$S_A^* = \begin{vmatrix} A_1 & A_2 & A_3 & A_4 \\ 0,25 & 0,25 & 0,25 & 0,25 \end{vmatrix}$ Optimal strategy of «*A*»
A_2	0,814	0,272	0,58	2,094	$S_A^* = \begin{vmatrix} B_1 & B_2 & B_3 & B_4 \\ 3,4559 & 0,8656 & 0,2677 & 0,25 \end{vmatrix}$ Optimal strategy of «*B*»
A_3	0,58	2,094	0,272	0,814	
A_4	2,094	0,58	0,814	0,272	
Lower cost of game – α = 0,272; higher cost of game – β = 2,094; cost of game ν = 0,94.					

The numerical values in the payment matrix are indicated as follows: 0.58 - 580 000 rubles, 0.272 - 272 000 rubles, 0.814 - 814 000 rubles. and 2, 094 - 2,094,000 rubles. Players' strategies: “A” - defense, “B” - attacks. The obtained solution of the optimization problem means that for the organization of the PE ACS in terms of radiation, financial expenses of no more than 940,000 rubles are needed, which are the initial data for estimating the economic gain from carrying out measures to protect the facilities using the integral indicator:

$$Э_П = \int_{t=0}^{T} \left[\left(|M_Б(t) - M_П(t)| - |P_Б(t) - P_П(t)| \right) \times \frac{1}{(1+K_{dc})} - (K_Б(t) - K_П(t)) \right] dt$$

Where $M_Б(t)$ and $M_П(t)$ the estimated material losses; $K_Б(t)$ and $K_П(t)$ - capital investments; $P_Б(t)$ and $P_П(t)$- operating costs for the implementation of measures to protect against radiation exposure in the baseline and planned options, rubles / year, respectively; K_{dc} - discount rate. Accept $M_Б(t)$= 2,094,000 rubles / year, $M_П(t)=0$, $K_Б(t)=0$ and $K_П(t)=$ 940,000 rubles / year, $P_Б(t)=P_П(t)$ = 0; $K_{dc}=0,1$. Substituting these values into the expression of IEE we get = 963 500 rubles / year.

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RESULTS & DISCUSSIONS

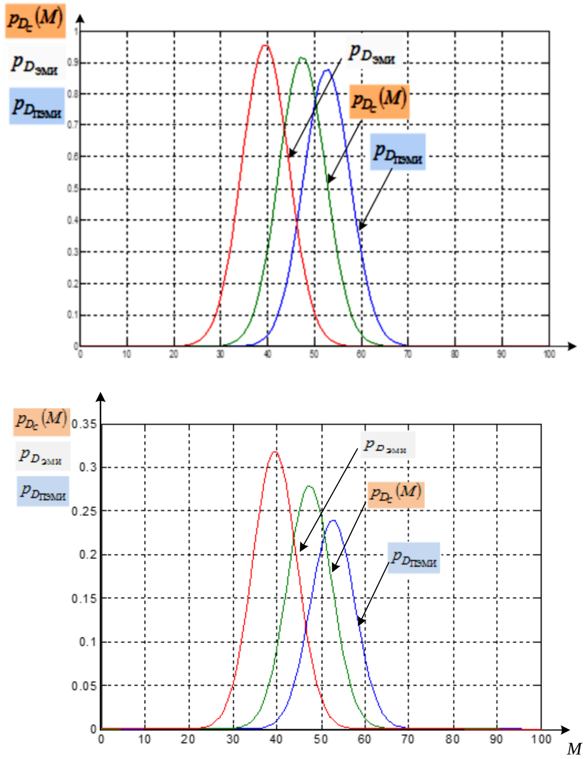

Fig. 5 - The probability distribution of damage to the facilities of the CII:

a - without the use of protective equipment; b - using protective equipment.

The application of the proposed protection measures leads to a significant reduction in the probability of causing damage and an increase in the level of complex protection of the facilities of the CII and the CE functioning in them, as evidenced by the graphs of the probability distribution of the damage to the objects when exposed to electromagnetic radiation, emissions and pickups of radiation.

II. CONCLUSION

The problem of increasing the level of complex protection of objects from radiation should be considered from the point of view of optimization and stabilization, which implies the development of fundamentally new approaches to technological solutions in the field of protection of complex non-equilibrium systems based on their inherent self-organization principles. Such a system will be able to solve problems of simultaneously protecting objects from external and internal radiation, which ultimately will lead to lower economic costs and more rational use of protection technologies or search for combinations of existing technologies and then finding the optimal trajectory to achieve maximum economic and technical effect.

REFERENCES

1. Dvilyanskiy, A. A. and others. Ensuring the security of information and telecommunications facilities when exposed to an electromagnetic pulse. Proceedings of the Second International Scientific Conference on Security Issues and Counter Terrorism. Moscow State University, 2006. - M.: MCCME, 2007. - 664 p.
2. Harker, D., Bacon P., Snyder J., et al. Intellectual buildings. Design and operation of the information structure. - M.: Networks MP, 1996. - 386 p.
3. Polezhaev, A. P. Optimization of an object-based system for protecting information about dual-use products / A. P. Polezhaev, V. I. Vasilets // Special equipment, No. 5. - Moscow: Electrozavod, 1996. - P. 1–5 .
4. Dvilyanskiy, A. A. A synergetic approach to building a system for protecting objects of infocommunication systems from electronic attacks / A. A. Dvilyanskiy, V. A. Ivanov // Instruments and systems. Management, control, diagnostics: Nauchtechlitizdat. - 2015. - № 6. - P.7–16.
5. Zhernenko, A. S. Multicriteria choice of optimal design solutions in telecommunications: studies. allowance / A. S. Zhernenko, V.V. Marakulin. - St. Petersburg: St. Petersburg State. University of Telecommunications prof. M.A. Bonch-Bruyevich, 2010. - 60 p.
6. Doroshenko, V. A. Method of multicriteria choice of options based on genetic algorithm / V. A. Doroshenko, L. V. Druk, M. S. Usachev // MGUL Bulletin - Lesnoy Vestnik, No. 3 (86). - Moscow: FGBOU VPO MGUL, 2012. - P. 160–166.
7. Gudkov, A. G. Interaction of technological innovations of technological heredity in the process of the evolutionary development of technologies / A. G. Gudkov, V. V. Popov // Science-intensive technologies. - № 9. - 2011. - P. 61–69.
8. Pisaruk, N. N. Introduction to the theory of games / N. N. Pisaruk. - Minsk: BSU, 2015. - 256 c.
9. Nash, J. Equilibrium points in n-person games. Proceedings of the National Acadamyof Science 36 (1950) 48–49.
10. Vereshchagin, N. K. The Beginning of Set Theory / N. K. Vereshchagin, A. Shen. - Moscow: ICNMO, 2012.
11. Peregudov, F. I. Introduction to systems analysis: a textbook for universities / F. I. Peregudov, F. P. Tarasenko. - Moscow: High School, 1989. - 367 p. : 4 Il.
12. Lewing, L. System Identification. Theory for user /L. Lewing: Per. from English ; by ed. Ya. Z. Tsypkina. - Moscow: Science. Ch. ed. Phys.-Mat. lit., 1991. - 432 p.
13. Dvilyanskiy, A. A. Methods for optimizing the system for protecting an information object from the effects of an electromagnetic pulse / A. A. Dvilyanskiy, V. A. Ivanov // News of Tula State. un-that. Series "Technological systems engineering". Issue 9. - Tula: TSU, 2006. - p. 20–25.
14. Dvilyanskiy A. A., Ivanov V.A. Optimization of the information security system of information communication objects from cyber-terrorist threats. // "Information Systems and Technologies". Mathematical and computer simulation № 3 (77) May-June. Pp. 118-126.