

Development of analytical model for managing emergency preparedness and response system to nuclear power facility accident

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Abstract. In this work, a control model of the emergency preparedness system for nuclear and radiation accidents was synthesized, a block diagram of the control system of the emergency preparedness system for nuclear and radiation accidents was developed, and the control vector of the emergency preparedness system for nuclear and radiation accidents was determined to achieve the required performance indicator of target emergency preparedness and response activities.

1 Introduction

A critically important area of strategic development of the state, which has a decisive impact on national safety, is power energy, including nuclear energy. In the process of functioning of nuclear industry facilities, if the goals of the management personnel's activities are not achieved, emergency situations arise. Among the challenges faced by nuclear energy, the need for timely implementation of measures aimed at modernizing information management systems and equipment to achieve safety goals at operating nuclear power plants was noted.

According [1] nuclear power development trends include strengthening the emergency preparedness review mission by expanding the circle of experts serving as reviewers, facilitating the self-assessment process using the Emergency Preparedness and Response Information Management System, increasing the transparency of findings and the use of performance indicators to assess the effectiveness of each mission. There are various threats to the physical security of energy infrastructure facilities, as well as nuclear energy infrastructure facilities [2]. It is obvious that there is a task in developing a model for managing an emergency preparedness and response system to a nuclear and radiation accident (EPRS to NRA). Without the methodological basis for solving management problems of EPRS to NRA in the form of conditions for the existence of the process, it is impossible to guarantee the achievement of the goal of the activity. This situation has given rise to a fundamental problem: "The results of activities to solve the problems of emergency preparedness and response to a nuclear and radiation accident do not meet the expectations of the decision maker (DM)". The purpose of the study is to develop the model for managing the EPRS to NRA.

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2 Materials and methods

The activity is based on decision of a human (DM) [3]. The activity is based on the model [4-5]. The DM operates on the basis of three categories: System, Model, Purpose [4]. Therefore, two problems need to be solved.

1. There are two known approaches to system development:

- Development of a system based on analysis.
- Development of a system based on synthesis.

Based on the analysis – the system is simple in construction, but achieving the goal of the activity is problematic. The direction – development of a system based on synthesis – is the most correct, but without knowledge of the law of construction and operation of the system, the implementation of such an approach is very problematic. The results of research by the leading scientific and pedagogical school "System Integration of Public Administration Processes", registered in the register of leading scientific and scientific and pedagogical schools of St. Petersburg, make it possible to implement a synthesis of the model based on the use of the Law of Object Integrity Saving (LOIS). LOIS – a stable, objective, repeating connection between the properties of an object and the properties of its actions for a fixed purpose [3].

2. The DM acts on the basis of the model. Therefore, it is necessary to synthesize adequate models. The use of LOIS allows us to ensure their adequacy.

For the adequacy of the decision, it is necessary to use a system-forming factor (SFF) – this is a consequence of the theory of functional systems by academician of the USSR Academy of Medical Sciences and the USSR Academy of Sciences P.K. Anokhin.[6] Therefore, the model for managing the EPRS to NRA in this research work is built on basis of the conditions for the existence of DM activity process.

A practical sign of the presence of SFF is that the developed (correctly constructed system) gives the required result (academician of the USSR Academy of Medical Sciences and the USSR Academy of Sciences P.K. Anokhin). From this chain of logical reasoning follows a fundamental and very useful for practice conclusion – all objects of the surrounding world created by man are an implementation of the decision model of a person, the chief designer.

If one is guided by the methodology for constructing a properly constructed system [4-5], then it is necessary to implement the scheme presented in Figure 1, a). Currently, well-known publications present the results of forming a solution model based on the diagram in Figure 1, b). The decision models obtained according to this scheme suffer from conceptual incompleteness and often will not guarantee the achievement of the goals of the activity.

It follows that if there is an adequate model of a human's decision, then the model of the construction and functioning of the object with which the human works will be adequate. And the object itself, when functioning, will give the required result.

To build models for solving problems of emergency preparedness and response to a nuclear and radiation accident, it is necessary to understand the physical meaning of the DM's decision.

In well-known publications that consider the issues of constructing and implementing decisions, both in the past, for example, the work of Academician of the USSR Academy of Sciences and the Russian Academy of Sciences Moiseev N.N., Orlovsky S.A., and in the present, for example, the work of Corresponding Member of the Russian Academy of Sciences Novikov D.A., a decision is usually understood as a "choice of alternatives". For this, the apparatus of game theory, nonlinear programming, etc. was often used. But as noted by famous systems engineers Druzhinin V.V., Kontorov D.S., the approach based on the "choice of alternatives" suffers from conceptual incompleteness [5]. And this in practice

leads to the fact that the result of the activity does not meet the expectations of the DM [4-5].

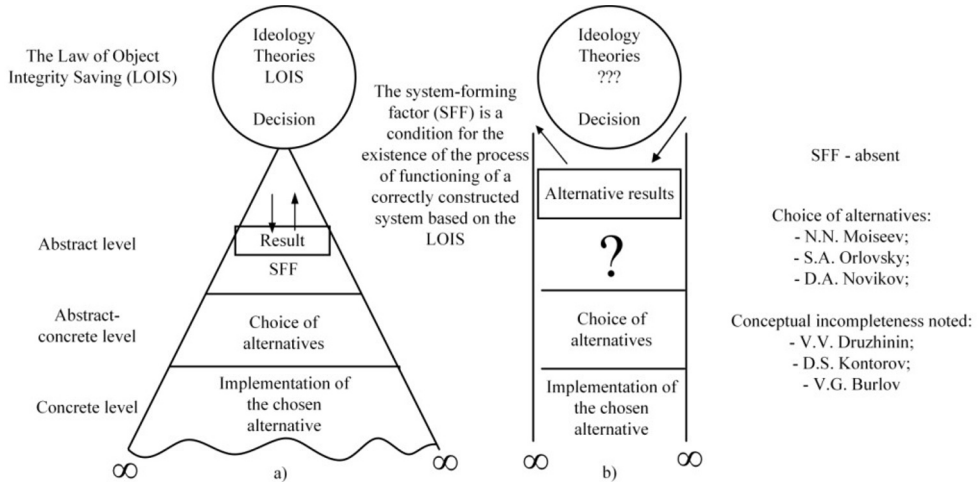


Fig. 1. SFF as a condition for the existence of the process of functioning of a correctly constructed system.

The unsatisfactory management result is justified by contradictory findings. To eliminate contradictory conclusions, the axiomatic method should be used. Only this method allows us to eliminate arbitrariness in reasoning. The axiomatic method assumes the existence of the following elements:

- Basic assumptions, usually expressed in basic principles.
- Basic concepts, keywords, Axioms; Deduction rules; Theorems.

The application of this method requires identifying the participants in the process:

- Man, his consciousness.
- The World around us.
- Something that is given by nature and allows for cognition (Universal connection of phenomena)

To create conditions that guarantee achievement of the goal of the activity, a Natural science approach (NSA) is used to solve the problems of emergency preparedness and response to a nuclear and radiation accident. NSA is determined by the integration of the properties of human Thinking, the surrounding World and Cognition. The three-component structure is reflected in three principles.

1. The principle of three-component cognition:

- Component A – abstract representation (condition of existence, methodology).
- component B – abstract-concrete representation (cause-and-effect relationships, methods).
- Component C – concrete representation (technologies, algorithms).

2. The principle of the integrity of the World. LOIS is being implemented.

3. The principle of the cognoscibility of the World. It is implemented using the following methods: decomposition, abstraction, aggregation.

Examples of systems built on the basis of synthesis are given in [7-9].

3 Results

The principle of three-component cognition is that a person, consciously or not, develops a decision at three levels of the situation representation. In the process of activity, a person operates with the categories "System", "Model" and "Purpose". Therefore, it is especially correct to consider and use these categories.

The basis of activity is always a decision of human (DM). A human forms the decisions based on a model. A model of object is a description or representation of an object that corresponds to the object and allows one to obtain characteristics about this object. Therefore, a decision is a model of the process with which a human works. For synthesis, an NSA based on the LOIS is used.

The synthesis of a mathematical decision model is carried out on the basis of a developed methodology for transforming a verbal decision model into a formal, mathematical one. The method of transforming a verbal model into a formal one consists in regulating the states of basic processes by the Principles of the three-component cognition, the integrity of the World, and the cognoscibility of the World.

Everything that exists is a process. A process is an object in action with a fixed purpose. Since a human actually carries out his activities through properties, it is necessary to determine three basic properties that correspond to the characteristics of the process. These are the properties "Variability", "Objectivity" and "Integrity" [4-5]. Variability is a property of an object that characterizes its ability to become different, not the same as it was. This is a property, in the absence of which there is always the possibility of an object losing its purpose. Objectivity is a property of an object that characterizes its possibility of existence outside the consciousness of the subject. Purpose is something that is predetermined. It is set by the meta system and evaluated by the indicator of the effectiveness of the object's use.

In accordance with the developed NSA, each process must be represented by three components corresponding to the properties "Objectivity", "Integrity" and "Variability" (or the concepts "Object", "Purpose" and "Action", respectively), which is a consequence of the application of the principle of the integrity of the World. These three components are arranged horizontally. On the one hand, they can be interpreted in three different levels of knowledge of the world (abstract, abstract-concrete, concrete), which is a consequence of the application of the Principle of three-component cognition. This approach determines the presence of three vertical levels. In Figure 2. a structural scheme of the deployment of the content of "Decision" category as a process is presented.

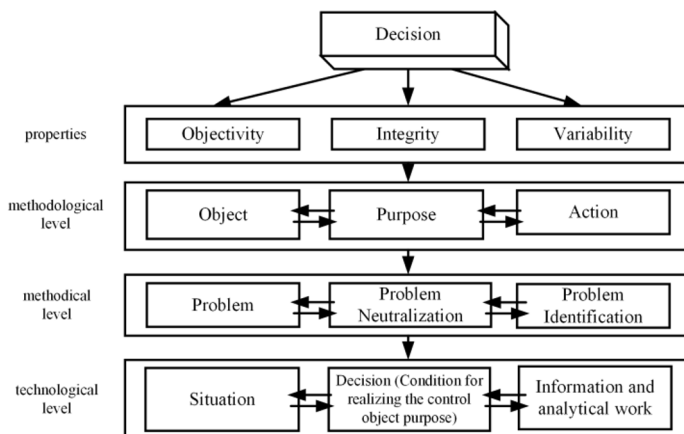


Fig. 2. Structural scheme of the deployment of the content of «Decision» category as a process.

The scheme shows that a human experience the world through three basic properties. These are "Objectivity", "Integrity", "Variability". The DM works with the "Process" category. Therefore, the decision is presented at the methodological level as a process in the form of interconnected components "Object", "Action", "Purpose". At the methodic level, "Object" corresponds to "Problem". "Action" corresponds to "Problem Identification", because "Identification" is based on identifying the fact of the manifestation of energy. "Purpose" corresponds to "Problem Neutralization". Since neutralization is possible only if the results of "Identification" correspond to the essence of the "Problem". This confirms the fact that cause-and-effect relationships have been identified. At the technological level, the "Decision" as a "Process" is represented as a connection of three components. These are "Situation", "Information and analytical work", "Decision" (Condition for realizing the control object purpose). "Situation" are the factors and conditions in which activities are carried out. "Information and analytical work" – continuous extraction, collection, study, display and analysis of data about the situation. "Decision" is a condition for realizing the control object purpose.

Having presented the "Decision" in the form of a connection between the three components considered, it is necessary to proceed to the development of a structural scheme for interpreting the process of the mathematical model synthesis of the "Decision".

In Figure 3 a structural scheme for interpreting the process of the mathematical model synthesis of the "Decision" is presented.

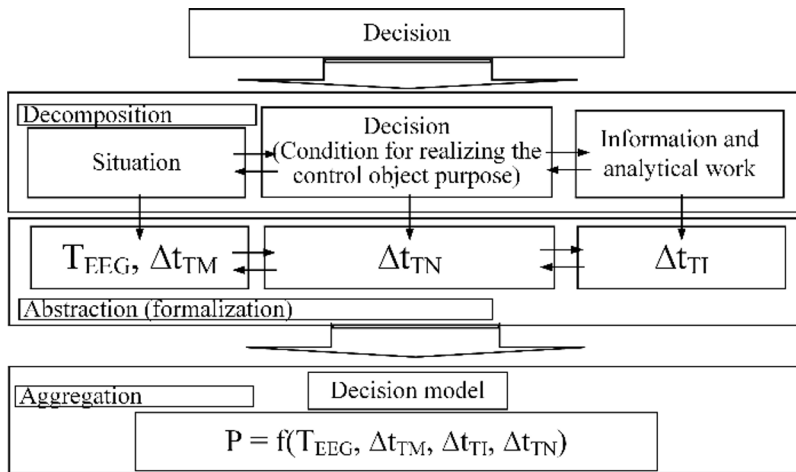


Fig. 3. Structural scheme for interpreting the process of the mathematical model synthesis of the "Decision".

To synthesize the model, methods of decomposition, abstraction and aggregation are used, which is a consequence of the application of the principle the cognoscibility of the World. Using the decomposition method, we will present the "Decision" in the form of three interconnected components: "Situation", "Information and analytical work", "Decision". The basis of such a connection is the LOIS. Again, a consequence of the application of the principle of integrity of the World. The application of the abstraction method allows us to obtain three elements corresponding to the elements obtained based on the decomposition. The "Situation" is characterized by two processes: the target process of the DM, the process of threat manifestation of a nuclear and radiation accident. The mathematical model of the target process is the average time of the target process of the DM: $T_{EEG} = f_0(\alpha_1, \alpha_2, \dots, \alpha_n, \alpha_{n+1}, \dots, \alpha_m)$, where vector \aleph characterizes the states of the target

process of the DM's activity. $\aleph \in G_{\aleph}$, where G_{\aleph} – bounded closed set. A mathematical model of the process of threat manifestation of a nuclear and radiation accident is the average time of threat manifestation of a nuclear and radiation accident for the DM: $\Delta t_{TM} = f_1(x_1, x_2, \dots, x_a, x_{a+1}, \dots, x_b)$, where vector X characterizes the states of the threat manifestation process. $X \in G_x$, where G_x – bounded closed set.

The mathematical model of information and analytical work is the average time of threat identification of a nuclear and radiation accident by the DM: $\Delta t_{TI} = f_2(y_1, y_2, \dots, y_c, y_{c+1}, \dots, y_d)$, where vector Y characterizes the states of the threat identification process. $Y \in G_y$, where G_y – bounded closed set.

The mathematical model of the decision (condition for realizing the control object purpose) is the average time of threat neutralization of a nuclear and radiation accident by the DM: $\Delta t_{TN} = f_3(z_1, z_2, \dots, z_e, z_{e+1}, \dots, z_f)$, where vector Z characterizes the states of the threat neutralization process. $Z \in G_z$, where G_z – bounded closed set.

These four elements are presented in the diagram in Figure 4, where a) average time of the target process, b) average time of threat manifestation of a nuclear and radiation accident; c) average time of threat identification of a nuclear and radiation accident; d) average time of threat neutralization of a nuclear and radiation accident). Application of the aggregation method allows us to obtain the condition for the existence of a decision in the form of the following relation $P = f(T_{EEG}, \Delta t_{TM}, \Delta t_{TI}, \Delta t_{TN})$ where P – characterizes the degree of achievement of the goal in conditions of emergency preparedness and response to a nuclear and radiation accident (a performance indicator for assessing the effectiveness of each mission). This is the probability that every threat arising in the nuclear power safety loop has been identified and neutralized. Thus, the analytical model for managing the EPRS to NRA was obtained.

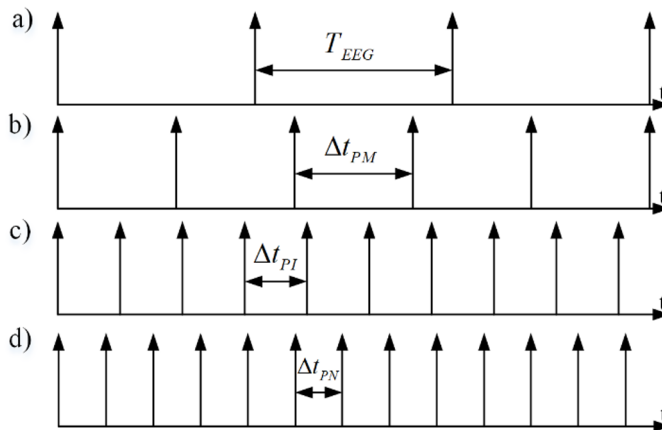


Fig. 4. Diagram of manifestation of the basic elements of forming a decision model.

A structural scheme of EPRS to NRA management, including variables of the model for managing the EPRS to NRA is presented in Figure 5. The Situation and Crisis Center (SCC), the Industry Functional Subsystem for the Prevention and Elimination of Emergency Situations, and a nuclear power plant are considered as management subjects. Interdepartmental interaction between the listed management entities is ensured by the information and communication system (ICS). The Industry Functional Subsystem for the Prevention and Elimination of Emergency Situations lays down the requirements for the process of threat neutralization of a nuclear and radiation accident. SCC lays down the requirements for the process of threat identification of a nuclear and radiation accident. A nuclear power plant lays down the requirements for the target process – the electrical

energy generation. To determine the suitability of the technical and personnel support of EPRS to NRA, an indicator of the frequency of failure of the electrical energy generation process was introduced – the average time of fact occurrence of the failure of target process (TTPF). This indicator shows how often the control results of a nuclear power plant may not meet the requirements of the electrical energy generation process. The scheme shows two states: S1 – the normal, initial state of EPRS to NRA operation (the beginning of the basic process description of the DM target activity), S2 – the required final state of functioning of EPRS to NRA, in which it is located as a result of the control action implementation of the generated by the DM based on the identification of the threat (task) and its neutralization (decision).

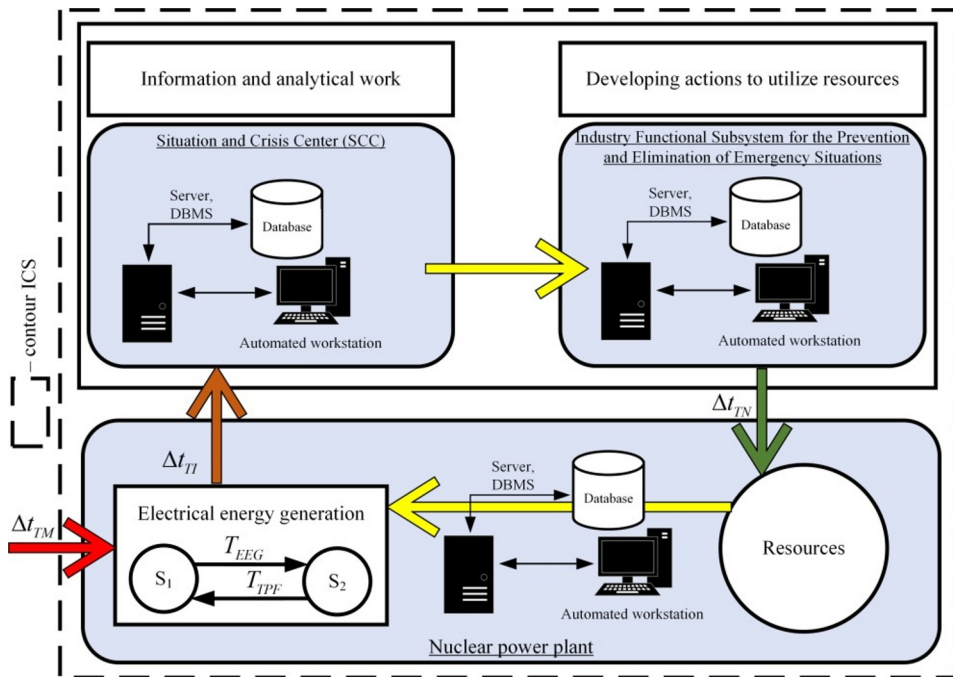


Fig. 5. Structural scheme of EPRS to NRA.

In the model for managing the EPRS to NRA, three parameters are associated. The analytical dependence of the generalized characteristics of the situation (Δt_{TM}), information and analytical work (Δt_{TI}) and neutralization of the threat (Δt_{TN}) has been established.

Taking into account the above, the control vector of EPRS to NRA is represented in the following form:

$$\vec{U} = [\Delta t_{TI}, \Delta t_{TN}] \quad (1)$$

Where Δt_{TI} , Δt_{TN} are components of the control vector. Thus, the DM has the opportunity to vary two control functions (identification and neutralization) in various combinations to achieve the required degree of goal implementation in conditions of emergency preparedness and response to a nuclear and radiation accident.

The formalized control criterion of EPRS to NRA is defined as a mapping of the Cartesian product of a set of functions onto a numerical set, the elements of which are the values of the effectiveness indicator of target activities for emergency preparedness and response to a nuclear and radiation accident:

$$G_x \times G_y \times G_z \rightarrow I_{TAEI} \quad (2)$$

$$P = f(T_{EEG}, \Delta t_{TM}, \Delta t_{TI}, \Delta t_{TN}) \in I_{TAEI} \quad (3)$$

Here I_{TAEI} – set of values of the target activity efficiency indicator from 0 to 1.

Only formalized connections make it possible to obtain adequate results, thereby ensuring the achievement of the goal of the activity.

4 Discussion

The importance for the international community of ensuring regulation and environmental justification of nuclear energy use, as well as confirmation of the need for further promotion in ensuring a high level of nuclear safety worldwide is emphasized in [10]. The developed analytical model of process control based on synthesis is applicable to any economic sector, including industry, trade, finance, services and others. It allows you to ensure the safety of the implementation of the purpose of the facility at every stage of its operation, which makes a significant contribution to the overall concept of national security. The model ensures optimal allocation of resources, minimization of risks and timely decision-making that contributes to the sustainable development of the facility and its adaptation to changing external destructive conditions

5 Conclusions

As a result of the study, first the EPRS to NRA managing model was synthesized. After that EPRS to NRA structural scheme has been developed, than the EPRS to NRA control vector has been determined to achieve the required efficiency indicator of target activities for emergency preparedness and response to a nuclear and radiation accident.

The model for managing the EPRS to NRA is based on the system integration of four basic processes:

- The target process (electrical energy generation)".
- The process of threat manifestation of a nuclear and radiation accident".
- The process of threat identification of a nuclear and radiation accident".
- The process of threat neutralization of a nuclear and radiation accident.

System integration of four basic processes allows us to ensure a sufficient level of interdepartmental interaction between the management subjects of EPRS to NRA, which is expressed in the guaranteed achievement of the required indicator of the effectiveness of target activities for emergency preparedness and response to a nuclear and radiation accident.

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