RISK ASSESSMENT OF NUCLEAR POWER PLANTS

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The objective of the present work is to develop recommendations for controlling the safety of nuclear power plants on the basis of risk assessments and safety certification of nuclear power plants. The Kursk nuclear power plant is considered as an example of a nuclear power plant with an RBMK reactor. The concept of risk assessment of a nuclear power plant consists in constructing a set of scenarios of the appearance and development of possible accidents followed by an evaluation of the realization frequency and determination of the scales of the consequences of each one. The result of an analysis is an evaluation of a system of risk indicators in accordance with the requirements of the safety compliance certificate of the nuclear power plant as well as the development of recommendations for increasing plant safety. In risk assessment, the consequences are divided into categories of the seriousness of the damage, for which their probability is evaluated separately. The graphical interpretation of risk due to any dangerous object consists of frequency–consequences curves. Recommendations are developed on the basis of the results of risk analysis.

The Federal Law “On the technical regulation” defines risk as the probability of doing harm to the life or health of citizens, damage to the property of individuals or legal entities, state or municipal property, the environment, the life or health of animals and plants taking account of the seriousness of this harm.

The safety of nuclear power plants, just as the safety of any other dangerous objects, is of a stochastic nature and is due to internal and external phenomena of natural and technogenic origin. The probabilistic characteristics of nuclear power plant safety correspond to the risks associated with accidents at the plants and other emergency situations of technogenic and natural origin with direct and indirect consequences for the population and supranormative contamination of the environment.

The Kursk nuclear power plant is examined here as an example of a nuclear power plant with an RBMK reactor. Probabilistic risk assessment is based on the methodology of probabilistic safety analysis of a nuclear power plant [1, 2]. The methodological approach used in the present work is based on the tree models – failure and event trees. In this approach, there exists a well-developed methodological base and an extensive database, and it uses many verified computational programs. Its main tenets for risk assessment include a deterministic analysis of safety, determination of weak points in the design which increase the probability of core damage, taking account of measures for controlling accidents and liquidating the consequences of an accident, criteria for the acceptability of risk, and development of measures for increasing the safety of a nuclear power plant.

The general procedure used for evaluating risk includes three successive stages:

1) Analysis of the natural and technogenic danger, errors made by workers at the nuclear power plant, failures of equipment and systems, destruction of buildings and structures in the nuclear power plant as a result of extreme external and internal events. The objective of the analysis is to determine the probabilities (frequencies) of radioactive emissions into the...
environment in accordance with the adopted categories of damage (corresponds to level 1 and 2 probabilistic analysis for nuclear power plants).

2) Evaluation (based on the results of paragraph 1) of the risk indicators for harming the life and health of physical individuals (public and plant works), property of individuals and legal entities (public, operating organization of the nuclear power plant, other legal entities defined individuals) in natural indicators in conformance to the categories adopted for harm (corresponds to a probabilistic analysis of level-3 safety for nuclear power plants). Natural indicators of harm are dose loads, the number of deterministic and stochastic effects of irradiation, and the concentration of radioactive substances on the grounds of a nuclear power plant and outside the sanitary-protective zone.

3) Evaluation (based on the results of paragraph 2) of the risk indicators of harming the life and health of individuals (public and plant workers), property of individuals and legal entities in accordance with the harm criteria adopted in the economic indicators. The economic indicators of harm are the costs of the measures for preventing or decreasing the harm to the health of the public and plant workers, payments as compensation for deaths, medical treatment, loss of property of individuals and legal entities.

To make a quantitative assessment of the integral (from all possible accidents) risk, it is necessary to know the probability (frequency) of dangerous situations $F$, the level of the corresponding dangerous actions on people $D$, for example, the possible level of the radiation dose, and the coefficient $k$ that relates with dangerous actions the probability (frequency) of death of people, for example, cancer deaths at dose 1 Sv. Then the integral individual risk is determined by the relation

$$R = \int kD(x)dF(x) < R_{at},$$

where $x$ is the integration parameter, and $R_{at}$ is a normative indicator [3].

The objective of risk assessments is to develop recommendations for increasing nuclear power plant safety (risk control) by analyzing the results of risk assessment, including a determination of the dominant contribution to risk, analysis of significance, sensitivity, and uncertainty of the results of the assessment. Failure of equipment and safety systems and failure for common-cause reasons and due to worker errors can all make the main contribution to risk. Determining the dominant contribution makes it possible to understand the significance of every event in the final probability function of an accident. In other words, the weakest points in the designs and technological processes in a nuclear power plant can be identified. The significance of a contribution to the risk of a nuclear power plant is determined by its location in the integral logical structure of a model of the object as well as the probability.

Sensitivity analysis is performed in order to evaluate the changes of the rate of equipment damage occurring in a nuclear power plant when the base events of the probabilistic analysis (operator action, equipment operation, and others) change. Such an analysis permits using the results of a probabilistic analysis as a means for investigation possible risk-lowering measures (validate the financial costs of upgrading the nuclear power plant).

There are two basic classes of uncertainty of the results: probabilistic and deterministic. In turn, each one is divided into two types: uncertainty of the parameters of the model and uncertainty of the model. The uncertainty of a probabilistic model can be evaluated by means of the Fisher and $\chi^2$ tests [2]. The uncertainty of the parameters of a probabilistic model can be evaluated by means of analytical-statistical modeling [4], the uncertainty of a deterministic model can be evaluated by stochastic approximation of a deterministic model [5]. The uncertainty of the parameters of a deterministic model can be evaluated by the Monte Carlo, Latin hypercube, and other methods [2].

In the general case, risk analysis of nuclear power plants for controlling plant safety consists in constructing a set of scenarios of the appearance and development of possible accidents followed by an evaluation of the frequency of realization and determination of the scales of the consequences of each of them. In the present work, risk is evaluated for two accident development scenarios within the framework of the development of a safety compliance certificate for the Kursk nuclear power plant – the most dangerous and most likely scenarios. An accident where the initiating event is loss of process water, in which the emergency reactor cooling system (including the water tank part) fails simultaneously with a loss of process water, is taken as the most dangerous scenario. An accident in which the initiating event is average steam leak with emission of radioactive steam directly into the environment (by-pass) is considered as the most likely scenario. Social risk diagrams (see Fig. 1) are constructed on the basis of the results of the risk assessment.