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Development of approaches to estimation of risk parameters

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Abstract

To a great extent, safety is ensured in the design and operation of hazardous production facilities (HPF) through identifying, analyzing and predicting the risk of accidents (failures), involving, where possible, a more complete quantitative risk estimation in determination of the HPF condition [1], which is the responsibility of the Federal Service for Environmental, Technological and Nuclear Supervision (Rostechnadzor). Among the HPFs, where multifactor risks exist at the stage of design, a special place is occupied by nuclear power installations, shelf development facilities, oil and gas platforms, as well as critical infrastructure facilities as the assets essential for the healthy state of society and the national economy in conditions of impacts from the catastrophic risk factors [2–4].

The issues involved in the estimation and prediction of hazards from unfavorable situations, emergencies, accidents and failures are considered in [2,3,5–7] where the safety of HPFs is defined by two major factors: probability of an unfavorable event (situation) and the damage from such event, using different risk identification methods, including recent advances in the asymptotic theory of the probability of extreme values.

To solve the risk estimation problems, issues involved in the estimation of risk parameters have been considered with different options of the HPF state graphical space interpretation. Peculiarities of estimating the risk sensitivity and the risk degree have been described and the evolution of approaches to the estimation of risk in the HPF design and operation has been shown. Big data analysis methods for risk management have been proposed.

Keywords: Risk degree; Risk sensitivity; Residual risk; Uncertainty indicator; Risk management; Big data.

Introduction

On the whole, the methodology of risk estimation has been investigated in detail by many distinguished scholars [1–7]. The first one worthy of note is Gumbel's approach based on statistics of extreme lifetime values for the HPF's individual accessories. In this case, the prediction is estimated as the minimum quantity among the extreme estimates of the fail-safe operation time for components. He developed respective concepts and provided a theoretical basis for the approach that opens up access to all of the information on the properties of the component lifetime distributions [2–4]. The second approach developed by Cox concerns with the construction of censored estimates for the results of specially planned experiments to investigate the limiting states. It is based on the assumed stability of the respective statistical properties of the HPFs under investigation. Presumably, the third approach is based on the concept of ensuring the HPF dependability properties which are represented in this case as dynamic objects operating on the given set of states. Commonly used in the system analysis of decisions made in the estimation and prediction of risks, e.g. in nuclear power, are Farmer's ideas concerning the graphical interpretation of technology-related risk areas using diagrams represented by lines of an equal level on the risk plane [2,3,5–8].

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The consideration of issues involved in the estimation and prediction of the understudied risk parameters, as shown above, seeks to look into the critical tasks of improving the quality of prediction in selection or decision-making in conditions of a risk in the design or operation of an HPF.

Improvement and evolution in estimation and prediction of risk parameters

An analysis with respect to the insufficient quality of the risk estimation and prediction for an HPF and its accessory equipment shows that there are system causes which, in a generalized form, are defined by the following outstanding issues [9]:

- models to estimate and predict the HPF and accessory equipment risk have been understudied;
- the dynamics of the safety characteristics behavior has not been taken sufficiently into account as applied to external influencing factors;
- no spectrum of unlikely unfavorable events leading to the HPF safety violation has been covered;
- the statistical data on the HPF accessory equipment failures is not complete;
- low reliability of risk estimates due to differences in the simplifications made, etc.

At the same time, the HPF and accessory equipment risk can be estimated and predicted using a generalized mathematical model which is described and interpreted graphically in [10].

The classical approach to determining the quantitative value of the risk R is interpreted by Farmer's diagram known as iso-risk curve or equiangular hyperbola the asymptotes of which coincide with the coordinate axes [10–13]. If the probability of the initial events P_i and the damage Z_i are independent random quantities defined in a general case by their own distribution laws $f_p(p/z_i)$ and $f_z(z/p_i)$, then $R=H\{p, z\}$, and the risk distribution function $F_R(\mu)$ has the form [11]

$$F_R(\mu) = \iint_W f_p(p) f_z(z) dp dz, \tag{1}$$

where W is the definition range given as

$$W : \begin{cases} 0 \le p \le 1; \\ 0 \le z \le z_{\max} \end{cases}.$$

Then it is possible to represent the set of equal-level risk (iso-risk) curves which depends on the functional structure and interactions of the HPF accessory equipment, environmental impacts, types of hazards and threats, etc [9,10]. So, there is a certain scatter of Farmer curves which can be represented in the form of an uncertainty range, including iso-risk curves in the optimistic and the pessimistic predictions F_O, F_P, as shown in Fig. 1 where Z is the level of damage; P is the probability of failures; and F_I is the initial iso-risk line. The inacceptable risk region lies above F_I, and the acceptable risk region lies below F_I; the probabilities P_d^1 and P_d^u, P_m^1 and P_m^u, P_o^1 and P_o^u characterize the lower and the upper values of the interval estimate for the probability of failures at the stage of development, monitoring (during different tests) and operation of the HPF accessory equipment; the characteristic risk areas in the said uncertainty regions A_O, B_O, C_O, A_P, B_P, C_P are associated with the presence of errors in development, monitoring and operation when the HPF accessory equipment moves into the limiting state region. Specifically, the regions A_O, B_O, C_O, A_P, B_P, C_P define the modules that characterize the behavior of iso-risk curves. Since a risk analysis involves intrinsically a great deal of uncertainty [12] due to variations in different parameters and assumptions, the application of such modules makes it possible to analyze the risk sensitivity depending on decreases in some of the individual input parameters.

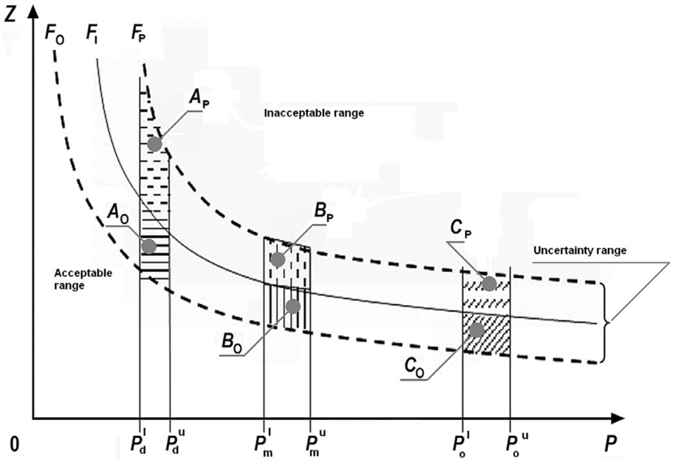

Fig. 1. Improvement of Farmer's diagram.

Using the materials in [12,13], one may show that only the cost-benefit analysis method contains the principle of risk division into three levels:

- the level above which the risk is inacceptable and shall not be accepted other than in extraordinary circumstances;
- the level below which the risk is low, and only monitoring is required to keep it;
- the central area where the risk shall be kept as low as possible, the presence of which defines the acceptable risk region, that is, risk is permitted if benefits have been gained. We shall consider the concept of plotting this region (Fig. 2).

There is an experience of computing the technology-related risk values [10,13], which shows that determination of the damage Z_i does not involve any fundamental difficulties, except organizational ones caused by subjective factors. In the cost-benefit analysis procedure, it is possible to introduce the upper (Z_u) and the lower (Z_l) damage levels that limit the acceptable risk region (see Fig. 2). Most problems are known [10] to turn up in determination of the probability values for the initial events of failures. By now, a variety of models based on logical-probabilistic methods has been devel-