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Technology for Probability Assessment of Elementary Hazard Events

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Author's contribution

This work was carried out by the author alone.

Research Article

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ABSTRACT

The aim of the work is to develop a technology for Basic Events (BE) probability assessment at a given predictive interval, with consideration of the situation at potentially hazardous facility (plant, factory, storage; armory) at the beginning of the predictive interval. With this objective, the following tasks are formulated: 1) Develop a logical basis for BE probability assessment which includes (a) formalization of possible situations, (b) formalization of situation impacts on cumulative distribution function (CDF) of BE, (c) computation of BE probability assessment; 2) Develop technological stages of the BE probability calculation. The computing technology for probability assessment of undesirable events occurring at the elements of potential hazard facilities is proposed. The technology uses the expert knowledge, statistical data and analytical methods. The user's role is reduced to the setting of predictive interval and formalizing of the situation description. Novelty: The proposed technology enables to use the failure models together with expert knowledge about the situations arisen at potentially-dangerous objects. Practical importance: since the technology reflects a real-life situation at a facility, the prognosis is more reliable.

Keywords: Prediction technology; failure models; expert knowledge; hazard factors; situation impact; cumulative distribution function; probability assessment.

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ABBREVIATIONS

AC: Adjustment Coefficient; BE: Basic Events; CDF: Cumulative Distribution Function; ECDF: Etalon Cumulative Distribution Function; EK: Expert Knowledge; ETA: Event Tree Analysis; FM: Failure Models; FTA: Fault Tree Analysis; KB: Knowledge Base; MCDF: Mono-Influence Cumulative Distribution Function; MEES: Method of Expert Evaluative Scales; PHF: Hazardous Facilities; PSA: Probabilistic Safety Assessment; VIB: Vibration Factor.

1. INTRODUCTION

Accident prevention at potentially hazardous facilities (PHF) is an urgent problem of technogenic safety. PHF include nuclear power plants, plants for chemically hazardous substances, stores for fire-hazardous and explosive objects and substances, as well as their separate units. The theoretical basis for the solution of this problem is the Probabilistic Safety Assessment (PSA) [1,2]. One of the central PSA tasks is the probability estimation of technological accidents and emergencies. However, the solution of this problem meets the objective difficulties, in particular, when formalizing the hazard origin at potentially hazardous objects.

Potentially hazardous facility (the "System" below) is the complicate system where the structural elements are clearly identified (for example, nuclear power consists of reactor, steam generator, turbine, circulating pumps). Events that happen at system elements are named Basic Events (BE). BE include: equipment failures, staff errors, and environmental phenomena. In certain combinations, BE may lead to a system failure (accident). Cause-and-effect relations between the events are formalized by logical-and-probabilistic modeling techniques: "Fault Tree Analysis" (FTA) and "Event Tree Analysis" (ETA) [3,4]. As a result, accident is formalized as a disjunctive normal form where BE are logical variables. After replacing logical variables by corresponding probabilities, and logical operations by corresponding arithmetic operations, the probability of hazard occurrence can be evaluated by means of analytic functions where BE probabilities are the arguments. Thus, the task of estimating the accident probability at a specified prognostic interval ($\tau_P, \tau_P + \Delta\tau$) adds up to the solution of two problems:

- formation of the accident model in the forms of FTA and ETA;
- BE probabilities assessment.

The first task does not cause technical difficulties. To solve the second problem, the following approaches are used:

- Living Probabilistic Safety Assessment (LPSA);
- Failure models (FM);
- Expert knowledge (EK).

1.1 The Use of LPSA

LPSA [5] was designed as a complement to the traditional PSA for online account of changes at PHF. These changes were caused by equipment replacing or by its failure. In the case of an element replacement, the probability of its failure (BE probability) is set equal to nominal. In the case of element failure, the probability of the corresponding BE is set to 1. In addition, the LPSA technology provides for the monitoring of parameters characterizing the state of equipment (monitoring of key parameters). Key parameter is physical setting that defines the equipment operability. Achieving key parameter threshold means that the equipment is in down state. The overrun of key parameter is considered as the BE realization. Its probability is set to 1. In both cases, after the registration of aberrations at PHF and corresponding BE probability adjustments, a new calculation of accident probabilities is provided according to the traditional PSA models [1-4].

1.2 The Use of FM

The task consists of two parts: the BE model formation and BE probabilities estimation. There are two types of failure models: probabilistic and probability-physical. Model has the form of the cumulative distribution function (CDF) of failures. Probabilistic models are used when failures are strictly stochastic. The most popular models are: exponential, log-normal, Weibull [6]. The input to these models is the statistical data on failures. Disadvantages of probabilistic models: the aging and the depreciation of equipment is not considered; there is no way to make a reliable probability assessment with a lack of statistical data; the influence of equipment physical characteristics and service conditions on the failure probability is not considered. Probability-physical models are used in cases when failures depend on the processes of equipment degradation (fatigue, depreciation, corrosion, and aging). Models of this type include: α-distribution; diffusion monotonous distribution (DM-distribution); diffusion nonmonotonic distribution (DN-distribution) [6,7]. The advantage of probability-physical models is that the model parameters can be calculated on the basis of both failure statistics and data on physical degradation. This feature is especially valuable when it is necessary limiting the amount of testing to prevent equipment destruction.

The process of model formation consists of following procedures: select the type of distribution, equipment testing, and estimation of distribution parameters (the scale and pattern parameters). Calculation of distribution parameters can be performed: by plausible estimate method, the method of moments, the quantile method, and method of key parameter dynamics determination [8,9]. In the latter case, the formation of failure model takes into account the threshold of key parameter [9].

Note. Probability of exceeding key parameter threshold characterizes the degree of technical risk [10].

The weak point in the formation of adequate failure models is the following. To create the BE model, data derived from failure statistics and test equipment results are used [9]. As a result, the parameters of the received model do not reflect the particular circumstances of the situation when the assessment of BE probability has been performed. Ultimately, the risk predictions calculated under normal situations are conservative, and the estimates calculated under abnormal situations are understated. To make BE probabilities estimation more accurate and reliable, specific system conditions must be taken into consideration when model formation.

1.3 The Use of EK

To establish the BE probabilities estimation, expert knowledge can be used in the form of knowledge base (KB). KB is specialized according to the types of adverse events and facility classes. It includes expert estimates of the causal hazard factor values, possible situations at PHF, and factor influences on BE occurrence. Such KB can be integrated into automated PSA complex. One of the methods for creating and using such KB is a Method of Expert Evaluative Scales (MEES) [11,12]. MEES allows for formalizing of the relationship between the situations that arise at PHF and BE probabilities.

Thus, BE probability can be defined according to:

- The fact of system component replacement, the fact of the actual failure or exceeding key parameter threshold (namely LPSA);
- Failure statistics (namely probabilistic and probability- physical models);
- Key parameter dynamics (namely probability-physical models);
- Formalized description of situations arising at PHF (namely MEES).

The natural problem appears to create a means for the formalization of relations between these three approaches (LPSA, FM, and EK) to be used in the united technology of BE probabilities calculation. Therefore, the most acceptable release for practical prediction is a combination of probabilistic and expert methods.

This work is the sequel to the cycle of previous papers [11-14,17].

Objective: (1) to develop the technology for joint usage of failure models and expert knowledge to assess the elementary hazard events probability, and (2) to concentrate the main results of previous works in one compact presentation in the form of BE probability assessment technology.

With this objective, the following tasks are formulated:

- Develop a logical basis for BE probability assessment which includes:
    - Formalization of possible situations;
    - Formalization of situation impacts on BE CDF;
    - Computation of BE probability assessment.
- Develop a technological stages of the BE probability calculating.

It is assumed that for any point of time, the operating time is uniquely defined. Then the prediction interval can be interpreted as the operating time interval $(t_p, t_p + \Delta t),$ where t_p - operating time at the τ_p moment; Δt - operating time increment during $\Delta \tau$ time.

2. LOGICAL BASIS FOR BE PROBABILITY CALCULATION

2.1 Formalization of Possible Situations at the System

Situation at the system is represented as a set of the causal hazard factor values $X_j(j = \overline{1,k})$. Causal factors influence the BE occurrence independently. For each factor, the possible values $(x_{j,1};x_{j,2};...;x_{j,L_j})$ are preliminarily defined. These values are ordered according to the degree of factor influence on BE probability, and the first value $(x_{j,1})$ is considered to be the norm factor $\left(x_j^N\right)$ [12]. The situation "C" is given if one specific value is determined for each factor $X_J\left(j=\overline{(1,k)}\right)$:

$$"C": X_1 = x^c_{1,i_1}; X_2 = x^c_{2,l_2},..., X_k = x^c_{k,l_k} \tag{1}$$

Note: Description of situations with the use of factors was firstly proposed by R.Axelrod [15]. Classification of the hazard causal factors characterizing equipment properties, its operating conditions and procedure is proposed in [16].

A simplified example of situation description:

Let us suppose: expert analysis has shown that the situation at the system is determined by factors: humidity(X_1), vibration(X_2), ambient temperature(X_3), mode of equipment usage(X_4), technological discipline at service(X_5), the quality of power supply(X_6), equipment remaining life(X_7). In addition, possible factor values are set as: normal (N), satisfactory (S), anxiety (A), and hazard (H). Then, the total number of possible situations at the system is equal to 4^7. Most safe situation is described by the vector (N, N, N, N, N, N, N), and the most hazardous – by (H, H, H, H, H, H, H,). Vector (S, N, N, S, A, S, A) defines the situation when $X_1 = S$; $X_2 = N$; $X_3 = N$; $X_4 = S$; $X_5 = A$; $X_6 = S$; $X_7 = A$.

2.2 Formalization of Situation Impacts on BE CDF

Assume that ***n*** of different BE ($BE_i\left(i=\overline{1,n}\right)$) can appear at system elements, and the situation described by conditions (1) could take place in the system. Notation: $F_i^c(t)$ is CDF of $BE_i\left(i=\overline{1,n}\right)$ probability. Function $F_i^c(t)$ is a result of the independent factor sets impact on *BE_i*, and the impact of each factor is described by a separate specific function.

Definition 1. Mono-influence cumulative distribution function (MCDF named as $F^M_{i,j}(t,x^c_{j,l})$) is a function that determines a relation between casual factor X_j $(j=\overline{1,k})$ and the probability of BE occurrence when $X_J = x^c_{j,l}$ and all other factors do not influence BE occurrence, i.e. provided:

$$(X_j = x^c_{j,l}) \cap (\forall_{(q=\overline{1,k},q\neq j)} X_q = x^N_q) \tag{2}$$

where x_q^N is ordinary value of factor X_q.

MCDFs have the property that the function $F_i^c(t)$ can be represented in the form of their superposition [11]. Suppose that the situation in the system is described by (1), and MCDF $F_{i,j}^M(t, x_{j,l_j})\ (j=\overline{1,k})$ are generated for situational values $x_{j,l}^c$ of factor $X_j\ (j=\overline{1,k})$ on *BE*

BE_i. Then CDF of $BE_i\ (i=\overline{1,n})$ probability can be represented by the expression [17]:

$$F_i^c(t) = 1 - \prod_{j=1}^{k} [\ 1 - F_{i,j}^M(t, x_{j,l}^c)\ ] \tag{3}$$

Thus, the problem of BE probability computing adds up to the MCDF construction.

Definition 2. The Etalon cumulative distribution function (ECDF named as $F_i^N(t)$) is a function that determines a relation between normal factor values and the probability of BE occurrence, i.e. provided:

$$\forall_{(j=\overline{1,k})} X_j = x_j^N \tag{4}$$

where $x_j^N = x_{j,1}$ are the normal factor values.

Properties and the relationship between ECDF and MCDF:

a. MCDF of X_j is monotonic according to ordered factor values, i.e.

$$F_{i,j}^M(t, x_{j,q}) \le F_{i,j}^M(t, x_{j,l}) \quad \text{when} \quad q \le l \tag{5}$$

b. ECDF does not exceed the corresponding values of MCDF for all $l \in \overline{1, L_j}$, i.e.

$$F_{i,j}^M(t, x_{j,l}) \ge F_i^N(t) \tag{6}$$

c. MCDF values of all factors coincide with each other when $l = 1$, i.e.

$$F_{i,j}^M(t, x_{j,1}) = F_i^N(t) \tag{7}$$

d. MCDF of X_j (when $X_j = x_{j,l}$) indicates an increase in *BE_i* probability relatively to ECDF. This increase has occurred as a result of $X_{j,l}$ deviation from the norm on the value of $\left|x_{j,l} - x_j^N\right|$. Denote $\eta_{i,j}(x_{j,l})$ as the degree of X_j influence on ECDF when $X_j = x_{j,l}$ and name it as situational amendment. The relationship between ECDF and MCDF can be written as:

$$F_{i,j}^{M}\left(t,x_{j,l}\right)=F_i^{N}(t)*\eta_{i,j}\left(x_{j,l}\right) \tag{8}$$

It is possible to propose a geometric interpretation of the expressions (5-8).

ECDF and MCDF functions describe the trajectory of CDF values during the operating time changing. Each value of the causal factor corresponds to one trajectory. Location of trajectories relatively to each other can be characterized by the terms "lower" and "higher." Trajectory "A" is located below the trajectory "B" if the ordinates of its points do not exceed the corresponding ordinates of "B" points. Then the expressions (5-8) can be interpreted as follows. Expression (5) means: The smaller the causal factor value, the lower the corresponding trajectory is located. Expression (6) means: the trajectory of the etalon functions (ECDF) is located below all other trajectories. The expression (7) means: all trajectories that correspond to the smallest value of the factors coincide with etalon trajectory. The expression (8) means: the trajectory corresponding to the situational values of hazard causal factors can be formed on the basis of etalon trajectory and situational amendment.

Thus, according to expressions (3) and (8), the formalization of situational impacts on BE CDF adds up to the construction of BE ECDF and the formation of situational amendments. The first component is created using the probabilistic and probability-physical failure models on the basis of test equipment in the most favorable (normal) conditions [8,9], and the second - on the basis of expert evaluations using the analytic hierarchy process [18]. This conclusion is new for Basic Events probability assessment.

2.3. Computation of BE Probability Assessment

The Computation is based on the fact that the failure probability in a given predictive interval is the opposite value to the operational availability function. It can be shown that the failure probability in this interval is defined by the following expression [14]:

$$P_c\left(BE_i \setminus [t_p, t_p+\Delta t]\right)=(F_i^{c}(t_p+\Delta t)-F_i^{c}(t_p)):(1-F_i^{c}(t_p)) \tag{9}$$

where $P_c\left(BE_i \setminus [t_p, t_p+\Delta t]\right)$ is *BE*$_i$ probability in the interval $(t_p, t_p+\Delta t)$ provided (1); $F_i^{c}\left(t_p\right)$, $F_i^{c}\left(t_p+\Delta t\right)$ are the function values $F_i^{C}(t)$ for the moments determined by t_p and $t_p+\Delta t$.

3. TECHNOLOGICAL STAGES OF THE BE PROBABILITY CALCULATING

There are two components in the calculating technological process of the BE probability assessment: KB preshaping necessary for solving computational problems, and BE probability calculation in verification mode of hazardous object.

3.1 KB Preshaping

KB includes: a description of the factors influencing the BE_i occurrence; adjustment coefficient (AC) for a separate factor value influencing BE_i; ECDF parameters and program calculation procedures for each BE_i.

3.1.1 Creating a set of independent factors influencing the BE_i occurrence. It is founded on expert judgment. The set of factors includes manufacturing quality of system element, maintenance, rate of exploitation, operating environment aggressiveness, etc. The description structure is given in section 2.1.

3.1.2 AC brief account for a separate factor value influencing BE_i. The expert uses the analytic hierarchy process (AHP) [18]. He performs paired comparison of factor X_j values. Criterion is the degree of separate factor value influencing BE_i. The result is a matrix of paired comparisons. Then automatic procedure is performed according to AHP which calculates AC. As a result, K vectors are formed for each BE_i:

$$\overline{\eta}_{i,j} = (\eta_{i,j}(x_{j,1}),...,\eta_{i,j}(x_{j,L_j}) \; \left(i=\overline{1,n}\right) \tag{10}$$

3.1.3 ECDF formation

This procedure is similar to the traditional CDF technology [9]: the selection of type failure distribution, testing of homogeneous elements group, the calculation of CDF parameters using testing results. The peculiarity of this procedure is that the tests are carried out under conditions (4). As a result, the analytic representation of ECDF probability is formed for each BE_j:

$$F_i^N(t) = Z_i^N(t,\mu,\upsilon) \tag{11}$$

where Z_i^N is the analytic representation of ECDF, μ,υ - scale and pattern parameters, t - operating time.

3.2 BE Probability Calculation in Verification Mode of Hazardous Object

The inputs to the procedure are:

- pre-formed KB;
- predictive interval $(t_p, t_p + \Delta t)$ specified by the user;
- description of the situation at the facility at the beginning of predictive interval $x_1^c; x_2^c,..., x_k^c$.

Situational values of hazard causal factors are the result of the monitoring facility.

3.2.1 Preparatory stage

Information about BE_i is selected from KB:

- BE_i ECDF description (distribution type, scale and pattern parameters, the software calculation procedure for $F_i(t)$);
- AC description relating to BE_i in the form (10).

3.2.2 Calculation of ECDF values for predictive interval boundaries is carried out by the substitution of t_p and $t_p + \Delta t$ values in the form (11).

Result: $F_i^N(t_p)$ and $F_i^N(t_p + \Delta t)$.

3.2.3 The selection of element $\eta_{i,j}(x_{j,l_j})l_j \in (\overline{1,L_j})$ from each vector $\overline{\eta}_{i,j}$ ($j = \overline{1,k}$) satisfying the condition $x_{j,l_j} = x_j^c$. The result is:

$$\eta_{i,1}(x_1^c), \eta_{i,2}(x_2^c), \ldots, \eta_{i,k}(x_k^c) \tag{12}$$

3.2.4 Calculation of MCDF ($X_j \; (j = \overline{1,k})$) values for t_p and $(t_p + \Delta t)$ is carried out by the substitution of pt 3.2.2 and pt 3.2.3 results in the form (8).

$$F_{i,j}^M(t_p, x_j^c) = F_i^N(t_p) \times \eta_{i,j}(x_j^c)\,;\, F_{i,j}^M(t_p + \Delta t, x_j^c) = F_i^N(t_p + \Delta t) \times \eta_{i,j}(x_j^c) \; \left(j = \overline{1,k}\right) \tag{13}$$

3.2.5 Calculation of $F_i^c(t)$ values for predictive interval boundaries by the substitution of the results of pt 3.2.4 in the form (3).

$$F_i^c(t_p) = 1 - \prod_{j=1}^{k} [1 - F_{ij}^M(t_p, x_j^c)]\,; \quad F_i^c(t_p + \Delta t) = 1 - \prod_{j=1}^{k} [1 - F_{ij}^M(t_p + \Delta t, x_j^c)] \tag{14}$$

3.2.6 Calculation of BE$_i$ probability for a given situation by the substitution of the results of pt 3.2.5 in the form (9).

$$P_c\left(\text{Б}C_i \setminus [t_p, t_p + \Delta t]\right) = (F_i^c(t_p + \Delta t) - F_i^c(t_p)) : (1 - F_i^c(t_p)) \tag{15}$$

Steps 3.2.1 - 3.2.6 are performed for all BE$_i$ $\left(i = \overline{1,n}\right)$. The problem is sold.

Note. The obtained probability values BE$_i$ $\left(i = \overline{1,n}\right)$ are substituted in the logical-probabilistic model of the accident. Accident probability assessment in the predictive interval is calculated. On this basis, the risk level of analyzed situation is determined as well as further analysis and decision-making to prevent the accident.

4. APPLICATION

This technology is a new one which has never been used for real objects. It does not serve as an alternative to the existing PSA but augments its capabilities. The scope is the prediction of technological hazards at potentially explosive and chemically hazardous facilities, nuclear and hydropower plants. The technology is especially effective when it is necessary to take into account the influence of material fatigue. Here there is the example of possible technology applicability.

It is based on a specific incident that occurred at Sayano–Shushenskaya (now Rus Hidro) hydroelectric power plant (Yenisei River, Russia) on August 2009. The information was taken from the open State Commission Report.

Background: Hydro power began operating in 1978. The estimated capacity is 6000 mgv, dam height is 200 m, number of turbines is 10, and designed useful life of each turbine is 30 yr. Management of turbines operation is carried out by an automatic control system. The control algorithms are focused on optimizing the electricity production. For the optimization of turbine complex operation, the following regimes are provided: 1) Regime 1, operation at medium pressure when the efficiency is not high; 2) Regime 2, transient regime (inadvisable) is fulfilled when Regime 1 is switching to Regime 3 and back; 3) Regime 3, operation at high pressure with high efficiency. The essential feature of Regime 2 is that the considerable pressure pulsation develops during this period, and the turbine undergoes excessive vibration. This process is a short-term (up to 10-15 seconds) and was not included in the control algorithm of the turbine.

Description of the accident: On 17 August 2009 the closure head of turbine № 2 broke away. Emergency systems did not snap into action. The flooding of plant lower storey occured. Note: The turbine #2 was overhauled twice in 2000 and 2005, and moving elements have been fully restored.

The causes of the accident: Multiple transitions from Regime 1 to Regime 3 and back (210 times after the last repair) have led to additional vibration load. Cumulative fatigue damage of fasteners turbine cover was developed. The exact name of these fasteners is "studs". Studs were made with a large safety margin. However, the fatigue damage caused their destruction. Then the turbine cover was broken away, and flooding of the station followed immediately.

Resume: When managing hydro power station «RusHydro», the problems associated with equipment fatigue damage have not been fully taken into account. Designed useful life of the turbine cover studs was overvalued. As a result, their timely replacement was not provided.

How to apply our technology for the accident prevention: Below we will discuss the basic event “Destruction studs “which was fatal to the described accident. The application of this technology for the design and operation is considered.

A1. The use of technology in the stage of turbine reliability design.

Objective: To calculate the designed useful life of studs at different vibrating impacts (useful life means operating time from the beginning of operation to the limiting state).

A1.1. Creating a set of factors influencing the event "Destruction studs" origination.

In this case, we can restrict the only factor "Total vibration load that studs undergo for the period from the operation start to a concrete moment" (VIB). A quantitative measure of VIB factor is the number of transitions into inadvisable regime # 2. An expert divides the set of possible VIB values into several intervals by points n_1, n_2, n_3 and establishes the possible qualitative values of VIB factor: "a" - the absence of vibration (completely stationary mode), $VIB = 0$; "b"- a small vibration exposure, $VIB \in (0, n_1)$; "c"- acceptable vibration exposure,

$VIB \in (n_1, n_2)$; "d"- anxious vibration exposure, $VIB \in (n_2, n_3)$; "e" - emergency situation, $VIB \ge n_3$. Thus, each qualitative possible VIB factor value defines the specific situation that occurs in the turbine.

A.1.2. Creating a set of adjustment coefficients for qualitative VIB factor values.

This action is executed by experts (see pt 3.1.2). The result: the adjustment coefficients $\eta(b)$, $\eta(c)$, $\eta(d)$, $\eta(e)$.

A.1.3. Creating the cumulative distribution function of the event "Destruction studs" (see pt 3.1.3). The result: $F^N(t)$.

A.1.4. Forming of mono-influence cumulative distribution function for each situation:

$$F_b^M(t) = F^N(t) \times \eta(b);\, F_C^M(t) = F^N(t) \times \eta(c);\, F_d^M(t) = F^N(t) \times \eta(d);\, F_e^M(t) = F^N(t) \times \eta(e) \qquad (16)$$

A.1.5. Calculation of the useful life studs ($T_b; T_C; T_d; T_e$) at different vibration exposures on turbine.

$$T_b = \arg\left[F_b^M(t) = 1\right]; T_c = \arg\left[F_c^M(t) = 1\right]; T_d = \arg\left[F_d^M(t) = 1\right]; T_e = \arg\left[F_e^M(t) = 1\right] \qquad (17)$$

At the designed stage, expression (17) gives an opportunity to execute reasonable scheduling of timely turbine repair and the replacement of turbine cover studs.

A.2. The use of technology during turbine operation.

In the operation, the operating time (t) and VIB parameters are monitored. Besides, a periodic checkup is carried out according to following steps.
Assume that the turbine operates at low vibration which corresponds to a "b" range. Project resource is T_b.

A.2.1. The condition (18) is checked regularly

$$T_b - t \le \varepsilon \qquad (18)$$

where ε -established measure of inequality.

The non-fulfillment of the condition (18) means that there is no cause for trouble. The transition to the pt. A.2.2. The fulfillment of the condition (18) means that the useful life is exhausted. The studs' replacement is necessary.

A.2.2. the condition (19) is checked:

$$VIB \in [n_1, n_2] \qquad (19)$$

The fulfillment of the condition (19) means that the situation does not change. The transition to the pt. A.2.1. The non-fulfillment of the condition (19) means that the situation "b" has been replaced by the situation "c". At this point, the value of the operating time t_i is fixed. The transition to the pt. A.2.3.

A.2.3. Adjustment of the useful life at the new situation.

The adjustment coefficient $\eta(c)$ corresponding to new situation “c” is taken from the database. Create a function $F_C^M(t) = F^N(t) \times \eta(c)$. Calculate new value of useful life $\overline{T_C}$:

$$\overline{T_C} = t_i + \delta \tag{20}$$

where

$$\delta = \arg\left(\frac{F_C^M(t_i + \delta) - F_C^M(t_i)}{1 - F_C^M(t_i)} = 1 \right) \tag{21}$$

The transition to the pt. A.2.1.

Note: $\overline{T_C}$ value is different from designed T_c.

5. CONCLUSION

In this paper we proposed the new computing technology for probability assessment of undesirable events occurring at potentially hazard facilities. The offered technique is not contrary to the existing methods of prediction but adds new opportunities. Technology is combinative: the full range of probabilistic and probability-physical failure models is utilized to calculate the parameters of etalon cumulative distribution function; expertise, statistics, and analytical methods are fully used. It takes into account the situation occurring at the beginning of predictive interval. The user’s role is reduced to setting the predictive interval and formalizing the situation description.

Novelty of this study is as follows: 1) the forming of mono-influence cumulative distribution function adds up to the construction of etalon cumulative distribution function (using failure models); 2) the formation of situational amendments are carried out using the expertise and the analytic hierarchy process.

Practical importance: Since the technology reflects a real-life situation at a facility, the prognosis is more reliable.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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