Journal of Scientific Research & Reports
3(18): 2382-2394, 2014; Article no. JSRR.2014.18.001

SCIENCEDOMAIN *international*
www.sciencedomain.org

Hazard Control Technology for Situation Monitoring at Potentially Hazardous Facilities

O. M. Serebrovsky[1*]

[1]Institute of Mathematical Machines and Systems of the Ukrainian National Academy of Sciences, 42, Acad. Glushkov Prospect, Kiev 03680, Ukraine.

Author's contribution

The sole author designed, analyzed and interprets and prepared the manuscript.

Original Research Article

Received 1st April 2014
Accepted 4th July 2014
Published 26th July 2014

ABSTRACT

This article focuses on the actual problem of preventing accidents at potentially hazardous facilities. The technology for risk control at potentially hazardous facilities by the criterion of possible accident probability is proposed. Monitoring of situations is a necessary component of the technology. The technology is founded on the knowledge base created beforehand. Knowledge Base includes a prior formalized knowledge about situations that are possible on potentially hazardous facilities and the impact of these situations on the occurrence of undesirable elementary (basic) events. Each step of monitoring includes calculating the probability of an accident and hazard assessment. The new hazard estimation is calculated at each change of situation at potentially hazardous facilities. The probabilities of basic events are the necessary input data for predicting accidents. The focus of the paper is concentrated on the calculation of the probabilities of basic events. This calculation takes into account: the new situation, the actual time and wear made at the time of changing the situation, and content knowledge base. The contribution of the study: Special procedures are developed within the monitoring technology that form new predictable trajectories and the adjustment of the predictive interval boundaries for each situational change at potentially hazardous object according to the cumulative effect of hazard causal factors.

Keywords: Hazard control technology; accident probability prediction; dynamic adjustment; equipment wear, cumulative distribution function.

**Corresponding author: E-mail: tsereb@voliacable.com;*

ABBREVIATIONS

PHF: Potentially Hazardous Facility; BE: Basic Event; CDF: Cumulative Distribution Function; KB: Knowledge Base; DNF: Disjunctive Normal Form.

1. INTRODUCTION

Preventing accidents at potentially hazardous facilities (PHF) is one of the most pressing problems of technological safety. The prediction of accidents occurrence is an important condition for their prevention. Herewith, the probability of basic events (BEs) occurrence is the necessary input data for this task. According to the methods of probabilistic safety assessment (PSA) [1], an accident is formalized as disjunctive normal form (DNF). The probability of an accident can be calculated by the analytic function in which the BEs probabilities are the arguments. BEs are adverse events that may occur at the elements of PHF. In particular, the BE is a failure of a certain equipment unit.

There are different ways of BE probability (P(BE)) calculation: failure models, expert evaluation, and the determination of P(BE) at a given predictive interval. In application of failure models to P(BE) calculation, the information about the failure statistics and test data is used. However, the failure models do not reflect the particular circumstances of the situations that can occur at PHF. 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.

Expert evaluation is used in cases when there is no opportunity to test the equipment, and statistical data are insufficient. The use of expert assessment in the daily hazard monitoring is not advisable. Rational is the following approach: (a) the gaining knowledge from experts; (b) formalization of this knowledge; (c) preservation of the knowledge in knowledge base (KB) for further use at prediction and analysis [2]. Application of this approach is difficult due to the high complexity of KB creating. Reduce this complexity is possible: a) by the formalization of the causal hazard factors and their impact on BE occurrence [3]; b) joint use of failure models and expert estimates. At that nominal values of BE probabilities are determined by failure modes and statistics. With expertise and the analytic hierarchy process (AHP) [4] the situational amendments are determined. Situational amendment is the characteristic of the impact of hazard causative factors on the BE probability. These tools make a real the KB formation that is necessary for automated estimation of hazard for certain classes of PHF.

However, estimates obtained are authentic until the situation at the PHF has been changed. After this moment the adequacy of previous estimate decreases.

Example: Suppose, the hazard prediction on the predictive interval $\left[\tau_L, \tau_R\right]$ is made at PHF. At the moment τ_L the factors that determine the situation had values "Normal". Result prediction: 6×10^{-4} that corresponds (according to diagnostic scale) to the value "Satisfactory". At the moment $\tau \in \left[\tau_L, \tau_R\right]$ the situation at PHF has changed: the factor "Operating mode" is set from the state "Normal" to state "Fast and Furious". Initially predictive hazard assessment "Satisfactory" is no longer adequate for $[\tau, \tau_R]$ interval. It is necessary to calculate the new estimate which reflects the dynamics of the situation at PHF.

This paper aims to develop a method for dynamic adjustment of hazard estimation after changing situations at PHF. As a result, the technology for the control and prevent hazards becomes more thorough.

With this objective, the following tasks are formulated:

- To develop a logical basis for adjusting the BE probabilities after changing situations at PHF;
- To develop technological stages of hazard control during dynamic correcting of BE probabilities.

2. LOGICAL BASIS FOR BE PROBABILITY CALCULATION

This item has been firstly described in detail in [2]. Additionally, the important element of the logical basis is proposed in this paper, following the use of the concept of "Equipment wear" in the calculation of BE probabilities. In the subsequent discussion it is assumed that at any time τ the operating time of each equipment unit at PHF can be determined. Therefore, the predictive interval $[\tau_L, \tau_R]$ can be interpreted as operating time interval $[t_L, t_R]$, where t_L - operating time of equipment at the moment τ_L; t_R - operating time of equipment at the moment τ_R .

2.1 Formalization of Possible Situations at the System

Situation at the PHF is represented as a set of the causal hazard factor values $X_j (j = \overline{1,k})$.

The situation "C" is given if one specific value $x^c_{j,}$ is determined for each factor $X_J\left(j = \overline{(1,k)}\right)$:

$$"C": X_1 = x^c_1; X_2 = x^c_2, ..., X_k = x^c_k \tag{1}$$

2.2 Formalization of Situation Impacts on Cumulative Distribution Function of BE_i Probability

Cumulative distribution function (CDF) of the BE probability can be represented by the expression [2]:

$$F^c_i(t) = 1 - \prod_{j=1}^{k} [\ 1 - F^M_{i,j}(t, x^c_j)\ ] \tag{2}$$

where $$F^M_{i,j}\left(t, x^c_j\right) = F^N_i(t) * \eta_{i,j}\left(x^c_j\right) \tag{3}$$

$F^N_i(t)$ - etalon CDF $BE_i\left(i = \overline{1-n}\right)$; t - operating time; $\eta_{i,j}\left(x^c_j\right)$ - situational amendments (the degree of X_j influence on probability $BE_i\left(i = \overline{1-n}\right)$ when $X_j = x^C_J$).

$F_i^N(t)$ are created by using the probabilistic and probabilistic-physical failure models as well as equipment testing at the most normalized conditions. As a result, for each $BE_i\left(i=\overline{1-n}\right)$ the rule for calculating the CDF at the given t values is generated [3-5]:

$$F_i^N(t) = Z_i^N(t, \mu, \upsilon) \tag{4}$$

Where Z_i^N is the analytic representation of etalon CDF $BE_i\left(i=\overline{1-n}\right)$, μ, υ - scale and pattern parameters; t - operating time.

Situational amendments $\eta_{i,j}\left(x_j\right)$ are based on expert judgment using the hierarchy analysis method [4] and stored in the knowledge base (KB) for the multiple use when calculating BE probabilities. Expressions (2) and (3) determine the relationship between the possible situations and their impacts on the BE occurrence.

2.3 Computation of BE Probabilities

BE probability in a given predictive interval $[t_L, t_R]$ at situation (1) is defined by the following expression [5]:

$$P_c\left(BE_i \setminus [t_L, t_R]\right) = (F_i^c(t_R) - F_i^c(t_L)) : (1 - F_i^c(t_L)) \tag{5}$$

Where $F_i^c(t_L)$, $F_i^c(t_R)$ - function $F_i^C(t)$ values at situation (1) for operating times t_L and t_R. The resulting values $P_c\left(БC_i \setminus [t_L, t_R]\right)\left(i=\overline{1-n}\right)$ are used for the calculation of the accident probability and risk assessment at PHF in this situation [1].

2.4 Using the Concept of "Equipment Wear" for BE Probability Calculation

Equipment wear is a degree of equipment resource loss resulting from its use. Wear may be represented by the expression:

$$d_\tau = [T - T_O(\tau)] : T \tag{6}$$

Where d_τ - wear at the moment τ; *T*– initial resource (useful lifetime); $T_O(\tau)$– residual life by moment τ.

Wear is an aggregate characteristics of equipment status. It is determined by: the initial resource, operating conditions, and operating time. Initial resource is defined by the following risk factors: the quality of the project; workmanship, quality materials, skilled personnel manufacturer; level of technical control; quality installation and commissioning of equipment. Such factors are called the initial state factors. Operating conditions are defined by the following risk factors: the level of maintenance and technical support; intensity of processes; and aggressiveness of environment operation.

There is an objective relationship between the equipment wear and the probability of equipment failure, i.e. the more wear occurred at the specified operating time, the higher the failure probability at the same operating time. This statement allows the author to propose the following postulate: the cumulative distribution function of equipment failures can serve as a quantitative measure of wear and tear, i.e.

$$d^C(t) = F^C(t) \tag{7}$$

Where $d^C(t)$- wear occurred at the operating time t in situation “C”; $F^C(t)$- CDF values at the operating time t in situation “C”.

Geometrically, each situation has its own trajectory. The trajectory is described by CDF $BE_i\left(i = \overline{1-n}\right)$ and characterizes the change of wear with increasing operating time. Ordinate of the trajectory corresponds to wear which achieved during given operating time.

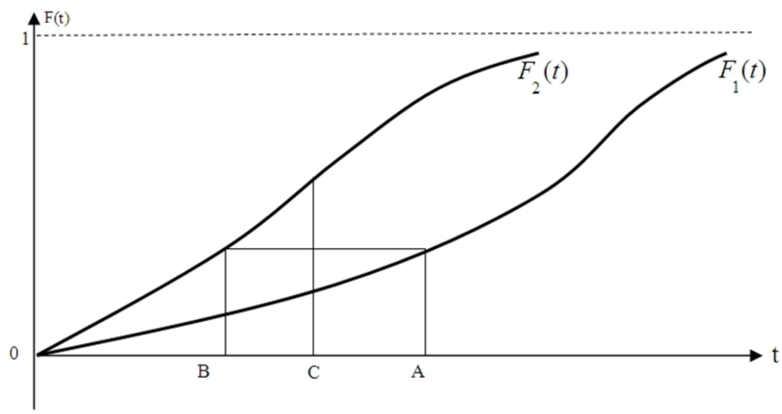

Fig. 1. The trajectories of wear for two identical equipment units under different operating conditions

Fig. 1 shows the trajectories of wear for two identical equipment units when operating conditions are close to normal (curved line $F_1(t)$), and when operating conditions are significantly different from normal (curved line $F_2(t)$). At the same operating time $t = C$ identical units reaches different wear $F_2(C) >> F_1(C)$ and vice versa: the same wear are achieved under different operating conditions and different operating time $F_2(B) = F_1(A)$.

Suppose, after the initial prediction the situation at PHF was changed. There was a need to adjust the previously obtained estimates

Let introduce the table of symbols:

- The initial situation « a »: $X_1 = x_1^a$; $X_2 = x_2^a$; …, $X_k = x_k^a$; (8)
- t_L^a, t_R^a - left and right boundaries of the initial predictive interval;

- New situation « b »: $X_1 = x_1^b$; $X_2 = x_2^b$; …, $X_k = x_k^b$; (9)
- t_L^b, t_R^b - left and right boundaries of the new predictive interval;
- $\bar{t}$ - operating time at the moment of changing situation;
- Δ^a, Δ^b - size of the original and the new predictive intervals.
- $\Delta^a = t_R^a - t_L^a$; $\Delta^b = t_R^b - t_L^b$. (10)

Correction of previous predictive estimates includes:

- CDF formation according to the situation « b »;
- Calculation of new borders of the predictive interval;
- Calculation of the $BE_i\left(i = \overline{1-n}\right)$ probabilities in new predictive interval according to new situation.

- The CDF formation according to new situation « b » is fulfilled using the rules (2) and (3); the result is an expression:

$$F_i^b(t) = 1 - \prod_{j=1}^{k}\left[1 - F_{i,j}^M\left(t, x_j^b\right)\right] \text{, where } F_{i,j}^M\left(t, x_j^b\right) = F_i^N(t) \times \eta_{i,j}\left(x_j^b\right) \tag{11}$$

- Calculation of the new borders of the predictive interval

After situation changing it is necessary to correct previous predictive interval. An important fact is that at the transition to the new trajectory the achieved wear value remains unchanged. With a geometrical point of view this means that the movement along the new trajectory begins from the point at which the ordinate is equal to wear value achieved during operating time $\bar{t}$. Thus, the left border of the new predictive interval defined by the rule:

$$t_L^b = \arg F_i^b(t) \setminus F_i^b(t) = F_i^a\left(\bar{t}\right) \tag{12}$$

Where $F_i^a\left(\bar{t}\right)$- CDF value of the initial trajectory at point when the situation is changed.

$$F_i^a\left(\bar{t}\right) = 1 - \prod_{j=1}^{k}\left[1 - F_{i,j}^M\left(\bar{t}, x_j^a\right)\right], \quad F_{i,j}^M\left(\bar{t}, x_j^a\right) = F_i^N\left(\bar{t}\right) \times \eta_{i,j}\left(x_j^a\right) \tag{13}$$

Right border of the new predictive interval $\left(t_R^b\right)$ under the new situation « b » defined according to the expression:

$$t_R^b = t_L^b + \Delta^b \tag{14}$$

After changing the situation, the size of new predictive interval Δ^b is reduced by the value) $\left(\bar{t} - t_L^a\right)$, that is $\Delta^b = \Delta^a - \left(\bar{t} - t_L^a\right)$. If to consider (10), then

$$t_R^b = t_R^a - \left(\bar{t} - t_L^b\right) \tag{15}$$

The above rule for the correction of predictive intervals is an element of novelty offering in this article.

- Calculation of BE probability $P_b\left(BE_i\right)$ at the new predictive interval $\left[t_L^b, t_R^b\right]$ in new situation "b".

The calculation is performed according to the rule (5).

$$P_b\left(BE_i \setminus [t_L^b, t_R^b]\right) = (F_i^b(t_R^b) - F_i^b(t_L^b)) : (1 - F_i^b(t_L^b)) \tag{16}$$

Where $F_i^b\left(t_L^b\right)$, $F_i^b\left(t_R^b\right)$ are the CDF $F_i^b(t)$ values at the boundary points of new predictive interval and calculated according to (11).

Figs. 2 and 3 demonstrate a geometric illustration of changes in the predictive trajectory and related adjustments of predictive interval.

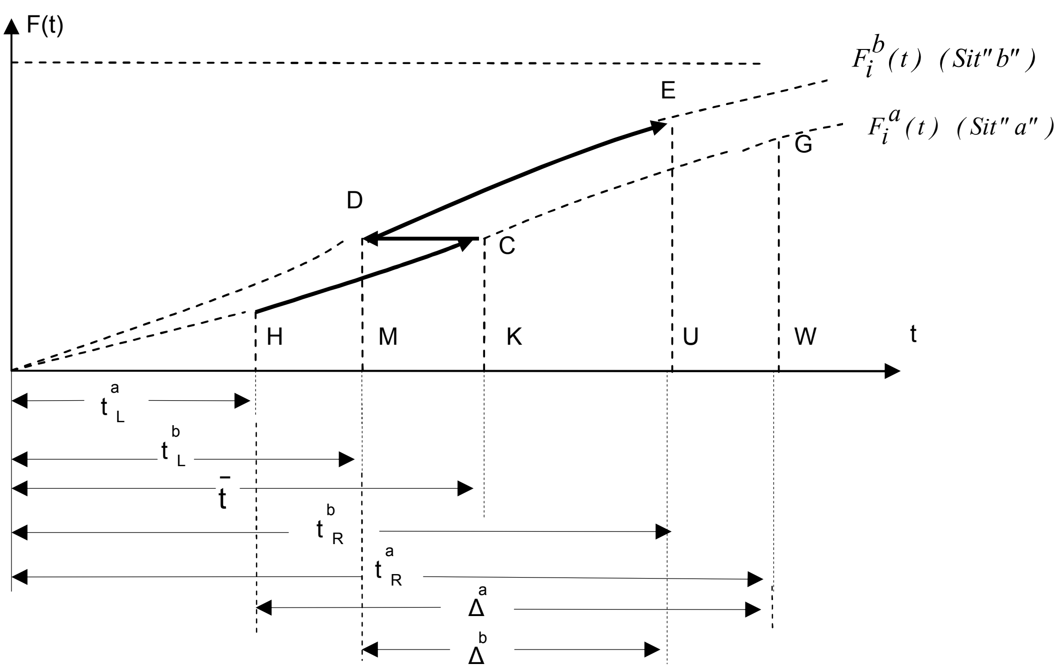

Fig. 2. The transition from the trajectory "a" to the trajectory "b". The situation was changed towards the hazard increasing

Comments to the figures.

$[\tau_L, \tau_R]$ - initial time predictive interval;

t_L^a - operating time at the moment τ_L;

t_R^a - operating time to be reached at the moment τ_R if the situation at predictive interval did not change;

$t_R^a = t_L^a + (\tau_R - \tau_L) \times K_u$, where K_u - steady state availability factor;

$\Delta^a = [t_L^a, t_R^a]$ - predictive interval of operating time in terms of the initial situation;

$F_i^a(t)$ - trajectory of equipment wear and tear at initial situation. ($F_i^a(t)$ is formed according to (2-4) using the KB and description of initial situation (8);

H - the initial point of the trajectory $F_i^a(t)$ which corresponds to the operating time t_L^a;
G - endpoint trajectory $F_i^a(t)$ which corresponds to t_R^a;

$\bar{\tau} \in [\tau_L, \tau_R]$ - the moment when the situation has changed, at that the initial situation "a" is replaced by situation " b";

$\bar{t}$ - operating time at the moment $\bar{\tau}$. After moment $\bar{\tau}$, for the prediction of situation it is necessary to create a new trajectory and boundaries of new operating time interval;

$F^a(\bar{t})$ - equipment wear and tear at the moment $\bar{\tau}$, (in the fig. $F^a(\bar{t})$=*KC*);

C - change point trajectory;

$F_i^b(t)$- new trajectory of equipment wear and tear (formed according to the description of the new situation (9) and KB similar to $F^a(t)$);

$\Delta^b = [t_L^b, t_R^b]$ - predictive interval of operating time for new situation;

t_L^b - left border of the predictive interval of operating time for new situation. (In determining t_L^b it is necessary to consider that when the trajectory is changed the wear value has not changed, i.e. *KC=MD*). It follows that to determine $t_L^b(t)$ the equation (12) must be solved. Geometrically, this means that it is necessary to find a point $M \in \{t\}$ that satisfies $OM = arg\,F^b(t) \;\; when \;\; F^b(t) = CK$);

t_R^b - right border of the predictive interval of operating time for new situation is determine according to (15).

In the segment (C,D) the wear value does not changed. Assumption: transition time in the segment (CD) is negligible. Thus, the segment (C, D) is a virtual trajectory part. Actual trajectory is defined as $(H \to C)\,\&\,(D \to E)$. Fig. 2 illustrates a case when $\bar{t} > t_L^b$, i.e. $\left(\bar{t} - t_L^b\right) > 0$. According to (15), this leads to a decrease in t_R^b. Fig. 3 illustrates a case when $\bar{t} < t_L^b$. According to (15), this leads to an increase in t_R^b.

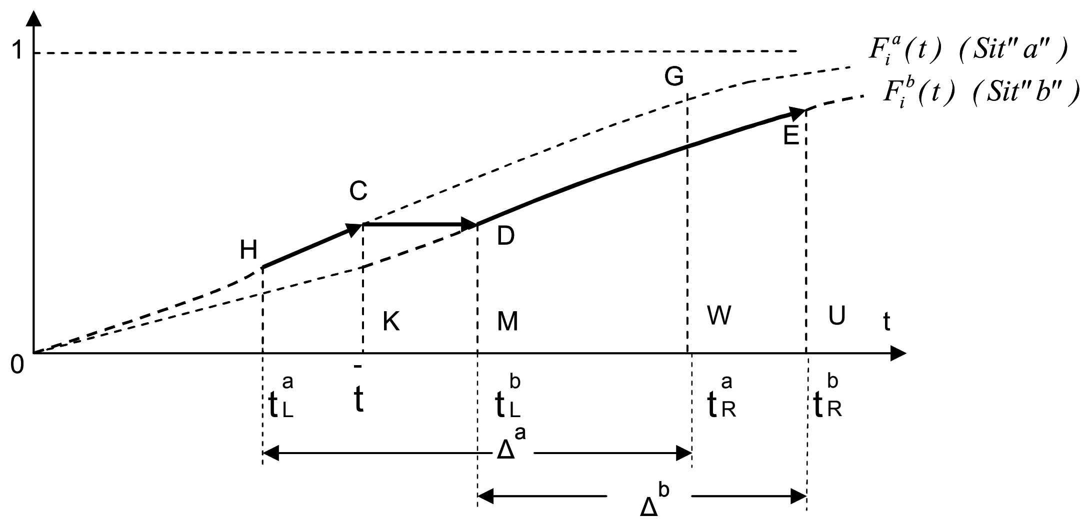

Fig. 3. The transition from the trajectory "a" to the trajectory "b". The situation was changed towards the hazard decreasing

3. CONTROL TECHNOLOGY OF PHF HAZARD

The problem of control includes the following aspects: KB preparation required for the calculation of risk indexes; procedures that implement the control; description of the control stages.

3.1 KB Formation Necessary for the Control

Formalization process of situations and their impact on CDF BE is described in [2]. Formalization of accident description as a disjunctive-normal form (DNF) is described in [1] in which the variables are $BE_i \ (i = \overline{1,n})$.

$$S = G(\{BE_i\} \ (i = \overline{1,n})) \tag{17}$$

where S is an accident caused by the failures; G - logic function in the form of DNF accident; $\{BE_i\} \ (i = \overline{1,n})$ - basic events that occur at different units of equipment.

DNF gives you the opportunity to present the accident probability $P(S)$ as an analytic function whose arguments are the basic event probabilities

$$P\left(S\right)=Q[P(BE_1),P(BE_2),...,P(BE_n)] \quad (18)$$

3.2 Description of Procedures that Implement the Control Technology

- *Procedure A₀*. Calculation of CDF $BE_i\ (i=\overline{1,n})$ for a given operating time t in a given situation "C".

Inputs: t - operating time, "C" - description of the situation in the form of (1), KB - the set of rules for the evaluation of etalon CDF BE_i according to given t values [6-8]; KB-set of situational amendments of X_j influence on probability $BE_i\left(i=\overline{1-n}\right)$ $\left\{\eta_{i,j}\left(x_j\right)\right\}$ [2].

Result of *A₀* procedure: $F_i^C\left(t\right)$ value for a given operating time t.
Contents of *A₀* procedure:

a_{01}) calculation of the etalon CDF BE_i $F_i^N(t)$ value by substituting t value in (4);
a_{02}) selection from KB the situational amendments of X_j influence on probability $BE_i\left(i=\overline{1-n}\right)$ when $X_J=x_j^c$. Result:

$$\eta_{i,1}(x_1^c),\eta_{i,2}(x_2^c),...,\eta_{i,k}(x_k^c) \quad (19)$$

a_{03}) calculation of $F_i^C\left(t\right)$ by substitution the results of steps a_{01}, a_{02} in the expressions (3) and (2).

- *Procedure* B_0. Calculation of BE_i probability for a given predictive interval $[t_L,t_R]$.

b_{01}) access to the procedure A_0 when $t=t_L$, $t=t_R$; the result: $F_i^C\left(t_L\right)$, $F_i^C\left(t_R\right)$.
b_{02}) substitution of $F_i^C\left(t_L\right)$, $F_i^C\left(t_R\right)$ in the expression (5); the result: $P_c\left(BE_i\setminus[t_L,t_R]\right)$

- *Procedure* C_0. Calculation of the probability of S accident for $[t_L,t_R]$ predictive interval.

c_{01}) access to the procedure B_0 for $BE_i\ (i=\overline{1,n})$; the result: $P_c\left(BE_i\setminus[t_L,t_R]\right)$ $(i=\overline{1,n})$.
c_{02}) substitution $P_c\left(BE_i\setminus[t_L,t_R]\right)$ $(i=\overline{1,n})$ in the expression (18); the result: $P\left(S\right)$.

- *Procedure* D_0: Correction of the initial prediction interval after situation changing.

Inputs: « a » $X_1 = x_1^a$; $X_2 = x_2^a$; …, $X_k = x_k^a$ - the initial situation; t_L^a, t_R^a - left and right boundaries of the initial predictive interval; $\bar{t}$ - operative time of equipment unit at the moment of the initial situation changing; « b » $X_1 = x_1^b$; $X_2 = x_2^b$; …, $X_k = x_k^b$ - new situation. *Result of procedure* D_0: t_L^b, t_R^b - left and right borders of the new predictive interval.

d_{01}) access to the procedure A_0 when $t = \bar{t}$; the result: $F_i^a(\bar{t})$.

d_{02}) solution of the equation (12); the result: t_L^b.

Note. The solution is performed by reusable calculation of $F_i^b(t)$ values for different $t \in [t_L^a, t_R^a]$. At each step, the t value is increased by the specified quantum value and then the access to the procedure A_0 is performed. The resulting $F_i^b(t)$ value is compared with $F_i^a(\bar{t})$.

$$\left| F_i^b(t) - F_i^a(\bar{t}) \right| \le \varepsilon \tag{20}$$

Where ε - established a priori measure of equivalence. Meaning of the operating time when this condition is satisfied is a solution of the equation (12), i.e. t_L^b.

d_{03}) calculation of the probability of S accident for $[t_L, t_R]$ predictive interval t_R^b value using the expression (15).

3.3 Technological Stages of Hazard Control

3.3.1 Target setting for hazard control (by the user)

- An indication of a controlled accident S;
- An indication of the initial predictive interval boundaries τ_L, τ_R;
- A description of the situation in which PHF is at the τ_L moment;
- An assignment of operative time at the moment τ_L for each PHF equipment unit.

3.3.2 Determination of the initial operative time range $[t_L, t_R]$ on the basis of the predictive interval [τ_L, τ_R]

$$t_L = t(\tau_L);\ t_R = t_L + (\tau_R - \tau_L) \times K_U; \tag{21}$$

Where $t(\tau_L)$ - operative time at the moment τ_L; K_U - coefficient of equipment utilization.

3.3.3 Calculation of the probability of the accident for predictive interval

The calculation of the accident probability is realized by the procedure C_0 that has been described in 3.2.

3.3.4 Hazard assessment of accident by the verification of the condition

$$[P_{TH} - P(S)] : P_{TH} \leq \sigma \tag{22}$$

Where P_{TH} - threshold probability of an accident; σ - priori measure of control risk. The fulfillment of this condition means the real hazard at PHF. In this case, a message about the threat is formed, and the switching to the unit of analysis and decision support for the prevention of accidents occurs (the latter is beyond the scope of this paper). Failure to comply with the condition (22) means the absence of a hazard, and control program goes into standby mode until the moment when the change of situation at PHF will be registered according to the results of monitoring. After registration of situation changing the correction of predictive horizon boundaries is fulfilled (access to the procedure D_0), and then the estimation risk for new situation implements by the transition to step 3.3.3.

Note. In the case of equipment unit i replacement, the BE_i probability is set equal to the nominal; and in the case of equipment failure i the BE_i probability is set to 1 [9]. After this, the transition to step 3.3.3 is performed.

4. APPLICATION

- During the hazard assessment, the peculiarities of concrete situations that occur at the PHF are taking into consideration. It increases the reliability of the predictive estimates.
- The ability to dynamically adjusting the predictive estimates during changing situations at PHF allows using these estimates as a tool for timely technological and environmental hazard prevention.

5. CONCLUSION

The technology for risk control at PHF by the criterion of possible accident probability is proposed. Monitoring of situations is a necessary component of the technology. The new predictive hazard estimation is calculated at each change of situations at PHF. This takes into account: the new situation, the actual operating time and equipment wear and tear which arose at the time of situation change. Such dynamic recalculation technology of predictive estimates is named dynamic prediction.

Novelty of this work:

- Predictive trajectories of equipment failure are formed and adjusted according to the cumulative effect of hazard causal factors as well as achieved status of the equipment.
- During the transition from the current to the new trajectory the correction of operative time interval is performed automatically.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Nuclear Regulatory Commission. An approach for using probabilistic risk assessment in risk-informed decisions on plant specific changes to the licensing basis. Regulatory Guide 1.174, USNRC: Washington, DC; 1998.
2. Serebrovsky OM. Technology for probability assessment of elementary hazard events. Journal of Scientific Research & Reports. 2013;2(1):324-336. Article No. JSRR.2013.021.
3. Serebrovsky AN. The analytic hierarchy process at creating knowledge base of the expert systems for estimation of hazard. Mathematical Machines and Systems. 2008;3:62-67. [In Russian].
4. Saaty TL. Theory and applications of the analytic network process. Pittsburgh: PA. 2005;152-13.
5. Serebrovsky OM. Prediction of hazard anthropogenic occasions based on the causal risk factors. Mathematical Machines and Systems. 2011;4:192-202. [In Russian].
6. Dependability in Technics. Failure models. Basic Principles: State Standard 27.005-97-[Enacted 05/12/1997] - K, the Interstate Council for Standardization; Metrology and Certification; 1997. [In Rusian].
7. Cheng RCH, Amin NAK. Maximum likelihood estimation of parameters in the inverse Gaussian distribution, with unknown origin. Technometrics. 1981;23(3):257-63.
8. Strelnikov V, Feduchin A. Evaluation and prediction of the electronic components and systems reliability. Kiev: Logos; 2002. [In Russian].
9. Living Probabilistic Safety Assessment (LPSA). IAFA. Vienna; 1999.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=611&id=22&aid=5493