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On Method Concept for Safety Culture Assessment with Application of Inductive Learning Algorithms

Предложен новый универсальный алгоритм расчета уровня культуры безопасности, применяемый для анализа состояния безопасности потенциально опасного объекта. Использован метод группового учета аргументов. Описана процедура расчета весовых коэффициентов и соответствующая процедура нормировки для адекватного учета вклада от разных индикаторов в интегральный показатель уровня культуры безопасности.

The new universal algorithm for safety culture level assessment is proposed, it is applicable for the safety analysis of any kind of the dangerous object. The Group Method of Data Handling is used. Weighting coefficients calculation procedure with corresponding normalization procedure are proposed for adequate account of the different safety indicators contribution to the integral safety culture level index.

Запропоновано новий універсальний алгоритм розрахунку рівня культури безпеки, застосовний до аналізу стану безпеки потенційно небезпечного об'єкта. Використано метод групового врахування аргументів. Описано процедуру розрахунку вагових коефіцієнтів та відповідну процедуру нормування для адекватного врахування внеску від різних індикаторів у інтегральний показник рівня культури безпеки.

Introduction. The modern concept of safety ensuring at the dangerous objects through development of safety culture is widely embedded in the world nuclear industry and begins embedment in other industries [1–19]. However, at present, as shown in [3, 4, 9–11, 14, 18], exists the problem of safety culture level assessment correctness with account of maximum number of factors to ensure the objectivity of the assessment. The existing methods for safety culture level assessment have the following disadvantages:

- ensuring only the qualitative assessment;
- essentially depending on expert`s qualification and the level of actual knowledge of respondents;
- have restricted possibilities on quantitative assessment of integral safety culture level.

The strong correlation relationship between the determined safety culture indexes and general safety performance indicators at the studied dangerous objects was obtained as a result of investigations [7, 8, 13, 15, 17–19]. It was proved, that the improvement of safety culture level results in corresponding improvement of general safety performance indicators at these investigated objects.

At present safety culture estimation at the dangerous objects is carried out by questionnaire survey of the personnel or by expert evaluation [1–19]. But such estimations could include significant errors due to the insufficient qualification of experts or due to errors of judgment of the respondents [10, 14, 18]. Additional difficulties arising as a consequences of the existence of huge number of discrepant safety culture definitions with corresponding methods of assessment [3, 4, 9, 10, 14, 16].

At the same time, the propagation of the modern concept of safety culture ensuring towards the other industries gives the possibility to improve the general level of technogenic safety for any country in the world. But at this direction there is a problem of absence of the universal safety culture level assessment method applicable to the wide range of dangerous objects [3, 4, 9, 10, 14, 16]. Therefore, the investigators of the problem call for the development of the universal safety culture level assessment method, which should include the modern risk management, the classical engineering principles and concepts, indices of dangerous object`s operational effectiveness [3, 4, 9, 10, 14, 16].

Therefore, in the work [18] the possibility of numerical evaluation of safety culture at NPP is proposed not by questionnaire survey of the personnel or by expert evaluation, but through numerical calculation based on documented during the operation of the dangerous object data. Only the data concerning psychological climate at the team and at the whole collective are investigated through questionnaire survey in this case (sociometric indicators) – all other data are taken from documentation or calculated based on documented data. The list of possible safety indicators, variables and indexes was developed for this purpose [18]. This list could be supplemented with new elements. Such numerical evaluation of safety culture level could be adopted for any kind of dangerous objects with development of corresponding set of object specific indicators, variables and indexes.

Safety culture is a complex characteristic of safety conditions at the dangerous object. Safety culture reflects both the technical component of safety and the contribution of human factor. The safety culture investigation includes the analysis of the financial currents, sufficiency and efficiency of financial resources directed to maintenance and improvement of safety, technical state of the object, risks related to technical state of the object, staffing level and qualification of personnel, risks related to human factor, performance of object operation [18, 19]. All these parameters have different dimensions and characterize different kinds of activity related to safety conditions level at the object. Therefore, relative units (dimensionless) for the safety parameters should be used under safety culture level assessment to reflect the sufficiency level of corresponding parameters. Weighting coefficients should be used for each safety parameter to reflect the adequate contribution of separate parameter to the general level of safety culture at the object.

Therefore, the next step was the development of the universal safety culture integral level assessment method for any kind of dangerous object according to the above mentioned requirements, which should be applicable for the occasional assessment of safety culture level as well as for the online calculations of current safety culture level at the dangerous objects.

Safety Culture Assessment Method Concept

We propose to calculate the Integral Safety Culture Index (SCL) at the dangerous object by the next formula:

$$SCL = \frac{1}{W} \cdot \sum_{i=1}^{n} \omega_i \cdot S_i \, , \qquad (1)$$

where n – the number of safety culture indicators; S_i – the relative value of i-th safety culture indicator, in relative units (dimensionless); ω_i – weight coefficient, which corresponds to the i-th safety culture indicator;

$$W = \sum_{i=1}^{n} \omega_i \, .$$

Coefficients ω_i in formula (1) are calculated using results of Probabilistic Safety Analysis (PSA), including analysis of human factor influence, which should be carried out before safety culture assessment. PSA is carried out using standard procedure as shown in the works [19–21]. Details of ω_i calculation procedure are given in the Part 4 of this article. Dimensionless relative values of indicators S_i are determined based on documented dimensional values of safety indicators $Sdoc_i$ with application of normalization procedure as shown in the Part 3 of this article. The stages of the calculation are given in the Part 5 of this article.

Group Method of Data Handling (GMDH) is already used for solving of the number of assessment and prediction problems as shown in the works [18, 22, 23], including application to assessment of safety level at Nuclear Power Plants, as shown in the works [18, 23]. Application of GMDH is especially appropriate in the case, when the construction of the full-scale physical model of the processes is complicated or unsuitable. We propose to use GMDH for the prediction of safety culture level and for the online assessment of safety culture to reduce time consuming measurements (determinations), calculations and questionnaire surveys.

To build the so called full-scale physical model for correct calculation of current value and for short-term and medium-term prediction of safety culture level one should take into account a lot of factors and interrelationships:

- the personnel;
- the equipment;
- the internal interrelationships like personnel-equipment, personnel-personnel, equipment-equipment;
- the external influences.

Therefore, the construction of physical model will be time-consuming and complicated problem. Thus, the application of nonphysical model based on GMDH for safety culture level estimation will be justified.

Thus, the GMDH is not used for calculation of ω_i coefficients in all cases and for S_i values only in the case of full scale investigation of safety culture level. We propose to use determined by GMDH dependences like shown in formulae (2) and (3) for the prediction of safety culture level purposes and for the online assessment of safety culture level.

$$S_i = f(S_j),\ i \neq j, \quad (2)$$

$$S_i = f(S_j, S_k, ..., S_m),\ i \neq j;\ i \neq k; ...;\ i \neq m. \quad (3)$$

This approach gives us the possibility to measure (direct determination) the part of indicators and the other part of the indicators could be determined by extrapolation. Dependences (2) and (3) in general could be nonlinear.

Correctness of the completed safety culture level investigation is tested by applying the correlation analysis to the investigation results – that is the way the most experienced experts are followed. The pairs of strongly correlated parameters and the pairs of anticorrelated parameters S_i and S_j are used for these purposes. If the ratio $\frac{S_i}{S_j}$ is out of certain interval under certain values of other parameters, then the investigation should be categorized as incorrect and the detailed error examination should be required with high qualified experts involvement. For this purpose, under computer data handling, the appropriate diagrams for different variants of strongly correlated parameters and anticorrelated parameters ratio $\frac{S_i}{S_j}$ should be included into the decision making algorithm.

Topicality of this task is determined by the lack of enough quantity of high qualified experts to investigate all the dangerous objects, especially in countries, where the transition from administrative management to risk oriented management with further transition to safety management based on safety culture level investigation is happen [19]. Computer data handling in the safety culture level investigation gives the possibility to involve the less qualified experts for data collection and data handling for the most of dangerous objects with high qualified experts involving only under conditions of determined incorrectness. This approach gives the possibility to carry out the high quality investigation of safety culture level and to optimize the working time of high qualified experts with the aim of maximum coverage of existing dangerous objects.

The existence of data time series is required to predict values of indicators by GMDH by construction of time (t) dependences like $S_i = f(t)$ with possibility of short-term and medium-term prediction. Determined time dependences of the parameters could be used for the optimization of time intervals between the measurements (the direct determination) with documentation of the full set of the parameters by comparing of prediction error with prescribed error level.

At this approach the task for the high qualified experts, besides the carrying out of expertise at the part of dangerous objects, will be creation of data handling algorithms with account of specific for certain types of dangerous objects. And one of the tasks will be the search for the strongly correlated and anticorrelated pairs of the indicators, the ratio of which $\left(\frac{S_i}{S_j}\right)$ could be used for testing of investigation results correctness. These determined dependences between strongly correlated and anticorrelated parameters will in addition simplify the investigation of the safety culture worsening causes and the determination of the most influence factors. The representative sampling should be selected by high qualified experts from the set of existing dangerous objects for this purpose, which according to GMDH should be split into two subsamplings. One of these subsamplings could be used as external criteria for dependency variant selection according to GMDH.

Normalization Procedure

We propose to restrict the range of values of Safety Culture Level index (SCL) by the interval of [0;1] for convenience of interpretation.

This will simplify the comparison of safety culture state of the different objects of the same type and at different objects of the different types.

We use the principle the greater the better in the formula (1). Therefore, the relative value of *i*-th indicator (S_i) should be calculated by different formulae dependent on the ratio of absolute value of *i*-th indicator from documentation ($S\mathrm{doc}_i$) to the absolute value of *i*-th indicator from industry standard ($S\mathrm{norm}_i$) and due to the influence of the values of these indicators on the safety level.

If $S\mathrm{doc}_i > 0$, $S\mathrm{norm}_i > 0$ and from the safety point of view the greater $S\mathrm{doc}_i$ the better, then the relative value of *i*-th indicator (S_i) we propose to calculate by the next formula:

$$S_i = \frac{S\mathrm{doc}_i}{S\mathrm{norm}_i}, \tag{4}$$

where $S\mathrm{doc}_i$ – the absolute value of *i*-th indicator from documentation or calculated based on documentation, in appropriate dimension;

$S\mathrm{norm}_i$ – the absolute value of *i*-th indicator from industry standard, in appropriate dimension. $S\mathrm{norm}_i \geq S\mathrm{doc}_i$.

If $S\mathrm{doc}_i > 0$, $S\mathrm{norm}_i > 0$ and from the safety point of view the lesser $S\mathrm{doc}_i$ the better, then the relative value of *i*-th indicator (S_i) we propose to calculate by the next formula:

$$S_i = \frac{S\mathrm{norm}_i}{S\mathrm{doc}_i}, \tag{5}$$

where $S\mathrm{norm}_i \leq S\mathrm{doc}_i$.

If $S\mathrm{doc}_i \geq 0$, $S\mathrm{norm}_i = 0$ and from the safety point of view the lesser $S\mathrm{doc}_i$ the better, then the relative value of *i*-th indicator (S_i) we propose to calculate by the next formula:

$$S_i = \frac{zv + S\mathrm{norm}_i}{zv + S\mathrm{doc}_i}, \tag{6}$$

where zv – the negligibly small value (for example 10^{-12}), which is used to avoid the situation of division by zero and the uncertainty of the type 0/0. $zv > 0$.

If the values of $S\mathrm{doc}_i$ are taken directly from the current documentation of the object, but the values of $S\mathrm{norm}_i$ should be predetermined in the national or international standards to characterize the relative state of investigated parameters of the object. From our point of view, the principle, like ALARA (As Low As Reasonably Achievable) principle in radiation safety, should be used under the development of $S\mathrm{norm}_i$ standards. The purpose of such approach is to take into account the real technical and economical possibilities of the certain type of industry in the certain country and inadmissibility of designed unreachable criteria. Periodic revaluation of $S\mathrm{norm}_i$ values should be applied in this approach according to improvement of technical and economical parameters of the industry. Using of such approach has an additional positive psychological effect related to the absence of hopeless situation and oppressive conditions in the variant of setting too stringent unreachable criteria. But, the appropriate international standards should be developed, when the possibility of transfrontier influence exists under accident or normal operation conditions at the dangerous objects (nuclear industry, chemical industry etc.). The consensus at the level of specialized international organizations should be reached in this case.

From our point of view, setting the 10% better than the best available at the industry values of parameters as $S\mathrm{norm}_i$ would be the best variant of $S\mathrm{norm}_i$ selection. Setting the excess level exactly at 10% concerned with the demand, that $S_i \leq 1$, and the psychology of human perception of changings.

Weighting coefficients calculation procedure

It is assumed, that PSA results for a given object are available with human factor analysis or appropriate industry average values of probabilities are available. Appropriate Event Trees (ET) and Fault Trees (FT) could be included as the input data for the calculation algorithm. Object specific data for the investigated object could be calculated using Bayesian methods and known methods of equipment ageing account if the average industry data are available with appropriate correction of data in the corresponding ET and FT.

We propose to set values of ω_i equal to the probability of appropriate minimum cut sets from the PSA results. Such choice gives the possibility to realize independent from expert influence calculation method and to provide the adequate contribution of the different indicators according to their influence on the general level of safety at the object.

Thus, the probabilities of minimum cut sets, in which a certain person or the part of the personnel are involved, should be used for the calculation of weighting coefficients for the sociometric indicators. The probabilities of minimum cut sets for the certain type of equipment should be used for the calculation of weighting coefficients for the financial indicators concerning maintenance or replacement of the equipment. If the weighting coefficients for the indicators concerning financing of education, training or qualification improvement of the personnel are investigated, then the probabilities of minimum cut sets, in which certain person or the part of the personnel are involved, should be used.

The stages of safety culture level assessment

The stages of the safety culture level assessment are given in the fig. 1. At this figure the main stages of the calculations are given with the appointed ones, where high qualified experts should be involved. The input data for the calculations are: the available documentation at the dangerous object, including process monitoring data by measuring devices; results of the additional measurements of the parameters by the group of investigators; results of the Probability Safety Analysis of this object; results of the questionnaire survey concerning psychological climate at the collective. The typical for this type of object values of the parameters could be used as the a priori data.

As was appointed out above, only the data concerning psychological climate at the team and at the whole collective are investigated through questionnaire survey in this case (sociometric indicators). All the other data are taken from documentation or calculated based on documented data.

The essential part of the routine work could be performed by the less qualified experts as you can see from the fig. 1.

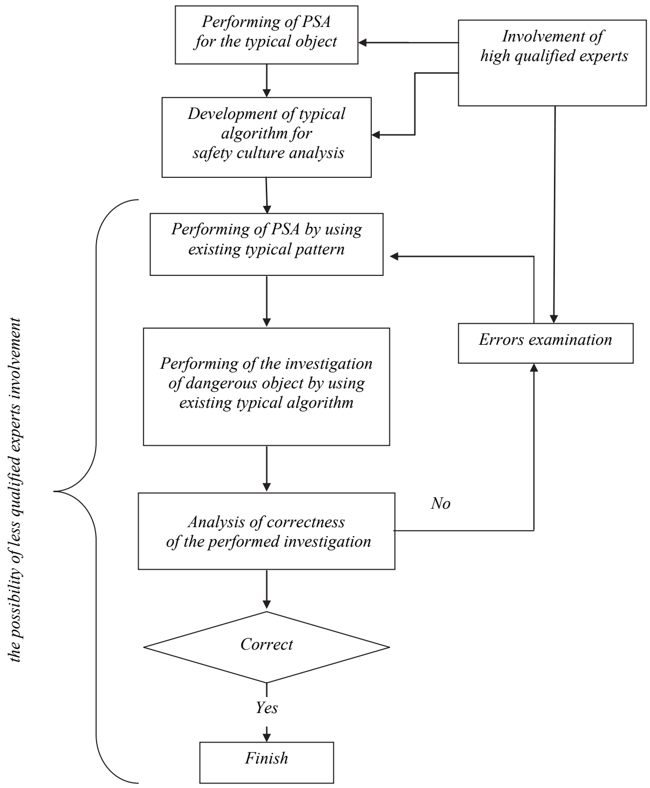

Fig. 1. The stages of the calculations of safety culture level at the dangerous object

Conclusions

The new universal algorithm is proposed for safety culture level assessment, which is applicable for the safety analysis of any kind of the dangerous object.

For the proposed safety culture level calculation method with GMDH application it is assumed, that PSA results for a given object are available with the human factor analysis or appropriate industry average values of probabilities are available.

Proposed variant of computer data handling in safety culture level investigation gives the possibility to involve the less qualified experts for data collection and data handling for the most of the dangerous objects with high qualified experts involving only under conditions of determined incorrectness. This approach gives the possibility to carry out the high quality investigation of safety culture level and to optimize the working time of high qualified experts with the aim of maximum coverage of existing dangerous objects.

Determined time dependences of the parameters could be used for the optimization of time intervals between measurements (direct determination) with documentation of the full set of the parameters by comparing of prediction error with prescribed error level.

Proposed approaches for the calculation of weighting coefficients and normalization procedure give the possibility to realize independent from expert influence calculation method for safety culture level index and to provide the adequate contribution of the different indicators according to their influence on the general level of safety at the object.

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