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REGULATORY ASSESSMENT OF NUCLEAR SAFETY CULTURE

The paper gives an overview of current practices in the area of regulatory assessment of safety culture in nuclear organizations and their associated problems. While assessing and controlling procedures are currently used by regulatory authorities and primarily aimed to check an abidance of a licensed base, there is a real need of more systematic approach to identify, collect and analyze data which relate a safety culture in licensees organizations. The paper presents a proposal of using the existing practice of an inspection regulation for gathering information which concerns with safety culture and for it complex evaluating.

Keywords: nuclear safety, safety culture, management systems, safety culture assessment, nuclear regulation.

Introduction. Since the introduction of the concept by the International Nuclear Safety Advisory Group (INSAG) [1, 2], there have been many definitions proposed for safety culture over the years [3]. The definition of safety culture used in this paper is that proposed by the International Atomic Energy Agency (IAEA): "the assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, protection and safety issues receive the attention warranted by their significance" [4–9].

Although not directly covered by the traditional approaches to the regulation of nuclear facilities and activities, safety culture has become one of the main areas of interest for nuclear safety authorities worldwide, particularly in what regards the regulatory capability for assessing safety culture and the means for influencing it. This paper presents the regulatory oversight process developed by the National Commission on Nuclear Activities Control (CNCAN), the nuclear regulatory authority in Romania, using the attributes for a strong safety culture promoted by the IAEA.

Assessment of the safety culture level is a time consuming task of operating organization and regulatory body. The level of safety culture reflects the overall picture of Nuclear Power Plant (NPP) safety, which is interesting not only for experts, but also for the population. The problem of NPP safety assessment has become of great importance at the end of the last century, and now there are many approaches to solving it. For example, the methods for reporting performance indexes were developed in the U.S. in 1987, (Performance Indicators Programs) [10], the standards for the assessment based on the reports on the current safety level for the Russian reactor designs were developed [11]. The basis of both these approaches is the monitoring of safety indexes over time. Therefore we can consider these two tasks as equivalent.

It is recognized that the main indexes of the NPP current safety level are:

1) the abnormal operation frequency index of the NPP units;
2) the readiness of safety systems;
3) the collective dose to the personnel;
4) the amount of radioactive emissions and discharges to the environment;
5) the index of unplanned automatic actuation of Emergency Protection System (EPS);
6) the index of the NPP unit energy availability factor;
7) the NPP unit capability factor.

All these indexes are the observables, or have a clear definition (formula) based on observable parameters (indicators) of operating NPP.

Description of the existing safety culture assessment methods. Safety culture is the most fundamental characteristic of the operation. The safety culture depends on the motives of personnel at all levels – this is rather characteristic of the potential field, it has no direct indicators. Shown above indexes of the current safety level reflect the nature of the occurring processes for some previous time T_1. The safety culture level assessment reflects these indexes and the NPP personnel commitment to safety principles that under the positive evaluations, ensures that at some subsequent time (T_1+t) safety indexes will remain positive. Currently safety culture assessments are carried out by experts on the basis of current NPP safety level main indexes dynamic monitoring with questionnaire survey of the personnel. The assessment of indexes is carried out based on interval score scales, which are developed in the operating organization. An example of such a scale is a well-known International Nuclear Event Scale – the INES scale. But all other rating scales of safety culture are not internationally harmonized, and the lists of safety indexes also have the recommended status, that is, the selection of indexes and its use in safety culture assessment practices depends on the qualification of the experts and other many internal and external factors at the NPP level and at the country level. As the safety of NPPs has international status, therefore it is logical to give the same international status to the methods of its evaluation.

The large number and variety of indicators exists for the assessment of the safety culture, which are recommended to take into account at the elements of the effective safety management system. This is indicated by a number of documents, including INSAG-4, INSAG-13, INSAG-15, ASCOT Manual [12–17].

These elements are observed in the organization's approach to safety management and improvement of the safety culture level. But, considering the number of these indexes from the formal point of view, we can draw the following conclusions:

1) all indexes are interdependent and have a high correlation. For example, the more (worse) abnormal operation frequency index of NPP units, the worse would be the other indexes, i.e. all the other indexes depend on this index, therefore it is possible to calculate appropriate regression coefficients (this task was not carried out).

2) all indexes, including the abnormal operation frequency index of NPP units, are depending on the technical conditions of the systems and elements of NPP unit and personnel experience, which can be characterized accordingly by the number of failures and the number of errors.

3) all indexes are complex (complicated). Principally, the qualified expert, taking any of them, can predict the range of the other with a high degree of reliability, therefore, these shown above parameters are the parameters of a high rank, and therefore, there are parameters (or indicators) of lower rank, taking which one can assess any parameter of

higher rank.

As the "safety culture" is estimated by all the above indexes, it stands over them, and is the even more common index of safety. At the same time safety culture can be (or is) the foundation of all, the beginning of all, because all other safety level indexes depend on its state.

In fact, we came to the conclusion of "ring" structure of the "safety culture" notion, i.e. the structure of the continuous improvement Deming-Shewhart type cycle, Fig. 1.

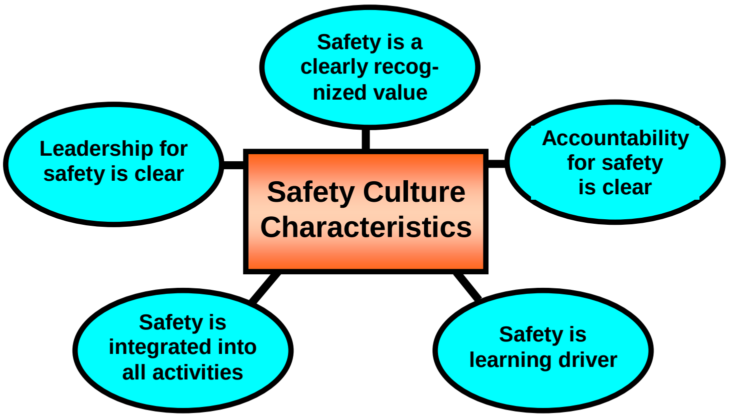

Figura 1 – Characteristics of safety culture (GS-G-3.1)

Let us consider the most typical methods of safety culture assessment that are currently exist, i.e. only the approved variants of safety culture assessment:

1) safety culture assessment methodology by questionnaire survey of the personnel based on the evaluation of several tens of indicators of safety culture – IAEA recommendations [13];

2) safety culture assessment methodology based on the monitoring of key indexes changes (the current safety level and other indexes from accounting of structural departments of the Company) - the method of National Nuclear Energy Generating Company Energoatom (NNEGC Energoatom), which is used in combination with the method of questionnaire survey for the assessment of the qualitative characteristics (organizational factors) [16];

3) the four-stages qualitative assessment methodology for the safety culture based on the assessment of violations occurred and indicators of safety culture (Russia) [17].

All these methods require time-consuming processes of expertise and time-consuming questionnaire survey. Let us consider a brief description of these options, Fig. 2.

Description of Option 1 is contained in INSAG-13 and SCART manual. Experts conclude (qualitative assessment) on safety culture level and its changes (improvement – deterioration) by questionnaire surveying of NPP personnel, based on estimates of each of the 300–400 respondents of tens of safety culture indicators.

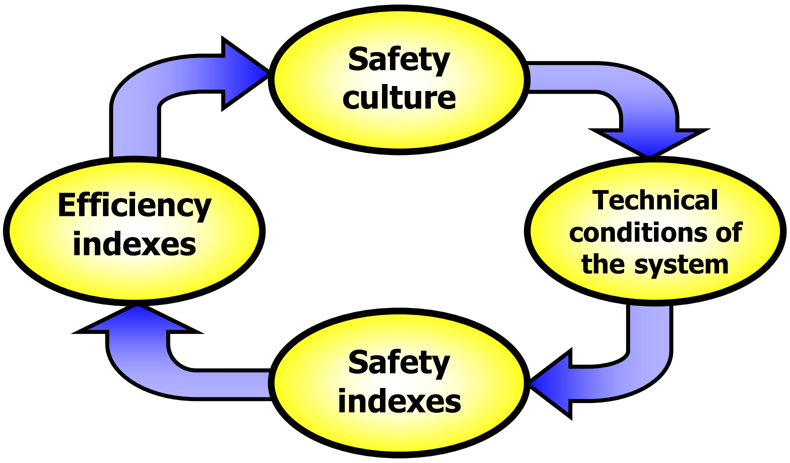

Figura 2 – Interdependence of safety notions

Description of Option 2 is contained in the current methodology of NNEGC Energoatom [16]. The dynamics of the 14 major safety indexes of the NPP unit is assessed using the three-level interval score scale. The resulting assessment of safety culture level is produced by the direct summation of scores on these 14 indexes.

Description of Option 3 is in the document RB-047-08, which is approved by the Order of the Federal Service for Environmental, Technological and Nuclear Supervision of 18 March 2009 № 169. Qualitative assessment of the safety culture level is carried out within the four-level ordinal scale. The evaluation rules are based on the assessment of the level of violations occurred and indicators of safety culture.

Hierarchy system of indexes. As we can see, the safety culture assessment in all existing variants is based on the observation of indicators. However, the notion "index (characteristic) of safety culture" and the notion "variables of safety culture" are frequently used in the shown above examples of assessment procedures. These notions do not have normative definitions in the nuclear industry and do not have the clear-cut relationship hierarchy. We propose in our previous work [15], by analogy with socionics, the next relations hierarchy, for example, Fig. 3.

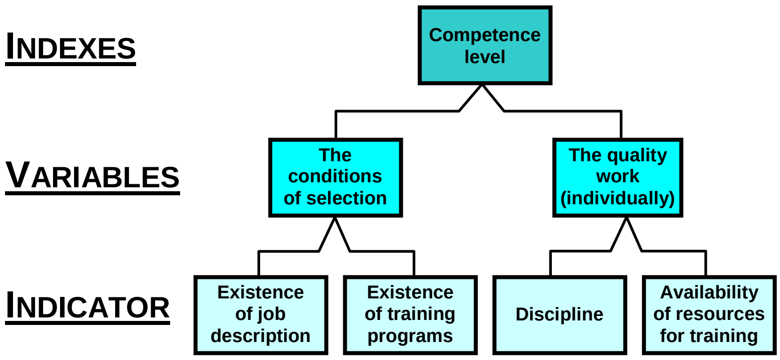

Figura 3 – Hierarchy in safety culture

Here are the following definitions of these notions:

Index – transmitter of social information. In a narrow sense indexes – such characteristics of the studied or managed events that mediate the relationship between unobservable and observable characteristics of the object, and, in the end – between subject and object of knowledge or management.

Variable – the notion that can have different values. Most sociological research seeks to identify and measure the variations, which are typical for the one particular phenomenon, and then to explain these variations by influence of another phenomenon. The first phenomenon is called the dependent variable. Second, which is the explaining or the cause of the first one, called the independent variable.

Performance indicator – characteristic of the process, which could be visually monitored, measured or calculated by the analysis of trends in order to determine or direct indication of the current and future implementation of the process with a focus on the satisfactory operation for the safety ensuring [16].

Let us note, that many industry experts, including specialists of NNEGC Energoatom, use the terms "characteristics" and "features", which are correspond to the given above definition of "index" and "performance indicators".

We propose the following indexes, variables and safety indicators, when considering the problem of measuring the safety culture on the basis of mathematical modeling, in accordance with the principles of latent variables separation, which are described in [17]:

A. Indexes of the safety culture: Level of competence; Working atmosphere; The position of individuals; Elucidation of operating experience; Attitude to safety; Attitude to production; Employee relations; Ensuring the quality of operation; Safety management; Control over the actions related to safety.

B. Variables (parameters) of the safety culture: The conditions of occupational selection; The conditions of personnel training; The conditions of functions and responsibilities distribution; Understanding of the responsibilities and the one's role in safety; Understanding the responsibilities of close colleagues and managers; Compliance of the responsibilities with job description; Compliance of competence with responsibilities; Elucidation of the experience in safety at the enterprise and beyond; The effectiveness of feedback from operating experience; Development of subjective motivators and practical efforts aimed at self-realization in work; The actual work behavior; The values (Development of subjective motivators and practical efforts aimed at self-realization in work); Status of group solidarity; State of social psychological climate; State of competition; The state with the implementation of occupational safety management system; Status of implementation of the quality system; The state of quality and safety audit system; Resources (personnel, money, tools); State of supervision and control system (management level); Personal motives and safety settings; Commitment to safety culture at the individual level; Planning, control and support; Availability of methods of analysis and changes; Account of analysis and scientific-research work etc results in a subsequent work; Providing the required level of control; The state of violations and errors analysis.

C. Safety indicators (accounting data), placed in the table with units explanation, min, max): The quality of work (individually); Discipline; Assessment and self-assessment of competence; The number of events (abnormal operation of NPP unit); The NPP unit energy availability factor; The NPP unit capability factor; Readiness of safety systems; Amount of radioactive emissions and discharges into the environment; Number of casualty; Indicators of personnel emergency preparedness; Indicators of operating experience feedback efficiency; Availability of job descriptions; Availability of documentation for all processes and equipment; The presence of regulations on occupational safety; Availability of training programs for the position; Quality of documentation and procedures; Availability of resources to improve safety; Availability of resources for training; Indicator of quality assurance in operation; Timeliness of performance appraisals; Publicity of testing procedures; Carrying out of seminars, conferences and other events on safety and quality; Maintenance and availability to personnel of the database on violations; Carrying out of inspections and self-tests; Carrying out of IAEA missions; Carrying out of quality and occupational safety audits; Participation in missions and commissions; Availability of requirements to suppliers of services and components; Availability of experienced personnel; The presence and correspondence to the statement of policy; Promotion of positions leading to increase of safety; Availability of personnel at the training center; The presence (carrying out) of the tasks, which are not in the regulations; The presence in the workplace regulations on accidents elimination; Availability of errors analysis reports; Availability of work procedures (technological processes), including repair and contractors; Sociometric coherence (communicativeness); Sociometric tension; Cohesion of personnel (interpersonal relationships); Dissociation of personnel; Documenting of work; Execution of work as work package; Indicator of unplanned automatic actuation of Emergency Protection System (EPS); The collective dose to personnel; Availability and knowledge of emergency response instructions; Education (number and quality of courses, training, seminars, etc.) and training; Education and training of leaders; Number of integrated training in emergency response; Analysis reports of technical conditions and its availability to the personnel; Availability of the desired degree of control and supervision ensuring method.

Thoroughly, from the point of view of authors, may be identified: indexes (Y_i) – up to10, where i =1..10; the variables (X_j) – up to 27, where j =1...27; the indicators (Z_k) – up to 50, where k=1...50.

Development of functional dependence. According to previously described theory [11–13], each index can be represented as a function of the dependent variables:

$$Y_i = F\left(X_j\right), \qquad (1)$$

where in its turn the argument variable X_j is a function independent or causal indicators:

$$X_j = \hat{O}\left(Z_k\right). \qquad (2)$$

Each of the indicators has a measuring range in the space of possible values, and some of indicators can take only binary values. It is convenient to consider the normalized values of the indicators. In this case the indexes and, accordingly, the final assessment of the safety culture will take values of 0–100 %.

Example of the construction of the functional dependence of the variables:

$$Y_1 = F\left(X_1, X_2, \dots X_{12}, \dots X_{26}, X_{27}\right). \qquad (3)$$

Similar relations can be written for all indicators and variables, i. e. eventually it is possible to explain indexes as a function of indicators:

$$Y = \Psi\left(\mathrm{Z}\right). \qquad (4)$$

There are 14 indexes of current safety level in the national industry standard [17], as already mentioned. The following list of (qualitative) characteristics and features of the safety culture for questionnaire surveying (this is the recommended list of the IAEA [2]).

Characteristics:

(A) Safety is the clearly recognized value;

(B) Leadership is clearly manifested in the safety issues;

(C) The responsibility is clearly manifested in the safety issues;

(D) Safety is ensured in all activities;

(E) Safety is the targeted training.

There are up to 10 targeted feature questions – totally – 37, i.e. together with 14 key indexes – there are 51 targeted feature questions. Here are examples of targeted feature questions (one for each attribute):

1) safety is one of the main aspects for the allocation of resources;
2) management ensures the sufficient number of qualified employees;
3) the roles and responsibilities are clearly defined and understood;
4) the level of quality of the documentation and procedures is high;
5) organizational and operating experience (both internal and external to the facility) is used.

Comparing these targeted feature questions with indicators list above, we could find that they are identical (correlation). In essence, these questions are nothing more than a reflection in questions of one or another of indicators listed above. Thus, the first targeted feature question – reflected in 17, 18 indicators; the second question – in 29, 32; the third – in 3, 12, 15; the fourth – in 1, 13, 16; the fifth – in 22–28, 35, 49. Since the questionnaire survey involves 300–400 people at the NPP, it can be concluded that the result of current practice (recommended by IAEA) is the reflection of the "point of views" of the various categories of NPP personnel towards the real facts (indicators).

In the first case (targeted feature question) – this is the fact of actual amount of resource allocation. The existing objective reality about allocation of resources on safety issues could be expressed, for example, as the percentage of real (ideal) requirements (indicators 17, 18). This reality is reflected in the financial statements of the accounting documentation of NPP, and the "ideal" is reflected in the documentation on safety requirements and planning. But during the questionnaire survey we do not consider this fact (indicator) in the indexes, otherwise – we "ask" the opinion of dozens (hundreds) of people who may not know the actual distribution resources, and they could judge under indirect features or by their subjective impressions. Therefore, as the result of questionnaire survey of the personnel, we have created the image of the indicator, which can be as sugarcoated or underestimated by the influence on the respondents of the circumstances of both internal (in the team) and external.

Processing the questionnaire survey data, we store the statistical errors of the survey (data error ε), (error of experts η), and, most important – the errors of judgment of the respondents – δ. The latter can be very significant - up to several hundred percent. Equation (4) in this case, can be rewritten as:

$$Y = \Psi\left(Z, \varepsilon, \eta, \delta\right). \qquad (5)$$

Thus, we come to a conclusion about the inevitability of subjectivity and perhaps inevitable high errors of important parameter assessment (safety culture) in the questionnaire survey. Reality, which corresponds to the formula (4), can be the "ideal" for the questionnaire survey method (5).

The analogical argumentation could be found concerning other indicated above targeted feature questions. I.e., under questionnaire survey method at the assessments and the self-assessments of safety culture we substitute the real (observable) indicator to its (fashion) – evaluation of processes by respondents to prepare answers on targeted feature questions. Consequently, the real situation may differ significantly. Taken into account the subjectivity and the "weight" evaluation of investigated factor, the inevitable errors in the processing of questionnaires depending on the NPP, there is a (high) probability of bias and the "embellishment" of the reality.

Variants of solution. At previous parts of the article we found that all the indexes are dependent on a number of indicators. There is a possibility to adopt a general agreement (based, for example, on the allocation of the main variables using mathematical statistics methods) in the form of function (4) of these relationships and, carrying out the calculation of indicator values – this is the first direct way of solving the problem. The numeric value of "safety culture" can be obtained by a linear combination of indexes:

$$SC = a_1 \cdot \ddot{I}_1 + a_2 \cdot \ddot{I}_2 + \ldots + a_{10} \cdot \ddot{I}_{10}, \qquad (6)$$

where a_1 – weights, $П_1$ – the calculated values of indicators.

The numerical values of safety culture index could also be determined as a vector *П* of dimension 10, in the case of normalized scales of indexes. It is also possible the definition of the matrix ($m \times n$) in the space of variables and indicators that will define all parameters and their own values, depending on the current values of the indicators.

Another solution to the problem is possible on the basis of successfully used Group Method of Argument Account (GMAA) [17].

The general problem definition of constructing models from observational data. Suppose we have *n* observations of the process, i.e. we have the sample of data, which contains information about the n observations of m initial variables X [$n \times m$] and one output variable y [$n \times 1$]. In the linear case, the relationship between the input independent variables X and output variable y can be written as:

$$y = \theta \cdot X + \xi, \qquad (7)$$

where θ – unknown vector of parameters of the model, a part of which may be zero; ξ – a random variable that characterizes the noise in the data.

In the more general case, the problem of structural-parametric identification reduces to the formation of a set of candidate models *Ф* structures from the sample experimental data:

$$yf = f\left(X, \theta f\right) \tag{8}$$

and finding the optimal model from this set as the solution of discrete optimization task under condition for a minimum of external criterion of selection *CR* (7):

$$y^* = arg\,min\,CR\left[y, f, \left(X, \theta f\right)\right], \quad f \in \hat{O}, \tag{9}$$

where estimations of the parameter θ*f* for each *f*∈*Φ* are the solutions of another task – continuous optimization:

$$\theta f = arg\,min\,OR\left[y, X, \theta f\right], \quad f \in R, \tag{10}$$

where *QR* (10) ≠ *CR* (9) – criterion for solving the task of parametric identification of each particular model, which is generated in the process of structural identification, *sf* – the complexity of the model f (number of estimated parameters).

This approach is the basis of well known methods as the method of least squares and GMAA [11]. Numerous examples of the use of these algorithms under various conditions and comparing of the results of their work shows significant benefits of GMAA algorithms in construction of the models based on the observational data.

Algorithm for solving the problem of safety culture monitoring using GMAA method Arrays of industry safety indicators observations are large enough and give us the possibility to create the dependence (4), (5).

1. Definition of indexes and indicators for safety culture model based operating experience (the set of operating parameters M). The set of parameters should be as complete as possible, taken into account all the possible equipment failures, external influences and human errors. The set has no clear boundaries and can be supplemented with new elements.

2. The choice of monitoring indicators – allocation of the elements *ñ*×*M*, which are the most affect on the safety and do not lead to unacceptable uncertainties. Requirements for vector dimension ñ are not rigid, since there is a multiple redundancy of information. Indicators, that provide the contribution to the simulation result to a number less than the chosen value ε, can be dropped; and all the elements, that have the importance less than chosen value η are considered as additional qualifying (for the precision improvement only).

3. To the obtained values of documentary monitoring will use GMAA algorithm for the scalar dependence – the approximate function $R_i = f(X, uf)$.

4. Recognition of the values of the indicator-based monitoring observations of the expert (Supervisory Authority) is a separate problem. From our point of view, the simple guidance should be developed for the selected monitoring indicators.

5. The calculation of the current values of safety culture is carried out by substituting in (7) the values of the observed indicators.

Conclusions. While it is difficult to ascertain to what extent the safety culture attributes are met by an organisation as a whole, the means for identifying areas where expectations are not met are already provided by the traditional assessment and inspections processes employed by regulatory authorities in their reviews of areas such as management systems, training, operational experience feedback. The establishment of a link between the safety culture attributes outlined in the IAEA publications and the functional areas and 5 processes reviewed as part of the regulatory oversight programmes could provide a better basis for the implementation of a performance based approach to regulation.

Solution of the problem of the current safety culture level is possible with preset parameters uncertainties by known methods in modern mathematics, under the conditions of prior modeling. The Safety Culture is a task of all staff that requires proactivity and dynamics in the pursuit of its continuous improvement. The human performance and the influencing factors on it, are keys to the safe operation of the plants. The existence of Safety Culture and Human Factors, in any case does not rule out the involvement of the plant management and the participation of the rest of organizational units in achieving the established objectives.

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