THERMAL POWER STATIONS

INCIDENTS AT NUCLEAR POWER PLANTS CAUSED BY THE HUMAN FACTOR

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Psychological analysis of the causes of incorrect actions by personnel is discussed as presented in the report "Methodological guidelines for analyzing the causes of incidents in the operation of nuclear power plants." The types of incorrect actions and classification of the root causes of errors by personnel are analyzed. Recommendations are made for improvements in the psychological analysis of causes of incorrect actions by personnel.

Keywords: nuclear power plant, personnel, incidents, human factor, types of error, psychological analysis.

Understanding the role of the human factor in incidents is important from the standpoint of preventing them in the future, as well as for formulating an effective culture of safety in which the principle of justice ("just culture") prevails [1]. Here we analyze the current methodological guidelines for analyzing the causes of incidents in the operation of nuclear power plants [2] from these points of view, with emphasis on one of its applications: psychological analysis of the causes of incorrect actions by personnel. This application includes a classification of erroneous actions by personnel and a classifier for the root causes of these. We examine modern approaches to the types of erroneous actions by people.

At present, the most widespread classification of human error is based on the principle of intentional actions [3 – 6].[2] To describe this classification, we make additional use of three important phases in the activity of an individual operator [7], which are characterized by different types of erroneous actions:

I. Evaluating the state of the system — diagnostics;

II. Planning (including establishing a goal) — decision making;

III. Carrying out a plan of action — execution.

We now briefly discuss the major aspects of the classification of human error and then expand on the content of individual erroneous actions, given that erroneous actions include both active and inactive steps by the participants.

Unintentional incorrect actions. In the foreign literature on the human factor unintentional actions (slips, lapses, and mistakes) are included in human error [3, 4]:

Slips [8] and lapses. The source process is III. Carrying out a plan of action — execution.

Evaluating the state of the system: correct.

Planning (*program, procedure*): correct.

Execution (*program, procedure*): actions deviated from the accepted plan (the basic content of the erroneous action).

The basic psychological mechanisms for this category of errors: random failures in carrying out of actions (often well known) take place because of insufficient attention or failures of memory.

The main types of incorrect actions in this category:

— slips — incorrect execution of actions;

— lapses — correct action not carried out (at the required time or place).

Mistakes. The source process is I. Evaluating the state of the system — diagnostics.

Evaluating the state of the system: erroneous.

Planning (*program, procedure*): a plan of action that cannot solve the problem (the basic content of the erroneous action) is chosen on the basis of an erroneous evaluation of the situation.

Execution (*program, procedure*): following all the steps in the erroneous plan.

The main psychological mechanisms for mistakes: incorrect diagnosis of the state of the system and situation based

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[2] In the Russian version of this article, the authors have avoided translating the English term "intentional actions," as the related terms in Russian ("prednamerennye" or "namerennye" deistviya) imply a clearly negative (often criminal) aspect which is inconsistent with the aim of analyzing the erroneous actions of individuals.

on distorted or incomplete information (data collected and evaluated for determining the state of the system).

Intentional incorrect actions. ***Violations of rules.*** The source process is II. Planning — decision making.

Evaluating the state of the system: correct.

Planning: an intentional deviation from the plan (procedure, program, and the rules and standards upon which it is based) without planning for the ultimate negative consequences (basic content of the erroneous action).

Execution (*program, procedure*): following all the items in the "corrected" plan.

The basic psychological mechanisms for the violations: formation of individual attitudes based on the organizational culture and safety culture (social settings, relationships, and values of an individual, which determine his behavior, the form of interaction with other individuals and ways of carrying out his work, interpersonal relationships and the relation to his work and to matters of safety [9]).

The main types of violations of rules:

— *necessary or situational* — an individual proceeds to a violation assuming that, under the given circumstances, he cannot perform the work if the procedures and rules are followed strictly;

— *organizational optimizing* — an individual violates procedures and rules assuming that this will be better for his company (organization);

— *personal optimizing* — an individual proceeds to violate the procedures and rules for personal gain; and

— *recklessness* — an individual proceeds to crude violation of the procedures and rules, knowing the high risks, while overestimating his capabilities and underestimating the consequences.

Sabotage or malevolent acts. The source process is II. Planning — decision making.

Evaluating the state of the system: correct.

Planning: an intentional deviation from the plan (procedure, program, and the rules and standards upon which it is based) with planning of ultimate negative consequences — malice aforethought (basic content of the erroneous action).

Execution: following all the items in the "malevolent" plan.

The main psychological mechanisms for this category of incident: the driving force is the personal motives of an individual (such as grievance, anger at perceived "unjust" punishment or firing).

After a short survey of the classification of human errors, we shall examine the content of the incorrect actions listed above.

Slips and lapses in the stage of executing planned actions (programs, procedures). ***Slips*** (or errors of choice: actions not taken in the planned manner) usually happen as a result of insufficient concentration (inattention). An operator who, for example, wants to shut off pump "A" accidentally takes pump "B" out of operation (the switches for the two are next to one another on the control panel). ***Lapses*** (failure to carry out planned actions) are characterized by violation of mnemonic processes (recollection, retaining and reproducing information) by an individual owing to diversion of attention (lapse in operation — errors of omission, change in the sequence of operation — sequential errors).

When this kind of incorrect action occurs it is important to analyze the ergonomics of the workplace, the conditions in the workplace (lighting, noise, distractions), and the content of the activity (time deficit, inadequate work load, things that interfere wit the customary activities). If these kinds of error have happened before, it is also important to evaluate their degree of recurrence (routine errors) using the accumulated base of data on the errors: how much the error is inherent in a given individual (personal history of errors) or a given task (similar mistakes by different people). In this way it is possible to obtain valuable information for searching for precursors of the errors and situations in which error is likely [10].

Mistakes are based on cognitive errors during operational diagnostics of the situation or the state of equipment. (Cognitive processes primarily involve judgments or decision making.) First, an operator may not have all the information required to construct a valid informational model of the situation, including special basic knowledge. The resulting situation may arise from an inadequate data collection system or from insufficient operator preparation. In addition, incorrect judgments can arise from cognitive distortions (cognitive or human biases) and heuristic ways of thinking. Cognitive distortions represent a tendency by a individual to form erroneous judgments because of peculiarities of his thinking, which can be reinforced under certain conditions (e.g., shortage of time, stress). Heuristic thinking, which reduces the psychic effort and time needed for decision making, can lead to a shortage of adequate, accurate information for the individual and lead him to a false understanding of the actual situation [4]. For example, an operator might undertake a search for additional data to confirm his hypothesis, while avoiding information in conflict with his point of view (confirmation bias) [4]. Or an operator might be inclined to make a decision that has served successfully more than once in similar situations without realizing that the actual situation is significantly different (availability heuristic) [4].

When analyzing mistakes it is of prime importance to evaluate the effectiveness of the information collection system (configuration of equipment and ergonomics of the worksite), the adequacy of staff training, and how much the content of the problem (shortage of time, inadequate work load, etc.) might affect the functional state of an individual (the ability of physiological and psychological processes to provide reliable and effective execution of an action) or the cognitive bias and erroneous heuristics in complex circumstances. With mistakes it is also important to evaluate the degree to which they are "routine" (both at an individual level and for all the personnel with a given task).

The main difference between ***violations of rules*** and the previously examined erroneous actions is an awareness of a modification or change in the procedure set by the program;

this is an intentional deviation from the rules or standards. However (and this is important to take into account), individuals who violate rules are truly convinced that they are "doing everything right" in the given situation. They are sure that only a deviation from the procedures or rules will make it possible to attain the set goal, save time and other resources, and maintain equipment and the necessary specifications for the engineering process. (Thus, personnel at the Chernobyl nuclear power plant were not trying to destroy the plant; in their actions the workers were guided by the desire to complete a program of testing and improve the safety system.) If there are risks, then they are insignificant and if there is a probability of negative consequences, then it is minimal; "in any case, the situation is under control." Therein lies the main difference between sabotage or a malevolent act, when a person perceives the dangerous consequences of his acts and deliberately sets them in motion.

In analyzing violations, we enter into the region of the attitudes held by an individual making a decision to deviate from the appointed program, existing procedures, rules, and standards. The organizational culture, including the safety culture, i.e., the set of values, relationships, standards, and forms of behavior generally accepted in a given organization, is an important factor that determines the attitudes of individuals and, therefore, their behavior in specific situations.

Necessary (*situational*) violations arise mainly because of a shortage of time, high worker load, unforeseen problems with equipment or with the work site, which make it impossible to complete the work in full compliance with procedures within a specified time [1]. The behavior of an individual will be determined by the organizational culture: if the economic interests of the organization predominate over the requirements of safety, or if the existing rules and standards of the organization dictate unconditional completion of work, regardless of "local" difficulties, personnel will proceed to violate rules in these circumstances. And this practice will be routine. Obviously, the responsibility for deviations from procedures, programs, and instructions will lie mainly with the organization, rather than with the operators who are drawn into these violations.

In *organizational-optimizing* violations, an individual may deviate from rules and procedures in order to improve some process, to attain its maximum efficiency in the interests of production and the organization as a whole. This may happen when the existing procedures do not always include the most efficient ways of completing the work and are often "rewritten" in practice by experienced specialists who discover the safest and least time consuming ways of doing the work. Another cause is the absence of necessary procedures (or documentation) at the work site or their unsuitability (being contradictory) for solving specific problems. For example, according to data from studies of the root causes of incorrect actions by people in significant incidents at nuclear power plants in the United States conducted by INPO during 1983 – 1984, the fraction of defective procedures or documentation was 43%, while failure of personnel to follow procedures accounted for 16% [11]. In studies for 1995, the fractions of erroneous procedures among the root causes of human error at German and Swiss nuclear power plants were 22 and 25%, respectively [12]. The responsibility for the development, coordination, and introduction of procedures and other documentation at nuclear power plants lies with the organization, as do incidents in which this factor turns out to be a root cause.

While in organizational-optimizing violations an individual tries to be guided by the interests of the organization (as he understands them), in *personal-optimizing* violations, the individual's personal interests and gains predominate. In this case, an individual consciously reduces his efforts (physical, intellectual) to complete the task without considering the demands of procedures and rules [1]: a responsible person places his signature on a document without fully checking the quality of repair work; an operator "doesn't notice" problems in the operation of equipment — "the next shift will take care of it." But in all these cases, an individual has assumed that the probability of negative consequences from his actions (inactions) is minimal.

The basis of *reckless* violations is most often an active bucking of all rules, instructions, procedures, standards, and values. The individual sets himself above all this; he, himself, establishes standards for himself, and "writes" the rules. His many years of experience, sure mastery, and vast self esteem — are a guarantee. It is especially dangerous when the organization closes its eyes to this. A textbook example of this kind of reckless behavior is the story of a 46 year old crew commander of a B-52 bomber, a pilot-instructor and colonel in the US Air Force [13]. He constantly disobeyed instructions when in flight. The crew of the bomber had repeatedly written reports to the command about unacceptable conditions during flights he piloted. The head of the squadron demanded suspension of the pilot from flying, accusing him of being a "cowboy" at the controls of the aircraft. But the command, which regarded him as one of the most experienced and best commanders of a B-52, did not agree with the opinion of his immediate supervisor. On June 24, 1994, during risky maneuvers dangerously close to the ground, the plane grazed an electrical transmission line and crashed just meters away from a weapons dump and a barracks. The entire crew (4 men) was lost. This example shows how it is possible to ignore "precursors" of a future catastrophe. Here the organization must share fully the responsibility for the behavior of the commander that led to the loss of the crew and the plane.

As in the case of errors (unintentional erroneous actions), violations can also be of a routine character and transform into a daily standard (simplify the problem, save time, "straighten out" a procedure). But, while in the first two types of violations (situational and organizational-optimizing) this daily standard is rather general, the latter two types of violations (individual-optimizing and reckless) are individual [14].

The types of erroneous actions described here lie on a scale of increasing individual responsibility and guilt of the people involved in the violation [14, 15]. According to the principles of "just culture," the boundary between acceptable behavior (requiring corrective measures in the form of consultations or training) and unacceptable behavior (requiring suitable punishment) should be drawn between organizational-optimizing and individual-optimizing violations [14 – 16]. Just culture is an atmosphere of trust, where all stimuli for providing important information relevant to safety are present, but people clearly recognize the need to draw a line between acceptable and unacceptable behavior [15].

After a brief review of the classification of erroneous actions by people, we shall examine the three types of error discussed in the methodological guidelines [2].

1. Random error — slips or blunders. In its description, this type of erroneous action belongs to the class of *lapses*: "reckless execution of a superfluous operation or failure to complete a specified operation" [2]. This type of erroneous action is typical of the execution stage and should be supplemented by other errors — *slips*, when we are dealing with incorrect execution of an operation itself.

In the methodological guidelines, it is stated more precisely that a random error-slip is the "result of an inappropriate psychological state of a person" (it would be more accurate to use the terms "functional state of a person"). As this review shows, the list of sources of errors of this kind is much wider. The reliability and effectiveness of the professional activity of a person are determined both by external (organizational) [the content of the problem, the working environment (equipment, documentation, and the physical, social, and organizational ambience)] and internal [motivation, training, cognitive processes, functional state] processes [7, 17, 18]. All of these factors can become sources of incorrect actions by people, both during the stage of execution and during evaluation of the situation and planning of actions. An example of a system analysis of these factors can be found in the SHEL model proposed by E. Edwards [19].

2. Errors arising from ignorance. This type of error can be fully assigned to the *mistake* category, where an incorrect solution is treated as "a failure to understand the situation" [2]. Here only two sources of incorrect actions are distinguished — "insufficient professional training of a person" and his "failure to meet the high standards of the profession in terms of intellectual factors." These are two organizational factors related to training and selection of personnel. A system analysis requires study of all the possible external and internal factors determining an action; here special attention should be paid to the effectiveness of the information transfer system and the content of problems (shortage of time, inadequate workload) in evaluating this type of erroneous action.

3. Intentionally incorrect actions. In formulating this type of error is is possible to find the characteristics of both *violations of rules* [actions "counter to the known instructions and rules] and *sabotage* (a subspecies of error, "an extreme subterfuge motivated by external reasons, unfit to the essence of the work, and a crude violation of rules or complete ignoring of safety, and violence against equipment" [2]). Two other subspecies of "intentionally incorrect actions ("simplification" and "rationalization") reflect the content of *optimizing violations* without differentiation into *organizational* and *personal* (individual). There is no description of *necessary* (forced) or *situational* violations because of lack of time, high work load, or problems with equipment or the work site, or *reckless* violations. On the whole, there are no clear criteria which might make it possible to differentiate among the different types of rule violations.

The description of "intentionally incorrect actions" emphasizes their deliberate character. There are several synonyms for this term in Russian [20] (more or less equivalent to the English "ill intention," "maliciousness," "premeditated," or "special interest"). But was the decision to change one of the points in the program for checking the synchronization circuits for a turbine generator, a decision reached by three technical shift supervisors (designated as NSÉTs, NSO-1, and NSAÉS) on the job who were genuinely convinced that this would ensure more reliable and safer operation of the unit, truly "malicious" [21]? Undoubtedly, their actions, which ultimately led to breakdown of the emergency protection system (AZ-1), were neither "malicious" nor "premeditated," nor brought on by "special interest." This was a conscious correction, a change in the program in order to improve it (an organizational-optimizing violation). It is necessary to look into what caused this: an incorrectly set up program, the absence of appropriate technical documentation at the work site for the shift supervisors, or their inadequate professional training [21]. Emphasis on the "intentional" in this case may lead us far away from the true sources of the incorrect actions. In legal practice, for example, there is the concept of "premeditated bankruptcy," which is treated as an "economic crime." Then a "premeditated deviation from a test program" could be regarded as an "industrial crime."

In the methodological guidelines, "intentional incorrect actions" are briefly designated as "motivational errors" [2]. But, as noted above, motivation is one of numerous sources which can cause incorrect actions by people, both in the execution stage (slips and lapses) and in the diagnostic and decision making stages (mistakes and violations). For effective and reliable activity, the motivational readiness of an individual must be combined with the necessary level of training, level of cognitive processes, and functional state. "External" factors, such as the content of the problem and the work environment, must also be taken into account here. For example, an extreme level of automation in the operator's activity may serve to demotivate him [22], i.e., lead to decreased attention and alertness, and, therefore, to a higher probability of making slips and lapses. It is not by chance that we never encounter the concept of "motivational errors" in studies of incorrect actions by personnel in foreign reports on significant incidents at nuclear power plants. But we are presented with a detailed analysis of organizational factors

which might facilitate the development of motivation and attitudes inconsistent with a culture of safety.

After describing the three types of human error, the methodological guidelines [2] turn to a definition of the sources of incorrect actions, i.e., to the "psychological causes," restricting itself exclusively to the level of the individual: the psychophysiological processes, cognitive processes (memory, thinking), motivation, and personality. Certainly, in a system analysis the methodological guidelines should be supplemented by a description of such sources of incorrect actions by individuals as the content of the problem, equipment, procedures, conditions at the work site, and interactions with colleagues and line management (communication).

Given the peculiarities of an individual, it is extremely important to examine the role of organizational factors in creating dangerous conditions which could influence the development of erroneous actions. For a long time during the development of nuclear power the concept of "human factor" (human error) was associated with incorrect actions of operating personnel — operators, repairers, shift supervisors. The books of J. Reason [3, 15] have revealed the important role of organizational factors in causing incorrect actions by personnel. During evaluations of human activities, close attention is paid to such organizational factors as design shortcomings, defects in equipment, unworkable procedures, inadequate education, and conflicting goals.

The influence of organizational factors on safety at nuclear power plants came to be widely recognized at the end of the twentieth century. Detailed analysis of the root causes of accidents leading to shutdown of power generation units has revealed deficiencies, primarily in organizational factors [3, 10, 23, 24]. The increased attention to organizational factors has meant that these factors have been more often identified in later analyses of incidents as root causes and facilitators of anomalous events [25]. The fraction of organizational deficiencies involved in significant incidents in the nuclear industry is customarily estimated to be 70% [10, 24]. The real fraction may, however, be significantly higher. For example, in 2005, organizational factors were the cause of roughly 94% of incidents at commercial nuclear plants in the United States [26].

In 1999, the IAEA commissioned a report from the nuclear energy agency of the OECD (OECD NEA) on the identification and evaluation of organization factors influencing safety at nuclear power plants [23]. The group of international experts at the NEA identified twelve most important factors:

— external influence factors;
— goals and strategy;
— control and supervision functions;
— distribution of resources;
— control of human resources;
— training of personnel;
— coordination of work;
— organizational knowledge;
— determination and introduction of procedures;
— organizational culture;
— organizational training;
— communication.

The manual of aircraft accident and incident investigation prepared by the International Civil Aviation Organization [4] examines the following additional organizational factors:

— design of equipment, workplace, and human-machine interface;
— setting of conditions at the workplace.

The role of line management in the actions of personnel is emphasized in the human factor analysis and classification system (HFACS) [5] and in the system error and risk analysis (SERA) method [6] (in particular, in stating a problem and assigning the resources for solving it).

Unable to examine the sources of incorrect actions [4 – 7, 10] in more detail in this article, we conclude with the method of psychological analysis of human error — a classifier of root causes of incorrect actions. These are divided into two classes: "psychological sources" and "external conditions and means of activity" [2].

In discussing ***psychological sources***, it is necessary to state that these are really "sources" and not "root causes" of incorrect actions. For example, "inadequate professional, important, personal psychological qualities," "inadequate characteristics of thinking, memory, attention," and "inadequate psychophysiological qualities," may be a consequence of inefficient recruitment of personnel ("control of human resources"), "a reduced functional state" [a result of inadequate control of the work load of personnel ("coordination of work")], or "insufficient professional competence" [ultimately, a problem in the system of staff training ("training of personnel")]. In his analysis of the causes of erroneous actions, an investigator can use this classifier to focus on the level of sources without uncovering root causes that might lead personnel to new incorrect actions in the future. It is, indeed, extremely important to clarify, for example, the reason for "inadequate motivation:"

— an individual lacked motivation for the activity from the start (personnel recruitment system — "control of human resources");
— during the process of working an individual lost interest in the activity (motivation system at the establishment — "control of human resources");
— economic interests predominate over the requirements of safety ("organizational culture").

Another class of root causes of incorrect actions is ***external conditions and work tools***. This is in the sphere of organizational factors. But only "administrative structure," "control," and "communication" are attributed to it in the methodological guidelines [2]. Root causes of organizational character such as operations documentation ("determination and introduction of procedures"), working conditions ("coordination of work," "provision of conditions at the workplace"), ergonomics of the workplace ("design of equipment,

the workplace, and the human-machine interface"), psychological climate ("functions of control and supervision"), and the social-political situation ("external factors of influence"), are listed separately.

The list did not include such important organizational causes of incorrect actions as the choice of personnel (one of the processes for control of human resources), organizational culture (which also includes the safety culture), the distribution of resources (ensuring a balance between economic pressure, the requirements of safety, and regulation of work), and training of personnel.

CONCLUSIONS

1. The method of psychological analysis of the causes of incorrect actions by personnel, which is a component of the "methodological guidelines for analyzing the causes of incidents in the operation of nuclear power plants" [2], includes a typology of human error, sources, and root causes of incorrect actions. But the incompleteness and contradictions of all three sections of this method limit the ability of an investigator to establish the real gaps related to the human factor in barriers to safety at nuclear power plants and to develop necessary corrective measures. A second important point is that, in using this method, an investigator may wrongly determine the degree of responsibility of the participants in an incident, thereby violating the principle of just culture, which is at the basis of an effective safety culture [1, 14, 16, 24].

2. A number of recommendations have been proposed for improving the method of psychological analysis of the reasons for incorrect actions by personnel presented in the "methodological guidelines for analyzing the causes of incidents in the operation of nuclear power plants:"

— the classification of incorrect actions by people and the criteria for differentiating them must be refined in light of modern ideas regarding human error;

— the sources of incorrect actions by people must be supplemented by a description of organizational factors;

— the list of root causes of incorrect actions must be reworked, eliminating the "sources" and adding factors which can actually give rise to human error;

— a procedure for analyzing incorrect actions by people must be developed that would include the following: an algorithm for searching and selecting data on a violation, establishing the chronology of events and dangerous conditions, determining the types of incorrect actions, determining the sources of the incorrect actions, determining the root causes of the incorrect actions, and providing corrective recommendations.

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