
"HUMAN FACTOR" IN EMERGENCY SITUATIONS DEVELOPMENT AT NUCLEAR POWER PLANTS IN THE CONDITIONS OF WAR

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Abstract

Since the beginning of Ukraine's full-scale war with the Russian Federation, the personnel of two Ukrainian Nuclear Power Plants (NPP) (Chornobyl and Zaporizhzhya) have been held hostage by the Russian occupiers and subjected to intimidation and abuse. An additional strong stress factor can significantly affect the decision-making of NPP control panel operators, increases the probability of erroneous actions in the event of emergency situations, and can even become their cause. The purpose of our study was to determine the possible influence of the "human factor" on the development of emergency situations, as well as additional parameters for monitoring the health and psychological state of NPP operators working as hostages. Fourteen expert psychologists with at least 10 years of experience in the field of extreme psychology were involved in the study. After the introductory seminar, they were offered a questionnaire to determine the range of professionally important qualities that have the greatest impact on the effectiveness of professional activity. The results of the expert evaluation became a hypothesis for the next stage of research on the possible influence of the temperament of operators on resistance to the stress of captivity. The technique of professionograms and psychograms separation, methods of scaling and balancing, methods of mathematical statistics and system analysis were used for the research. One hundred and twenty-four anonymous psychological examination cards and occupational profiles of NPP control panel operators who received a license for professional activity in Ukraine or improved their qualifications within the period of 2017–2020 were analyzed. The predominant types of psychological reactions according to subjective-objective indicators in response to significant stressful situations were studied, and the types of temperaments were determined. The ability to perform professional functions at high and medium levels was recorded in 79 sanguine operators (63.2% of the total number of examined), in 16 choleric operators (12.8%), and was not recorded in melancholic operators. Also, high and medium levels of neuropsychological stability of operators were recorded in 74 sanguine operators (59.2% of the total number of examined), in 6 choleric operators (4.8%), and was not recorded in melancholic operators. To assess the psychological state of NPP control panel operators, it is proposed to use a retrospective analysis of interrelated parameters necessary for the performance of professional functions and indicators of neuropsychological stability. The study of additional parameters of the psychological state will allow to reduce the influence of the "human factor" on the risks of creating or untimely correction of emergency situations.

Keywords: *professionally important qualities, nuclear terrorism, hostages, performance of professional functions, neuropsychological stability, NPP control panel operators.*

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INTRODUCTION

Nuclear energy provides approximately 10% of the energy needs of the OECD countries (Organization for Economic Co-operation and Development) and about 1% of the world's energy needs [1, p. 7]. For 50 years, global energy demand has

increased approximately 2.4 times: from 254 EJ in 1973 to 606 EJ in 2019. In Ukraine, 15 blocks of 4 Nuclear Power Plants (NPP) produce approximately 53.5% of electricity (which amounted to 76,203 GWh in 2020) [2; 3]. The nuclear terrorism of the Russian Federation at NPP in Ukraine during the last six months [4] constantly draws the attention of scientists and society to the possible scenarios and consequences of radiation accidents.

It is known that even in peacetime, the "human factor" is responsible for 40–50% of emergency situations at NPPs, when personnel make incorrect, untimely, illogical decisions that lead to the failure of technological processes of energy production, unscheduled equipment shutdowns. Another 50–60% of accidents occur due to natural disasters and the technical condition of equipment. In particular, aging, when instead of replacing the equipment with a new one, its service life is extended [5; 6]. Often the effect of the "human" and technical factors is negatively combined.

The use of Ukrainian nuclear power plants as a "nuclear shield" for Russian terrorists endangered the lives and health of not only the personnel of the Chernobyl and Zaporizhzhya NPPs, but also 410,000 people in the 50-kilometer zones around the plants, who will have to be evacuated in the event of a nuclear incident. At Zaporizhzhya NPP captured by the Russians, station personnel are being held hostage, subjected to intimidation and abuse. The plant and its satellite city of Enerгодar are constantly under fire, Russian military equipment and ammunition are located on the territory of the station [7; 8]. The work of the station personnel under pressure naturally increases the risk of erroneous actions during reactor operation control, which, in turn, increases the risks of a nuclear accident [9].

The aim of the study was to determine additional parameters for monitoring the state of health and psychological state of NPP control panel operators in the conditions of the seizure of the station by terrorists.

Materials and methods

The bibliosemantic method and the system analysis method according to E.P. Golubkov (1975) [10], with minimal detailing of research stages (problem formulation; research; analysis; preliminary judgment; confirmation; final judgment; implementation of the decision) were used for the research. To determine the range of professionally important qualities that have the greatest influence on the decision-making of NPP control panel operators, 14 psychological experts who spe-

cialize in working in extreme conditions and have at least 10 years of work experience been involved. The assessment was carried out during the seminar by filling in a specially developed questionnaire after expert instruction by the participants of the research group. The method of expert evaluations was combined with the statistical method. To determine the list of investigated qualities, the separation of professions, scaling and balancing methods were used.

An analysis of the psychological examination cards (psychograms) and profессиograms of NPP control panel operators who received a license for professional activity in Ukraine or improved their qualifications within the period of 2017–2020 was conducted. For the purposes of scientific research, 124 profiles are provided anonymously. Based on the profiles data, the distribution of the types of temperament of the operators, the quality of the performance of professional tasks while working on the simulators of the Zaporizhzhya NPP in simulated training extreme situations, and the neuropsychological stability according to the types of temperament of the operators, and the predominant types of psychological reactions according to the subjective and objective indicators in response to significant stressful situations. For the analysis, extreme situations were chosen, which, according to the experts, are comparable in terms of force and vectors of influence to situations associated with being in captivity [11–15], and cause both adaptive and maladaptive reactions. Statistica 10 and MS Excel LTSC programs were used for statistical processing of the results. A result of $p < 0.05$ was considered statistically significant.

In order to correctly compare the results of training at the NPP training center with the real working conditions of operators held captive by Russian terrorists, we chose simulated training situations of the maximum level of complexity. We considered a *high level of performance of professional functions* of NPP control panel operators in extreme conditions to be the ability to flawlessly perform his duties in regulating the emergency situation and to cooperate effectively with other NPP employees. We considered the *average level* to be a few errors that do not affect the performance of professional tasks with the simultaneous ability to see and partially correct one's errors. We considered a *low level* of professional performance to be a significant number of mistakes that do not critically affect the situation, but do not correct it, with the simultaneous inability to critically evaluate and correct one's mistakes.

We considered a *high level of neuropsychological stability* to be the operator's ability to maintain emotional balance, indicators of attention, speed of information perception and memory for error-free performance of their functional duties (score 5–6). We considered the *average level of neuropsychological stability* to be a partial decrease in indicators of attention, speed of information perception and memory, necessary for performing professional tasks without significant errors that could affect the result of anti-crisis actions, with the ability to quickly restore a state of emotional balance (7–13 points). We considered a *low level of neuropsychological resistance to significant stress* to be a short-term significant decrease in attention indicators, the speed of information perception and memory, which can lead to incapacity due to stupor or chaotic panic actions, with a gradual independent return to a functional state (14–29 points). It should also be noted that the persons with an unsatisfactory level of neuropsychological stability (29–33 and more points) are not allowed to work as NPP control panels operators even during professional selection.

Research results and their discussion

Ukraine belongs to the group of countries in which the share of nuclear energy in the total volume of electricity production will only increase [16]. Even the accident at the Chernobyl NPP in 1986 did not affect this vector of energy development. Therefore, it is urgent for Ukraine to improve the rules of work safety and process management at NPPs, including those related to the "human factor".

Major accidents at NPPs (*table 1*) made adjustments to the rules of personnel selection, control of their health and psychological state, the training system, changed approaches to the safety of nuclear energy production, and even prompted the transition from LWGR (Light Water Graphite Reactors – such were, for example, at the Chernobyl NPP) to PWR (Pressurized Water Reactor – the most common type in the world). Material and technical support of NPP by means of fire extinguishing, radiometric control, physical protection of personnel from the effects of radiation, and their improvement is mandatory [17]. Instead of the experiments like Chernobyl (it was conducted in the interests of the country's energy sector, but led to catastrophic consequences), computer experimental models using artificial intelligence are used [18].

The analysis of large accidents data confirms that accidents are caused by the combined action

of unsuccessful technological solutions, imperfect design of the main NPP elements, lack of necessary equipment, and erroneous actions of personnel (both those actions that lead to the accident and actions during the accident). In open scientific sources, there is practically no data on the health and psychological state of NPP control panel operators and other personnel who overcame emergency events. For example, about those employees of the Chernobyl NPP who survived their stay at the station and in the exclusion zone of the occupiers (9 employees died, 5 were kidnapped). The occupiers themselves, having looted the property of the station (including dosimeters and fire extinguishers), were exposed to radiation. Their actions at the station threatened a radiation accident, and in connection with this, in April 2022, the Ministry of Health of Ukraine approved Methodological recommendations for actions in nuclear damage zones [22]. Also in August 2022, reports appeared in the mass media about the possible exposure of Russian military personnel at the Zaporizhzhya NPP, after which the Ministry of Health of Ukraine reminded the population of recommendations for iodine prophylaxis in the event of a radiation accident [23].

The overall outcome of accidents is affected by the number and severity of errors. On average, a NPP unit operator makes 1–2 mistakes for every 100 operations [5]. An increase in the number of errors leads to: 1) inconsistency of the requirements with the capabilities of the specialist; 2) uncertainty of possible ways to solve problems; 3) uniformity and monotony of activity; 4) nervous tension from individual responsibility and work in frequent extreme situations. Up to 30% of emergency shutdowns of NPP units occur due to personnel errors, which are only partially compensated by the capabilities of protective systems, computer programs with elements of artificial intelligence, knowledge and the ability to use the results of analysis of previous accidents, which are reflected in emergency protocols.

The effectiveness of energy system operators is affected by [5]:

1) level of education, experience and training, duration of work load, somatic health (so, for example, the analysis of the heart rhythm makes it possible to make a forecast of the operator's behavior in emergency situations;

2) condition, in particular, wear and tear, of the equipment being serviced;

3) availability of motivation, level of purposefulness and self-control;

Table 1. Data on some large accidents at Nuclear Power Plants around the world

The place of the accident	Kyshtym, Southern Urals, RSFSR, USSR	Windscale, England	Three Mile Island, Pennsylvania, USA [19; 20]	Chernobyl, Ukrainian SSR, USSR	Fukushima, Japan [21]
The date	29 Sep 1957	10 Oct 1957	29 Mar 1979	26 Apr 1986	11 Mar 2011
Evaluation of the level of the event on the scale INES* (risk to the environment)	6 (serious accident)	5 (accident with wider consequences)	5 (accident with wider consequences)	7 (major accident)	7 (major accident)
The cause of the accident and radiation contamination	Equipment failure, failure to repair within a year, personnel errors during an accident. Explosion of radioactive waste storage.	Lack of control and measuring devices, staff errors. Burning graphite, uranium.	Technical malfunctions, violations of repair and operational procedures, erroneous actions of personnel during an accident. Melting of components of the active zone of the reactor.	Low level of technological culture of personnel and management in the field of energetics. A failed electrical experiment. Staff mistakes during the accident.	Earthquake, tsunami, erroneous actions of personnel during an accident.
Emissions of radionuclides (radioactivity)	Iodine-131 basic, 20 thousand Cu (740 TBq), including 54 Ku from Strontium.	Iodine-131 basic, 20 thousand Cu (740 TBq), including 20 Ku from Strontium.	The radioactivity of the gases released into the air ranged from 2.5 to 13 million Cu (92.5–481 thousand TBq).	1,000 thousand Cu, including ~150 thousand Cu from Iodine-131.	Iodine-131 – $1.5 \cdot 10^{17}$ Bq, Cesium-137 – $1.2 \cdot 10^{16}$ Bq
Pollution area, km ²	15,000	500	1,000	160,000	The entire territory of the country and sea water areas.
Evacuated, thousands of people	10–12	No evacuation was carried out.	144 (left their homes on their own). No evacuation was carried out.	1,200	200
Died, persons	200	30 (the data is doubtful: underestimated)	0	31 (information is incomplete)	1 person 15 people were injured.
Sick, thousands of people	9–10	1,000	30 (increased risk of cancer for 20 years)	200–600	6 cases of induced cancer

Note: *INES (International Nuclear Event Scale) – international scale of nuclear events, developed by the International Atomic Energy Agency in 1988 to assess NPP accidents with radiation emissions.

4) relations with colleagues, level of conflict, ability to work in a team;

5) individual psychological qualities (sensory, mnemonic, intellectual and motor). In particular, the following features of the character affect the quality of work: decisiveness, absent-mindedness, nervousness, the level of possible formation of fear and underestimation of danger, reduced attention, stress resistance (equilibrium);

6) in emergency situations, the level of theoretical training, education and practical skills is significant.

The activity of a human operator is evaluated with the help of numerous tests, the construction of professionograms and psychograms [24]. The professional profile assesses readiness for emergency actions, for making complex decisions and the accuracy of their implementation; psychodrama

determines cognitive qualities (attention, memory, imagery and analytical thinking), communicative qualities (culture of behavior and language), emotional qualities (restraint, honesty, compassion, readiness to make decisions), will-power qualities (stress resistance, endurance, concentration and etc.).

Health control of NPP control panel operators is regulated by the Law of Ukraine "On the Use of Nuclear Energy and Radiation Safety" [25], but it does not take into account the situations of work under pressure and when there is a threat to life. Professional selection takes into account the researched data of sensorimotor reactions, assessment of attention and the speed of its switching, stress and fatigue resistance, ability to make decisions in emergency situations. In addition to professional selection, the operator needs constant health control, which determines admission to work. For peacetime, there are recommendations for improving procedures for monitoring the physiological state of NPP control panel operators who have been under the influence of severe stress for a certain time (in order to prevent cardiovascular crises) [26]. The level of fatigue, work of the heart, organs of vision and hearing, coordination of movement, absence of alcohol and drugs in the blood, absence of acute diseases and the period of exacerbation of chronic diseases, increase in body temperature above subfebrile, impaired consciousness, memory, attention, adequacy of perception in space, time, his personality, absence of hallucinations are subjects of control.

Only licensed specialists with appropriate education, work experience [27], who have undergone special psychological training [28], simulator training and passed the licensing exam are allowed to work at the control panel of the NPP unit. The specialty of NPP control panel operator must correspond to the list of the industry standard [29]. Only operators who have passed a daily medical examination with an assessment of their psychological state are allowed to work [30]. The state of physical health of the staff is checked during employment, periodic and daily medical examinations.

It is expected that a NPP control panel operator should have [31; 32] such professionally important qualities as: responsibility; honesty; the ability to quickly make the right decisions; adherence to principles; discipline; sense of duty; organization; stability of attention; high speed of attention switching; high speed of a simple sensorimotor reaction; well-developed short-term

and long-term memory; the ability to qualitatively assess time intervals; strong will; analytical and communicative abilities; highly developed deductive thinking; operational thinking; reaction speed; physical and mental endurance; initiative. These professionally important qualities are formed in the process of professional education and training, professional orientation and candidate selection according to the requirements for the profession, adaptation to professional activity, actual activity, professional improvement, attestation (as a stage of training and professional development), rehabilitation after burnout, long-term somatic illness or psychological breakdown.

In the conditions of work at the captured Zaporizhzhya NPP, we predicted an increase in the influence of the "human factor" on making wrong decisions and committing wrong actions in the event of accidents. Therefore, in an expert way, with the involvement of 14 expert psychologists we limited the range of professionally important qualities that have the greatest impact on the effectiveness of the professional activity of NPP control panel operators to the following: information processing speed; stability and distribution of attention; accuracy of perception; decision-making in a difficult situation, under conditions of obstacles; resistance to stress, monotony; physical endurance; efficiency; professional responsibility; stable professional orientation. The stability of attention to the main information has a strong influence on the reliability and accuracy of decisions made by operators. It is emphasized that the lack of time can distort the result of the activity, prevent the achievement of the goal, that is, professional reliability may not be fully realized in the activity.

Similar conclusions were reached by other experts [24; 33]. Adequacy of information perception and limitation of its volume in normal working conditions depends on the influence of distracting factors (sound interference, poor visibility, etc.), for example, in the situation of searching for victims, assessing the location of an emergency situation. The power of the impact increases if the emergency event continues (fire continues, shelling) [34; 35]. The influence of these factors can be felt at the decision-making stage. But the psychological consequences of being in captivity can have the strongest impact. It is known [36] that prisoners feel helplessness, doom; are oppressed by the expectation of an indefinite improvement in their own situation. One fifth of them feel constant anxiety, every fourth – constant

fear for their life. Aggression and anger, or, conversely, depression and apathy are also possible.

Most professional tasks are characterized not only by significant physical, but also emotional tension [37]. The impact of this tension on reliability can be manifested in a decrease in professional orientation. The significance of the uncertainty factor, unpredictability of development of an emergency situation, the high probability of an emergency situation associated with a risk to one's own life or even a radiation incident, determine the importance of such a feature of activity as the ability to quickly and adequately make independent, non-standard decisions, to make changes in the activity process. The unpredictability of the situation causes difficulty in setting goals, determining priority tasks, and choosing adequate methods of their implementation. In extreme conditions, there are signs of behavioral disorganization, inhibition of stable skills, reduced work capacity, inadequate response to sharp stimuli, difficulty switching attention, narrowing and errors of perception, memory lapses, excessive impulsive actions or confusion and stupor, inability to focus on the main activity, easy distraction, decrease in mental stability and productivity of mental operations. The flexibility of behavioral reactions, which is characteristic of most specialists in normal working conditions, decreases. Complex

coordinated team actions and even ordinary personal bodily movements, which are usually automatic in nature, are particularly affected. The influence of temperament and psychotype can amplify or smooth out these negative effects.

On the basis of expert evaluations, we obtained the data that the most qualitatively perform the professional tasks of individuals with a predominant sanguine type of temperament. To verify this belief of the majority of experts, we investigated the ability to perform professional functions, as well as a compared the levels of this ability with the levels of neuropsychological stability of operators. The percentage ratio of the quality of performance of professional functions according to the predominant types of temperament is presented in the *figure* (percentages are rounded to whole numbers).

We investigated the quality levels of the performance of professional tasks by operators while working on simulators of the Zaporizhzhya NPP according to their temperament types. The percentage ratio of the quality of the performance of professional functions and the relationship of the level of neuropsychological stability of the NPP operator according to the predominant types of temperament are shown in *Table 2*. The number of variants of the studied indicators corresponded to the pattern of normal distribution, the results were statistically significant ($p < 0.05$).

Table 2. The relationship between the temperament type of control panel operators, the levels of professional functions performance quality and neuropsychological stability

Indicator	Level	Predominant types of temperament			Total, persons
		Amount (percentages rounded to whole numbers), $p < 0.05$			
		Sanguines	Cholerics	Melancholics	
		89 (100%)	31 (100%)	4 (100%)	124
Professional functions performance	high	45 (51%)	-	-	45
	medium	34 (38%)	16 (53%)	-	50
	low	10 (11%)	15 (47%)	4(100%)	29
Neuro-psychological stability		high level of professional functions performance 45(100%), $p < 0.05$			
	high	25 (58%)	-	-	25
	medium	16 (35%)	-	-	16
	low	4 (7%)	-	-	4
		medium level of professional functions performance 50 (100%), $p < 0.05$			
	high	-	-	-	-
	medium	30 (78%)	6 (37%)	-	36
	low	4 (12%)	10 (63%)	-	14
		low level of professional functions performance 29 (100%), $p < 0.05$			
	high	-	-	-	-
	medium	3 (30%)	-	1 (25%)	4
	low	7 (70%)	15 (100%)	3 (75%)	25
			Total		

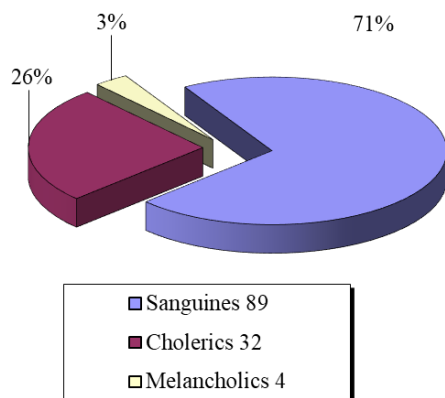


Fig. The ratio of temperament types of NPP control panel operators.

The result of the study confirmed the hypothesis that sanguine operators are better suited to act in extreme conditions. Thus, the ability to perform professional functions at high and medium levels was recorded in 79 sanguine operators (63.2% of the total number of examined), in 16 choleric operators (12.8%), and was not recorded in melancholic operators. The sample had an insufficient number of respondents to calculate the correlation coefficients. Also, high and medium levels of neuropsychological stability of operators were recorded in 74 sanguine operators (59.2% of the total number of examined), in 6 choleric operators (4.8%), and was not recorded in melancholic operators.

The outcome and consequences of an emergency situation depend on the operator's choice of decision. Mistakes caused by distracting his attention even for 30–50 seconds lead to accidents. Incorrect actions are possible in cases of insufficient qualification of operators, receiving inaccurate information by them, a special mental state (for example, the appearance of a "false alarm" – a reaction to a signal that does not exist). Some of the signals are processed at an unconscious level, in the case of making the right decision, it depends on the developed automatism. Excessive stress and fatigue cause a violation of the self-regulation of mental processes, which increases the frequency of errors.

Destructive reactions are possible in emergency situations on the part of operators with a weak nervous system, which is defined as tense, cowardly, inhibiting, aggressive-uncontrollable, fussy, focused on small things to the detriment of correct assessment [5]. The operators with a strong nervous system, on the contrary, demonstrate strong-

willed, constructive and overcoming behavior, owing to which it is possible to correct the mistakes of "distracted", "frivolous", "weak-willed" colleagues and "stubborn", which allows control of an emergency situation. Such relations explain why the ability to work in a team (planning, division of functions, mutual assistance, mutual control) and unacceptable conflict relationships are important for a team of operators. Team behavior is determined by the presence of introverts and extroverts: introverts usually make compromises or step aside, extroverts are more constructive and look for practical solutions. Cooperation of these types of personalities in a team helps to control emergency situations more effectively [24].

Conclusions

1. In the conditions of the training center for NPP control panel operators, it was possible to create conditions that, in terms of stress, are comparable to the working conditions in captivity of the Russian occupiers. Through an expert assessment, we identified a range of professionally important qualities that have the greatest impact on the effectiveness of the professional activity of NPP control panel operators, including: speed and accuracy of information perception; stability and distribution of attention; the ability to make decisions in difficult situations, under conditions of obstacles; resistance to stress, monotony; physical endurance; efficiency; professional responsibility; stable professional orientation.

2. Analysis of the psychological state of the operator of the NPP control panel, who performed official duties in extreme conditions with significant psycho-emotional stress caused by the presence of a real vital threat, allows us to assert that the influence of psychogenic factors of such a threat causes negative changes in the structure of personal characteristics and the mental state of employees. The research confirmed the hypothesis of a better ability to act effectively and without mistakes in extremes and the greatest neuropsychological stability in sanguine operators, slightly less in choleric operators and the least in melancholic operators. This conclusion allows us to recommend giving preference to applicants with a sanguine temperament when hiring (licensing) NPP control panel operators.

3. To analyze the psychological state of NPP control panel operators, we suggest using a retrospective analysis of the parameters necessary for the performance of professional functions and indicators of neuropsychological stability, which are related to each other. The study of additional

parameters of the psychological state will allow to reduce the influence of the "human factor" on the risks of creating or untimely correction of emergency situations on NPPs.

DECLARATIONS:

Statement of Ethics

The authors have no ethical conflicts to disclose.

Consent for publication

All authors give their consent to publication.

Disclosure statement

The authors have no potential conflicts of interest to disclose.

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