MENTAL WORK CAPACITY AND RELIABILITY AMONG NUCLEAR POWER PLANT OPERATORS

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Summary. Examination is performed on the mental work capacity of the operators in NPP – Kozloduy, and its importance for the control of the operative staff's reliability. Psycho-physiological studies on 50 operators were performed. By computer-based psycho-physiometer (PPM) the following examinations were carried out: Simple sensorymotor reaction (SSMR), Visual-motor reaction of moving object (VMRMO), Landolt's test, Dynamic and static tremor-reaction as well as the dynamic of their changes in the real work time. At the same time, there were measured the heart rate (HR) and the skin resistance (SR). The operators kept high level of mental work capacity during the whole shift, also an indicator for high reliability. In all tests at the end of the shift, the HR was slightly raised, an indicator for a higher "physiological price" of the fulfilment. The SR was constant, which shows emotional steadiness in the examined operators. The evaluation of operator's behavioral reliability is closely related to the evaluation of their mental work capacity. The proposed PPM-system could be used for periodical control of the work capacity and the functional state of the operators and is suitable for work in the services of occupational medicine.

Key words: *nuclear operators, reliability, mental work capacity*

INTRODUCTION

The work of the operative staff in the Power Plants (PP) is exclusively cognitive with expressed mental stress, high responsibility, necessity of taking non- alternative decisions in conditions of shortage of time. Therefore, the problems related to the reliability of the human team in management of PP are of vital importance for ensuring a safe work with no accidents [1, 2, 3, 4, 5]. The term "human reliability" is usually defined as a probability that a person will correctly perform some system-required activity during a given time period (if time is a limiting factor) without performing any extraneous activity that can degrade the system [6]. Short and complete definition of human reliability is adequacy, timeliness and underlying [7]. Here are comprised: type of higher nervous activity, intellect and memory (lasting, brief and operative); the characteristics of attention (scope, concentration, stability, distribution, commutation, mobility of the psychic processes), velocity of the sensory-motor reactions; functional status, psychosomatic health; emotional stability/non-stability, self control; reactions during stress and frustration, motivation, etc [8, 9, 10].

Index of importance for evaluating the human reliability in PP are the changes in the mental work capacity during work shift [11, 12, 13, 14].

On the one part, the behavioral reliability depends on the experience and knowledge of the individual and personal resource, of the psychosomatic health, etc. qualities and requirements, which are evaluated on professional choice level [7, 15].

On the other part, the operative staff reliability is affected by the development of the stress reactions related to the work activity, the rate of nervous tension, motional stability/instability and the approach of fatigue, which can lead to taking inadequate and wrong decision [16, 17, 18].

In the present work, there are given data of indices on the mental work capacity of operators in NPP – Kozloduy, and its importance for the control of the reliability of the operative staff. The given results are part of the complete study “Assessment of Kozloduy Nuclear Power Plant Operator’s Work Load and Health Risk”.

SUBJECTS AND METHODS

Psychophysiological studies are performed in the Command Desks of the management of 5th and 6th block in the NPP – Kozloduy, during working shifts (at the beginning and the end of work during day shift 8-16 hrs). Fifty persons of the operation staff were examined.

A computer-based psycho-physiological testing-system (Psycho-Physio-Meter – PPM) is used. By the latter quantitative indices can be received, objectively characterizing the state of the central nervous system (CNS) and some functional indices – heart rate (HR) and skin resistance (SR).

The examined person receives stimuli from the computer screen by preliminary entered instruction on the same screen. The response is by functional keyboard – divided into separate sectors, responding to the individual tests and activated one by one according to the test performed. The following examinations were carried out.

1. *Simple sensorymotor reaction (SSMR).* 30 sound stimuli with frequency 1000 Hz are handed over in pseudo-accidental way in previously given interval of 0,50 – 2,50 sec. In response to the sound stimuli the person has to press one button as quickly as possible. The time of the person’s reaction is measured from the moment of giving the signal (sound) to the moment of touching the sensory button.

On the basis of 30 given stimuli the average time of reaction (in sec) is recorded. This is the test by which the total level of the agitated processes (activation level) and the psychomotor activity's changes are studied.

2. *Visual-motor reaction of moving object (VMRMO).* On the screen static marker (reper – green hexagon) is represented, which is disposed on the perimeter of the basic circumference of accidently generated from the program place. On the outside circumference, there is represented a moving marker – white hexagon of the same size. The movement of the hexagon starts from position zero to the right or left direction in pseudo-accidental order at preliminary given velocity of the movement 0.40 m/sec. Every new movement of the white hexagon from position zero is registered as separate stimulus – 30 stimuli were set. The person has to perform a quick motor reaction (press the button) when the both repers fall in line. The test serves to evaluate the psychomotor activity, the concentration and distribution of the attention, possibility to take fast decision. The number of correct and wrong answers is recorded in left and right movement.

3. *Landolt's test* – On the screen, "Landolt's circle" is displayed – with cut out sectors in one of the eight possible directions. The person has to press the button from the functional keyboard, where the respective circle is displayed. The number of wrong and correct answers is recorded as well as the average time of reaction. By this test the short-time memory, reaction time in the condition of choice, i.e. the speed of coding the relevant information is evaluated.

4. *Static and Dynamic tremor-reaction (tremometry).* To evaluate the static *tremor-reaction* (STR), the person takes a "pen" with sharp nib and strives to hold the nib of the pen in the 5 mm-opening, without touching its walls. The number of touches, the average time of touches and the coefficient of steadiness are recorded. The latter represents the relation of total time for touchings to the total time of the investigation multiplied by hundred (in %). When examining the dynamic tremor-reaction (DTR), the examined person has to take over a "pen" along a labyrinth (one meter) without touching its walls. The time of passing through the labyrinth (in sec), the number of touchings, the average time of touchings and the coefficient of steadiness (%) are measured. Both data for STR and DTR give information on the basic quality of attention – steadiness, visual-motor coordination, as well as on the will-power qualities of the examined person and the emotional status.

5. *Heart rate (HR) and skin resistance (SR).* Before starting the examinations and during performance of the separate neuropsychic tasks, the pulse (beats/min) and skin resistance (kΩ) are registered. The average values and variety of both indices are taken into consideration. This gives information about the effort by which the different neuropsychic tasks are performed and emotional status.

The results were statistically processed by SPSS-variation, alternative and correlation analysis, Wilcoxon Matched Pairs analysis. Reliability of the change $p < 0.05$.

RESULTS

Table 1. Results of the neuro-behavioral tests

Indices	Beginning of the shift		End of the shift		Beginning/End
	x	Sx	x	Sx	p
Simple sensory-motor reaction (SSMR)					
Reaction time (sec)	0,250*	0,037	0,228*	0,035	p<0,05*
Heart rate (beats/min)	84,50	11,76	87,01	10,87	p>0,05
Steadiness Coefficient of Pulse (%)	5,27	2,18	5,73	1,35	p>0,05
Skin resistance (kΩ)	419,63	217,97	413,48	125,53	p>0,05
Visual-motor reaction of moving object (VMRMO).					
Number of correct answers – in left – in right	 10,80 10,20	 3,79 4,10	 13,00 13,85	 3,12 2,85	 p<0,05* p<0,05*
Number of incorrect answers – in left – in right	 4,30 4,55	 2,00 2,14	 1,28 0,75	 1,85 1,30	 p<0,05* p<0,05*
Heart rate (beats/min)	87,70	12,54	89,00	11,42	p>0,05
Steadiness Coefficient of Pulse (%)	5,40	2,30	7,27	2,30	p>0,05
Skin resistance (kΩ)	329,61	112,97	363,48	150,32	p>0,05
Landolt's Test					
Number of correct answers	27,94	4,11	29,86	3,62	p>0,05
Number of wrong answers	1,27	1,16	1,34	0,90	p>0,05
Average Reaction time (sec)	1,56	0,26	1,32	0,16	p<0,02*
Heart rate (beats/min)	97,60	13,53	104,70	10,12	p<0,05*
Skin resistance (kΩ)	337,40	120,70	432,60	170,32	p<0,05*
Static tremor-reaction (tremometry)					
Number of touchings	2,66	1,97	2,00	1,43	p>0,05
Average time of touchings (sec)	0,051	0,006	0,036	0,003	p>0,05
Coefficient of steadiness (%)	0,323	0,047	0,122	0,080	p=0,02*
Heart rate (beats/min)	83,80	9,31	87,00	12,50	p>0,05
Skin resistance (kΩ)	376,40	102,70	432,60	107,32	p>0,05
Dynamic tremor-reaction (tremometry)					
Time for fulfilment (sec)	36,56	14,78	37,00	12,10	p>0,05
Number of touchings	99,80	25,1	81,20	23,40	p<0,05*
Average time of touchings (sec)	0,035	0,006	0,030	0,007	p>0,05
Coefficient of steadiness (%)	8,86	3,73	6,56	4,90	p>0,05
Heart rate (beats/min)	86,70	13,10	90,70	13,20	p>0,05
Skin resistance (kΩ)	371,40	120,70	398,51	170,32	p>0,05

x – average value of the result; Sx – standard deviation; * – statistically reliable difference

The results point out to reliable time decrease of the SSMR at the end of work in comparison with the beginning, an indicator for improved attention. The heart rate inreliability increases to the end of the shift. The skin resistance shows unconsiderable variations.

At the end of the work shift, the VMRMO improves in both directions (in left and in right), the number of correct answers reliably increases, while that of wrong answers reliably decreases - index for good mobility of the basic nervous processes at the beginning and at the end of work. In the HR and SR values, a tendency of increase with no statistical reliability is established.

Table 1 shows that in Landolt's test the number of the correct answers at the end of work slightly increases, at unchanged time for finding the button, corresponding to the displayed figure. The HR and SR reliable increase when performing the test at the end of the work day in comparison with the beginning.

The STR render an improvement at the end of the work shift – there is a tendency of decrease in the number of touches and reliable improvement of the coefficient of steadiness. At the performance of this test, the HR and SR are higher towards the end of the work day.

By the task of evaluating the DTR, a slight increase in the total time for fulfilment of the task is registered, combined with reliable decrease in the number of touches.

The data given in tables 1 point out that the HR and SR values are different during the carrying out the separate nervous-behavioral tests.

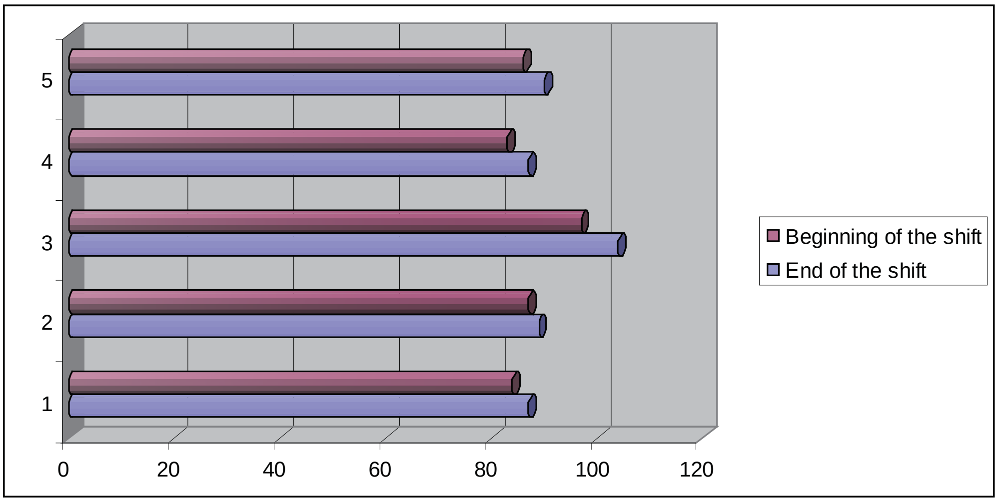
For the HR the difficulty of the tests could be classified in the following way: 1) Landolt's test – 99.5 beats/min; 2) DTR – 93.3 beats/min; 3) VMRMO – 90.4 beats/min; 4) SSMR – 85.7 beats/min; 5) STR – 85.1 beats/min.

Landolt test's HR is reliably higher than the HR in the remaining 4 tests (Wilcoxon Matched Pairs $p < 0.05$). Reliably higher is the HR during the VMRMO in comparison with the HR for studying the time of SSMR ($p < 0.05$). HR in dynamic tremometry is reliably higher in comparison with the HR in the static tremometry ($p < 0.05$).

On Figure 1, the results of the daily dynamic of the HR's changes are given.

The results surveyed in dynamic point out to higher HR at the end of the work day in comparison with the beginning in all used tests (fig. 1). Best expressed is the pulse increase in the fulfilment of the Landolt's test ($p < 0.05$), followed by the tests static and dynamic tremometry ($p > 0.05$), SSMR and VMRMO ($p > 0.05$). These data to a great extent correspond and confirm the mentioned above rating in difficulty by the used tests in the study. The SR in daily dynamic shows no clear changes.

The comparison between the separate tests points out that the SR is highest in time during the fulfilment of SSMR (421.9 kΩ) which, according to the difficulty, is on one of the last places and on the lowest in time for completion of the task for VMRMO (329,2 kΩ) and the Landolt's test (337.4 kΩ), which in difficulty take the first two places. It is accepted that SR values to a great extent confirm the rating in difficulty, mentioned above, met in the performance of the tasks.



1-SSMR; 2-VMRMO; 3-Landolt's test; 4-STR; 5-DTR

Fig. 1. Heart rate (p/min) dynamics for different neurobehavioral tests

As far as HR and SR are affected by emotional stress, there is a negative dependence between them – at high emotional stress the HR increases, while the SR decreases. The data given show such dependence during the performance of the DTR (KK = -43; p = 0.06) and during the time of performance of the VMRMO (K = -51; p = 0,028). During the examination of the Landolt's test and the STR, a tendency of negative dependence is observed.

DISCUSSION

The data of the used tests carried out show that the operative staff keeps good abilities for the completion of complex neuro-sensorial tasks during a whole work day.

The fulfilment of the SSMR task is very simple, but the changes in absolute values are good integral index for the level of the general excited processes and the processes of attention. In this case, they show an increase of the excited processes in the central nervous system in the end of the shift. On the background of the raised excitability at the end of work the neuropsychic capacity for work, evaluated after the other used behavioural methods remains unchanged and even improved [19].

The number of correct and wrong answers in VMRMO to the left and to the right in both examinations (in the beginning and in the end of the shift) is index for good mobility of the basic nervous processes, good concentration and distribution of the attention during the work time.

The results from Landolt's test (the correct answers at the end of work slightly increases without change in the reaction time) besides index for quick codification of the relevant information are index for fast and accurately short-term (operating) memory, good concentration and distribution of the attention, possibility for maintaining the active attention and the differential ability during the work shift. It is important that the short-term memory is more sensitive to fatigue and more often correlated with the parameters of the cardiovascular system (CVS) than attention [20]. Confirmation of this is that Landolt's test is fulfilled with highest HR in the beginning and the end of the shift.

Tremor-reaction is good indicator for mental load's influence and expresses the emotional state. Study of Haider E et al. [22] shows that tremor-reactions with informatory-mental stress can be interpreted by considering performance. Reactions with informatory-emotional stress are task specific when tremor is inter-individually normalized.

The good results in the static tremor-reaction also confirm the general tendency for keeping on high level the neuropsychic work capacity during the whole work day.

In the dynamic tremor-reaction, at the end of the shift, there is registered a reliable decrease in number of touches (i.e. improving the accuracy of work) combined with slight increase in time for performing the test (i.e. worsen the velocity). The alteration of the correlation "velocity/accuracy" is an index for a change in the "strategy" of the examined person while accomplishing this task. The change in the "strategy" is a mechanism for maintaining the neuropsychic (mental) working capacity [20], but it reflects on CVS parameters – the data from the pulse show a tendency of increase at the end of the shift. Because of this mechanism the mental work capacity shows to be less dependent on the fatigue as compared to the CVS activity [23].

As the neurobehavioural tests used raise demands for velocity and accuracy on behalf of the operating memory and the motor response, good steadiness and distribution of the attention and engagement the emotional will-power sphere, the heart rate to a higher degree reflects the difficulty with which the person accomplished the task – the so called "physiological price" for good answer [21, 24].

At the end of the work, the HR in fulfillment of all tests is insignificantly higher in comparison with the beginning of the day, i.e. at the end of the shift the neurobehavior tasks are performed with higher "physiological price" – a stronger tension is needed on behalf of the nervous system for keeping the initial level of work capacity, which reflects on CVS [20, 24].

The SR expresses the emotional stress during the performing of a given task – the calmer a person is, the higher is the SR. On the other part, the emotional instability strongly decreases the reliability of the human team in the system "man-management" of the NPP. The results point out that during work the emotional state of the examined operators is kept on constant level – indicator for this are the SR values, where there are no differences during the work shift. This emotional steadiness is an index for high reliability of the operative staff in NPP Kozloduy.

The high level of mental (nervous-psychic) work capacity in the operators of NPP Kozloduy we connect with their high individual resources and strong motivation. These individuals have strong feeling for responsibility, work control, high labour morality, reflecting the effect of the strict professional selection [7]. Most of the examined operators are satisfied with their work – their knowledge and experience are used completely. They are sure in their activities during work, they have the possibility to advance in hierarchy, nice payment. Of importance is also the young age of the operators – average age 33,3 ± 2,5 years [25].

The work satisfaction, the high personal resources and strong motivation are factors for powerful reserve to counteract to the stress [8, 26]. The operators with high levels of psychic stability revealed that individuals with high emotional stability, good self-control, low frustration and sthenic reactivity type demonstrate higher resistance to psychologic stress at work. Opposite personal features lower resistance to stress and result in transfer of stress at work into family relationships sphere that itself could become a stressor [8]. These factors are of importance in maintaining high level of mental work capacity and decrease the state of fatigue [26].

It could be generalized that the examined operators are with preserved abilities for the fulfilment of complex psycho-sensorial tasks and with high behavioral reliability for ensuring safe work without accidents.

The following nervous-behavioral tasks are objectively identifying the operator's mental work capacity – good criteria for evaluating the reliability of the human team in the operative staff in NPP. For that reason we consider that the evaluation of operator's behavioral reliability is closely related to the evaluation of their mental (nervous-psychic) work capacity.

The system of psycho-physiological examinations used for this study reports the basic nervouspsychic processes and the "physiological price" – the effort thanks to which the tasks are fulfiled. The proposed psycho-physiological test-system could be used in periodical control of the health and functional state of the operators and is suitable in the work of the services related to occupational medicine.

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