


CONCEPT OF MEDICAL PSYCHOPHYSIOLOGICAL EXAMINATION OF PERSONNEL OF NUCLEAR FACILITIES

Torubarov FS, Bushmanov AYu, Zvereva ZF , Kretov AS, Lukyanova SN, Denisova EA


State Scientific Center of the Burnazyan Federal Medical and Biological Center, Moscow, Russia

Ensuring safety of the facilities employing radiation and nuclear hazardous technologies is a priority task for medical organizations serving these facilities. To perform safely at their jobs, it is important for the personnel of nuclear facilities (NF) to have their central nervous systems functioning flawlessly. Certain categories of nuclear industry workers are required to undergo compulsory annual medical examinations (ME) and psychophysiological examinations. This study aimed to develop a concept of psychophysiological examination of NF personnel allowing to assess the central nervous system's functional status. The study involved three groups of nuclear corporation employees (male) counting 720, 364 and 24 people aged from 46 ± 5.3 to 49 ± 6.1 years. The report describes the suggested concept of psychophysiological examination of the specified category of workers, discusses goals, objectives and the procedure of such an examination at all stages of compulsory ME, covers the developed hardware and software sets. The proposed methodological approach is evaluated through consideration of the results of psychophysiological examination of the specified category of workers.

Keywords: workers, nuclear facilities, psychophysiological examination, concept, functional state, central nervous system

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 **Correspondence should be addressed:** Zoya F. Zvereva
Pestelya, 9, ap. 146, Moscow, 127490; zvereva01@yandex.ru

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КОНЦЕПЦИЯ ПСИХОФИЗИОЛОГИЧЕСКОГО ОБСЛЕДОВАНИЯ ПЕРСОНАЛА ОБЪЕКТОВ ИСПОЛЬЗОВАНИЯ АТОМНОЙ ЭНЕРГИИ В МЕДИЦИНСКИХ ОРГАНИЗАЦИЯХ

Ф. С. Торубаров, А. Ю. Бушманов, З. Ф. Зверева , А. С. Кретов, С. Н. Лукьянова, Е. А. Денисова

Государственный научный центр Федерального медико-биологического центра имени А.И. Бурназяна, Москва, Россия

Обеспечение безопасности объектов, использующих радиационно и ядерно опасные технологии, является приоритетной задачей медицинских организаций, обслуживающих эти предприятия. Для безопасной реализации работниками объектов использования атомной энергии (ОИАЭ) профессиональной деятельности важно высокое функциональное состояние их центральной нервной системы. Отдельные категории сотрудников атомной отрасли обязаны проходить обязательные ежегодные медицинские осмотры (МО) и психофизиологические обследования. Целью исследования было разработать концепции психофизиологического осмотра персонала ОИАЭ для оценки функционального состояния центральной нервной системы. В исследовании участвовали три группы работников (мужчины) атомной корпорации численностью 720, 364 и 24 человека в возрасте от $46 \pm 5,3$ до $49 \pm 6,1$ года. Предложена концепция психофизиологического обследования указанной категории работников, обсуждаются цели, задачи, порядок проведения психофизиологического обследования на всех этапах обязательных МО, разработаны аппаратно-программные комплексы. Для оценки предлагаемого методического подхода рассмотрены результаты психофизиологического обследования указанной категории работников.

Ключевые слова: работники, объекты использования атомной энергии, психофизиологическое обследование, концепция, функциональное состояние, центральная нервная система

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Соблюдение этических стандартов: исследование одобрено этическим комитетом ГНЦ ФМБЦ им. А. И. Бурназяна (протокол № 32с от 31 октября 2018 г.); все процедуры, выполненные в исследовании с участием людей, соответствуют требованиям институционального и/или национального комитета по исследовательской этике и Хельсинкской декларации 1964 г. и ее последующим изменениям.

 **Для корреспонденции:** Зоя Фёдоровна Зверева
ул. Пестеля, д. 9, кв. 146, г. Москва, 127490; zvereva01@yandex.ru

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Ensuring safety of the facilities employing radiation and nuclear hazardous technologies is a priority task for the relevant services and medical organizations serving such facilities. Despite technological advancements and widespread automation, human factor still plays a significant role. To mitigate the possible adverse impact thereof, certain categories of specialists permitted to work in the field of atomic energy are required to undergo medical examinations (ME) and psychophysiological examinations (PPE) in medical organizations.

Currently, under normal operating conditions, the staff of nuclear facilities cannot be exposed to ionizing radiation in doses exceeding the established standards. Professionally, such specialists perform under the burden of high responsibility, significant mental stress, need to be able to quickly perceive

information, process it and respond. To successfully discharge these duties and work in the conditions described, they need their central nervous system (CNS) to have a high functional state (FS).

According to the current concepts, FS of CNS determines the general functional state of the body [1]. Nervous system is considered to be the physiological basis of regulation mechanisms. From the psychophysiological viewpoint, FS of CNS is conditioned by the level of activation of and interaction between modulating — specific and nonspecific — structural-functional formations (SFF) of the brain [2, 3]. In case of nuclear facility employees, process safety and efficiency directly depends on the FS of their CNS. PPE allows assessing FS of CNS.

The purpose of PPE is to identify persons with psychophysiological contraindications for employment at NF. The goals of PPE include assessment of the functional activity of SFF of CNS and conclusion about FS of the employee's CNS [4, 5].

As of 2019, there are 26 psychophysiological examination laboratories (PEL) operating under medical organizations serving nuclear facilities in Russia. This fact necessitates development and implementation of common methodological approaches and methods, as well as a single PPE protocol applicable at all stages of medical monitoring of the personnel's condition [4, 5].

This study aimed to develop nuclear industry personnel PPE concepts and evaluate the suggested methodological approach.

METHODS

The study involved three groups of nuclear corporation employees that underwent PPE in 2015–2017 as part of routine medical checkups. The inclusion criteria required the participants to not have any contraindications for working at a nuclear facility.

Group 1: 720 employees of ten nuclear power plants (NPP), mean age 49 ± 6.1 years; inclusion criterion — underwent PPE as part of routine medical checkup.

Group 2: 364 NPP operators, mean age 46 ± 5.3 years; inclusion criterion — underwent PPE as part of pre-shift medical examination.

Group 3: 24 people, mean age 48 ± 6.3 years; inclusion criterion — underwent PPE as part of evaluation of the results of rehabilitation and health improvement courses (RHIC) in a hospital.

PPE in the context of routine medical checkups of NPP employees, as well as those that underwent RHIC, relied on the PFS-Kontrol hardware and software set (H&S) [6]. The subject of evaluation were the results of application of the following tests/methods.

- psychodiagnostic techniques: MMPI methodology; Sixteen Personality Factor Questionnaire, 16PF; Raven's Matrices; subjective control level (SCL);

- psychophysiological techniques (visual-motor tests): simple visual-motor reaction test, SVMRT; complex visual-motor reaction test, CVMRT, reaction to moving object (RMO)

- physiological technique: heart rate variability (HRV).

Prognoz H&S was used in the context of pre-shift examinations [7].

The statistical differences were assessed with the help of the χ^2 test, the level of significance was set at $p < 0.05$.

RESULTS

The search for a common approach to assessment of the FS of CNS based on the employee's PPE results yielded a psychophysiological examination concept (Fig. 1).

Three structural and functional formations in the brain were selected as those allowing assessment of FS of CNS relying on the PPE results. Psychodiagnostic techniques (MMPI, 16PF, Raven's Matrices, SCL) allowed identifying the "cortex" SFF, psychophysiological techniques (SVMRT, CVMRT, RMO) — the "cortical-subcortical interaction" SFF, physiological techniques (HRV) — the "cardiovascular system central regulation" SFF [6, 8, 9].

The functional activity (FA) of the SFF could be high, medium and low, all within the limits of acceptable values. It could also

go beyond those limits. The SFF FS indicators allowed making a final conclusion about FS of CNS.

All stages of medical monitoring routines should include PPE, but the purpose attached to each stage is unique. Figure 2 shows the medical monitoring diagram.

During the preliminary ME, the main task is to identify psychophysiological contraindications for work. PPE results are included in the preliminary ME's general report; if there are psychophysiological contraindications, the candidate is not hired. It should be noted that it is advisable to accumulate indicators registered with each PPE test and the general conclusion drawn thereof in a special database.

For persons hired, further medical monitoring routines are shaped by the results of preliminary ME and PPE.

In the context of regular ME, PPE solves two tasks:

- 1) identify persons with unacceptable values of indicators of functional activity of CNS SFF, who are suspended from work for an in-depth medical examination to make a decision on the possibility of continuing the employment;

- 2) identify persons with low but permissible values of indicators of functional activity of CNS SFF, who are added to the risk group and sent to RHIC.

As a rule, regular medical examinations take place once a year, and on the daily basis, the employee's FS of CNS is controlled with pre-shift ME and PPE.

Pre-shift ME allow identifying persons in a disabled state, including those intoxicated with alcoholic, narcotic or other toxic substances or exhibiting residual effects thereof. Pre-shift psychophysiological control uncovers functional disorders of CNS that may significantly hamper professional reliability of an employee.

Thus, the goal of pre-shift PPE is to identify workers whose FS of CNS prevents them from working the given shift. The time allocated for PPE as part of the pre-shift control routine is limited. Therefore, the important technical requirements for PPE of this stage are efficiency, personalized character, exhaustive descriptiveness.

At the RHIC stage, PPE aims to objectively assess the FS of CNS before and after the procedures.

It is mandatory for medical organizations conducting PPE to develop and deploy a special database that summarizes the results of examinations at all stages.

A PPE database enables timely medical, organizational and managerial decisions made with the aim to improve radiation and nuclear safety of the nuclear industry plants and facilities.

From our point of view, in the context of laboratory ME, PPE should not only apply a set of methods and techniques common to all such examinations, but also employ H&S sets that meet a unified list of requirements. Such an approach would allow comparing PPE results obtained at different (all) laboratories.

PFS-Kontrol H&S set enables full-scale PPE as part of preliminary, regular and RHIC-related ME, with the output being a medical report on the FS of CNS delivered without any delay.

Prognoz H&S set enables PPE as part of pre-shift control. The psychophysiological methods used by this H&S set are designed to assess visual and auditory sensory systems, as well as optical-motor reactions. The results of application of each method translate into a systemic function organization stability indicator (SFOSI), which describes CNS as a single functional system.

Prognoz H&S set employs an innovative admission control method, which allows determining whether an NF operator may be admitted to work. The method relies on the indicators reflecting normal state of each operator (personalized

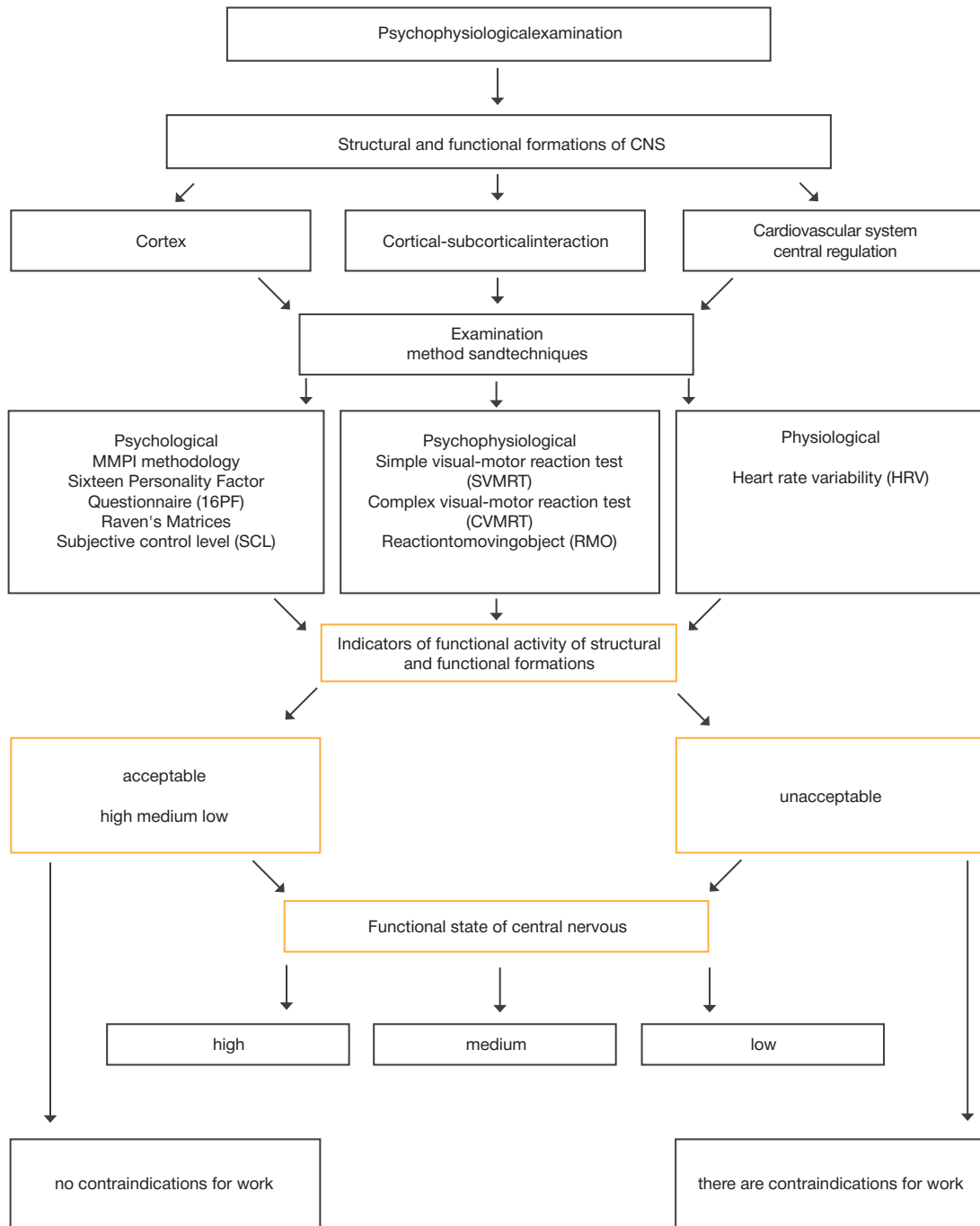


Fig. 1. Concept of psychophysiological examination

approach), the values of which accumulate and are shaped into "norms" for the given operator automatically after 20th pre-shift checkup, provided the operator had no health complaints and was always admitted to work during the corresponding period. Personal norms factor in psychophysiological characteristics and their daily fluctuations. As the personal norm data are accumulated, it is automatically recalculated every month.

Examination of Group 1: assessment of the results of PPE as part of regular ME

Tables 1 and 2 show the results of PPE performed in the context of regular ME of 720 NPP employees. The examination made use of PFS-Kontrol H&S set.

The FS of CNS in the majority of examined individuals was medium (56.4%) and high (28.5%); only 15.3% had it at the

low level. The differences between groups were significant: $\chi^2, p < 0.05$.

To determine the contribution of each SFF into fluctuations of FS of CNS, we analyzed the SFF indicators peculiar to high, medium and low functional activity (Table 2).

The dominating (50.6%) SFF in cases of high FA was "Cortex". The number of "Cortical-subcortical interaction" SFF was significantly less (24.8%), and that of "Cardiovascular system central regulation" even less (10.3%) ($\chi^2, p < 0.05$).

In cases of medium FA, the dominating SFF indicators were "Cortical-subcortical interaction" and "Cardiovascular system central regulation" (61.9% and 59.9%, respectively). The "Cortex" SFF was slightly less (47.7%), however, the differences with the number of "Cortical-subcortical interaction" and "Cardiovascular system central regulation" SFF were significant ($\chi^2, p < 0.05$).

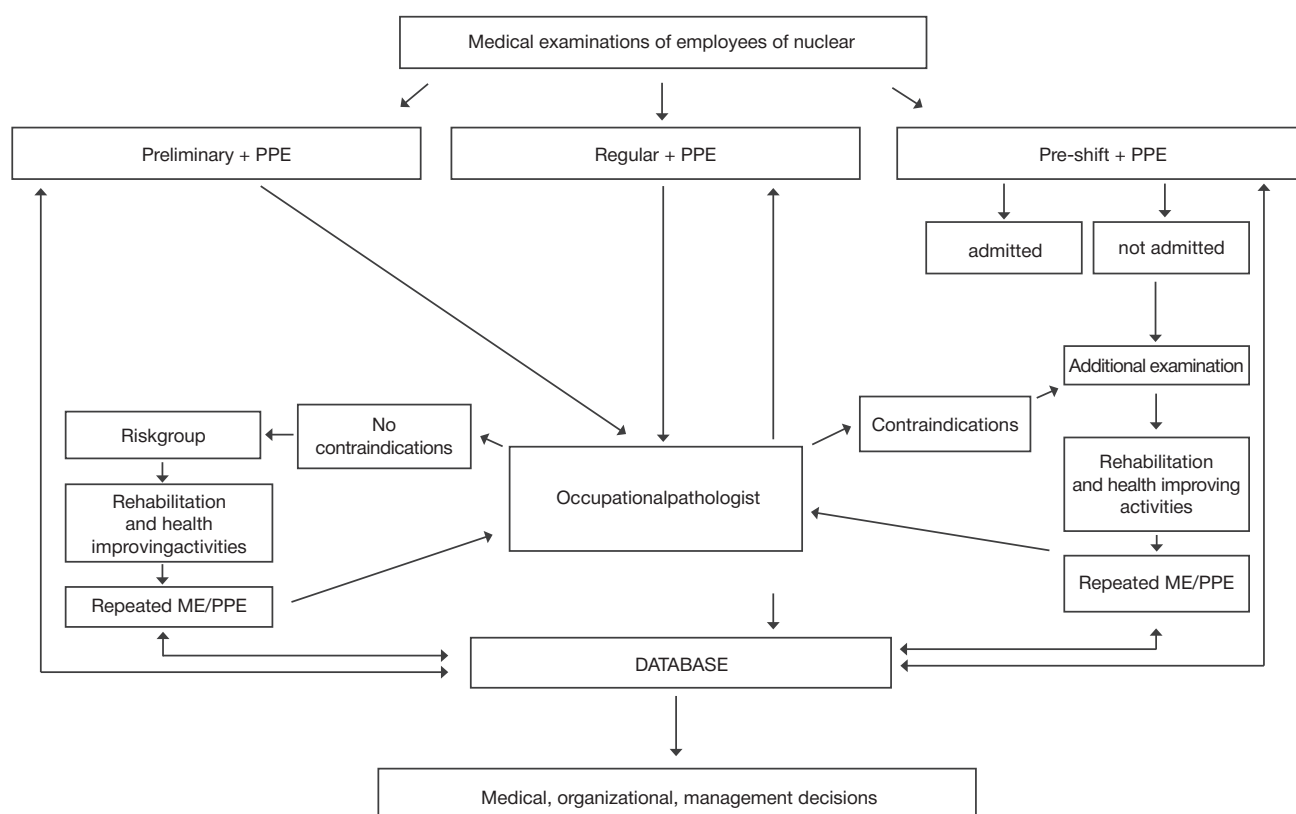


Fig. 2. Medical monitoring system for employees of nuclear facilities

At high FA, the dominating indicators were those of "Cardiovascular system central regulation" (relative to the indicators of the "Cortical-subcortical interaction" and "Cortex" SFF) — 29.9% versus 12.3% and 3.2% (the differences between the groups are significant: $\chi^2, p < 0.05$).

Based on the data presented, it can be assumed that when SFF function at a high level, the SFF influencing FS of CNS most is the "Cortex" SFF. When the FA is medium, the most influential as the "Cortical-subcortical interaction" and "Cardiovascular system central regulation" SFF. In cases of low FA, the FA of CNS is mostly shaped by the "Cardiovascular system central regulation" SFF.

Examination of Group 2: assessment of the results of pre-shift examinations

At Kursk NPP, Prognoz-enabled PPE has been part of the pre-shift checkup since 2010. Every year, 260–400 people undergo such examinations. Overall, Prognoz H&S set is used in over 70,000 pre-shift examinations a year. Every day, one or two persons are not admitted to work because of the low FS of CNS. Within a year, the figure is 80. After examination by a paramedic, 75–80% of them receive a conditional admission to the shift with notification of the shift manager. About 15% are not admitted and sent to the workshop therapist for additional examination.

Table 1. FS of CNS registered in Group 1 (n = 720)

FS of CNS	Examined individuals	
	abs.	%
High	205	28.5
Medium	406	56.4*
Low	110	15.3*

Note: * — significant differences with the group showing high indicator value at ($p < 0.5$), as established by the χ^2 test

The results of PPE are the basis for the report (Table 3) that contains all the indicators and admission data.

As the report above shows, operator 2 had the current SFOSI value significantly exceeding his personal norm, which was the reason for him not being allowed to work.

Examination of Group 3: PPE before and after RHIC

The pre- and post-RHIC PPE was carried out in the psychophysiological laboratory of the Center for Occupational Pathology of the State Scientific Center of A. I. Burnazyan Federal Medical and Biological Center.

Before RHIC, all patients had the mean time of sensorimotor reactions slightly increased, although within the permissible value range. The integral indicator of visual-motor reaction tests (SVMRT, CVMRT) determined by the mean time of sensorimotor reactions and the number of precise reactions, was below normal in all of them (Table 4).

RHIC improved the visual-motor test indicators significantly, which confirms improvement of the FS of CNS.

DISCUSSION

The presented concept of psychophysiological examination of NF personnel corresponds to the existing concepts of adaptation, the basis for which is the theory of functional

Table 2. SFF CNS indicators at high, medium and low functional activity, Group 1 (n = 720)

SFF CNS	Functional activity					
	High		Medium		Low	
	abs.	%	abs.	%	abs.	%
"Cortex"	365	50,6	340	47,2	15	3,2
"Cortical-subcortical interaction"	179	24,8*	446	61,9*	95	13,2*
"Cardiovascular system central regulation"	74	10,3**	431*	59,9*	215	29,9**

Note: * — significant differences with SFF "Cortex" at (p < 0.5), as shown by the χ^2 test; ** — significant differences with SFF "Cortical-subcortical interaction" at (p < 0.5), according to the χ^2 test

Table 3. Automated PPE report example

# Name	Shop	Position	SFOSI indicators				Admitted/ Notadmitted
			Mean	RMS (σ)	Personal admission threshold (mean + 2 σ)	Current SFOSI value	
1	*****	«-----«	1145	682	2505	1953	Admission
2	*****	«-----«	3241	1498	6237	7320	Non-admission

Table 4. Integral indicator of visual-motor reaction tests, RHIC patients (n = 24)

Integral indicator of visual-motor reaction tests. Indicator values in %					
Before RHIC		After RHIC			
Abovenorm		Norm		Without changes	
abs.	%	abs.	%	abs.	%
24	100	21	87,5	3	12,5

systems [3]. These concepts state that adaptation, through structural and functional changes, leads to development of a system functioning to support the body's activities.

Adaptation is a multilevel process. The levels of adaptation are interrelated, have a direct impact on each other and determine the integral characteristic of the general level of functioning of all systems of the body, or the functional state of a person [1].

The functional state of a person is considered as a process reflecting the interaction of levels of adaptation. This is the integral indicator of psychophysiological adaptation. The existing concepts have the level of psychophysiological adaptation determined by the structural and functional formations of CNS, which, combined, shape its FS [1, 2]. Determination of the FS of CNS and the functional activity of its structural and functional formations is an important objective pursued by PPE of NF personnel.

Psychophysiological examination based on the presented concept allows determining FS of CNS, level of psychophysiological adaptation, assess the state of individual

structural and functional formations of CNS ("Cortex", "Cortical-subcortical interaction", "Cardiovascular system central regulation"). Considered cumulatively, this information allows prescribing, if necessary, targeted and personalized rehabilitation and health-improving courses, and evaluate the results thereof afterwards. Data on the "Cortical-subcortical interaction" SFF enables PPE during pre-shift checkup and allows quick and accurate evaluation of the FS of CNS of the examined persons.

CONCLUSION

Introduction of a common methodological approach to PPE and a unified H&S set to the NF employee medical care system significantly expands its diagnostic and preventive capabilities, enabling early detection of functional disorders of CNS, psychophysiological contraindications for work, timely interventions with RHIC and objective assessment of the results thereof. This helps to reduce the risk of human error accidents and extends professional longevity of NF personnel.

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