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COMPUTER-INTEGRATED COMPONENTS OF THE AUTOMATED DECISION-MAKING SUPPORT SYSTEM FOR OPERATIONAL AND MAINTENANCE PERSONNEL OF NUCLEAR POWER PLANT UNITS WITH WWER

The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS variants for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. The results of studies aimed at the development of computer-integrated components of the automated decision-making support system (ADMSS) for operational and maintenance personnel of NPP units by the criterion of technical and economic efficiency, taking into account the diagnostics of the state of the power unit equipment, are presented. The general structure of the software package interaction for the analysis of the performance and parameter diagnostics of NPP units with WWER has been developed. When creating the software package, the integrated programming environment Microsoft Visual Studios was used. The structure of the program block for the parameter diagnostics of the equipment of nuclear power units is presented. The main types of problems arising during the operation of NPP units with WWER, that can be solved with the help of the developed ADMSS are considered, and a form for presenting the results to the operational and maintenance personnel of power units is proposed. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and equipment, including obtaining operational (energy) characteristics of power unit systems and equipment, optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Keywords: computer-integrated components, automated decision-making support system, nuclear power plant units with WWER, software package, simulation model, parameter diagnostics.

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КОМП’ЮТЕРНО-ІНТЕГРОВАНІ КОМПОНЕНТИ АВТОМАТИЗОВАНОЇ СИСТЕМИ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ДЛЯ ЕКСПЛУАТАЦІЙНОГО ТА РЕМОНТНОГО ПЕРСОНАЛУ ЕНЕРГОБЛОКІВ АЕС З ВВЕР

Метою статті є опис результатів досліджень, які направлені на розробку комп’ютерно-інтегрованих компонентів одного з вариантів АСППР для експлуатаційного і ремонтного персоналу енергоблоків АЕС за критерієм техніко-економічної ефективності з урахуванням діагностики технічного стану устаткування на базі імітаційної моделі, що описує за допомогою сучасних математичних методів технологічні процеси в основному і допоміжному устаткуванні енергоблоків на рівні деталізації, яка відповідає їх принциповим і розгорнутим тепловим схемам. Представлені результати досліджень, які направлені на розробку комп’ютерно-інтегрованих компонентів автоматизованої системи підтримки прийняття рішень (АСППР) для експлуатаційного і ремонтного персоналу енергоблоків АЕС за критерієм техніко-економічної ефективності з урахуванням діагностики стану устаткування енергоблоків. Розроблена загальна структура взаємодії блоків програмного комплексу для аналізу ефективності роботи і параметричної діагностики енергоблоків АЕС з ВВЕР. При створенні програмного комплексу використовувалось інтегроване середовище програмування Microsoft Visual Studios 6. Представлена структура блоку програм параметричної діагностики устаткування енергоблоків АЕС. Розглянуто основні типи задач, що виникають при експлуатації енергоблоків АЕС з ВВЕР, які можуть бути вирішені за допомогою розробленої АСППР і запропонована форма представлення результатів для експлуатаційного і ремонтного персоналу енергоблоків. Розроблена на основі описаних комп’ютерно-інтегрованих компонентів автоматизована система підтримки прийняття рішень експлуатаційним і ремонтним персоналом енергоблоків АЕС може бути використана для вирішення широкого діапазону задач, що виникають в практиці кратко-, середнє- и довгострокового управління режимами роботи систем і устаткування енергоблоків, в тому числі для отримання експлуатаційних (енергетичних) характеристик систем і устаткування енергоблоків, оптимізації режимів і параметрів їх роботи, діагностики і прогнозування технічного стану устаткування енергоблоків, прогнозування кількості виробки енергоблоком електричної і теплової енергії, оптимізації ремонтних циклів на АЕС.

Ключові слова: комп’ютерно-інтегровані компоненти, автоматизована система підтримки прийняття рішень, енергоблок АЕС з ВВЕР, комплекс програм, імітаційна модель, параметрична діагностика.

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КОМПЬЮТЕРНО-ИНТЕГРИРОВАННЫЕ КОМПОНЕНТЫ АВТОМАТИЗИРОВАННОЙ СИСТЕМЫ ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ ДЛЯ ЭКСПЛУАТАЦИОННОГО И РЕМОНТНОГО ПЕРСОНАЛА ЭНЕРГОБЛОКОВ АЭС С ВВЭР

Целью настоящей статьи является описание результатов исследований, направленных на разработку компьютерно-интегрированных компонентов одного из вариантов АСППР для эксплуатационного и ремонтного персонала энергоблоков АЭС по критерию технико-экономической эффективности с учетом диагностики технического состояния оборудования на базе имитационной модели, описывающей с помощью современных математических методов технологические процессы в основном и вспомогательном оборудовании энергоблоков на уровне детализации, соответствующей их принципиальным и развернутым тепловым схемам. Представлены результаты исследований, направленных на разработку компьютерно-интегрированных компонентов автоматизированной системы поддержки принятия решений (АСППР) для эксплуатационного и ремонтного персонала энергоблоков АЭС по критерию технико-экономической эффективности с учетом диагностики состояния оборудования энергоблоков. Разработана общая структура взаимодействия блоков программного комплекса для анализа эффективности работы и параметрической диагностики энергоблоков АЭС с ВВЭР. При создании программного комплекса использовалась интегрированная среда программирования Microsoft Visual Studios 6. Представлена структура блока программ параметрической диагностики оборудования энергоблоков АЭС. Рассмотрены основные типы задач, возникающих при эксплуатации

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энергоблоков АЭС с ВВЭР, которые могут быть решены с помощью разработанной АСППР и предложена форма представления результатов для эксплуатационного и ремонтного персонала энергоблоков. Разработанная на основе описанных компьютерно-интегрированных компонентов автоматизированная система поддержки принятия решений эксплуатационным и ремонтным персоналом энергоблоков АЭС может быть использована для решения широкого перечня задач, возникающих в практике кратко-, средне- и долгосрочного управления режимами работы систем и оборудования энергоблоков, в том числе для получения эксплуатационных (энергетических) характеристик систем и оборудования энергоблоков, оптимизации режимов и параметров их работы, диагностики и прогнозирования технического состояния оборудования энергоблоков, прогнозирования количества выработки энергоблоком электрической и тепловой энергии, оптимизации ремонтных циклов на АЭС.

Ключевые слова: компьютерно-интегрированные компоненты, автоматизированная система поддержки принятия решений, энергоблок АЭС с ВВЭР, комплекс программ, имитационная модель, параметрическая диагностика.

Introduction. Nuclear power plant units, which are complex technical systems, are characterized by a large number of parameters, multifunctional links between them, a variety of equipment for various technological purposes and physic-chemical processes occurring in it, as well as operation under the influence of external random processes, etc. To study the parameters, characteristics and performance of NPP units as complex technical systems, methods of mathematical modeling using computer-integrated technologies for their implementation are now widely used. They make it possible to simulate the set of functional states of both systems and equipment of power units in a simulation experiment [1–26].

It should also be noted that the technological processes occurring in the equipment of NPP power units under various modes of their operation, including dynamic (transient) ones, are generally described by complex systems of nonlinear differential equations in partial derivatives. To describe the technological processes in steady-state (quasi-stationary) modes of the power unit operation, nonlinear equations with their own characteristics are used. To solve them, the use of numerous methods in the process of simulation modeling, and in some cases their linearization, makes it possible to obtain an approximate solution with the accuracy, which is sufficient for engineering practice [1, 2, 3].

The purpose and objectives of the research. The purpose of this article is to describe the results of the research aimed at developing computer-integrated components of one of the ADMSS variants for operational and maintenance personnel of NPP units according to the criterion of technical and economic efficiency, taking into account the diagnostics of the technical equipment state based on the simulation model describing by means of up-to-date mathematical methods the technological processes in the main and auxiliary equipment of power units using up-to-date mathematical methods at the level of detailing, corresponding to their principle and deployed thermal schemes. This simulation model, methods and approaches to its creation based on the graph theory are described in sufficient detail in [1, 3–6] and several others.

The main components of the approaches presented in these works are the simulation model that adequately describes the technological processes, both in individual elements and in the power unit as a whole, and its computer implementation in the form of an automated set of programs. The listed computer-integrated components can be considered as the basis for the creation of an automated decision-making support system (ADMSS) for operational and maintenance personnel of NPP units, which allows to perform:

- calculation of the parameters of technological processes in the elements, nodes and systems of the power unit;
- parameter diagnostics of the technical state of the power unit equipment;
- calculation of the reliability and safety indicators of the systems and equipment of the power unit;
- calculation of the projected electricity and heat generated by the power unit in a given period of operation;
- calculation of the technical and economic indicators of the unit efficiency;
- calculation of the performance indicators of repair work (repair cycles) at the power unit.

The effectiveness of using such ADMSS in the process of operation of NPP units as parts of their APCS, the accuracy and number of decision-making options offered by the system significantly depend on the level of the unit simulation model detailing and the accuracy of the mathematical methods used in the computer programs of the above-mentioned calculations to describe the technological processes in the equipment of the units.

Computer-Integrated Components of ADMSS. Based on the simulation model of the NPP power unit withWWER-1000 (Fig. 1), computer-integrated components of ADMSS were developed as a set of computer programs for analyzing technical and economic efficiency of operation and parameter diagnosing the technical state of two-loop cycle NPP unit equipment.

These components are used for a new, more advanced version of the automated complex of programs for analyzing the operation of two-loop cycle NPP units [6], expanded by developing programs for computing diagnostic parameters of the main and auxiliary equipment of power units.

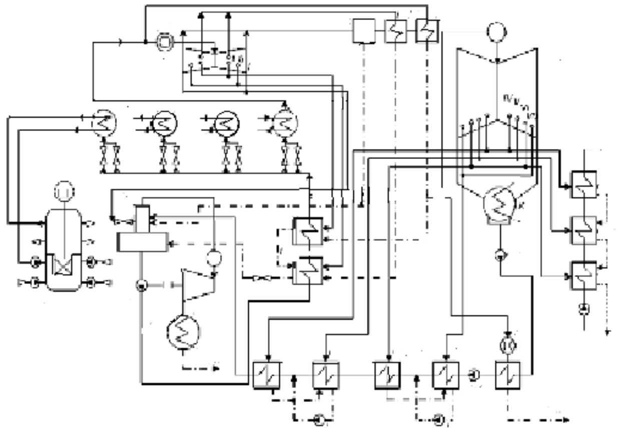

Fig. 1. Scheme of NPP power unit withWWER-1000 (water-water energy reactor)

The structure of individual components (blocks) of the automated computer program complex for analyzing technical and economic efficiency of operation and parameter diagnosing NPP power units with WWER is shown in Fig. 2. When creating it we used the Microsoft Visual Studio 6 development environment and the algorithmic language Fortran 95 as integrated programming environment, as in [6], which proved to be quite good as software tools when creating software packages for computing the parameters of technological processes in complex technical systems.

This set of programs, which is controlled by the MAIN file (Fig. 2), can be divided into two parts: conservative and operational, which is quite typical for automated decision-making support systems for operational personnel of power facilities as complex technical systems [6].

The conservative part of the program complex, which provides the adequate description of the technological processes in the systems and equipment of the NPP power unit at different operation modes, includes:

- a database operation block n which is used to store the information accumulating during the operation of the power unit (Fig. 2);
- a block for processing information about the values of the parameters and characteristics of technological processes in the power equipment received from the instrumentation of the power unit (Fig. 2);
- a block for identifying the simulation model with the actual technical state of the power unit equipment (Fig. 2);
- a block of the modification of the structure and parameters of thermal power unit scheme (TS) that provides for connecting, disconnecting, switching, replacing, eliminating and including equipment into the TS, as well as entering and correcting the initial data necessary to compute the parameters of the technological processes in the power unit equipment (Fig. 2).

The operational part of the program complex, which provides the computation of parameters in the power unit systems and equipment, contains the following program blocks:

- a block of programs for computing parameters, characteristics and indicators in the reactor plant equipment by means of the corresponding algorithms given in [2, 3], including programs for computing thermal and hydraulic parameters and characteristics of the heating agent in the primary loop equipment, in particular, in main circulation pumps, as well as working substance in steam generators;

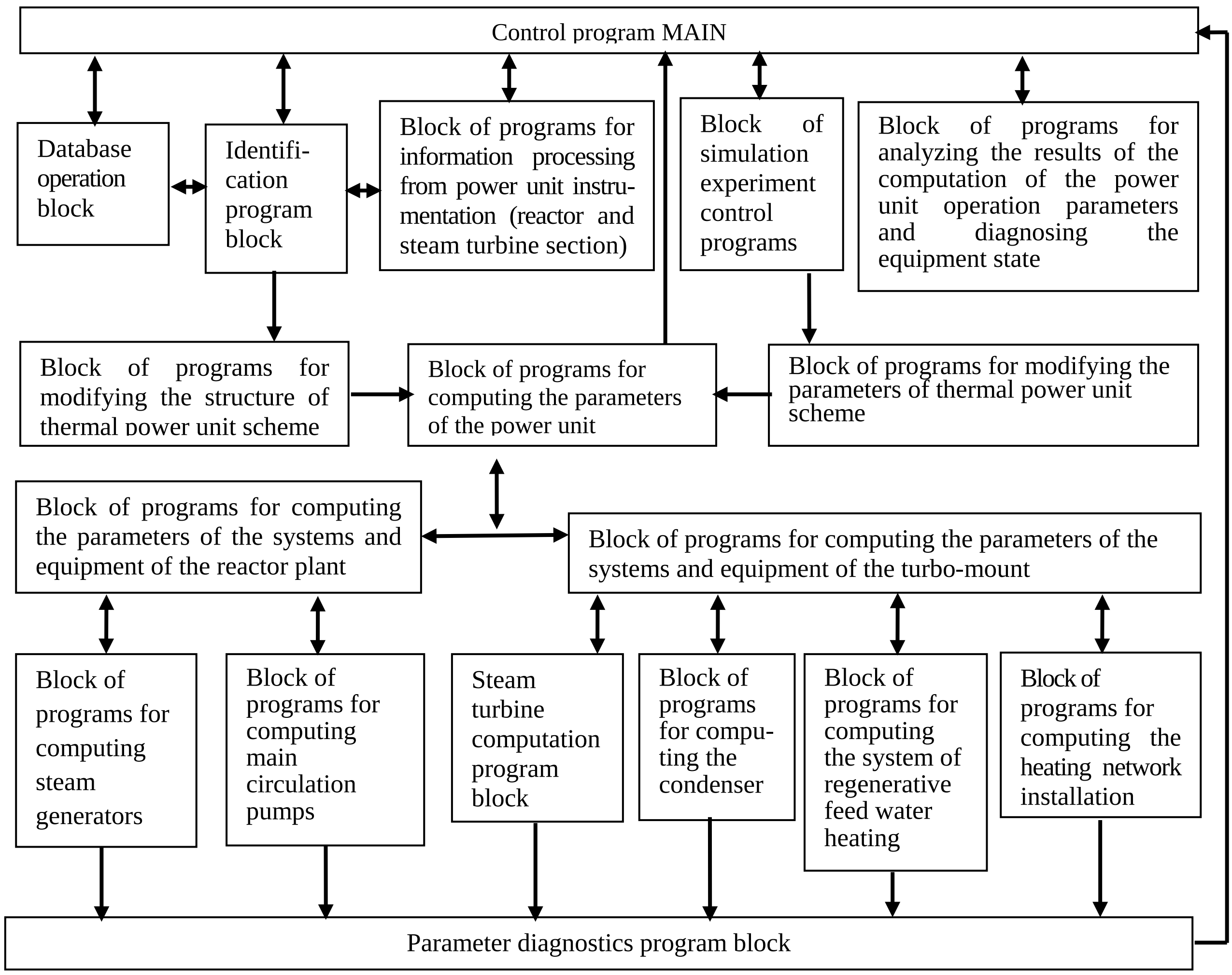

Fig. 2 The structure of the interaction of components (blocks) of the automated system performance analysis and parameter diagnostics of NPP power units with WWER

- blocks of programs for computing the parameters, characteristics and indicators of the turbine installation by means of the corresponding algorithms given in [2, 3], including: a block of programs for computing the parameters, characteristics and indicators in the flow sections of the main turbine and the turbo drive of the feed pump;
- blocks of programs for computing the parameters, characteristics and indicators in the systems of condensation and regenerative heating of the main condensate and feed water;
- a block of programs for computing the parameters, characteristics and indicators in the system for heating the network water (heating system);
- a block of programs for the parameter diagnostics of the main and auxiliary equipment in the power unit, created on the basis of the approaches, methods and models described in detail in [1, 2, 3].

The structure of the parameter diagnostics program block is presented in Fig. 3.

The factors causing the deviation of diagnostic parameters (functions) from standard values for various dimensions of the power equipment of NPP power units with WWER are summarized, systematized and entered into the database of the program complex.

The operational part of the program package for analyzing the quality of the operation of NPP units also includes a block of programs for controlling simulation experiments (Fig. 2).

The presented computer-integrated components in the form of a program complex allow to solve the following types of problems arising during the operation of NPP power units with WWER:

- problems of analyzing the influence of the equipment parameters, the structure of thermal schemes and external operating conditions on the performance of power units:

$$\Omega(\chi) = f\left(\chi, G^T, \Lambda, B, Y\right); \qquad (1)$$

- problems of structural and parameter optimization of the performance indicators of power units:

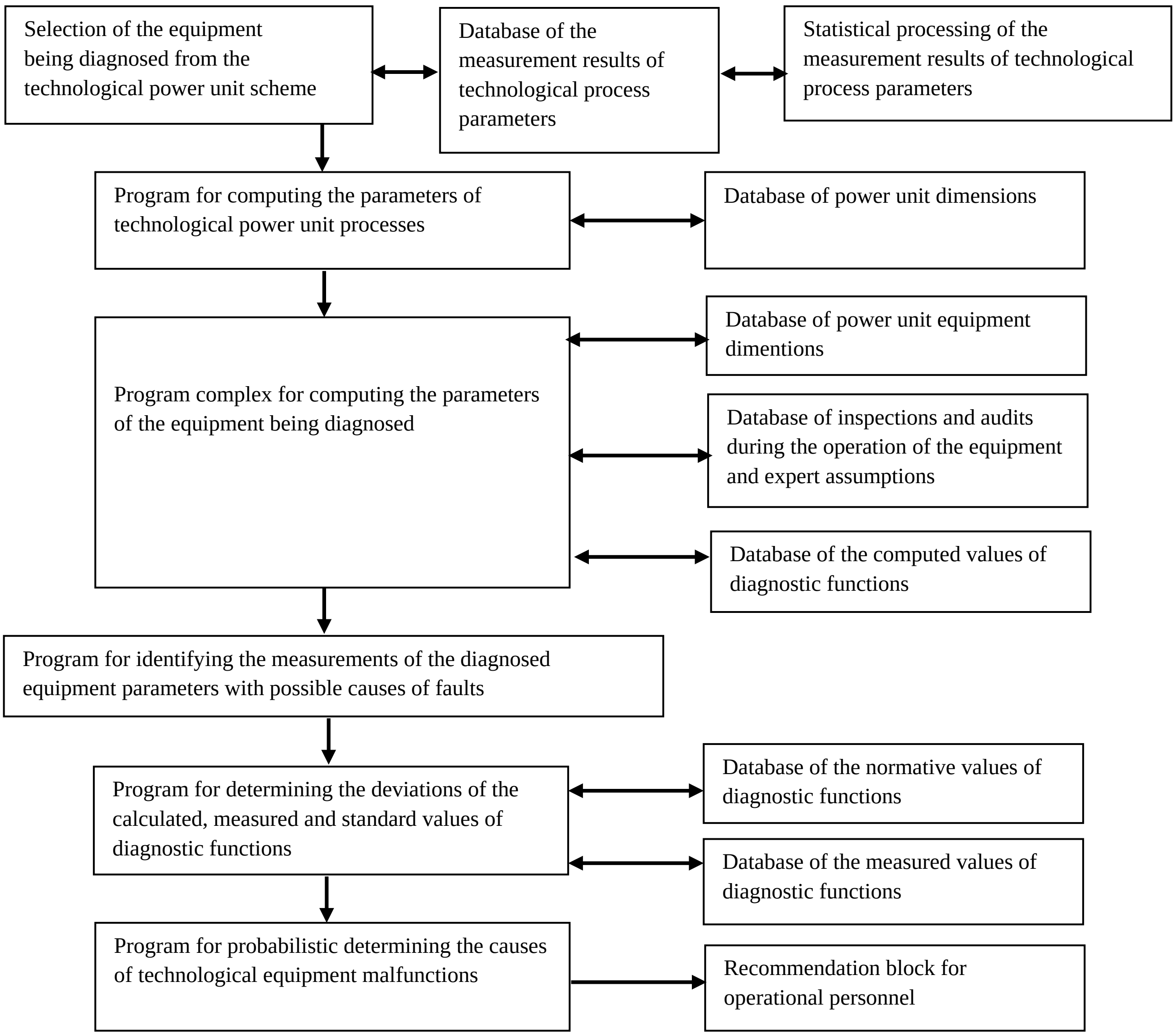

Fig. 3. Block of programs for parameter diagnostics of NPP power unit equipment with WWER

$$\text{extr}\Omega\begin{Bmatrix}\Omega(\chi)\big|\varphi_i(\chi)=0;X_{\min}\le X\le X_{\max};Y_{\min}\le Y\le Y_{\max}\\ G^T\in\left(G_1^T,G_2^T,...,G_k^T\right);\Lambda\in\left(\lambda_1,\lambda_2,...\lambda_\gamma\right);i=\overline{1,s}\end{Bmatrix};(2)$$

- problems of optimal distribution of electrical and heating loads in time *t* between *n* power plant units depending on the technical state of their equipment under various external operating conditions in order to achieve optimal performance indicators of the entire NPP:

$$\Omega_{station}=\text{extr}\left[\frac{1}{n}\sum_{i=1}^{n}\Omega_i\left(X_i(t),G_i^T,(t),\Lambda_i(t),Y_i(t)\right)\right];\quad(3)$$

- the problems of evaluating the performance of power units during the forecast period of their operation t based on the analysis of reliability indicators *R*(*t*) (for example, probability of failure-free operation) of their thermal schemes and equipment obtained by means of technical state parameter diagnostics:

$$\left\{\Omega\left(\chi,R(t)\right)\big|\varphi_i\left(\chi,R(t)\right)=0,\chi\in K,i=\overline{1,s}\right\}.\quad(4)$$

In (1)–(4) $\Omega(\chi)$ and $\varphi_i(\chi)$ – mathematical expressions describing the performance of the power unit as a technical system ($\Omega(\chi)$) and technological processes occurring in it ($\varphi_i(\chi)$);

i – the number of mathematical expression;

s – the number of expressions in the simulation model;

$\chi=\left(X,Y,G^T,\Lambda,B\right)$ – information structure of the simulation model, in which *X* is the vector of independent parameters of the power unit equipment, *Y* is the vector of dependent parameters of the power unit equipment;

G^T – technological graph;

$\Lambda=\left(\lambda_1,\lambda_2,...\lambda_\gamma\right)$ – the vector of the parameters describing the influence of external conditions of the power unit operation;

B – the vector of the parameters describing the simulation detailisation level;

K – the area of all possible functional states of the power unit equipment that can be described using the simulation model $\Omega(\chi)$ and $\varphi_i(\chi)$.

Discussion of the research results. The form of presenting information in the ADMSS about the values of parameters, characteristics and technical and economic indicators of the operation modes and diagnostic results of WWER NPP units, their individual systems and equipment obtained using the developed set of programs is shown in tabl. 1–3 as a fragment of the output information about the values of parameters, characteristics and indicators of the NPP power unit with WWER-1000, PGV-1000 steam generator and K-1000-60-1500/2 (K-1000-5.9/25) turbo-installation at nominal mode operation. This form of presenting information may be modified in accordance with the specific requirements of the ADNSS users at nuclear power plants.

The analysis of the results of computing a number of specific problems of the above-mentioned types using the described complex of programs showed that their values in terms of the initial data error, caused by errors in measuring technological process parameters by means of standard instrumentation, as well as errors in formula which were used in the computation algorithms, do not exceed the limits acceptable for assessing technical and economic efficiency, reliability and safety of NPP power units.

Conclusions. Developed on the basis of the described computer-integrated components, the automated decision-making support system for the operational and maintenance personnel of NPP power units can be used to solve a wide range of problems arising in the practice of short-, medium- and long-term control of the operation modes of power unit systems and optimizing operation modes and parameters, diagnosing and forecasting technical state of power equipment, predicting the amount of electrical and thermal energy generated by a power unit, as well as optimizing NPP repair cycles.

Table 1 – Main indicators of power unit operation

Electricpower *N* (kW)		Specific heat consumption *q* (kJ/(kWh))		Efficiency
net	1077247,91	9992,9		31,99
gross	1103572,93	10237,1		32,76
Total consumption of generated steam *G* (kg/h)	Pressure of generated steam *P* (atm)	Temperature of generated steam *T* (°C)	The degree of dryness of the generated steam *X*	Feedwater temperature at the inlet to steam generator *T* pit (°C)
6430000,0	61,98	274,20	0,995	224,74

Table 2 – Reactor plant heating agent parameters

Sitename	Heating agent temperature *T* (°C)	Heating agent pressure *P* (atm)	Specific volume of heating agent *V* (m^3/kg)	Heating agent enthalpy *I* (kJ/kg)
At the inlet to steam generator	319,93	158,87	0,0014698	1452,52
At the outlet of steam generator	289,81	157,66	0,0013391	1282,77
At the inlet to reactor core	290,45	162,16	0,0013399	1285,99
At the outlet of the reactor core	319,97	159,06	0,0014696	1452,73

Table 3 – Tturbo-mount computation of the process of steam expansion in turbine

Names of the elements of turbine flow part	Steam consumption *G* (kg/h)	Vapor pressure *P* (atm)	Steam temperature *T* (ºC)	Degree of steam dryness *X*	Steam enthalpy *I* (kJ/kg)	Specific volume of steam *V* (m^3)	Power compartment (kW)
High pressure turbine inlet	6157865,01	58,3646	272,53	0,9954	2775,12	0,0340	169844,00
Compartment 1	5651553,03	30,5538	233,81	0,9291	2675,88	0,0620	98398,71
Compartment 2	5359023,02	19,8102	210,94	0,9041	2613,24	0,0927	87456,32
High pressure turbine outlet	5077590,02	12,6117	189,32	0,8849	2554,49	0,1404	0,00
Low pressure turbine inlet	4347883,04	11,7270	250,01	1,0000	2935,99	0,2011	126963,10
Compartment 3	4158750,03	6,6920	192,51	1,0000	2830,94	0,3151	117642,80
Compartment 4	3846209,05	3,5678	139,13	1,0000	2729,14	0,5244	210286,90
Compartment 5	3606599,07	0,9673	98,24	0,9393	2532,41	1,6715	166163,30
Compartment 6	3404928,01	0,2580	65,31	0,8940	2366,64	5,4855	126817,80
Low pressure turbine outlet	3404928,02	0,0410	29,12	0,8700	2232,62	30,1089	0,00
Pressure in the condenser P_c = 0,03983 atm							

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