# ANNOTATION

of the thesis for the degree of Doctor of Philosophy ( PhD )
in specialty 6D072300 – «Technical physics» by
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## Research of characteristics of the computational model of a gas-cooled reactor with a water moderator

The dissertation work presents the results of a study of the possibility of increasing the efficiency of a nuclear power plant using thermal neutrons by improving the technical characteristics of the elements of the core and heat exchange equipment of the primary circuit.

### Relevance of the research topic

The development of nuclear energy based on reactors with a thermal spectrum of neutrons is possible only if the efficiency of the designed reactor facilities and NPPs is increased by means of technical improvement of equipment and reduction of capital costs for the construction of power units. Further adherence to the development of the technology of pressurized thermal neutron reactors is likely to lead to uncompetitiveness of nuclear power, as well as the development of new little-studied technologies. To support the development of nuclear energy, projects are needed that can prove their effectiveness in the current market conditions. Many modern scientists come to this conclusion and offer their own ways out of this situation.

In this dissertation work, a channel gas-cooled reactor with a water moderator and a Rankine cycle is proposed as such an alternative. The uniqueness of this type of reactor plant is due to the fact that the proposed configuration combines the best characteristics of high-temperature gas-cooled reactors and time-tested pressurized water power reactors. At the same time, a number of technical and design features allow not only achieving high efficiency, but also significantly reducing capital costs for construction and maintenance.

Within the framework of this research work, technical solutions are proposed that can significantly increase the efficiency of reactor and heat exchange equipment and, at the same time, reduce capital costs for the construction of power units.

### Purpose of the work

The aim of the thesis is to study the possibility of increasing the efficiency and competitiveness of nuclear power by developing a highly efficient gas-cooled water-moderated reactor.

To achieve this goal, it is necessary to solve the following **tasks**:

– to develop a computational model of the core of a gas-cooled reactor for carrying out a series of neutron-physical calculations and calculations of the characteristics of the reactor campaign;

– to develop a computational model of the primary circuit heat exchange equipment for carrying out thermophysical calculations;

– to carry out the necessary neutron-physical calculations of the reactor core and thermophysical calculations of the heat exchange equipment;

– to develop the design of an experimental installation for studying the processes of vaporization and steam overheating in a single circuit of a nuclear power plant;

– to carry out the necessary experimental work at the installation;

– analyze the obtained experimental data;

– compare the characteristics of the gas-cooled reactor and heat-exchange equipment with those of the VVER-1000 and VTGR reactors.

**The main provisions for the defense**

–Calculation model of a gas-cooled reactor for neutron-physical calculations and neutron-physical characteristics of the reactor core;

–Improved thermophysical characteristics of the modernized design of heat exchange equipment;

–Installation of research of processes of steam generation and steam superheating.

**Scientific novelty**

For the first time, a neutron-physical computational model of a gas-cooled reactor with a water moderator and a thermal model of the primary circuit equipment for performing complex calculations have been developed.

A scheme of a nuclear power plant based on a gas-cooled reactor with a water moderator is proposed.

A modernized design of the primary heat exchange equipment is proposed.

For the first time, a device was developed and experimental studies of the process of formation and superheating of steam in a thin-walled heat-exchange tube simulating a single circuit of a nuclear power plant based on a gas-cooled reactor were carried out.

**Object of study**

Heat exchange processes occurring in the equipment of the primary circuit of a nuclear power plant based on a gas-cooled reactor with a water moderator.

**Subject of study**

Neutronic and thermophysical characteristics of the computational model of a gas-cooled reactor with a water moderator, heat exchange equipment of the primary circuit and an experimental setup for studying the processes of vaporization and steam superheating.

**Research methods**

In the dissertation work, both general scientific and special research methods were applied. Special research methods include: computational and experimental study of the processes occurring in the heat exchange equipment of the primary circuit of a nuclear power plant based on a gas-cooled reactor with a water moderator; computer modeling of complex thermophysical processes occurring in the thermal equipment of a gas-cooled reactor with a water moderator.

**Practical significance**

A computational model of a gas-cooled reactor with a water moderator has been developed for neutronic calculations and calculation of the reactor campaign. An improved design of a fuel assembly without a heat shield has been substantiated by calculation.

The proposed effective design of heat exchange equipment for the primary circuit of a nuclear power plant, in particular, a feed water heater and a steam generator, which will attract the attention of manufacturers to alternative approaches in the design of this equipment.

An experimental setup has been developed to study the processes of vaporization and steam overheating in a single loop. Practical research has been carried out to prove the correctness of theoretical assumptions.

The obtained neutron-physical and thermal characteristics of NPP equipment based on a gas-cooled water-moderated reactor will serve as the basis for the development of this type of reactors in the future of their use in future NPP projects.

The Act on the Implementation of the "Procedure for Preparing and Conducting Experiments", a patent for a utility model and "Testing Protocol for an Experimental Installation" are given in the Appendices to this dissertation.

**Personal contribution of the author**

The author's personal contribution consists in setting and formulating research tasks, conducting an analytical review of literature data, carrying out theoretical and computational studies, developing and creating a steam generation and superheating unit, preparing and carrying out commissioning and experimental work, analyzing and processing the obtained experimental data, developing computer computational models for neutron-physical and thermophysical calculations, as well as optimization of the classical methodology for carrying out computational studies of the characteristics of heat exchange equipment. All work was carried out in close cooperation with the specialists of the IAE RSE NNC RK. The analysis of the results obtained in the course of the dissertation research, as well as the formulation of the main conclusions were carried out in cooperation with scientific consultants.

**Relationship of the topic with the plans of research programs**

A significant part of this work was carried out with the financial support of the State Institution "Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan" in the framework of Contract No. 271 dated February

12, 2015 on the topic " NPP based on a gas-cooled water-moderated reactor " for 2015-2017.

**The degree of validity and reliability of the results**, obtained in operation, ensured the correctness, accuracy and originality of tasks, using well-proven scientific methods research and experimental techniques, large amount of the calculated and experimental data, their statistical processing and comparing the obtained data with the previously published results of known studies scientists from the CIS and far abroad. The main results of the dissertation were published in publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, as well as peer-reviewed foreign scientific journals included in the Scopus database.

**Approbation of work results**

The main results of the dissertation were reported and discussed at seven international conferences:

VII Eurasian conference "Nuclear Science and Its Application", Institute of Radiation Problems Azerbaijan National Academy of Sciences (Baku, Azerbaijan, October 21-24, 2014);

X International Conference "Nuclear and Radiation Physics", National Nuclear Center of the Republic of Kazakhstan (Kurchatov, Kazakhstan, September 8-11, 2015);

International conference "21 Century: Nuclear technologies and Nonproliferation problems" (Astana, Kazakhstan, 2015, October 7-9);

V III International Scientific and Practical Conference "Physical and Technical Problems in Science, Industry and Medicine", Physics and Technology Institute NITPU (Tomsk, Russia, June 1-3, 2016);

Scientific and technical conference "Neutron-physical problems of nuclear power" (Obninsk, Russia, October 12-16, 2015);

XXIII International Scientific and Technical Conference of Students and Postgraduates "Radioelectronics, Electrical Engineering and Power Engineering", National Research University MPEI (Moscow, Russia, March 2-3, 2017);

World Congress of Engineers and Scientists WSEC-2017 (Astana, Kazakhstan, June 19-20, 2017);

VIII International scientific and practical conference "Actual problems of the uranium industry (Astana, Kazakhstan, 03-05 August 2017);

Semipalatinsk test site: Legacy and Prospects for Scientific and Technical Potential Development (September 11-13, 2018, Kurchatov, Republic of Kazakhstan);

In addition, at six conferences-competitions and scientific schools:

XIII Conference-competition of R&D of young scientists and specialists of RSE NNC RK, National Nuclear Center of RK, (Kurchatov, Kazakhstan, May 14-16, 2014);

XIV Conference-competition of R&D of young scientists and specialists of RSE NNC RK, National Nuclear Center of RK (Kurchatov, Kazakhstan, May 13-15, 2015);

Scientific and technical conference "Neutron-physical problems of nuclear power" (Obninsk, Russia, October 12-16, 2015);

XV Conference-competition of R&D of young scientists and specialists of RSE NNC RK, Institute of Atomic Energy NNC RK (Kurchatov, Kazakhstan, May 18-20, 2016);

XIV Kurchatov Interdisciplinary Youth Scientific School (Moscow, Russia, November 8-11, 2016);

X International School-Seminar for Young Scientists and Specialists “Energy Saving. Theory and Practice "(Moscow, Russia, October 19-23, 2020);

Also, the main results of the dissertation were reported and discussed at scientific seminars of the Department of Technical Physics and Heat Power Engineering, at the joint scientific seminars of the Faculty of Engineering and Technology of the Shakarim State University of Semey city and at the scientific and technical councils of the Institute of Atomic Energy of the National Nuclear Center of the Republic of Kazakhstan and at seminars of PhD students at the Wroclaw Polytechnic University (Wroclaw, Poland).

**Publications**

The main results of the dissertation work were published in 25 printed works, of which: 1 article is included in the Scopus database, 4 publications in publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan.

**The structure and scope of the thesis**

The work consists of an introduction, five sections, a conclusion and a list of sources used. It is presented on 118 pages, contains 42 figures, 36 tables and a list of used sources of 109 titles.