# Approaches to improvement of safety requirements associated with development and implementation of small modular reactor technologies

ANTON KURYNDIN

SEC NRS

Moscow, Russian

Email: kuryndin@secnrs.ru

ANDREY KIRKIN

SEC NRS

Moscow, Russian

Email: kirkin@secnrs.ru

SERGEY SINEGRIBOV

SEC NRS

Moscow, Russian

Email: sinegribov@secnrs.ru

VALERII KHLOBYSTOV

SEC NRS

Moscow, Russian

Email: hlobystov@secnrs.ru

**Annotation**

Innovative technologies development in the field of atomic energy use, including small modular reactors, is accompanied by development and implementation of new design decisions as well as technical and organizational measures to ensure safety. This, in turn, leads to the necessity to develop new safety requirements for small modular reactors to ensure successful and safe functioning of the nuclear power industrial complex. The above-mentioned activities should be preceded by the comprehensive work, including assessment of the completeness and sufficiency of the national legal and regulatory framework; analysis of the international experience; analysis and evaluation of proposed innovative solutions; development of approaches to account the specifics of small modular reactors when regulating safety.

Over the past few years in the Russian Federation, as part of the development of nuclear energy technologies, a significant amount of work has been carried out on the creation of small modular reactors, including the water-cooled reactors (RITM-200N) and high temperature gas-cooled reactors (VTGR).

The report demonstrates the impact of the development of small modular reactor technologies on the processes of improving the legal and regulatory framework in order to establish additional rules and regulations that take into account the specifics of the most promising small modular reactors.

## Introduction

Starting in 2020, within the framework of the Federal Project «Design and Construction of Reference Power Units of Nuclear Power Plants, Including Low-Power Nuclear Power Plants» of the State Program of the Russian Federation «Development of the Nuclear Power Industry Complex» and the corresponding order of the Rosatom State Corporation, intensive work is underway to create a project for a nuclear power plant with RITM-200N reactor installation. The construction of the plant is planned in the village of Ust-Kuiga, located in the Arctic zone of the Republic of Sakha (Yakutia) [1].

RITM-200N SMR, on the basis of which NPP is being developed, provides electricity production with a capacity of 55 MW, features integral layout of the first reactor circuit equipment in the reactor vessel as well as active and passive safety systems, which technologies are in operation on nuclear icebreakers and floating nuclear power units [2].

Another example of activities on design of an innovative nuclear installation in the Russian Federation in the next decade is the development of a reactor installation with a high-temperature gas-cooled reactor for a nuclear power plant, which thermal energy (of 200 MW) is planned to be used for technological processes, including industrial production of hydrogen [3]. The construction of a nuclear power plant is planned on the territory of the Republic of Tatarstan [4].

The above-mentioned nuclear facilities, as will be shown below, have a number of specific features due to the implementation of technical solutions that were previously either not used at nuclear power plants with either VVER or other types of reactors in operation, or were used but did not find wide application and, accordingly, were not taken into account in the requirements of regulatory documents.

## preceedings of safety regulation improvement of nuclear power plants

Safety regulation in the field of atomic energy use resolves itself into the establishment of special requirements aimed at achieving a certain level of nuclear facilities safety corresponding to the development of technology, science and industry.

To date, in the Russian Federation has implemented a state safety regulation system for nuclear power plant, which combines the features of the target and prescriptive models of safety regulation. As part of this system, along with general requirements that set safety targets, also special requirements are applied, which for the most part are applicable only to individual technical solutions. The presence of prescriptive requirements in the regulatory system due to the development of the new reactor technologies requires constant consideration of new technical solutions and making appropriate changes to regulatory documents.

In this connection, the highest state authorities of the Russian Federation, such as the Government of the Russian Federation and the State Duma, have repeatedly voiced, for example, within the framework of the recommendations of the State Duma Committee on Energy [4], have formulated the tasks of updating approaches to safety regulation of innovative technologies aimed at:

* providing timely creation of framework for safety regulation of innovative technologies in the field of atomic energy use;
* exclusion of factors constraining the potential for the development of new technologies, since compliance with some requirements that are not relevant for specific technologies does not lead to an increase in the level of safety, but significantly increases the cost and reduces the effectiveness of technology implementation;
* maintaining the achieved safety level of new technologies in comparison with existing installations;
* limiting the impact of changes made to the regulatory framework on ensuring the safety of existing facilities.

In order to consider the features of innovative technologies, the regulatory legal framework in the field of atomic energy use is constantly being expanded by corresponding regulatory documents. Federal rules and regulations are being developed, as well as safety guides containing recommendations on meeting the requirements of federal rules and regulations, including methods of work, methodologies, conducting safety reviews and assessments during licensing, as well as explanations and other recommendations on meeting safety requirements in the field of atomic energy use.

## ORGANIZATION OF INTERACTION BETWEEN THE REGULATORY BODY AND INDUSTRY ORGANIZATIONS TO ENSURE safety regulation of innovative FACILITIES

The introduction of advanced reactor technologies requires proactive measures aimed at establishing special requirements that consider innovative technologies before the start of licensing activities for a new nuclear facility.

At the initiative of the Rosatom State Corporation, inter-agency working groups are being established, the activity of which is to analyze the sufficiency of the legislation of the Russian Federation, the requirements of federal rules and regulations in the field of atomic energy use and to ensure the formation of a regulatory framework.

These inter-agency working groups is formed from representatives of operating organizations, designer organizations and other industry organizations involved in the deployment of nuclear power plants with small modular reactors, as well as representatives of the national regulatory authority and its technical support organization.

As a positive practice of effective improvement of the regulatory legal framework in the field of atomic energy use, an approach can be highlighted in which the main measures for the development of special requirements or for making changes are included in the appropriate plans for the development and/or updating of federal rules and regulations in the field of atomic energy use.

The development and approval of plans is preceded by a preparatory stage, at which, within the framework of the activities of inter-agency working groups, an analysis of the compliance of innovative designs with current requirements is performed and work is carried out on:

* analysis of international approaches and practices of safety regulation, for example, [5 − 11];
* analysis of technologies of new prospective reactors, including foreign designs;
* assessment of the applicability of current regulatory documents requirements to innovative designs;
* evaluation of design documents of a prospective reactor installation, including documents containing the safety concept and the preliminary design of the reactor installation, for compliance with the requirements of current federal rules and regulations;
* analysis of solutions that compensate for non-compliance with the requirements of federal rules and regulations in the design documentation;
* joint preparation of proposals for the development of draft amendments to federal rules and regulations that take into account the design features of new technologies.

The implementation of measures within the framework of the above sequence allows, before the start of licensing of an innovative facility, at least to determine and form a unified position of the industry and the regulatory authority on the identified safety deficiencies (if any), and at most to form an appropriate plan to improve regulatory framework and proceed to its implementation.

The activities of inter-agency working groups are carried out systematically in accordance with approved and, as necessary, reviewed work plans. At the moment, within the framework of six meetings of the inter-agency working group on nuclear power technological plant with HTGR (VTGR) and eleven meetings of the inters-agency working group on NPP with RITM-200N, as well as a series of additional meetings of the regulatory body and industry organizations, answers to a sufficient number of questions have been formed so that it is possible to talk about the possibility of ensuring effective safety regulation these objects in the future.

## CONSIDERATION OF THE SPECIFICS OF INNOVATIVE NUCLEAR POWER PLANTS IN THE CURRENT REGULATORY SYSTEM

*Nuclear power plant with a RITM-200N reactor installation*

The RITM-200N reactor, designed for ground-based realisation, is an integral pressurized water-water reactor with vertical steam generators. RITM-200N was developed in accordance with regulatory documents for ships with nuclear reactors, since its prototype (RITM-200S reactor installation) is already being operated on universal nuclear icebreakers [1, 2].

The NPP with RITM-200N is designed in accordance with the requirements of the current federal rules and regulations for ground-based nuclear power plants. Therefore, the General Safety Provisions for the Nuclear Power Plants Units, Rules for Nuclear Safety of Reactor Installations of Nuclear Power Plants and Requirements for the Content of Safety Analysis Report of a Nuclear Power Plant Unit with a VVER Type Reactor, etc. are used as evaluation criteria for safety review.

The consistent implementation of defense-in-depth in the NPP with RITM-200N design is based on the application of physical barriers on way of ionizing radiation and radioactive substances propagation into the environment and on the implementation of a system of technical and organizational measures to protect these barriers and preserve their effectiveness, as well as to protect personnel, the public and the environment. Also, compliance with the target (probabilistic) safety milestones in terms of excluding large emergency releases and severe accidents is demonstrated for the NPP with the RITM-200N.

Based on the results of interaction between representatives of the regulatory body, designer organizations, lead scientific organization and the technical support organization of the regulatory body, it was decided that it would be advisable to amend the requirements of federal rules and regulations in the field of atomic energy use to reflect those features of NPP with RITM-200N reactor installation which are derived from the specifics of reactor installations for ships and other floating craft:

* application of new types of welded joints, threaded-soldered joints;
* compactness and factory manufacturing of the reactor installation;
* specifics of the operational control of metal and welds.

*Nuclear power technological plant with high temperature gas-cooled reactor*

In contrast to the approach implemented for NPP with RITM-200N reactor installation, within the framework of which discrete aspects of safety regulation are being worked out, the plan developed in 2022 (approved by Rostechnadzor) for nuclear power technological plant with HTGR (VTGR) provides for an integrated approach to ensure safety regulation of the designed plant with HTGR (VTGR) [2, 3]. within which work is underway both to amend the general safety provisions and rules for nuclear safety, and to develop new documents, establishing requirements for the content of the safety analysis report for nuclear power plants with HTGR (VTGR) and safety requirements for handling hydrogen-containing mixtures at the nuclear facilities.

The list of specific safety aspects, on the basis of which proposals for updating are formulated, was developed based as the results of a series of works on the analysis and evaluation of the safety concept and materials of the nuclear power technological plant design documentation with the VTGR reactor installation and includes the following safety issues:

* utilization of a gaseous helium coolant with high permeation, the temperature of which exceeds 800 ℃ during normal operation;
* nuclear fuel in the form of fuel particles in which the core of low-enriched uranium dioxide is covered with several layers of shell, usually made of pyrocarbon of various densities and silicon carbide (TRISO);
* heat removal from nuclear fuel is carried out mainly by passive radiation and convection processes, and safety systems that ensure heat removal from nuclear fuel can be located outside the primary circuit;
* application of new reactivity control system that do not have individual drives;
* the establishment of natural circulation in the primary circuit in accident conditions may lead to damage to individual elements of normal operation systems as a result of thermal impacts;
* high-potential heat generated by HTGR (VTGR) can be used to produce hydrogen-containing, explosive, flammable and toxic substances in the immediate vicinity of the reactor. Such production sites can be either included in a nuclear power plant or may not be related to nuclear facility, but the consequences of possible accidents at them should be taken into account in design and safety analysis of the NPP with the HTGR (VTGR);
* the ingress of a significant amount of oxygen-containing media into the core (for example, air, water) can lead to ignition of graphite of nuclear fuel and reactor in-vessel components;
* the hazard factor for the reactor due to the proximity of the building containing the production of target products (for example, hydrogen) to the reactor building, as well as the possible presence of common systems and elements between them (for example, pipelines containing hydrogen, to be started directly into the reactor building).

Within the framework of regulatory documents in the field of the atomic energy use, safety requirements for the industrial production of hydrogen on an industrial scale using atomic energy, in particular with the application of thermal or electric energy generated by the NPP, are not established. The development of the draft regulatory document that is fundamentally new for the nuclear industry implies the establishment of specific safety requirements for management of hydrogen-containing mixes on nuclear facilities. The new document will be developed taking into account all potential factors of hazard (that an industrial facility at the site of a nuclear power plant have) on both personnel, the population and the environment, as well as on the possibility of ensuring the normal operation of the reactor.

## conclusion

Taking into account the experience of safety regulation of new technologies in the field of atomic energy use, there is an obvious necessity to improve the regulatory framework for safety regulation in parallel with the development of innovative technologies both to ensure the safety of personnel, the public and the environment, and for the purpose of rational planning of technology development activities and conducting experimental studies to justify their safety. However, as shown by the example of NPP with RITM-200N reactor installation, for some technologies it is enough to work out safety regulation issues on individual safety aspects, while for others, such as HTGR (VTGR), it is necessary to update the main issues of safety regulation and take into account what was not previously reflected and was not intended by the requirements of federal rules and regulations in the field of atomic energy use.

Building relationships on the basis of a principle that is understandable by both the regulatory body and industry organizations, allows us to work on the design of new nuclear facilities and on improvement of safety regulation framework in harmony with the timely identification and elimination of design and regulatory deficiencies.

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