**FEATURES OF APPLICATION OF IAEA**

**SAFEGUARDS DURING REFUELING OF**

**SPENT FUEL ON FLOATING POWER UNIT**

**FOR FOREIGN MARKETS WITH**

**A REACTOR UNIT OF THE RITM TYPE**

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**Abstract**

After the Floating Power Unit Akademik Lomonosov with the KLT-40S reactor plant had been successfully commissioned, the next step for ROSATOM was to develop optimized floating power units (OFPU). OFPUs powered by the RITM reactor plant are an export-oriented product, and they are designed to operate on foreign sites. OFPU engineering solutions are based upon the practical design and operation experience of nuclear-powered icebreakers and upon problem solving to assure safety for operation of nuclear plants under severe northern conditions. The period between OFPU refueling can be up to 10 years, depending on the capacity at which the reactor plant is operated, with nuclear fuel enrichment below 20%. The technology of refueling of the RITM series reactors has a number of features compared to the technology of refueling of other nuclear power plants with water-powered reactors. RITM plants have never been placed under the IAEA Safeguards, and capabilities and features of applying the IAEA Safeguards to such plants require an additional analysis. The developed operation model assumes that the OFPU can be operated on a deployment site for a long period, and all fuel handling operations will be done at a specialized facility in the Russian Federation. The paper contains the major fuel handling features in the life cycle of the OFPU equipped with RITM-200M—these are the critical features in terms of the IAEA Safeguards. Also, the paper provides the designers’ perspective on solving the key non-proliferation problems through adapting the Safeguards approaches with regard to the OFPU technical features.

## INTRODUCTION

Currently in the world there is a stable interest in small-sized nuclear power plants because they can satisfy the energy demands of customers located remotely from central power grids. After the Floating Power Unit Akademik Lomonosov with the KLT-40S reactor plant had been successfully commissioned, ROSATOM companies have developed a conceptual design of the optimized floating power unit (hereinafter – OFPU) fitted with the RITM-200M reactor plant [1].

The OFPU was designed with regard to its possible operation abroad, including in the countries that are non-nuclear weapon States according to the terminology of the Treaty on the Non-Proliferation of Nuclear Weapons [2].

According to the Treaty on the Non-Proliferation of Nuclear Weapons, the Russian Federation belongs to the nuclear-weapon States and is not obliged to put its nuclear energy facilities under safeguards obligatorily [3]. However, when moving the OFPU to the operation site in a non-nuclear-weapon State, such a State will be obliged to place the OFPU under IAEA safeguards. The rights and obligations of the IAEA, the host State and the supplier State can be fixed in agreements concluded in a trilateral format, in particular on the basis of existing model of comprehensive safeguards agreements and voluntary safeguards agreements [4]. The host State will have to provide the IAEA with information on the nuclear material and nuclear facility as early as possible after making a decision on the deployment of the OFPU on its territory [5]. Using information on the design, installation scheme, shape, quantity, location and movement of nuclear material, the IAEA is developing a unique approach to the application of safeguards, taking into account the characteristics of the facility.

Unlike the approaches used to place large water-cooled water-moderated reactors under the Safeguards, there is no sufficient experience in applying the IAEA Safeguards for small-sized nuclear power plants and there is no the experience that might allow the development of generic approaches. To adapt the existing IAEA approaches and procedures, the OFPU design features and approaches to nuclear material handling on board the OFPU will have to be studied. At the same time, it should be taken into consideration that the OFPU engineering solutions and the proposed operation model exclude fuel handling operations on the territory of a deployment site.

## DESCRIPTION of OFPU AND THE OPERATION

The optimized floating power unit (OFPU) is a non-self-propelled vessel with two reactor units on board. The reactor units have total net electric power of 100 MW. Placing the reactor plants in limited space requires that engineering solutions be used to ensure not only the safe operation but also the equipment compactness. Compared with the *Akademik Lomonosov* floating power unit, the displacement of the OFPU was reduced by 4,320 tons, including due to the use of the RITM-200M reactor unit.

The RITM-series reactor units were developed by Afrikantov OKBM JSC. Currently, RITM-series reactor units are installed on multi-purpose nuclear-powered icebreakers *Arktika*, *Sibir* and *Ural*. The first two of them have already been commissioned and are a part of the Russian Federation icebreaker fleet. The same class icebreakers *Yakutiya* and *Chukotka* are currently under construction and they will be fitted with the RITM-series reactor units.

The RITM-200M reactor units used on the OFPU allow the electric output to be increased by 40% compared to the KLT-40S reactor unit, whereas the overall dimensions of the RITM-200M reactor unit are nearly 45% less [1].

Either a reactor unit is placed in its own containment that serves as a reliable barrier against release of radioactive products into the environment and ensures personnel safety. A special feature of the Russian floating power unit designs is that there is a containment made of concrete. The containment integrity is ensured by an overpressure relief valve, a containment cooling system and hydrogen recombiners [1].

The RITM reactor unit design uses a cermet fueled core comprised of an array of fuel assemblies. The fuel is contained in the form of particles placed in an aluminum alloy matrix, which ensures high thermal conductivity. The nuclear fuel enrichment is below 20%. As a function of the power factor in the course of operation, the cycle of operation is up to 10 years.

The power unit is constructed at a factory up until the stage where the power unit is fully prepared for operation. In a specialized facility, the fuel is loaded, comprehensive harbor trials are performed, and the reactor unit achieves its first criticality. This allows the construction and installation work scopes to be minimized on the territory of the deployment site. The OFPU is a non-self-propelled vessel and therefore it is transported to the operating site on board a semi-submersible heavy-lift vessel or by towing for short distances. At the OFPU deployment site, the OFPU is rigidly connected to the coastal hydroengineering structures, which ensure safe operation and transfer of electricity to the shore. At the deployment site, the equipment is annually provided with preventive maintenance — note that no operations will be done with the fuel at the deployment site. Upon completion of the assigned service life, which is determined on the basis of customer’s needs, the reactor unit is shut down. After that, the OFPU is transported to a specialized facility in the Russian Federation, where the OFPU is refueled.

The designated service life of the OFPU is 60 years with annual preventive maintenance, factory repairs with a frequency of up to 10 years and major repairs after 20 years of operation. The operation model assumes that the factory maintenance of the OFPU will be interconnected in time with the reloading of nuclear fuel.

## CONCEPT OF REFUELING

The OFPU hull is quite compact compared to the Floating Power Unit *Akademik Lomonosov*. On board the OFPU, there is no new nuclear fuel storage, no spent nuclear fuel storage, no fuel handling or lifting equipment without which it is impossible to open a nuclear reactor. The absence of fuel handling equipment and a limited number of rooms required for nuclear material handling is critical in terms of using the IAEA Safeguards approaches.

The design features of the RITM-200M reactor plant prevent any possibility of fuel handling under water with the use of a fuel handling machine. Also, the OFPU design uses a process with a fuel transfer container for fuel unloading from the reactor. An analogous spent nuclear fuel unloading process is used on board the Floating Power Unit *Akademik Lomonosov* and as part of recharging nuclear-powered icebreakers.

Among other things, safe fuel handling is ensured through the structural materials and optimal equipment structure thicknesses selected to meet the personnel radiation protection requirements, as well as through using the container inherent safety features with the required water inventory and with the equipment to restore the water inventory. In whole, the safety level of this process satisfies the provisions of SSG-63 Design of Fuel Handling and Storage Systems for Nuclear Power Plants.

The fuel is loaded into the reactor according to the following algorithm. New fuel with the appropriate accompanying documentation is brought to the OFPU maintenance site. To load the fuel into the reactor, appropriate safety measures are taken, which do not provide for storing the nuclear fuel on board the OFPU but rather prescribe that the fuel should be loaded into the reactor immediately. The fuel is put into a container, which is an unsealed basket for moving new fuel assemblies.

After that, access to nuclear fuel is excluded without the use of fuel-handling equipment. Upon completion of the fuel campaign, the OFPU is transported back to a specialized enterprise in the Russian Federation, where refueling is carried out. The refueling of the reactor cores is implemented after the shutdown of the reactor plant, its cooling and pressure relief of the primary circuit to atmospheric pressure. Work on refueling of reactor cores must be carried out using reloading equipment and the necessary infrastructure. At a specialized enterprise, operations are carried out to dismantle the reactor cover, to unload spent nuclear fuel from the reactor plant and to load fresh fuel into the reactor.

It is not possible that any operations with the fuel or with an open reactor can be done in the host State. To get any access to the nuclear material, special and lifting equipment is required, which may remove the reactor pressure vessel head and a number of in-vessel internals in order to withdraw the nuclear fuel. The said equipment is high-tech equipment, and it requires special knowledge of the reactor plant design and the reactor core design. This equipment has large overall dimensions and there is no way to place it inside the OFPU without being noticed. The required equipment placed near the OFPU on the operating site may be detected with the use of satellite images.

## APPROACHES TO APPLICATION OF THE IAEA SAFEGUARDS DURING OFPU OPERATION

Every year, the IAEA forms a unique plan for the application of safeguards and ensuring the non-proliferation regime, taking into account the characteristics of the facility. The IAEA also determines the types of inspections that will be carried out in relation to a specific facility. In particular, the IAEA can verify the actual amount of nuclear material, information about the design, facility scheme, shape, and so on. The so-called field inspections include both direct interaction with nuclear material and verification of documentation. In particular, the actual amount of nuclear material is estimated – this is the sum of all measured or derived estimates of the quantities of nuclear material in a batch that are actually available at a given time in the material balance area, obtained in accordance with agreed procedures. In the OFPU project, the material balance area can be defined within the compartment with reactor units, since this is the only room on board the OFPU where nuclear material can be located. Accordingly, it is advisable to carry out all activities by the IAEA in this and adjacent compartments.

From the technical point of view, throughout the OFPU operating period at the deployment site in the host State, the nuclear material physical inventory verification provided for by the IAEA procedures may be performed annually. However, the effectiveness and expediency of this verification will be minimal because all the procedures implemented by IAEA employees will be limited to inspecting the nuclear material documentation. Within this period, the information provided in the documentation cannot be verified through verifying the physical inventory because there is no access to the nuclear material.

From the viewpoint of the IAEA Safeguards and compliance with the non-proliferation regime on the OFPU deployment site, it appears that the only effective procedure is to check for the absence of unauthorized access from the outside to the reactor and between OFPU compartments via hatch covers sealing the equipment space room. This problem may be solved through a justified use of containment and surveillance equipment. Such equipment guarantees that there is no unauthorized access to the nuclear material and it enables verification of the fact that no unauthorized operations can be performed with the nuclear material during the refueling interval. It appears to be expedient to use surveillance video cameras and seals that would register opening of the hatch covers to equipment space room and the reactor pressure vessel head. In the course of in-person inspections, the key task for the IAEA inspectors will be to verify the integrity of seals and cameras in order to verify that there is no tampering, which might result in data changes.

The possibility of remote monitoring of equipment readings of containment and surveillance measures can also be assessed, which will reduce the financial costs of conducting face-to-face inspections by the IAEA staff. Due to the fact that the equipment of containment and surveillance measures should not interfere with the normal operation of the OFPU, the implementer of the OFPU project must provide for the possibility of placing this equipment at the design stage.

## IAEA SAFEGAURDS APPROACHES for OFPU FUELING and REFUELING

During the fueling of the OFPU’s reactors, it is possible to verify the actual amount of nuclear material available. Such a procedure will require the full-time presence of the IAEA staff and can be organized on the basis of special arrangements.

Within the material balance area, checks on nuclear material on board the OFPU can be carried out at four key measurement points, at the entrance and exit of nuclear material into the premises of each of the two reactor units. The key point for measuring the movement of nuclear material and the key measurement point for determining the inventory amount of nuclear material may be located near the entrance hatch on the OFPU and in the equipment space room. As part of the verification of the movement of nuclear material on board the nuclear vessel, IAEA staff can verify the factory markings of fresh fuel assemblies with the markings stated in the documentation. They can also determine the weight of fuel assemblies and compare it with factory values. The upload date can also be checked by the log.

When unloading spent fuel, only verification of accounting documentation can be carried out. Procedures for determining burnout, nuclear losses of the total amount and amount of fissile uranium isotope, as well as nuclear production of plutonium and other procedures for spent fuel on board the OFPU are not relevant, since fuel becomes spent when extracted from a reactor facility in the Russian Federation. Spent fuel is not stored on board the OFPU and immediately leaves the vessel. Further handling of spent fuel is carried out in the Russian Federation.

At the same time, it should be noted that if the information of the equipment of containment and surveillance measures for the period of operation confirms the absence of unauthorized access to nuclear material, any checks of spent nuclear fuel will be redundant.

## CONCLUSIONS

The existing IAEA procedures for the application of safeguards and verification of the absence of unauthorized removal or diversion of nuclear material are based on the experience of conventional high capacity nuclear power plants of land-based design. The physical location of these stations is fixed, and the movement of nuclear material is strictly declared. With regard to the OFPU, such IAEA procedures will require adaptation, since within the framework of the life cycle, the location of the OFPU, as well as the world community, must be sure that the nuclear material used at the OFPU has not been subjected to unauthorized actions and will not be used for the purpose of creating nuclear weapons. The IAEA acts as a guarantor of non-diversion of nuclear material.

The OFPU operation model assumes that there is no access to nuclear material during the operation of the OFPU at the site in the host State, and all fuel handling operations are carried out in the Russian Federation at a specialized enterprise. The IAEA can verify the accounting documentation, as well as request data on the calculated indicators of the fuel condition in the reactor, but these indicators will not be possible to verify by actual verification. During the operation of the OFPU at the operation site, conservation and monitoring measures, as well as indicators of appropriate equipment confirming the absence of unauthorized access to the OFPU nuclear material during the entire period of operation, will be of key importance. Optimization of the procedure for conducting IAEA activities at the deployment site will make it possible to adapt the safeguards mechanisms to the innovative design of the OFPU and similar transported installations with fuel loading at the manufacturer.

Due to the inability to verify the actual available nuclear material during operation at the deployment site due to the lack of access to it, such a check can be carried out when loading fuel into the reactor. From a legal point of view, this can be done on the basis of special agreements between the supplier State and the IAEA.

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