# SMALL NUCLEAR POWER: CHALLENGES AND SOLUTIONS

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Estimates show that, for remote localities difficult of access, nuclear power technologies offer a reasonable alternative to conventional power based on fossil fuels. Still, the deployment of nuclear power sources in the country's northern and eastern territories with hard climatic and complicated social conditions calls for novel designs that satisfy to the requirements beyond the scope of those for the conventional nuclear plant designs, including the following:

- the capability of long-term autonomous operation of the nuclear plant's reactor facility;
- the smallest possible number of attending personnel (formed preferably of locals);
- no any or limited water resources because of water bodies and rivers staying frozen for about 9 months (for example, in Yakutia) during the year due to low temperature and permafrost;
- preservation of the natural environment, including during the plant construction and utilization, which helps avoid the ecosystem dysfunctions requiring many years to eliminate;
- high quality of the nuclear island manufacture by the existing machine-building industries and delivery as functionally tested large-size units;
- possibility of deployment in the vicinity of farms, industrial sites and residential areas;
- no radionuclide release during operation and in emergencies.

A small nuclear power plant with a water-cooled water-moderated reactor facility, called Unitherm, is one of the most advanced autonomous nuclear heat and power supply designs that satisfies the best to the above requirements, based on the experience in design, manufacture and operation of nuclear propulsion systems.

Being in line with the requirements placed by the IAEA on advanced nuclear power plants of Generation IV, the Unitherm plant satisfies to the present-day requirements for safety, reliability, environmental friendliness and nonproliferation of weapons-grade nuclear materials. The safety of the Unitherm plant is ensured by the following features:

- an integral design of properly the water-cooled water-moderated reactor with all primary circuit components located inside a single vessel. This makes it possible to eliminate the use in the reactor facility of non-isolated piping lengths which are the coolant pressure retaining components, minimize the number of isolated piping segments, and ensure a high level of natural coolant circulation (Fig. 1). The reactor features a high heat-accumulating capacity of structural metal and a great inventory of coolant, which ensures that transients are relatively slow during accidents caused by primary circuit depressurization and other disturbances of normal heat removal from the reactor core;
- implementation of intrinsic safety properties based on natural feedbacks on power and coolant temperature and density;
- a passive cooldown and residual heat removal system that does not require any automatic or personnel actions or outside power or fluid delivery to operate. This is a continuously operating system designed as heat exchangers which transfer heat from the intermediate circuit to the atmosphere. The continuously operating system for autonomous heat removal enables the reactor facility to be kept for a long time in the hot standby mode at a power level of about 5 % of the rated value;
- natural coolant circulation in all vital systems (primary, intermediate and autonomous circuits of the normal and emergency cooldown and residual heat removal system) that supports autonomous operation of the plant for a continued unattended period, including in the event of the customer disconnection;

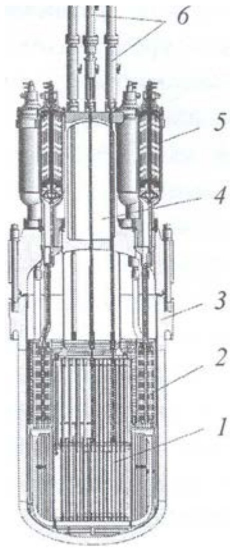


Fig. 1. Unitherm, a small-power integral reactor: 1 – reactor core; 2 – steam generator; 3 – pressure vessel; 4 – pressurizer; 5 – intermediate circuit heat exchanger; 6 – control and scram rod drives

- a unique design of the CPS actuators that guarantees that rods are inserted into the core by both the spring force and gravity and excludes unauthorized control rod withdrawal from the reactor core in the course of commissioning or repair as well as during power operation;
- protection against the spreading of ionizing radiation and radioactive products into the environment by way of a defense-in-depth barriers. Apart from those commonly used in nuclear power plants (fuel matrix, fuel cladding, primary circuit, containment), this system comprises the following safety barriers: an intermediate circuit between the primary coolant and the consumer circuit, a safeguard vessel, and a set of engineered features for protection of these barriers against internal and external impacts (Fig. 2). The safeguard vessel is designed such that the reactor core is flooded during primary circuit depressurization, the circulation circuit is not broken and the residual core heat is removed without the primary circuit being additionally made up or the ECCS actuated;

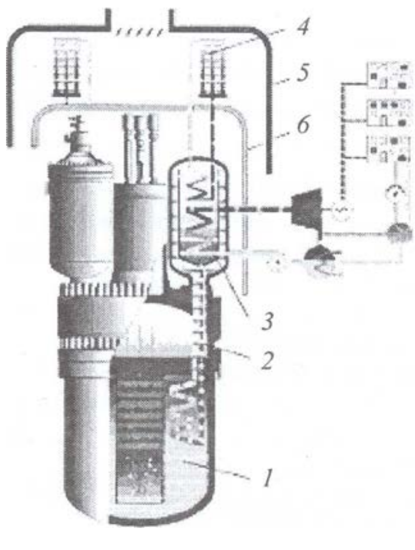


Fig. 2. Diagram of the Unitherm reactor facility:
1, 2, 3, 4 – primary circuit, intermediate circuit, consumer circuit and autonomous circuit respectively; 5 – containment; 6 – safeguard vessel

- no access to the vital systems of the reactor facility inside the containment, self-regulation during power operations, including when changing over to the hot standby mode, repairability and replaceability of any off-containment heat engineering, instrumentation or electrical equipment during power operation. The personnel of the plant attend the electricity generating and heating systems, as well as the site security equipment. The operation of the plant is monitored from the regional center using satellite communication;
- use of an intermediate circuit as an additional barrier between the reactor core and the consumer, which makes it possible to protect the consumer circuit against the entry of radionuclides even when there is a leakage between the primary circuit and the intermediate circuit, and to deploy the plant infrastructure attending personnel beyond the containment (category B). This enables regular personnel made up of locals to be engaged in the plant attendance;
- a reactor core with a low power density (about 20 kW/l) that excludes the risk of the core meltdown caused by the loss of all primary water inventory (considered for hypothetical emergency situations), which is the evidence of a qualitatively new safety level.

A safety analysis for the Unitherm plant has shown that some of the initial events representative of NPPs with VVER reactors are avoided thanks to the absence of components which may potentially cause malfunctions. For example, no circulation pumps are used in the primary circuit, in the intermediate circuit and in the autonomous cooldown system circuit, this excluding the potentiality of the coolant flow breakdown in these circuits.

Many of the accidents leading to an abrupt change in the feedwater supply or the generated steam extraction (up to the termination thereof), and to termination of the out-site power supply do not involve safety complications. If any, the reactor, by a self-regulation function, changes over to the hot standby mode with heat removed through the autonomous system or is stopped.

Much attention in the plant design is given to searching for more environmentally safe technical concepts that limit the plant impacts on the natural environment and make it possible to minimize the unfavorable effects from generation and use of thermal energy. Of a top priority during the Unitherm design was the issue of ionizing radiation impacts on the flora and fauna, heat dumps and environmental pollution. The biological shielding adopted for the design excludes harmful environmental effects. Thanks to the highly efficient shielding and leak-tight safety barriers, the reactor facility does not have radiological impacts on the environment at any power level during normal operation. It is even in the conditions of the most severe hypothetical accident caused by partial core damage that the exposure dose for objects at a distance of 100 m from the reactor facility exceeds the natural background by just 10 %.

The Unitherm plant does not require intermediate in-service refueling which is a nuclear- and radiation-hazardous operation and makes the plant less proliferation-resistant. For the reliable and uninterruptible supply of power to the consumer, as well as depending on the electrical and thermal power demand, the nuclear plant may have several reactor facilities designed as independent modules. A serial and factory-tested modular reactor facility delivered to the operation site is capable of operating for a long time (up to 25 years) without refueling, and is taken to its manufacturing site for refueling or disposal and replaced by a new module with fresh fuel after its service life expires. This has been the reason for these units to become known as ‘nuclear batteries’. The plant site does not require rehabilitation after decommissioning.

The Unitherm nuclear plant can be deployed on the ground, on a barge or in abandoned jet silos. It is installed in the immediate vicinity of the consumer which makes it unnecessary to lay expensive transmission lines and minimizes the electricity and heat loss. For the time being, it can be manufactured by the existing machine-building industries. The Unitherm design makes the maximum possible use of commercial components and has functionally tested prototypes. The reactor facility uses the materials and the fluid parameters and characteristics broadly used in Russian- and foreign-made reactors. As combined with the practically proven elements of the major equipment designs, this makes it possible to employ the current scientific know-how in thermal hydraulics, properties of structural materials, corrosion, water chemistry and so on, so excluding the need for research and reducing the work scope to the minimum volume of development efforts for the prototype construction.

In a ground-deployed version, the nuclear plant has its building structures ensuring protection against severe external impacts (hurricanes, tsunamis, aircraft crashes and others). The plant remains serviceable after an earthquake of the magnitude up to 8, inclusively, on the MSK-64 scale. The reactor facility is automatically shut down and transferred to a safe state during earthquakes of the magnitude 8 to 9 on the MSK-64 scale or other technological impacts, including aircraft crashes.

As estimated, the most acceptable range of the plant's power is 3 to 10 MWe. A power below this range leads to an intolerable growth in the cost of electricity generation, while a higher power will require a larger power unit size, which makes the plant more difficult to transport to its ground deployment site. The Unitherm two-unit small nuclear power plant has the following main characteristics:

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|---|---|
| Thermal power, MW | 2 x (15-50) |
| Electrical power (for operation in condensation mode), MW | 2 x (3-10) |
| Installed capacity utilization hours (utilization factor 0.7) per year | 6132 |
| Annual electricity output, mln kWh | 2 x (8.5-55) |
| Power in heating mode operations: | |
| electricity, MW | 2 x (I.5-5.2) |
| thermal, Gcal/h | 2 x (4-29) |
| Core life, years | up to 25 |
| Continuous unattended operation, months | 11.5 |

Any consumer-preset load variations, e.g. thanks to an increase or a reduction in the coolant flow rate in the consumer circuit, result due to the self-regulation effect, in the respective variation in the reactor power. This eliminates the need for the reactor facility attending personnel to be present immediately at the nuclear plant site provided periodic maintenance operations are conducted (on a yearly basis). Routine and preventive repairs are conducted for 1 to 2 weeks by highly skilled field personnel sent in from the regional center. This also makes it possible to avoid the attending personnel errors and limit the consequences of these errors or deliberate actions seeking to bring the plant out of operation by blocking the access to rooms which accommodate all of its vital systems for the period of unattended continuous operation. Another important feature of the Unitherm design is a small emergency response area, which makes it possible to deploy the plant in the vicinity of the consumer. The current demand for such plants in Russia is estimated at 40 to 90 ones with the total number of the required units reaching 100 to 200.

Therefore, full compliance to the requirements of effective regulations and the IAEA requirements to nuclear power plants of Generation IV allows the Unitherm small nuclear power plant to be classified as an innovative project, the introduction of which could contribute to the successful evolution of the energy infrastructure and economic development in the country's regions with decentralized power supply.