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Environmental Safety of Nuclear Power Plants Built as per Russian Projects

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Abstract: This article provides analysis of issues related to environmental safety of nuclear power plants. It demonstrates that NPPs of Russian design have always been exhibiting a high level of environmental safety. The article gives brief characteristics of all safety barriers and focuses on stress tests showing a high safety level at operating NPPs. Special attention is given to NPPs equipped with new-generation 3+ VVER reactors with the capacity of 1200 MW.

Keywords: Environmental safety, nuclear reactor, safety barriers, stress tests, nuclear power plant (NPP).

Introduction

All Russian nuclear power plants are operated reliably and safely as confirmed by results of regular inspections performed by both independent agencies and international organizations such as the IAEA, etc. Over the last 16 years, no serious violations of nuclear safety have been reported at Russian NPPs.

Safety assurance in the course of nuclear energy use is the top priority for Rosatom State Corporation [1, 2]. Within the entire service life, nuclear power plants demonstrate reliable and safe operation in all areas including environmental safety issues.

Pressurized water reactors (VVER) represent the main Russian technology used for construction of NPPs both in Russia and abroad. Its efficiency, reliability, and safety of have been proved by more than 50 years of operation of the Russian VVER reactors.

The NPP nuclear and radiation safety strategy is based on the system of several protective barriers aimed to prevent propagation of ionizing radiation and radioactive substances to the environment and/or unauthorized movement and accumulation of nuclear materials in the amounts creating conditions for the self-sustaining chain fission reaction as well as on implementation of technical and administrative measures for protection of the barriers, maintenance of their performance, and protective measures for the personnel, population, and the environment.

Design solutions ensuring nuclear, radiation, and environmental safety of NPPs are based upon the requirements of national regulations supported by recommendations of the IAEA, the International Radiation Protection Committee, and by the experience of design, construction, and operation of civil nuclear power facilities constructed as per Russian projects.

Additional measures for safety enhancement at operating NPPs were implemented subsequent to assessment of the causes and consequences of the Fukushima NPP accident (Japan, BWR reactor). Back in 2011, additional safety analyses and stress tests were performed with due regard for extreme external impacts.

Stress tests of Russian NPPs confirmed design protection of nuclear power plants against external natural and man-induced impacts. Subsequent to the results of the studies, Rostekhnadzor concluded that potential floods caused by failure of dams, scouring of dikes, or extreme precipitations present no danger for the majority of Russian NPPs.

A set of additional safety measures was implemented on the operating NPPs. Specifically, for NPPs where site flooding is possible in case of extreme external impacts negative effects of such floods for the NPP safety was compensated by measures aimed to equip such nuclear power plants with mobile systems for arrangement of heat removal to the ultimate heat sink (diesel driven pumps, motorized pumps, fast-assembly pipes). Justifying calculations and experimental validation of the possibility of passive (air) core cooling were additionally performed for power units with RBMK reactors. Extra measures were implemented at individual NPPs in order to increase reliability of the normal operation power supply along with the measures aimed to arrange redundant (additional) cooling systems for regular emergency diesel generators that can be used in case of loss of the main DG cooling systems.

All these measures have a common goal, which is to assure further and more sustainable development of the Russian nuclear power engineering and export of the VVER technology.

The high safety level at Russian NPPs is provided by many factors. The main factors are self-protection of the reactor plant, presence of several safety barriers, and multiple redundancy of safety trains. It should be also noted that active (i.e. requiring human interference and availability of a power source) and passive (not requiring any operator interference and power source) safety systems are used. Moreover, passive devices assure time-unlimited emergency core cooling in case of loss of all alternating current sources or of the ultimate heat sink (sea, cooling pond, spray pond, etc.) loss.

Safety principles of Russian NPPs:

- Defense-in-depth
- Self-protection of the reactor plant
- Safety barriers
- Multiple redundancy of safety trains
- Application of passive safety systems
- Safety concept providing not only for the accident prevention means but also for the means for managing consequences of severe accidents while assuring confinement of radioactive substances within the containment
- Safety culture throughout the entire life cycle: from site selection to decommissioning
- In-house resources for civil defense and emergency situations at each NPP
- Principle of selecting only locations with no prohibiting factors present for NPP sites

Self-Protection of Russian NPPs Reactors

The core composition providing for "self-protection" or "self-control" of the reactor is applied in VVER reactors. In case of the neutron flux increase, temperature in the reactor rises and void fraction grows. However, reactor plants are designed in such a way so that void fraction increase in the core results by itself in accelerated neutron capture and termination of the chain reaction. Specialists call this effect a "negative reactivity coefficient" (both temperature and steam.) Thus, the reactor physics itself provides for self-protection based on natural responses ("negative reactivity.")

Russian NPPs have 4 safety barriers. The first one is the fuel matrix preventing release of fission products under the fuel element cladding. The second one is the fuel element cladding itself that prevents ingress of fission products to the primary coolant circuit. The third one is the primary reactor coolant circuit preventing release of fission products under the containment. And finally, the fourth one is the containment system eliminating release of fission products to the environment. In case of any accident in the reactor hall, all radioactivity will remain within this containment.

Russian NPPs mainly use double-circuit arrangements allowing for heat to be removed directly into the air without any external water supply sources. The double-circuit arrangement is essentially safer than the single-circuit one as all radioactive media are inside the containment; there is no steam in the primary circuit, and therefore, the risk of the fuel exposure and overheating is crucially lower. In addition, VVER reactors are equipped with 4 steam generators, and the heat removal systems are multi-looped, thus significant water reserves are provided in them. Nevertheless, if water supply via redundant pipes is necessary, individual emergency cool-down pumps (one pump per each pipe) are installed at the NPP.

The defense-in-depth principle also implies a safety concept providing not only for the accident prevention means but also for the means of managing consequences of severe accidents while assuring confinement of radioactive substances within the containment.

The severe accident management system includes:

- Hydrogen removal system (with passive recombiners)
- Primary circuit overpressure protection system
- System of passive heat removal through steam generators
- Passive containment heat removal system
- Molten core localization device (core catcher)

Passive heat removal is a major Russian know-how. It is a system where heat is removed by air flow even in the absence of water supply. Air is always available at the power plant. The following comparative analysis was performed, whereunder modern Russian-made power units were put in the same conditions as the reactors of the Fukushima NPP after the tsunami (without any water and power supply.)

The analysis showed that a Russian power plant would be able to withstand an emergency without any core melting in the absence of water and power supply, and in case the personnel should have left the plant completely for any reason. Passive protection systems of Russian NPPs include a system of passive heat removal through steam generators (SG PHRS). SG PHRS systems in Russian designs are represented by two types:

- With air cooling of steam in a special-purpose steam-air heat exchanger
- With water cooling of steam in a special-purpose cooler tank

One more innovation implemented to enhance the NPP safety level is also intended to prevent propagation of radioactive substances beyond protection barriers in case of a severe accident.

The molten core localization device (core catcher) provides:

- Protection of the reactor cavity against thermal and mechanical impacts of corium

- Receipt and accommodation of solid and liquid corium components
- Heat removal from the corium to cooling water
- Corium sub-criticality assurance
- Reduced release of hydrogen and radionuclides under the containment
- The core catcher ensures confinement of the corium and eliminates the possibility of its release outside the containment in any scenario

The new generation

2016 became a landmark year for the Russian nuclear industry. In August 2016, a trial grid connection of the first power unit in the world based on a VVER reactor of 3+ generation with the capacity of 1200 MW took place. Voronezh region and, more specifically, the site of Novovoronezh NPP-2 became the pioneer.

Apart from improved technical and economic parameters, this power unit fully complies with the post-Fukushima requirements of the IAEA. The 3+ generation design is a combination of innovative and, at the same time, well-proven reference NPP technologies with a balanced system of active and passive safety systems.

At present, similar projects are being implemented in Turkey, Finland, Hungary, and Belarus. All of them comply with the following parameters:

- Rated electrical capacity: 1200 MW
- Service life of the main equipment: at least 60 years
- Improved fuel re-utilization parameters, application of advanced fuel cycles
- Double containment
- Four trains of active safety systems as well as passive safety systems
- Use of well-proven solutions and equipment
- Severe accident management methods (core catcher, hydrogen recombiners, passive heat removal system, etc.)

Rich operational experience in many countries [3–10] and especially in Russia [1, 2, 11] have proved that NPPs of Russian design have a high level of environmental safety.

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