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ADVANCES IN NEW WWER DESIGNS TO IMPROVE OPERATION AND MAINTENANCE

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Abstract

Economic operational indices of WWER-type reactors show their competitiveness in all the countries where these reactors operate. Advanced WWERs being designed and constructed now have the improved characteristics of economical efficiency and are more convenient for operation and maintenance. Many technical solutions aimed at improvement of the operational performance are implemented in the design of WWER-1000/V-392 and WWER-640/V-407, and these reactors are the important basis for the nuclear power expansion in Russia. Some of these solutions are considered in the present paper.

1. INTRODUCTION

Nowadays in eight European countries 48 commercial reactors of WWER-type are in operation with total power exceeding 32 GW, including 20 reactors WWER-1000 and 28 reactors WWER-440. More than 700 reactor-years of operation without serious incidents with radioactivity release outside NPP site have demonstrated high level of WWER type reactors safety. Economic operational indices of such reactors in Russia point out the competitiveness of WWER reactors as electric power producers in many regions of the country.

Nevertheless, operation experience, new national and international safety standards and changes in economy of Russia govern the necessity of development of new advanced reactors. New reactors of WWER type shall possess the improved characteristics of safety and economical efficiency, be more convenient for operation and maintenance. In Russia a complex of R&D work is being performed on development of power units of new generation with WWER-1000/V-392 and WWER-640/V-407 reactor plants meeting new requirements for safety and economical efficiency of electric power production.

2. REACTOR PLANT WWER-1000/V-392

The advanced design of WWER-1000/392 has been developed on the basis of standard reactor plant of V-320 design, which has been in operation for a long time at nuclear power stations in Russia, Ukraine and Bulgaria. New power units with WWER-1000/320 (in Czechia, Russia, Ukraine) are being constructed or planned. So, the design of WWER-1000/392 is based on the approved technical solutions and is an evolutionary development of the operating reactor plant with the following main characteristics:

- power - 3000 MW(th)
- primary/secondary pressure - 15,7/6,3 MPa
- coolant temperature at the reactor outlet - 320°C
- average burnup in equilibrium cycle - 40 MW.day/kg U
- effective time of operation at nominal power - 7000 hours.

Many technical solutions aimed at improvement of safety and operational performance of the plant are implemented in the design, in particular:(1) advanced reactor WWER-1000; (2) passive system of residual power removal; (3) passive system of the core flooding under loss-of-coolant accidents; (4) passive system of rapid boron injection for the reactor shutdown; (5) primary coolant pump preventing coolant leak under long-term station blackout.

2.1. Reactor vessel

The length of reactor vessel V-392 is increased in comparison with reactor V-320 at the expense of larger length of the supporting shell, keeping the possibility to transport the vessel by railway. With this, the core top elevation is decreased in relation to the elevation of the reactor supporting structure that allows to reduce considerably the personnel dose commitment in maintenance of reactor, steam generator and electric drive of the reactor coolant pump. Thus, neutron flux in the region of support is reduced almost two times in direct passing from the core through the vessel, and from the streaming out of the gap between the reactor vessel and «dry» shielding - more than 10 times.

The vessel extension allows also to reduce the neutron irradiation intensity of critical weld between the supporting shell and the shell of nozzles zone. Owing to this, the margin is increased for the vessel integrity under pressurized thermal shock. The vessel extension allowed to increase the coolant inventory between the core top and the lower generant of the inlet nozzle, that is, to improve the core cooling conditions under loss-of-coolant accidents.

Containers with surveillance specimens in reactor V-392 are placed on the vessel inner wall, whereas in reactor V-320 the surveillance specimens are placed on the upper end of the core baffle. Such upgrading brings together the conditions of neutron flux effect on the surveillance specimens and on the vessel metal allowing to predict more exactly the variation of the vessel mechanical properties in the course of operation.

2.2. Internals

In reactor V-392 the stops are installed on the core barrel bottom, and arms are placed on the upper end of the core baffle (these components are not provided in the operating reactors V-320). The stops are installed with a small clearance in relation to the core barrel bottom, therefore in case of hypothetical guillotine break of the core barrel a part, broken away, will move only slightly and the arms will keep the core baffle in engagement with the PTU lower plate under such downward motion of the core barrel.

Elastic clamping element is transferred from the core barrel flange end to the supporting shoulder of the protective tube unit. This upgrading simplifies maintenance of the clamping element.

On the cylindrical part of the core barrel in the zone of flow separator the compensating plates are placed with the help of which the design value of mounting clearance is achieved. In heating-up the reactor vessel and internals this clearance is decreased and the core barrel is clamped to the flow separator over the whole perimeter that reduces the vibration loads on the core barrel. Design of the core baffle channels is changed to smooth temperature fields in the baffle and to decrease the resulted deformations of the baffle.

Distance between the middle and upper plates of the protective tube unit is increased. This allows to increase the bending radius of the guiding channels where the in-core instrumentation elements are arranged. Owing to this upgrading all channels are brought into periphery nozzles of the upper unit that improves the reliability of the in-core measurement system and simplifies its maintenance.

2.3. Reactor upper unit

On the upper unit of V-392 reactor 121 nozzles are provided for the members of reactivity control system and reactor emergency protection (CPS) in comparison with 61 nozzles in V-320 reactor. This gives a possibility to vary the number and arrangement of CPS members and to optimize each fuel cycle for reaching the best characteristics of the core safety and efficiency.

In V-392 reactor the measurements of coolant temperature and core power are combined and brought through the common nozzles of in-core instrumentation (ICI), while in V-320 reactor there are separate nozzles for temperature monitoring and nozzles for core power monitoring. With this, all ICI nozzles are arranged on the periphery of the reactor upper head that facilitates the access to them when reactor assembling or removing the upper head unit, and reduces the repair personnel dose commitment.

In V-392 reactor the upgraded control rod drive is used with the improved maintainability and more simple procedure of the drive mounting-dismounting. The drive service life (including electrical part) is 30 years with the outlook of its further extension to the reactor service life. Position indicator, used in the drive, provides for monitoring the position of control rod in the core in each 20 mm (instead of 350 mm in the existing analogs). Monitoring of drop time and position of control rods in the core is also provided under the reactor scram, that is, the functions of diagnostics are also fulfilled.

2.4. Main coolant pipeline

Design of reactor plant V-392 is developed with application of «leak-before-break» concept that allows to give up the massive supports-restraints on the main coolant pipelines. Owing to this, all sections of pipelines become accessible for in-service inspection that improves their reliability. The personnel dose commitment during the inspection of pipelines bending is also reduced because the labour consuming procedures on removal of the upper parts of the emergency supports are excluded.

2.5. Other components of the reactor plant

Many other components of reactor plant V-320 are upgraded in design of V-392 with the aim to enhance the station safety and efficiency and improve the conditions for operation and maintenance. In particular, for reactor plant V-392 the reactor coolant pump GZN-1391 is used. This pump is the upgraded GZN-195M, which is used for the operating reactor plants V-320. In GZN-1391 pump water is applied as the lubricant and cooler of the main bearing; in combination with the improvements in the system of motor lubrication this allows to give up the outside oil system and exclude possible fire.

In reactor plant V-392 it is supposed to use some passive systems intended for fulfilment of the main safety functions (reactor shutdown, decay heat removal, core cooling). These systems, in the first turn, are intended to improve considerably the plant safety. Alongside with this, passive systems, as a rule, are simpler in operation and maintenance, and therefore improve also the plant economical characteristics.

3. REACTOR PLANT WWER-640/V-407

In the primary circuit of reactor plant V-407 the same equipment is used mainly as in reactor plant V-392, though there is a number of important differences. In particular, in comparison with V-392 in the reactor plant V-407:

- the core specific power intensity is decreased;
- neutron fluence to the reactor vessel is reduced;
- axial loads on fuel assemblies are decreased;
- no loop seals in the primary loops;
- passive safety systems are widely used.

3.1. Improvement of operational availability

High operational availability of the reactor plant is assured owing to:

- application of the equipment and technical solutions proven by operation;
- using of the approved materials and manufacturing processes for the main equipment;
- optimal water chemistry of the primary and secondary circuits;
- reducing the number of process systems and simplification of their schemes.

The design provides for on-line monitoring the state of equipment and components with the help of special diagnostic systems (noise diagnostics, monitoring the equipment vibration, detection of loose and poor fixed objects, primary-to-secondary leak monitoring). Special systems are provided for information support of the operation (safety parameters display system, equipment residual life assessment system, operator support system).

3.2. Maintenance improvement

To improve the conditions of maintenance of the reactor plant systems and equipment the appropriate experience is taken into account as well as the practices applied by Western specialists, including the results of international assessment of technical solutions accepted in the design of V-407. Many components of the reactor plant were designed in such a way that their service life will be equal to the station service life, as a whole.

Reactor plant designing was carried out with regard for the requirements related to inspection, maintenance and repair of equipment. In particular, good access is provided to the equipment requiring periodical examination and repair, the non-destructive inspection systems included. For the primary equipment the materials are used mainly with low content of cobalt and other elements with long half-life period. Together with designing of systems and equipment the process specifications for their maintenance and repair were developed.

3.3. Consistency of technical solutions

Design of reactor plant V-407 makes maximum use of technical solutions proven by operation experience of existing power units and justified in the designs of advanced WWER-1000. Such consistency improves technical characteristics of the reactor plant including also operational availability and maintenance.

4. CORE AND FUEL HANDLING

The cores of reactor plants V-407 and V-392 are similar as to design and use practically all technical solutions on the advanced core of operating WWER1000/320. The prototype of the advanced fuel is standard fuel assemblies (FA) with stainless spacing grids and guiding channels which have been in operation at WWER-1000 since 1982. Originally the standard fuel was operated in the mode of two-year fuel cycle, then the transition was done to three-year fuel cycle with the corresponding increase of average burnup.

Operation experience of standard fuel revealed certain drawbacks both concerning efficiency of fuel utilization, and design of fuel assembly (highly absorbing material within the active part; boron-based burnable absorber; low design service life; one-piece structure). Therefore designers and manufacturers of russian fuel for WWER-1000 have developed the advanced FA with zirconium structural materials and this FA is being implemented at present.

4.1. Advanced fuel assembly

Advanced fuel assembly (AFA) has been developed both for replacement of standard fuel at the operating reactors, and for new nuclear power plants with advanced WWER. The main difference of AFA, being the most effective as to economy, from standard fuel is application of only zirconium structural materials in the assembly active part. This allowed (in combination with specially developed refuelling patterns) to reduce the specific consumption of uranium approximately by 13%. Application of gadolinium burnable absorber instead of boron absorber allows to reduce this index by approximately 5% more. Application of AFA allows also to reduce enrichment of makeup fuel. Using of uranium-gadolinium fuel allows to reduce neutron fluence to the reactor vessel, to improve flexibility of fuel cycle, to exclude expenses for operation and storage of burnable absorber rods.

Guiding channels (GC) for absorbing elements are optimized by outer diameter and wall thickness in such a way that to improve the conditions of insertion of absorbing elements under the mode of free drop, to keep sufficient DNBR in the surrounding fuel rods and to provide for the required strength of GC, as the load-carrying component. Tests are being performed of GC of zirconium alloy Э635 of decreased radiation creep that could be used at higher burnup.

Difference in linear expansions coefficients of guiding channels of the assembly and reactor core barrel is compensated by increase of the working stroke of spring block of FA cap. For connection/disconnection of AFA stainless cap and GC a simple device is used not requiring replaceable fasteners or complicated fixtures with power nut drivers. As the inspection stand is available the procedure on dismounting or mounting the AFA cap takes a minimum time.

Absorbing elements are upgraded as well. The combined absorber is used in them comprising boron carbide and dysprosium titanate. This allowed for two times increase of absorbing element service life. For the absorbing element cladding the new alloy is applied with improved mechanical properties and radiation strength. This allows to decrease the cladding thickness and improve the efficiency of absorbing rod.

So, the advanced fuel provides for improvement of safety and economic efficiency of reactor plants of new generation. Nowadays all the mentioned improvements of the core are being checked and implemented at the operating NPP with WWER-1000, therefore the experience obtained is a reference one for the advanced reactor plants V-407 and V-392.

4.2. Fuel handling system

In design of fuel handling systems for the advanced reactor plants V-407 and V-392 some changes are introduced into the process and structure of fuel handling equipment. These changes provide for improvement of safety, of maintenance conditions and simplification of fuel handling procedures.

For example, in V-407 design the «lower» supply (shipment) of nuclear fuel to the reactor compartment is used at power unit. With this, the height of lifting of in-station packing set for fresh fuel and transport container for spent fuel is about 1,5 m excluding by this the occurrence of nuclear accident in case of drop of fuel packages. In the design of fuel handling system of reactor plant V-392 the nuclear accident in case of drop of transport packing set is prevented by installation of shock absorbers at the places of packages lifting to the height exceeding the design one for these packages.

All fuel handling equipment of reactor plants V-407 and V-392 (in-plant transport packing set for fresh and spent fuel, leak-tight bottles, bottles of defective assembly detection system) has the cells for fuel assemblies made of hexahedral tubes. This measure provides for improvement of nuclear safety under accident situations and also prevents mechanical damage of fuel assembly during its installation and withdrawal from the fuel handling equipment.

5. MONITORING AND CONTROL SYSTEM

The existing nuclear power plants were constructed by designs of 60-70-ties with the use of automatics, equipment, cables and actuating mechanisms manufactured mainly at the enterprises of the Soviet Union at that time. Monitoring and control system (MCS) of Russian plants may be conventionally divided into three generations.

The first generation includes MCS of the reactors commissioned before 1975. Specific feature of these systems is wide application of remote control from the operator's panels, remote control of process parameters and relatively simple automatic devices (process protections, automatic control, interlocks, signalling). MCS of the second generation is characterized by wide application of measuring and control instruments with the unified electric signal, logic control devices, aggregated monitoring systems for the plant process systems. In the systems of the second generation the links between the control devices for the reactor, turbine and other system were considerably extended, the scope of monitoring and automation of processes was increased. In the devices of automatic control and protection of the reactor the elements of microelectronic technique are applied. The specific feature of MCS of the third generation is wide application of microprocessing and computing technique for control of processes. For representation of information to operator both the mimic panels, and alphanumeric and graphic displays are applied.

For reactor plants V-407 and V-392 new systems of monitoring and control are developed. They apply widely the microprocessing technique for implementation of all MCS functions including safety functions. The requirements of new regulatory documents are taken into account as well as recommendations of international standards, up-to-date principles of system construction, such as:

- high automatization level of processes;
- regard for operation experience of the existing systems and the latest achievements in the world practice in creation of control rooms;
- developed information support to operator, high functional reliability and self-diagnostics of hardware;
- redundancy, independence, diversity, resistance to common cause failures;
- assurance of serviceability under internal and external impacts including accident conditions;
- reducing the maintenance work scope and the number of personnel engaged.

Development of hardware for new MCS is performed according to complex programme of Minatom of Russia prescribing the development of software-hardware for MCS engineering for the stations reconstructed, under construction and under design, including WWER-640/407 and WWER-1000/392.

6. CONCLUSION

In Russia a complex of R&D work is being carried out on development of power units of new generation with reactor plants WWER-1000/V-392 and WWER-640/V-407, meeting the new requirements for safety and economic efficiency of electric power production.

In the advanced WWER many new technical solutions are applied with a view to improve safety, to optimize economical indices and to minimize the expenses on maintenance of the station equipment and systems.