IMPROVEMENT OF OPERATIONAL PERFORMANCE AND INCREASE OF SAFETY OF WWER-1000/V-392

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Abstract

The national program of nuclear power development approved by the Russian Federation Government in 1998 considers the design of WWER-1000/V-392 power unit as a priority project of the new generation NPP with improved operational performances and increased safety. The pilot unit of this design (NVAES-2) is licensed for construction at the Novovoronezh NPP site. The NVAES-2 design is developed on the basis of standard power unit with reactor plant V-320. Twenty units of this type are in operation at the nuclear power plants in Russia, Ukraine and Bulgaria having totally about 270 reactor-years of operation. Two more V-320 units are being commissioned this year at Rostov NPP and Temelin NPP. So, the WWER-1000/V-392 design is as a whole an evolutionary development of the operating standard unit WWER-1000/V-320. Many technical solutions aimed at increase of safety and improvement of operational performance of the plant are implemented in the NVAES-2 design, such as advanced reactor WWER-1000, passive system of residual power removal, passive system of the core flooding under loss-of-coolant accidents, and others. NVAES-2 design refers to a class of advanced light water reactors and corresponds to the international requirements imposed to the nuclear power plants to be put into operation after the year 2000. New V-392 power unit has a good perspective from the view point of extensive implementation in the framework of the nuclear electricity production in Russia. Design decisions on NVAES-2 power unit with WWER-1000/V-392 reactor plant which assure significantly higher safety level and improve economical performance as compared to the operating WWER-1000 units are briefly considered in the present paper.

1. INTRODUCTION

Nowadays in eight countries 49 commercial reactors of WWER-type are in operation with total power exceeding 32 GW, including 20 reactors WWER-1000 and 29 reactors WWER-440. More than 800 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 these reactors point out the competitiveness of WWER reactors as electric power producers.

Nevertheless, operation experience of WWER nuclear power plants, new national and international safety standards and changes in economy of Russia govern the necessity of development of advanced nuclear power plants. New reactors of WWER type shall possess the increased characteristics of safety and economical efficiency, be more convenient for operation and maintenance.

The national program of nuclear power development for the period until 2010 was approved by the Russian Government in July 1998. The program is aimed at development of nuclear power with NPP siting in those regions, for which appropriate permission for construction of nuclear power plants is received. In particular, development of perspective NPP designs on the basis of the advanced safety technologies and construction of advanced WWER units of increased safety are being planned. The program is also intended to expand nuclear technologies export including WWER nuclear power plant construction abroad (in particular, in Iran, China and India in accordance with the existing inter-governmental agreements and contracts for construction of NPP with the advanced WWER-1000 reactors).

Within the context of these tasks, Russian design and scientific organisations are performing a complex of R&D work on development of power units of new generation with advanced reactor plants of 1000 MW(e) power which meet new requirements for safety and economical efficiency of electric power production. Design decisions on Novovoronezh NPP-2 with WWER-1000/V-392 reactor plant which assure significantly higher safety level and improve economical performance are briefly considered in the present paper.

2. NVAES-2 POWER UNIT

Power unit 1000 MW(e) design with reactor plant WWER-1000/V-392 [1] is developed for construction in Russia and elsewhere; the power unit forerunner is planned for commissioning at the Novovoronezh NPP site (NVAES-2). The design is based on the application of equipment and processes that have proved their operability at existing nuclear power plants. At the same time, this design is aimed at achieving higher safety level and essentially better economical indices as compared to operating WWER-1000/V-320 units.

Power unit V-392 presents itself a mono-unit with four-loop reactor plant, working pressure in the primary circuit 15,7MPa, reactor outlet coolant temperature 593K, steam pressure 6,3MPa, steam capacity about 6000 t/h.. Layout of the reactor building, turbine hall, safety and auxiliary system buildings ensure minimum routing of communications and high reliability of normal operation and safety functions. Reactor plant is placed in the double containment which prevent from radioactivity release to the environment and protect reactor plant against of external impacts. The design is intended to take up the external impacts from natural and man-induced phenomena such as earthquake of magnitude of 8 as per MSK-64 scale, tornado, hurricane, shock wave with front pressure to 30kPa, etc.

The advanced design of NVAES-2 has been developed on the basis of standard power unit with reactor plant V-320. These units are in operation for a long time at nuclear power stations in Russia, Ukraine and Bulgaria. Today 20 power units with WWER-1000 reactor operate, and total time of their work is 270 reactor-years. Power units of this type are also being constructed or planned in Czechia, Russia, Ukraine. In particular, unit 1 of Rostov NPP in Russia and unit 1 of Temelin NPP in Chechia are being commissioned this year.

Many technical solutions aimed at increase of safety and improvement of operational performance of the plant are implemented in the NVAES-2 design. Some examples of such advancements are as follows:

- advanced reactor WWER-1000;
- passive system of residual power removal (under certain conditions, this system can also facilitate to the emergency containment cooling);
- passive system of the core flooding under loss-of-coolant accidents;
- passive system of rapid boron injection for the reactor shutdown;
- primary coolant pump preventing coolant leak under long-term station blackout;
- passive system to create the rarefied atmosphere in the inter-containment gap and to clean the emergency leaks under accident conditions including severe ones.

So, the WWER-1000/V-392 design is as a whole an evolutionary development of the operating standard unit WWER-1000/V-320. The design refers to a class of advanced light water reactors and corresponds to the international requirements imposed to the nuclear power plants to be put into operation after the year 2000. This conclusion was confirmed by a few peer reviews of NVAES-2 design including the reviews performed by Western experts.

3. IMPROVEMENT OF OPERATIONAL PERFORMANCE

High operational availability of the power unit with WWER-1000/V-392 reactor plant is assured owing to:

- application of the equipment and technical solutions proven by operation;
- using of proven materials and technologies for the equipment manufacturing;
- optimal water chemistry of 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's support system).

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 V-392 design.

Power unit NVAES-2 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. During the design process of WWER-1000/V-392 power plant, all the comments of Russian Gosatomnadzor related to correspondence of the previous V-320 unit to national safety norms have been solved. Also, the relevant recommendations of the IAEA missions to operating plants have been taken into account.

Design of the WWER-1000/V-392 power unit makes maximum use of technical solutions proven by operation experience of existing WWER-1000 power units. Such consistency improves technical characteristics of the reactor plant including also operational availability and maintenance. At the same time, a number of new technical decisions on the unit systems and equipment are applied in V-392 design to take into account operating experience of WWER-1000 units and modern requirements to nuclear power plant competitiveness. Some examples of advancements aimed to improve the operational performance and plant economical efficiency, to decrease the costs of construction, repair and maintenance of the systems and equipment are given below.

3.1. Reactor plant

The length of reactor pressure 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 pressurised 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.

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 protective tube unit lower plate under such downward motion of the core barrel.

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.

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 optimise 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 analogues). 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.

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.

Many other components of reactor plant V-320 are upgraded in V-392 design 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 MCP-1391 is used. This pump is the upgraded MCP-195M, which is used for the operating reactor plants V-320. In MCP-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.

3.2. Core and fuel handling

The core of V-392 reactor uses practically all technical solutions on the advanced core of operating WWER-1000/V-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 two-year fuel cycle, then the transition was done to three-year fuel cycle with the corresponding increase of average burn-up.

Operation experience of standard fuel revealed certain drawbacks both concerning efficiency of fuel utilisation, 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.

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 optimised by outer diameter and wall thickness. The aim was 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 burn-up.

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 plant V-392.

In design of fuel handling system for the advanced reactor plant 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-392 design a 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 the fuel handling equipment of V-392 reactor plant (in-plant transport packing set for fresh and spent fuel, leak-tight bottles, bottles of defective assembly detection system) have 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.

3.3. Safety systems

Technical solutions on the safety systems of NVAES-2 design are aimed, in the first turn, at significant increase of the safety level of new unit as compared to the operating WWER-1000/V-320. Safety system structure and configuration have been also optimised from the viewpoint of economical characteristics (number of equipment, repair and maintenance costs, dose loads to personnel, etc). Task to enhance the safety level as compared to V-320 power unit has predetermined the implementation of the design solutions dealing with protection against common-cause and dependent failures in the safety systems including:

- application of functional and structural diversity in the systems that perform each
- critical safety function;
- protection of the safety-related systems and equipment against internal and external
- impacts;
- protection against erroneous operator's actions.

Analysis of technological possibilities of implementation of the above issues has shown that the simplest and the most economical way is equipping of the modular safety system with active and passive principles of operation that duplicates each other as regards the critical safety functions. Functional and structural diversity in the safety systems permits to provide in-depth defence against the common cause failures and operator errors. The fulfilment of a number of safety functions is based on this principle in NVAES-2 design, for example:

- reactor shutdown and maintain the sub-criticality;
- decay heat removal;
- maintain the reactor coolant inventory;
- maintain the continuous rarefaction in inter-containment gap.

Application of the above principles and solutions in practice have come across with a problem of uncertainty with respect to achievable efficiency; the latter is connected with necessity of quantification of the safety level. To evaluate and assess the achievable safety level, one has to perform the full-scale PSA in addition to deterministic principles. Common realisation of the deterministic and probabilistic analyses during the NVAES-2 design process has permitted to obtain optimal solution with respect to balance of the active and passive trains of the modular safety systems. As a result of this optimisation, total core melt frequency for NVAES-2 is about three orders of magnitude less than for unit 1 of Balakovo NPP with V-320 reactor plant.

In WWER-1000/V-392 design 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.

From the reliability and economical efficiency viewpoint, so-called "principle of adjustment" of safety and normal operation functions has a great importance, and in the NVAES-2 design a number of safety systems are based on this principle. Following to this principle, a safety system performs the designated normal operation function, and at the accident signal appearance the system begins to fulfil the required safety function. At this, no (or minimum number of) changes in the status of the system's elements (valves, pumps, etc) are required. Such solution permits, as compared to the traditional on-duty safety system, to increase in 5-6 times the reliability of the safety function fulfilment due to small sensitivity to latent failures. From the economic viewpoint, the quantity of devices, valves, pumps, cables, I&C and automation is decreased essentially. For example, the NVAES-2 active system for emergency heat removal via primary circuit has 4 pumps, whereas the same functions with the traditional approach would require 12 pumps.

3.4. Instrumentation 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 characterised 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 micro-processing 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 the advanced V-392 design, new systems of monitoring and control are developed. They apply widely the micro-processing 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 automation 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 nuclear power plants being reconstructed, under construction and under design, including advanced power unit WWER-1000/V-392.

4. SAFETY INCREASE

The NVAES-2 design is developed on the modern level of the national and international requirements which envisage:

- the probability of limiting release and serious core damage at beyond-design accidents less than 10^{-7} and 10^{-5} per reactor-year, respectively;
- reduction of urgent evacuation area to 300-500 meters and emergency planning area to protect the population in case of beyond-design accidents to 700-3000 meters.

This power unit is designed so, that its safety level exceeds the above requirements, and radiation impact of NVAES-2 on the population and environment is essentially below the allowed limits established by up-to-date safety standards.

Significant safety increase in V-392 design as compared to the operating V-320 units is achieved due to extensive application of passive safety means, using natural physical processes, along with the traditional active systems. The IAEA Conference on “The Safety of

Nuclear Power: Strategies for the Future" [2] has noted that the use of passive safety features is a desirable method of achieving simplification and increasing the reliability of the performance of essential safety functions, and should be used wherever appropriate. However, the application of passive means is connected with some problems, which have to be solved by each plant designer. The passive systems have their own advantages and drawbacks in comparison with the active systems both in the area of plant safety and economics. Therefore a reasonable balance of active systems and new passive means is adopted in V-392 design to improve safety and public acceptability of nuclear energy.

One important problem related to the implementation of the passive means is that, in the most cases, sufficient operating experience of the passive systems/components under real plant conditions does not exist. Besides, the existing computer codes for transient and accident analysis are not sufficiently validated for the conditions and phenomena which are relevant to the passive system functioning. Therefore, the extensive experimental investigations and tests have been already performed and are being planned to substantiate the design of the safety features proposed for the NVAES-2 power unit. On this basis, a number of relatively innovative passive safety means are implemented in V-392 design to ensure or to back up the fundamental safety functions: reactivity control, fuel cooling and confinement of radioactivity.

4.1. Reactivity control

Traditional gravity-driven control rods are the main system to ensure reactor scram both in currently operating and new WWERs. For existing pressurized water reactors, this system is not sufficient to bring the reactor to a cold shutdown state; therefore the control rod system of existing WWERs is supported by pumped emergency supply of the borated water to the primary circuit. New WWER designs V-407 and V-392 have an increased number of gravity-driven scram rods to maintain shutdown margin even in the absence of boron supply during the reactor cooling down.

Although very good reliability records exist for scram excitation, some failures of the gravity-driven control rod insertion have been recognized. The failures occurred for the different reasons; in particular, the cases of insertion speed reduction and incomplete insertion due to fuel assembly deformation have been reported during last ten years (see for example [3]). Besides, some failure modes may be considered which could prevent all the control rods to insert, and it was the basis for designers to analyze Anticipated Transient Without Scram events.

Keeping that in mind, for WWER-1000/V-392 a special quick boron supply system has been designed as a diverse system to the gravity-driven scram system. A concentrated boron solution tank is connected to the suction and discharge pipes of each main coolant pump. The valves in the connecting pipes will automatically open if there is a demand for reactor trip but the reactor power after some time is higher than its value after scram should be. The concentrated boron solution is supplied to the reactor due to pressure difference between discharge and suction of the main coolant pump (pump head). Inventory and concentration of the boron solution is selected to ensure compliance with safety criteria in the design events accompanied by control rod system failure to trip the reactor. The operability of the quick boron supply system has been confirmed by extensive experimental investigation using a scaled model.

4.2. Fuel cooling

The safety function «fuel cooling during transients and accidents» is ensured by provision of sufficient coolant inventory, by coolant injection, sufficient heat transfer, by circulation of the coolant, and by provision of an ultimate heat sink. Depending on the type of transient/accident, a subset of these function or all of them may be required. Various passive systems and components are proposed in V-392 design to fulfill these functions.

The passive residual heat removal system (PHRS) is included in the V-392 design to remove heat from the reactor plant. The design basis of this system is that in case of station blackout, including loss of emergency power supply, the removal of residual heat should be provided without damage of the fuel and of the reactor coolant system boundary for a long time period. The PHRS consist of four independent trains; each of them is connected to the respective loop of the reactor plant via the secondary side of the steam generator. Each train has pipes for steam and condensate, valves and modular air-cooled heat exchanger installed outside of the containment. The steam that is generated in the steam generator due to the heat released in the core condenses in the air-cooled heat exchanger, and condensate is returned back to the steam generator. The motion of the cooling media (steam, condensate and air) takes place in natural circulation.

The passive system for reactor flooding during LOCA in V-392 design comprises two groups of hydro-accumulators. First group (so called first stage accumulators) consists of four traditional ECCS accumulators being used at operating WWER-1000 reactors; these accumulators are pressurized by nitrogen to 6MPa and connected in pairs to the upper and lower plenums through special nozzles in the reactor pressure vessel. Second stage accumulators are 8 tanks connected to the reactor coolant system through the check valves and special spring-type valves. These valves are kept closed by the primary pressure; when the primary pressure drops below 1,5MPa, the spring open the valve. Such a connection configuration and valve design ensures continuity of hydrostatic head irrespective of the primary pressure change during an accident. Installation of hydraulic profiling of the outlet route ensures a step-wise limitation of the water flow rate from the tank when the water level in the tank is decreasing. The water inventory in the second stage accumulators (about 1000t) ensures the core cooling for 24 hours during a LOCA even if all active ECCS mechanisms are inoperable. Joint operation of the second stage accumulators and SPOT gives a possibility to increase this period by natural way and/or by a simple means of the accident management.

4.3. Confinement of radioactivity

This safety function is ensured by protecting and maintaining the integrity of the potential radioactivity release barriers (fuel, reactor system boundary and containment). These barriers are passive components as themselves; in addition, several passive means are proposed in V-392 design for the protection of these barriers (some of them are reflected above). The V-392 design implies substantial improvement of the containment protection against different loads related to design basis and severe accidents, and various passive systems are important part of this protection.

To limit considerably the release of fission products beyond the containment, a permanent under-pressure is maintained in the inter-containment gap of the V-392 design. This safety function, one of the most important, is fulfilled by two systems: (1) an exhaust ventilation system equipped with a filtering plant with suction from the inter-containment gap and outlet into the stack; (2) a passive system of suction from the inter-containment gap. The first system is intended to control removal of steam-gas mixture from the inter-containment gap under design basis accidents with loss of external power. The system is capable to remove and clean the leaks from the inner containment 1.5% of containment volume per 24 hours. The second system consists of lines connecting the inter-containment gap with the PHRS exhaust ducts, which are always in the hot state. This solution enables permanent removal and purification of inner containment leaks irrespective of the electricity supply and operator actions. According to estimations, the under-pressure is maintained at any point of the inter-containment gap with inner containment leaks up to 1.5% of containment volume per day (the design basis for the containment is 0.3%). The technical solution described above in combination with the systems for the containment pressure decrease (spray system and passive heat removal system) allows to give up the filtered venting system designed for NVAES-2 in spite of this system follows the current requirements that filtered venting should not increase the risk of loosing the containment function and filtered venting is not required in the short term of a core melt accident.

Special systems and components are implemented in NVAES-2 design to prevent hydrogen burning or explosion. The hydrogen suppression system comprises passive catalytic hydrogen igniters based on an efficient high porosity cellular material. Each of 50 elements of this system is capable to oxidize about 30 grams of hydrogen per hour at its volumetric concentration 4%. This system prevents the explosive concentration of hydrogen even if 100% of the core Zr will be oxidized during an accident.

5. CONCLUSIONS

In accordance with the national program of nuclear power development, a complex of R&D work is being carried out by the Russian design and scientific organisations on development of advanced power units of new generation with reactor plant WWER-1000/V-392. These units meet up-to-date national and international requirements for safety and economic efficiency of electric power production. Permission of the Gosatomnadzor RF has been issued for the construction of the forerunner unit of this design at Novovoronezh NPP site.

In the advanced WWER-1000/V-392 power unit design many new technical solutions are applied with a view to improve safety, to optimise economical indices and to minimise the expenses on maintenance of the station equipment and systems.

The power demand prognosis [4] shows that even based on a conservative scenario, power use in Russia will increase by about 30% by the year 2010, and by the year 2030 — in 2 times as compared 1995 level. The tendency during the last few years in Russia is to double-triple lead the rate of increase in fossil fuel cost compared to the rate of increase in nuclear fuel cost. So, new WWER-1000/V-392 power unit has a good perspective from the view point of extensive implementation in the framework of the electricity production in Russia.

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