



Project AES-2006



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Project management structure
AES-2006

Customer: JSC Rosenergoatom Concern.

General Designer of AES-2006: The Joint Stock Company’s “East-European leading scientific research and design institute for energy technologies” branch “SPbAEP”.

Chief Designer of the reactor plant: JSC OKB «GIDROPRESS».

Scientific Supervisor for the Design: National Research Centre «Kurchatov Institute».

Other Russian design organizations with a wide operational experience in nuclear power engineering sphere are involved in this project.



I. Introduction

Tasks to be solved

Current Tasks

- minimization of risks and improvement of operational performance by the use of proven technical solutions and equipment with reference analogs;
 - improving performance of equipment and systems by eliminating excessive conservatism and optimizing design margins;
 - ensuring required level of safety, including in the event of a BDBA, by selecting rational configuration of safety systems with active and passive elements to achieve maximum diversity and reduce the risks associated with human factor;

Reference

The concept of AES-91 (Tianwan NPP) and AES—91/99 (for the tender in Finland) modernized taking into account operating experience of VVER-1000/320 power units and solution incorporated in the designs of nuclear power plants with VVER-640 reactors and in AES-92.

Regulatory framework

- Federal laws applicable to peaceful application of nuclear energy;
- Technical Assignment for the basic design AES-2006;
- Technical Assignment for RP AES-2006;
- Norms, rules and standards of the Russian Federation applicable to nuclear energy use;
- IAEA safety series;
- EUR requirements for designs of new generation high-output power units with light water reactors (EUROPEAN UTILITY REQUIREMENTS FOR LWR NUCLEAR POWER PLANTS).

- reducing capital and operational costs by:
 - 1) using serial equipment and reducing the range of equipment;
 - 2) optimizing solutions for radioactive waste and spent fuel handling;
 - 3) improving repair techniques.
- minimization of expenditures for R&D work required to justify design solutions;
- competitive advantage on the domestic market over other sources of energy (such as steam and gas installations);
- service life of irreplaceable equipment not less than 60 years;
- self-protection against accidents, sufficient safety margins and supply of electric power, compressed air, decontaminating solutions and other vital resources for a long period of time;
- resistance to human errors and external events (both natural and man-caused) and internal events during both unit operation at power and outages;
- using the invariable (basic) part of the design providing applicability for construction of facilities in areas with greatly varying natural climatic conditions and unification of the main and auxiliary equipment;
- consumer appeal of the facility to be constructed due to technical and fire safety, comfort and ease in operation, as well as high degree of repairability of equipment and instruments with minimized amount of spare parts required in the process of operation;
- minimization of production (especially radioactive) waste;
- possibility of decommissioning after the expiration of the design service life, utilization or conversion without technical or organizational problems, with minimum dose load, minimum potential amount of radioactive waste, and acceptable financial, material and labor costs;
- high-quality design solutions and documentation based on Russian quality assurance standards, internationally adopted ISO 9000 standards, recommendations of Code 50-C/SG-Q and its related safety guides, EUR, INSAG, IRPC, IEC and recommendations of other international organizations to ensure competitive ability of the design on the world market.



II. AES-2006 design concept described by the example of Leningrad NPP-2

Basic lay-out solutions for the General Layout and main buildings and structures

General layout

The following principles were taken into account in course of designing the planning diagram for the general layout:

- modular approach to site development - construction of independent power units with the possibility to perform construction by phases and startup sets;
- rational interlocking of the buildings to reduce the built-up area and service lines length;
- provision of the possibility to implement measures on physical protection of the nuclear island buildings.
- rational zoning, including:
 - determination of invariable area of the general layout,
 - arrangement of explosive and fire-hazardous objects at a distance from objects important for nuclear and radiation safety assurance, as well as for the power unit viability;
 - accounting for aesthetic requirements to architectural aspect of the NPP, landscape requirements.



The orientation of the power units is determined by the technical solutions adopted in the design of the service water supply systems for the main equipment of the turbine buildings and important consumers located in the reactor buildings, and also depends on the conditions of electrical and thermal power output.

The NPP site is conventionally divided into the main production area and the area of plant auxiliary buildings and structures.

The main production area is located at the center of the plant site and consists of module power units grouped into united structural volume. Each of them includes reactor building with transportation lock trestle, steam cell, safety building, auxiliary building, control building, fresh fuel and solid radioactive waste storage, nuclear service building, utility rooms for outside personnel – (nuclear island), turbine building, normal operation power supply building, water treatment building with tanks – (turbine island), and detached structures: ventilation stack, emergency diesel generator station building of the emergency power supply system with diesel fuel storage tanks, structure for unit transformers, condensate storage tank, pump station for automatic spray water fire fighting with water storage tanks, unit diesel generator station.

The power units are oriented by the turbine buildings towards the electrical power output.

The spacing between the power units is 200 m to provide space for service lines and transport routs, and to enable flow-line construction and independent commissioning of individual startup facilities.

In case of necessity the chimney-type cooling towers with pump stations are arranged within the site boundaries.

Located north-west from the reactor buildings at the minimum possible distance are coolings spray ponds for important consumers of the reactor buildings. At the same location the design provides a reserve tank for emptying the spray ponds.



Reactor building

The reactor building is the main building of the nuclear power plant, around which other buildings and structures of the nuclear island are grouped. The nuclear steam generating plant and its emergency cooldown systems are located in the reactor building.

The double containment minimizes effects that may be caused by potential radioactive releases into the environment. The outer containment provides physical protection for the inner containment in any external event. The inner containment maintains air-tightness of the internal volume under all operating conditions including emergencies.

The inner containment is a pre-stressed reinforced concrete structure, consisting of a cylindrical part and a dome. The inner surface of the containment is lined with six millimeter carbon steel to ensure tightness.

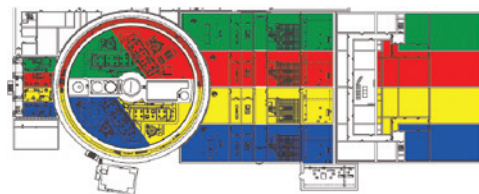
The internal diameter of the pre-stressed containment is 44.0m. The thickness is determined by calculation and according to the calculation data is 1200mm for the cylindrical part and 1000mm for the dome. The upper elevation of the cylindrical part is +44.600.

The proposed containment design ensures higher reliability than those developed earlier and is a step forward in the direction of enhancing safety of nuclear power plant.

Adjacent to the reactor building is the transportation lock trestle which is used to transport large size equipment into the reactor building.

Steam cell

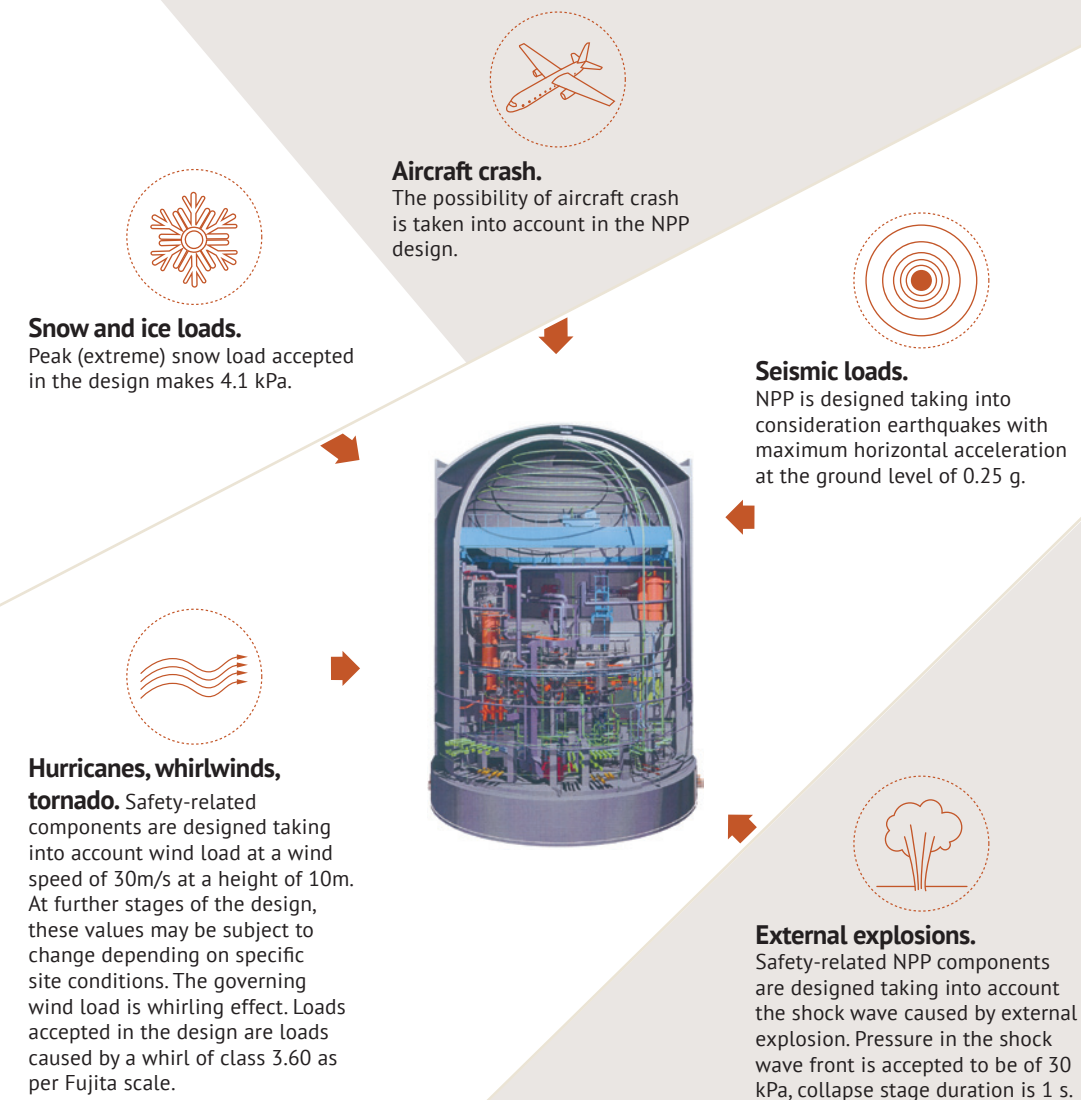
The steam cell is designed to contain equipment and pipelines that are part of the system providing SG protection against overpressure, cutoff valves of the primary circuit, feed water system and demineralized water supply system. Equipment and pipelines of all systems are divided into four independent safety trains.



Safety building

The safety building is designed to contain the equipment and pipelines of the protective safety systems. The building is divided into four independent and isolated safety trains. The safety trains are isolated from each other by building structures. The safety building also contains the equipment of intermediate cooling circuit and process water system for important consumers, fuel pool cooling system, residual heat removal system.

NPP Reactor building protection against external impacts



Control building

The control building is designed to contain electric and measurement/communication systems used for power unit control. The rooms of the control building contain systems ensuring operation, monitoring and control of the power unit, as well as power supply.

Auxiliary building

The auxiliary building contains equipment of auxiliary systems intended for primary circuit, equipment of special water and gas treatment system, waste treatment system, and ventilation systems of the controlled access area.

Standby diesel generator station building of the emergency power supply system

The standby diesel generator station building of the emergency power supply system is designed to provide power supply for consumers of the safety systems under plant blackout conditions. The building is divided by reinforced concrete walls into four parts, where equipment of the four completely independent safety trains is located.

Fresh nuclear fuel and solid radioactive waste storage building

At power unit one, the fresh fuel storage is united with the radioactive waste storage into one building. At power unit two, with the transportation and handling equipment storage. The fresh nuclear storage is intended for the reception and storage of fuel in an amount sufficient to provide fuel supply for two power units.

Turbine building

The turbine building contains the turbine, generator, their auxiliary systems, such as the water super-heating and separation system, condensate purification system, low pressure heating system, feed water system, high pressure

heating system, turbine and generator oil systems, etc. Space planning solutions adopted for the turbine building are basically determined by the structure and dimensions of the turbine set, layout of the systems and equipment of the secondary circuit, and equipment selected for the deaeration-feeding unit, the basic provisions being as follows:

- one end of the turbine building faces the reactor building;
- the turbine is located in the main bay on the same longitudinal axis with the reactor plant;
- turbine set (turbine and generator) is installed on shock-proof foundation.

Service water supply buildings and structures

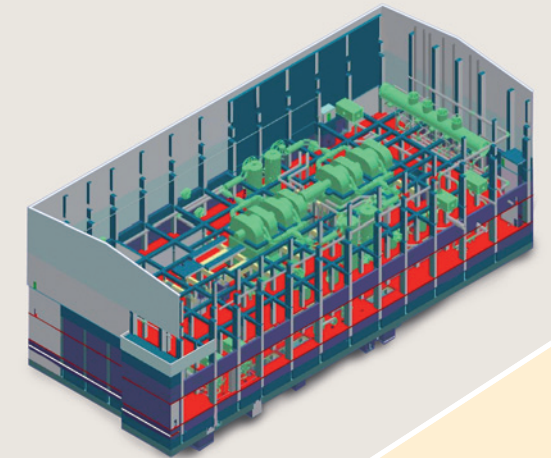
The service water supply buildings and structures include:

- pump station for turbine building consumers;
- evaporative cooling tower;
- pump station for important consumers;
- spray pond;
- switching chamber;
- reserve tank;
- makeup pump station.

Other structures of the power unit

Other buildings and structures of the power unit proper include:

- unit diesel generator station building;
- automatic water fire fighting pump station with water storage tanks;
- structures for unit transformers (included in the invariable part of the design);
- ventilation stack (included in the invariable part of the design), etc.;
- general plant buildings and structures.



Process solutions

General description of the power unit process part

The schematic flow diagram of the power unit with B-491 reactor plant is presented in the figure, where the main reactor plant equipment is indicated and schematic diagrams of the primary and secondary circuits, safety systems, supporting safety systems, auxiliary power supply systems are provided.

The primary circuit is radioactive. It is limited by the boundaries of the reactor plant (RP), which consists of a reactor, four main circulation loops, four reactor coolant pump sets (RCPS), tube side of each of four steam generators (SG) and one steam pressurizer. All the RP equipment is arranged inside the tight containment of the Reactor building.

Provisions are also made for spent fuel storage on racks for compacted storage of fuel inside the spent fuel pool in the Reactor building.

The secondary circuit is non-radioactive. It consists of the steam generating part of steam generators, steam pipelines of main steam, one turbine set comprising a turbine plant and a turbine generator, condensate pumps, system of regenerative low pressure heaters, main condensate system, deaerator, feedwater system, including feedwater pumps, and system of regenerative high pressure heaters.

The conditions are created in the reactor core so that the nuclear reaction proceeds on thermal neutrons with thermal energy output.

The primary coolant is heated passing through the reactor core and is then supplied to the SG tube side along four parallel circulation loops, where it releases its energy generating the secondary circuit steam. The coolant is then returned from SG to the reactor for reheating. Circulation in loops is performed by four RCPS. Pressure fluctuations and temperature changes of the primary coolant volume are taken up by the pressurizer. In case of significant pressure increases in the primary circuit (under anticipated operational occurrences), steam from the pressurizer is discharged through the pilot-operated safety valves into the bubbler tank, which is cooled by the intermediate cooling circuit.

The radioactive corrosion products of structural materials, radionuclides and chemical impurities are removed from the primary coolant using the ion-exchange filters of special water treatment plant (SWT-1).

From the steam generating part of the steam generators steam is supplied to turbine along the main steam pipelines via stop-control valves. Steam releases its energy to turbine passing through the high pressure cylinder and four low pressure cylinders. At the same time thermal energy is transformed into the mechanical rotation energy of the turbine rotor. The generator (with the rotor being at the same shaft with the turbine rotor) transforms the mechanical energy into the electrical energy.

After passing through the turbine the spent steam is supplied into the condenser, where it is condensed by means of cooling with the circulating water.

The condensate is supplied to the unit demineralization plant by condensate electric pumps of the 1st step. After treatment at the unit demineralization plant, the condensate is supplied through the first group of low pressure heaters (LPH) to the suction side of the condensate electric pump of the 2nd step, and then to deaerator through the second group of LPH. When passing through LPH the condensate is heated by steam, which is supplied to LPH from the turbine steam extraction.

The main condensate is deaerated and heated in the deaerator by means of counterflow of the supplied

condensate and steam from the turbine extraction.

The feedwater is then supplied through high pressure heaters from the deaerator to the steam generators by feedwater electric pumps.

Circulating water for the main turbine condensers and auxiliary cooling water intended for heat removal from the intermediate cooling circuit for unimportant consumers is supplied via pressure water lines from the pumps of the pumping station of the Turbine building consumers. Water is supplied to the pumping station from the cooling tower basins via closed supply channels. After turbine condensers and from the auxiliary cooling system water is supplied to the cooling towers for cooling via discharge water lines.

Apart from the systems which are directly involved in electric energy generation process, the safety systems intended for prevention of design basis accidents and/or limitation of their consequences are shown in the figure. To supply the NPP safety systems consumers with power, provisions are made for the emergency power supply system (EPSS), which ensures reliable power supply under all operating conditions, including loss of working and standby power grid sources. EPSS comprises independent power supply sources (diesel generators and storage batteries), switchgears and switching devices.

The basic technical characteristics and parameters of the power unit are listed in Table 1.

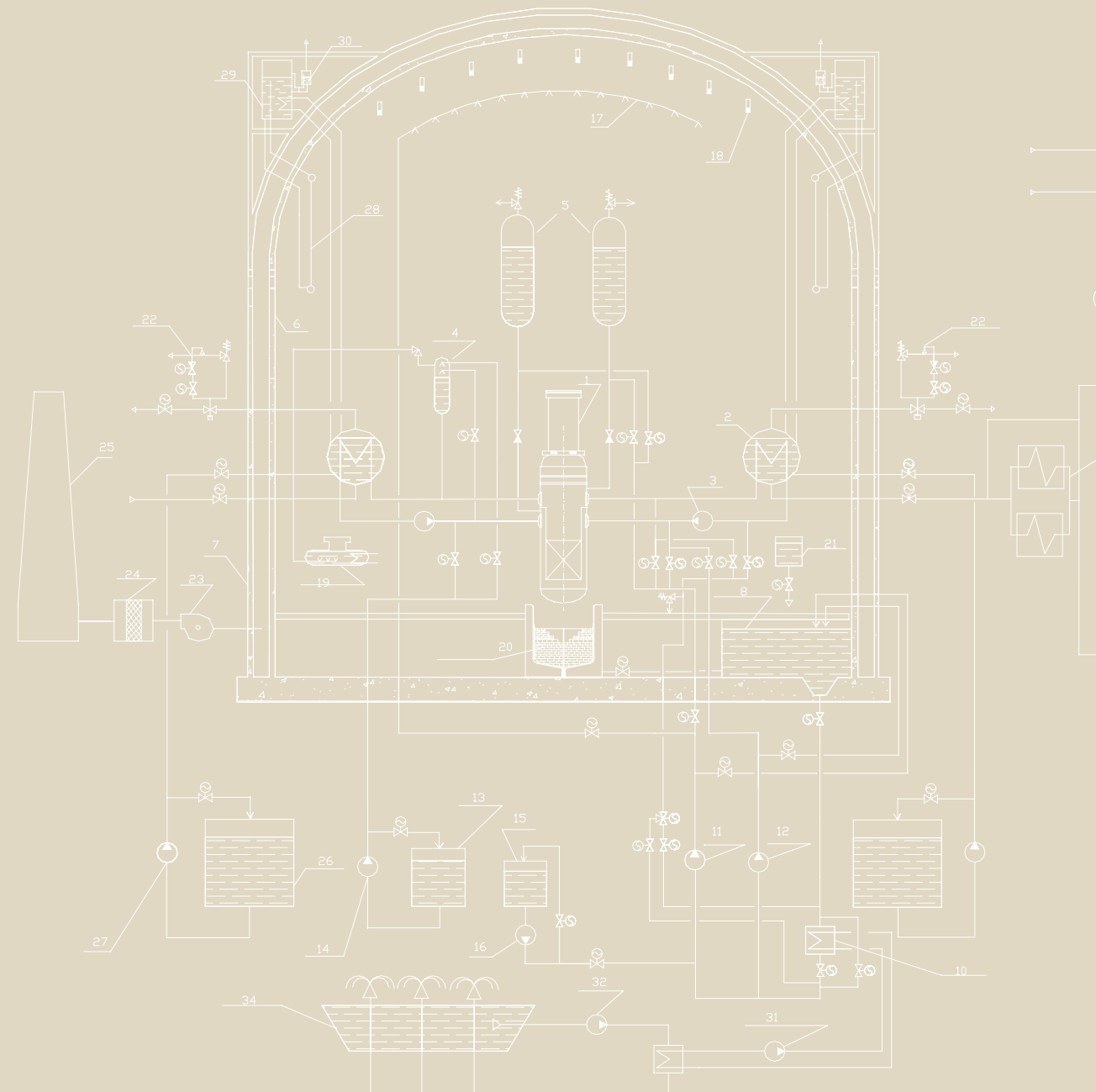
Table 1. Basic technical characteristics and parameters of the power unit

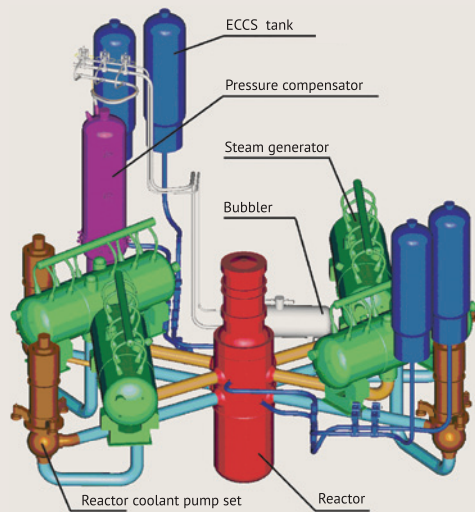
| Characteristics, units of measurement | Value of parameter (characteristic) |
|--|-------------------------------------|
| General parameters of power unit | |
| Rated thermal power of reactor, MW | 3200 |
| Rated electric power, MW | 1198,8 |
| Effective hours of rated power use, hour/year | 8065 |
| NPP lifetime, years | 50 |
| Seismic stability: | |
| Safe shutdown earthquake (SSE), g | 0,25 |
| Operation basis earthquake (OBE), g | 0,12 |
| Number of fuel assemblies in core, pcs. | 163 |
| Time during which fuel is in core, years | 4–5 |
| Basic parameters of the primary circuit | |
| Number of loops of the primary circuit, pcs. | 4 |
| Coolant flow through the reactor, m ³ /h | 85600±2900 |
| Coolant temperature at reactor inlet/outlet, | 298,6/329,7 |
| Nominal steady-state pressure at core outlet (abs.), MPa | 16,2 |
| Basic parameters of the secondary circuit | |
| Turbine: | |
| Rotation frequency, 1/s | 50 |
| Design scheme | 2LPC+HPC±2LPC |
| Nominal steam pressure at turbine inlet, MPa | 6,8 |
| Feedwater temperature under nominal conditions, °C | 225±5 |
| Generator: | |
| Rated voltage, kV | 24 |



Fig. Power unit schematic diagram.

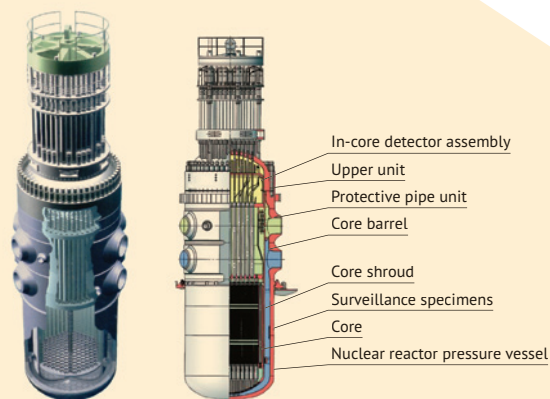
| | | | |
|----|---|----|---|
| 1 | reactor, | 26 | demineralized water storage tank, |
| 2 | steam generator, | 27 | emergency feedwater pump, |
| 3 | RCP, | 28 | containment PHRS condenser, |
| 4 | pressurizer, | 29 | PHRS tank, |
| 5 | ECCS tanks, | 30 | hydroseal, |
| 6 | containment, | 31 | intermediate cooling circuit pump, |
| 7 | outer containment, | 32 | service water pump for important consumers, |
| 8 | sump tank (low concentration borated water inventory), | 33 | service water pump for unimportant consumers, |
| 10 | ECCS heat exchangers, | 34 | spray pond, |
| 11 | low pressure emergency injection pump, | 35 | secondary circuit deaerator, |
| 12 | high pressure emergency injection pump, | 36 | high pressure heater, |
| 13 | high concentration borated water storage tank, | 37 | low pressure heater, |
| 14 | emergency boron injection pump, | 38 | condensate pumps of the 1st step, |
| 15 | chemicals supply tank, | 39 | condensate pumps of the 2nd step, |
| 16 | chemicals injection pump, | 40 | cooling tower, |
| 17 | spray header, | 41 | unit demineralization plant, |
| 18 | passive hydrogen recombiners, | 42 | condensers, |
| 19 | bubbler, | 43 | circulation pumps, |
| 20 | core catcher, | 44 | turbine building consumers, |
| 21 | alkali emergency storage tank, | 45 | low pressure cylinder, |
| 22 | main steam valve unit, | 46 | power supply panel, |
| 23 | ventilation plant for emergency underpressure in the annular space, | 47 | turbine generator, |
| 24 | filter, | 48 | feedwater electric pumps, |
| 25 | ventilation stack, | 49 | auxiliary feedwater electric pumps, |
| | | 50 | grid. |





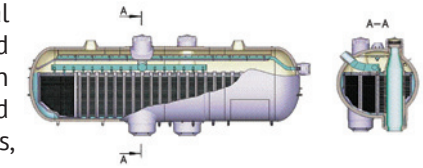
Reactor plant

The reactor is designed to convert fission energy of the nuclear fuel to thermal energy and transfer it to the primary circuit coolant of the two-circuit reactor plant of the power unit. A pressurized water-cooled and water-moderated, thermal neutron reactor of vessel type is used in the design. Vessel-type VVER reactor with nominal thermal power of 3200 MW at coolant pressure of 16.2 MPa; water with boric acid is used as coolant and moderator; the concentration of boric acid changes in the process of operation; slightly enriched uranium dioxide is used as fuel in the reactor core;



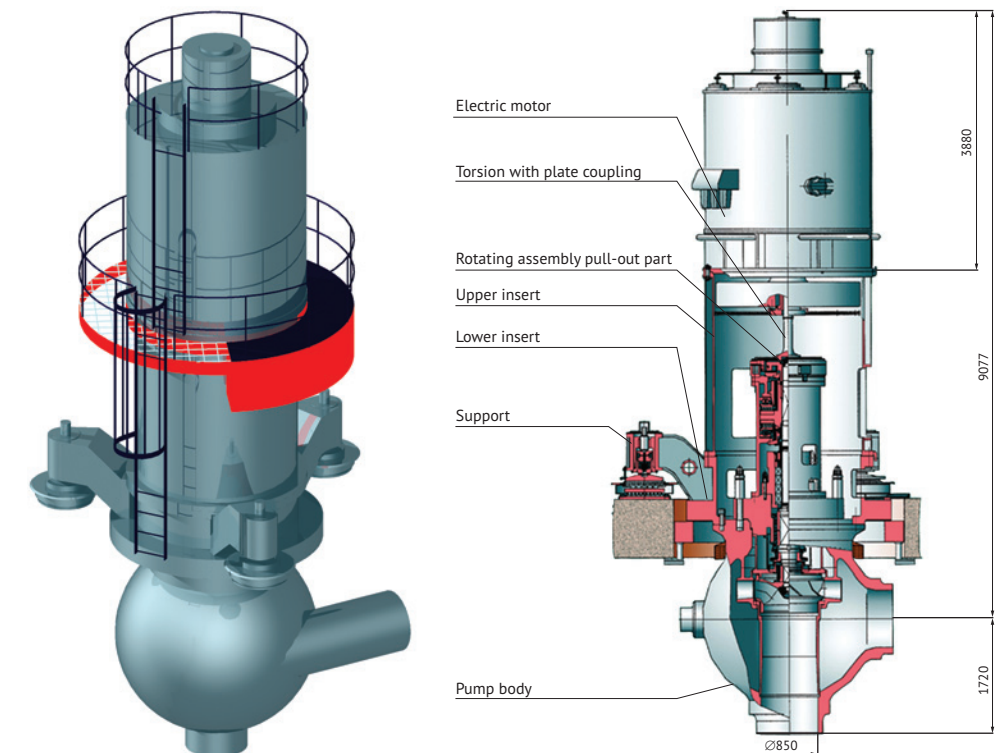
The reactor core consists of 163 fuel assemblies (FA) wherein the absorbing rods of the control and protection system (CPS AR) are located.

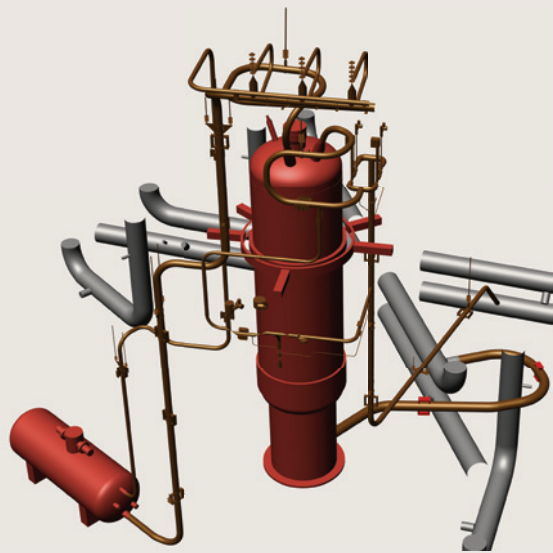
The steam generator is designed for heat removal from the primary coolant and generation of saturated steam. Steam generator of the following type is used in the design: a horizontal one-vessel SG with submerged heat exchange surface made up of horizontal tubes, main and emergency feedwater distribution system, submersible perforated plate and steam header. Four ПГБ-1000МКП horizontal steam generators with rarefied in-line arrangement of heat exchange tubes in the tube bank; capacity of each SG is (1602+112) t/h of dry saturated steam with a pressure of 7.0 MPa;



The reactor coolant pump set (RCPS) is intended for creation of coolant circulation in the primary circuit of the reactor plant.

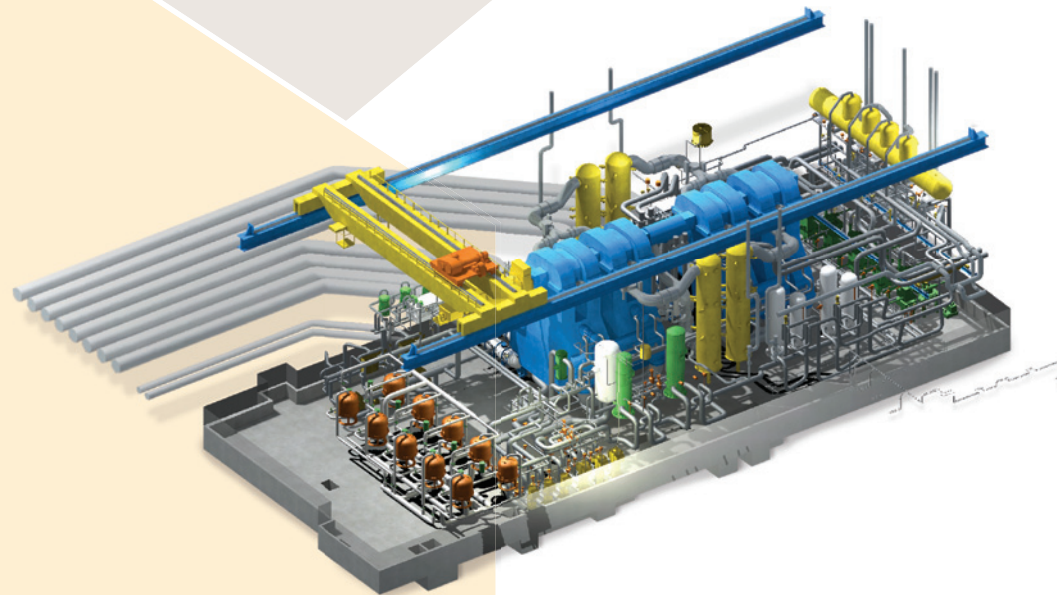
Four ГЦНА-1391 reactor coolant pump sets are used in the design;





Pressurizing system in the primary circuit is intended to limit pressure deviations during power operation and under transient modes, to protect the primary circuit equipment and pipelines against overpressure exceeding the permissible values, as well as to generate pressure in the primary circuit during heat-up and to reduce pressure during RP cooldown.

Steam-turbine plant is intended to convert the potential energy of steam, compressed and heated up to saturation temperature, into kinetic rotation energy of turbine rotor. It includes a steam turbine and auxiliary equipment.



Main auxiliary systems of RP

Primary circuit blowdown-makeup system

Normal operation functions performed by the blowdown-makeup system shall be the following:

- to make up controlled and uncontrolled leakages of the primary circuit;
- to ensure the primary coolant supply for purification at ion-exchange filters of the special water treatment plant and return of the purified coolant to the circuit;
- to ensure chemicals supply to the primary circuit for maintaining of the primary coolant chemical composition;
- to ensure filling of the primary circuit and ECCS tanks, as well as adjustment of boric acid level and concentration in hydrotanks;
- to ensure generation of the shutdown concentration of boric acid in the circuit;
- to ensure cooldown of the pressurizer, when RCP is shut down;
- to ensure degasification of coolant at its removal, during the primary circuit makeup and in course of cooldown.
- to ensure compensation for changes in the coolant volume during heat-up and cooldown of the reactor plant, during power changes and under other modes;
- to ensure testing of the primary circuit system for strength and tightness;
- to ensure the power unit maneuvering modes.

Supporting systems for the primary circuit water chemistry

Primary circuit water chemistry shall ensure the following:

- suppression of radiolysis oxidative products generation during operation at power;
- corrosion resistance of structural materials of equipment and pipelines during the design life of NPP;
- minimization of depositions on the surface of fuel elements of the reactor core and on heat-exchanging surface of steam generators;
- minimization of accumulation of activated corrosion products.

Primary coolant purification system

Primary coolant purification system shall ensure the following:

- removal of radioactive corrosion products of the primary circuit structural materials (disperse form) from the primary coolant;
- removal of dissolved impurities (anionic and cationic forms) from the primary coolant in compliance with the norms requirements.



Primary coolant treatment system

Primary coolant treatment system shall ensure the following:

- treatment of boron-containing water removed from the primary circuit under different operating conditions of NPP with the aim to obtain boron concentrate and pure condensate to be reused in the NPP process cycle;
- treatment of controlled boron-containing drains from systems related to the primary circuit and preparation of boric acid;
- purification of concentrated boric acid solution from the storage tanks of high concentration borated water.

Reactor building equipment drainage system

The system shall fulfill the following basic functions:

- collection of the primary coolant leaks and drains into the controlled leakage tank (with its further return into the reactor coolant system);
- collection of boron-containing leaks and drains into the corresponding collection tank of the Reactor building.

Hydrogen burning system

The basic purpose of the system is the following:

- collection of the hydrogen-containing gaseous media from the equipment of the reactor plant, deaerator, heat exchanger and controlled leakage tank, bubbler tank;
- burning of hydrogen from the gas mixture inflowing under power operation of the unit and under startup and shutdown modes of the unit;
- gas mixture supply from the gaseous medium circulation circuit into the special gas treatment system after hydrogen burning.

Spent fuel pool cooling system

Spent fuel pool cooling system shall be provided with the required degree of system active elements redundancy, taking into account that the system is to operate constantly and certain equipment is to be periodically maintained. The possibility for the spent fuel pool to be dewatered in case of loss of integrity of any system pipeline shall be eliminated. Provisions shall be made for the possibility to adjust water chemistry and maintain the design concentration of boric acid in the spent fuel pool medium under all considered conditions.

Decontamination system

The system shall ensure high decontamination factor, minimum corrosion impact on the structural materials and minimum generation of the radioactive waste, which is achieved by application of the up-to-date low-waste decontamination methods and mobile modular facilities.

Safety systems and systems for beyond design basis accidents (BDBA) overcoming

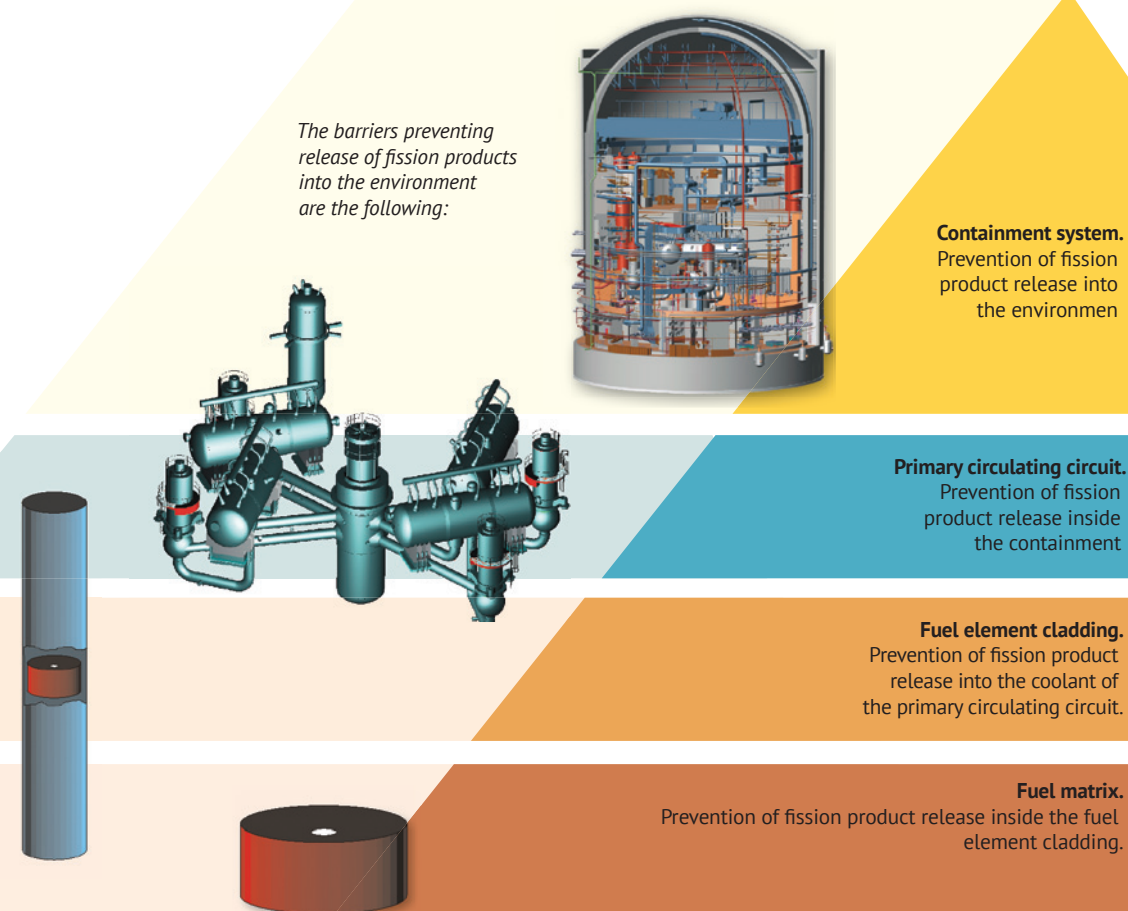
General concept of the NPP safety

Defense in depth principle

In the NPP design safety assurance is based on defense in depth principle – use of barriers system to prevent propagation of ionizing radiation and radioactive substances into the environment, and system of technical and organizational measures on protecting barriers and maintaining their efficiency, and on direct protection of population.

Application of the defense in depth principle allows to fulfill requirement to take into account the possible NPP states in full scope providing reasonable sufficiency of safety measures.

Defense-in-depth



The system of technical and organizational measures

- Level 1:
- conservative design on the basis of applying up-to-date norms;
 - quality assurance at all stages of the NPP construction;
 - condition monitoring of safety barriers during operation;
 - safety culture.
- Level 2:
- control in case of anticipated operational occurrences and detection of failures. This level includes protections and interlocks, standby mechanisms of normal operation, it is provided to ensure continuous integrity of the barriers.
- Level 3:
- protective, control, localization and support safety systems being provided in the design to prevent the failures and personnel errors transformation into Design Basis Accidents and these ones – into Beyond Design Basis Accidents, as well as to retain radioactive product within the localization system.
- Level 4:
- accident management, including protection of localization functions.
- Level 5:
- emergency measures to be realized beyond the site with the purpose of mitigating the consequences of radioactive product release into environment.

Safety systems concept

The NPP safety concept is based on the *active safety systems* provided with both normal power supply and emergency power supply (from diesel-generators).

In order to prevent severe accidents or mitigate their consequences provisions are made for *passive systems*, which operate without interference of NPP personnel and require no electric power supply.

In order to meet the requirements of normative documentation and technical assignment concerning the NPP safety level, the design provides a complex of safety systems and additional hardware for BDBA management

| Design principle | Implementation in the design |
|--------------------------|---|
| Single failure principle | deterministically serves as a basis of all safety systems due to four train structure |
| Passivity | 1. Applied for certain systems/elements of safety systems (e.g. check valve, ECCS hydroaccumulator under nitrogen pressure, rupture disk (relief tank); 2. Passive technical means of BDBA management (SG PHRS, containment PHRS), redundant critical safety system |
| Multitrain | Applied. The design envisages the four train structure of safety systems, including service and control safety systems |
| Diversity | Applied. Redundancy of safety systems as for implementation of main safety functions is fulfilled by the systems using equipment different from safety system and operating principle, if possible. |
| Physical division | Applied. All four safety trains including service and control safety systems are divided by territory, which ensures protection from common cause failure during fire, airplane crash, terrorism. Power unit control rooms (MCR, SCR, EACPC) are also distributed within different rooms/buildings. |

Special feature of technical solutions adopted in AES-2006 design with VVER-1200

The special feature of technical solutions adopted in AES-2006 design with VVER-1200 is that the severe beyond design basis accidents can not be caused by simple overlapping of ranges of single and additional failures.

Conditions during design basis accidents are design conditions for safety systems.

In accordance with the deterministic method of designing hardware aimed at prevention of design basis accidents, the following is taken into account for each design initiating event:

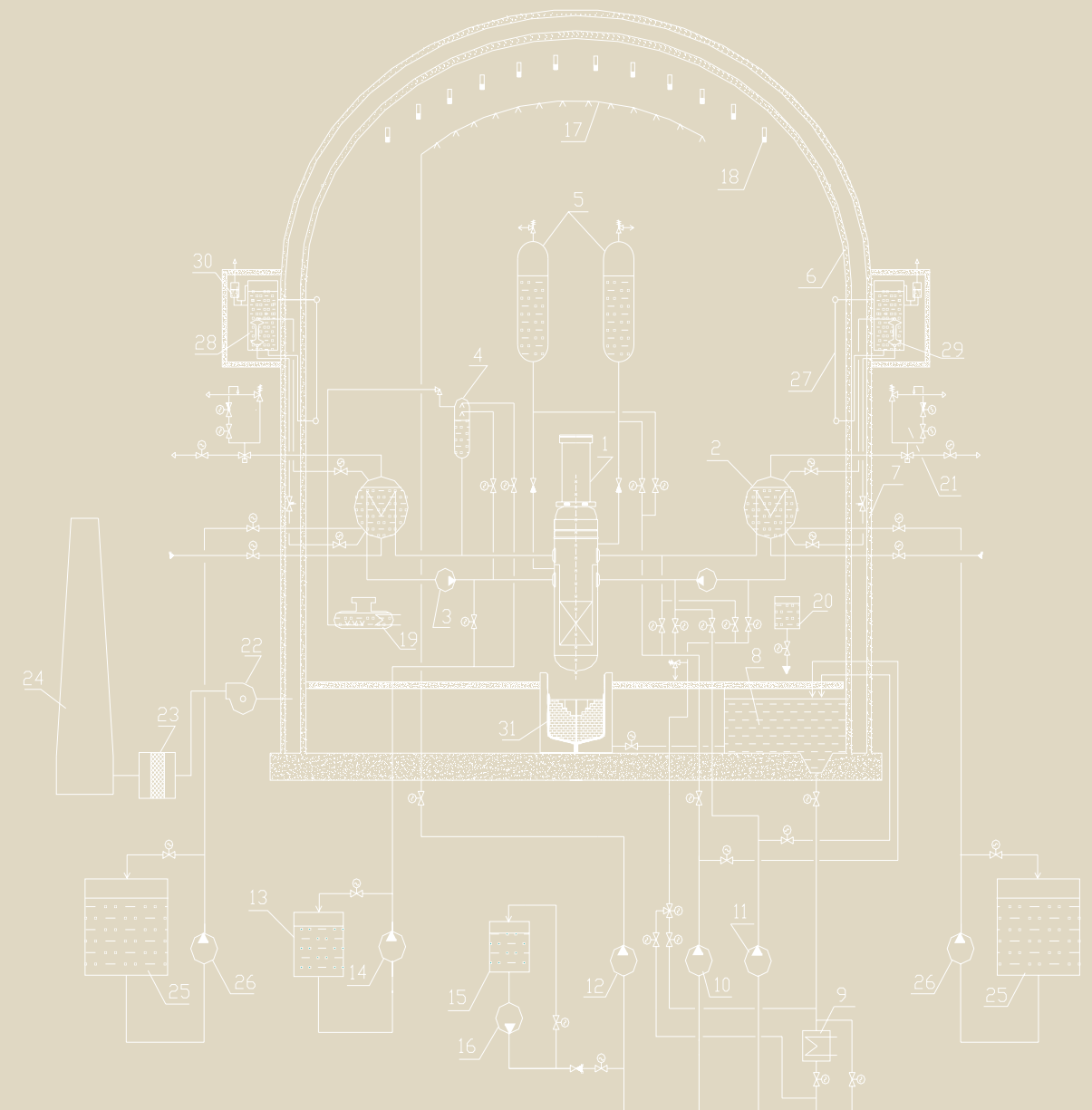
- one human error independent from the initiating event;
- non-detectable failures (which result in breaching normal operation limits) of the elements uncontrolled during operation and influencing the accident progression;
- the selection of initial and boundary conditions that has negative influence on the results.

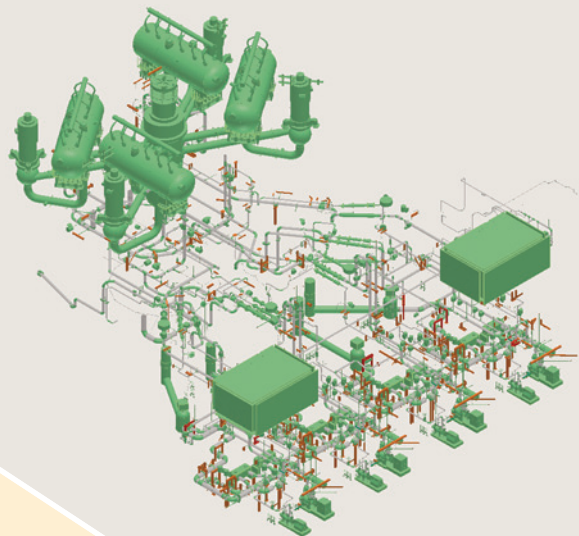


Safety systems structure

Schematic diagram of safety systems and systems for BDBA management in AES-2006

- | | |
|---|--|
| 1 – reactor, | 16 – chemicals injection pump, |
| 2 – steam generator, | 17 – spray header, |
| 3 – RCP, | 18 – passive hydrogen recombiner, |
| 4 – pressurizer, | 19 – bubbler, |
| 5 – ECCS tanks, | 20 – emergency alkali storage tank, |
| 6 – containment, | 21 – main steam valve unit, |
| 7 – outer containment, | 22 – ventilation plant for emergency generation of |
| 8 – sump tank (low concentration borated water | underpressure in the annular space |
| inventory), | 23 – filter, |
| 9 – heat exchangers, | 24 – ventilation stack, |
| 10 – emergency low-pressure injection pump , | 25 – demineralized water storage tank, |
| 11 – emergency high-pressure injection pump | 26 – emergency feedwater pump, |
| 12 – spray pump. | 27 – condenser-heat exchanger of Containment PHRS, |
| 13 – high concentration borated water storage tank, | 28 – emergency heat removal tank of PHRS, |
| 14 – emergency boron injection pump, | 29 – heat exchanger of SG PHRS, |
| 15 – chemicals supply tank, | 30 – hydroseal, |
| | 31 – core catcher. |





Protective safety systems

High pressure safety injection system

– The high pressure safety injection system is aimed at supplying boric acid solution into the reactor coolant system during LOCA, exceeding the compensation capacity of the normal makeup system at coolant system pressure below working parameters of the system (less than 7.9 MPa).

Besides, part of pipelines and equipment of the system constitutes a barrier preventing radioactivity release beyond the containment.

Low pressure safety injection system –

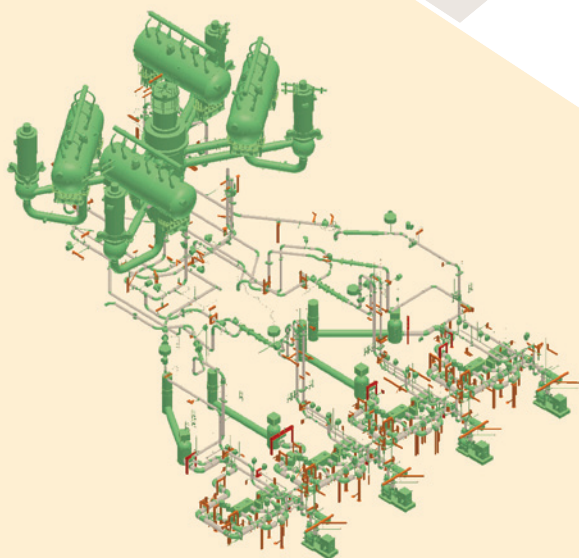
Low pressure safety injection system is aimed at boric acid solution supply into the reactor coolant system during LOCA, including break of the primary circulation circuit Dnom 850, when the coolant system pressure drops below working parameters of the system.

Primary circuit overpressure protection system

The primary circuit overpressure protection system is intended for protection of equipment and pipelines of the reactor plant from excessive overpressure in the primary circuit under design conditions of categories 2-4 and BDBA due to operation of the pilot operated relief valve of a pressurizer, installed at the pipeline of steam discharge from the steam volume of pressurizer into a relief tank.

Secondary circuit overpressure protection system

The secondary circuit overpressure protection system is intended to prevent overpressure in steam generators and main steam lines over admissible parameters.



Emergency gas removal system

The emergency gas removal system is intended to remove the steam-gas mixture from the primary circuit of the reactor plant (reactor, pressurizer and SG collectors) and decrease primary pressure along with the pilot-operated safety valve of a pressurizer in order to eliminate the consequences of design and beyond design basis accidents.

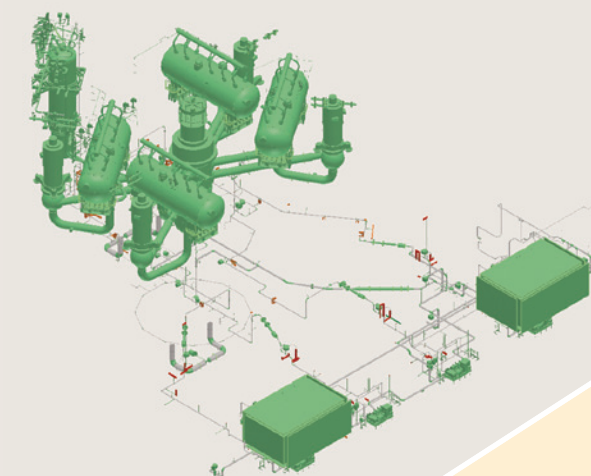
Emergency boron injection system

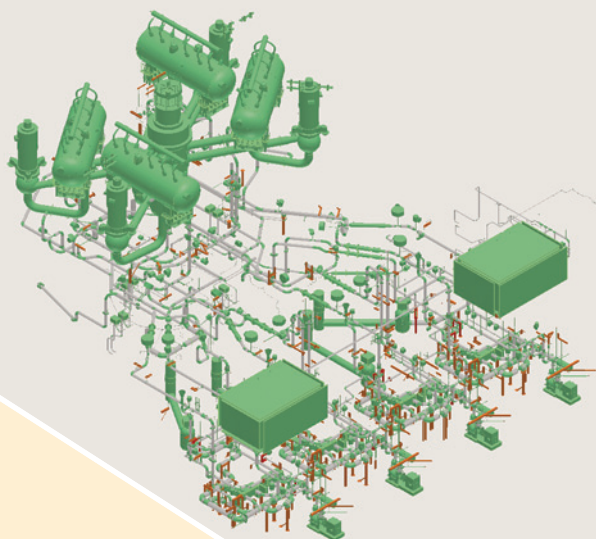
The emergency boron injection system is aimed to fulfill the following functions:

- boric acid injection into the pressurizer during accidents with primary-to-secondary leaks;
- high concentrated boric acid solution (40 gH3BO3/kgH2O) supply into the primary circuit for quick transfer of the reactor plant into subcriticality under anticipated operational occurrences attended by scram failure;
- bringing the reactor plant into subcritical state and compensating primary coolant volume reduction to ensure safe shutdown of the Unit.

Emergency feedwater system

The emergency feedwater system is intended to provide steam generators with feed water under anticipated operational occurrences and design basis accidents, when feedwater supply from regular system and auxiliary system is impossible. The system shall operate during initiating events associated with the decrease of water level in steam generators and requiring emergency cool-down or maintenance of hot standby condition of the power unit.





Borated water storage system

JNK system is aimed for storing of borated water with low ($16\text{g H}_3\text{BO}_3/\text{kr H}_2\text{O}$) and high ($40\text{g H}_3\text{BO}_3/\text{kr H}_2\text{O}$) boric acid concentration that is needed for all NPP operation conditions.

Residual heat removal system

The residual heat removal system is intended to remove residual heat and to cool down the Reactor plant during NPP normal shutdown, in the event of anticipated operational occurrences as well as design basis accidents, provided that the primary circuit and the low pressure safety injection system integrity is maintained.

Also the residual heat removal system is aimed for protection of the primary circuit from superpressure under the conditions of cooldown and residual heat removal in case of low temperatures of the primary circuit.

System of emergency use of water from reactor internals inspection shaft

The system of emergency use of water from reactor internals inspection shaft is employed for:

- borated water supply from the reactor internals inspection shaft to the core catcher during beyond-design basis accidents which involve melting of the reactor's core and corium leaks outside the reactor's pressure vessel;
- filling of heat exchangers of core catcher room with water from sump tanks during DBA attended by loss of coolant from elev. 0.00 and BDBA with core melt;
- alkali NaOH solution supply into the containment sump tanks with the view to decrease the generation rate of the volatile iodine forms inside the containment;
- filling and draining of RI inspection shaft during the operations, which involve refueling and RI inspection;
- removal of all possible leaks from the reactor cavity (core catcher room).

Steam main isolation system

The steam main isolation system is intended to operate under all emergency conditions, requiring SG isolation.

Localizing safety systems

Localizing systems are intended to prevent or limit the distribution of radioactive substances, escaping during an accident, inside NPP and their release into the environment.

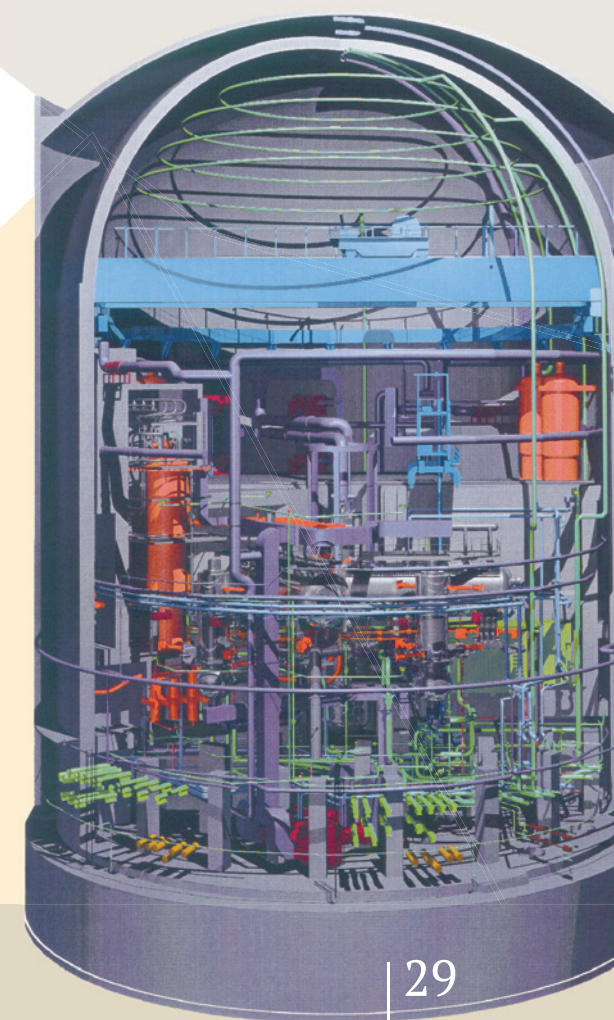
Double containment

Inner containment represents a cylindrical structure from a prestressed ferroconcrete with a hemispherical dome and foundation plate made of reinforced concrete. The inner surface of the containment is lined with welded carbon steel to ensure tightness.

The outer containment represents a cylindrical structure made of ferroconcrete with a hemispherical dome.

NPP design excludes physical phenomena associated with severe accidents, which can threaten the containment integrity, i.e.:

- steam explosion in the reactor pressure vessel;
- hydrogen detonation;
- recurrent criticality of the core or core melt;
- steam explosions beyond the reactor pressure vessel;
- direct containment heating;
- flying objects;
- molten core impact onto the floor and walls of the under-reactor space.



Hermetic steel liner

The purpose of the containment is as follows: to prevent radioactivity release into the environment in case of Maximum design basis accident, limit the releases in case of beyond design basis accidents, as well as protect the equipment and internal structures in the Reactor building from possible external impacts.

As a leak-proof element the design provides a carbon steel lining along the internal surface of the inner prestressed containment.

Ferroconcrete enclosing structures

The inner containment is a prestressed reinforced concrete structure, consisting of a cylindrical part and a hemispherical dome.

The outer containment is made of cast-in-situ reinforced concrete without prestress. The containment consists of cylindrical part with inner diameter 50 m and hemispherical dome, on which the Passive heat removal system tanks are located.

Embedded parts

For fixing of process, electric and other equipment to the internal surface of the inner containment the installation of embedded parts is envisaged.

Penetrations

All pipeline electric and instrumentation penetrations going through the containment are embedded into the wall of the inner prestressed containment.

Manholes, locks, doors and their embedded parts

In order to provide transportation of equipment through the hermetic enclosure and to preserve the containment integrity a special transfer floor is envisaged, the integral part of which are the manhole and hermetic gate from the outdoor side.

The containment is equipped with locks in order to provide passage of service personnel through the accident localization area and preserve its tightness. Two locks are provided: main and emergency one. Besides using the main lock for service personnel, it can be used to transport small-size equipment into the containment

Isolating devices

Isolating devices are intended to isolate pipelines with different process media going through the border of the containment in order to prevent the fission product releases as the result of a loss-of-coolant accident of the primary circuit.

Spray system

The spray system is designed for reduction of pressure and temperature in the accident localization area (ALA) with simultaneous fixing of radioactive iodine in the airspace of ALA during DBA in order to limit the radioactive products release into the environment through systems and elements of hermetic enclosure.



Supporting systems

Emergency power supply system (EPSS)

The Emergency power supply system of the Power Unit (EPSS) is aimed at electric power supply of the consumers of the safety systems, support safety systems of the Unit, systems controlling and monitoring the specified systems, including sensors of the reactor plant control system.

Service water supply system of safety systems

The intermediate cooling circuit for important consumers is designed to supply cooling water and remove heat from the reactor plant equipment, the reactor plant auxiliary systems and the NPP safety systems in the normal operating conditions, during anticipated operational occurrences and design basis accidents, as well as to provide for the barrier between the auxiliary systems, containing radioactivity, and the service water system for important consumers.

Cooling water system for important consumers is intended to fulfill the functions of heat removal to the ultimate heat sink from the system consumers located in the safety building under all Power Unit operation conditions, including emergency ones.

Passive fire protection system

The passive fire protection system of fire zones is applied for the following tasks:

- exclude simultaneous fire impact on equipment and elements of the main and standby variants of safe shutdown and cooldown of the reactor plant and thus ensure that these systems fulfill the design functions during and after the fire;
- if necessary, provide for localization and control of radioactive releases into the environment during fire;
- protect personnel/population from exceeding the set radiation doses.

Supporting ventilation systems

The plenum-and-exhaust ventilation system is intended to form air exchange and maintain the required temperature limits of inner air in the rooms of 1, 2, 3, 4 safety trains.

Exhaust ventilation system is intended to remove air from rooms of accumulator batteries of safety trains 1, 2, 3, 4.

The chilling medium supply system is intended to cool the plenum air of the ventilation systems.

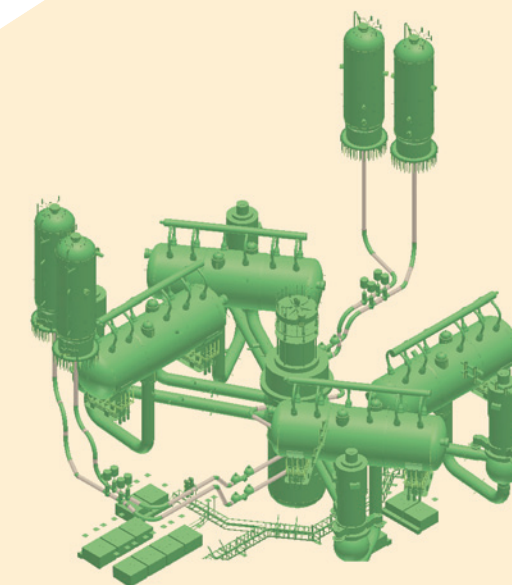
Life-supporting systems of MCR and SCR

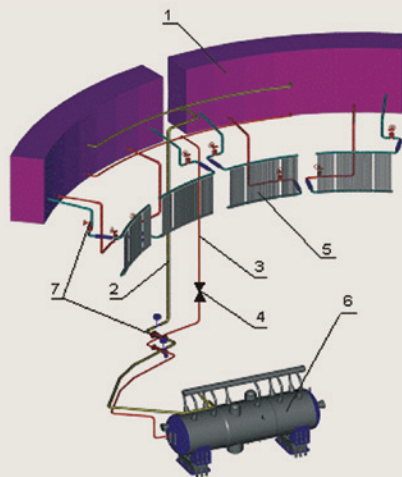
Life-supporting systems include process systems, additional equipment, supply and instructions envisaged at NPP to form safe normal conditions for operators to control the Power Unit, as well as to keep it in a safe state in case of extreme site conditions and emergency operating conditions, including accidents with loss of integrity of the primary circuit.

Control safety systems

Control safety systems are designed for initiating of the safety systems operation, for control and monitoring of their operation.

According to the defense-in-depth concept the design envisages safety systems intended for fulfillment of safety functions under the conditions of failure or design basis accident.





- 1 – Emergency heat removal tanks
- 2 – Steam lines
- 3 – Condensate pipelines
- 4 – PHRS-SG valves
- 5 – Heat exchangers of Containment PHRS
- 6 – Steam generator
- 7 – Cutoff valves

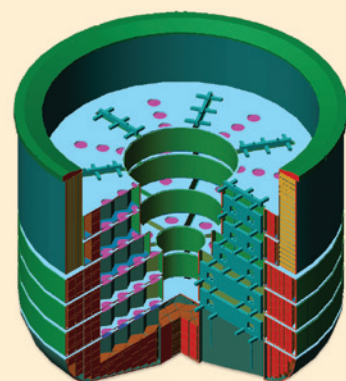
Passive safety systems

System of passive heat removal from containment

The system of passive heat removal from containment refers to technical means of BDBA overcoming and is intended for continuous (no less than 24 hours in autonomous operation) heat removal from the containment during BDBA.

System of passive heat removal through steam-generators

The system of passive heat removal through steam-generators is designed for continuous residual heat removal of the core to the ultimate heat sink through the secondary circuit during BDBA. The system doubles the corresponding active system of heat removal to the ultimate heat sink in case the system fails to fulfill its design functions.



Corium localization system

The corium localization system (or core catcher) is one of the technical means specially envisaged to manage severe beyond design basis accidents at the off-vessel stage. The core catcher performs intake, placement and cooldown of the molten materials of the core, reactor internals and reactor pressure vessel up to complete crystallization.

Containment hydrogen removal system ensures:

Under design basis accidents the system maintains hydrogen concentration in water steam and air mixture lower than the concentration limits of the flame propagation within the design range of medium parameters changing in the under-containment compartments.

Under design basis accidents the system maintains hydrogen concentration at levels excluding a hydrogen detonation and rapid combustion progress in large spaces (comparable with dimensions of the containment main compartments).

The hydrogen removal system equipment includes a set of passive autocatalytic hydrogen recombiners and a stand for inspection sampling tests.



Volatile iodine chemical fixation system

Means of emergency pressure reduction in the primary circuit

Ventilation system of keeping underpressure in the annulus space



Process instrumentation and control system (Process I&C)

Main design approaches realized in NPP I&C design

NPP instrumentation and control system (NPP I&C) is intended for control and monitoring of the main and auxiliary processes and provision of safety in all Power Unit operation conditions, during anticipated operational occurrences and accidents.

The accepted technical solutions meet the requirements of active normative-technical documents of the Russian Federation and approaches used in Russia and all over the world.

In NPP I&C design the following approaches have been realized:

- While elaborating the control safety system the following principles were taken into account as per the documents of RF Gosatomnadzor and IAEA recommendations: single failure, common cause failure, redundancy, physical separation, independence, variety, safe failure.
- NPP I&C is built as a system open for further improvement and expansion on all its levels, due to the system's protocols corresponding to international standards, unification of interfaces and module structure of I&C system soft- and hardware.
- Hardware applied in NPP I&C includes advanced self-diagnostics means, which allows significant improving NPP I&C availability and the NPP as a whole.
- NPP I&C is built on the basis of modern computer-based hardware.
- Application of modern engineering means on the basis of high-performance software-hardware engineering complex allowed reaching the highest quality of I&C design.
- According to the safety requirements NPP I&C has a physical and functional separation between safety I&C and operational I&C.
- To reduce the probability of Safety I&C common cause failure through fault of software component of I&C means, the diverse subtrain based on conventional I&C means with hard-wired logic is applied.
- In order to provide the operative personnel with all required information, the design provides for a wide application of display control desks in combination with application of principles of hierarchical and functionally oriented information displaying.

With the aim to enhance the NPP I&C availability, provisions are made in the design for keeping conventional mosaic control panels and individual monitoring and control means for safety systems.

I&C hierarchical structure

NPP I&C has a three-level hierarchical structure:

- **Lower level** (level of monitoring, control and protection);
- **Unit level** which realizes informational, controlling and calculation tasks as well as archiving of data related with power unit as a whole;
- **Plant level** which realizes common (for all power units of NPP) functions, monitoring and control for general-plant systems.

Concept of three-level hierarchy is realized as «informational pyramid» where maximum information is processed at the lower levels. The information is transferred to the upper levels aggregatively that allows ensuring optimal distribution of automation functions realized by the system.

The Main I&C comprises the following I&C subsystems:

- Instrumentation and control system of Safety Systems (safety I&C);
- Instrumentation and control system of Normal Operation (NO I&C);
- Normal Operation safety-related I&C;
- Complex of electrical equipment of control and protection system (EC CPS);
- Reactor plant monitoring, control and diagnostics System (MCDS);
- Main process equipment diagnostics system;
- Automated radiation monitoring system (ARMS);
- Automated chemical monitoring system (ACMS);
- Fire protection control system (FP CS);
- Anti-seismic protection system (ASPS).



Hierarchical structure of Normal Operation I&C

Normal Operation I&C system (NO I&C)

NO I&C and NO safety-related I&C consist of hardware, which realizes automation functions of main process and specialized sub-systems of I&C performing the local automation tasks, as well as informational and diagnostics functions. Integration of all I&C subsystems into the uniform plant I&C is made by means of a high-capacity network.

Architecture of I&C has several sub-levels extending two main levels of Main I&C:

upper level:

lower level

process control level

communication level

information processing level

communication level

automation level

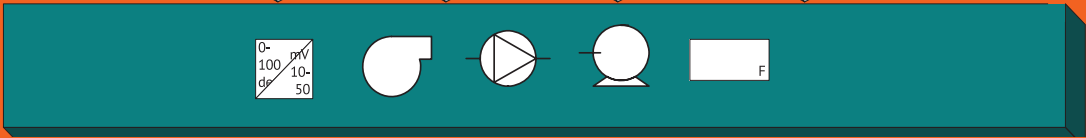
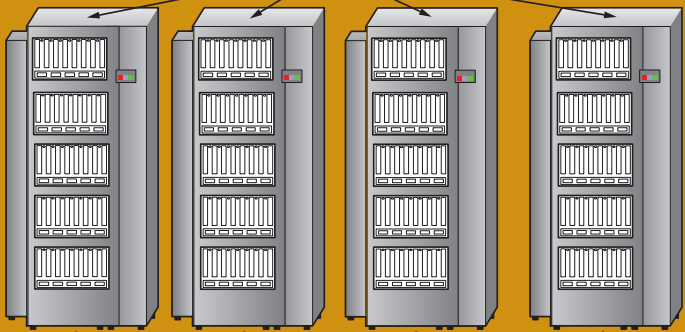
individual control level

process level (sensors and actuators)

Conventional controls



Included in Safety I&C



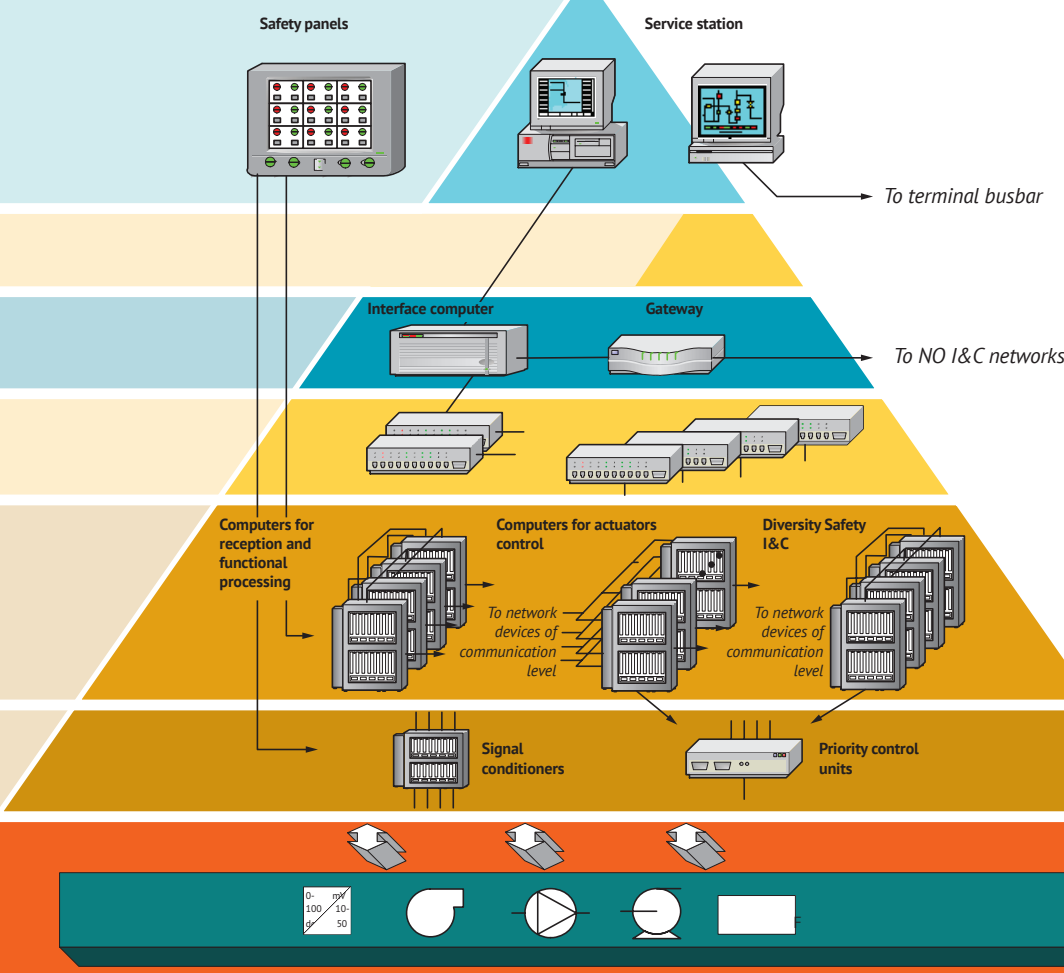
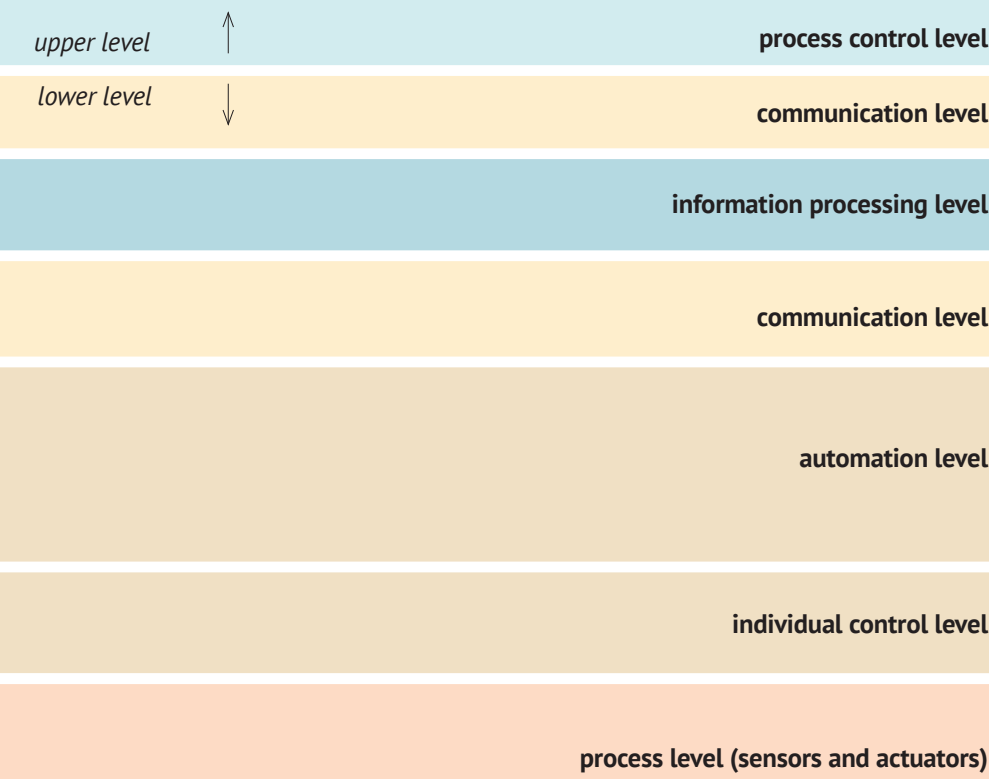
Safety I&C Hierarchical Structure

Safety I&C system

Safety I&C system applies a principle of integration into a single system of functions of reactor protection and of process safety systems' control.

According to the process splitting the control safety systems have a four-train structure. Diversity principle is realized by means of functional and hardware diversity. Application of the diversity sub-train created basing on traditional I&C means with a «strict logic» allowed sharp decreasing of a possibility of safety I&C hardware failure caused by software faults.

Architecture of Safety I&C has several sub-levels extending two main levels of Main I&C:



NPP Electrical part

NPP Electrical system description

NPP electrical systems consist of power production and supply into the power system and auxiliary power supply systems.

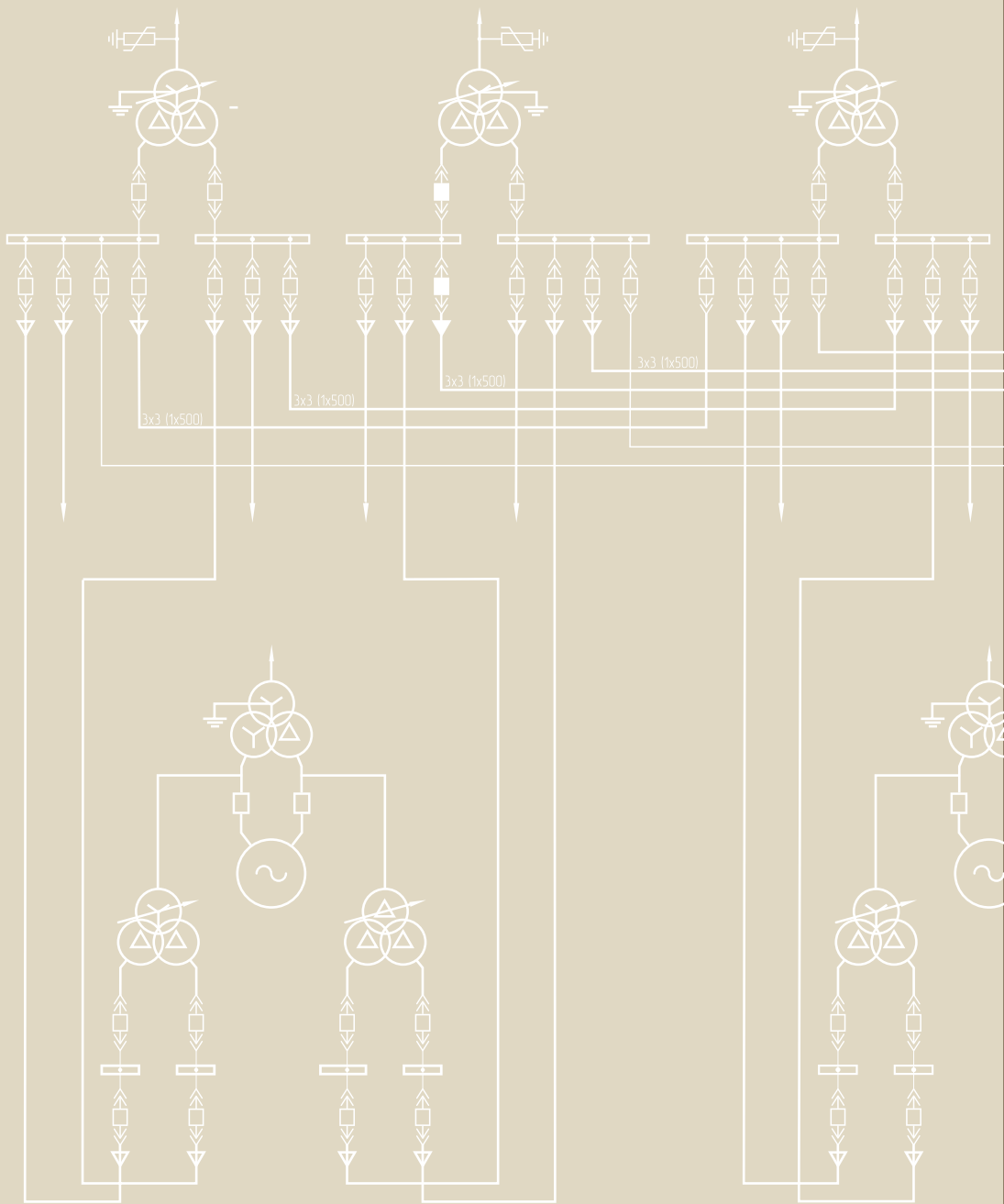
The system of power production and supply realizes the plant power supply into the power lines of the power system, operating and standby power supply of the auxiliary system. The system includes generators, step-up transformers, generators voltage path equipment, high-voltage switchgears, operating, standby and general auxiliary transformers, coupling autotransformer.

Schematic electric diagram of Power Units 1-2 of Leningrad NPP-2.

Auxiliary system of the power unit

The auxiliary system of the power unit supplies power for normal operation process systems and systems important for safety, including safety system, reactor and turbine plant and generator set control and monitoring systems (classes 4H, 3H and 2O), ensuring the following:

- operation under normal operation conditions;
- cooldown and transfer of the reactor into safe subcritical state, maintaining it in this state under normal operation conditions, during emergency situations, accidents, as well as BDBA management;
- reactor plant condition monitoring and necessary control, monitoring of main safety functions performance in case of loss of all external power sources (operational and standby ones) and diesel generators failure;
- preservation of main equipment in case of loss of operational and standby power sources.



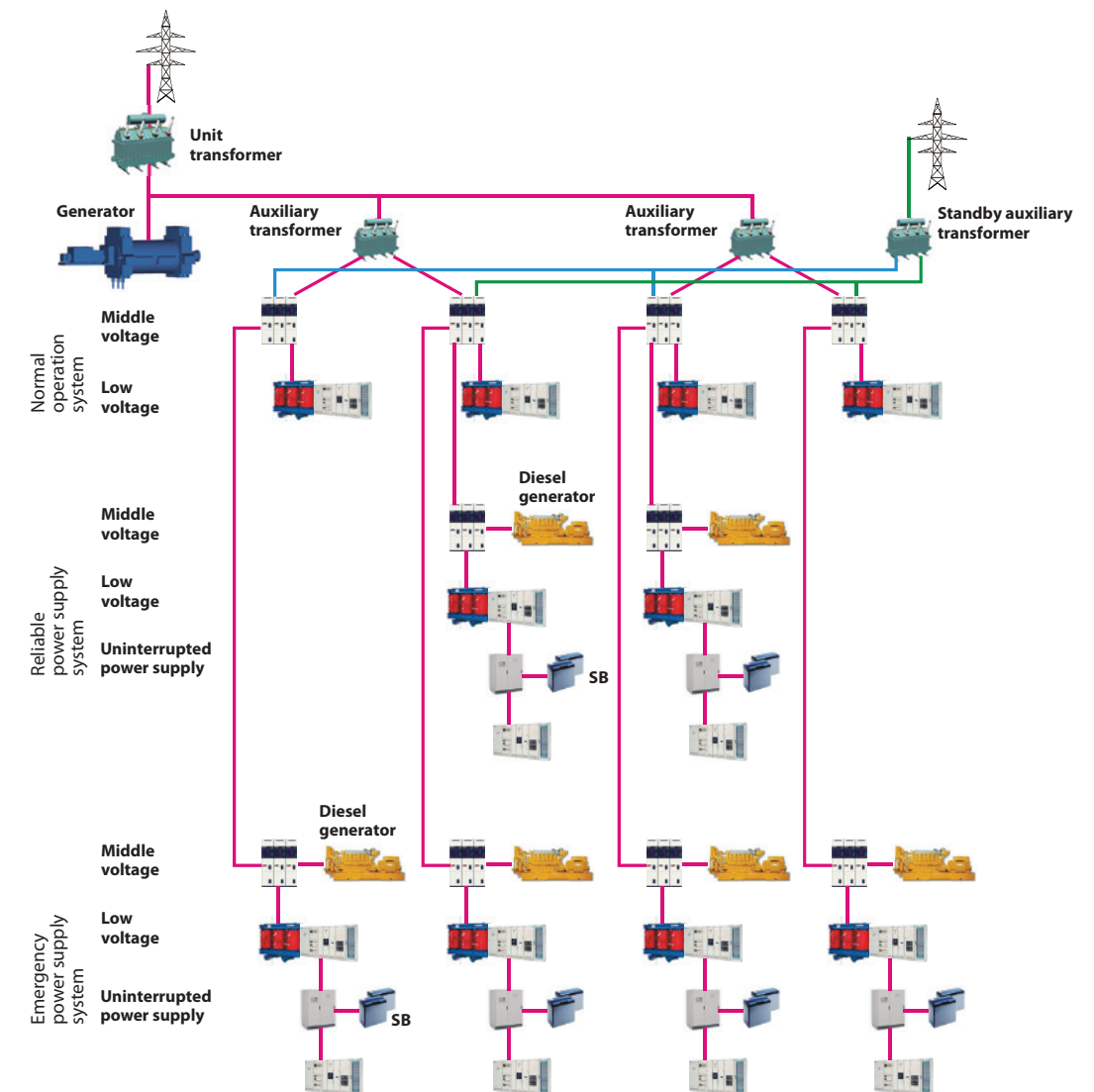
Auxiliary system of the power unit

According to the main solutions applied in the process part, concerning the division of active process systems important for safety into four trains (each of these trains doubles another in equipment and fulfilled function); similar division into four trains is performed in the emergency power supply system.

The power supply system structure is defined by the requirements for power supply from the NO process systems, safety-related systems, safety systems, according to which the auxiliary consumers are divided into the following groups as per fail-safe power supply:

- first group - AC and DC power consumers, due to safety conditions not allowing supply breaks for more than a fraction of a second in all conditions including total collapse of voltage from operational and standby sources of external power supply, and requiring obligatory presence of voltage after reactor emergency protection actuation;
- second group - AC consumers allowing breaks in power supply for the period defined by safety conditions and integrity of the main equipment, requiring obligatory presence of voltage after reactor emergency protection actuation;
- third group - consumers for which there are no special requirements for power supply, allowing breaks for the period of Automatic Switch-over to Backup and not requiring power after emergency protection actuation.

Auxiliary schematic diagram



Ecological safety

AES-2006 design is executed according to the requirements of nature conservation legislation and normative documents valid in Russia, and taking into consideration IAEA recommendations.

The natural and ecological characteristics are considered for the priority construction site, taking into account operating Leningrad NPP, industrial objects of the location area, social-economical and health conditions for population.



III. AES-2006 design implementation

Leningrad NPP-2

Leningrad NPP-2 is a head nuclear power plant of AES-2006 series with VVER-1200 reactor.

The object is located on the shore of the Koporye Bay of the Gulf of Finland of the Baltic sea, about 80 km from St. Petersburg.

The Leningrad NPP-2 project is included into the Long-term Program of Rosatom State Nuclear Energy Corporation.

The ceremony of breaking ground for the future Leningrad NPP-2 was held on August 30th, 2007.

Leningrad NPP-2 is the result of evolutionary development of the most widespread and, as a consequence, the most technically perfect type of plant - NPP with VVER (Pressurized water reactor). The coolant and neutron moderator in such a reactor is light (regular) water. The world-known abbreviation for such reactors is PWR – pressurized water reactor.

Leningrad NPP-2 design corresponds to all up-to-date international safety requirements. The design envisages four active trains (doubling each other) of safety systems, core catcher, passive heat removal system from the containment and passive heat removal system from steam generators. None of operating plants is equipped with similar configuration of safety systems.

Electrical power of each Power Unit is defined as 1198.8 MW, heating power - 250 Gcal/h. The designed service life of Leningrad NPP-2 - 50 years, of main equipment - 60 years.



Belarus NPP

In 2007 JSC SPbAEP (now – JSC Leading Institute VNIPIET Branch) and the Joint Institute for Power and Nuclear Research - Sosny signed agreement No. 2475/KONS for advisory services concerning the issues of NPP arrangement and design. Besides, in 2007 agreement No.249/KONS was signed for advisory services concerning materials investigation on the sites for NPP, considered on the territory of Belarus.

After a series of consultations with specialized organizations the Belarus party selected and agreed a site for NPP in Astravyets district, Grodno region.

In 2009 CJSC ASE and JSC SPbAEP signed an agreement on elaboration of some sections of justification of investments into construction of Belarus NPP. These sections describe the main process, architectural and engineering solutions, physical protection issues, NPP structure, and working conditions at NPP. Other sections, including Environmental Impact Report are fulfilled by the Belarusian specialists with our advisory support.

Within the framework of Addendum No.1 to agreement for justification of investments Technical Assignment for NPP in Belarus Republic was developed. This assignment was developed taking into account application of a low speed turbine (by Alstom company) and shopfloor control structure of NPP.

28.05.2009 the RF Government and the Belarus Government concluded Agreement on collaboration in the field of nuclear energy peaceful use.

March 15th, 2011 during the meeting of the Council of Ministers of allied states of Russia and Belarus under the chairmanship of governments of two countries the Intergovernmental Agreement was concluded on collaboration of Russia and Belarus in NPP construction on the territory of Belarus, according to which Rosatom State Corporation is defined as a competent authority from the Russian Party, and the Ministry of Energy from the Belarus Party. The Belarus customer is the State enterprise «Directorate for Nuclear Power Plant Construction», controlled by Nuclear Energy Department of the Belarus Ministry of Energy.

31.05.2012 according to the working documentation of design phase 1, issued by JSC SPbAEP, the foundation pit of NPP was started.

10.10.2012 JSC NIAEP and JSC SPbAEP concluded a contract for development of Design documentation for Belarus NPP.

Project AES-2006 is also a basic project for NPP Hanhikivi-1 which will be constructed in Finland according to the contract between Rosatom and Finnish consortium Fennovoima.



The Joint Stock Company “East-European leading scientific research and design institute for energy technologies” (JSC “Leading Institute VNIPIET”) - is the only company in Russia designing NPP with different types of reactors: VVER (Pressurized water reactor), BN (fast reactor) and RBMK (high-power channel-type reactor), as well as thermal power engineering projects.

By now in Russia and other countries 118 power stations, including 18 nuclear power plants, have been built as per Leading Institute VNIPIET design or with its participation. Geography of the projects includes 19 countries.


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