MINISTRY OF ENERGY OF THE REPUBLIC OF BELARUS

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DESIGN SCIENTIFIC AND RESEARCH REPUBLICAN UNITARY ENTERPRISE

VALIDATION OF INVESTMENTS IN THE NUCLEAR POWER PLANT CONSTRUCTION IN THE REPUBLIC OF BELARUS

BOOK 11

ENVIRONMENTAL IMPACT ASSESSMENT

1588-ПЗ-ОИ4

PART 8

EIA REPORT

Part 8.1. NPP Description

EXPLANATORY NOTE

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Project components

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1	1588–ПЗ–ОИ4	Initial data preparation	
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2	14444-01	Power delivery to the energy system,	
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3	09-042	Off-site water supply and drainage system,	
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4	82/09-ОИ	External communications, Giprosvyaz	
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Contents

1 TERMS AND DEFINITIONS

EP (emergency protection) is the safety function providing quick transition of the reactor to the subcritical condition and keeping it in this condition; the set of safety systems implementing the emergency protection function.

Beyond design basis accident, or **anticipated accident**, is an accident caused by the initiating events not considered for the design basis accidents, or accompanied by additional (in comparison with the design basis accident) failures of safety systems beyond the single failure, or accompanied by the implementation of personnel's wrong decisions.

Design basis accident is an accident for which the initiating events and final conditions are determined and the safety systems are provided in the design, and these safety systems provide that the accident consequences are kept within the limits specified for such accidents, taking into consideration the safety system's single failure principle or the principle of a single personnel error that does not related to the initiating event.

Core is a part of the reactor that accommodates the nuclear fuel, moderator, absorber, coolant, reactivity control means and structural components intended to implement the controlled nuclear chain fission reaction and the energy transfer to the coolant.

Activity (A) is a measure of radioactivity of some amount of the radionuclide being in the particular energy state at the particular time instant: A= dN/dt, where dN is the expected number of spontaneous nuclear transformations from the existing energy state that take place during a period of time (dt). In SI, the activity unit is a reciprocal second (s^{-1}) called Becquerel (Bq). The off-system activity unit, curie (Ci), that was in use earlier, is $3{,}7\times10^{10}$ Bq.

Alpha radiation is a type of ionizing radiation consisting of a flow of positively charged particles (alpha particles) emitted during radioactive decay and nuclear reactions.

Alpha particle is a positively charged particle emitted from the atomic nucleus during the radioactive decay. Alpha particles are helium nuclei that contain two protons and two neutrons.

Annihilation is an interaction between an elementary particle and antiparticle; as a result, both particles disappear, and their energy is transformed to the electromagnetic radiation.

Antiparticle is an elementary particle identical to its “twin”, i.e. the normal particle, in terms of weight, lifetime and other characteristics, but having a different sign of the electrical charge, magnetic moment and some other characteristics.

NP is a nuclear plant.

ARSMS is an automated radiation situation monitoring system.

Atom is the smallest particle of a chemical element carrying its chemical properties. The atom consists of a positively-charged atomic nucleus and negatively-charged electrons moving in the nucleus' Coulomb field according to the laws of quantum mechanics.

Atomic mass is a weight of chemical element's atom expressed in atomic mass units (a.m.u.). 1 a.m.u. is 1/12 of the mass of carbon isotope with the atomic mass equal to 12. 1 a.m.u. =1,6605655×10^{-27} kg.

Nuclear power plant (NPP) is a nuclear plant for electric and thermal energy production in specified modes and application conditions, situated in a particular area where the nuclear reactor(s) and the set of systems, devices, equipment and facilities, necessary for the reactor(s) operation, are in use for this purpose.

Atomic power, see **Nuclear power**.

Atomic nucleus is a positively charged central part of an atom, around which the electrons are rotating and that contains almost all weight of an atom. It consists of protons and neutrons.

Nuclear ship is a generic name of ships with nuclear propulsion units.

Basic load is a part of the electric energy demand that is constant and does not vary during 24 hours; it is approximately equal to the minimum daily load.

Becquerel (Bq) is a unit of activity of radioactive isotopes in SI, named after Anry Becquerel, the French physicists. 1 Bq corresponds to one decay per second.

Nuclear safety and radiation safety of a nuclear power plant (hereinafter referred to as a nuclear power plant safety) is the nuclear power plant's capability to keep the radiation impact on the personnel, population and environment within the prescribed limits during normal operation and in case of normal operation violations, including accidents.

Beta-particle is a particle emitted from the atom during the radioactive decay. Beta-particles can be electrons (with negative charges) or positrons.

Biological protection is a set of structures and materials surrounding the nuclear reactor and its units, intended to reduce the radioactive radiation to biologically safe level. The biological protection is a barrier designed to prevent or limit the radiation impact on the personnel during normal operation and in case of normal operation violations, including the designed basis accidents. The main material of biological protection is a concrete; metals are also good absorbing protective materials.

Radioactive wastes bituminization is a process of liquid concentrated or dry radioactive wastes hardening by mixing them with fused bitumen and thermal dehydration of the resulted mixture.

Nuclear power plant unit is a part of a nuclear power plant, including a nuclear reactor with generating and other equipment, providing functions of the nuclear power plant within the scope determined by the project.

FN is a fast-neutron reactor, in which the first and second circuits use sodium as a coolant, and the third circuit uses water and steam. In Russia, FN reactors are in operation at the Beloyarsk NPP.

Boric campaign is a period of WWER reactor operation between two consecutive refueling procedures (until the time when boric acid concentration in the coolant of the first circuit becomes zero).

Breeder, see **Breeder reactor**.

Fast neutrons are neutrons with kinetic energy exceeding some specified level. This level can vary widely, depending on the application (reactors' physics, protection or dosimetry). In reactors' physics, this value is usually assumed to be 0.1 MeV.

Rem (roentgen-equivalent-man) is an off-system unit of an equivalent dose. 1 Rem= 0,01 Sievert.

PSA is a probabilistic safety analysis.

Commissioning is a process when the constructed NPP's systems and components are brought into operable condition, and their correspondence to the NPP project is assessed.

WWER (water-water energetic reactor) is a pressurized-water reactor where water is used as a coolant and a moderator. This is the most common type of reactors in Russian NPPs, with two modifications, WWER-440 and WWER-1000.

External exposure is a body exposure by the sources of ionizing radiation that are outside the body.

Internal exposure is a body exposure by the sources of ionizing radiation that are inside the body or have penetrated into the body.

Heavy water (D_2O) is a type of water in which the common hydrogen (H) is replaced by its heavy isotope, the deuterium (D).

Environmental impact is the single-shot, periodic or continuous process resulting in negative changes in the environment.

Fertile material is a material containing one or several fertile nuclides that can transform, directly or indirectly, into the fissile nuclides by neutron capture (uranium–238 and thorium–232).

Secondary nuclear fuel includes plutonium–239 and uranium–233 obtained in nuclear reactors from uranium–238 and thorium–232 by way of neutron absorption.

Decommissioning is a process intended to terminate the subsequent NPP operation in a way safe for the operating organization's employees (personnel), population and environment.

Nuclear fuel burn-up is a reduction of concentration of any nuclide in the nuclear fuel as a result of nuclear transformations of this nuclide during the reactor operation.

Burnable poison, or **burnable absorber,** is a material that is inserted into the critical system, intensively absorbs neutrons, compensates the excess critical mass of fissile material at the initial stages of system's operation, and later burns out.

Highly enriched uranium is the uranium with the uranium–235 isotope content (by weight) is 20 per cent or more.

Gamma radiation is an electromagnetic radiation with very short wave length (less than 0.1 nm) appearing during the radioactive transformations, nuclear reactions, and during the charged particles' deceleration, decay or annihilation.

IAEA Safeguards includes the international system of monitoring adopted within the scope of the international policy of nuclear weapons non-proliferation, and the system of inspection applied to the peaceful use of nuclear energy, entrusted to the International Atomic Energy Agency (IAEA) in accordance with the IAEA Statute, Nuclear Non-Proliferation Treaty and Treaty for the Prohibition of Nuclear Weapons in Latin America and the Carribeans.

GW is the gigawatt (10^9 W).

Genetic consequences of radiation are undesirable radiation consequences of ionizing radiation impact on living organisms resulting in changes in its hereditary properties and affecting the descendants of the exposed organism.

Uranium ore hydrometallurgical processing is an extraction of uranium and its compounds from natural ore, with the chemical reagents' water solutions used for this purpose, and subsequent extraction of uranium from these solutions. This is the main method used to process chemically the uranium ore and to obtain the uranium concentrate, resulting in change of minerals' composition.

Burn-up depth is a percentage of the initial number of nuclei of a particular type that was affected by nuclear transformation in the reactor as a result of an exposure to neutrons (the amount of energy per unit weight of the fuel, expressed in MW·day/kg U).

Graphite is a mineral, one of crystal forms of carbon. The nuclear grade graphite (i.e. the graphite from which the neutron-absorbing substances were removed) is used as neutron moderator in nuclear reactors.

Gray (Gy) is a unit of absorbed radiation dose in SI. One gray (Gy) corresponds to absorption of 1 joule of energy per 1 kilogram of tissue.

GTU is a gas-turbine unit.

MCP is a main circulating pump.

Decontamination is a removal or reduction of radioactive contamination at the particular surface or environment.

Deuterium is a “heavy” hydrogen isotope with the atomic mass 2.

Nuclear fission is the process when a heavy nucleus splits into two parts, accompanied with extraction of relatively large amount of energy and, as a rule, two or three neutrons.

Fissile material is a material that contains one or several fissile nuclides and, under the appropriate conditions, can reach criticality.

Fissile nuclide is a nuclide for which the interaction with slow neutrons can result in nuclear fission. There are three important fissile nuclides that are of interest for nuclear power industry. One of these nuclides, uranium – 235, exists in nature; two other nuclides, uranium – 233 and plutonium – 239, are artificial.

Ionizing radiation detector is a sensing element of a measuring device (instrument) intended to detect the ionizing radiation.

Uranium dioxide is a chemical compound, being the basic substance for the nuclear fuel. The uranium dioxide powder is used to make fuel pellets.

Stringer is an element of the fuel assembly used to fasten the fuel elements.

Annual effective (equivalent) dose is the value obtained by adding the effective (equivalent) dose of an individual’s external exposure received during a calendar year and the expected effective (equivalent) dose of internal exposure resulting from radionuclides that have penetrated into the organism during the same year. The unit of the annual effective dose is sievert (Sv).

Absorbed dose is the amount of ionizing radiation energy transmitted to the substance. The energy can be averaged by any particular volume; in such a case, the average dose will be equal to the total energy transmitted to the volume divided to the weight of this volume. In SI, the absorbed dose is measured in joules per kilogram; the special name is applied for this unit, gray (Gy).

Preventable dose is a predictable dose resulting from a radiation accident that can be prevented by protective measures.

Equivalent dose is an absorbed dose in an organ or tissue multiplied by the appropriate weight coefficient for the particular type of radiation.

Effective dose is a value of impact of an ionizing radiation used as a measure of risk of late consequences of radioactive exposure affecting an individual’s body and its particular organs, taking into consideration their radiation sensitivity. This value is calculated by adding the products of equivalent doses in organs or tissues and corresponding weight coefficients for appropriate organs or tissues.

Collective effective dose is a measure of collective risk of radioactive exposure’s stochastic effects; it is calculated as a total of individual effective doses. The unit of the collective effective dose is man-sievert (man-Sv).

Dosimeter is a device intended to measure the absorbed dose or the ionizing radiation dose rate.

Dosimetry is a field of applied nuclear physics that studies the physical processes characterizing the ionizing radiation effects for various objects.

Natural radiation background includes the cosmic radiation and radiation created by natural radionuclides contained in soil, water, air, other elements of biosphere, in foodstuffs, and in organisms of humans and animals.

LRW means liquid radioactive wastes.

Permanent (fixed) surface contamination includes radioactive substances that are not transferred to other objects at contacts and cannot be removed by decontamination.

Removable (unfixed) surface contamination includes radioactive substances that are transferred to other objects at contacts and can be removed by decontamination.

Radioactive contamination is presence of radioactive substances on the surface or inside a material, in the air, in a human body or in any other place in a quantity exceeding the levels prescribed in accordance with appropriate procedure.

Uranium oxide (U_3O_8) is a compound having several modifications depending on the conditions of its preparation; it can be obtained by oxidation of uranium dioxide or by strong heating any uranium oxide, uranium oxide hydrate or uranium salt with volatile base or acid at air.

Moderator is a material (e.g., light or heavy water or graphite), used in the reactor to slow down the fast neutrons by way of their collisions with lighter nuclei and, as a result, to facilitate further fission of the nuclear fuel.

Closed nuclear fuel cycle is a nuclear fuel cycle in which the spent nuclear fuel, unloaded from the reactor, is recycled for extraction of uranium and plutonium that would be used again to produce the nuclear fuel.

Radioactive wastes disposal is a safe placement of radioactive wastes with no intentions to extract and use them later.

Reactor containment is a technical facility provided to prevent the discharge of inadmissible amounts of radioactive substances from the nuclear reactor to the environment even in case of an accident.

Protective safety systems (elements) are the systems (elements) that shall prevent or limit the damage of nuclear fuel, fuel element claddings, equipment and pipelines containing radioactive substances.

Sievert (Sv) is a unit of equivalent and effective radiation dose unit in SI, named after G. R. Sievert, the Swedish scientist.

Breeding blanket is a part of the nuclear reactor containing the fertile nuclear material and designed to obtain secondary nuclear fuel.

Observation area is a territory beyond the controlled area where radiation monitoring is provided.

Radiation accident area is a territory where the fact of radiation accident has been proved.

Isotope is an atomic form of the element having a definite number of neutrons. Different isotopes of an element have the same number of protons but different numbers of neutrons and, therefore, different atomic mass, for example, U-235, U-238. Some isotopes are unstable; they decay, producing the isotopes of other elements.

Inert radioactive gases are gaseous chemically inertial products of the nuclear fuel fission in the reactor, including radionuclides of argon, krypton and xenon.

INES (International Nuclear Event Scale) is the international scale for classification of nuclear incidents that shall be used to assess their danger level. The scale includes 8 levels (zero level and seven danger levels).

Ion is an atom, electrically charged as a result of loss or acquisition of electrons.

Ionization is a conversion of electrically neutral atoms and molecules into positive and negative ions.

Ionizing radiation is a radiation that originates from radioactive fission, nuclear transformations or charged particles slowing-down in a substance and that produces ions with different signs of charge when interacts with the environment.

Research reactor is a nuclear reactor used for fundamental and applied researches and for radio isotope materials production.

Natural radiation source is a natural source of ionizing radiation that is within the scope of NRB-2000 radiation safety norms.

Anthropogenic radiation source is a source of ionizing radiation that is intentionally manufactured for useful applications or is a by-product of such activity.

Ionizing radiation source is a device or radioactive substance that emits or can emit the ionizing radiation.

Sealed radionuclide source is a source of radiation, the design of which prevents the radionuclides, contained in it, from ingression to the environment, while its operation and wear conditions are within the design scope.

Unsealed radionuclide source is a source of radiation, the operation of which can result in ingression of radionuclides, contained in it, to the environment.

Source material is a material that contains uranium or thorium with the same isotope ratio as in natural uranium and thorium.

ITER, International Thermonuclear Experimental Reactor, is the reactor the construction of which is now in progress under the auspices of the international group of scientists, managed by IAEA. It is expected that it will be the prototype of DEMO, the first nuclear fusion plant in the world.

Channel-type reactor, or **pressure tube reactor,** is a nuclear reactor in which the fuel and circulating coolant in the reactor's core are contained in separate sealed channels that can withstand high pressure of the coolant.

Ceramic fuel is a nuclear fuel consisting of high-melting compounds, e.g. oxides, carbides, nitrides.

Capacity factor is an energy actually produced at the reactor installation during the period of operation divided by an energy that would be produced in case of operation at the rated power. The capacity factor characterizes the NPP operation effectiveness and reliability.

Wastes classification is a process of wastes distribution by special categories specified to ensure that the wastes are processed in a way providing maximum protection for people and environment.

Safety classes cover the NPP equipment and systems classification by their roles in the NPP safety (safety class 1 includes fuel elements and nuclear plant components, the failures of which are the initiating events for the beyond design basis accidents leading to fuel elements damage beyond the limits established for the design basis accidents).

Containment is a protective concrete sealed shell of the reactor hall.

Radiation monitoring is a collection of information about the radiation situation in the organization and in the environment and about the levels of population exposure to radiation. Radiation monitoring includes dosimetric and radiometric monitoring.

Nuclear reactor vessel is a sealed container designed to contain the reactor core and other devices and to provide the nuclear fuel safe cooling by the coolant flow.

Tank reactor is a nuclear reactor, with the core placed in a vessel that can withstand the coolant pressure and heat loads. Because of high pressure of coolant in light-water reactors (that are, in terms of their design, shall be considered as tank reactors), durable steel vessel with thick walls is necessary for these reactors.

Cosmic radiation consists of energetic particles, including protons, reaching the Earth from the space.

Multiplication factor is the characteristics of the chain fission reaction, calculated as the number of neutrons of a particular generation divided by the number of neutrons of a previous generation.

Safety criteria (limits) are the values of parameters and (or) characteristics of a nuclear plant, prescribed by normative and legal acts and (or) by the governmental safety regulating authorities, and used to validate the nuclear plant safety.

Critical mass is the smallest mass of nuclear fuel in which the self-sustaining chain fission reaction can occur. It depends on the reactor design, core components and other factors.

Reactor's critical condition is a steady-state condition of the reactor, when the number of neutrons doesn't change in the course of time (see **Multiplication factor**).

Curie (Ci) is the off-system unit of activity. Initially, it was defined as the activity of 1 g of radium-226 isotope. 1 Ci = $3{,}7 \times 10^{10}$ Bq.

Light-water reactor is a nuclear power reactor in which the common, i.e. light water is used as a moderator and, at the same time, as a coolant. There are two types of these reactors, pressurized water reactors and boiling water reactors.

Localizing safety systems (elements) are the systems (elements) designed to prevent or limit the spreading of radioactive substances and ionizing radiation, in case of an accident, beyond the design boundaries and in the environment.

Radiation syndrome is a systemic disease with specific symptoms resulted from the ionizing radiation impact.

Radiation injury is the pathological change of blood, tissues, organs and their functions resulting from the ionizing radiation impact.

International Atomic Energy Agency (IAEA) is the international supervisory organization monitoring the nuclear safety and nuclear weapons non-proliferation worldwide.

Megawatt (MW) is the unit of power, 10^6 watt. The term MW(e) is applied for the electric power of the generator, the term MW(h), for the thermal power of the reactor or heat source (for example, reactor's total thermal power is usually three times higher than its electric power)

Micro is one millionth part of a unit (for example 1 microsievert is 10^{-6} sievert).

IRPC, International Commission on Radiological Protection, is an independent expert commission providing consulting services and recommendations on protection of population and the nuclear power industry personnel from ionizing radiation.

"Wet" repository is a repository for the nuclear fuel (as a rule, spent fuel) where the water is used.

MOX fuel, Mixed Oxide Fuel, is a mixed oxide nuclear fuel, as a rule, uranium- and plutonium-based.

Monitoring is a system of regular observations carried out in accordance with the prepared schedule to assess the current condition of the particular object and to forecast its future changes.

Dose rate is a radiation dose per unit time, e.g., rem/s, Sv/s, mrem/h, mSv/h, μrem/h, μSv/h).

MPa is megapascal (10^6 Pa).

Population includes all people (including the personnel) beyond the scope of work with ionizing radiation sources.

Independent systems (elements) are systems (elements) such that the failure of any system (element) doesn't result in failure of another system (element).

Once-through nuclear fuel cycle is a nuclear fuel cycle where the spent nuclear fuel, unloaded from the reactor, is not subject to reprocessing.

Neutron is an uncharged elementary particle existing in the nucleus of each atom except for hydrogen. Single neutrons, moving with different speeds, originate as a result of fission reactions. Slow (thermal) neutrons, in turn, can easily initiate fission of nuclei for fissile isotopes, e.g. U-235, Pu-239, U-233; fast neutrons can initiate fission of fertile isotope nuclei, e.g. U-238. Sometimes, atomic nuclei simply capture neutrons.

Undetectable failure is a failure of a system or an element that does not demonstrate itself at the time of its onset at normal operation and cannot be detected by control means within the scope of scheduled maintenance and test procedures.

Low-level radioactive wastes are radioactive wastes that can be treated without any special means of protection because of low content of radionuclides.

Low-enriched uranium is the uranium with uranium-235 isotope content less than 20% by weight.

Normal operation is the nuclear plant operation within the scope of operational limits and conditions determined by the project.

Nuclide is the kind of atom with a definite number of protons and neutrons in its nucleus. Its characteristics include the atomic mass and the atomic (serial) number.

Fissionable (threshold) nuclide is a nuclide that is induced to fission by neutrons when their energy exceeds a definite threshold. Natural fissionable nuclides are U-238 and Th-232 (they are also referred to as source or fertile nuclides).

Fissile nuclide is a nuclide that can be induced to fission by neutrons with any kinetic energy including zero. There is only one natural fissile nuclide, U-235. Pu-239 and U-233 are artificial (reproducible) fissile nuclides.

Nucleon is a common name for protons and neutrons, i.e. the particles making up the atomic nuclei.

Depleted uranium is an uranium in which the content of uranium-235 isotope is lower than in the natural uranium (i.e. less than 0.7 %). The depleted uranium is a by-product of the fuel cycle. It can be mixed with enriched uranium for the nuclear fuel production.

Supporting safety systems (elements) are the systems (elements) designed to supply energy and operating media for the safety systems, and to provide conditions necessary for the safety systems operation.

Irradiation or **Exposure** is a process by which a human is exposed to ionizing radiation.

Emergency exposure is an exposure resulting from the radiation accident.

Medical exposure is an irradiation of humans (patients) when they undergo medical examination or treatment.

Natural exposure is an irradiation from natural radiation sources.

Industrial exposure is an irradiation of personnel from all anthropogenic and natural sources of ionizing radiation during labor activities.

Occupational exposure is an irradiation of personnel during the work with anthropogenic sources of ionizing radiation.

Anthropogenic exposure is an irradiation from anthropogenic sources under normal and emergency conditions, except for medical exposure.

Uranium (uranium ore) processing is a set of processes with the uranium-containing mineral raw materials that shall result in separation of uranium from other mineral components of raw materials and increase the U-235 / U-238 content ratio. The processes include ore reduction and grinding and various chemical processes intended to separate the uranium from waste (also referred to as “tails”). The on-site leaching enrichment includes chemical processes separating the uranium from the solution.

Enriched nuclear fuel is a nuclear fuel with the fissile nuclides contents higher than in a source natural raw material.

Enriched uranium is a uranium in which U-235 / U-238 content ratio is higher that in the natural uranium (0,7%). As a rule, the reactor grade uranium is enriched up to 3,5 - 4 % content of U-235; in the weapon grade uranium, U-235 content is more than 90 %.

Radioactive waste processing is a set of processes intended to reduce the volume of radioactive waste, to change its composition or to transform the waste into a form in which the radionuclides are firmly fixed. These processes include the radioactive waste solidification, vitrification, calcination, bituminization, cementation and burning.

Radioactive waste management includes all kinds of activities relating to radioactive waste gathering, transportation, processing, storage and (or) disposal.

SVR means Safety Validation Report.

NPP SGR means NPP Safety General Requirements

Optimization is a strategic principle of radiological protection. According to this principle, doses and exposure risks shall be kept as low as reasonably achievable (the **ALARA** principle), taking into consideration the economic and social factors.

Pilot operation is a stage of nuclear plant commissioning procedure, from the start of the first power to the acceptance for commercial operation.

Vitrification is an inclusion of high-level radioactive waste into the borosilicate glass, approximately 14 % by weight. The purpose of vitrification is to fix the radionuclides in an insoluble stable matrix ready for disposal.

Radioactive waste solidification is a process intended to transform the liquid radioactive waste into solid substances and fix the radionuclides in a solid phase.

Common cause failures are the failures of systems or elements resulting from one failure or personnel error, or from internal or external impact, or some other internal cause.

Spent nuclear fuel is a nuclear fuel irradiated in the reactor core and permanently removed from it.

Reactor poisoning is the process of absorption of neutrons by the part of nuclei that have large absorption cross-sections in the energy region of thermal neutrons (i.e. that are originated from uranium and plutonium fission) and that have their concentration relatively quickly reaching the equilibrium level.

Radioactive gaseous wastes are radioactive wastes in the form of aerosol, inert gases, iodine and iodine compounds vapors.

Radioactive liquid wastes are radioactive wastes in the form of aqueous or organic liquids or pulps containing radionuclides in dissolved form or as suspensions.

Radioactive solidified wastes are liquid radioactive wastes transformed into solid state.

Radioactive wastes are substances in any aggregate state not intended for further use, with the content of radionuclides exceeding the levels specified in Radiation Safety Norms, NRB-2000.

Spent nuclear fuel is a fuel (or fuel assemblies) that, after being in use in the reactor, have lost their properties and must be removed for reprocessing or disposal.

“Greenhouse” gases include carbon dioxide and water vapors that absorb long-wave heat radiation from the Earth’s surface and repeatedly radiate it, returning it back to the Earth and, thus, causing the greenhouse effect.

Pascal is the unit of pressure and mechanical stress in SI. One Pascal is the pressure exerted by 1 N force, uniformly distributed on 1 m^2 surface perpendicular to the force direction.

Passive safety system (element) is a system or element, operation of which depends only on the event that has initiated this operation, and doesn't depend on any other active system or element, e.g. control system, energy source etc.

NSR means "Nuclear safety rules for nuclear plant reactor installations".

First circuit is a circuit, including the pressure compensation system, where the coolant is circulating through the core under the operating pressure.

Core refueling is a dangerous (in terms of nuclear safety) work on the reactor installation including loading, removal and relocation of fuel assemblies (fuel elements), reactivity controls and other components having an effect on reactivity, for their repair, replacement or dismantling.

Spent fuel reprocessing is a combination of chemical processes carried out to remove the fission products from the spent nuclear fuel and to recycle the fissile material for reuse.

Radioactive wastes reprocessing is a combination of operations carried out to change the aggregate state and (or) physical and chemical properties of radioactive wastes with the purpose of their transformation into the forms acceptable for transportation, storage and (or) disposal.

Half-life is a period of time during which the activity (or the number of radioactive nuclei) is reduces, in average, by half.

Plutonium is a radioactive chemical element, atomic number 94, mass number of the longest-lived isotope 244. The plutonium isotope, plutonium-239, is used in nuclear power industry as a nuclear fuel.

Absorber rods are movable elements within the control and safety system, made of neutron absorbing material, affecting the reactivity and used to control the nuclear reactor. (See also **Control rods**).

Positron is an antiparticle of the electron, with the mass equal to that of the electron, but with the positive electrical charge.

NPP safe operation limits are the process parameter values, specified in the project, any deviations from which can result in an accident.

Annual limit on intake (ALI) is a permissible level of the particular radionuclide intake by the organism during a year that, in case of the single-factor impact, results in reference man's expected irradiation dose equal to the respective annual dose limit.

Dose limit (DL) is an annual effective and equivalent anthropogenic exposure dose that must not be exceeded at normal operation conditions. If the annual dose limit is not exceeded, then any deterministic effects are prevented, and the stochastic effect probability is kept at acceptable level.

Preoperational adjustment is a stage of the nuclear plant commissioning procedure, when the nuclear plant's systems and elements, completely built and mounted, are brought to operational readiness condition, including their tests for meeting the design criteria and characteristics. As a result of this stage, the nuclear plant shall be ready for the reactor physical startup.

Natural uranium is the uranium available in nature, with U-235 isotope content about 0,7 %. Natural uranium can be used as a fuel in heavy-water reactors and as a moderator.

Fission product is a nuclide resulting from fission or subsequent radioactive decay of the radioactive nuclide produced in the same way.

Decay product is an atomic nucleus, stable or radioactive, that is produced when the unstable nucleus undergoes radioactive decay.

Design is the process and the result of preparation of the concept, detailed drawings, supplementary calculations and specifications for the nuclear plant and its equipment.

Design documents include a set of documents (texts and diagrams) that define the designed plant structure and costs for its construction.

Design limits are the values of parameters and characteristics of the nuclear plant's systems, elements and the nuclear plant as a whole, specified in the design for normal operation and for violations of normal operation, including the pre-accident situations and accidents.

Fuel production is a nuclear fuel production. Usually, it is produced in the form of ceramic pellets inserted in metal tubes that are subsequently assembled making up the fuel assemblies.

Commercial operation is an operation of the nuclear power plant that was commissioned in accordance with the established procedure and, during the commissioning, it was confirmed by the test results that the plant meets the design and shall be considered safe.

Production reactor is a nuclear reactor intended predominantly for production of fissile materials (e.g. plutonium).

Proton is a positively charged particle within the atomic nucleus.

CSS AR is an absorbing rod in the control and safety system.

Accident sequence is a sequence of NPP's systems and elements conditions that arise during the development of the accident.

Rad is an off-system unit of absorbed radiation dose. 1 rad = 0.01 gray.

Radiation accident is a situation when the ionizing radiation source comes out of control, as a result of failure, equipment damage, personnel's incorrect activities, natural disasters or other causes, and that could lead or has leaded to radiation exposure of people or radioactive contamination of the environment beyond the prescribed limits.

Radiation safety of population is a condition of safety for the current and future generations against harmful impact of the ionizing radiation.

Radiation incident is an event when the exposure occurs in doses beyond the prescribed limits for the respective categories of persons.

Radiation monitoring is a monitoring of observation of radiation safety norms and basic sanitary rules with regard to radioactive substances and ionizing radiation sources handling.

Radiation is an energy emission and spreading by electromagnetic waves or particles.

Radium is a product of radioactive decay of uranium, frequently occurring in uranium ore. It has several radioactive isotopes. When radium-226 decays, radon-222 is produced.

Radioactive substance is a substance in any aggregate state containing radionuclides with the activity exceeding the levels specified in the normative legal acts including technical normative legal acts.

Radioactivity is a spontaneous decay of an unstable atomic nucleus that includes changes in nucleon composition and radiation emission process.

Radioactive wastes are nuclear materials and radioactive substances not intended for further use.

Radioactive source, see **Ionizing radiation source**.

Radioactive material is a material containing radioactive substances.

Radioactive decay is a spontaneous transformation of nucleus when particles and gamma-radiation are emitted, or X-rays are emitted, or spontaneous nucleus fission occurs.

Radioisotope is a radioactive isotope of any element.

Radiometer is a device used to measure the radionuclide activity in the source or in the sample (within the volume of liquid, gas, aerosol, or on contaminated surfaces) and to measure the ionizing radiation flux density.

Radionuclide is a nuclide that demonstrates radioactivity (having radioactive atoms of a particular chemical element).

Radionuclide source is a substance that contains radionuclide (or radionuclide mixture) placed in the cladding or otherwise fixed within the volume of some material or on its surface and that is used as an ionizing radiation source.

Chemical radioprotectors are chemical compounds that can reduce the harmful impact of the ionizing radiation on a human's organism.

Radiotoxity is an unfavorable influence of a radionuclide on human's health because of the nuclide radioactivity.

Radiochemistry is a part of chemistry studying the properties of radionuclides, their emission and concentration methods, and scopes of radionuclide application in various fields of science and engineering.

Power excursion is a very fast growth of reactor's power beyond the normal operating level.

Reactor runaway, see **Power excursion**.

Separation technologies include the process and special equipment for separation of isotopes (e.g. Uranium-235 and Uranium-238) by way of different speeds of gas molecules driven by centrifugal forces developed inside the cylinder (rotor) that rotates around its axis. These technologies are used to enrich uranium.

RAW means **"**Radioactive wastes"**.**

Nuclear fuel breeding is a nuclear fuel breeding with a conversion ratio higher than 1, i.e. when the amount of fissile material produced exceeds the amount of this material consumed in the reactor.

RBMK (from Russian*, reaktor bolshoy moshchnosti kanalniy*), High-power Channel-type Reactor, is a type of single-circuit power reactor where water is used as a coolant and graphite is used as a moderator.

FNR means "Fast-neutron reactor".

Breeder reactor is a fast reactor where the nuclear fuel breeding, i.e. fuel production, is carried out.

Reactor installation is a set of systems and elements of the nuclear plant designed for transformation of nuclear energy into thermal energy, including the reactor and other systems directly connected with the reactor and necessary for its normal operation, emergency cooling, emergency protection and keeping in safe condition, subject to the necessary supplementary and supporting functions provided by other systems of the nuclear plant. The reactor installation boundaries are determined for each reactor installation in the design.

Fission reaction, see **Nuclear fission.**

Regenerated uranium is the uranium extracted from spent nuclear fuel during radiochemical reprocessing for reuse in the nuclear fuel (recycled fuel).

Nuclear reactor control is a function of the nuclear reactor control and safety system that keeps the chain nuclear reaction rate constant or provides its change.

Control rods are movable elements within the control and safety system, made of neutron absorbing material, affecting the reactivity and used to control the nuclear reactor. (See also **Control rods**).

Regulatory authority is a national authority (or the system of authorities), appointed by the government, that has appropriate legal powers to supervise the nuclear plants operation safety, provides the licensing procedures, issues the licenses and, in such a way, regulates the safety during the construction site choosing, design, construction, commissioning and operation, or regulates the particular matters related to these stages of licensing.

Redundancy means that the number of elements or systems in use is higher than their minimum required number, and these elements or systems are used in such a way that the failure of any of them does not lead to the failure of the necessary function as a whole.

Roentgen is the off-system unit of the exposure dose of X-rays and gamma radiation determined by their ionizing effect on dry atmospheric air: 1 roentgen = $2{,}58 \times 10^{-4}$ C/kg.

X-rays means short-wave electromagnetic ionizing radiation, $10^{-7} \ldots 10^{-12}$ m wavelength, produced as a result of an interaction between the charged particles (or photons) and electrons.

Radiation risk is a possibility of any harmful effect, resulting from an exposure, for a human or his/her descendants.

TNR means “Thermal neutron reactor”.

RRC means “Regional Response Centre”.

Self-sustaining chain reaction is a chain nuclear reaction characterized by the value of the effective neutron multiplication coefficient (Ceff) equal to or higher than 1.

Controlled area is an area around the ionizing radiation source where, even during normal operation of this source, the human exposure level can exceed the prescribed exposure dose limit for the population. In the controlled area, permanent or temporary habitation is prohibited, economic activities are limited, and radiation monitoring is provided.

Radioactive waste collection means concentration of radioactive waste at the sites specially allocated and equipped for this purpose.

Interaction (fission, absorption, etc) cross-section is a value characterizing the possibility of interaction.

Synthesis is a formation of heavier nucleus from two lighter ones (usually, hydrogen isotopes) accompanied by the emission of large amount of energy.

Control and safety system (CSS) is a combination of equipment, software and data intended to provide safe chain nuclear reaction. Control and safety system is of high importance for safety. The system integrates the functions of normal operation and safety; it includes the control systems for normal operation and protection, controlling and supporting safety systems.

Radioactive waste management systems are the systems for radioactive waste collection, and (or) storage, and (or) processing, and (or) conditioning, and (or) transportation.

TASIS is a program of technical assistance for the CIS countries, implemented by the European Union; within the scope of this program, several nuclear safety improvement projects have been implemented or in progress.

Tveg, the Russian abbreviation that means “Gadolinium fuel element”. This is a fuel element consisting of a sealed tube with fuel pellets made of uranium dioxide with gadolinium oxide admixture, used as a burnable absorber.

Tvel, the Russian abbreviation that means “Fuel element”.

Fuel assembly (FA) is a device containing nuclear materials and designed to produce thermal energy in a nuclear reactor by way of implementation of the controlled nuclear reaction.

Fuel element is a separate assembly containing nuclear materials and designed to produce thermal energy in a nuclear reactor by way of implementation of the controlled nuclear fission reaction and (or) for nuclides accumulation.

Coolant is a liquid or gas used to transfer heat from the reactor core to the steam generators or directly to the turbines.

Fusion reactor is a reactor where the controlled nuclear fusion (see below) is implemented to produce energy.

Nuclear fusion is a process of interaction (fusion) of light nuclei at high temperatures, resulting in formation of heavier nuclei and energy release.

Anthropogenic radiation is an irradiation from radiation sources appearing as a result of labor activities.

Fuel campaign is a number of years of a fuel assembly operation in the reactor core.

Fuel pellet is a pellet of pressed uranium dioxide. These pellets are the basic material of the nuclear fuel. The pellets are placed inside fuel elements (see **Fuel element**).

Thorium is a chemical radioactive element (metal) with the atomic number 90 and the atomic mass of the most common and stable isotope 232 (in total, eight thorium isotopes occur in nature).

Thorium-232 is a natural thorium isotope with atomic mass 232. This is the only thorium isotope that is common in nature, with $1{,}4\times10^{10}$ years half-life.

Transmutation is a conversion of atoms of one element into atoms of another element through the neutron bombing resulting in neutrons capture.

Propulsion reactor is a nuclear power reactor used as an energy source for propulsion of a vehicle (e.g., a ship).

Transuranium element is a radioactive element obtained artificially by way of neutrons capture, possibly with the subsequent beta decay. It has higher atomic number than uranium (92). The most common transuranium elements are neptunium, plutonium, americium, and curium.

SRW means “Solid radioactive waste”.

Turbine is a prime engine with rotary motion of a working element (rotor with blades) converting the kinetic energy of a working body (steam, gas or water) into mechanical work.

Heavy water reactor is a nuclear reactor in which the moderator is heavy water. CANDU, the Canadian reactor, is an example of the heavy water reactor.

TPS is a thermal power station.

Radioactive waste package is a packaging set (container) with radioactive waste placed in it, prepared for transportation, and (or) storage, and (or) disposal.

Control (absorber) rods are rods made of material absorbing neutrons. These rods can be used to inhibit or stop the chain reaction in the reactor. Control rods are the part of the CSS system.

Control systems (elements) for normal operation are systems (elements) providing and implementing the control over the equipment of the normal operation systems withat the nuclear plant unit in accordance with the determined goals, criteria and limitations.

Uranium (U) is a chemical radioactive element (metal) with the atomic number 92. The natural uranium is a mixture of uranium isotopes, with U-235 isotope content about 0,7 % (by volume).

Uranium-233 is an artificial uranium isotope with half-life $1{,}6\times10^{5}$ years. It is produced as a result of transmutation of thorium-232 after the neutron capture. Uranium-233 is a fissile nuclide.

Uranium-235 is a natural uranium isotope with half-life $7{,}1\times10^{8}$ years, atomic mass 235. This is the only fissile material occurring in nature.

Uranium-238 is a natural uranium isotope with atomic mass 238, half-life $4,47 \times 10^9$ years. It can be used as a fertile material for getting plutonium-239.

Uranium ore is an ore with high content of uranium, making its extraction feasible in economic terms.

Uranium oxide fuel is a nuclear fuel consisting of uranium dioxide pellets, sintered at high temperature and pressure, enriched to 2 – 4 % of uranium-235. It is used in light-water reactors.

Uranium concentrate is a product of the uranium ore hydrometallurgical processing. It contains up to 70-90 % of uranium (by weight) in the form of the oxides mixture, with the general chemical formula U_3O_8.

Emergency preparedness level is a prescribed degree of preparedness of the personnel, civil defense and emergency situation authorities, other involved forces and equipment for the personnel and population protection activities in case of an accident at the nuclear plant.

Intervention level includes the parameters and characteristics that determine the radiation situation and its trends and that, as a whole, demonstrate that the measures for protection of the personnel and population are necessary.

Safe operation conditions include minimum limitations, specified in the design for several characteristics of the reactor installation that are important for its safety; these limitations, if met, ensure that the plant operation is safe.

Physical barrier is a structure, equipment or device limiting the emission of radioactive substances and ionizing radiation into the premises of the object, dangerous in terms of radiation, and to the environment.

Physical protection of a nuclear plant includes technical and organizational measures intended to keep intact the nuclear materials and radioactive substances at the nuclear plant, prevent any unauthorized access to the nuclear plant territory or unauthorized access to the nuclear materials and radioactive substances, promptly reveal and prevent any subversions and acts of terrorism threatening the nuclear plant safety.

Physical barrier is a natural obstacle in the way of propagation of ionizing radiation, nuclear material or radioactive substance.

Reactor startup is a stage of the NPP unit commissioning procedure that includes the nuclear fuel loading into the reactor, bringing the reactor to the critical condition and all necessary physical measurements with the power level corresponding to the condition when the heat is removed from the reactor by way of natural heat losses (dispersion).

Radioactive waste storage is a radioactive waste placement in special facilities designed for waste's safe isolation and provided with the means to monitor the waste condition and to remove the waste later, if necessary, for processing, transportation, and (or) disposal.

Radioactive waste cementation is a method of conditioning of liquid and solid radioactive waste by mixing the waste with the cement and subsequent hardening of the mixture.

Chain nuclear reaction is a sequence of the nuclei fission reactions involving heavy atoms when they interact with neutrons and other elementary particles, resulting in formation of lighter nuclei, new neutrons or other elementary particles, and in the nuclear energy release. Depending on the average number of fission reactions, the reaction can be waning, damped, self-sustaining or growing.

Decay chain is a sequence in which every nuclide transforms into the next nuclide, as a result of the radioactive decay, until the stable nuclide appears.

Zirconium is a chemical element (metal), weakly absorbing thermal neutrons. It is widely applied in the equipment for the nuclear power industry.

Chernobyl NPP is the Chernobyl Nuclear Power Plant.

EGP (from Russian), Graphite Channel-type Power Reactor with Steam Superheating, is a reactor used at Bilibino NPP, Russia.

Environmental safety is a condition of safety for the environment, life and health of people against possible harmful impact of industrial and other activities, natural and anthropogenic emergencies.

Environmental damage is an estimated harmful impact calculated as an amount and cost of works necessary to restore the environment quality.

Experimental reactor, see **Research reactor.**

Operating limits are the values of parameters and characteristics of the nuclear plant’s systems, elements and the nuclear plant as a whole, specified in the design for normal operation.

Operation includes all activities carried out, in a safe way, to achieve the goal for which the plant was built, including power operation, startups, shutdowns, tests, maintenance, repair, refueling, inspections in operation and other related activities.

Operating conditions are the conditions specified in the design with regard to the quality, characteristics, operability and maintenance of systems and elements that are necessary for operation not violating the operating limits.

Electron-volt (eV) is the unit of energy that is equal to the change of energy of an electron when it passes through 1 V potential difference.

Nuclear station first power is a stage of the nuclear plant commissioning procedure, from the completion of the physical startup to the beginning of the electric energy production.

Power reactor is a nuclear reactor intended for the electric energy production.

Nuclear accident is an accident involving damage of fuel elements beyond the prescribed limits of safe operation and (or) exposure of the personnel beyond the acceptable limits. The nuclear accident can result from:

– failure to monitor and control the chain nuclear fission reaction in the reactor core;
– criticality during refueling, transportation or storage of fuel elements;
– failure of heat removal from the fuel elements;
– other causes leading to the fuel element damage.

Nuclear safety is a condition of safety for people and environment against harmful impact of the ionizing radiation from the nuclear installation and (or) storage site. To ensure the nuclear safety, appropriate conditions for the nuclear installations and (or) storage sites operation shall be provided, and the nuclear materials (including spent nuclear materials) and (or) radioactive waste occurring in operation shall be appropriately treated.

Nuclear reaction is a conversion of atomic nuclei, caused by their interaction with elementary particles or with each other and accompanied by changes of mass, charge or energy state of the nuclei.

Nuclear installation includes facilities and structures with nuclear reactor(s), including the facilities and structures with industrial, experimental and research nuclear reactors, critical and subcritical nuclear stands and assemblies.

Nuclear power is a field of modern engineering dealing with transformation of nuclear energy into other types of energy (heat, mechanical, electric energy) and its application for industrial and household purposes.

Nuclear energy is an internal energy of an atomic nucleus related to motion and interaction of nucleons that the nucleus consists of. There are two ways to obtain the nuclear energy: chain nuclear reaction (heavy nuclei fission) and fusion reaction (light nuclei synthesis).

Nuclear fission is a process including the fission of a nucleus of a heavy atom when it interacts with a neutron or other elementary particle, resulting in formation of lighter nuclei, new neutrons or other elementary particles, and in the nuclear energy release.

Nuclear transformation is a transformation of one nuclide into another.

Nuclear fuel is a substance that can be used in a nuclear reactor for implementation of the heavy nuclei fission chain reaction. Nuclear fuel contains fissionable material and substances, the nuclei of which interact with neurons resulting in production of the secondary fissionable material.

Nuclear material is a material that contains or can produce fissile materials (substances).

Nuclear reactor is an installation for controlled chain nuclear reaction.

Nucleus, **see Atomic nucleus.**

Nuclear fuel cycle (NFC) is a combination of activities implemented with the purpose to provide operation of the nuclear power industry, including the uranium ore mining and processing, fuel production, fuel transportation to the NPP, spent nuclear fuel storage and reprocessing. If the spent nuclear fuel is subject to disposal, the nuclear fuel cycle is open; if the spent nuclear fuel is subject to reprocessing and reuse, the cycle is closed.

NPI means “Nuclear power installation”.

English terms and abbreviations

ALARA (As Low As Reasonably Achievable) is the principle in the radiological protection strategy. In accordance with this principle, the exposure dose and risk are kept at reasonably achievable low level, taking into consideration the economic and social factors.

BWR (Boiling water reactor) is the tank-type reactor with boiling water containing heavy water for use as a coolant and natural uranium as a fuel. These reactors are operated in Canada.

EUR (European utility requirements) are the requirements of European energy companies applied to NPPs with light-water reactors.

IAEA, International Atomic Energy Agency

INES, International Nuclear Events Scale

ITER, International Thermonuclear Experimental Reactor

MOX, Mixed Oxide Fuel, as a rule, uranium- and plutonium-based.

PWR (Pressurized water reactor), type of reactors with pressurized water, similar to Russian WWER reactors.

2 INTRODUCTION

Power engineering is the basis of successful development of economy and society as a whole.

On October 8, 1975, on the scientific session devoted to the 250th anniversary of the Academy of Sciences of the USSR, Academician Piotr Leonidovich Kapitsa, who was awarded the Nobel Prize in physics three years later, has delivered a conceptual report covering various sources of energy. In brief, Academician Kapitsa's considerations are as follows: any source of energy can be characterized by two parameters:

- energy density, i.e. its quantity in the unit volume;
- speed of its transmission or spread.

The product of these values is the maximum power that can be obtained from the unit surface using the particular type of energy.

The development of power engineering in the world during the recent 34 years demonstrates that Kapitsa's forecast was valid.

In foreign countries, the successful development of power engineering, based on renewable energy sources, results primarily from the stable and multifactor support provided by the governments [1], including:

- tax benefits, tax holidays, free access to the utilities for the private owners of electric power stations that use the renewable energy sources;
- mandatory governmental procurements of energy, produced from the renewable energy sources, with the fixed tariffs;
- governmental financial support for R&D and other pilot projects in the field of renewable energy sources;
- governmental participation in the projects that involve construction of electric and thermal power stations with the renewable power sources;
- no-interest credits for the power engineering industry enterprises.

Coal thermal power stations poison the environment so badly that the operating life of existing stations should be shortened, as far as possible, and the new stations shall not be constructed, at least until new emission-free technologies are developed.

Gas electric power stations burn not just a fuel but a very expensive raw material, in terms of the gas usage in the chemical industry. Unreasonable waste of gas deposits results in loss of raw materials for scientific experiments and for the development of new materials and substances.

Biological fuel is a new suggestion for electric power stations but it appears to be blasphemous [1]:

- first, nobody can guarantee that the biological fuel resources will be sufficient for continuous work of the world power engineering or at least for power generation in one country for a long period of time;
- second, we are not sure that the planned allocation of large territories for biological fuel growing will not lead to the food shortage.

In his report Academician P.L. Kapitsa paid especial attention to the nuclear power industry and noted three main problems on its way to become the most important energy source for the mankind:

- radioactive waste disposal;
- critical danger of catastrophes at nuclear plants;
- uncontrolled proliferation of plutonium and nuclear technologies.

The development of nuclear power industry was accompanied by significant catastrophes (Three Mile Island NPP in 1979 and Chernobyl NPP in 1986), and by signing the treaties for the control of nuclear technologies and proliferation of weapon-grade plutonium. In spite of several unsolved problems, it's difficult to expect that any alternatives of nuclear power generation can appear within 50 – 100 years. And it is likely that such alternatives will involve the construction of the electric power plant with the pulse-type fusion power reactor.

It was said by Mohamed El Baradei, the IAEA Director General, for the Organization of Economical Cooperation and Development in Paris (France) that, by now, more than 50 countries have informed the IAEA about their intention to develop nuclear power industry for peaceful purposes. The IAEA Director General has expressed that 10 years ago the future of nuclear power plants was questioned. Now the situation has changed and many developing countries ask IAEA to help them in NPPs construction.

Now, 10 countries, including Belarus, are working with the programs of development of their nuclear power industry. In China, the construction of 6 nuclear reactors is in progress. In Russia, plans exist to construct dozens of small and large nuclear reactors by 2020. In the world, there are 439 NPPs in operation in 30 countries [2].

Today about 20 % of electricity in the USA is produced by the nuclear power industry. As the population is growing, and the electric energy consumption is growing respectively, the number of nuclear plants must be increased to keep the nuclear power industry share in the total energy production at the same level, 20 %. However, taking into consideration that the growth of energy consumption makes it necessary to use predominantly the energy sources with low emissions of CO_2, the share of electric energy produced by using nuclear generation will be much higher than 20 %. Nuclear energy is of great importance because, unlike the wind energy and solar energy, it is capable to produce high amounts of the main electric energy, for which the wind and solar energy contribution can be additional because these energy sources are available. One more benefit of the nuclear energy is that it requires very little amounts of the fuel as compared with coal and natural gas; thus, much less mining works are required, and the waste amounts are relatively small (1 g of uranium produces million times more energy than 1 g of coal). So, the uranium mining and the spent nuclear fuel disposal are much less harmful for the Earth [3].

Since the very beginning of development of the nuclear power industry, the potentially dangerous radiation impact on the environment has determined high requirements for the environment monitoring, both in an NPP controlled area and in an observation area. Several confirming facts are as follows:

- Kursk nuclear plant was awarded the annual prize of the Ministry of Natural Resources of the Russian Federation, "Best Ecological Project of the Year" ("In Harmony with Nature" nomination). The project name is: "Studying the Biological Diversity of Kursk NPP's Anthropogenic Landscapes" [4];
- by the decision of the Organizational Committee of IV All-Russian Ecological Conference, "New Priorities of National Ecological Policy in Real Sector of Economy", Balakovo NPP was awarded the honorary title, "Leader of Nature Protection Activity in Russia – 2008", for its active efforts in the field of environmental protection and rational use of natural resources. The NPP Director, V. Ignatov, was awarded the honorary medal, "For Environmental Safety", and the NPP Chief Engineer was awarded the honorary order, "Environmental Shield of Russia" [5].

Resulting from the analysis and comprehensive consideration of information about the environment protection and condition, about the behavior of contaminating substances from NPPs in the environment and about the ecosystems' responses to the impacts related to the NPP operation, the main environmental concepts of the nuclear power industry were formulated [6, 7]. These concepts are as follows:

- NPP is a system that includes the NPP itself, its auxiliary and construction-related organizations and enterprises, and the town (or settlement) for the NPP personnel including its utilities enterprises and organizations;
- NPP is a source of four types of impacts affecting the quality of life of the population and the natural environment. These impacts are as follows: radioactive, chemical, thermal and urbanization-related;
- when the NPP operates normally, the population and environment are absolutely protected against the NPP radiation impacts; however, in case of any deviations from normal operation, the radiation impact can become the most significant;
- when the NPP operates normally, the most significant impact on the ecosystem it the cooling towers' thermal impact;
- the main types of impact on the terrestrial ecosystems include the impacts related to construction works, region urbanization and, maybe, chemical impact;
- in the NPP area, groups of population, biogeocenosis, landscapes, species of plants and animals exist for which the NPP impacts are critical.

Considering all facts given above, special attention is paid to the environmental safety during the NPP design, construction and operation. For the general structure of the environmental safety validation, see Figure 1 [8].

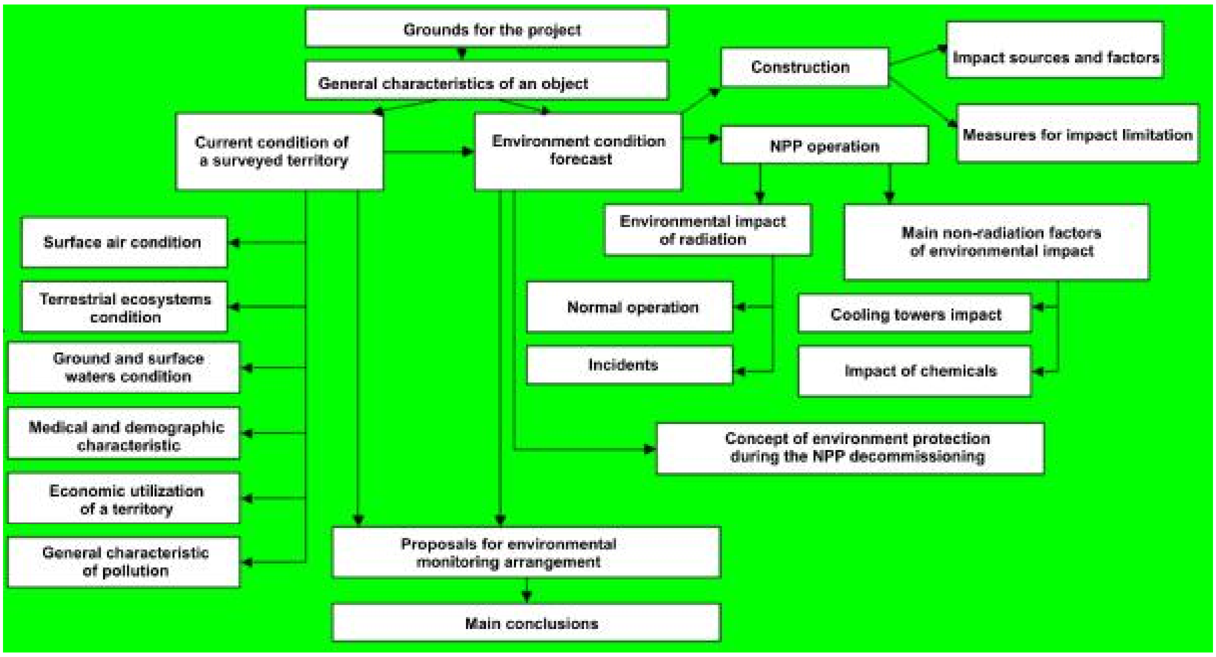

Figure 1 – NPP safety validation

As can be seen from Figure 1, the main tasks on the stage of the environmental impact assessment are as follows:

- obtain any possible information concerning the environment condition at the NPP site and its observation area;
- determine the groups of population, biogeocenoses, landscapes, landscape couplings, species of plants and animals that are critical to the NPP impacts;
- develop the proposals for the environment monitoring system arrangement.

The materials used for preparation of the Belarusian NPP environmental impact assessment (EIA) include normative documents of the Republic of Belarus [9, 10], international recommendations [11] and EIA documents from other nuclear plants [12-16].

3 GENERAL. NPP CONSTRUCTION NECESSITY VALIDATION

The main purposes of the environmental impact assessment (EIA) are as follows: determine the condition of the most important environmental natural components in the NPP construction area; assess the NPP construction and operation impact on these components and forecast their possible changes; validate the NPP construction environmental acceptability.

EIA is the integral part of the validation of investment in the NPP construction in the Republic of Belarus.

This work shall be carried out in accordance with the agreement No. 551-307-08 (12.12.2008) for the preparation of the validation of investments in the nuclear power plant construction in the Republic of Belarus, concluded between the State Institution “Nuclear Power Plant Construction Directorate” and the Design Scientific and Research Republican Unitary Enterprise “Belnipienergoprom”.

For the EIA Requirements Specification and the Endorsement Letter of the Ministry of Natural Resources of the Republic of Belarus, see Annexes A and B.

3.1 Information on the documents providing the grounds for the construction of the Belarusian NPP

The works related to the Belarusian NPP are carried out in accordance with several governmental decisions and regulations. The most important of them are as follows:

1) Concept of national security of the Republic of Belarus, approved by the Edict of the President of the Republic of Belarus, July 7, 2001, No.390 (National Register of Legal Acts of the Republic of Belarus, 2001, No. 69, 1/2852);

2) State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus in 2006-2010, approved by the Edict of the President of the Republic of Belarus, August 25, 2005, No. 399, “On approval of the Concept of energy-related safety of the Republic of Belarus and the State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus in 2006-2010” (National Register of Legal Acts of the Republic of Belarus, 2005, No.137, 1/6735);

3) State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus for the period until 2011, approved by the Edict of the President of the Republic of Belarus, November 15, 2007, № 575

4) Program of social and economic development of the Republic of Belarus for 2006 -2010, approved by the Edict of the President of the Republic of Belarus, June 12, 2006, No. 384 (National Register of Legal Acts of the Republic of Belarus, 2006, № 92, 1/7667);

5) Directive of the President of the Republic of Belarus No.3, June14, 2007, "Saving and thrift are the main factors of economic security of the state" (National Register of Legal Acts of the Republic of Belarus, 2007, № 146, 1/8668);

6) Plan of the main organizational activities for construction of the nuclear power plant in the Republic of Belarus, approved by the Decision of the Council of Ministers, January 21, 2009, № 64-2.

3.2 Basic normative documents regulating the activities in the field of the nuclear energy in the Republic of Belarus

Several normative documents are adopted for the purposes of regulation of activities in the field of the nuclear energy in Belarus [17 – 20].

Because there is no system of regulatory documents, and taking into consideration that the Belarusian NPP will be constructed in accordance with the Russian project (NPP-2006), the work group was established, headed by the Chairman of State standardization Committee of the Republic of Belarus, to arrange the activities for preparation of Technical Normative Legal Acts. The regulating document was prepared by this group, the Directory of the Basic Valid Normative Documents of the Russian Federation Regulating the Provisions for Safe Operation of the Nuclear Plant Energy Units with WWER Reactors, Brought into Force on the Territory of the Republic of Belarus, No. OUP-06/01, approved by the Deputy Prime Minister of the Republic of Belarus, V.I. Semashko. The rationale for this decision is as follows:

- technical normative legal acts cannot be prepared soon, because there is no experience in design and operation of nuclear energy installations;
- contradictions exist between the Russian and Belarusian normative documents (e.g. in Russia, the NPP personnel is subdivided into two categories, but in Belarus, there is no such subdivision);
- application of Russian technical normative legal acts is reasonable, because the Russian organizations will participate in design, construction and operation of the Belarusian NPP.

3.3 Brief information about the organizations that have requested, designed and prepared the EIA

In accordance with the Edict of the President of the Republic of Belarus, November 12, 2007, № 565, “On some measures for construction of nuclear power plant”, the following organizations were established in the Republic of Belarus:

1) State Institution “Nuclear Power Station Construction Directorate”, to implement the functions of the requester in the set of preparatory, design and survey works for the construction of the nuclear power plant (hereinafter referred to as the NPP).

2) Nuclear and Radiation Safety Department, to implement the governmental supervision with regard to nuclear and radiation safety in the Ministry of Emergencies of the Republic of Belarus.

The Design Scientific and Research Republican Unitary Enterprise “Belnipienergoprom” is appointed the General Designer to coordinate the preparation of the design documents for the NPP construction.

The organizations that have prepared the EIA:

Republican Unitary Enterprise "Central Scientific and Research Institute of Comprehensive Use of Water Resources", the institute of the Ministry of Natural Resources of the Republic of Belarus, studying the surface waters. Its goal is to assess the impact of the nuclear power plant in the Republic of Belarus on the aquatic environment, prepare the quality and quantity characteristics of surface waters, and assess the transborder transfer of radioactive contamination.

State Institution "Republican Centre of Radiation Control and Monitoring", the state institution within the Ministry of Natural Resources of the Republic of Belarus, engaged in environmental objects monitoring in the Republic of Belarus (with regard to chemical and radioactive contamination). Its goal is to develop the monitoring system in the observation area of the Belarusian NPP, assess the current condition of the environmental objects, arrange the monitoring in the observation area for the period of construction of the Belarusian NPP, calculate the surface radioactive contamination for the normal operation mode of the Belarusian NPP, in case of normal operation violations and in case of radiation accidents (including heavy accidents beyond the design basis), and the transborder transfer of radioactive contamination by air.

State Institution "Republican Hydrometeorological Centre", the state institution within the Ministry of Natural Resources of the Republic of Belarus. Its goal is to characterize the current condition of the air environment, the climate and conditions for mixture dispersion in the atmosphere, and to assess the impact of the Belarusian NPP on the air environment and microclimate.

State Scientific Institution "Institute for Nature Management of the National Academy of Sciences of the Republic of Belarus", the leading scientific institution in the Republic of Belarus in the field of nature management, environmental protection and water resource technologies, geoecology, geography and paleography, climatology, hydrogeochemistry, hydroecology, geodynamics. Its goal is to provide the characteristics of the current condition of environment (landscapes, flora and fauna) and underground waters (quality and quantity estimates); estimate the Belarusian NPP impact on the before-mentioned components, and forecast the transboundary transfer of chemical and radioactive contamination by underground waters.

Scientific and Research Department – Main Directorate of Science of the Belarusian State University (BSU), BSU Scientific and Research Laboratory of Hydroecology, the leading scientific and research institution in hydroecology in the Republic of Belarus. It has an extensive experience of work in Naroch Nature Reserve. Its goal is to study the current condition of biological components of aquatic ecosystems and processes determining the quality of waters, to assess the NPP operation impact on the condition of aquatic ecosystems and quality of surface waters.

Republican Scientific and Practical Centre "Hygiene" of the Ministry of Health of the Republic of Belarus assesses the risk for human health. Its goal is to characterize the current condition of population in the area of the Belarusians NPP site, assess the radiological impact of NPP on the Belarusian population (during the NPP normal operation and in case of radiation accidents), and assess the risk of impact for the public health resulting from the air contamination by thermal power stations using the various kinds of fuel.

Republican Scientific and Research Unitary Enterprise "Institute of Radiology" is the leading scientific and research institution in the Republic of Belarus in the field of agricultural radiology. Its goal is to describe the current condition of the agriculture in the area of the Belarusians NPP site, assess the radiation impact on the agricultural ecosystems resulting from the planned activities, and prepare recommendations with regard to agricultural activities in case of radioactive contamination of the environment resulting from radiation accidents.

“Scientific and Research Institute of Fire Safety and Emergency Situations” of the Ministry of Emergency Situations of the Republic of Belarus, the specialized institution engaged in estimation of the risk of emergency situations and problems related to these situations. Its goal is to assess the impact of emergency situations on the NPP and to prepare the plans for elimination of emergency situations at the Belarusian NPP.

3.4 Technical and economic backgrounds for the development of nuclear power industry in Belarus

For the evaluation of technical feasibility, commercial and economic reasonability of investments into the construction of the NPP, including the consideration of alternatives, see [21].

The forecast data for engineering and economic calculations were based on the “State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus in 2006-2010” and on the forecasts of social and economic development of Belarus. In these calculations, the scenarios of the energy system development with and without the nuclear power plant were considered.

As a part of calculations for each scenario chosen, the optimal schedule of the energy units commissioning was determined, providing minimum expenses for the electric energy production by the power industry as a whole. For each scenario, it is assumed that the prevailing share of the electric energy is produced by the existing thermal power stations and combined heat and power plants. The calculations have resulted in the main conclusions as follows:

1) Reasonability of the nuclear power industry development in Belarus has been confirmed. Various scenarios of balancing the expected electric power shortage demonstrate that the commissioning of a source of energy, that uses the nuclear fuel, would lead to the reduction of costs of the electric energy, produced by the power industry; however, the optimal scenario includes combination of use of the natural gas and nuclear fuel.

2) For each scenario chosen, the optimal schedule of the new energy units commissioning was determined, providing minimum expenses for the electric energy production by the power industry as a whole. In all scenarios chosen, it is assumed that the prevailing share of the electric energy is produced by the existing thermal power stations and combined heat and power plants.

3) It was demonstrated that the optimal scenario for the development of the nuclear power industry in Belarus includes commissioning of the nuclear energy units with a total electric power about 2 GW. It is expected that by 2020, the NPP will produce 27 – 29 % of electric energy in Belarus.

4) Inclusion of the nuclear power industry into the fuel and energy balance of Belarus will make it possible to diversify the use of heat and power resources; to save the valuable organic fuels, oil and gas first of all, for their use as raw materials; to reduce the greenhouse gases emissions from thermal electric power stations; and to increase economic effectiveness of the fuel and energy industry. It will also provide

opportunities for rapid development of non-traditional energy sources, for which the energy facilities redundancy is necessary, and for stable development of economy and society as a whole.

3.5 Fuel and energy balance of the Republic of Belarus till 2020

For the preliminary power and energy balance of the Belarusian Energy System, in accordance with the forecast of the average growth of electric energy consumption in Belarus, see Table 1.

The growth of electric energy consumption is 5-10 % higher than the growth of the gross energy resource consumption in all countries in the world. For the Republic of Belarus, in the forecast period, this trend is kept at the same level; as for the thermal energy, its growth is only half as high as the growth of the gross energy resource consumption. This is because the energy saving potential with regard to the thermal energy saving is high in Belarus.

As we can see from Table 1, the basic loads will be covered by the NPP power; at the same time, the amount of the regulating power in TPS structure will grow, and the total annual operation time of the TPS installed capacity will decrease. However, NPP commissioning will influence not only the modes of operation of the energy sources but also the structure of fuel and energy balance as well (see Table 2). Growth of the nuclear fuel consumption by 2020, in combination with other structural changes in the fuel and energy balance, will make it possible to compensate the growth of gas consumption and significantly stabilize it.

In the future it is possible to terminate the electric energy import and implement the energy system as self-sufficient, as it is the case in most countries of the world. However, if reasonable in economic terms and in terms of energy security, the possibility to resume the electric energy import must be taken into consideration.

In line with the trends of industrial development, use of fuel and energy resources as raw materials in chemical, petrochemical and other industries, not related to fuel, will grow.

In the fuel and energy balance, growth of use of coal (for building materials production and in power engineering) and growth of use of nuclear fuel (as a result of the NPP construction) is taken into consideration.

Inclusion of coal into the fuel and energy balance results from the necessity to diversify the coal import. Coal can be purchased, at comparable prices, not only from the Russian Federation but also from Poland, Ukraine and other countries.

Plans exist to include the nuclear fuel into the fuel balance as soon as possible, because it is the best resource for strengthening the energy security of the Republic. It can be supplied by different manufacturers without high transportation costs; it is possible to accumulate the nuclear fuel reserves with rather small storage costs; also, the expected costs for the nuclear fuel are lower than those for any other kinds of energy resources. In terms of environmental factors, the environmental impact of the nuclear fuel is minimum in comparison with other fuels.

The amounts of local fuels (oil products, associated gas, peat, firewood, lignite), non-traditional and renewable energy sources (wind, sun, phytomass, geothermal sources, biofuel, hydropower resources etc) are specified in accordance with limited potential reserves of energy sources, economic and environmental reasonability of the expenses for their production and use.

To achieve the expected parameters of the fuel and energy balance, along with other activities, the energy security concept provides construction of the NPP, with the capacity about 2 GW, and inclusion of 2,5 – 5,0 million tons of equivalent nuclear fuel into the fuel and energy balance.

Table 1 - Preliminary balance of the Belarusian energy system till 2020 according to the expected average growth of electric energy consumption

Parameter	UOM	Years			
		2005	2010	2015	2020
Total demand for electric energy	billion.kW-h	35,0	39,3	42,5	47,1
Net import	billion.kW-h	4,04	5,1		
Energy system output	billion.kW-h	30,96	34,2	42,5	47,1
TPS and other power engineering facilities installed capacity	MW	7900	8900	9700	9900
NPP installed capacity	GW	-	-	-	2
Total installed capacity	MW	7900	8900	9700	11900
Peak capacity	MW	5871	7012	7814	8970
Required capacity, taking into consideration the 20 % reserve	MW				
		7525	8939	10551	12400

Table 2 – Demand for various types of energy resources and energy in Belarus, in case of maximum GDP growth and minimum reduction of its energy intensity

Types of energy resources	Years							
	2005		2010 forecast		2015 forecast		2020 forecast	
	million tons of e.f.	Per cent	million tons of e.f.	Per cent	million tons of e.f.	Per cent	million tons of e.f.	Per cent
Natural gas (according to the balance of the Union State)			25,3		26,4		27,5	
Gaseous fuel	23,41	77,9	25,2	74,9	25,5	68,7	27,3-24,6	64,3-58,0
including: associated gas extraction	0,30	1,0	0,27	0,8	0,26	0,7	0,22	0,5
as a raw material and for transportation	1,52	5,1	1,80	5,3	3,00	8,1	3,00	7,1
Liquefied gas	0,35	1,2	0,39	1,2	0,38	1,0	0,38	0,9
Oil refinery gas	0,63	2,1	0,76	2,3	0,77	2,1	0,77	1,8
Domestic stove fuel	0,09	0,3	0,09	0,3	0,05	0,1	0,03	0,1
Fuel oil	1,74	5,8	1,74	5,0	1,74	4,6	1,74	4,1
Coal including coke and small coke	0,21	0,7	1,22	3,6	2,7	7,4	3,0	7,2
Gross fuel and energy sources	37,08	41,6		45,9		52,4		
Thermal energy, million Gcal	73,5	77,9		81,8		87,5		

Table 2 (continued)

Types of energy resources	Years							
	2005		2010 forecast		2015 forecast		2020 forecast	
	million tons of e.f.	Per cent	million tons of e.f.	Per cent	million tons of e.f.	Per cent	million tons of e.f.	Per cent
including the equivalent secondary thermal energy resources	0,8	1,0		1,3		1,9		
Electric energy, billion kW-h	35,00	39,9		44,0		50,3		
Local fuels, including secondary thermal energy resources	4,56	6,48		8,46		9,72-9,92		
Local fuels share in boiler and furnace fuels consumption, not including raw materials		16,8	20,5		25,0		26,6-29,1	

E.f. – equivalent fuel

The general characteristics of the majority of energy system stations include high and growing physical depreciation and obsolescence of the main equipment, auxiliary equipment and energy transport communications. Depreciation of the main power generating equipment of electric and heat networks is about 60%, proving the necessity of modernization of the energy system's main equipment.

In accordance with the Concept of the energy safety of the Republic of Belarus, approved by the Edict of the President of the Republic of Belarus No. 433 (17.09.2007), the main lines of improvement of safety of the Belarusian energy system are as follows:

- advance rates of renovation of the fixed assets in comparison with the rates of depreciation in order to achieve the depreciation level not more than 45% by 2020;
- diversification of fuel types for power-generating sources;
- maintenance of existing trunk line interconnections with energy systems of neighboring countries and development of new interconnections.

In order to implement these lines by 2020, the State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus in 2006-2010, the State program of innovative development of the Republic of Belarus in 2007-2010, approved by the Edict of the President of the Republic of Belarus No.136, March 26, 2007, No. 136 (National Register of Legal Acts of the Republic of Belarus, 2007, No. 79, 1/8435) and other programs consider modernization of electric power stations functioning on the basis of steam and gas technologies and implementation of the automated control systems for energy units, allowing to decrease the specific fuel consumption for the heat and electric energy generation and to improve the operational safety of electric power engineering plants.

The main contribution to the improvement of safety of the energy generation sources shall be provided by the construction of the new nuclear-fuel and coal electric power stations, including:

– the NPP, about 2000 MW;

– several thermal electric coal-burning power stations, 800 – 900 MW total power.

To control the NPP energy system loads, several high-power and readily-switchable energy sources will be required.

Along with new sources of power, small TPS at industrial enterprises and in small towns (including district towns) shall be further developed, making the energy supply for the enterprises and towns more safe and cost-effective.

According to the forecasts of social and economic development of Belarus, and considering the energy saving activities, it is expected that the electric energy demand in 2020 will be 47.1 billion kW-hours, and the thermal energy demand, 84.5 million Gcal.

Contradicting the provisions of the State comprehensive program of modernization of the basic production assets of the Belarusian Energy System, energy saving and increase of the share of own fuel and energy resources in Belarus in 2006-2010, the consumption of electric energy and peak power loads will not drop but will grow, because of the GDP growth, first of all, in industry and agriculture.

The growth of electric energy consumption, with the rates higher by 5-10% than that of the gross energy resources consumption, exists in all courtiers of the world. For the Republic of Belarus in the considered period this tendency is kept at the stable level, and as for the thermal energy, its growth is twice slower than that of the gross energy resources consumption. This is due to the fact that Belarus has a high potential for thermal energy saving.

The concept of national energy security provides construction of the NPP (2 GW power) and inclusion of 2.5 – 5.0 million tons of equivalent nuclear fuel into the country’s fuel and energy balance. NPP commissioning shall influence not only the modes of operation of energy sources but the structure of the fuel and energy balance as well (Table 2).

Nuclear fuel consumption growth by 2020, along with other structural changes in the fuel and energy balance, will provide opportunities to compensate the growing demand for natural gas and to stabilize its consumption in a large extent.

4. ALTERNATIVE NPP SITES. ALTERNATIVE ENERGY SOURCES

4.1 Alternative sites for NPP construction

Initially, 74 alternative sites for NPP were considered. Later 20 of them were excluded because they were within the prohibiting factors determined by the main requirements to NPP sites. So, 54 sites were analyzed in terms of unfavorable factors based on the archive data and other similar records [22, 23].

To reduce the amount of surveys, the group of experts was established that have analyzed the hydrological, seismic, tectonic, ecological, meteorological, radiological engineering and geological factors, conditions for agriculture, and have carried out several additional surveys. As a result, three most promising areas were chosen for the detailed analysis:

– Bykhov (Mogilev Region);
– Schklov-Gorki (Mogilev Region);
– Ostrovets (Grodno Region).

In 2006-2008, three sites were chosen in these areas:

– Krasnaya Polyana site (Bykhov area);
– Kukshinovo site (Schklov-Gorki area);
– Ostrovets site (Ostrovets area).

In these sites researches were carried out in order to choose the preferable site for NPP construction.

To compare the sites, all survey results were summarized in Tables 3 – 5 [24].

Table 3 – Characteristics for NPP sites comparison

Characteristic	Sites to be compared		
	Kukshinovo	Krasnaya Polyana	Ostrovets
Seismotectonic conditions			
Area of extended sites on stable blocks, km^2	4.0	2.0	4.5
Distance to the nearest area of possible earthquake source (PES), km (in accordance with IAEA recommendations, at least 5 km)	12 km (to Orsha PES)	24 km (to Mogilev PES)	39 km (to Oshmyany PES)
Soil category, in accordance with seismic properties	II	II	II
Design earthquake magnitude	5	5	6
Maximum design earthquake magnitude	6	6	7
Geological and hydrogeological conditions			
Composition of bed rocks under Quaternary sediments	Dolomite, limestone, clay, silt, siltstone	Chalk, marl, clay	Silt, marl, dolomite
Quaternary sediments thickness, m	68-72	45-55	72-103
Quaternary sediments composition	Primarily moraine, lacustrine and ice-borne loams; moraine sands	Primarily inter-moraine sands; moraine loams and loamy sands	Primarily moraine, loamy sands and loams; moraine sands
Surface occurrence of weak loess-type and lacustrine or boggy soils, 5 m or thicker	No	No	No
First inter-moraine aquifers	Artesian	Free	Intermediate
Depth of occurrence of the first aquifer, m	1,8	10	15
Ground waters protection against pollution from surface (upper confining layer)	Good	Satisfactory	Good
Hydrological conditions for water supply			
Natural source of process water supply	Dnieper river	Dnieper river	Viliya river

Table 3 (continued)

Characteristic	Sites to be compared		
	Kukshinovo	Krasnaya Polyana	Ostrovets
NPP process water supply (makeup) (2.54 m^3/s required)	12.58 m^3/s	18,18 m^3/s	17,3 m^3/s
Weather conditions			
Conform to the standard requirements on all sites considered			
Anthropogenic effects			
Steam and moisture emissions of cooling towers:			
in summer	Increasing of relative humidity by 0.2% over the background level. No influence on the processes of dew, haze or fog formation		
in winter	Increasing of relative humidity by 1% over the background level. No influence on the processes related to humidity variations. No increasing of electric power lines icing		
Radiation conditions on the site, resulting from steam and moisture emissions	Small increasing of radioactive aerosols concentration within 1.5 km from an emission source		
Effect of emissions of other industrial plants on the site area (30 km)	No	No	No
Effect of emergencies outside the site			
Radioactive aerosols transfer in case of forest or peatbog fires	Small	Small; radiation monitoring is necessary	Small
Smoking from emergencies and fires on gas pipelines	Small	No	Small
Smoking from emergencies and fires on oil pipelines	Possible	No	No
Radioactive pollution			
Natural soil pollution by radioactive nuclides at the time of the NPP commissioning, Ci/km^2 (standard pollution: 5 Ci/km^2 max)			
	0.17 max	4.99	0.28
Demographic characteristics			
Population density, per km^2 (100 max permissible)	34	20	24

Table 4 – Characteristics of construction conditions at alternative sites

Data on construction conditions	Sites to be compared		
	Kukshinovo	Krasnaya Polyana	Ostrovets
1 Population density and distribution within 25 km - population density, per km^2	34	20	24
- settlements (direction, distance, population[1)]	- Mogilev, SW, 50 km, 365 000; - Gorki, SE, 15 km, 33900; - Shklov, SW, 28 km, 15000; - Orsha, NW, 25 km, 130500.	- Mogilev, NW, 35 km, 365 000; - Bykhov, SW, 30 km, 16700; - Chausy, NE, 25 km, 10600; - Slavgorod, SE, 25 km, 8300; - Godylevo, E, 25 km, 1000.	- Ostrovets, SW,19 km., 8000; - Svir, 22 km., NE, 1500; - Vilnius, 40 km, W, 542000.
2 Main facilities foundation conditions	Because of high level of confined ground waters and weak soils, constructional dewatering, substantial waterproofing, substitution of soils with low strength characteristics is required. Suffosion and karst processes activation is possible in cavernous and karst dolomites.	Suffosion and karst processes are possible in marls and chalks under quaternary sands.	Construction of main facilities is possible on the natural ground (the most economical choice). Dry construction area.
3 Design earthquake, points	5	5	6
4 Maximum design earthquake, points	6	6	7

Table 4 (continued)

Data on construction conditions	Sites to be compared		
	Kukshinovo	Krasnaya Polyana	Ostrovets
5 Climatic and aeroclimatic conditions	Squalls and whirlwinds are possible	Squalls and whirlwinds are possible	Squalls and whirlwinds are possible
6 Relief (average surface slope) within the main site	15 %	14 %	14 %
7 Radioactive pollution of the site	The site is free of radioactive pollution	The site is within an area of partial radioactive pollution resulting from Chernobyl NPP accident (within the periodic radiation monitoring zone)	The site is free of radioactive pollution
8 Water supply required for facilities to be constructed	2.54 m^3/s	2.54 m^3/s	2.54 m^3/s
9 Conduits for process makeup water supply (length, diameter)	39 km Two lines, ∅1200 mm	36 km Two lines, ∅1200 mm	6 km Two lines, ∅1200 mm
10 Process water supply system	Circulating water supply system with cooling towers	Circulating water supply system with cooling towers	Circulating water supply system with cooling towers
11 Access railway, km	4	27	32
12 Outside highways, km	4	3	4

Table 5 – Analysis of alternative sites correspondence to the requirements of normative documents

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Conclusions	Characteristic	Conclusions
Prohibiting factors (NPP construction is prohibited in accordance with TKP 097-2007)						
The site is located directly on tectonically active fractures	No active fractures	Conforms	No active fractures	Conforms	No active fractures	Conforms
The site seismicity exceeds 9 (maximum design earthquake magnitude, MSK-64 scale)	Design earthquake magnitude: 5 Maximum design earthquake magnitude: 6	Conforms	Design earthquake magnitude: 5 Maximum design earthquake magnitude: 6	Conforms	Design earthquake magnitude: 6 Maximum design earthquake magnitude: 7	Conforms
The NPP site is over water supply sources with proven ground water reserves, being in use or planned to be used for drinking water supply, and it's impossible to prove that these water supply sources cannot be polluted by radioactive substances	No water supply sources	Conforms	No water supply sources	Conforms	No water supply sources	Conforms
There are no water resources in the site area, sufficient to provide 97% compensation of losses in the NPP cooling systems, and there are no reliable sources for compensation of water losses in the reactor plant cooling systems, that are important for the NPP safety. Water requirements: 22 000 m^3/day	150 000 - 200 000 m^3/day water supply is provided, taking environmental limitations into consideration	Conforms	150 000 - 200 000 m^3/day water supply is provided, taking environmental limitations into consideration	Conforms	150 000 - 200 000 m^3/day water supply is provided, taking environmental limitations into consideration	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Characteristic	Conclusions	Characteristic
Active karst is found, or activation of suffosion and karst processes is possible in the site area	No active karst. Suffosion and karst processes activation is possible in cavernous and karst dolomites.	Conforms	No active karst. Suffosion and karst processes activation is possible in marls and chalks under quaternary sands.	Conforms	No active karst. Suffosion and karst processes activation is impossible	Conforms
In the site area, development of active landslides or other dangerous slope processes (landfalls, mud torrents) is possible	No dangerous processes	Conforms	No dangerous processes	Conforms	No dangerous processes	Conforms
Catastrophic flashes or floods are possible in the site area with 10000 years intervals, taking into consideration ice blockages, wind-induced water surges, tidal phenomena	No danger	Conforms	No danger	Conforms	No danger	Conforms
The site area can be flooded in case of water inrush from upstream reservoirs	No danger	Conforms	No danger	Conforms	No danger	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Characteristic	Conclusions	Characteristic
The territory where the NPP construction is prohibited in accordance with nature conservation regulations	No prohibitions	Conforms	No prohibitions	Conforms	No prohibitions	Conforms
The territory with population density 100 1/km^2 or more (including the NPP builders and personnel)	Population density is 34 1/km²	Conforms	Population density is 20 1/km²	Conforms	Population density is 24 1/km²	Conforms
Adverse factors						
The territory, where contemporary differentiated Earth crust movements are found (vertical, more than 10 mm/year; horizontal, more than 50 mm/year)	Vertical, less than 10 mm/year; horizontal, less than 50 mm/year	Conforms	Vertical, less than 10 mm/year; horizontal, less than 50 mm/year	Conforms	Vertical, less than 10 mm/year; horizontal, less than 50 mm/year	Conforms
Territories with saline soils, where the processes of salinization or leaching exist	No territories with saline soils and processes of salinization or leaching	Conforms	No territories with saline soils and processes of salinization or leaching	Conforms	No territories with saline soils and processes of salinization or leaching	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Characteristic	Conclusions	Characteristic
Territories with abandoned mines or other similar works	No	Conforms	No	Conforms	No	Conforms
There are floodplain terraces of rivers or water body coasts in the territory, with a shear line or an abrasive terrace edge movement exceeding 1 m/year.	No	Conforms	No	Conforms	No	Conforms
Slopes, 15º or more	No	Conforms	No	Conforms	No	Conforms
Chemical or biological pollution of water in the supply source exceeds permissible levels	Chemical and biological pollution of water in the supply source is within permissible levels	Conforms	Chemical and biological pollution of water in the supply source is within permissible levels	Conforms	Chemical and biological pollution of water in the supply source is within permissible levels	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Characteristic	Conclusions	Characteristic
Supply area of main aquifers	In accordance with available information, the site territory is not a supply area for main aquifers. Final assessment is possible during the following survey stages.	Conforms	In accordance with available information, the site territory is not a supply area for main aquifers. Final assessment is possible during the following survey stages.	Conforms	In accordance with available information, the site territory is not a supply area for main aquifers. Final assessment is possible during the following survey stages.	Conforms
The site with ground waters at a depth less than 3 m from the leveling surface in soils 10 m or thicker, with a filtration coefficient 10 m/day or more, or in highly fractured or coarsely-fragmental soils with low sorption capacity	Ground waters are at a depth less than 3 m from the leveling surface	Does not conform. Dewatering is required.	Ground waters are at a depth 10 m or more from the leveling surface	Conforms	Ground waters are at a depth 10 m or more from the leveling surface	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Conclusions	Characteristic	Conclusions
Structurally and dynamically unstable soils are common in the site area (frozen or permanently frozen soils, loess subsiding and swelling soils, saline and peaty soils, loose sands, soils with a modulus of deformation less than 20 MPa etc.)	Practically no dynamically unstable soils. Surface lacustrine and boggy peaty soils will be removed; boggy and lacustrine peaty soils in the lower part of the quaternary sediment profile, thicker than 10 m, are occurring everywhere at 40-50 m depth	Conforms	Practically no dynamically unstable soils. Loess-type, lacustrine and boggy peaty soils, appearing at the surface in some areas, will be removed during leveling	Conforms	No dynamically unstable soils.	Conforms

Table 5 (continued)

Factors considered for the site selection	Sites to be compared					
	Kukshinovo		Krasnaya Polyana		Ostrovets	
	Characteristic	Conclusions	Characteristic	Conclusions	Characteristic	Conclusions
Hurricanes and whirlwinds are possible in the territory	Squalls and whirlwinds are possible	Does not conform. Risk of whirlwinds must be considered during the NPP design	Squalls and whirlwinds are possible	Does not conform. Risk of whirlwinds must be considered during the NPP design	Squalls and whirlwinds are possible	Does not conform. Risk of whirlwinds must be considered during the NPP design
Unacceptable changes in a behavior, temperature or composition of ground waters or surface waters are possible in the territory, resulting from planned industrial development, construction of waterworks or utilities, development of agricultural irrigation	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms
Unacceptable changes in a behavior, temperature or composition of ground waters or surface waters are possible in the territory, resulting from planned industrial development, construction of waterworks or utilities, development of agricultural irrigation	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms	There are no forecasts of changes in a behavior, temperature or composition of ground waters or surface waters	Conforms

The results of comparison are as follows [27]:

– there are no prohibiting factors (i.e. factors or conditions, making the NPP construction impossible in accordance with normative documents) for any of three sites considered;

– on Krasnaya Polyana and Kukshinovo sites, activation of suffusion-karst processes is possible, that is a complicating factor, requiring further studies. Engineering geological and hydrogeological conditions of Kukshinovo site are difficult (irregular location of soils with various composition and properties, presence of confined waters with a piezometric level near the surface, up to 1.5 m);

– considering all significant factors, Ostrovets site is more preferable than Krasnaya Polyana or Kukshinovo.

Considering all facts given above and IAEA recommendations, and taking into consideration the importance of safety factors, the Ostrovets site has been determined as a preferable one.

4.2 Alternative electric energy sources

Nuclear fuel, as well as other conventional fuels, is a nonrenewable energy source. The annual industrial consumption of uranium in the world is about 60 thousand tons.

The Nuclear Energy Agency (NEA) of the Organization of economic cooperation and development (OECD) has published a report (3 June, 2008), asserting that, if consumption is kept at the present level, the world uranium deposits shall be sufficient for all existing reactors for at least one hundred years. As it was noted in the report, assuming that the cost of extraction of one kilogram of uranium will be less than 130 US Dollars, the explored uranium deposits that shall be extracted at low costs are about 5.5 million tons, and undiscovered deposits, 10.5 million tons [1].

It is said in the report that the world amount of electricity production from the nuclear energy in the previous year was 372 GW, and by 2030, 80% growth is expected. The OECD NEA supposes that the explored deposits of uranium can fully balance the growth of demand for electricity produced from the nuclear energy; further, with the development of technologies, the world deposits of uranium will be able to satisfy the world demands fully for several thousands years.

In the world, the average cost of electric energy produced by the new NPP is 5 cents/kW-h. According to the WEA* assessments, the nuclear power industry is profitable if the natural gas cost is higher than 4.70 USD/million BTU, and the coal cost is higher than 70 USD/ton. The economic effect can be larger if the enterprises will pay fines for contamination of the environment. In 2007, 439 NPP units were in operation, and the construction of 34 units was in progress; the nuclear energy percentage in the total energy consumption was as follows: in France, 39 per cent; in Sweden, 30; in Latvia, 24; in Switzerland, 22; in Finland, 20; in Ukraine and Belgium, 15; In the Republic of Korea, 14; in Japan, 12; in Germany, 10 [1].

According to the common opinion [25,26], in the period to 2020, the nuclear power industry will be developed on the basis of thermal reactors using U-235 as a fuel. Later, preparation of thermal reactors for transition to the thorium-uranium cycle,

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* WEA – World Energy Agency.

[1] BTU – British thermal unit. 1 BTU = 252 kcal or 1055 J.

with lacking U-233 produced in the thorium blankets of fast reactors, will be started. With U-235 accumulation in these reactors, with thorium concentration appropriate for thermal reactors, extraction of pure U-235 shall become unnecessary for production of thorium-uranium fuel. Also, the developments intended to make the MOX fuel (i.e. the mixture of weapon-grade plutonium and spent NPP fuel) applicable in thermal reactors are in progress during many years. For example, the construction of the average-capacity installation, intended to provide eight WWER-1000 reactors with the MOX fuel, is in progress, managed by the Russian Nuclear Energy Agency (Rosatom). The installation project is based on the experience, technologies and equipment obtained at the MOX fuel production facility in Hanau, Germany. With the production amount approximately 1 ton of plutonium per year, the cost of MOX fuel is twice as high as the cost of uranium fuel.

So, in spite of the fact that the available deposits of uranium are comparable with the deposits of oil and gas, the new technologies provide the nuclear energy resources growth, 60 times at least, making these resources sufficient for 3000 years (subject to the nuclear energy consumption remaining at the level existing now).

4.3 Comparative characteristics of different types of fuel, TPS and NPP

For the purposes of comparison of different types of fuel, the term “equivalent fuel” is introduced. The combustion heat of 1 kg of the equivalent fuel (e.f.) is 29.3 MJ or 7000 kcal, approximately the same as that of 1 kg of black coal. For the characteristics of different types of fuel, see Table 6.

Table 6 – Characteristics of different types of fuel

Type of fuel	Calorific value, MJ/kg	CO_2 emission factor	Calorific value of a unit amount, MJ/kg	% of carbon content, CO_2 MJ/kg (l)
Crude oil	45-46	89	70-73	37-39
LPG	49	81	59	
Natural gas	39	76	51	55
Black coal (NSW and OLD)	21,5-30	67	90	
Black coal (SA and WA)	13,5-19,5			
Black coal (Canadian bituminous)	27,0-30,5			
Black coal (Canadian sub-bituminous)	18.0			
Brown coal (average)	9,7	25		
Brown coal (Low Yang)	8,15		1,25 kg/kW	
Wood (dry)	16	49	94	
Natural uranium (in light-water reactors)	500 GJ/kg			
Natural uranium (in light-water with U and Pu of repeated cycle)	650 GJ/kg			
Uranium (up to 3,5 % U-235 in WWER)	3900 GJ/kg			
Natural uranium (in fast neutron reactors)	28000 GJ/kg			

Taking into consideration that the available uranium and coal deposits are maximum, in comparison with other fuels, it is reasonable to compare these two types of fuel in more details.

For the comparative characteristics of the coal and nuclear fuel energy cycles, see Figure 2 [8].

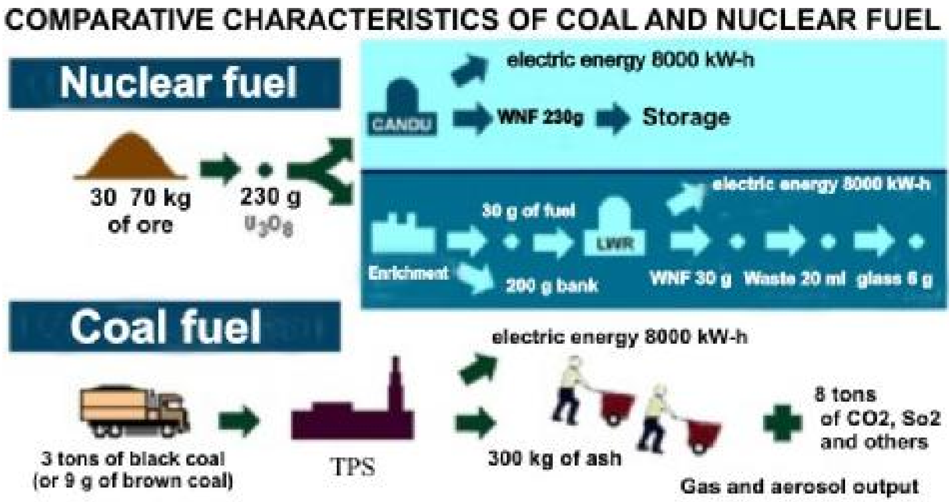


Figure 2 – **Comparison of types of fuel and waste at burning**

Figure 2 demonstrates that: 30 … 70 kg of uranium ore is necessary to obtain a small amount (230 grams) of uranium dioxide concentrate. In this concentrate, the uranium, called "natural uranium", contains approximately 0.7% of U-235, the fissile uranium isotope. Natural uranium is used to fuel CANDU type reactors (Canada), widely applied throughout the world. In the countries using light-water reactors (so-called PWR and BWRS reactors), natural uranium is enriched with regard to U-235 isotope content; as a result, about 30 g of enriched uranium, with U-235 concentration up to 3.5%, can be obtained from 30 – 70 kg of uranium ore. Spent uranium in CANDU reactors contains very small amount of nuclear fuel, and it is processed as waste. The uranium spent in light-water reactors contains rather large amount of nuclear fuel, and in some countries it is processed for recycling. After the fuel reprocessing in light-water reactors, about 20 ml of liquid highly active waste remain. Such highly radioactive waste, not more than 1 cubic centimeter, is "vitrified", i.e. placed in special pellets made of special glass, up to 6 g, having a size comparable with a large coin. During the nuclear reactor operation, other wastes also appear, but they are much less important [28].

These data demonstrate several advantages of the nuclear power industry in comparison with other energy technologies:

- no emissions of greenhouse gases and harmful chemical substances;
- no emissions of radioactive substances during normal NPP operation (emissions are limited by permitted quotas, radioactive wastes are localized, concentrated and buried), while at TPS radioactive wastes (natural radionuclides of potassium, uranium, thorium and their decay products) are involved in biological life cycle;
- small influence of raw material costs on the cost of produced electric energy.

4.4 Description of alternatives

Now, the nuclear power industry is one of the main world sources of electric energy, covering 17% of the total amount of produced electric energy; in Russia, the NPP-produced energy percentage is approximately the same. Environmental and economic advantages of the nuclear power industry provide good perspectives for it in the future. Such advantages of the nuclear power industry as competitiveness in comparison with the organic fuel energy units, replacement of nonrenewable resources, much lesser demands for transportation and negligibly small emissions of harmful substances into the atmosphere (including the carbon oxides, that is also important in terms of greenhouse effect), provide favorable conditions for its further development.

The alternatives suggested by several public environmental organizations as the means to cover the regional needs in energy in the future are as follows:

- thermal electric power stations burning the organic fuel (coal, gas, fuel oil);
- hydroelectric power stations of medium and low power, in terms of available water resources;
- wind electric power plant;
- other non-conventional energy sources (solar power plants, hydrogen power engineering, fuel elements).

These alternatives shall be compared in terms of technical and economic factors (energy production costs), environmental factors (influence on the environment) and factors of assessment of total energy production cost including the environmental effects for the fuel chain and the influence on the occupation rates and the society (local, regional and global).

For the comparison of total cost of electric energy production, taking into consideration the external and social expenses for the compared technologies of energy production (including the environmental effects for the fuel chain and the influence on the occupation rates and the society in local, regional and global scopes), see Table 7 [29].

Table 7 – Total cost of electric energy production (Eurocents per kW-h)

Technology	External expenses (expenses on fuel cycle)	Financial expenses	Total
Coal	2.0	5.0	7.0
Oil	1.6	4.5	6.0
Gas	0.36	3.5	3.9
Wind	0.22	6.0	6.2
Hydroelectric energy	0.22	4.5	4.7
Nuclear energy	0.04	3.5	3.5

The results of the assessment of the resource base for thermal electric power stations are as follows.

The goal for the future is to make the natural gas consumption percentage less than that for the coal.

Wind energy units also have a definite perspective which should be assessed according to the set of technical and geographical factors.

A very important factor for comparison of suggested in the project and alternatives means of covering perspective electric loads is a factor of guaranteed output of electric energy.

It is determined by the value of the installed capacity usage factor (ICUF) of the energy source.

Project ICUF of the NPP is less than 90%, ICUF of TPS on gas, coal and fuel oil is approaching to this value but is less than for NPP. By their technological specifications NPP can operate only in deep base mode. So the necessity to cover of a part of loads belongs to TPS. Refusal from NPP will lead to increase of average ICUF for TPS.

TPS ICUF can be up to 50 %, and ICUF of wind plants and solar energy sources is less than 50 %. So to be equal in electric energy supply safety with other sources whose ICUF is 50 % and less it is necessary to have reserve sources of the same power using probably, organic fuel (as a rule diesel generators).

Comparative assessment of environmental safety by the atmospheric outputs of NPP and alternative sources at different fuel types including stages of electric energy production and operation is given in Table 8 [30.31].

Table 8 – Atmospheric outputs from different fuel cycles including stages of electric energy production and operation, g/(kW-h)

Type of output	Fuel cycle			
	NFC	Coal	Oil	Natural gas
SO_x	1,500	12,500	8,300	13,700
NO_x	0,400	3,000	4,500	3,400
CO	0,010	0,240	0,610	0,060
CH_4	0,005	0,050	1,250	0,010
CO_2	8,000	1100,000	640,000	530,000
Solid particles	0,400	0,900	0,860	0,140
Note: NFC output is spread in different distant territories.				

The main greenhouse gases of atmospheric output according to Kyoto Agreement are CO_2 and CH_4.

Advantages of TFC over other energy technologies by greenhouse gases are obvious.

Brief comparison of NPP and TPS by environmental safety shows that 1 GW of NPP set power allows to save annually $5{,}9\cdot10^6$ tons of coal or $2{,}2\cdot10^6$ tons of fuel oil or $2{,}6\cdot10^9$ m^3 of gas. Besides it prevents output of great amount of gases formed at burning of organic fuel and formation of solid wastes – $8{,}3\cdot10^5$ tons/year (for coal). Thermal electric power plant emits more radioactivity into the atmosphere than NPP of the same power. It has been experimentally proved that individual radiation doses in the region of TPS 5-10 times more than in the region of NPP.

Parameters of influence on the environment of different electric energy producers using different types of fuel are given in Table 9 [30 – 33].

Nuclear power industry in Russia is not the main source by any parameter of environmental contamination. Its part in total industrial output is 0,6 %, in output of contaminated water is 4,6 %, in the total volume of toxic chemical wastes formed annually and stored – 1,1 %.

Atomic branch enterprises' part in total irradiation of the population is only 0,1 %.

Specific peculiarity of NPP is output of radioactive substances at operation. Permitted output of NPP into the atmosphere set by the RF regulating authorities determine population dose of 10 μSv per year [34]. Actual output is 1-2 % of the value of permitted output creating for population doses equal to fluctuations of natural radiation background.

Table 9 – Comparison of specific values of population health damage from harmful outputs of electric power stations into the atmosphere in natural and monetary values β per unit of produced electric energy for European part of the Russian Federation

Electric power stations	$L/10^6$, years /(kW-h)	$N_{x.6}/10^6$,1/(kW-h)	$N_{day}/10^6$,1/(kW-h)	β, Rubles/ kW-h
TPS in operation: on natural gas on coal	 0,03 0,44	 0,01 0,14	 3 50	 0,03 0,50
TPS to be built, on coal	0,20	0,06	20	0,20
NPP (WWER-1000)	$1{,}0 \cdot 10^{-4}$	-	-	$3{,}0 \cdot 10^{-5}$

Given comparison allows recommending NPP as the safest, economic and ecologically available energy source to meet the requirements of the Republic of Belarus for future perspective.

5 POSSIBLE ALTERNATIVES FOR IMPLEMENTATION OF DESIGN SOLUTION

Nuclear power engineering is a technology based on utilization of heat energy released as a result of fission of heavy nuclei of uranium and plutonium. The amount of energy, released in a single act of nucleus fission, is about 200 MeV, or 3.2×10^{-11} J. In general, 200 MeV is very small amount. However, taking into consideration the particle masses, this energy is extremely high. E.g., to obtain heat energy equal to 1 MW*day (i.e., to generate 1 MW of heat energy, or 0.33 MW of electric energy during a day), only 1.24 g of Uranium-235 is required. The equivalent amount of coal, with 30230 kJ/kg combustion heat, is 2860 kg/day. Thus, the coal/Uranium-235 ratio for obtaining equal energy is 2300000:1.

Heat power, released in a reactor core during a controlled reaction of fission of heavy nuclei, is transferred by a coolant to a heat exchanger, where it is utilized for generation of steam, driving a turbine-type generator for electricity generation (similar to thermal power plants).

The majority of nuclear reactor units in the world are light water reactors (LWR). In these reactors, water is used for maintaining a chain reaction and for transferring heat from a reactor core. Water is used also as a moderator of neutrons. There are two types of these reactors:

- boiling water reactor (BWR);
- pressurized water reactor (PWR), such as a Russian reactor, WWER.

Also, there are two types of reactors with other moderators:

- pressurized heavy water reactor (HWR);

- high-power channel-type reactor (in Russia, RBMK), a reactor with a graphite moderator. This type of reactors is not described here, because there are no plans now to construct these reactors.

In spite of the variety of types and sizes, there are only four main categories of reactors:

– generation 1 – reactors of this generation were developed in 1950 – 1960 and are enlarged and moderated military nuclear reactors designed for moving submarines and for production of plutonium;

– generation 2 - most reactors that are in industrial operation are referred to this category;

– generation 3 - currently reactors of this category are being put into operation in some countries mainly in Japan;

– and finally, **generation 4** – it includes reactors that are at the stage of development and are planned to be put into operation in 20-30 years.

Generation 1

First reactors of Soviet design **WWER 440-230** are referred to generation 1. In these power units water is used for cooling and their construction is similar to PWR type reactor. The main drawback of these reactors is absence of alarming systems of atomic reactors and systems of emergency cooling of atomic reactor core.

Generation 2

Probably, the most sadly known reactor in the world is CTPR reactor referring to generation 2. It is a graphite nuclear reactor with boiling water. This reactor is also called channel reactor. The most widespread reactors are pressurized water reactors; there are 215 of them in the world. Initially PWR reactor construction was developed for military submarines. In comparison with other reactors this type has small dimensions but produces a big amount of energy. Russian WWER reactor has similar design and history. Currently there are 53 reactors of this type in 7 countries of the Eastern Europe. Third modification of WWER reactors of 1000-320 type was greatly changed; it has a grater power (up to 1000 MW).

Second most common type of reactors is with boiling water (BWR) (now there are about 90 such plants in the world) that is an advanced type of PWR. In this type the attempt to simplify the construction and to increase the heat effectiveness was tried. But this reactor hasn’t become safer. It is more dangerous PWR reactor with a big number of new problems.

One more currently spread construction is pressurized heavy water reactor **(PHWR)**. At present there are 39 reactors of this type in seven countries. The most typical representative of them is Canadian reactor CANDU using natural uranium as a fuel and cooling is carried out by heavy water. Protective cover of the reactor is surrounded by 390 separate tubes. One of its drawbacks is too big amount of uranium in the core what leads to instability of the core. The tubes under pressure contain uranium pipes and are subjected to neutron bombing. As we can see from the Canadian experience after 20 years of operation it is necessary to carry out expensive repairing works.

Generation 3

Reactors of generation 3 are called “advanced reactors”. Three reactors of this type are functioning in Japan; a great number is at the stage of development or construction. About 20 types of reactors of generation 3 are at the stage of development (IAEA 2004, WNO 2004a). Most of them are evolutional models developed on the base of reactors of the second generation with changes on the basis of innovational approaches. According to the data of the World Nuclear Association, generation 3 is characterized by the following items (WNO 2004b):

– standardized project of each type of the reactors allows to make the procedure of licensing shorter, decrease the main expenses and duration of construction works;

– simplified and firm construction makes them easy to work with and less sensitive to failures during the operation;

– high coefficient of readiness and longer period of operation life – about sixty years;

– decreasing the possibility of accidents connected with melting of core;

– minimum impact on the environment;

– full fuel combustion to decrease its expenses and amount of wastes.

Currently there are many projects of reactor of the third generation at different stages of development. We give a partial list with the most important examples marked by the World nuclear association (WNO 2004Ь) and International Atomic Energy Agency (IAEA 2004).

Pressurized water reactor

There are the following types of design of big reactors: APWR (developed by companies Mitsubishi and Westinghouse), APWR (Japanese company Mitsubishi), EPR (French company Framatome ANP), AP-1000 (American company Westinghouse), KSNP+ и APR-1400 (Korean companies) and CNP - 1000 (Chinese national nuclear corporation). In Russia companies Atomenergoproject and Hydropress developed an advanced WWER-1000. the main representatives of advanced small and medium reactors are AP-600 (American company Westinghouse) and WWER-640 (Atomenergoproject and Hydropress).

Boiling water reactor

The largest advanced plants are ABWR and   ABWR- II (joint project of Japanese Hitachi and Toshiba, American General Electric), BWR 90+ (Swiss company Westinghouse Atom of Sweden), SRW - 1000 (French company Framatome ANP), and ESBWR (American company General Electric).

HSBWR and HABWR (designer - Japanese Hitachi) are advanced reactors with boiling water of small and medium sizes.

Three reactors of ABWR type are functioning in Japan – two of them were put into operation in 1996, the third one – in 2004 in NPP Kasivazaki Kariva.

Heavy water reactor

ACR - 700 reactor is an evolutional construction of CANDU reactor (Atomic Energy of Canada Limited). India is developing AHWR (advanced heavy water reactor) [36].

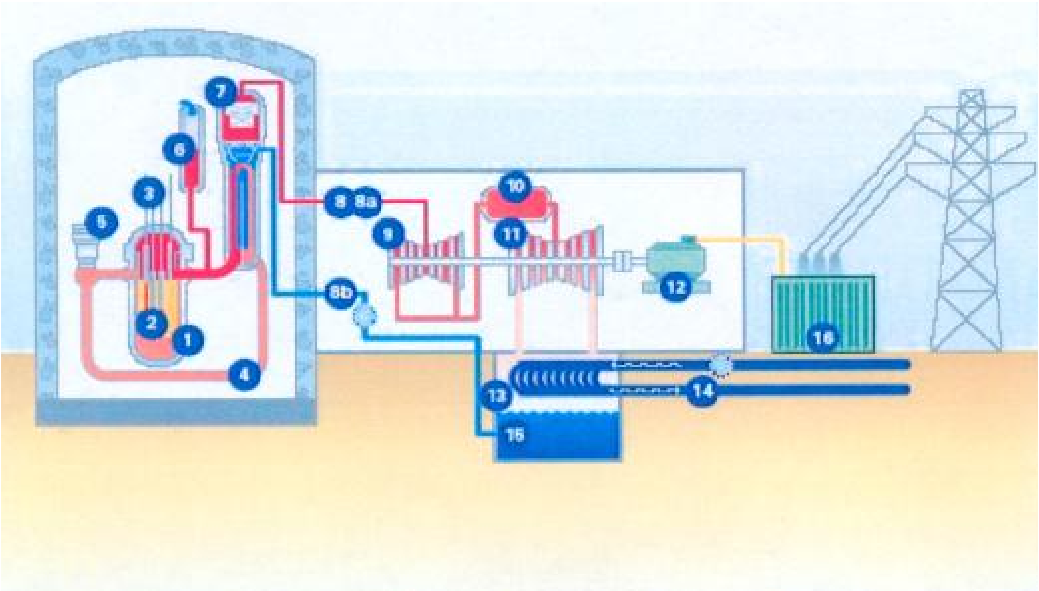
5.1 Pressurized water reactor (PWR)

This is a most common type of industrial reactors in the world. About 60% of the NPPs currently in operation use the reactors of this type.

Uranium dioxide (UO_2) with 3-5% enrichment with regard to Uranium-235 is used as a fuel; it is placed in zirconium tubes, 3.5-4 m length. Pressurized water is used as a moderator and, as a coolant, transfers heat from a core in a steam generator; in a secondary cooling circuit, water is heated for steam generation. Steam is used to drive turbine(s) (see Figure 3).

To increase a boiling point and provide more effective transfer of heat, a coolant in a primary cooling circuit is under high pressure (16 MPa). During passing through a core, a coolant removes heat, released during a reaction of fission of Uranium-235 nuclei; a coolant temperature is increased to 300-330ºC. In a steam generator, heat is transferred to a coolant of a secondary cooling circuit, pressurized up to 7.8 MPa. Then, pumps are used to deliver a primary coolant to a core inlet. A secondary coolant is heated in a steam generator, up to 290°C, and is delivered to a turbine generator. The heat efficiency of a NPP with PWRs is about 32-37%.

A reactor and main equipment of a primary cooling circuit are mounted in a containment, designed to provide integrity in case of an internal impact (breakage of a pipeline in a primary cooling circuit, explosion of detonating mixture generated during a reactor operation) or an external impact (earthquake, small aircraft impact, act of terrorism).

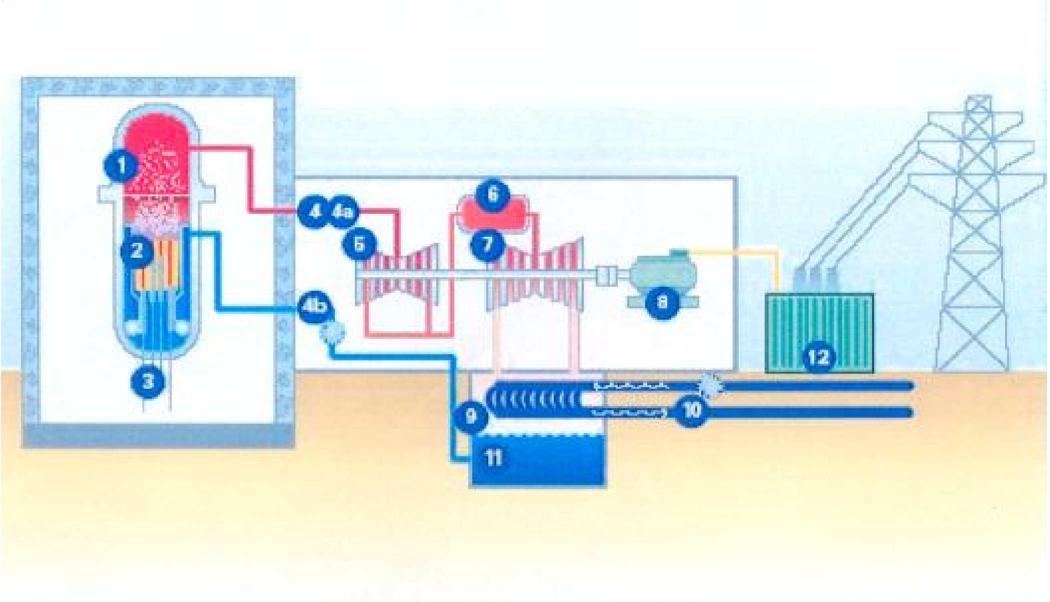


(1) reactor, (2) core, (3) absorbing rod, (4) primary cooling circuit, (5) main circulating pump, (6) pressure compensator, (7) steam generator, (8) secondary cooling circuit, (8a) steam for turbine, (8b) water for steam generators, (9) high-pressure cylinder, (10) steam superheater, (11) low-pressure cylinder, (12) generator, (13) condenser, (14) condenser cooling water circuit, (15) condensate, (16) transformer.

Figure 3 – Main components of the NPP with pressurized water reactor

5.2 Boiling water reactor (BWR)

BWR is a single-circuit reactor without a steam generator (see Figure 4), with water circulating through a core, serving as a moderator and a coolant. As a result of heat removal in a core, water is heated up to 300°C, boils and generates steam under about 7.0 MPa. About 10% of water is converted to steam and transferred to steam turbines. After condensation, water is returned to a core by pumps, completing a circulation cycle. Fuel is similar to that in PWR, but its specific volume power (power per unit of core volume) is two times less, with lower temperatures and pressures. It means that, to produce equal quantity of heat, a BWR vessel must be larger than that for a PWR, but, because there is no steam generator, and pressures are lower, a protective containment can be smaller. The significant drawback of this nuclear unit is an existing risk of pollution of a circuit by radioactive fission products in case of failure of a fuel element cladding; also, radioactive pollution of internal surfaces in a cooling circuit by radioactive corrosion products must be taken into consideration during preventive and current maintenance. With lower pressures (7.0 MPa) and temperatures, the heat efficiency of a NPP with BWRs is about 30-35%.



(1) reactor, (2) core, (3) absorbing rods, (4) primary cooling circuit, (4a) steam for turbine, (4b) water for reactor, (5) high-pressure cylinder, (6) steam superheater, (7) low-pressure cylinder, (8) generator, (9) condenser, (10) cooling water circuit, (11) condensate, (12) transformer.

Figure 4 – Main components of NPP with boiling water reactor (BWR)

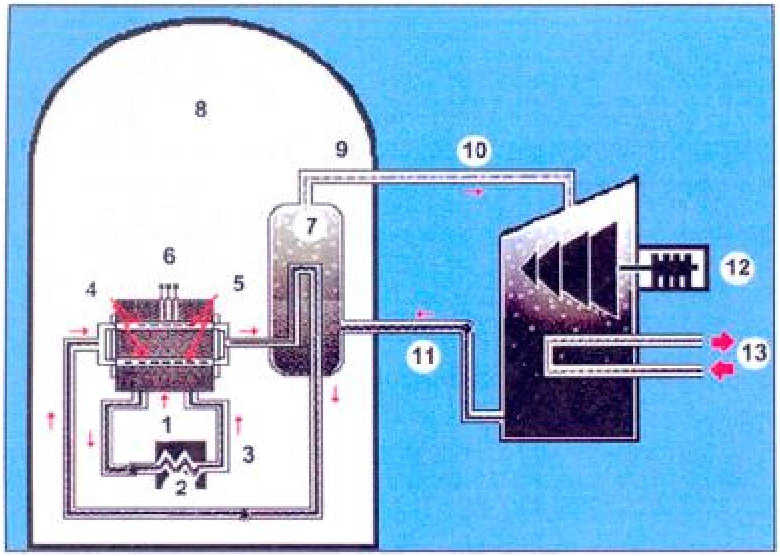
5.3 Pressurized heavy water reactor (CANDU)

In CANDU reactors, deuterium oxide (as a special type of water) is used as a cooler and a moderator. As a result, low-enriched or natural uranium (UO_2), placed in zirconium tubes, is applicable as a fuel. A CANDU reactor design is similar to PWR, but, instead of large strong vessel, fuel elements are placed in many (several hundreds of) horizontal tubes (channels), being under the working pressure of a coolant. Heavy water is used to cool these tubes; it removes heat from a reactor core, similarly to PWR. Tubes under pressure are placed in a large vessel, or a calender, containing separate heavy-water moderator under low pressure (see Figure 5).

The specific volume power of CANDU reactors is about one tenth from that of PWR; as a result, for CANDU reactors, a protective containment must be much larger than for PWR having equal power.

CANDU fuel is different from that of PWR or BWR: it is much shorter, with several bundles of fuel elements (usually, 12.5 cm each), placed against each other in a fuel channel. Such mounting of a fuel tube and a bundle of fuel elements means that it is possible to replace fuel during operation, with a reactor not stopped; as a result, availability ratio of an installation is increased. As a rule, for a primary cooling circuit, the operating pressure is 12 MPa, and the operating temperature is 285ºC, resulting in heat efficiency about 30%.

Modified CANDU reactor, ACR, is a hybrid of PWR and CANDU. In this type of reactors, slightly enriched fuel and light water, as a coolant, are used. As a result, power density and fuel burn-out are increased, making it possible to reduce a reactor size and quantity of spent fuel, in comparison with its natural equivalent.



(1) reactor, (2) heat exchanger, (3) moderator, (4) fuel channels, (5) fuel, (6) control rod, (7) steam generator, (8) protective containment, (9) steam, (10) steam line, (11) pump, (12) turbine generator, (13) water for a condenser cooling.

Figure 5 – Main components of NPP with pressurized heavy water reactor (CANDU, ACR type)

5.4 Reactor types comparison in terms of the main criteria

For the comparison of reactor types described above, see Table10.

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Table 10 - Main parameters of different types of reactors

Reactor type, heat energy conversion cycle	Fuel	Coolant	Operating pressure, MPa	Core outlet temperature, °C	Specific volume power (1,0 for PWR)	Efficiency, %	Containment	Note
PWR, double-circuit	Low-enriched uranium, 3 – 5% ^{235}U	water	16	300 - 330	1.0	32 - 37	yes	The secondary cooling circuit is not radioactive. The primary cooling circuit equipment is fully protected by the containment
BWR, single-circuit	Low-enriched uranium, 3 – 5% ^{235}U	water	7.0	about 300	0.5	30 - 35	reactor only	The circuit is radioactive everywhere. High dose burdens during maintenance. Larger size than that of PWR.
CANDU, hybrid, double-circuit	Natural uranium	heavy water	12	285	0.1	30	yes	The secondary cooling circuit is not radioactive. The primary cooling circuit equipment is fully protected by the containment. Larger size than that of PWR.

Thus (see Table 10), PWR reactors have some positive characteristics:

- maximum power density in a core and, therefore, minimum size per unit power;
- double-circuit structure of NPP provides location of radioactive equipment (primary circuit) within a protective containment;
- minimum dose burden during maintenance.

As a result of these advantages, reactors of this type are widely applied in electric energy production (about 60% of world energy production).

The main worldwide vendors of NPPs with PWR units are Westinghouse-Toshiba (USA, Japan), Atomstroieksport (Russia), Areva NP (France and Germany) (see Table 11).

Table 11 – Reactors considered as alternatives for the Belarusian NPP

Electric power, MW	Type of reactor	Model	Manufacturer	Generation	Web-site
600	PWR	AP -600	Westinghouse-Toshiba	III+	www.ap600.westinghousenuclear.com
1006 1200	PWR	B-428, B-412 B-491	Atomstrojexport	III+	www.gidropress.podolsk.ru/energlish/raszrad_e.html
1100	PWR	AP - 1000	Westinghouse-Tosiba	III+	www.ap1000.westinghousenuclear.com
1660	PWR	EPWR	Areva NP	III+	www.areva-np.com

These NPPs meet the requirements of IAEA, EUR, and national norms of nuclear and radiation safety. For the main characteristics of reliability of these NPPs, see Table 12.

Table 12 – NPP reliability

NPP type	Heavy damage of core, per reactor, annually	Emergency limit radiation release from a reactor unit, per reactor, annually
AP - 600	$< 1.0 \times 10^{-7}$	$< 1.0 \times 10^{-8}$
AP - 1000	$< 2.4 \times 10^{-7}$	$<3.7 \times 10^{-8}$
AES - 2006	$< 5.8 \times 10^{-7}$	$<1.0 \times 10^{-8}$
EPWR	$< 3.9 \times 10^{-7}$	$< 6.0 \times 10^{-8}$

From the NPP types given above (Table 12), in this century, the following have been implemented:

– AP-600 and AP-1000: drafts only, never built;

– EPWR: the first NPP constructions during the recent 15 years in Finland and France are in progress (by French companies);

– AES – 2006 (NPP-2006). Russia is the only country that has been actively building NPP with WWER-1000 abroad for the last 10 years: China, India, Iran, and Bulgaria. Rostov NPP was put into operation in 2001, Kalinin NPP – in 2007, NPP Temelin – in 2001 and 2002, and NPP Tyanvan – in 2007. The nearest prototype of

NPP-2006 project was commissioned in 2007 in China (two energy units). Construction of two plants is being completed in India, construction of two plants has been started in Bulgaria and four in Russia according to the Russian projects of the third generation.

In September 2009 protocol about completing of warranty operation of the second energy unit of "Tyanvan NPP". Operation of both power plants is stable with power of 1060 MW, have high technical and economic characteristics and have been recognized as the most secure NPP in the world.

Purpose reference points of project NPP – 2006 are given in Table 13 [37].

Table 13 – Purpose reference points of the project NPP – 2006

Required quality and quantity safety level а) safety systems б) calculated value of the possibility of core damages by the initial events б) calculated possibility of reaching of limit emergency output at beyond design basis accident	 active and passive not more than 10^{-5} reactor $^{-1}$ H year $^{-1}$ less than 10^{-7} reactor^{-1} H year $^{-1}$
Low sensitivity to human factor (errors, wrong decisions of the personnel)	5.6×10^{-8}

6 DESCRIPTION OF THE NPP. OPERATIONAL SYSTEMS AND TECHNICAL SOLUTIONS

6.1 Main technical and economic characteristics of NPP-2006

For the main technical and economic characteristics of NPP-2006, see Table 14 [38].

Table 14 – Main technical and economic characteristics of two-unit NPP with power of 2340 MW

Characteristics		Measuring unit	Parameter value
1 General parameters of the unit			
1.1	Rated thermal power of the reactor	MW	3200
1.2	Rated electric power	MW	1170
1.3	Effective number of use of rated power	hour/year	8400
1.4	NPP service life	years	50
1.5	Seismic resistance		
1.5.1	Maximum design earthquake (MDE)	g	0,25
1.5.2	Project value (PV)	g	0,12
1.6	Number of fuel elements in the core	pieces	163
1.7	Time of fuel presence in the core	years	4 - 5
1.8	Depth of fuel burning, maximum	MW day/kg U	up to 60 (expected, up to70)
1.9	Maximum linear energy density of fuel elements	W/cm	420
2 Main parameters of the first circuit			
2.1	Number of circuit loops	pieces	4

Table 14 (continued)

Characteristics		Measuring unit	Parameter value
2.2	Coolant expenses through reactor	m^3/hour	85600 ± 2900
2.3	Coolant temperature at the entrance to the reactor	^{0}C	$298{,}6_{-4}^{+2}$
2.4	Coolant temperature at the exit from the reactor	^{0}C	329 ± 5
2.5	Rated pressure of stationary mode in the exit from the core	MPa	16,2 ± 0.3
3 Main parameters of the second circuit			
3.1	Turbine		
3.1.1	Rotation frequency	1/s	50
3.1.2	Constructive diagram		2RPC+HPC+2RPC
3.1.3	Rating steam pressure at the entrance to the turbine	MPa	6,8
3.1.4	Temperature of feeding water in rating mode	^{0}C	225 ± 5
3.2	Generator		
3.2.1	Rating voltage	kV	24
3.2.2	Cooling of rotor winding and stator core		water
3.2.3	Cooling of stator winding		water
4	Main characteristics of double protective cover		
4.1.1	Internal diameter	mm	44000
4.1.2	Thickness	mm	1200
4.1.3	Calculated pressure at design basis accident	MPa	0,5
4.1.4	Calculated temperature	^{0}C	150
4.2	External cover		
4.2.1	Internal diameter	mm	50000
4.2.2	Thickness	mm	800 (600)
4.3	Distance between covers	mm	1800

NPP – 2006 is an evolutional project on the base of NPP with series reactor installation B-320 (Table 15).

Table15 – NPP with RI B-320 in operation

Country	NPP	Number of energy units
Russia	Balakovo Kalinin Rostov	4 3 1
Ukraine	Zaporozhje Southern Ukrainian Khmelnitsk Rovno	6 3 2 1
Bulgaria	Kozloduy	2
Czech Republic	Temelin	2
	Total number	24

Operating time of prototypes of NPP energy units with RI B-320 is more than 120 reactor/years. During this period of nuclear plants operation the main specific characteristics, safety and stability of operation both of systems and separate equipment units of RI B-320 put into initial technical project have been proved.

By the results of operation of separate equipment units and RI systems measures of increasing safety and safety have been developed and implemented in operating NPP. These modernizations have been considered in PWR-1000 NPP recently put into operation and in design analogues of RI for PWR-1000 NPP (NPP 91. NPP 92 and NPP 91/99) which have been built or are being built at present (Novovoronezh NPP-2, unit No. 5 of Balakovo NPP, NPP “Kudankulam” in India, “Tyanvan” in China, “Belene” in Bulgaria, “Busher” in Iran). Besides, in these projects RI equipment is structurally advanced that allows to increase safety and reliability of the RI and to improve service conditions and operation of the equipment.

6.2 Information on the trends and current situation in the development of the new-generation Russian NPP projects

Specific characteristics of the project NPP – 2006 is a new reactor installation (RI) and additional safety systems:

- new characteristics of the RI;
-system of passive heat removal;
- system of reset and cleaning of the cover;
- cooling system of the melted fuel catcher (corium) at the beyond design basis accident.

The project considers principle of overcoming and control of beyond design basis accidents.

At choosing of technical solution preference was given to deeply studied processes and constructions that do not cause doubts but at this their combination gives possibility to

In order to increase the plant reliability the project considers the following points:

- implementation of advanced safety system providing principle (passive and active) fulfillment of critical safety functions allowing essentially (in 500 – 1000 times) decrease the possibility of heavy damages of the reactor core and at the same time to decrease (in 5 – 7 times) sensitivity of the NPP to the personnel errors;
- combining the functions of normal operation and safety systems in order to reduce the probability of unrevealed failures, decrease the number of equipment units and simplify the plant systems;
- closed systems of blowing of the first circuit and steam generators;
- water lubrication of HCP and if possible the electro engine;
- injector installation of core emergency cooling and spent fuel ponds cooling.

Time of autonomous operation of the station in case of heavy accident safety systems project is oriented to functioning during to 72 hours.

As a result of analysis of arrangement of reactor compartment considering foreign experience the following main solutions were made:

- position of cooling ponds inside a hermetic cover;
- upper position of transport hatch in the hermetic cover wall;

- presence of corium cooling system in the hermetic part of the reactor compartment;
- separating hermetic area into unserviceable area and area of limited access for servicing;
- double cylinder reinforced concrete cover with a distance of 1,8 – 2,0 m;
- position of important safety systems in the foundation part and in accessory constructions of the cover on the same base of seismic stability category 1;
- position of the main systems of special water cleaning in the reactor compartment in a cover;
- possibility of the plant localization systems functioning at parameters in the protective cover of 3A – 0,7 MPa, 200^{o}C (parameters for PA – 0,5 Mpa, 150 ^{o}C).

All mentioned technical solutions show their progressivity and aiming to reaching higher safety, in accordance with international trends.

6.3 Information about expert conclusions of the international contests

Project NPP-92 has been considered at different levels. For example it was considered by the expert commission of Ministry of Nuclear Power of the Russian Federation within the scope of comparison of safety characteristics of projects NPP-91 and NPP- 92 in May, 1992 which came to the conclusion that project NPP-92 "…reflects world tendencies of NPP safety increasing".

Project NPP-92 was also considered by the jury of international contest in Saint Petersburg in May, 1992. The jury underlined that "Project NPP-92 is a perspective modernization of the base project with advanced technological systems. It is necessary to complete the development of passive safety systems and adequate safety analysis".

Report of EDF company on the project |NPP-92 gives as assessment of ideology and technical solutions of NPP-92 safety and its comparison with the base reference project EUR (France) in the sphere of safety.

It is necessary to say that technical solutions in the base and safety ideology correspond to the recommendations oa the international safety conference of IAEA "Strategy for the future" of 1991 and to the recommendations of the international advisory safety group INSAG-3 IAEA.

Club EUR (EUROPEN UTILITY REQUIREMENTS FOR LWR NUCLEAR POWER PLANTS) is a specialized club of European exploiting organizations formed in late 1991 by leading European exploiting organizations to develop technical requirements to new NPP with light-water reactor installations for further development of nuclear power industry in Europe on the base of NPP modern safety and economy concept for NPP which will be built in Europe in XXI century.

Having become a member of club EUR in December, 2003 concern "Rosenergoatom" as the owner of the project send to EUR a request for analysis of project NPP-92 (HB NPP-2) for its correspondence to European requirements. Representative of this project in EUR club after preliminary studying of documentation was French company EDF.

Positive analysis of project NPP-92 to EUR requirements means that the project safety level corresponds to the highest scientific and technical level of the developed countries and proves the possibility of further development of the project and its realization both on internal and external markets. Certificate of EUR club was issued in April, 24, 2007, signed by Bernard Roshe, the Director of EUR leading committee.

Before the certificate was issued in the period from 2003 to 2006 coordination group of EUR carried out a detailed check of correspondence of technical solutions of project NPP-92 to the requirements of European exploiting organizations for volumes 1 and 2 of EUR revision C dated from April, 2001 which was characterized by the following conditions:

- Representativeness in the coordination group of the experts from the exploiting organizations in member-EUR countries;
- Cross comparison of answers of designers of projects NPP-92, EPR and AP-1000 to the questions related to meeting the most important requirements of EUR;
- Multilevel consideration of complicated requirements (on CG meetings, administrative groups meetings and EUR control committee).

Analysis on correspondence was carried out for each EUR chapter and includes a detailed analysis and final report of Volume 3 for project NPP-92.

Principle lacks of correspondence able to make the process of licensing the project in European countries have not been revealed.

Assessment of project NPP-92 showed a good level of correspondence to EUR purposes and requirements including requirements to the following positions:

– full assessment of safety level;
– results of joint tests in SPOT system and system of gas removing;
– service life of the generator body.
- principles of system of leading remain heat from the reactor;
- core stores: possibility of operation with MOX-fuel at 24-month fuel cycle;
- using of seismic spectrum and soil conditions recommended by EUR.

At the same time there were several items whose project solutions do not completely correspond to European and world characteristics including:

– terms of construction;
– digital means of FPACS and computerized processes;
– capacity of spent fuel pond;
– duration of overloads and periodical stops for maintenance.

This analysis including description of the NPP and other information on which it is based is a result of a big work carried out by EUR exploiting organizations and Russian designers.

Besides, one of the conclusions made on the analysis is determining of some positions on which EUR document need in amendments to become more adoptable to modernized technologies of Russian PWR and probably needs to be revised on some other reasons.

In late 1990 Finish company TVO started to prepare parliament decision on the construction of a new energy unit. Russian side presented project NPP with PWR-1000 (NPP-91) whose analogue was being built at that time in China. At present construction of two NPP energy units with PWR-100/428 in China has been completed. In the period from 1995 to 1999 IAEA expert examinations were carried out on materials of project NPP with PWR-1000/428 for CDR. Results of the expert examinations are given in IAEA reports:

- Safety Review Mission Report on Design Features of NPP-91 with VVER-1000/428 Reactors for Liaoning NPP, IAEA-RU-5137, 1995;
- Safety Review Mission Report on Resolution of VVER-1000/320 Safety Issues in NPP-91 Design, EBR-ASIA-06,1998;

- Expert Mission to Peer Review Selected Solutions Adopted in the NPP-91 Design with VVER-1000/428 Reactors foe Tianwan NPP, Sistems, EBP-ASIA-24 Limited Distribution, November 26, 1999;

- Expert Mission to Peer Review Selected Solutions Adopted in the NPP-91 Design with VVER-1000/428 Reactors foe Tianwan NPP, COTAINMENT AND ACCIDENT MANAGEMENT, EBR-ASIA-26 Limited Distribution, November 24,1999;

- Expert Mission to Peer Review Selected Solutions Adopted in the NPP-91 Design with VVER-1000/428 Reactors foe Tianwan NPP, COTAINMENTINTEGRITY INCLUDING, LEAK BEFORE BREAK, EBR-ASIA-25 Limited Distribution, November 24,1999;

- Expert Mission to Peer Review Selected Solutions Adopted in the NPP-91 Design with VVER-1000/428 Reactors foe Tianwan NPP, Fuel,EBR-ASIA-27 Limited Distribution, November 24,1999;

- Expert Mission to Peer Review Selected Solutions Adopted in the NPP-91 Design with VVER-1000/428 Reactors foe Tianwan NPP, PRELIMINARY PROBABILISTIC SAFETY ASSESSMENT FOR INTERNAL INITIATING EVENTS, November 22-30.1999.

Finish requirements were again increased to achieve the highest level that is why the designers had to complete the project and in Finish documents it was named as VVER-91/99. To meet Finish normative and technical requirements a certain modernization of the project had to be done whose completeness was proved by Russian designers and manufacturers of reactor and turbine equipment. It was suggested to buy technologies that had not been developed enough in Russia (such as digital means of control and check systems) from Germany, Finland and other countries. By the maximum set power this tender was won by company AREVA with project power of 1700 MW (e).

At present all developments of NPP-91/99 project were used in NPP-2006 with high power PWR named NPP-2006 with RI B-491. This project is being prepared for next tender in Finland and is being considered in Finish supervisory organs for including into the principle solution of the Parliament about possibility of construction in Finland.

6.4 Description of similar NPP project and main project characteristics

6.4.1 Source and purposes of the project

Operation of NPP with PWR reactors is:

- NPP with PWR-440 – more than 700 reactor-years;
- NPP with PWR-1000 – more than 300 reactor-years.

Necessity of the project of PWR type reactor of a new generation with electric power of 100 MW is determined by its high economic characteristics and the level of nuclear and radiation safety corresponding to the external international requirements. The main aim of creating of new generation NPP is making a unified competitive NPP project corresponding to modern safety requirements.

This development largely accumulated knowledge of leading designers and their experience designing, manufacturing and operating of NPP with PWR-440 and PWR-100 NPP according to the international requirements.

The project corresponds to all Russian requirements in safety and to recommendations of IAEA, international advisory group of regulating safety INSAG and others.

Correspondence of the project to Russian norms by safety on the base of valid Russian legislation is provided by the procedure of licensing adopted by Russia state safety regulating authority.

Apart from the procedure of licensing in Russian supervising authorities in order to prove its correspondence to the world criteria and safety requirements the project was analyzed by the leading specialists of EDF company (France) to check its correspondence to the requirements of leading European exploiting organizations set for new generation of NPP with light-water reactors. The project got positive assessment by its correspondence to EUR main requirements.

The main purposes that the designers of the project put ahead can be achieved by solving the following tasks:

а) increasing of safety level by:

- improvement of characteristics of nuclear fuel and the main equipment of the reactor installation;
- creating of advanced safety systems with active and passive systems;
- decreasing sensibility of the NPP to the personnel errors;
- increasing of the NPP equipment operational reliability:
- maximum use of experience in creating and operating of plants with reactors of PWR-440 and PWR-1000 types;

б) improvement of technical and economic characteristics of the NPP by:

- lowering money expenses;
- lowering operational expenses;
- using of evolutional approach in taking technical solutions and adopting new equipment.

The main differences of the project and other existing NPP projects with PWR reactors of the previous generations allowing to carry out the solution of the given above tasks are:

- providing of quick stop of nuclear reactions in the core by operation of two independent systems of influence on reactivity;
- providing of continuous leading of remained heat and keeping the reactor in safe state by a set of active and passive systems;
- using protective covers for localizing accident products: both internal (pre-voltage) and external (monolith counted on wide spectrum of external and internal activities) are used.

The project uses evolutional approach to using of technologies, Units, systems, and experience in designing, manufacturing and operating of the previous generation of NPP with pressurized water reactors.

6.4.2 Description of the project

Figure 6 gives the overall view of one-unit NPP.

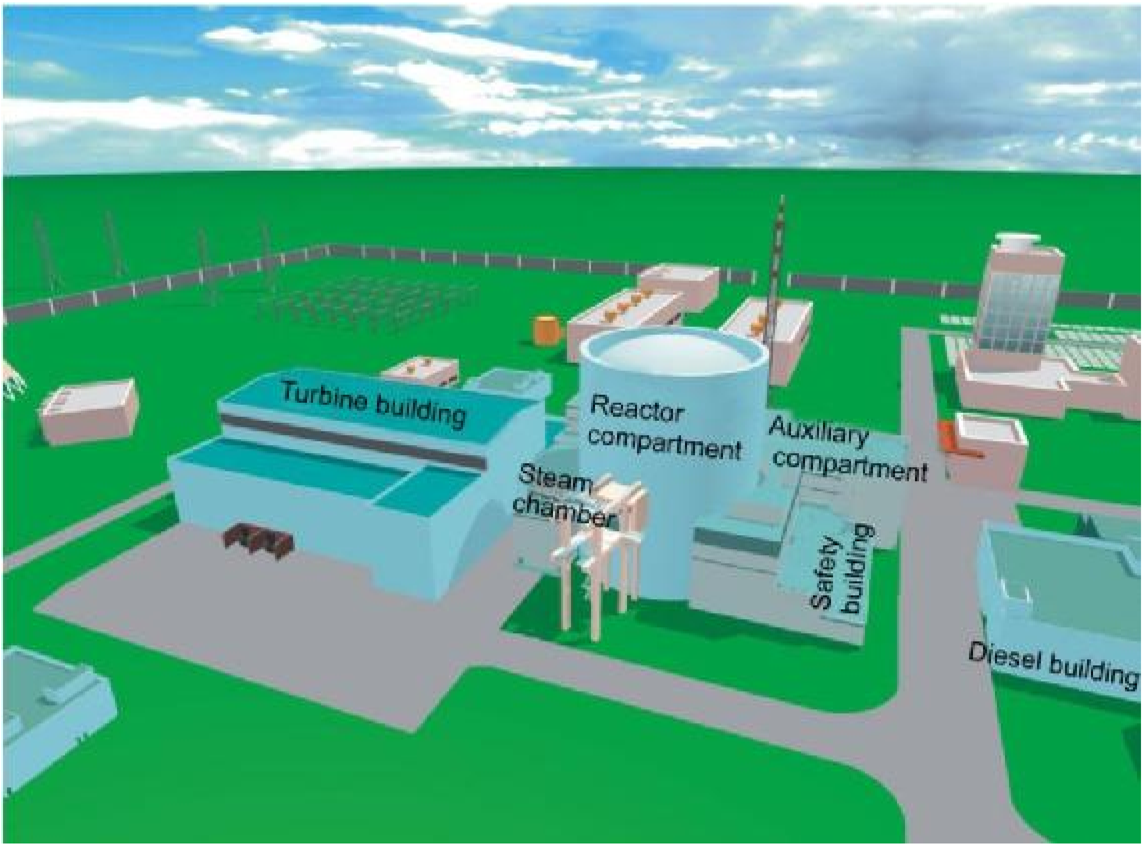

Figure 6 – Overall view of one-unit NPP

The main technological process includes nuclear and nonnuclear parts (general-purpose station buildings and constructions), electric part and heating part.

Nuclear part combines main and auxiliary technologies of conversing nuclear energy into thermal energy.

Nonnuclear part combines technologies of conversing thermal energy into electric energy.

Electric part provides output of electric energy to energy system and provides electric energy for NPP demands.

Heating part provides heat output for consumers situated in the NPP region.

The whole technological process is controlled by technological processes automated system control.

Nuclear part includes a number of buildings and constructions the main of which are:

– reactor building with double protective cover where the reactor installation is situated; it includes:

1) reactor;
2) steam generators;
3) pressure condenser;
4) main circulating pumps and main circulating pipes;

5) passive part of core emergency cooling, in the protective cover there is equipment for operations with nuclear fuel, systems of passive heat leading, system of localization core melting and other systems;

– safety building containing equipment and pipelines of core emergency cooling with low and high pressure, sprinkler system, boron emergency input system, intermediate cooling circuit for priority consumers, heat pond cooling system, remained heat leading system, ventilation systems of space between covers of the reactor building, and tanks with borated water stores;

– steam chamber with equipment and pipelines of high pressure protection system in steam generators, system of emergency water supply, and steam pipes, feeding water pipelines and tanks with desalted water stores;

– control building containing equipment of systems of automation, control and protection, "strict mode" electric power supply, unit and reserve control boards;

– auxiliary building with equipment of auxiliary systems of the first circuit, special water cleaning, collecting and storage of radioactive water, ventilation systems of "strict mode" area, and equipment for liquid radioactive wastes processing;

– building for storage of new fuel.

Central part in the nonnuclear part is occupied by the turbine building with installation and turbo generator and auxiliary systems providing their functionality in all modes.

6.5 NPP functional layout. Main equipment components

6.5.1 NPP functional layout

Functionally all objects of the nuclear plant can be divided into main objects and auxiliary and service objects.

The main objects include:

- the main buildings and constructions of energy unit 1;
- the main buildings and constructions of energy unit 2;
- electric buildings of 330 kV;
- cable channels and tunnels of energy units 1 and 2 at the NPP site;
- trestle bridges and channels for technological pipelines at the NPP site;
- technical water supply buildings.

The rest objects are included into auxiliary and service part.

The main buildings and constructions of energy unit include buildings and constructions of nuclear part and buildings and constructions of nonnuclear part (turbine composition).

Heat diagram of RI is two-circuit.

Energy unit includes reactor installation and one installation.

The first circuit is formed by the reactor, main circulating pump, pipe space of the steam generator.

Water moderated energy reactor is a tank reactor, heterogeneous operating on thermal neutrons. Coolant and inhibitor is water with boron acid solution as absorbent. Calculated service life of the reactor tank is 60 years at calculated service life of the nuclear plant of 50 years.

Low-enriched uranium dioxide is used as a nuclear fuel.

Coolant of the first circuit passing through the core is heated and passes to the steam generator pipe heater (SGPH) through the main circulating pipeline of four parallel circulating loops; there it gives its energy to the second circuit. From SGPH the coolant returns to the reactor for repeated heating through the main circulating pipeline. Circulation in the loops is carried out by four main circulating pumps (MCP). Arrangement of reactor installation is shown in Figure 7.

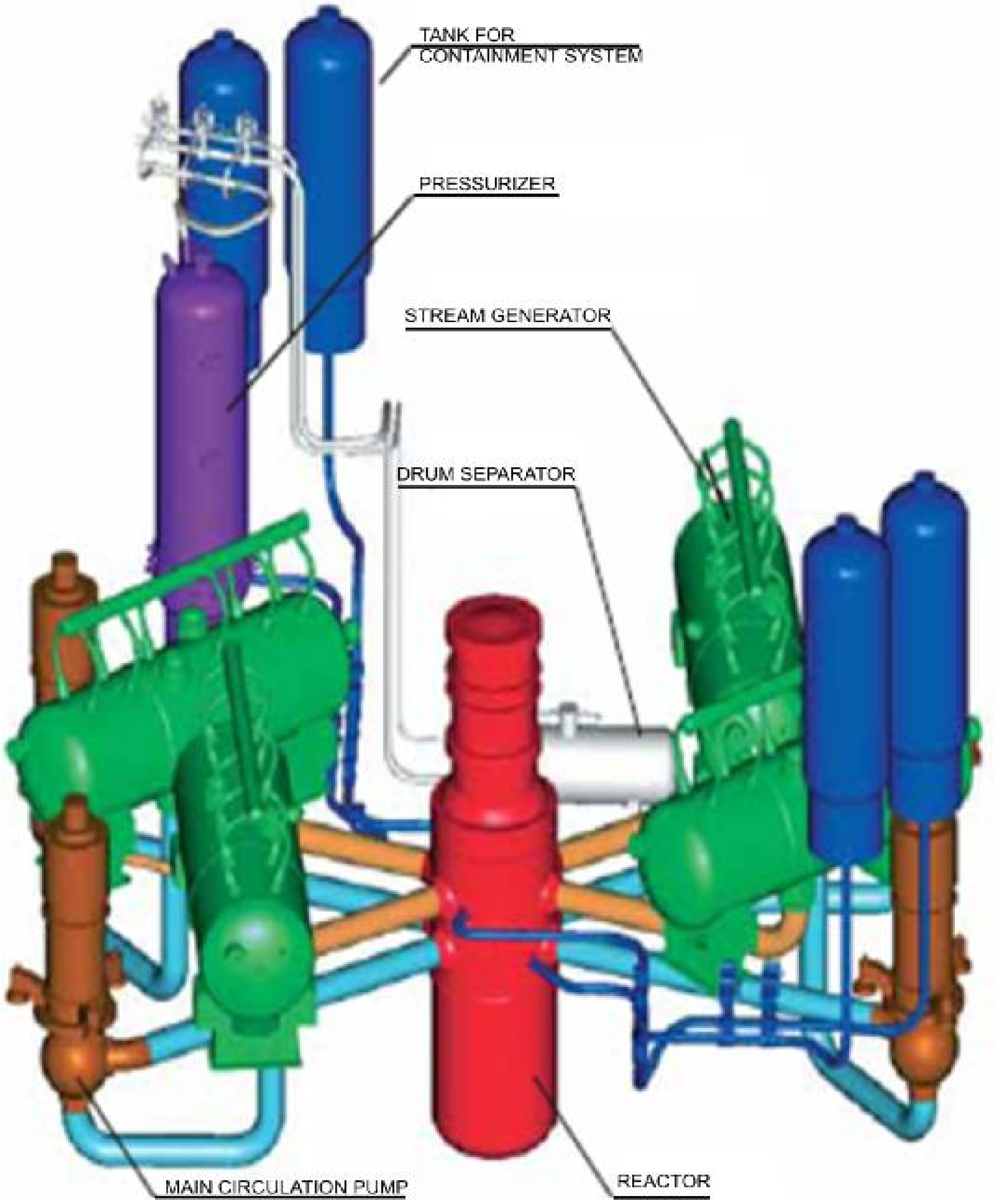

Figure 7 - Arrangement of reactor installation is shown

The second circuit is nonradioactive. It consists of:

– steam producing part of the steam generators;

–steam pipes with new steam;

– turbines;

– condensate pipes;

– generative heaters systems;

– deaerator;

– systems of feeding pipes and pipelines are mainly referred to nonnuclear composition. Pumps with electro drive are used as main and auxiliary feeding pumps.

Turbo plant provides conversion of thermal energy into mechanical energy of turbine rotor rotation. Generator set on the same shaft with turbine rotor converts mechanical energy of rotor rotation into electric energy.

Functional technological diagram of NPP-2006 energy unit is given in Figure 8.

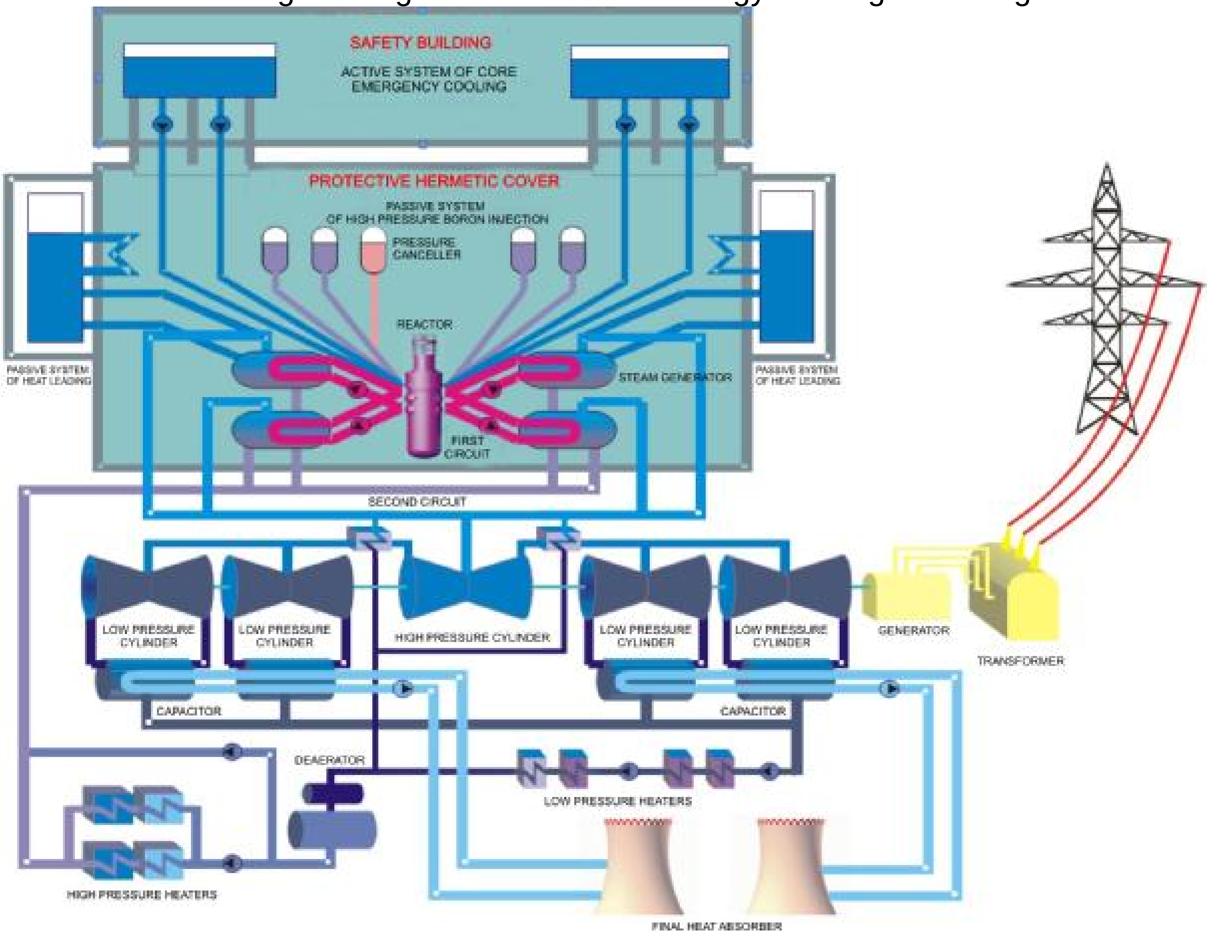

Figure 8 – Functional technological diagram

6.5.2 Main NPP equipment components

List of the main NPP equipment is given in Table 16.

Table 16 – List of the main equipment

Name	Quantity
Main equipment of normal operation systems	
Main equipment of the first circuit	
Reactor B-491	1
GNHA-1391	4
Steam generator PGV-1000MKP	4
Pressure canceller	1
Main equipment of the second circuit	
Turbine (K-1200-6,8/50)	1
Condensing plant:	1

Table 16 (continued)

Name	Quantity
- one-stroke two-flow condenser	4
- hermetic condenser system:	
main water-jet injector	4
water-jet injector of circulating system	2
water-jet injector of steam thickening condenser	1
First stage condenser pumps	3
Second stage condenser pumps	3
Vertical, two-stage jalousie separator-steam overheater	4
Feeding electro pump	5
Auxiliary feeding electro pump	2
High pressure deaerator	1
Turbo aggregate lubrication system:	
- oil box	1
- lubrication system pump	2
- lubrication system pump (emergency)	1
- oil cooler	3 (is being detailed in the project)
Regulation oil supply system:	
- oil box	1
- regulation system pump	2

Creation of PWR-1200 RI is based on evolutionary modernization approach and including proved and reliable systems and equipment checked at PWR RI operation in active NPP. The main RI equipment will be manufactured by Russian enterprises using modern proved technologies.

Materials for the main equipment and pipelines are chosen according to the requirements of valid normative technical documentation and are based on long-term experience of designing, manufacturing and operating of PWR RI considering its service life of 60 years.

RI equipment is calculated for operation in stationary modes and in the modes of regulating frequency and power that are necessary for half-peak energy units.

Manufactured RI equipment can be transported by railroads, by automobile and sea and river transport.

RI includes the following main components:

– first circuit and systems connected with it;
– reactor mine equipment;
– second circuit within protective cover and systems connected with it;
– transportation and technological part of the RI;

– complex of systems of control, check, regulation, protection, blocking, signaling and diagnostics forming ACS in RI part;
– heat isolation of RI equipment and pipelines;
– fixing elements of equipment and pipelines;
– equipment and systems for assembly and adjustment works;
– equipment for repairing and maintenance of RI;
– set of control systems for equipment and pipelines metal;
– complex of systems and control means for of-design basis accident and decreasing consequences including system of warning and core melting cooling.

The main parameters in rating mode and technical characteristics of the RI are given in Table 17.

Table 17- The main parameters and technical characteristics of the RI

Names and units	Value
Heat rated power, MW	3200*
Steam productivity of one steam generator (at feeding water temperature of 225 °C and continuous blowing of 15 tons/h), tons/h	1600+112***
Coolant expanse through the reactor in the rating mode, m^3/h	85600±2900**
Rating pressure of stationary mode at the exit from core (absolute), MPa	16,2±0,3
Temperature of coolant in core in rating mode, °C – at the entrance – at the exit	$298{,}6^{+2}_{-4}$ ** 329,7±5**
Pressure of generated saturated steam at the generator output at rating load (absolute), MPa	7,00±0,10
Humidity of generated steam at the steam generator exit in normal operational conditions, % not more than	0,2
Maximum linear energy intensity of fuel elements, W/cm	420
Feeding water temperature in rating mode, °C	225±5
Time of fuel presence in core, year	4-5
Depth of fuel burning, maximum, MW day/kg U	Up to 70
Effective use time of set power during a year, not less than, h	8400
Number of TVS in core, pieces	163

* during project design on the base of planned researches it is possible to increase RI thermal power to 3000 MW by implementation of tabulators, lowering conservatism of calculated codes and methods, optimization of fuel cycle.

** Is being detailed at RI technical design.

*** Maximum deviation caused by differences in SG thermal powers.

6.6 Arrangement of reactor installation equipment

Equipment and pipelines of the RI operating under the first circuit pressure and parts of pipelines and systems designed for localizing active coolant at accidents, are situated inside double protective cover.

Development of RI arrangement at the first design stage is carried out for internal diameter of the protective cover (PC) of 44 m.

Reactor is set in concrete mine with biological protection. Construction of the lower part of the mine is developed considering designing a system of warning and cooling of core melting outside the reactor vessel at heavy beyond design basis accidents.

The arrangement considers the possibility of RI equipment replacement when it is damaged including large-dimension equipment (except the reactor vessel).

6.6.1 Reactor

Water-moderated reactor PWR-1200 is a vessel heterogeneous reactor on thermal neutrons. Coolant and inhibitor is water with using of boron acid as absorbent.

Low-enriched uranium dioxide in combination with gadolinium oxide is used as a fuel.

Reactor vessel is a high pressure cylinder made of high-strength heat-resisting alloyed steel. Inferior surface of the vessel is plated with anti-corrosion welding.

Coolant is given by circulating pumps through four input connecting branches, lowed along the ring clearance between the vessel and mine of the core and passes to NVC through the perforation in the bottom and mine support tubes.

Passing through EMC the coolant is heated by nuclear fuel fission reaction. Through the perforation in the bottom and protective tubes the coolant gets to ring clearance between mine and vessel and gets from the reactor through four output branches.

Core of the reactor is designed for generating heat and its transition from the surface of heat emitting elements to the coolant during project operation terms without exceeding permitted limits of fuel elements damage.

Neutron-physical characteristics of core and reactivity control systems are chosen according to the initial project safety requirements.

Reactor includes:

- nuclear reactor vessel (including vessel, cover, support ring, stop ring, main connetor elements);
- installations inside the vessel;
- upper plant with CRS drives;
- core;
- interior reactor assemblies;
- main connector leak control device;
- testing samples;
- attachment device.

Service life of vessel, reactor cover is not less than 60 years.

RI equipment and reactor core in perspective must provide the possibility of work with interoverload period up to 24 months.

Reactor is placed in concrete mine with biological and heat protection and cooling system.

With its support clamp the reactor vessel rests and is fixed on the support ring set in the support system.

Horizontal shifts of the reactor are prevented by a stop ring set on the flange edge and by the ground restrictors set on the ground of electro distribution unit (EDU).

Stop ring and EDU ground are attached to the concrete mine.

Attaching reactor in the concrete mine at three levels allows its safe fixing at shifts of seismic impacts and at pipelines distortions.

Concrete mine, electro equipment, interior reactor control system branches, and drives are cooled by the air.

Core of the reactor is designed for generating heat and its transmission from the surface of fuel assembly to the coolant during project operating terms without exceeding permitted limits of fuel elements damage.

Core of one reactor consists of 163 fuel assemblies of six-edge section part of which contains regulation and emergency protection devices.

Regulation and protection devices (absorbing rods) are designed for quick stop of nuclear reaction in the core, keeping power on the set level and its transition from one level to another, equalizing of energy emitting field to core height, preventing and suppressing of xenon fluctuations.

Action of internal nuclear back connections of the core is directed to balancing of quick changes of reactivity and limiting of power increase.

Reactivity coefficients characterizing changes of the core reactivity at changes of parameters of fuel, coolant, boron concentration, are negative in normal operation modes, in modes of irregular operation and at design basis accidents.

Influence on reactivity is carried out in two independent ways: with help of absorbing rods and boron inject system. Absorbing rods are made of $B_4C+(Dy_2O_3TiO_2)$.

Reactor and control systems are designed in such way that possible changes in energy distribution connected with xenon instability are timely revealed and suppressed without exceeding the design limits for fuel and power range.

PWR-1200 reactor construction was developed on the base of experience in design and operating of PWR type reactors in the Russian Federation, CIS countries and abroad.

RI project with PWR is not a new development; it considers modernization of B-320 reactor and equipment improved in order to increase the safety level, technical and economic, operational and maneuver characteristics and to increase competitiveness of the RI and NPP in the whole.

PWR-1200 reactor as PWR-100 series reactors has a loop coolant leading system with two-row branch Du 850 position on the reactor vessel, thickening of the main distributor, organization of coolant leading to the core, and general arrangement of the upper unit; this structure has been proved during operations.

Dimensions and weight of the vessel and cover allow transporting by road, water and rail transport.

Vessel is a high pressure vertical cylinder providing with the cover and main thickening hermetic space inside the vessel. Interior surface of the vessel is covered with austenite welding protecting the main metal from corrosion influence of coolant and providing possibility of vessel interior decontamination. Longitudinal plan of the reactor is shown in Figure 9.

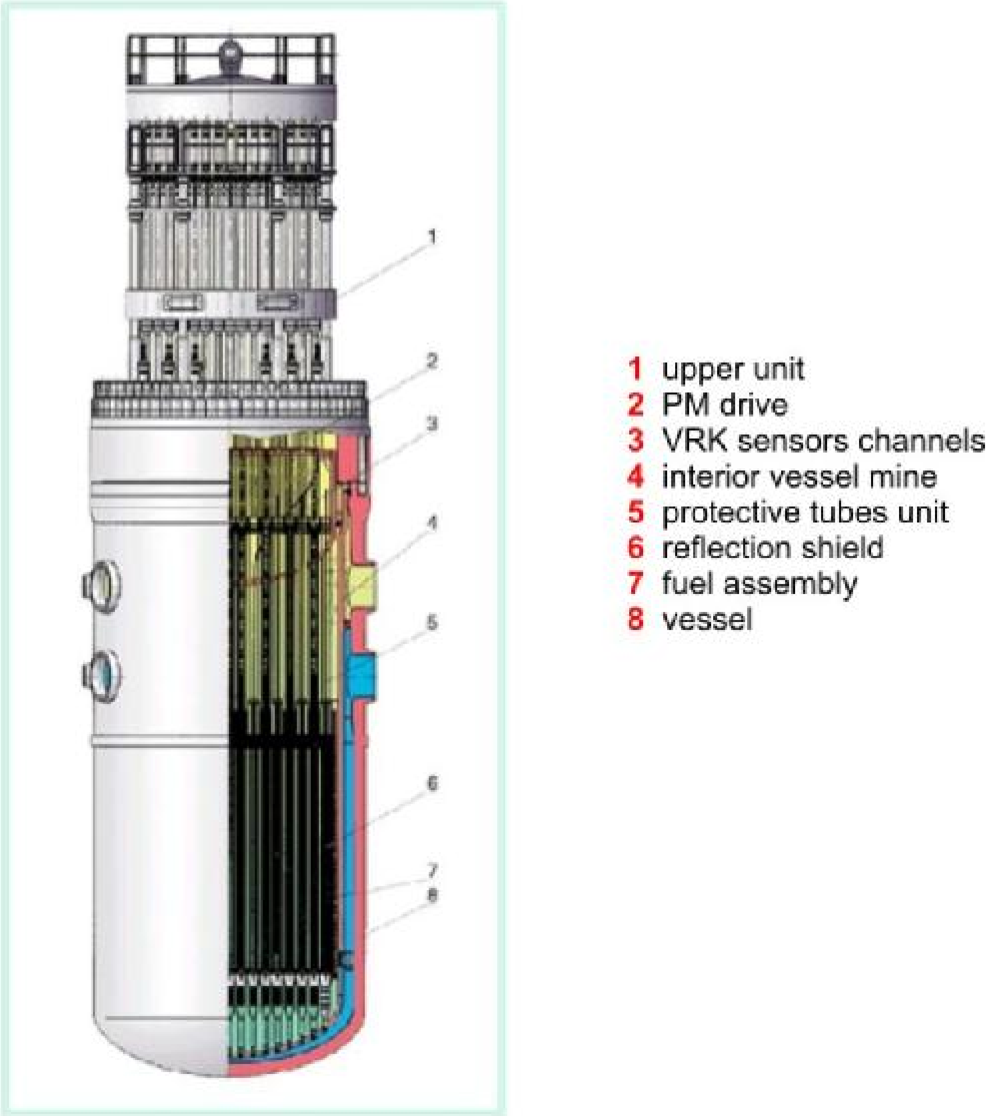

Figure 9 – Longitudinal plan of the reactor

Vessel length is 300 mm more due to lengthening support shell. Enlarging vessel length allows making core top mark lower related to supporting truss. It allows to decrease dose loads of the personnel working with steam generators because at power operation of the reactor (by calculated assessments) neutron flow density decreases in the reactor support place at straight passing from the core through the vessel (twice less) and from the clearance between the reactor vessel and heat isolation (greatly decreases).

Vessel manufacturing technology has not been changed as lengthening is carried out by shell lengthening.

Dose loads of the personnel working with the reactor are decreased. Water volume over the core increases – it is important at accidents connected with coolant leakages from the first circuit.

Length of interior vessel mine in cylinder part has been increased for 300 mm.

Position of holes in mine cylinder part perforation area has been changed in accordance with holes position on BZT.

Increasing of length corresponds to increasing length of the reactor vessel and has been made for the same reasons with increasing of vessel length.

In the reflection shield holes positions and longitudinal channels diameters have been changed. It decreases inequality of radiation and temperature changes in reflecting shield metal reducing possibility of its damages.

The following changes have been made in protective tubes unit:

- temperature measuring channels at the exit of fuel assembly have been removed because neutron and temperature control is carried out in one channel;
- number of protective tubes with directional carcass for control devices has been increased and correspondingly, their diameter become more due to branch enlarging from 61 to 121;
- tracing of interior reactor control channels directional tubes has been changed due to placing them in peripheral branches;

The following changes have been made in the upper unit:

- number of CSS branches has been increased to 121;
- interior reactor control branches have been put on the cover periphery to make access to them easier;
- total number of branches has been increased from 91 (upper unit of series RI B-320) to 141 (upper unit of RI of Novovoronezh NPP, plant 5 of Balakovo NPP, “Kudankulam” NPP in India).
- Number of distribution connections for interior reactor control leads has been reduced by combining neutron and temperature control in one channel simplifying operation and increasing reliability.

6.6.2 Core

Core is developed considering experience of operation and modernization of PWR-100 reactor fuel.

Construction of reactor core includes fuel assemblies and CSS regulating devices (to 121 pieces). Spacer grids and guide channels of the core are made of zirconium. Increasing of economic parameters is achieved by fuel overload cycle with periodicity of 10 to 24 months and increasing of fuel burning depth to70 MW day/kg U.

FA-2M construction (Figure 10) has been chosen as prototype for NPP-2006 as meeting all FA requirements. The main requirements to RI core are given in Table 18.

Figure 10 - FA-2M

Table 18 – Main requirements of RI to the core

Parameter	PWR-1000	PWR-1200*
1 Rating thermal power of the reactor, MW	3000	3200/3300*
2 CSPU	0,78	0,92*
3 Coolant pressure at the output from core, MPa	15,7	16,2
4 Coolant temperature at the reactor input, °C	290	298,6
5 Coolant temperature at the reactor output °C	319,6	329,7
6 Maximum linear heat flow, W/cm	448	420
7 Fuel cycles	3x350; 3x1,5; 4x1; 5x1	4x1; 3x1.5; 5x1; 2x2*
8 Maximum fuel burning in FA, MW*day/kgU	68	70*

Table 18 (continued)

Parameter	PWR-1000	PWR-1200*
9. Operation mode with power changes, maximum. Speed	Base mode 3 % Nrat /min	Base + maneuvering modes 5 % Nrat/min
10 Number of regulated FA	61	121
11 Position of measuring channel	central	shifted
12 Maximum lengthening of core, mm	150	200 - 250
13 Relative position of lower fuel edges, mm, rating	52,5	0 *

Based on target parameters determined for PWR-1200 RI in the composition of NPP-2006 the main requirements to PWR-1200 core can be formulated as providing the following factors:

– reliability;
– safety;
– economic parameters (CSPU, etc).

Modern level of safety is provided by meeting the following requirements to FA and CSS constructions:

– using of best proved technical solutions with evolutional approach to modernization;
– using technical solutions providing maximum unification and succession towards developed FA;
– providing FA disassembling construction with the possibility of replacement of damaged fuel elements;
– serviceability at high levels of fuel burning;
– serviceability in maneuverable mode with speed to Nrat/min 5 %;
– serviceability at increased coolant parameters.

Safety of the core is provided by:

– high reliability of its elements constructions;
– high geometrical stability of the construction elements.
– quality of construction solutions related to the function of emergency stop and excluding excessive reactivity leading to breaking the project criteria.

Modern economic characteristics are determined by meeting the following requirements to FA:

– providing minimum possible fuel load in FA to achieve high CSPU;
– maximum possible fuel enrichment (to 5 %);
– providing fuel cycles with maximum fuel burning to 70 MW day/kg U.

Among FA currently existing these requirements are most completely met by FA-2M which is now being industrially tested in the unit 1 of Balakovo NPP. Its prototype is FA-2 with firm carcass in 2006 successfully finished tests and was put into industrial operation.

FA-2 and FA-2M (Figure 11) are evolutionary developments of the previous FA constructions (FA-M, UFA) in comparison with which no new elements were added. All new characteristics were achieved by operational solutions and construction modernization of its component elements.

FA-2 construction is more reliable, simple and technological what was proved by its operation in NPP. FA-2 proved its high geometry stability and quality of technological and design solutions.

FA-2M construction provides possibility of maximum lengthening of fuel column (Table 19). It is also adoptable to all modernizations and can be used in any fuel cycles.

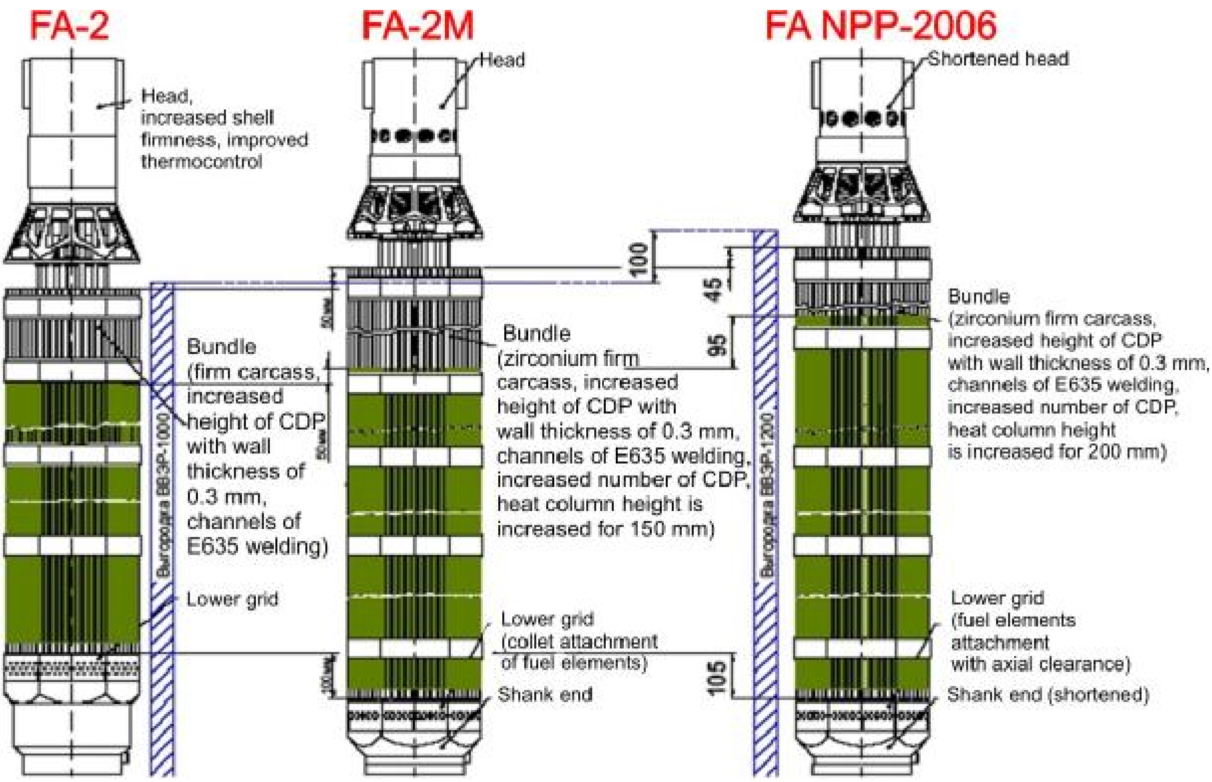

Figure 11 – FA evolution in lengthening of fuel column

FA-2M construction (considering developed solutions on reducing its KGS to UFA level) provides heat technical reliability and increasing of RI power. KGS is reduced due to optimization of SG cells (Figure 12) without changing the number of SG and bending flexibility of the carcass.

Table19 - Increasing of fuel charging

Reactor	FA	pellet diam, mm, hole diam, mm	Fuel column height, mm	Fuel mass, kg in fuel element/ in FA/ in core	Per cent of increasing, %	Grain, mcm
PWR-1000	FA-2	7,57 1,4	3530	1,575 491,4 80098	----	10
	FA-2M	7,6 1,2	3680	1,671 521,3 84973	6,1	10
	FA-2M	7,8 0,0	3680	1,805 563,1 91793	----	20-30
PWR-1200	FA-1200 stage I	7,6	3730	1,694 528,4 86128	7,5	10
	FA-1200 stage II	7,8 0,0	3730	1,829 570,8 93040	16,2	20-30
	FA-1200 stage III	7,8 0,0	3780	1,854 578,5 94287	17,7	45-60

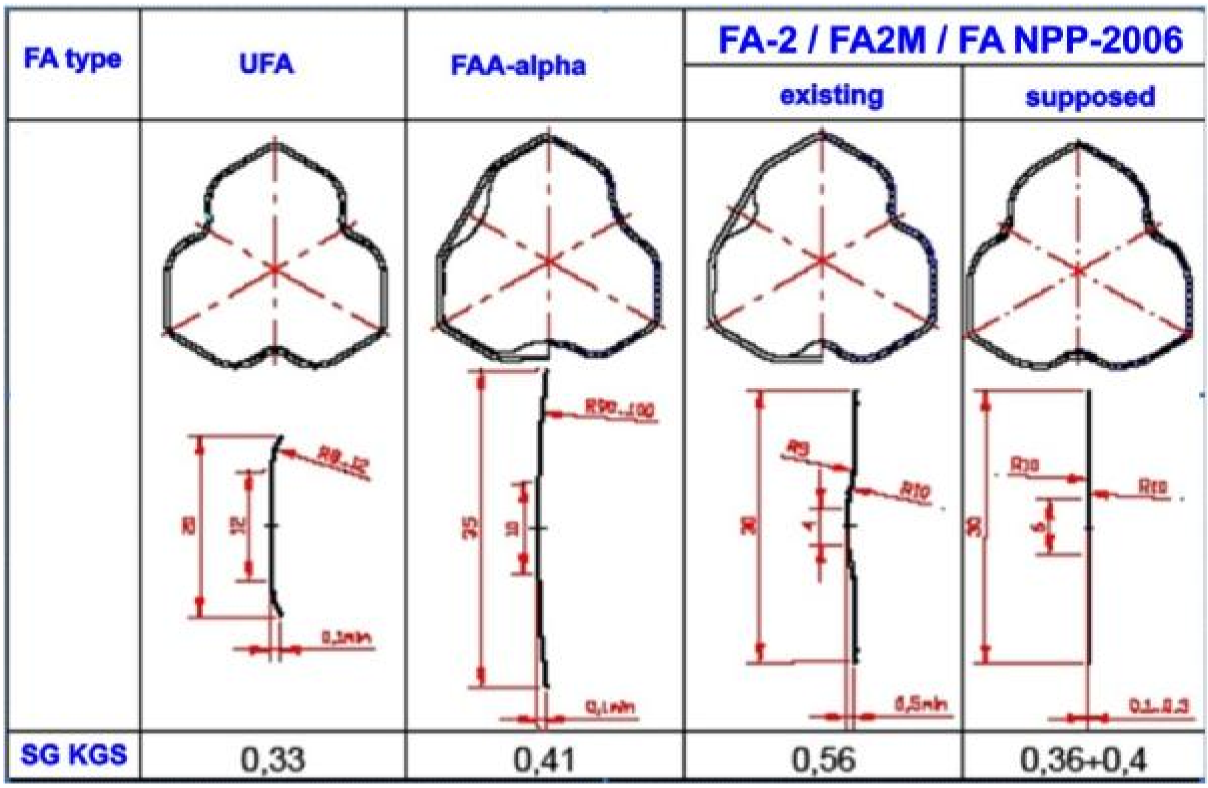

Figure 12 – SH cells of different FA types

FA-2M construction provides full visual inspection of all periphery fuel elements including angular that are the most loaded.

FA-2M construction provides repairing without risk of removable elements loss. At that expenses on utilization of replaced elements are not required (Figures 13, 14).

Figure 13 – Head and collet unit

Serviceability and easy removability of the construction is proved not only by repairing in LJS NZCHK but reactor studying on six prototypes with similar heads.

FA-2M construction has been proved for emergency and seismic loads; it better (in comparison with UFA) bears these loads.

Absence of “unnecessary” elements in the construction provides a high reliability of FA-2M at fuel loads (there were no cases of FA-2 or FA-2M damages in NPP). FA-2M construction is aimed to TTC with speed to 4 m/min.

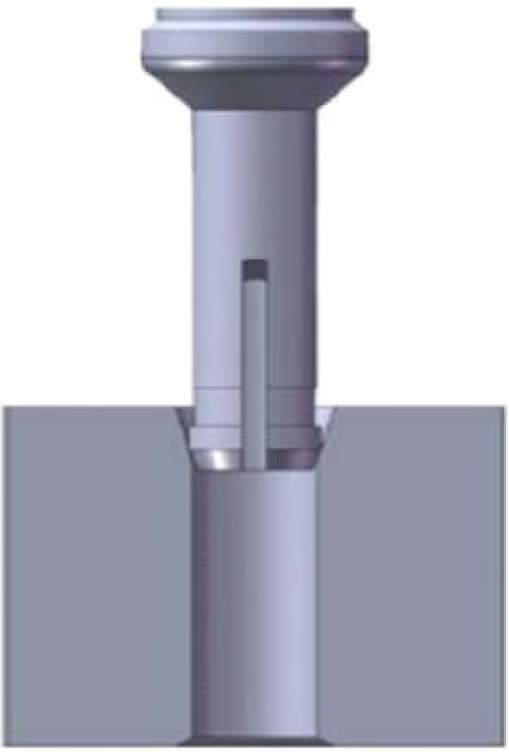

Figure 14 – Collet unit of fuel element

FA-2 and FA-2M carcasses are tested on models for quick power release which are dangerous especially for new FA. At first FA-2 load in plant 1 of Balakovo NPP in 2003 immediately after power increase emergency protection was activated. The whole series of FA-2 overstood this mode, later inspections didn’t reveal any faults, all FA worked out their resource.

In the result of FA-2 operation the core has been rectified and inter cassettes clearances have reduced to the project values (Figure 15). FA-2 construction has proved to be highly reliable – only one failure during all operating time since 2003.

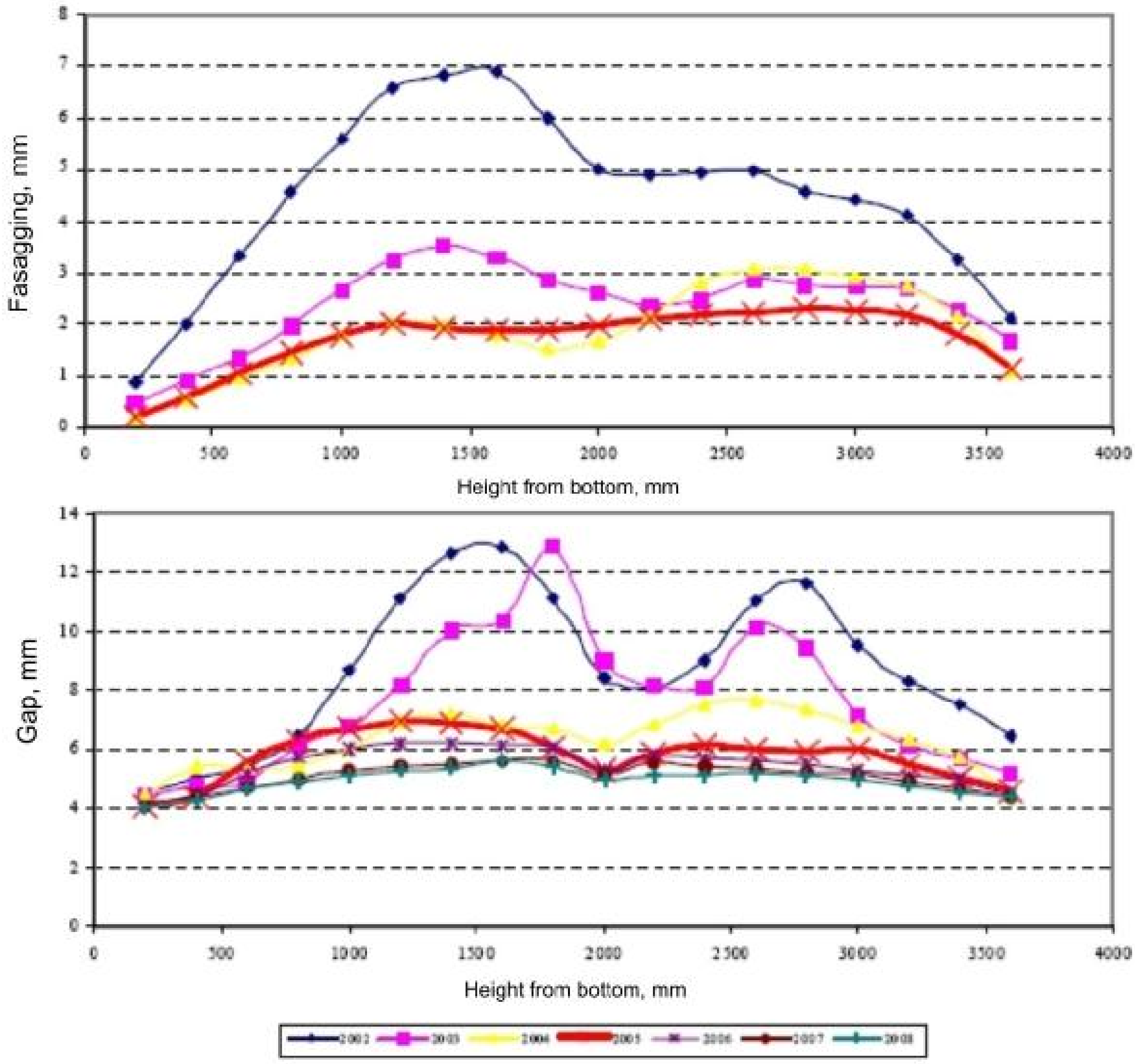

Figure 15 – Changing of bends and inter cassettes clearances in plant 1 at increasing FA-2 in the area

The main FA-2M elements (head, shank end, NK) have been recognized as the most successful and adopted for NPP-2006 FA construction.

By NPP-2006 RI CSS and its elements are similar to PWR-1000 CSS construction (Figure 16).

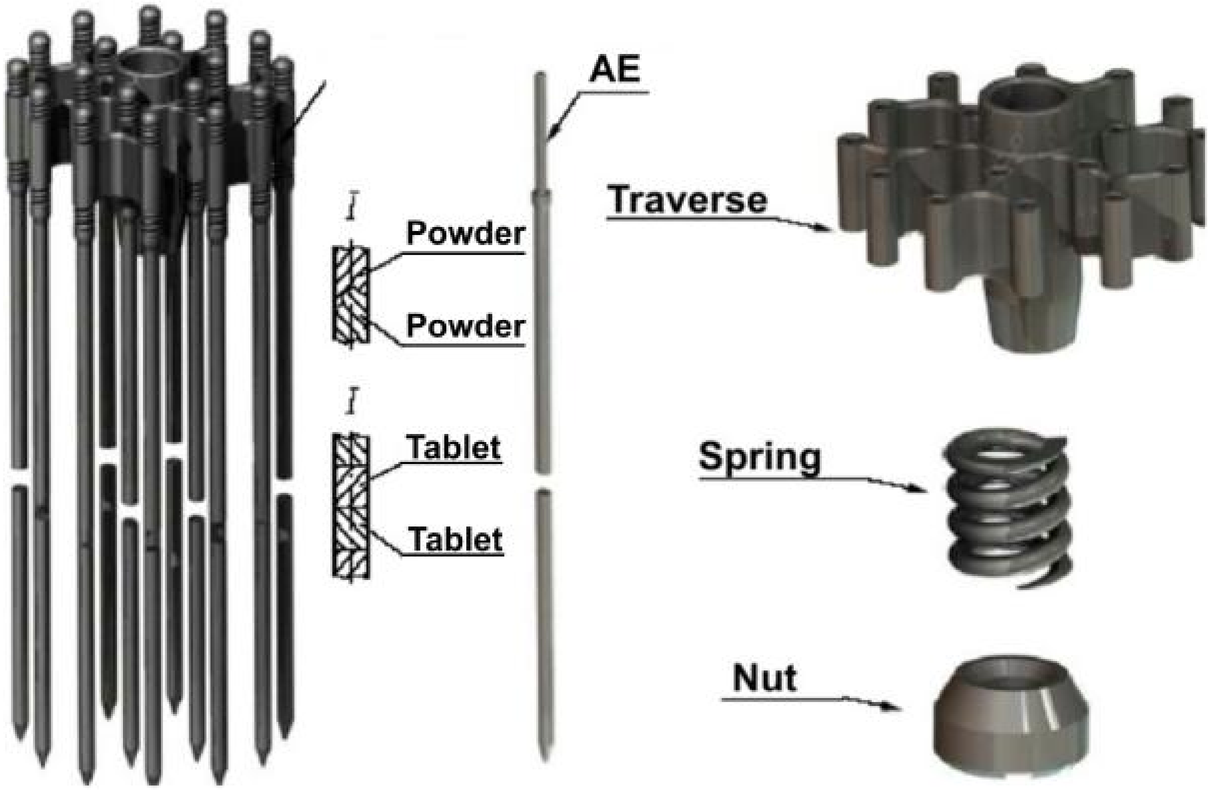

Figure 16 – CSS PS

FA-2M shaft end construction allows fulfilling the requirement of FL in RI in bridging of fuel column by absorber when CSS RS are on firm supports. For this NK is attached on special grid allowing lengthening them lower than fuel elements attachment level. This solution complicates the technology but strengthens (by firmness) the shank end construction (Figure 17).

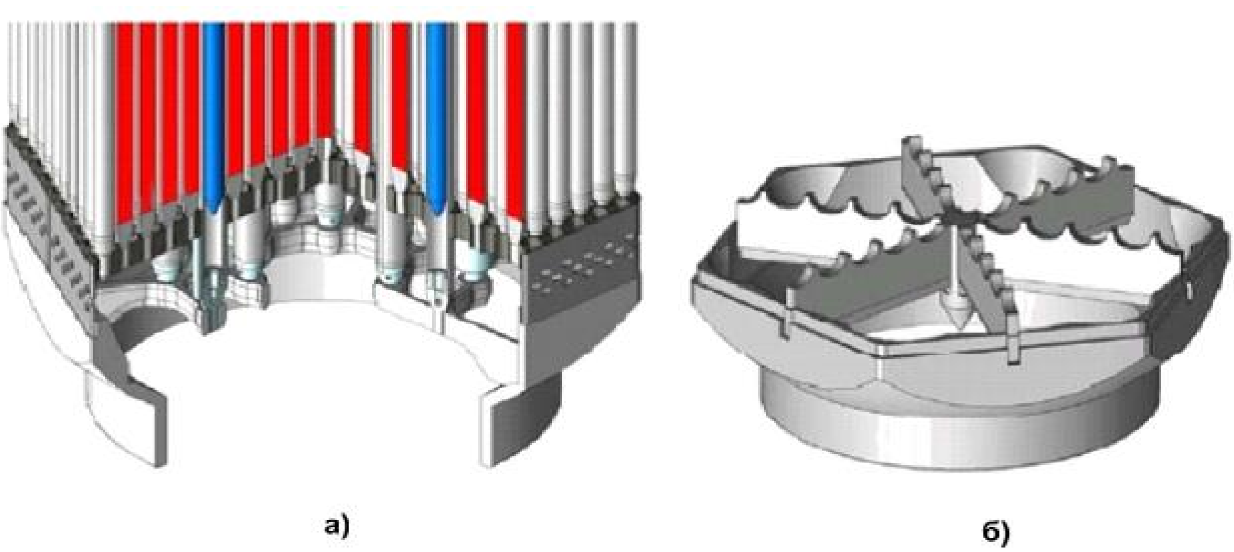

Figure 17 – Shank end with long NK а) and standard FA-2M shaft end б)

A typical feature of PWR-100 reactor is that absorber doesn't come to the bottom of the core. Considering the fact that for NPP-2006 RI core uncovered area is smaller (in comparison with PWR-1000) it was decided to use FA-2M shaft end in NPP-2006 RI construction.

Comparative diagram of positions of fuel and absorber for PWR-1000 and PWR-1200 is given in Figure 18.

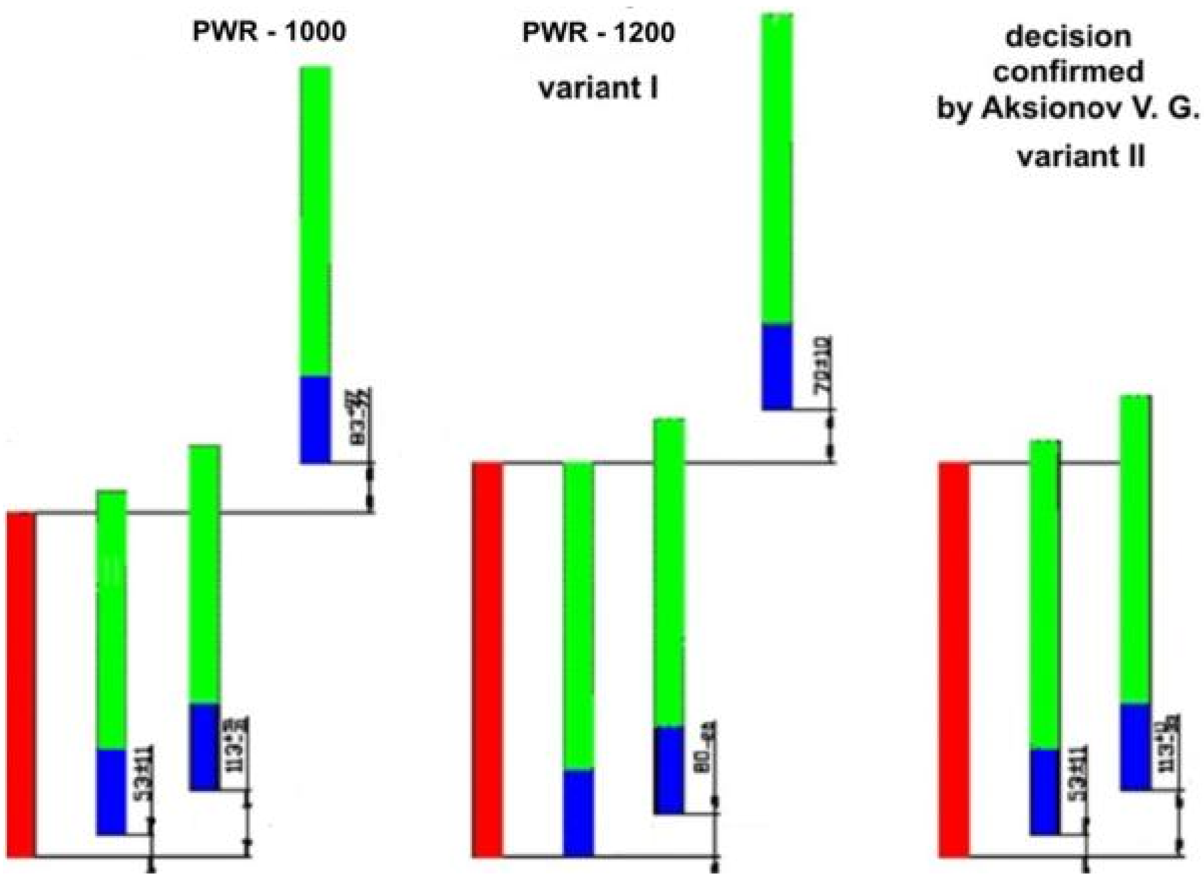

Figure 18 – Relative positions of fuel and absorber

To meet the requirements of effective emergency protection and keeping it in this condition while cooling to approximately 100 °C at existing boron concentration in first circuit water in any moment without one most effective CSS OP the number of drives in core has been expanded to 121 (Figure 19).

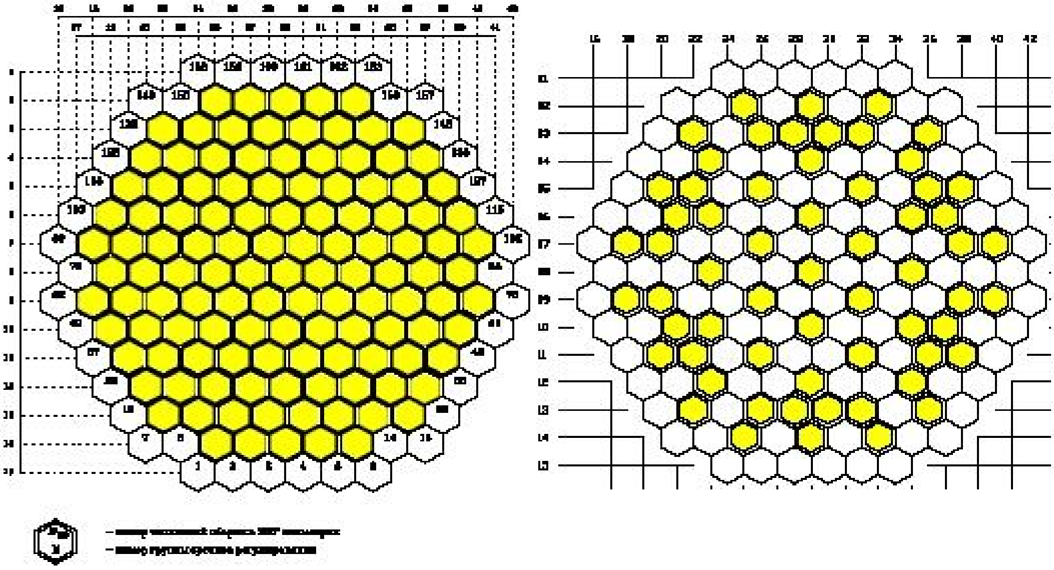

Figure 19 – Diagrams of CSS positions for PWR-1200 а) and PWR-1000 б)

The main stages of NPP-2006 core elements development are given in Figure 20.

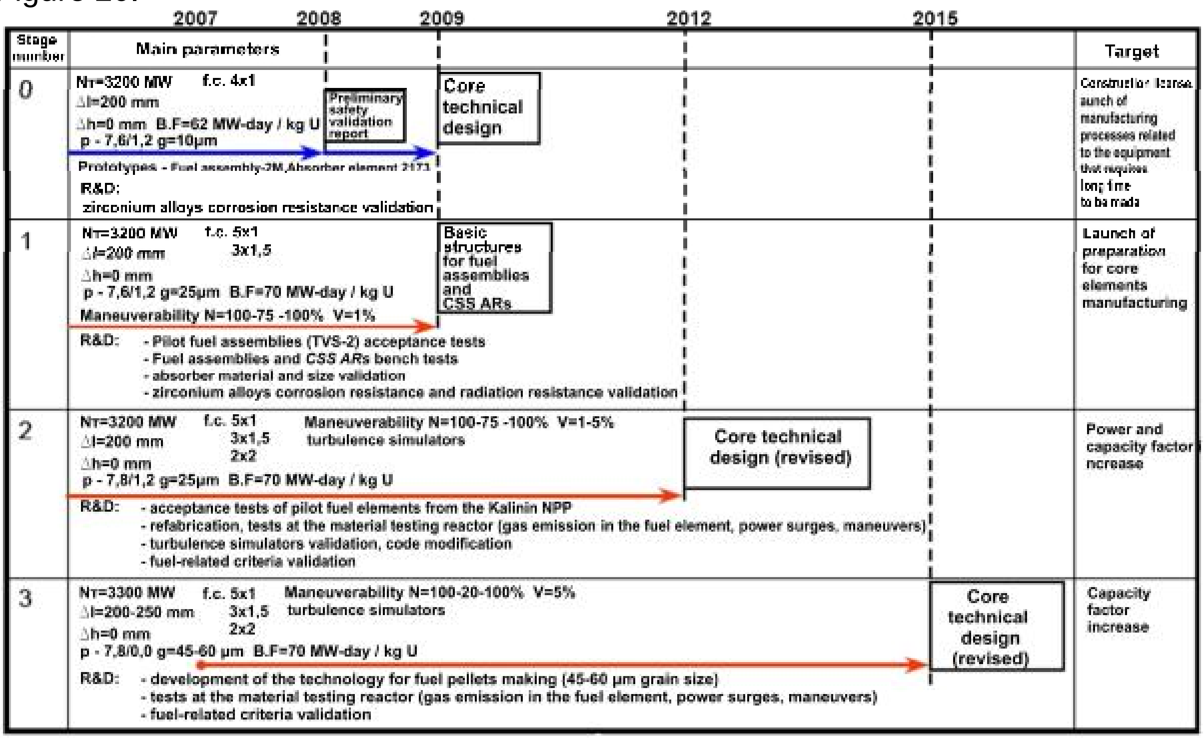

Figure 20 – Stages of development of NPP-2006 RI core elements

Lowering FA KGS allowed developing mixing grids with cellular construction in fuel element bundles permitting to form coolant twisting around fuel elements (“cyclone” type) (Figure 21) and coolant mixing between cassettes (Figure 22).

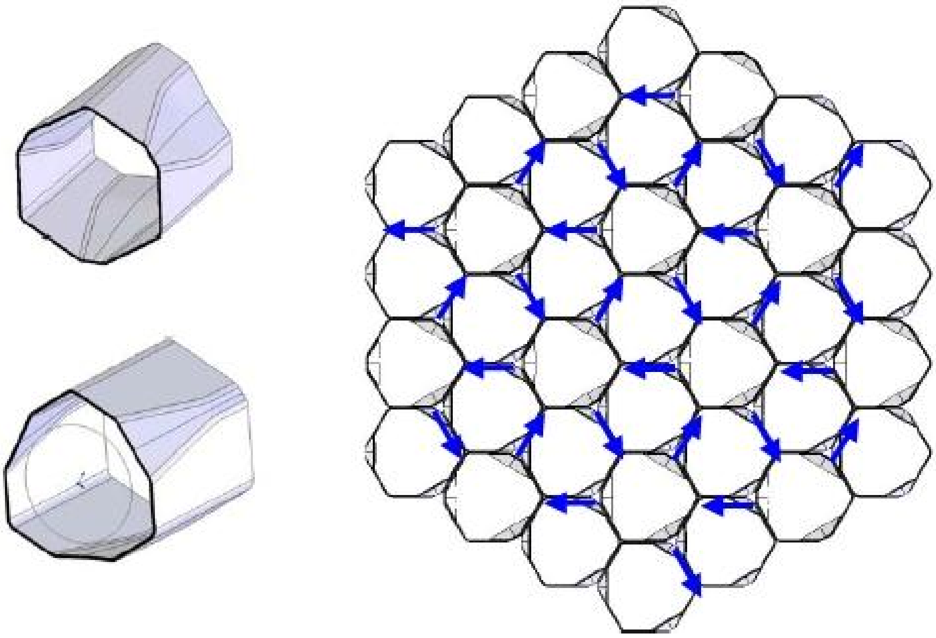

Figure 21 – Cells and a part of mixing grid of “cyclone” type.

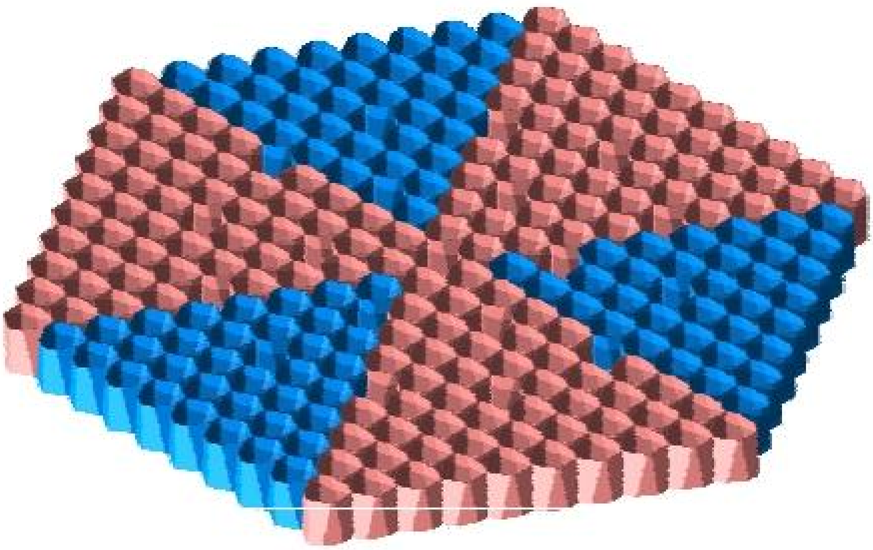

Figure 22 – **Cells and a part of mixing grid of “sector” type**

Implementation of these grids can provide increasing KTP and decreasing steam content in coolant and finally, increasing reactor power. At that FA carcass doesn’t interfere with coolant mixing between cassettes. Implementation of mixing grids is planning at the stage of power increase to 3300 MW.

So, among all kinds of PWR-1000 fuel assemblies FA-2M most of all corresponds to FL requirements for NPP-2006 RI. FA-2 (FA-2M) is the most technological, reliable in operation and simple construction for PWR-1000. Big experience in the construction operation and positive results permitted to develop NPP-2006 RI core on base of FA-2M [39].

6.6.3 Drives

For RI a modernized drive SHEM-3 of CSS is used which is the newest modification of SHEM-3 drive and is designed for replacement of worn drives of SHEM type in operating plants and for installation on all PWR-1000 NPP.

6.6.4 Steam generator

Steam generator SG-1000 MKP is suggested for NPP similar by construction to SG-1000M of the referent plant with corridor arrangement of tube bundle with service life of 50 years.

Using of space corridor tubes arrangement in heat exchanger allows:

– increase circulation speed in tube bundle decreasing the risk of heat exchange tubes damage because of low speed of sediments in heat exchanging tubes and concentrating of corrosion mixtures under them, increasing SG service life and operational reliability;

– reduce the risk of blocking space between tubes with slum;

– make access to space between tubes easier for the inspection and cleaning of heat exchanging tubes;

– increase water store in steam generator;

–enlarge space under tube bundle for easy slug removal.

At corridor arrangement of tube bundle its hydraulic resistance is lower. At that minimum clearance between the tubes is 6.0 mm what is actually equal to minimum clearance in SG-1000 drafts arrangement. It gives foundation to consider that all positive peculiarities of SG-1000 hydro dynamics will be kept in a new construction with increase of circulation speed in tube bundle.

Reference by steam generator is provided by using separated operationally tested solutions on SG-440 and SG-1000M and keeping SG-1000M manufacturing technologies at corresponding calculation reasonability.

These steam generators are used in PWR-1000, 1200 NPP plant 5 of Balakovo NPP, Novovoronezh NPP-2) being constructed at present.

Longitudinal section of a steam generator is given in Figure 23.

PWR-1200 SG frame length is the same with SG-1000M, and external diameter is 200 mm more.

SG project is based on our own experience in development, manufacturing and operating of horizontal SG.

Service life of a SG is equal to service life of RI and is 60 years.

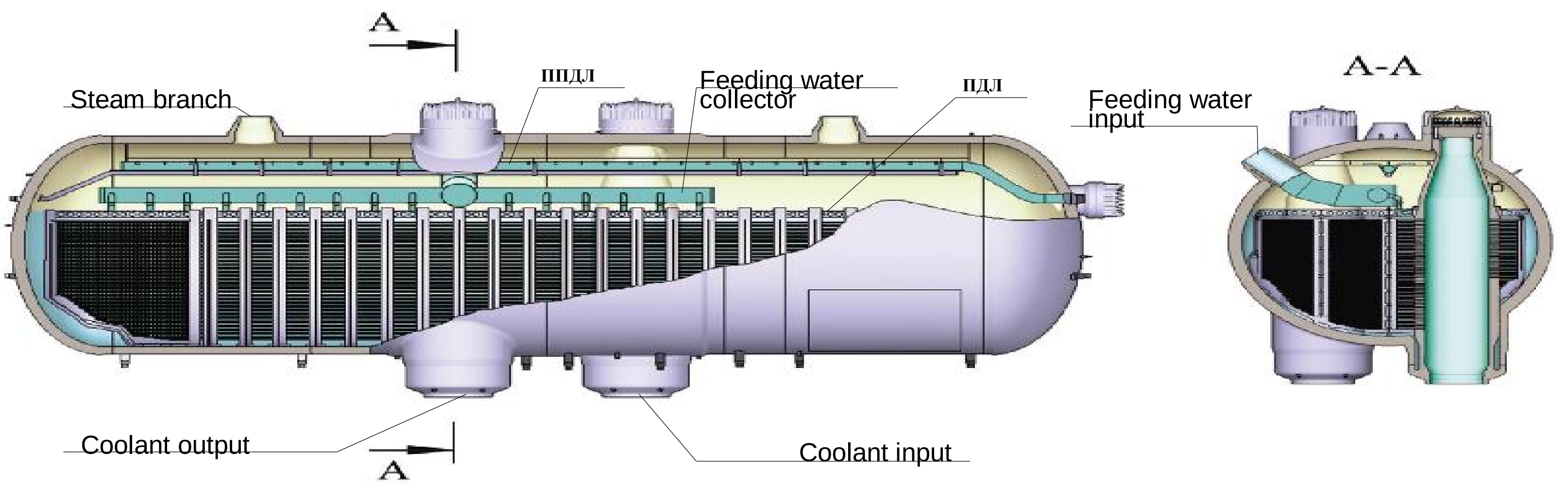

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Figure 23 – Longitudinal section of a steam generator

6.6.5 Main circulating pumping aggregate (MCPA)

MCPA -1391 is used as a main circulating pump for NPP.

At MCPA -1391 construction development modernization of its separate Units was carried out allowing excluding failures typical of this model by using the following constructive solutions:

MCPA -1391 has radially axial bearing on water lubrication with friction pair in axial bearing having high turbo-engineering characteristics. Resource testing of the aggregate during 6134 hours didn't reveal wearing in friction pair. Radially axial bearing on water lubrication allowed decrease volume of oil system, carry it out on each aggregate and exclude numerous cutting reinforcement.

Transition of feeding system of thickening unit to the passive principle of delivery first circuit cooled water allowed to exclude regulating reinforcement in water delivery line and to exclude its influence on reliability of operation.

Thickening is carried out from feeding pumps not connected with emergency sources of energy supply.

Based on MCP-195M operation experience and experimental works on MCPA -1391 on the whole and radially axial bearing and plate clutch reasonability of MCPA -1391 using in PWR-1000 plants is proved by the following facts:

- Constructive diagram, positions of Units of MCPA -1391 and MCP-195M are similar what allows using MCPA -195M use experience for MCPA -1391;
- Running part of the pump is in spherical case with a guide vain. That is why radial force influencing on the lower radial bearing is not higher than in MCPA -195M. Using in MCPA -1391 the similar construction and pump lower radial bearing friction pair materials is based on its operation experience in the composition of MCPA - 195M in NPP (whose mean time to failure is 70590 hours);
- Interpolator MCPA -1391 is completely similar to series interpolator MCPA - 195M, whose mean time to failure is 70590 hours, what validates its reliable operation in MCPA -1391;
- Constructionally radial-axial bearing unit is similar to MCPA -195M bearing unit with a replaceable friction pair (due to using of water lubrication). Upper radial bearing is identical to lower radial bearing what also proves its reliable operation in the composition of MCPA -1391 in NPP;
- Plate clutch used in MCPA -1391 has been successfully tested in the composition of its test component. Plate clutch construction has been tested for 3000 hours on actual stands during the aggregate testing. During revisions there weren't revealed any defects of the clutch and it proved the fact of its using in MCPA -1391. At nominal load the clutch mean time to failure in the composition of MCPA -1391 is 6130 hours.

MCPA -1391 has passed acceptance inspection under the supervision of a specially created committee consisting of the representatives of the Chief Designer of the reactor installation and supervisory bodies. Inspection was held according to a special program on actual stand allowing to check MCPA -1391 operation in normal operation conditions in the composition of NPP unit at full loads.

MCPA -1391 is used in RI projects of NPP under construction (Novovoronezh NPP, plant 5 of Balakovo NPP, NPP"Kundalkulam" in India, NPP-2, "Tyanvan", "Belene). Appearance of the main circulating aggregate is given in Figure 24.

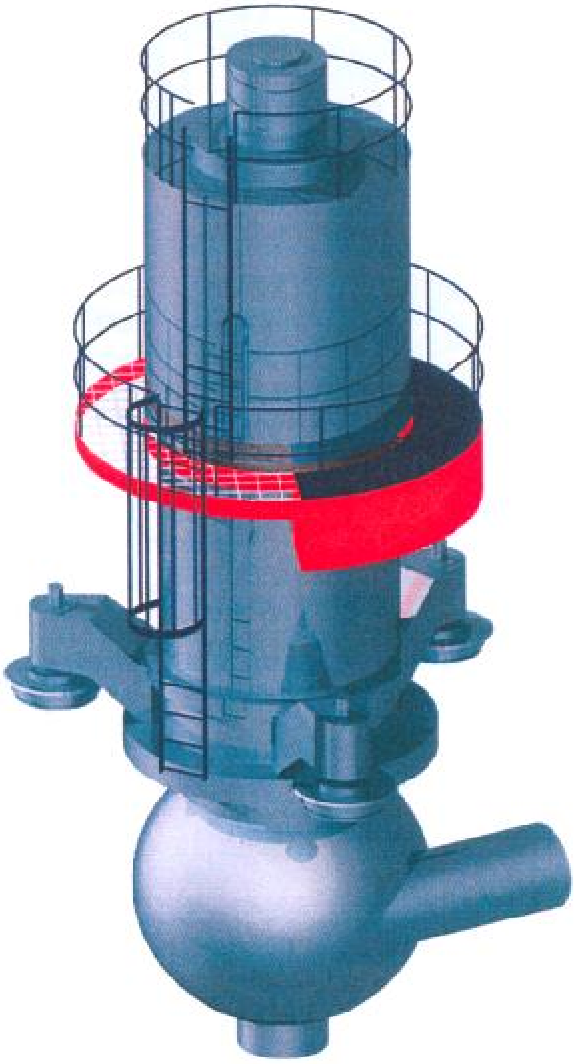


Figure 24 – Main circulating aggregate

6.6.6 Reference of the turbine plant main equipment

Steam condensation installation K-1000-60/3000 suggested for the NPP was produced by LJS “LMZ” (Saint Petersburg); it has intermediate separation and one-stage steam overheating, operation rotation frequency of 3000 rev/min and is designed for direct activation of alternative current generator produced by LJS “Electrosila” (Saint Petersburg) mounted on the common foundation with the turbine.

Steam turbine plant includes:

– complete steam turbine with automatic regulation, control and check devices, foundation frame and bolts, barring gear, steam distribution valves, and other units, details and devices;

– condensers with receiving and reset devices, spring supports;

– lubrication oil support and regulation systems (tanks, pumps, oil coolers, hydraulic hoisting pumps, etc);

- equipment of vacuum system and turbine thickening system;

– equipment of intermediate steam separation and overheat system;

– equipment of generation system;

– pipelines of steam, condensate, water and oil designed for connection of pumps, heaters, ejectors, oil coolants, and other auxiliary equipment.

Creation of K-1000-60/3000 type turbine was based on long-term experience of "LMZ" in designing, manufacturing and operating of high-speed TPS turbines with power of 800-1200 MW.

Using experience of creation of K-1200-240 turbine "LMZ" manufactured a line of turbines with power of 1000 MW for NPP. CPE used in K-1000-60/3000 turbine is of the same type with the engine used in K-1200-240 turbine with unique titanic blade 1200 mm long. At present three turbines of this type are being assembled in NPP of Ukraine and Russia. "LMZ" is manufacturing 5 turbines of 1000 MW for NPP with PWR reactors.

1000 MW LMZ turbine with 3000 rev/min for NPP is unique in the world turbine manufacturing by number of engineering solutions and takes leading positions in the world. Distinguishing constructive solutions are realized in this turbine on which the concept of the manufacturing plant is based:

- revolution frequency - 50 1/s;
- application of the newest last stage blades of extreme length developed by modern metallurgy and machine building. Last stage blade 12000 mm long of titanic alloy with whole milled band and edge tail. At present these are the longest operating blades for fast speed turbines in the world manufactured serially;
- application of solid-forged rotors with half-clutches.
- application of solid-forged rotors with half-clutches. Low pressure solid-forged rotors with half-clutches for 3000 rev/min are without a central hole; they are made of 235 tons ingot; their pure weight is 72 tons. Creation of such rotor increases operation reliability in comparison with welding variant due to absence of welded joint, high quality of forging giving possibility to exclude a central shaft hole and decrease voltage level, worked manufacturing technologies and comprehensive control program;
- application of operating blades of all stages with whole-milled bands;
- electro beam welding of separate operation blades;
- operating blades damping by friction in bands excluding the necessity to set damp connections in running parts. These solutions on operation blades construction provides high vibration reliability and efficiency of blade aggregate;
- all operating connections with HPC and LPC are made only in the lower part of the case and are welded what excludes leakage caused by bolt connections reliability and improves repairability of the turbine;
- bearings are used for operation with friction losses and are low-sensible to rotors decentreing. Synthetic flame-resistant oil is used for bearings lubrication in turbine regulation system. Application of flame-resistant OMTI oil or its analogue greatly increases flame safety;
- regulating and check valves are installed in front of HPC and LPC. Valves of two types in front of LPC provides reliable overspeed protection system of the turbine which is especially actual considering great steam volumes and moisture in separator-overheater (SO);
- volumes and existence of moisture in separator-overheater (SO);
- the following active and passive measures are taken for protection of turbine elements from erosion:
- turbine high pressure cylinder, races and diaphragms are made of stainless

steel. Manufacturing of lower and higher halves of HPC case is a great engineering achievement. Creating of HPC case and units of stainless steel allows to avoid crack erosion requiring repairing and maintenance during operation;

- After each stage in HPC except the first one steam is taken for generation. It provides intensive moisture leading out off the peripheral area behind the operating blades;
- HPC operating blades bands are made with bending internal surface providing stable stream of film moisture and its further leading out with steam;
- P3C last stage has increased heat drop, enlarged axial clearances and inter-channel moisture separation;
- turbine regulation system is hydraulic with electric part of regulation based on microprocessor engineering;
- turbine is installed on vibro-isolated foundation.

New technical solutions are used in relation to auxiliary equipment of turbine plant.

6.7 Main criteria and principles of safety

6.7.1 Safety criteria and design limits

Safety criteria and design limits must be adopted according to valid regulative normative documentation recommended the International radiological protection committee (IRPC) and IAEA recommendations. Project NPP-2006 limits on dose loads set on the valid normative documents are given in Table 20 (according to RF radioactive standards (RS)-99 and RS-2000 of the Republic of Belarus).

Table 20 – Design limits on effective irradiation dose

Name	Effective dose, mcSv/year
Population, lower limit at NPP normal operation	10
Population, higher limit	100
Population, critical group in SPZ boundary: on the whole body and separate organs during the first year after the accident	5000 50000
Acceptance categories at design basis accidents: - at accidents with probability of more than 10^{-4} event/year - at accidents with probability of less than 10^{-4} event/year	 <1 mSv/event <5 mSv/event
Population, equivalent irradiation dose of critical group at beyond design basis accidents: of the whole body of separate organs during the first year after the accident	 5000 50000
Personnel (group A): average annual for any sequent 5 years, But not more than a year	20000 <50000
Personnel (group A) at normal operation: - average value - average value of collective effective dose per one energy unit of 1000 MW (el) at working during the whole project operation period	 <5000 0,5 manSv/year
Target annual limit for the plant control post personnel (for accidents taken into consideration in the project)	25000

At normal operation and deviations from normal operation annual liquid radionuclides output from the energy unit into the environment (excluding tritium), annual aerosoloutput of inertial gases, aerosols and iodine isotopes must correspond to the requirements of “sanitary norms of design and operating of nuclear plants” AS-03 SP considering EUR recommendations.

In order to prevent nuclear catastrophe the project should follow nuclear safety criteria at which:

- control and check of reactor core are provided;
- local criticality at overloads, transportation and storage of nuclear fuel is excluded;
- fuel elements cooling is provided.

Operational limits set by valid norms and regulations are given in Table 21.

Table 21 – Operational limits and safety limits

Name	Value
Permitted amount of fuel elements with damages of "gas indensity" type: - operational limit - safe operation limit	 0,2 % of fuel elements 1,0 % of fuel elements
Permitted amount of fuel elements with direct contact of fuel and coolant: - operational limit - safe operation limit	 0,02 % of fuel elements 0,1 % of fuel elements
Fuel elements cover temperature	< 1200 C
Local depth of oxidation of fuel elements covers	< 18 %
Part of reacted zirconium in % of its mass in fuel elements covers	< 1 %
Number of damaged fuel elements in core for design basis accidents: - with probability of more than 10^{-4} one/year - with probability of less than 10^{-4} one/year	 < 1 % < 10 %
Calculated values of total probability of beyond design basis accident considering all initial events, 1react/year	< 10^{-6}

Table 22 gives values of time reserves required for reliable fulfillment of correcting activities. These directions should be used for analysis and foundation of beyond design basis accidents control measures.

Table 22 – Required time reserves

Characteristics of correcting activities	Time reserve, (hours)
1 Operative personnel activities from PCP, not less than	0,5
2 Operative personnel activities from reserve control posts (RCP) and in places with special equipment (jumple cables, reinforcement drives, etc), not less than	1
3 NPP personnel activities using portable equipment, not less than	6
4 External help, not less than	24

These directions are given with conversation reserves on the base of stationary and transportable power plants operation considering IAEA recommendations.

6.7.2 Purposes of providing radiation safety

The general purpose is to provide radiation safety and protection of the personnel, population and environment from radiation danger by means of using effective engineering and organizational protective measures in the NPP.

Achievement of the general purpose is provided by safety control at all stages of NPP life cycle, at all its operational conditions by fulfillment of radiation protection purpose and engineering safety purpose.

Radiation protection purpose is limiting of irradiation doses of personnel, population and output of radioactive wastes into the environment at normal operation of the energy unit, design basis accidents, beyond design basis accidents.

At normal operation limitation of irradiation doses of the personnel, population and output of radioactive substances into the environment must be lower than the set limits at rationally achievable social and economically reasonable level proved by the operational experience of NPP PWR energy units produced in our country and foreign NPP with PWR (ALARA principle – providing irradiation at reasonably achievable low level).

At design basis accidents limits of irradiation doses of the personnel, population and output of radioactive substances into the environment must be lower than irradiation doses for population determined by NTD at accidents due to protection and localizing systems operation in project modes.

In combination with purpose probability rate at beyond design basis accidents it is necessary to provide limitation of consequences of accident with heavy damages of core in order to protect the population; calculated radius of urgent evacuation area must not exceed 800 m what excludes the necessity of urgent evacuation and long-term migration of the population. Radius of the area within which it is possible to carry out population protection actions after the early stage of accident must not exceed 3 km (iodine preventive measures, sheltering, etc). Radiuses of the mentioned areas must be calculated for the worst weather conditions.

Boundaries for protective measures planning areas are determined in the project of a certain NPP considering characteristics of the site.

Purpose of providing radiation safety in the project must be achieved by development of engineering and organization measures of activity directed to accidents prevention, limitation of their radiological consequences, providing “practical impossibility” of the accident with heavy radiological consequences.

Term “practical impossibility” implies the probability values lower than1,0x10^{-7} per one year of energy unit operation.

Radiation safety must be achieved by engineering and organizational measures and activities given below:

- high reliability of the equipment including modernized equipment on the base of operation experience of NPP with PWR reactors with implementation of alternative solutions proved by exploiting of different types of nuclear energy units with prevention of failures;
- low frequency of initial events disturbing normal operation;
- probability of heavy damages of core including damages of stopped reactor of less than 10^{-5} (OPB-88/97) per reactor a year;
- probability of appearance of radiation factor (interference level) level exceeding of which requires measures of population evacuation outside area with radius of 800 m, less than 10^{-7} per reactor a year;
- increasing reserve time for personnel controlling beyond design basis accidents during which project characteristics of protective barriers are provided:
- protection from failures caused by personnel errors;
- “practical impossibility” of such events as:
- secondary criticality of melting;
- heavy accident with unlocalizable protective cover bypass;
- heavy accident at high pressure in “reactor-protective cover” system;
- heavy accident with protective cover failure after transition of accident process to

“”low pressure scenario”.

6.7.3 Basic principles and project foundation of safety systems

At development of safety systems [40 – 43] it is necessary to solve the task of their safe functioning considering the following types of potentially possible failures:

- initial events of accidents including possible connected with them failures;
- single failure or personnel error not connected with the initial events;
- long-term unrevealed failure;
- general purpose failure.

While development of SS it is necessary to consider failures causing the following events as project initial events:

- input of positive reactivity;
- heat sink damage;
- depressurization of the first and second circuit pipelines;
- errors at refueling and repairing works.

In the mode of NPP blackout the project should provide carrying out of safety functions enough for prevention of transition to heavy accident stage for at least 24 hours.

It is necessary to consider single errors of the personnel in control from PCP or at operating with systems and equipment that may cause distortions (initial events) given above (excluding external impacts). The project must provide low sensitivity to the personnel errors and/or error actions of the operative personnel.

Initial events are considered for all conditions of energy unit including conditions at stopped reactor.

By character of fulfilled functions the safety systems are subdivided into protective, localizing, providing, and controlling.

By its technologies and structure a safety system must have the following configuration:

– it must include active and passive channels (elements) in relation to the main safety functions;

– actions of active and passive SS channels (elements) must be considered totally both at design basis accidents and at beyond design basis accidents; contribution of all elements of SS must be considered at safety justification;

– in order to provide functional and economic advantage it is recommended to use the principle of joint functions of normal operations and safety by the same active mechanisms;

– structure of active and passive safety systems channels must be directed to achieving of optimal characteristics of functional properties and of minimum expenses.

The purpose of a new NPP project was not only to follow the main criteria and principles based on valid normative documents in providing NPP safety at design, constructing and operating. A number of requirements has been added to the existing normative base such as:

- recommendations of international consultative group INCAG;
- recommendations of IAEA on new generations of reactors;
- solutions of international safety conferences.

Decisive value for the creation of new generation of NPP belongs to the stage of technologies development on the evolution base when along with scientific end engineering studying of the problem, operation experience, probability safety analysis, and results of reliability researches especially from the point of view of heavy accidents control directed to decrease radioactivity output into the environment are used . The main safety characteristics are:

- preventing of deviations from normal operation which require safety systems activation. Preference is given to Firm constructions with high heat inertance and increased reserves between rating values and operating parameters values and values of safety systems activation;
- maximum possible reducing of general purpose failures and dependent failures by means of choosing the corresponding constructive and arrangement solutions, safety function doubling;
- existence of multifunctional system of reactor emergency cooling based on multiple approaches to carrying from the safety functions, interconnection of active and passive channels; such system provides probability rate of corey damage over the set limits for design basis accidents not worse than 10^{-6} per one reactor a year;
- application of system of localization of accident products based on capability to keep accident products without exceeding the value of permitted output by main dose-forming nuclides at heavy accidents;
- deceasing of irradiation doses achieved due to the corresponding construction, material choice, protection and arrangement.

6.7.4 Principle of deep echeloning of the protection

The principle of deep echeloning of protection is carried out by creating a number of barriers (fuel matrix, fuel cover, first circuit boundaries, localization system) which should be protected and which in their turn must be disturbed before harm can be done to people and environment. These barriers may have safety and operation purposes or only safety purposes. Diagram of deep protection echeloning is shown in Figure 25.

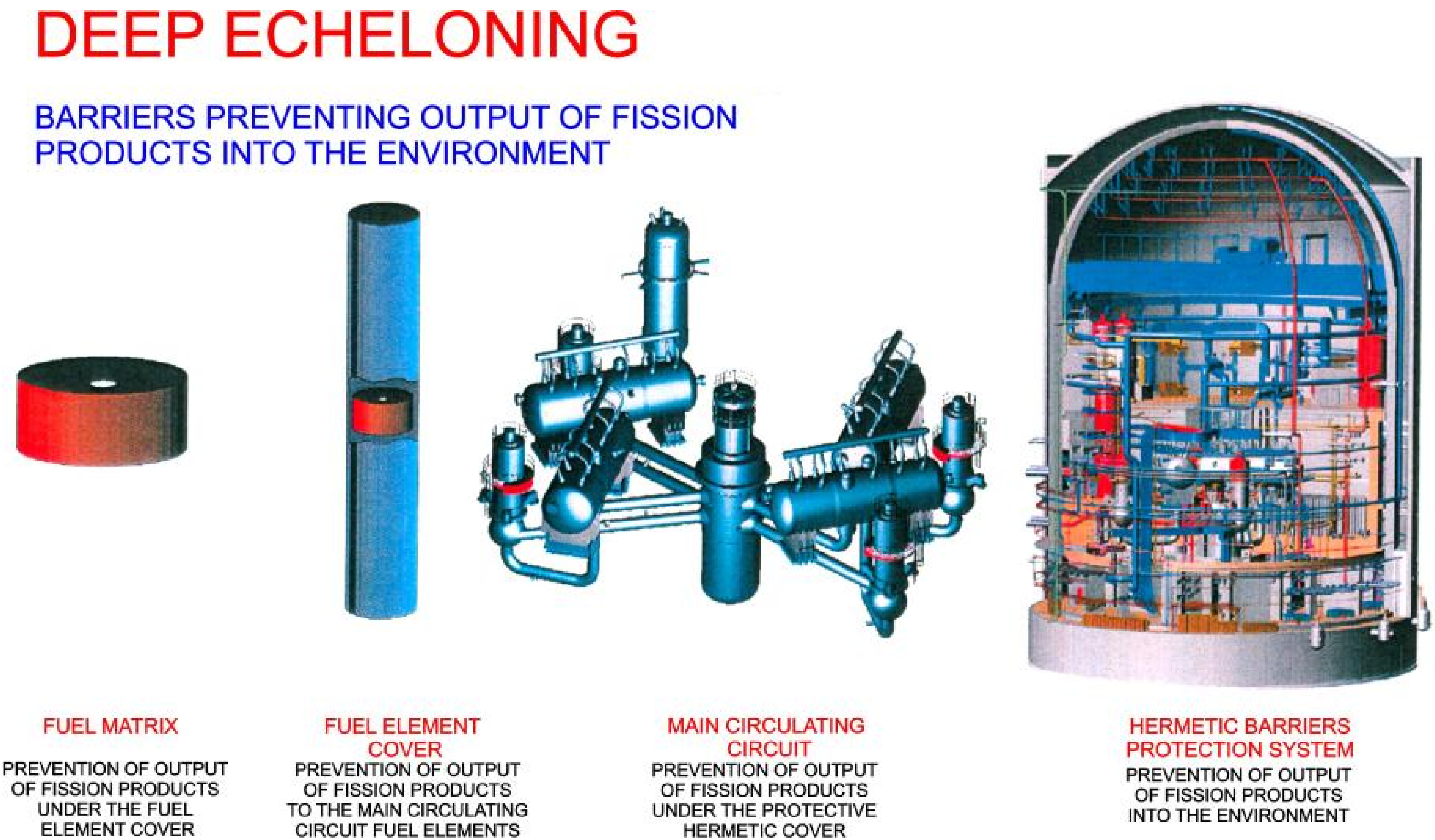


Figure 25 - Diagram of deep protection echeloning

The first level of deep echeloned protection is provided by:

- the project based on using of modern norms, rules and standards;
- using of advanced reactor installation in the project;
- providing high quality at all stages of NPP creation (designing, constructing, equipment manufacturing, assembling, and operating);
- safety barriers control during the operation.

The second level of deep echeloned protection is provided by:

- interior characteristics of safety and reactor;
- control at normal operation including diagnostics, preventive reactor protection and indication of the systems failures and errors. This level provides continuity of the first three barriers.

The third protection level is provided by safety systems – protective, control, localizing and support which are considered by the project to prevent the progress of failures and personnel errors at design basis accidents and the progress of design basis accidents into heavy accidents and to keep the radioactive materials inside localizing systems.

The fourth level – beyond design basis accidents is provided by measures considered by the project including accident control and measures directed to localizing barrier (protective cover) protection.

The fifth level includes emergency preventive measures outside NPP site directed to reduce the consequences of output of radioactive materials into the environment.

To meet all safety requirements the project considers safety system consisting of active and passive parts, each of them capable of carrying out the corresponding safety requirements.

6.8 Safety systems. Project principles and project solutions

Safety systems are designed resistant to failures and capable of carrying out their functions after energy supply stops. Project principles and project solutions on providing resistance to failures of the systems are given in Table 23.

Table 23 – Project principles and project solutions

Type of failure	Project principle	Project solution
(A) Single failure	Excessiveness	Separation of each safety system into several channels each of which is able to carry out its own safety function
(B) General purpose failure	Multiple principles	Each safety system consists of active and passive (practically passive) parts each of which is able to carry out its own safety function
(C) Prevention of failure caused by internal and external reasons	Space separation and constructive protection	Space separation of safety channels and constructive protection inside channels
(A), (B), (C) and loss of energy supply	Failure safety	1 design in such way that system failure causes actions directed to safety. 2 Application of passive systems. 3 Application of additional source.
Operator's error	Automatic control	Application of automatic systems for protection action and blocking of operator's control disturbing safety functions.

To carry out safety requirements and carrying out the corresponding safety functions the project considers safety systems given in Table 24.

Table 24 – Main safety systems

Safety functions	Safety systems	
	Active part	Passive part
1 shutdown of the reactor and keeping it in this condition	Emergency protection	Emergency boron input system
2 Emergency cooling and remained heat sink		
2.1 If the first circuit is not damaged	Systems of emergency cooling by steam generators and supply systems	System of passive heat sink (PHSS)
2.2 If the first circuit is damaged	System of emergency cooling of core (AZECS) and supply systems	System of passive heat sink (PHSS). System of passive water delivery to core
2.3 Heat sink from spent in cooling pond	System of cooling pond cooling and supply systems	Additional water store in cooling pond
3 Keeping of radioactive products and reducing of radioactive substances output. Limitation of radiation output, protection from explosive hydrogen concentrations, protection from pressure increase.	Sprinkler system support systems and isolating devices.	Localizing system – protective cover with passive protection elements (pressure drop and cleaning system, system of keeping damaged fuel and hydrogen suppressing).

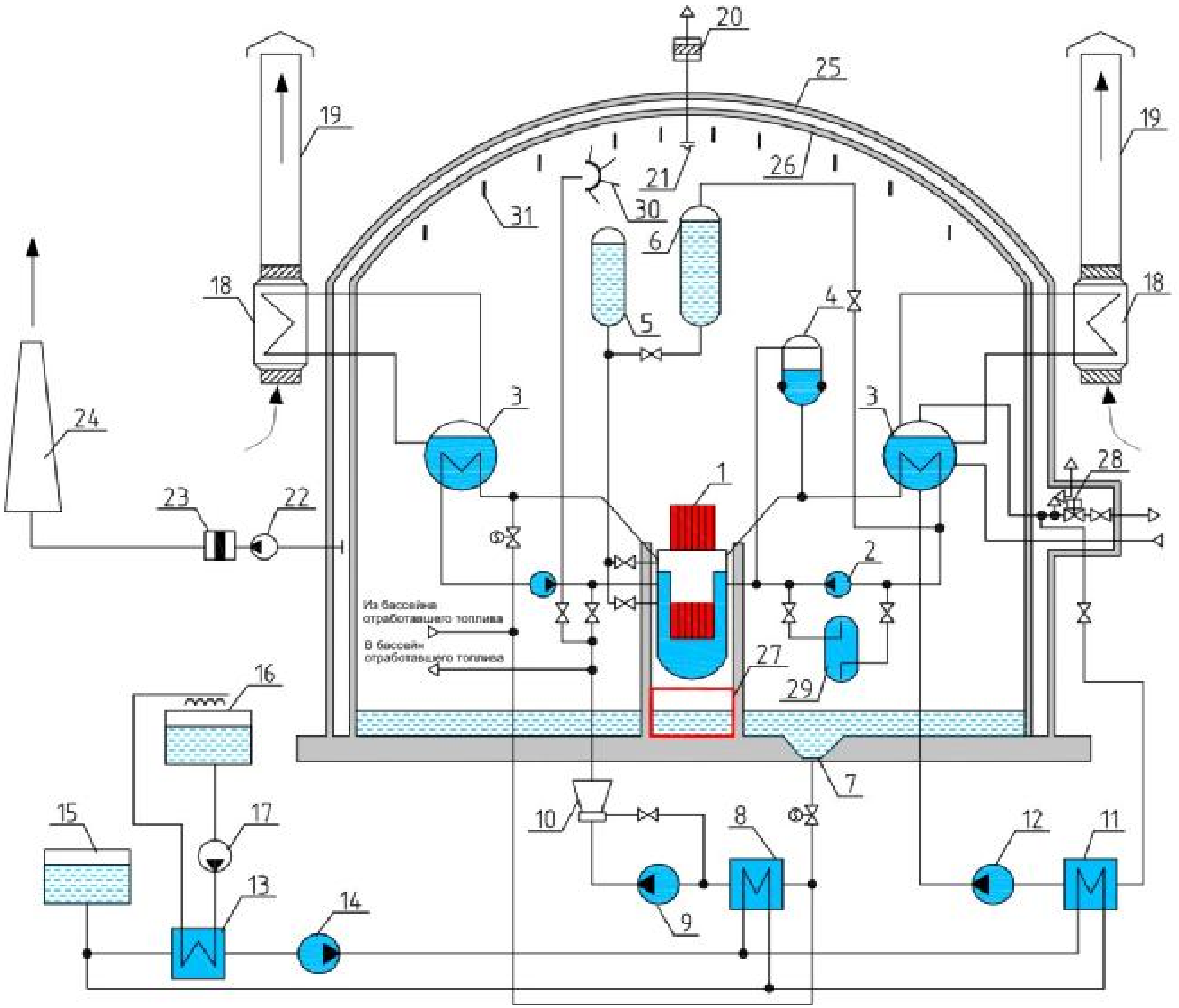
Brief description of adopted technical solutions on SS active and passive parts.

Functional diagram of the plant safety system is given in picture 26. According to the project purposes safety system includes active and passive parts each of them capable of independent carrying out of main safety functions. Figure 27 gives list of safety functions included into SS active and passive parts.

Two nuclear plants are being constructed according to project-2006:

- project NVAES-2, chief designer is LJS “Atomenergoproject”, Moscow;
- project LAES-2, chief designer is LJS “Atomenergoproject”, Saint Petersburg.

Table 25 gives comparative characteristics of safety systems of these two projects:



1. reactor
2. main circulating pump
3. steam generator
4. pressure condenser
5. stage 1 accumulator
6. stage 2 accumulator
7.water intake
8. circuit cooling heat exchanger
9. circuit 1 pump
10. injector
11. steam generator emergency cooling heat exchanger
12. steam generator emergency cooling pump
13. тoperating circuit heat exchanger
14. pump
15. breathing tank
16. spray pond
17. technical water input pump
18. PHSS heat exchanger
19. PHSS gas pipe
20. filter of steam-air sink from hermetic volume
21. membrane device
22. ventilator
23. filter
24. ventilation tube
25. protective cover
26. hermetic cover
27. device for catching and keeping of reactor melted core
28. fast-acting stop shut-off valve
29. quick boron input container
30. sprinkler system
31. hydrogen safety provide system

Figure 26 – Energy unit safety system diagram

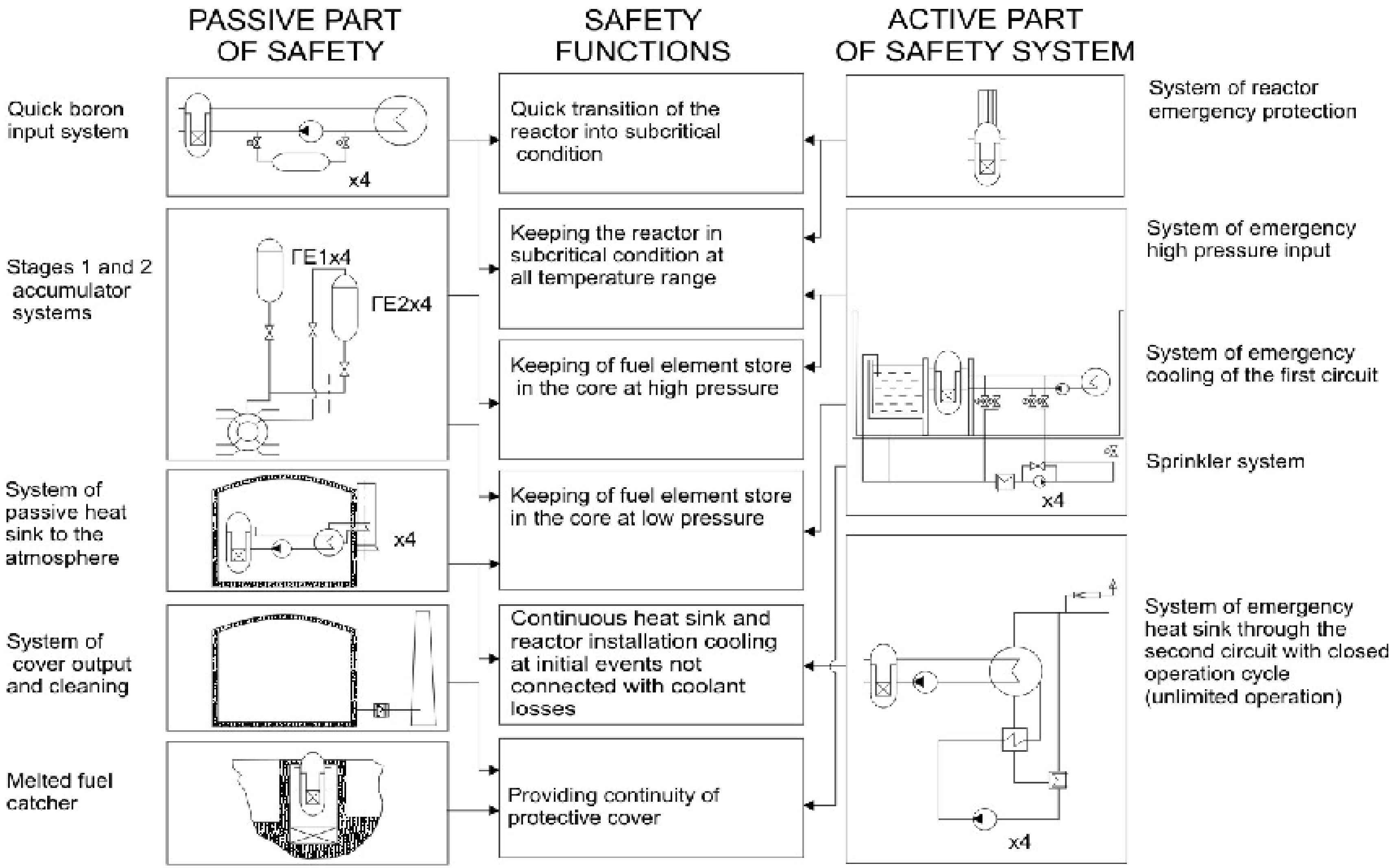


Figure 27 – Basic solutions on providing safety functions in project NPP-92

Table 25 – Safety systems structures of NVAES – 2 and LAES- 2

System name	NVAES - 2	LAES - 2
Feeding and blowing system of the first circuit	Feeding: three pumps x 60 tons/hour carrying out all required functions in the whole regulation range – one is in operation, two are in reserve	Feeding: two pumps x 60 tons/hours for ”large” boron regulation and coolant leakage compensation. Three pumps x 6,3 tons/hours for “flexible” regulation and leakages compensation.
AZECS active part	Combined two-channel high and low pressure system with redundancy of 2 x 200 % and internal redundancy of 2 x 100 %	Separate four-channel systems of high and low pressure with channel redundancy of 4 x 100% each
System of emergency boron acid input	Two-channel system with channel redundancy of 2 x 100 % and internal channel redundancy of 2 x 50 %	Four-channel system with channel redundancy of 4 x 50 %
Emergency feeding water system	Absent	Four-channel system with channel redundancy of 4 x 100 % with storage tanks of emergency feeding water
System of SG emergency cooling	Closed two-channel system with redundancy of 2 x 100 %	
System of passive reflooding of core (GE-2)	Passive four-channel system with channel redundancy of 4 x 33 % and two containers in each channel	Absent
System of passive heat sink (PHSS).	Passive four-channel system with channel redundancy of 4 x 33 % and two heat exchangers cooled with air in each channel	Passive four-channel system with channel redundancy of 4 x 33 % with 18 heat exchangers cooled by water in each channel
Safety systems (for providing free lance operation modes of the energy unit)		
Active part of core emergency cooling system	Combined two-channel high and low pressure system with redundancy of 2 x 200 % and internal redundancy of 2 x 100 %	Separate four-channel systems of high and low pressure with channel redundancy of 4 x 100% each
System of emergency boron acid input	Two-channel system with channel redundancy of 2 x 100 % and internal channel redundancy of 2 x 50 %	Four-channel system with channel redundancy of 4 x 50 %
Emergency feeding water system	Absent	Four-channel system with channel redundancy of 4 x 100 % with storage tanks of emergency feeding water
System of SG emergency cooling	Closed two-channel system with redundancy of 2 x 100 %	Absent

Table 25 (continued)

<table>
<tr><th>System name</th><th>NVAES - 2</th><th>LAES - 2</th></tr>
<tr><td>System of passive reflooding of core of stage 2</td><td>Passive four-channel system with channel redundancy of 4 x 33 % and two containers in each channel</td><td>Absent</td></tr>
<tr><td>Passive heat sink system</td><td>Passive four-channel system with channel redundancy of 4 x 33 % and two heat exchangers cooled with air in each channel</td><td>Passive four-channel system with channel redundancy of 4 x 33 % with 18 heat exchangers cooled by water in each channel</td></tr>
<tr><td>Melting localization device</td><td colspan="2">The system is designed for keeping of liquid and solid fragments of destroyed core, parts of reactor vessel, interior body devices at heavy accidents with melting of core. The device carries out the following protective functions:
- receiving and placing inside of liquid and solid elements of core and reactor constructive materials;
- heat transmission from melting to cooling water;
- keeping the reactor bottom at its breaking off;
- preventing of melting coming from the boundaries of its localization set by the project;
- providing subcriticality of the melting in concrete mine;
- providing cooling water input to the device and steam sink off the device;
- providing minimum output of radioactive substances into the hermetic cover space;
- minimization of hydrogen output;
- proving of not exceeding of maximum permitted voltages in constructions situated in under-reactor room of the concrete mine;
- providing the fulfillment of its functions with minimum operator’s control.</td></tr>
<tr><td>Protective covers system</td><td colspan="2">Protective covers system consists of primary (internal) and secondary (external) protective covers. Primary protective cover is made of stressed ferroconcrete and is designed for keeping radioactive substances in limits set by the project to limit their spreading into the environment during design basis accidents. External cover is designed for protection of systems and elements of reactor building from special natural and anthropogenic impacts. Both covers provide biological protection from ionizing radiation.</td></tr>
</table>

6.8.1 Melt localization system

Existing containments for NPP with PWR-1000 type atomic reactors are not counted for localization of heavy accidents. Heavy accident connected with melting of the reactor core materials may cause destruction of the reactor vessel and fall of 200 tons of melt in its mine. Melting localization and avoiding forming of dangerous explosive hydrogen is possible with help of melt catcher situated on the bottom of reactor mine. The catcher is lined with refractory material on the base of zirconium dioxide and includes a layer of victim material. The catcher area is 100 $м^2$ (Order No. 99117898 with priority dated12.08.1999).

System or device of melt localization (MLD) is one of the technical means specially considered to control off-project heavy accidents at non-body stage. MLD carries out receiving, placing and cooling core materials melt, interior body devices and reactor vessel to full crystallization. At that the following points are provided:

– keeping the reactor vessel bottom at its breaking-off or plastic deformation;

– not exceeding maximum permitted voltages in constructions carrying out melt cooling and construction;

– subcritically of melt;

– minimization of output of radioactive substances into the hermetical space;

– minimization of hydrogen generation;

– protection of dry protection system and support constructions of the reactor from destroying.

At normal MLD functioning contact of high-temperature and chemically active melt with building constructions, equipment and protective cover is completely excluded.

System functioning is based on “passive” principles. Chosen construction of the system provides its autonomous work for at least 72 hours. Activation of the system is carried out automatically by the signals of temperature sensors set over the core and in melt localization device with the possibility of distant control by the operator from control panel.

Water from interior devices revision shafts and fuel pond and water from receiving tanks is used for melt cooling.

Figure 28 gives schematic arrangement of the core melt localization device.

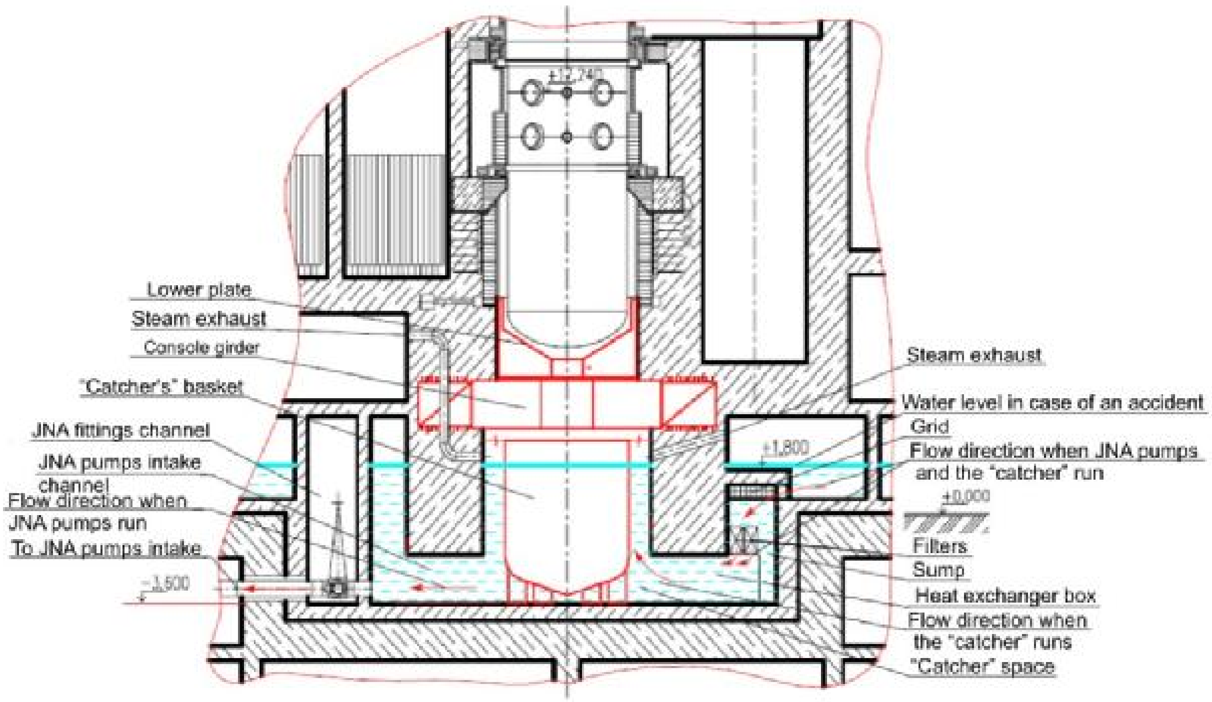


Figure 28 - Core "catcher" components

Corium localization device is a heat exchanger box filled with victim material where products of fuel heavy damages with elements of interior body devices and reactor vessel get.

The device construction includes lower board and truss-console carrying out distribution of corium which getting to the basket interacts with victim material resulting the process a inversion leading to melting of metal corium materials in the lower part of the basket; it allows to avoid formation of a great amount of hydrogen at water input to the heat exchanging basket. Steam formed at that leaves under-reactor space through special holes connecting MLD with cover.

6.8.2 Sealed barriers system (containment)

The system of protective hermetic cover is designed for reactor protection from external impacts and to limit output of activity into the environment in all plant modes including accident modes.

Protective cover meets the following requirements:

– the cover is hermitic enough considering pressure and temperature loads at guillotine break of circuit 1 pipeline or steam pipes;

–interior design cover pressure considers store more than maximum calculated cover pressure;

– pressure under cover is decreased more than for 50% of maximum pressure during 24 hours after the postulated accident;

– cover stands maximum pressure drop as a result of unintended activation of the cover sprinkler system;

– automatic separation of pipelines with technological environments passing through the protective cover is considered in emergency modes with pressure increase inside protective cover;

– KIP able to operate in accident and after-accident conditions to control pressure and temperature under the cover and hydrogen concentration;

– protective cover construction is counted on external and internal accidental impacts. At beyond design basis accident continuity of protective cover is provided and leakage of radioactive products into the environment are limited;

– protective cover is equipped with the system of diagnostics of its dense damped condition;

– fire-resistance of the protective cover is guaranteed which is set by calculating out of fire load value and time of its full combustion (without considering using fire-extinguishing means);

– construction and elements of protective fire are available for control, maintenance and repairing;

–choice of materials for protective cover provides keeping of its functional characteristics during the whole calculated service life;

– cover construction is of safety category 1 (PiNAE-5.6) and of seismic-resistance category 1 (NP-031-01). All shut-off valves in the protective cover shut-off system are made according to the 2L safety equipment class requirements;

– protective cover is double. Internal enclosure is a cylinder construction of pressed ferroconcrete with half-spherical dome and ferroconcrete foundation board. Internal enclosure of the cover has welded surface made of sheet carbon steel;

– internal protective cover is designed for carrying out functions of localization in all NPP operation modes considered by the project including emergency modes and for providing biological protection;

– external cover surrounding the first cover is a cylinder ferroconcrete construction with half-spherical dome and is a screen protecting from the external impacts (aircraft falls, hurricanes, earthquakes, air shock wave, extreme meteorological and climatic impacts, etc). the external enclosure contains tanks of passive heat sink leads systems;

– access under the cover is carried out through transport hatch and two hatches for personnel. Hatches' construction considers impossibility of simultaneous opening of all doors of a hatch during operation of the station.

6.8.3 Reference of safety systems and equipment used in NPP project

Design equipment and safety systems of NPP is referred to RI B-320 line being exploited at NPP and un NPP built in China, being built in India, Iran, Bulgaria, Czech Republic and Russia (project of completing plant 5 of Balakovo NPP, NVAES-2).

Adopted in the project technical solutions allow to provide the required level of RI reliability and safety by balanced number of active and passive safety systems and by measures directed to prevention and limitation consequences of accidents including heavy ones.

NPP project uses the following active and passive safety systems implemented and operating with B-320 reactor installation in NPP. The systems are the following:

– system of emergency boron input;
– system of emergency steam sink;
– system of RPC-A;
– system of main pipelines separation;
– system of stage one accumulators;
– system of the first and second circuit protection from high pressure;

– support systems of ventilation and conditioning;
– system of diesel generators;
– hermetic cooling system (active part).
In addition to systems listed above NPP safety system includes;
– system of passive heat sink (PHSS);
– passive system of filtering of inter-covers space;
- system of hydrogen concentration control and emergency output;
- system of catching and cooling of the first circuit and cooling pond cooling;
– combined system of emergency and planned cooling of the first circuit and cooling of cooling pond;
– system of cooling and blowing of steam generators;
– system of operation circuit of reactor compartment consumers.

Given safety systems are used partially or fully in the projects of NPP being built in China (NPP "Tyanvan"), Iran (NPP "Busher"), India (NPP "Kudankulam"), Russia (project of completion of plant 5 of Balakovo NPP, LAES-2, NVAES-2).

Scientific and research works on justification of serviceability of these systems proved by experimental base allow to adopt their results as reference justification.

6.8.4 Main results of safety system use

Figure 29 shows the results of improvements of passive safety systems

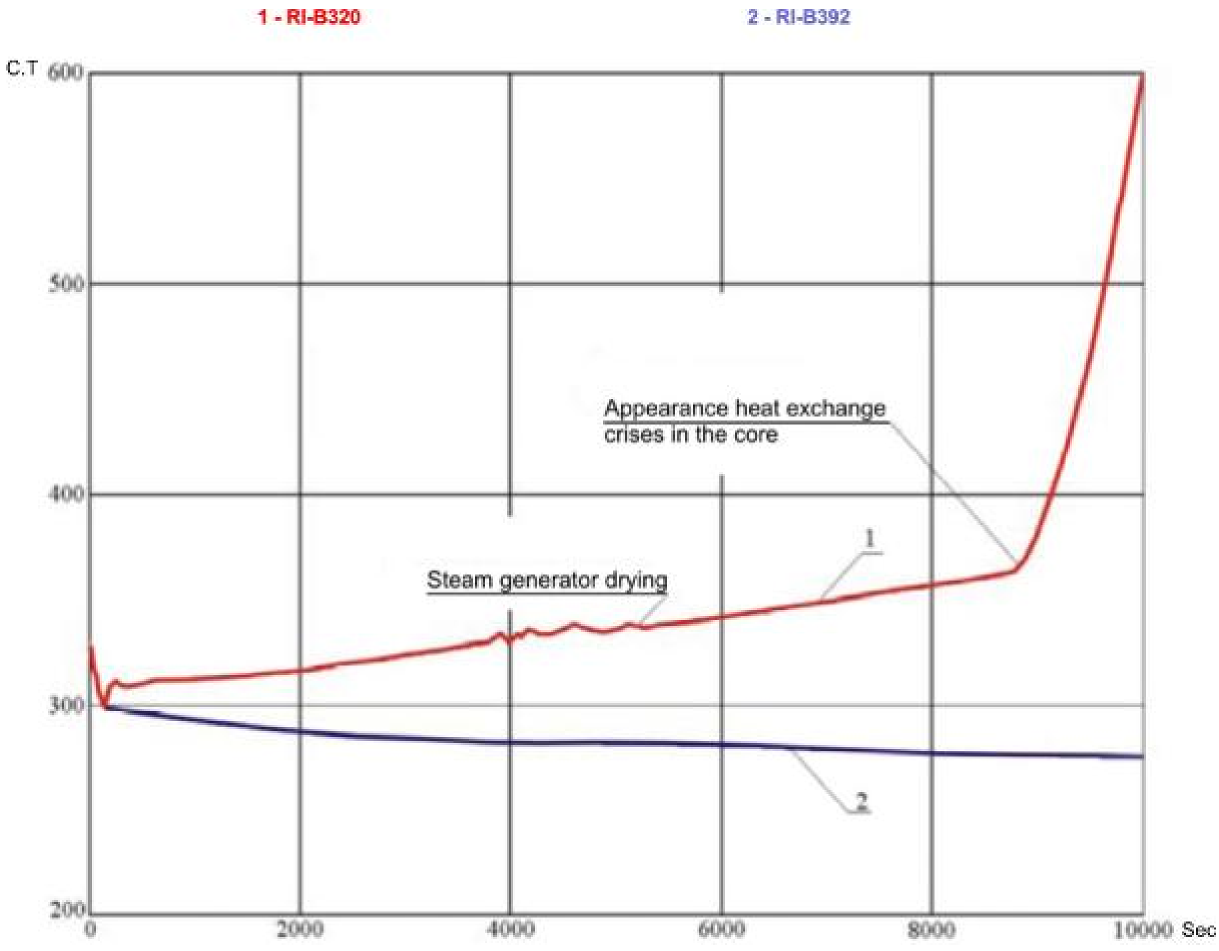


Figure 29 – Maximum temperature of fuel element cover at full loss of alternative current sources

This Figure shows diagram of FE covers temperatures for emergency situations. In this case mode black-out (complete loss of energy source) is chosen.

The Figure shows that this mode is not practically dangerous for NPP-2006 project but for the previous project damage of core can occur 2 – 2,5 hours after the beginning of this mode.

One more important result is given in Figure 30.

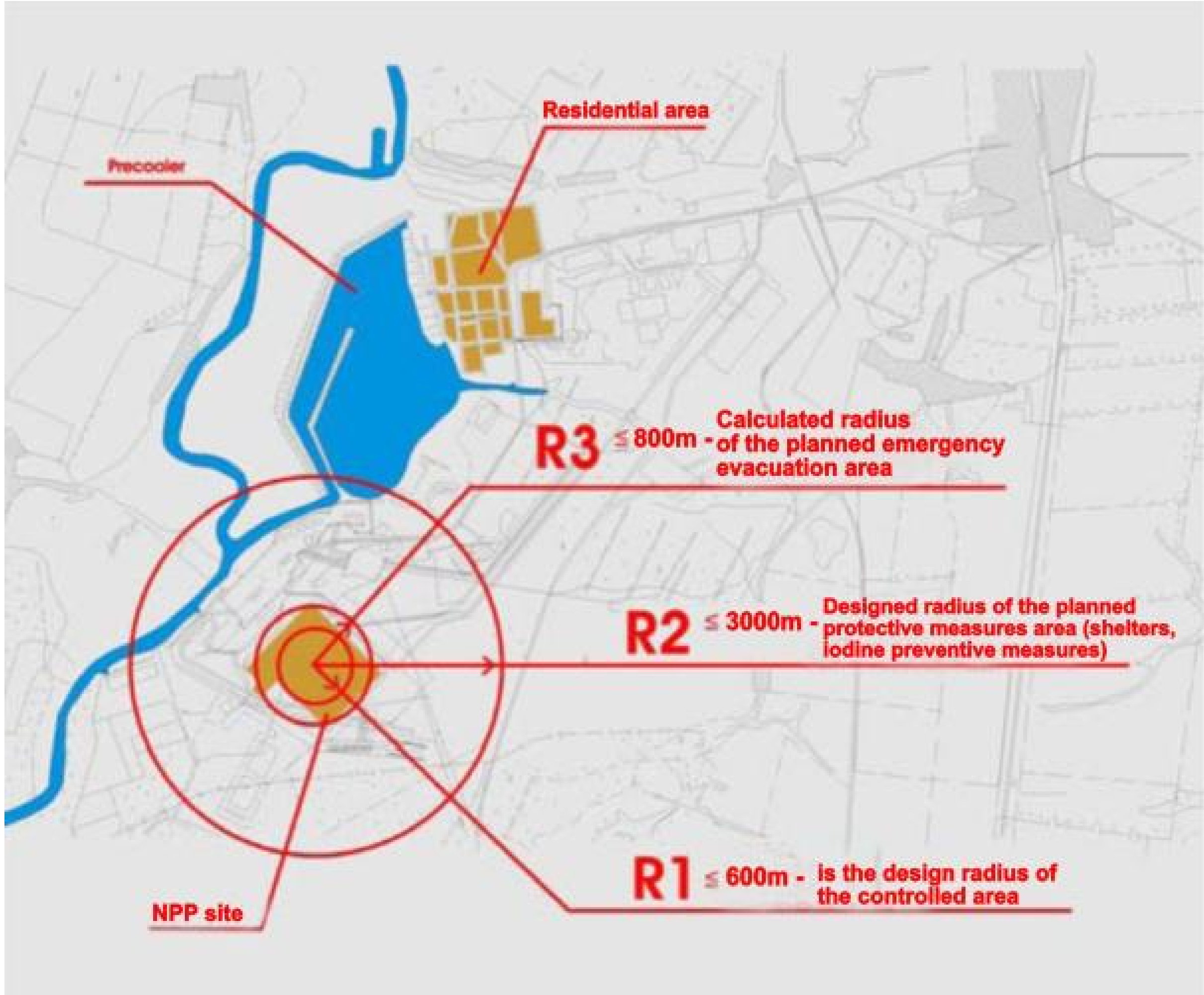


Figure 30 – Territory zoning at accident

Figure 30 shows calculated values of radiuses for different areas where different activities at accidents are planned; so the calculated radius value of planning urgent evacuation area doesn't exceed 800 m; this fact proves the absence of practical need in such activities.

Project NPP-2006 successfully combines reference qualities and positive experience of equipment and systems operation in operating NPP, great progress in technology allowing to rise at high level of safety and at the same time to reach economic advantages over the previous projects.

6.9 General plan

NPP-2006 is compound with two monoplants with power of 1200 MW (e) each and is designed for producing electric energy in base mode. NPP equipment and systems give the possibility of operation in maneuver power regulation modes. Load regulation range is 20 – 1000 % of Nrat. SPUC at energy unit operation in base mode is not less than 90 %. Effective use at reactor operation with rated power is 8400 effective hours/year.

Calculated service life of the main NPP equipment is 60 years.

Refueling is carried out once a year. Further transition to 18 and 24 operation cycle is planned.

Energy unit consists of reactor installation with water-moderated energy reactor with pressurized water and turbine plant. Heat diagram is two-circuit.

The first circuit is radioactive and consists of heterogeneous reactor on thermal neutrons, four main circulating loops, steam pressure condenser, and auxiliary equipment. Each circulating loop includes: steam generator, main circulating pumping aggregate, main circulating pipeline Du850.

Fuel is low-enriched uranium dioxide. Coolant of the first circuit heated at passing through the reactor core passes to the steam generators where it gives its heat to second circuit water through pipe system walls.

The second circuit is non-radioactive; it consists of steam producing part of steam generators , main steam pipes, one turbo aggregate, their auxiliary equipment and supply systems, deaeration equipment, heating and delivering of feeding water to steam generators.

Turbo plant includes steam turbine and generator mounted on the common foundation with the turbine. Turbine is lowered with condensing device, regenerative plant for feeding water heating, separators-steam overheaters; it has unregulated steam intake to regeneration system heaters, for own demands and for chemically purified water heating.

General plan of Belarusian will include two energy units with PWR-1200 RI.

Further a brief description of NPP-2006 general plan is given.

Plants orientations are determined by technical solutions on the systems of technical water supply of the main equipment in turbine buildings and reactors buildings consumers and by conditions of electric power output.

The following requirements were considered at general plan arrangement:

– providing maximum autonomy of energy units (nuclear part);

– module principle of the construction site with unified modules-energy units;

– territory zoning by main industrial buildings and auxiliary buildings with dividing the territory into “free” and “strict” mode areas;

– optimal blocking of main construction buildings and auxiliary buildings;
– providing straight main lines (corridors) of engineering communications laying;
– reducing of technological, transport and pedestrian lines;
– possibility of organization of line construction.

NPP site is divided into main production area (nuclear part) and area of general station auxiliary buildings. Nuclear part is fenced.

The main production area is situated in the centre of the site and includes unit modules-energy units united into one construction unit. Each module includes:

- reactor building;
– transport hatch bridge;
– steam chamber;
– safety building;
– auxiliary building;
– control building;
– new fuel and solid radioactive wastes reservoir;
– nuclear service building with service rooms of controlled access area;
– turbine building;
– normal operation electric power supply building;
– heating building;
– water preparation building with chemical water cleaning auxiliary tanks;
– And separate construction:

a) ventilation tube;
b) building of reserve diesel electric power plant of emergency electric power supply system with intermediate diesel fuel stores;
c) unit transformers buildings;
d) pumping station of automatic wet fire extinguishing;
e) water store reservoirs for automatic fire extinguishing;
f) unit electric power plant building.

Units step is enough for providing placement of engineering and transport communications between units and for organization of line construction and independent power input by activation complexes.

Spray ponds for cooling of reactor buildings consumers are situated at minimum distances from the reactors buildings. Each unit has two pumping consumers stations with switching chambers.

Main buildings and energy units site will be fenced. Two road approaches are planned.

Personnel passage from check post of free-access area service building to energy units buildings is along pedestrian tunnel.

Two evaporation cooling towers with turbine building consumers pumping stations are situated on the NPP site from the side of turbine buildings.

The following general station buildings and constructions are planned in NPP site from the side of the first plant:

– free access area workshops and material depot;
– administrative and laboratory part;
– canteen;
– united gas part;
– heat centre with storage tank;
– activation and reserve electro boiling room;

– combined pumping station of fire safety, industrial and drinking-auxiliary water supply;

– oil-diesel part including: oil and diesel pumping station, receiving buildings for oil and diesel, oil storage, diesel storage;

– purifying constructions of industrial drains and drains containing oil products, free access area waste water and other auxiliary buildings.

General station buildings and constructions area is arranged considering the possibility of enlarging objects for NPP second construction stage (for plants 3 and 4).

NPP electric power output to the energy system will be carried out through complex distribution gas-insulated of 330 kW (KRUE-330 kW).

Territory KRUE includes:

– KRUE – 330 kV building;

– KRU-6 KV building of reserve feeding with reserve transformers constructions;

– General station RUSN 6 kV building with general station transformers;

– 330 kV relay panels buildings.

In order to provide short pedestrian lines between administrative and laboratory complex, canteen and service building of free access area NPP project considers free access area gallery.

NPP territory has triple protective fencing: external fence, main fence and internal fence with protection area width of 20 m which includes all buildings of the station. Energy units fencing will be installed around nuclear part.

There are three drives to the NPP site: automobile – from the side of the first plant neat the main check post and from the side of the second NPP plant where there will be rail and automobile drives with check posts, according to GO the third drive from the site is required.

Within the site fence NPP railway station will be designed mainly for removing of spent fuel and receiving of new fuel. The station will also have an open station refueling Unit.

For organization of safety means the NPP will have a complex of physical protection buildings situated in the area of general station auxiliary buildings including: physical protection centre buildings, diesel generator plant buildings, garage, service dog breeding buildings.

Civil protection shelters are situated considering radiuses of places with most concentrations of people and are in auxiliary buildings area and behind the second energy unit.

General plan of NPP-2006 is given in Figure 31.

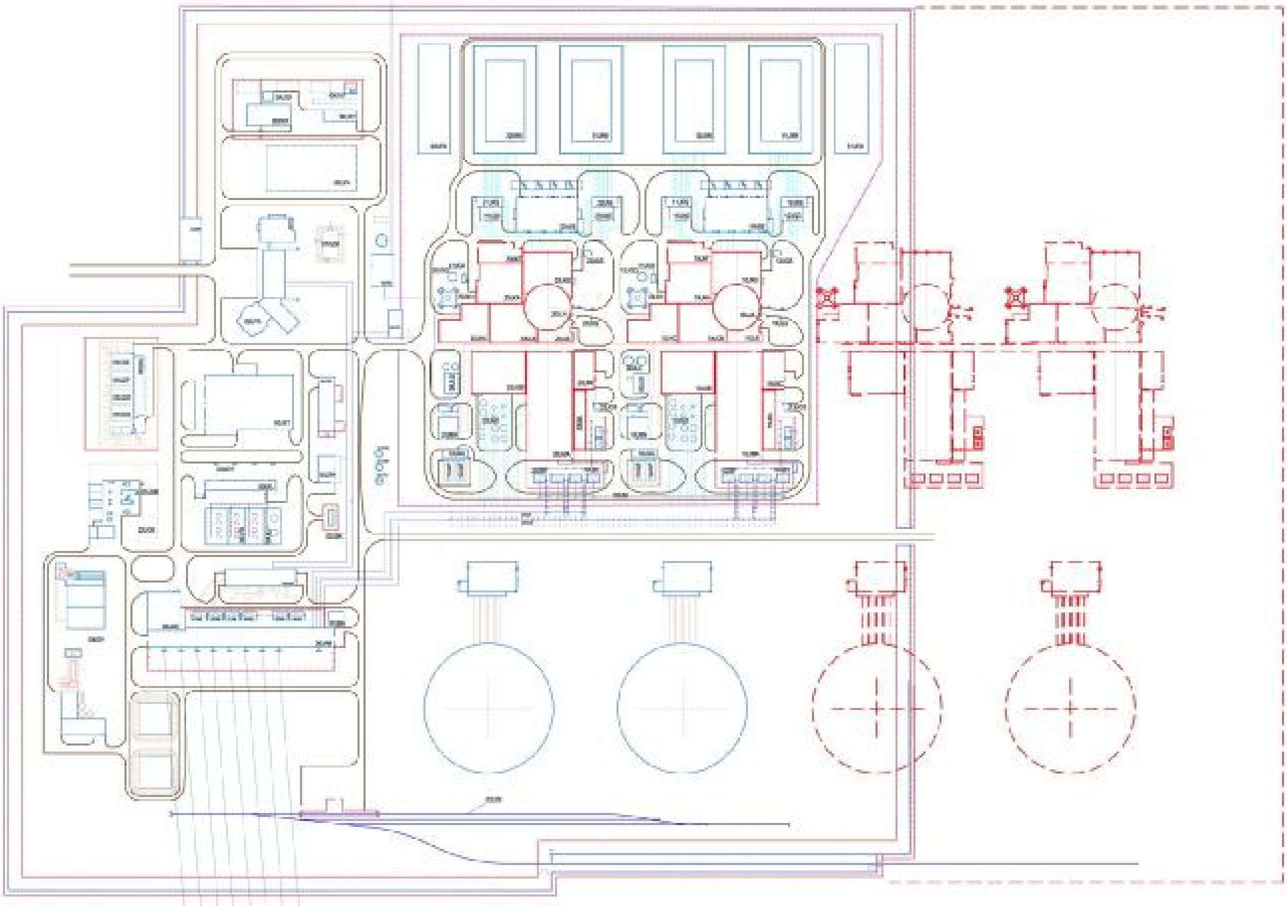


Figure 31 – General plan of NPP-2006

Approximate appearance of Belarusian NPP is given in Figure 32.

Figure 32 – Approximate appearance of Belarusian NPP

7 CHARACTERISTICS OF BELARUSIAN NPP SOURCES OF IMPACT ON THE ENVIRONMENT

NPP service cycle is more than 100 years and it consists of the following stages:

- designing and construction of the station - 6 – 8 years;
- operation of the station (project term) - 50 years;
- preparation and decommissioning - 10 – 15 years;
- decommissioning with preliminary stage of conserved energy unit part - 30 years;
- equipment dissembling - 5 – 10 years.

At each stage of NPP service cycle different types and sources of impact on the environment occur, the character of impact also changes. At the first stage mechanical impact is typical due to big amount of construction (ground) works, and a long operation stage is characterized by long-term heat, chemical, physical and radiation impact in amounts not exceeding the set norms. This section describes NPP sources of impact on the environment, quantitative estimates of different types of impact and waste formed during station service cycle are given.

7.1 Nuclear plant construction

Potential sources of impact on the environment during NPP construction are:

- some constructional sectors (concrete-spreading and asphalt-concrete sectors, automobile sector, mechanization base, storage sector, etc);
- temporary roads;
- storage grounds and construction materials assembling;
- processes of carrying out some construction and assembling works (ground and concrete works, etc).

The main impact factors are:

- dust of drives and roads;
- unorganized removal of ground, debris and construction waste;
- concrete and inert fillers dust;
- smoke output;
- exhaust gases of construction mechanisms and transport means;
- service drainage of construction site;
- technical drains of concrete sector, sector of anti-corrosion works, car-washing sites, etc;
- leakages of fuel and lubrication materials in depots and fuel stations.

During NPP construction a large amount of debris is formed at producing of monolith concrete and mixtures, at constructions assembling and carrying out of construction and assembling works. Supposed volumes of construction debris are given in Table 26 [11].

Table 26 – Volumes of construction debris

Main materials used in construction	Hard-to remove waste and looses, thous. m^3
Central-mixed concrete	13,3
Ready mixture	0,35
Roll hydro isolation and roofing materials, thous m^3	0,05
Mineral wool articles, thous m^3	1,06
Paint-and-lacquer materials and bitumen compounds	0,1
Saw timber	0,31
Unrecycled tara and package	9,00
Unconsidered waste	0,73
Total construction waste	24,90
Total domestic waste	7,1

To estimate the influence of harmful chemical substances output of construction equipment, machines and mechanisms used in NPP construction on the atmospheric conditions calculations of substances concentration in ground air of the working area (construction site, Table 27) and in the atmospheric air of the nearest centre of population (2 km from the construction site, Table 28) in the object-analogue to Belarusian NPP – Nizhniy Novgorod NPP [14].

All materiel used on the site can be divided into three groups:

- road-construction materiel (360 pcs with total power of 25500 kW);
- road transport (482 pcs);
- diesel plants (13 pcs with total power of 440 kW).

Table 27 – Maximum concentration of substances in working area MCD parts in atmospheric air in the construction site at simultaneous work of all materiel

Substance	Maximum concentration in MCD doses	MCD, mg/m^3	Danger class
CO	0,35	20	4
NO_2	0,79	5	2
NO	0,13	5	3
CH	<0,01	900	4
C	0,13	4	3
SO_2	0,02	10	3
NH_3	<0,01	20	4
CH_2O	<0,01	0,5	2
Benzpyrene	<0,01	$1{,}5 \cdot 10^{-4}$	1
Summation group (NH_{3+} CH_2O)	<0,01	-	-
Summation group (NO_{2+} SO_2)	0,80	-	-

Table 28– maximum concentration dose of substances for population in the nearest population centre (2 km from the construction ground) at dangerous speed of wind (0.5 m/s) by types of simultaneously working materiel

	Maximum concentration in MCD doses				MCD, mg/m^3
	road-construction materiel	Road transport	Diesel plants	All materiel	
CO	0,15	0,13	0,81	0,98	5
NO_2	5,0	0,57	0,22	5,79	0,2
NO	0,41	0,05	0,02	0,47	0,4
CH	0,19	0,04	0,02	0,24	1
C	0,98	<0,01	0,01	1,01	0,15
SO_2	0,08	0,05	0,01	0,14	0,5
NH_3	<0,01	<0,01	<0,01	<0,01	0,2
CH_2O	-	-	0,02	0,02	0,035
Benzpyrene	-	-	0,01	0,01	$1 \cdot 10^{-6}$
Summation group (NH_3+ CH_2O)	-	-	-	0,02	1
Summation group (NO_{2+} SO_2)	5,08	0,62	0,23	5,93	1

As we can see from Table 28 at dangerous speed of wind there is MCD exceed by presence of NO_2 substances and summation group (NO_{2+} SO_2) from HCS output by working road-construction materiel that is why its total power must not exceed ~5000 kW. No limitations are required to road transport as its simultaneous presence at the ground is impossible.

Equipment assembling stage is connected with leaving of great amount of usual solid waste usually including construction and domestic waste. Type and predicted volume of waste at this stage is given in Table 29.

Table 29 – Type and predicted volume of usual waste at NPP construction stage

Waste type	Reactor 1	Reactor 2
Paper	Total volume:	Total volume:
Glass	14500 tons of them	27000 tons of them
Packing waste		
Scrap metal	1000-2000 tons are not intended for further use (lower limit)	2000-4000 tons are not intended for further use (lower limit)
Electronics waste		
Tire waste		
Transport out-of service	Approximate maximum waste volume is 385 tons/month	Approximate maximum waste volume is 740 tons/month
Remained waste water		
Concrete sediments		
Lead batteries		
Soil contamination		
Used oil	730 000 m^3	1 400 000 m^3
Remained paint		
Drinking and unprocessed water - drain after processing	20 000 m^3/month as maximum volume	40 000 m^3/month as maximum volume

Exact volume and properties of waste can be determined only after choosing NPP project, development of NPP architectural design, NPP equipment suppliers, etc.

Considering the fact that construction period will last 6-8 years maximum annual solid waste production will be achieved by the end of the first year and during the second year of construction, after that it will be slowly decreasing.

Waste can be divided into different categories:

- repeatedly used materials: they must be separated and put aside;
- biological waste: must be put into separate tare;
- electric devices and electron waste;
- energy waste (waste potentially combusted on energy unit such as paper and carton);
- wooden waste;
- waste situated on dumps;
- dangerous waste.

Solid waste will be processed with help of used processing technologies and will be kept until finally removed from the site to the refuse dumps outside NPP ground. Contractor must remove all waste formed during construction and carry out necessary works to keep construction site clean and tidy.

Dangerous waste will be sorted, packed and pressurized by the contractor and later they will be transported to the refuse dumps for dangerous waste outside the ground. Other dangerous waste such as chemicals and hydro carbonates (coolants, oil refuses, solvents and other chemicals) will also be produced during construction stage. It is difficult to estimate the volume of this waste because it largely depends on construction works and on operations on the construction ground.

Liquid waste (including drain, oil remains, etc) will be directed to the corresponding intermediate storage and/or drainage systems. Direct output of contaminated canalization water will be strictly forbidden. Drains will be correspondingly processed in waste water purifying installation. Rain water gathering system will be developed.

Reclaiming objects are construction ground spoil banks and open casts. After the end of temporary constructions use they are dissembled and layout design providing surface drain is provided. On the whole reclaiming territory after its layout design soil ground is put, all required fertilizing is carried out and grass is seed.

After spoil banks and open casts ground processing territory reclaiming is carried out. For this purpose layout design is carried out.

Soil taken off during the construction is stored in temporary spoil banks situated not far from the construction ground and later is used for reclaiming and improvement.

Organization of works on linear constructions (roads and railroads, technical water supply channels, pipelines) considers maximum use of linear construction spots for drives.

Disturbed adjoining stripes are designed, covered with taken-off soil and seed with grass.

Construction waste and debris are removed to refuse dumps for industrial waste.

7.2 Brief description of types of NPP impacts on the environment

Let’s consider NPP with pressurized water reactor PWR-1000 with NPP total efficiency coefficient 33 %. Figure 33 shows the main elements of PWR [35].

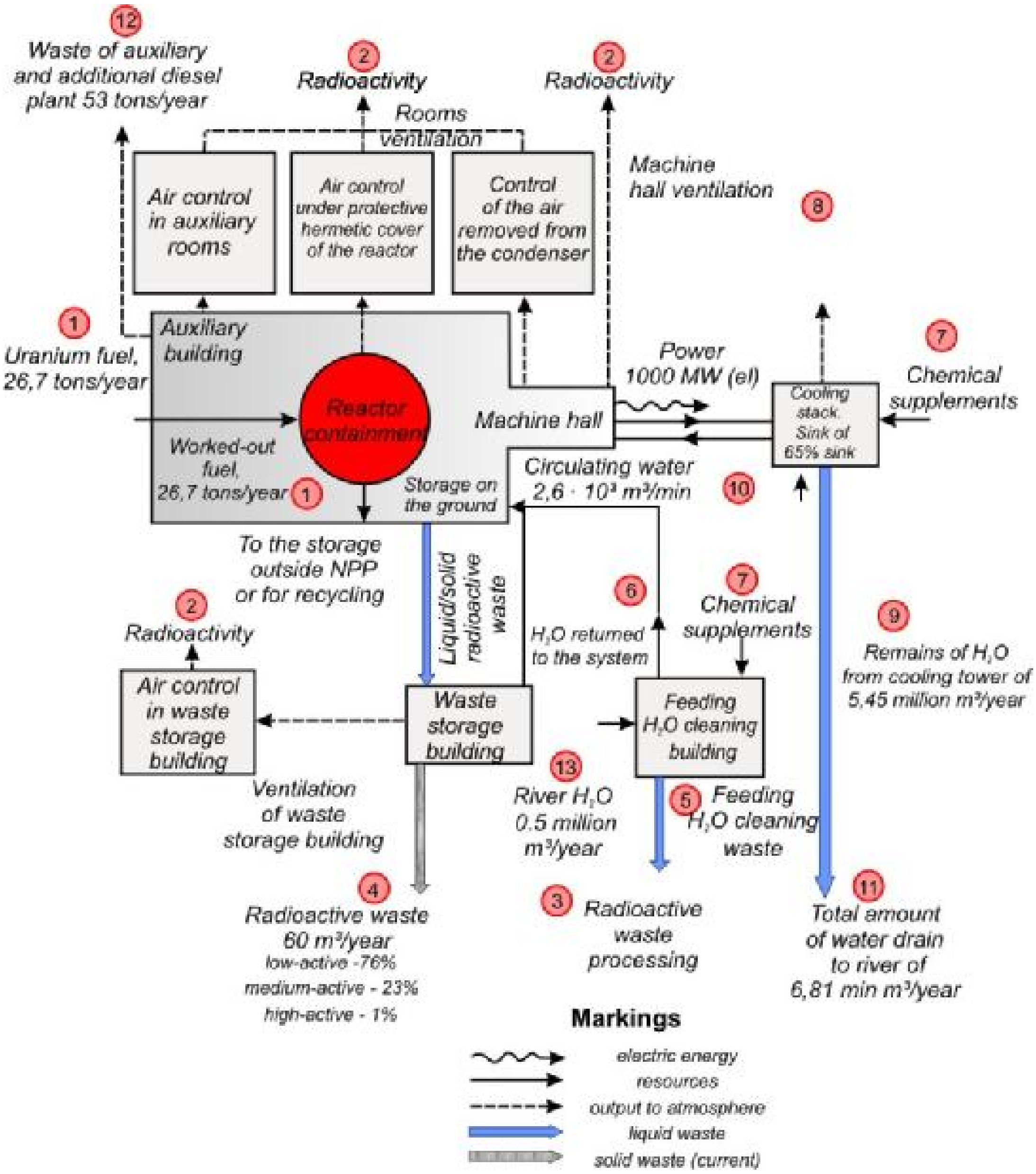


Figure 33 – PWR reactor Units of impact on the environment

Critical by their impacts on the environment Units are marked with circles on the Figure. These Units are the main sources of radioactive and non-radioactive outputs and the main consumers of fuel and water resources. Special attention should be paid to the places of waste storage with systems of processing of gaseous, liquid and solid waste, feeding building with water purifying system, hyperbolic cooling towers with natural air thrust using river water. The following critical Units are marked with numbers:

Unit 2. Uranium demand and spent fuel placement. For core fueling 80 tons of fuel are required - UO_2. One third of this amount (26,7 tons) is removed during refueling. Refueling cyclicity is determined by fuel cycle – 12, 18 and 24 months. Unloaded spent fuel after that is kept in NPP in spent fuel cooling ponds. Activity of spent fuel after unloading is about 10^{20} Bq.

Unit 2 (Figure 33). Annual permitted output of radioactive gases and nuclear plant aerosols are rated as SP AS-03. For PWR reactors the following values of extreme annual outputs are determined:

- IRG - 6,90 x 10^{14} Bq;
- ^{131}I (gas + aerosol forms) – 1.8 x 10^{10} Bq;
- ^{60}Co - 7,4 x 10^{9} Bq;
- ^{134}Cs - 0,9 x 10^{9} Bq;
- ^{137}Cs - 2,0 x 10^{9} Bq.

Besides, annually NPP outputs about 2,3 x10^{11} Bq of ^{14}C and about 3.0 x 10^{13} Bq of ^{3}H. The reason of gaseous outputs in NPP is leakage through fuel elements non-compactness and getting of gaseous fission products into first circuit coolant. These gases are removed from the coolant and get to the environment through different filters. Purifying systems used in project provide removing of 99 % of molecular iodine, 99 % of organic iodine forms, 99 % of aerosols. Radioisotopes in outputs are quickly mixed with the air to the concentrations much less than permitted before they reach the boundaries of the NPP territory.

Unit 3. Liquid radioactive waste of corrosion products and tritium with activity of 4,44x10^{9} and 1.12x10^{13} Bq/year. But for many reactors much lower amount of waste is typical due to low number of fuel elements defects and less leakage from the first circuit to the second one. Liquid output is kept at low level with help of recycling of the main amount of spent liquids for reuse.

Unit 4.Predicted activity of low-active solid radioactive waste (including remains after liquid waste evaporation) is about 1,96 x10^{14} Bq/year.

Units 5, 6, 8-11 and 13. These are drains of non-radioactive water and drainage activities. They may be classified as follows:

1) Water remains from feeding system returning to river. This water contains river water purifying products; it had been purified before being used for feeding.

2) Water used for different purposes of NPP in amount to 302800 m^3/year. Most part of this water is used for washing, shower and in different technical systems of the station.

3) Water waste through evaporation in cooling stocks is about 15,14 million m^3/year. Evaporation of water in such amount can cause fogs and icing in local scales; this effect is typical of all stations where cooling stocks are used.

4) Water remains in cooling stocks of about 3,785 million m^3/year return back to the river. In addition to unsoldered solid particles this water will contain chemicals added to prevent erosion and blockage in cooling stocks. Usually sulfuric acid inhibitors on chromium are used for these purposes.

5) Water used in cooling stocks (items 3 and 4) in amount of about 19 million m^3/year comes directly from rivers.

Unit 7. Different chemicals are added to river water before it is used at the station. These chemical are necessary for purifying, demineralization, stabilization, pH control and chlorination of water. The chemicals' amount greatly differs depending on quality of used water.

Unit 12. Organic fuel combustion products are formed even at nuclear plant. Relatively small amounts of SO_2, NO_x, CO and their compounds will be formed during operation of reserve diesel generators (they work only at accidents or at tests about 2 h/month) and additional activation-reserve boiling room used before the station activation or for 6 – 8 weeks a year during refueling.

All listed above parameters are related to the station with electric power of 1000 MW. Modern stations have project power of 1700 MW per a plant. In future it will be possible to calculate resources expanse and station output in proportion to power. For cases when linear dependency is made not exactly error will not exceed 25 %.

So, during operation period and decommissioning in the region of NPP the following types of impact will be fixed:

- heat connected with operation of technological equipment cooling systems (spray ponds and cooling stocks);
- chemical caused by using of chemicals in the NPP technological processes, purifying systems operation, preparation of water, etc;
- electromagnetic whose sources may be VL-330 kV, high-volt equipment;
- noise;
- radiation.

7.3 Physical and chemical impacts

7.3.1 Heat impact

It is suggested to use two evaporating cooling towers with counter-flow movement of air and water coolant as energy units turbine equipment coolant for Belarusian NPP. Evaporating cooling tower is a tower inside which water from cooling circuit is being sprayed. At falling in rising air stream water drops are cooled by evaporation and convective heat exchange. At cooling tower operation a large amount of warm wet air is output into the atmosphere through output mouth of the tower; this air forms a torch out of steam and air mixture. Cooling stacks influence on the environment mainly through this torch.

Torch parameters: elevation, geometrical dimensions, content of heat and moisture is determined by NPP ground atmosphere boundary layer.

As an example for commissioning and decommissioning stage of Belarusian NPP let’s take estimation of impact of atmospheric outputs by evaporating cooling towers at Nizhniy Novgorod NPP on the micro climate of nearby areas.

It is suggested to use tower evaporating cooling tower on energy unit with rated power of 1200 MW; the cooling tower calculated heat load is 1717 Gcal/h and it has the following parameters:

a) geometrical parameters of cooling tower:
- – tower height -170 m;
- – tower mouth diameter – 86,8 m.

b) expanse of air through the tower mouth:
- – in summer – 21300 m^3/s;
- – in winter – 22750 m^3/s.

c) average rate of steam and air mixture in tower mouth output:
- – in summer – 3,6 m/s;
- – in winter – 3,8 m/s.

Calculations have shown that maximum annual values of ground humidity and temperature increase can reach 0,0129 g/kg and 0,0133 ^{0}C correspondingly at distance of 3360 to 4490 m from cooling towers at southern wind direction.

Figure 34 shows distribution of calculated increases of ground specific humidity around Nizhniy Novgorod NPP cooling towers [14].

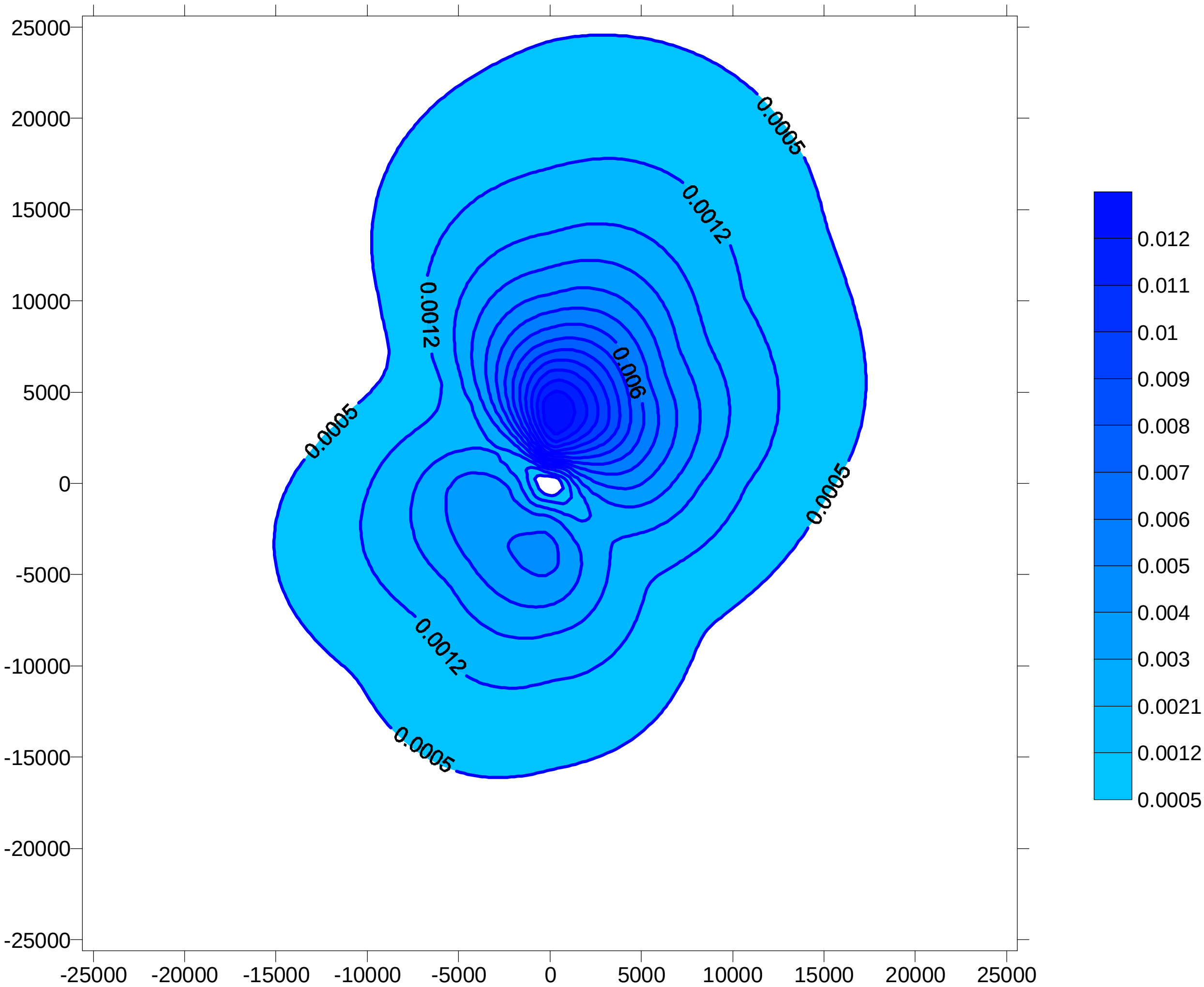


Figure 34 – Distribution of calculated increases of ground specific humidity (g/kg) around Nizhniy Novgorod NPP cooling towers. Point with coordinates (0.0) is the place where colling stacks are sitiated. Distance from the cooling towers (m) to the north and east is positive, to the south and west is negative

We can see that geometry of field of annual ground specific humidity increase is mainly determined by repetition of wind direction. Maximum ground values of specific humidity increase are formed at most frequently repeated wind directions, namely when wind is blowing to the south and south-east.

Analyzing the results of calculations we can conclude that heat and humidity outputs of cooling towers in Nizhniy Novgorod NPP with described characteristics will not impact greatly on the microclimate of the nearby territory because average annual ground temperature and humidity increase is insufficient.

Preliminary estimates of average annual values of temperature and specific humidity increase in ground atmosphere layer is greatly lower than average annual change values of these meteorological elements in the region around Nizhniy Novgorod NPP. Average annual air temperature in the ground region is 4.3^{o}C. On the base of this we can make a conclusion that cooling towers don’t make great influence on the microclimate of the nearby territories.

It is necessary to note that droplet entrainment negatively influencing on the surrounding territory can be regulated by installing special water catching devices over cooling stock water distribution system.

At present special water catching devices are used to decrease droplet entrainment. In 2005-2006 WSRI named after Vedeneev B. E. Carried out a big complex of model researches of polymer water catchers for tower cooling stocks with water spray area of 10000 m^2, designed for LAES-2 technical water supply. Researches showed that at using of effective polymer water catchers droplet entrainment decreases from 0,6 % (without water catchers) to 0,002 % of the cooling tower expense. Water catcher is made of plastic fiber or angular elements with distance between elements of 50 mm.

Operation experience of large HEA and NPP with tower evaporating cooling towers and complex calculations with use of hydrodynamic model of forming steam and moisture torch in the region of cooling towers showed:

- circulating water supply system with tower cooling towers is satisfactory from the point of view of environment protection;
- cooling towers influence on the environment mainly through steam and moisture torch;
- application of modern highly-effective polymer catchers in cooling towers allows to reduce droplet entrainment from 0,6 % (without water catcher) to 0,002 % and minimize negative influence of cooling towers on the environment;
- region of cooling towers influence on microclimate is restricted by NPP site with a slight (not more than 150-200 m) outside it;
- temperature and humidity changes created by cooling towers heat and steam and moisture outputs are slight and reach maximum values of 6 – 8 ^{0}C (for air temperature) and 5 – 6 % for relative humidity;
- maximum values of water remain intensity on the surface by gravitation sedimentation of water drops through the tower output section and formed in the atmosphere as a result of steam condensing is not more than 1 – 2 mm/h in summer and to 3 – 4 mm/h in winter; such values are typical of such meteorological event as “drizzle”.

The Belarusian NPP chimney-type cooling tower parameters shall be calculated during the structural design stage.

7.3.2 Chemical impact

Chemical impact on atmosphere, water and soil may be caused by chemical elements in the composition of waste.

Sources of chemical impact on the atmosphere are gaseous outputs at operation of technological equipment coming through ventilation systems and chimneys.

The main source of this waste at present is activation-reserve boiling room which gives 85-90 % of total annual NPP outputs. Continuous control is carried out over the station output level.

Industrial and domestic drain waters are purified and processed. Purified water is used in technological cycle and is not put to water basins.

Chemical impact on soil can occur as a result of chemical elements and their compounds sedimentation from the atmosphere.

Table 30 gives sources of outputs and characteristics of their impact on the environment [12, 14-16]**.**

Table 30 – Sources of chemical impact on the surrounding water environment

Source	Impact type	Impact result
1 Main building. Unit desalted installations	Regeneration water drain	Practically don't influence because after neutralization this water is put into cooling pond. At that salt content in this water increases for 1.1 %.
2 Main building. Free area rooms	Oil waste discharge	Doesn't influence because it is cleaned off oil and oil products and caught contamination is burnt.
3 Main building. Equipment and devices cooling systems	Cooling water discharge	Doesn't influence as there are no harmful components in cooling water.
4 Diesel-generator stations	Cooling water discharge	Doesn't influence as cooling is carried out in closed circuit.
5 WPS	Misbalancing water discharge	Doesn't influent because this water is returned to the second circuit cycle or discharged after radiation check.
6 WPS	Wash and shower water discharge	Doesn't influence because it is purified and checked for radiation.
7 Activation-reserve boiling room (will work only at emergency shut-off of the plants)	Cleaning and blowing water, cooling water, leakages, discharges	Doesn't influence because it is cleaned of oil products.
8 Oil-oil fuel-diesel sector	Cooling water, rain water, contaminated with oil products, pure and contaminated with oil products discharge	Doesn't influence because it is purified and checked for radiation.
9 Nitrogen-oxygen installation	Cooling water discharge	Doesn't influence as cooling is carried out in closed circuit.
10 Compressing rooms in the site	Cooling water discharge	Doesn't influence as cooling is carried out in closed circuit.
11 GPW. Repair workshops	No harmful discharge	–
12 Transport sector	Industrial water from car-washing discharge	Doesn't influence as it is purified in purifying water circulating systems
13 GPW. Desalted device, heat network feeding, group "A" consumers cooling system feeding	Blowing and regeneration water discharge	Practically doesn't influence as blowing water after slug sediments is returned to DWC and regeneration water after neutralization is put into the environment. At that salt content in the water basin increases for 1.1%
14 All industrial rooms with constant presence of the personnel	Industrial and domestic water discharge	Doesn't influence as is completely biologically purified.
15 Industrial ground territory	Rain water drain	Doesn't influence as is purified and returned to DWC cycle.

Outputs from main and auxiliary rooms situated on sites come into the air environment. These outputs contain chemicals and elements negatively influencing on the environment. Most sources operate in periodical mode that is why amount of total annual output is small.

Sources of non-radioactive impact on air environment are given in Table 31.

Table 31 – Sources of chemical impact on the air environment

Source	Operation mode	Main harmful components of outputs
1 activation –reserve boiling	Emergency source	NO_x, $S0_2$, CO, V_20_5, carbon
2 Oil-fuel oil sector	Periodically	Kerosene, carbon vapors
3 Diesel-generator stations	Periodically	NO_x, $S0_2$, CO, carbon
4 Centralized repairing workshop	Periodically	Mg, welding aerosol, abrasive metal dust
5 Repairing and construction sector	Periodically	Inorganic dust with SiO_2 content of less 20 to more than 70 %, wood dust, NO_x, $S0_2$, CO, carbon black
6 Road transport	Periodically	NO_x, SO_2, CO, carbon black, пaoil products vapors, petrol, kerosene and others.
7 Housing and communal control	Periodically	CO, NO_X, wood dust, welding aerosol, oil products vapors
8 Complex of solid radioactive waste recycling	Periodically	$C0_2$, NO_x, $S0_2$, HCl

7.3.3 Liquid output into the environment

Technical drain water led from the station is formed by:

- blowing of circulating technical water supply systems with cooling towers;
- sludge water after cleaning grid and disk filters and ultra filtration installation membranes (FIM);
- concentrate from installation of stage 1 back osmosis;
- neutralized drain water from neutralizing tank.

In these calculations the following drains neutralized in neutralizing tank are considered:

- ASF cleaning water (1000 mck);
- ASF cleaning water (200 mck);
- Drains from FIM acid washing;
- Drains from FIM alkaline washing.

Quality and quantitative characteristics of technical drain water are given in Table 32 [44].

Table 32 – Composition and volume of technical drain water at operation of one energy unit of Belarusian NPP

Component	Blowing of circulating systems of technical water supply	Concentrate drains of back osmius first stage installation	Neutralized drains from neutralizing tanks at mixing with regeneration solutions	Sludge water from FIM (neutral)	Characteristics of drains led to r. Vilia
Rating consumption, m^3/hour	2322	73,5	14,6	62,9	2473
Input mode	Constant	Constant	Intermittent	Constant	
Weighted substances, mg/l	12,4	0	9	175,3	11,7
Water temperature, ^{0}C	winter -27,2	25	30	25	27,1
	summer – 37,7				37,0
Mineralization, mg/l	679	1513	728	387	697
pH	8,25	7,51	7,5	7	8,19
Calcium . Ca^{2+} (mg/dm^3)	116,74	253,4	65	63,71	119,1
Magnum. Mg^{2+} (mg/dm^3)	31,96	68,13	19	17,13	32,58
Sodium. Na^{2+} (mg/dm^3))	10,08	35,76	94,89	7,75	11,28
Potassium. K^+ (mg/dm^3)	4,66	9,49	2,5	2,5	4,74
Ferrous general (mg/dm^3)	0,06	0,2	0,095	0,05	0,064
Manganese. Mn^{2+} (mg/dm^3)	0,02	0,2	0,100	0,098	0,028
Aluminum. Al^{3+} (mg/dm^3)	0,042	0,2	0,453	0,05	0,049
Zinc. Zn^{2+} (mg/dm^3)	0,026	0,052	0,013	0,013	0,0264
Phosphates. PO_4^{3-} (mg/dm^3)	0,238	0,4	0,103	0,103	0,238
Chlorides Cl^- (mg/dm^3)	24,86	68,17	17,18	17,18	25,9
Sulfates. SO_4^{2-} (mg/dm^3)	37,8	229,2	330,9	57,47	45,7
Bicarbonates (equivalent mg/dm^3)	428,7	779,1	166	197	432

Table 32 (continued)

Component	Blowing of circulating systems of technical water supply	Concentrate drains of back osmosis first stage installation	Neutralized drains from neutralizing tanks at mixing with regeneration solutions	Sludge water from FIM (neutral)	Characteristics of drains led to r. Vilia
Silicon. SiO_3^{2-} (mg/dm^3)	14.86	35.8	9.3	9.21	15.3
Ammonium. NH_4^- (mg/dm^3)	0.08	2.26	0.6	0.6	0.161
Nitrates. NO_3^- (mg/dm^3)	0.80	29.79	7.8	7.8	1.88
Nitrites. NO_2^- (mg/dm^3)	0.012	0.14	0.074	0.074	0.0177
Oil products	0.016	0.02	0.013	0.013	0.0160
Synthetic surfactants	0.002	0.01	0.05	0.05	0.0037

7.3.4 Characteristics of chemical outputs

Buildings situated on the site of Belarusian NPP are the source of periodical impacts on the environment as a result of non-radioactive outputs and waste. These output appear as consequence of technological processes in the buildings. Their harmful influence is in the fact that they contain chemical elements and substances whose content is restricted by valid sanitary norms and regulations.

Harmful components of chemical outputs into the atmosphere by NPP sources are:

- dust;
- sulfuric dioxide (sulfuric anhydride);
- carbon dioxide;
- nitrogen dioxide;
- ammonia;
- benzyl;
- xylene;
- toluene;
- phenol;
- manganese and its compounds;
- anhydrous hydrogen fluoride;
- carbon black;
- sulfuric acid vapors.

7.4 Radiation impact

7.4.1 Outputs of radioactive gases and aerosols from the station

Purified from radioactive contamination gas and aerosol waste of energy unit and exhaust air from the buildings are thrown into the environment through the ventilation tube. The tube construction is counted on CL and is not counted on aircraft crush. Output control is continuously carried out by radiation control automated system (RCAS).

At operational disturbances on the station accompanied by additional output of radioactive substances into the air low level of iodine isotopes and aerosols in gas and aerosol ventilation output is kept by effective filtration of exhaust air. Balance system of possible gases and aerosol outputs into the atmosphere is given in Figure 35.

In Russian Federation there are restrictions for NPP in radioactive gases and aerosol output into the environment on the level of PO restricted by SP AS-03. Amounts of inert radioactive gases (IRG) and aerosols on the NPP (with PWR reactor) in Russia in 2005 estimated in relation to annual permitted outputs (PO) set by SP AS-03 are given in Table 33 [45].

Table 33 – Amounts of radioactive outputs

NPP	IRG	I-131	Co-60	Cs-134	Cs-137
	TBq(% of PO)	MBq (% of PO)			
NPP with PWR-1000 and PWR-440					
Novovoronezh	110 (16)	1700 (9.4)	350 (4.7)	41 (4.6)	140 (7)
Kolskaya	4.2 (0.6)	134 (0.7)	88 (1.2)	0.01	53 (2.7)
Rostov	0.2 (0.02)	57 (0.3)	0.8 (0.01)	0.2 (0.03)	0.1 (0.01)
Balakovo	0.2 (0.02)	223 (1.2)	7.7 (0.1)	2.4 (0.3)	7 (0.4)
Kalinin	49 (7)	512 (2.8)	4.1(0.1)	0.7 (0.1)	1.8 (0.1)

In 2005 gas and aerosol outputs of NPP were lower than PO and didn't exceed level set by SP AS-03.

There were no cases of exceeding radionuclide outputs during a day or a month higher than control levels permitted by SR AS-03.

7.4.2 Dumping of radioactive substances from NPP

After radiation control carried out by RCAS system sensors in control tanks and by analysis of samples in radiochemical laboratory imbalanced plant's water from the controlled access area is discharged. If necessary, water from control tanks passes to secondary purification to trap water processing system.

Balance system of possible output of radioactive substances to the hydrosphere at continuous energy unit operation in normal mode is shown in Figure 36.

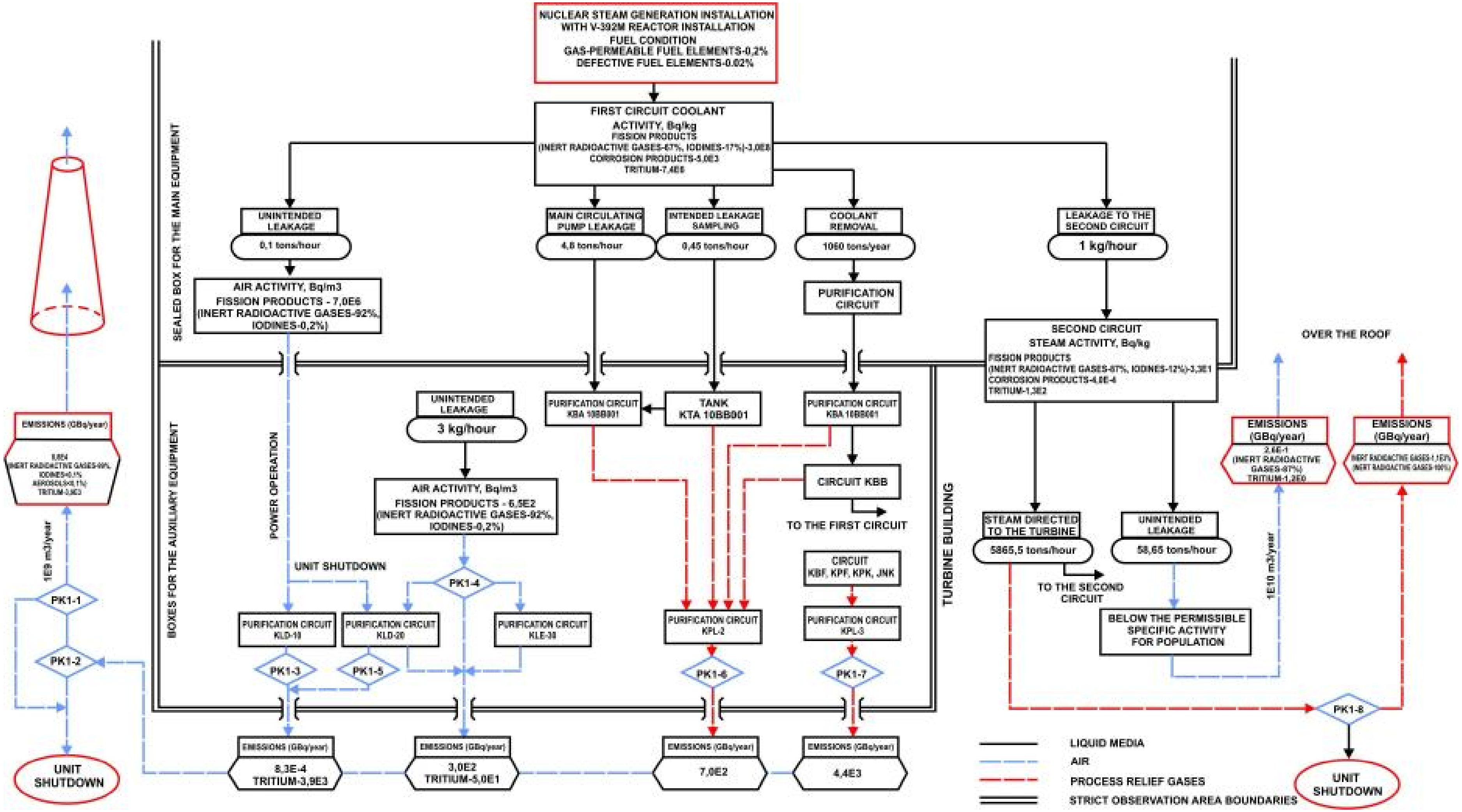


Figure 35 – Balance diagram of possible output of radioactive gases and aerosols into the atmosphere

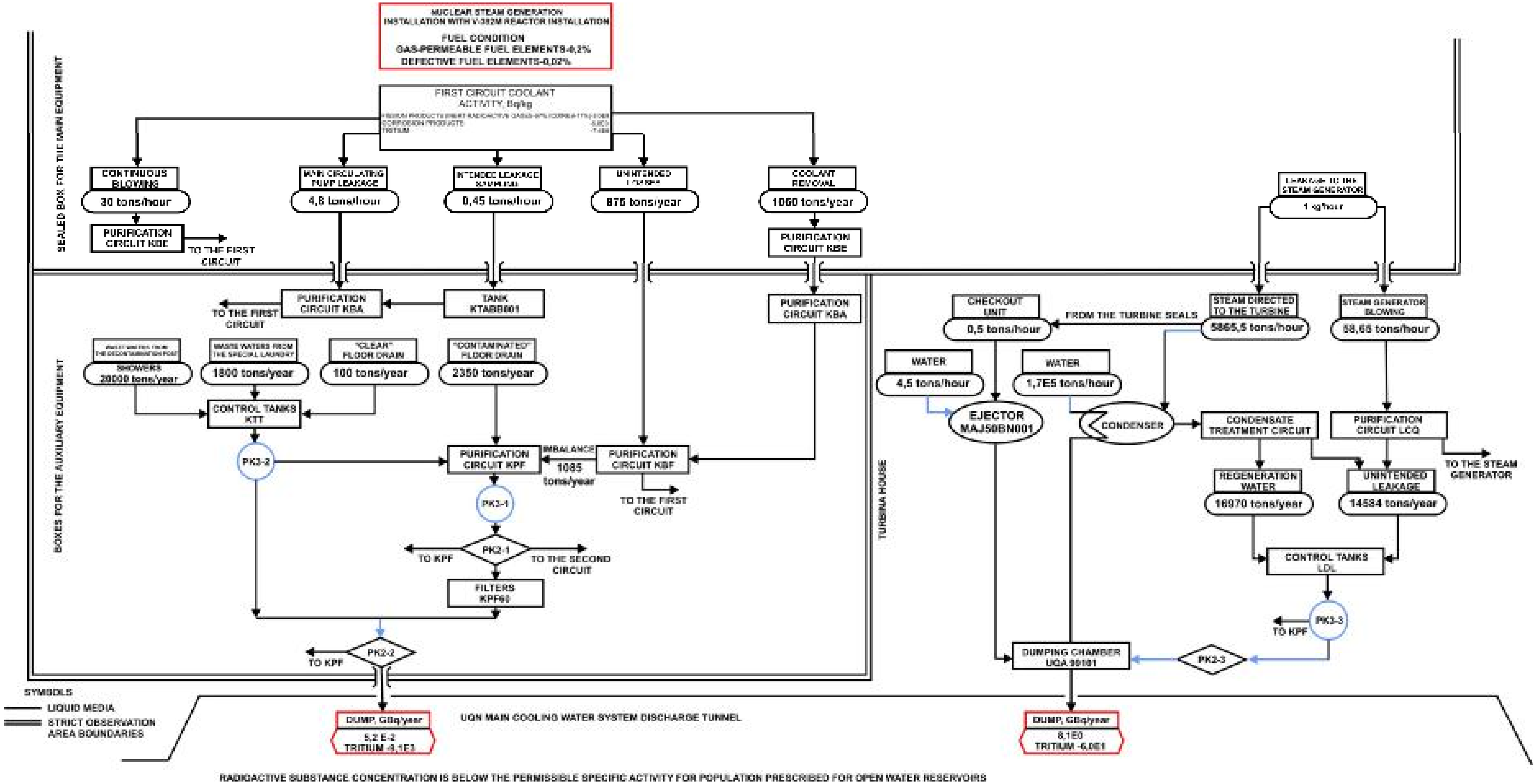


Figure 36 – Output of radioactive substances into the environment with liquid non-radioactive dumps at plant operation in normal mode

Volumes of liquid dumps into the environment and radionuclides passing to the surface water in 2005 in relation to permitted output (PO) for NPP are given in Table 34 [45].

Table 34 – Volumes of liquid dumps and passing of radionuclides to water basins

NPP	Volume of dumped water, m^3	Radionuclides passing to water basins, % of PO
NPP with PWR-1000 and PWR-440 reactors		
Novovoronezh	51000	18,9
Kolskaya	16102	0,01
Rostov	NPP uses circulating water supply	—
Balakovo	40500	0,4
Kalinin	79097	8,1

Radionuclides passing with liquid dumps in Russian NPP were less than the permitted volume and didn't exceed 18,9 % of PO value (Novovoronezh NPP).

7.5 Radioactive waste disposal

Main tasks solved at RW disposal are:

- at disposal of solid RW – minimization of volumes and safe storage during the project term;
- at disposal of liquid RW – purifying of the main part of liquid waste of radionuclides, concentrating radionuclides in minimum volume and transition of liquid concentrated waste in suitable for storage forms;
- at disposal gaseous waste – purifying before output into the atmosphere to the quality satisfying safety criteria.

Main production functions carried out by waste disposal systems on NPP are:

- localization of liquid waste not intended to be reused, named further as liquid RW;
- changing liquid misbalances characteristics to the condition when they can be considered inactive and permitted to be output into the environment;
- processing of liquid RW – concentrating (in order to decrease their volume), concreting by mixing them with hardening composite (concrete), putting waste to the containers for safe storage and transportation;
- collecting, sorting, partial processing (reduction, pressing, burning low-active RW) of solid RW, putting low and medium active waste into containers for safe storage and transportation with further mixing with hardening concrete, collecting and sorting high-active RW (radioactive control means) in storage packing (capsules from high active radioactive waste equipment set);
- transportation of waste to storage places, putting to the cells for long-term (to 50 years) storage in NPP;
- storage of solid and hardened active waste;
- purifying of technological and ventilation systems waste put into the atmosphere to the safe conditions.

These functions are carried out in NPP by technological systems, situated in reactor buildings, auxiliary reactor buildings and in buildings for storage and processing of radioactive waste (with SRWS in them). Safety of waste disposal function is based on energy unit project materials.

Solid and liquid radioactive waste is classified according to the activity degree or radiation impact on SP AS-03, OSP-2002 and NRB-2000 criteria, Table 35.

Table 35 – Liquid and solid radioactive waste classification by specific activity

Waste category	Radiation level, mSv/h	Specific activity, kBq/kg		
	Gamma-radiating	Beta-radiating	Alpha-radiating (without trans-uraniums)	Trans-uranium
Low-active	10^{-3} to 0.3	Less than 10^3	Less than 10^2	Less than10
Medium-active	0.3 to 10	10^3 to 10^7	10^2 to 10^6	10 to 10^5
High-active	More than 10	More than 10^7	More than 10^6	More than 10^5

Additional SRW classification recommended by SP AS-03, OSP-2002 and operational operation is its classification according to gamma-radiation power level at distance of 0,1 m from the surface:

- low-active – 1 μSv/h to 300 μSv/h;
- medium-active – 0,3 μSv/h to 10 μSv/h;
- high-active – more than 10 μSv/h.

Radioactive waste disposal systems are designed so that personnel irradiation level is in the permitted limits set by valid sanitary norms for all NPP project systems equipment modes including maintenance mode considering philosophy of “safety culture” and ALARA principle.

Radioactive waste disposal systems are equipped with technological radiation control means, systems continuity estimate and control of outputs into the environment.

7.5.1 Sources of RW forming

Initial factor of radioactive waste contamination (spent materials, equipment and environments) is peculiarity of the main production process characterized by formation of artificial radionuclides in nuclei fission reactions (of fuel) resulting in appearance of active fission products and activation reaction of some radionuclides in the core (coolant, construction materials), in neutron radiation field.

Through leakages in fuel elements covers active products can pass to first circuit coolant. Mixtures of radionuclides activation products also pass there as a result of construction materials corrosion; besides, radionuclides in the coolant are activated (oxygen, hydrogen, WCS technological mixtures). Active radionuclides from the first circuit are spread into the technological circuits (environments); moreover through inter-circuit leakage they can get to the second circuit, contaminate equipment, pass through leakages into the controlled access rooms causing appearance of radioactive substances (RS) in liquid, solid and gaseous waste.

Solid waste include equipment elements, filters, used tools, spent devices, wasted materials, hardened waste.

Liquid waste include trap water processing remains, special washing room water, filtering materials, trap water tanks sludge, etc.

Quality and quantitative radioactive characteristics of RW passing as a result of fuel elements leakages into the coolant, RW spreading into technological and auxiliary circuits and systems of NPP, processing of technological means both final and directed to keeping rating modes are described in the corresponding parts of the project.

At operations with RW it is necessary to follow safety requirements given in main normative documents [46 – 48].

In accordance with the RW management basic procedures, the RW management for three states of matter (liquid, solid, gaseous) can be described, in a simplified form, as follows:

7.5.2 Solid RW

Solid waste is formed in controlled access area buildings (most part oa solid WR is formed in reactor building). Main types of the wastes, their volume and activity, place of formation and other characteristics are given in technological solid waste disposal diagrams (in technological parts of the project).

Solid wastes are primarily sorted by their activity in collecting rooms, low-active wastes – by the possibility of further reclaiming are directed to:

- low-active RW in special containers are directed to low-active waste reclaiming building. Recycling purpose is to minimize RW volumes.
- medium-active and unreclaimable low-active wastes are packed into the transport containers and are directed to storage and reclaiming building. If necessary, before being put into the containers big SRW are cut or dissembled for transportation. Medium-active SRW are transported to the storage and reclaiming building in protective containers.
- high-active wastes whose range is determined include spent RI detecting units; they are directed to special cells of radioactive waste storage and transportation building in capsules.

Specific group and most part of NPP solid wastes include hardened wastes as a product of liquid active environments conditioning, whose reclaiming and preparing for storage is formed by liquid RW disposal systems. Processes of liquid active environments reclaiming are carried out in reactor building and in reclaiming and storage building. LRW hardening projects include mixing with concrete, in the reactor building the compound is poured in containers, in reclaiming and storage building it is put into containers with SRW (unreclaimable SRW and carbon black in barrels, reclaimed SRW – in the form of briquettes).

7.5.3 Liquid RW

LRC is purified by evaporator with productivity of 6 tons/h. as a result of trap water reclaiming pure condensate is formed which is reused in NPP cycle and salt concentrate (vat residue) which is also LRW. Used technologies provide reusing in NPP cycle of 95 % of trap water.

The following systems are designed for intermediate storage and further reclaiming of LRW:

– system of intermediate storage of vat residues and spent sorbents;

– liquid radioactive waste conditioning and hardening system.

LRW intermediate storage system provide LRW storage for at least 3 months to reduce their radioactivity level by short-living radionuclides decay.

LRW that are hardened before storage include:

- concentrated salt solution (filtrate) from trap waters purifying installations thickening filters of reactor buildings and storage and reclaiming buildings special rooms and liquid concentrate (vat residue) with these buildings trap waters reclaiming systems evaporators;
- special water purifying systems filter;
- trap water tanks sludge (clay souring plant).

To get hardened product for further disposal the project considers LRW hardening system. The system provides possibility of vat residue concentration, mixing it with concrete and concrete compound packing into irrevocable concrete containers NZK-150-1,5P(S).

Irrevocable containers are designed for temporary RW on NPP ground and further transportation to regional centers for long-term storage. Thanks to using little-waste technologies and optimization of engineering solutions predicted volume of hardened LRW in NPP with PWR-1200 is ~ 30 m^3/year, less than in operating NPP with PWR-1000 in Russia.

During NPP operation disbalanced water are formed not required by the station technological processes for reuse. This water mainly from special washing rooms and showers drains is removed to spray ponds situated on the station construction ground. It is permitted to remove disbalanced waters with active admixtures content less than boundary levels between active and inactive environments (10 UV according to NRB-2000 article 3). Besides, normative documentation of the RF specially restricts total NPP drain (liquid drain norms limit is permitted PO output by activity). PO value is calculated.

7.5.4 Gas and aerosol waste

Gas and aerosol wastes are formed during functioning of some NPP systems and are caused by output of gaseous components out of liquid active environments. Gaseous wastes are not utilized in the NPP; they are removed to the surrounding atmosphere with NPP air outputs. As station gaseous outputs containing admixtures of aerosols and gases are the main factors of NPP dose impact on the population and RS content in NPP outputs is strictly limited in their quantity and structure, gaseous waste are removed outside the ground only after highly effective purification. Calculated admixture content in removed air is lower than PO.

Main channels of RW admixtures passage into gaseous wastes removed from the station are:

- process of technological blowing of operating equipment in reactor buildings and auxiliary reactor buildings;
- process of ventilation of UJA and UKC buildings controlled access areas; in the atmosphere of these buildings a slight amount of radioactive aerosols or radioactive gases caused by equipment leakages can be found;

Radioactive gas purifying system is designed to reduce gas outputs activity, caused by technological equipment relief gases. The system consists of two similar interchangeable operation threads and one zeolitic filter regeneration thread. One operation thread purifies relief gas from first circuit feeding deaerator, pressure condenser barometer relief gases passed through hydrogen burning system. Auxiliary operation thread cleans relief gases from coolant storage system tanks, “pure” condensate stores tanks, boron containing drainages tanks. The systems are equipped with aerosol and iodine filters with highly effective purifying capability. IRG relief gases efficiency in accordance with preliminary estimates is 20 m^3, at coal sorbent coefficient for krypton of 14, for xenon – 280.

Purification degree with help of aerosol filters is 0.999; with help of iodine filters is: for molecular iodine – 0.99 and for organic compounds – 0.9.

Besides listed above ways of passing less important ways are radioactive gases and aerosols output from cooling ponds, from PRP when the cover is removed for refueling, from draft hoods of radio and chemical laboratories with local "suctions" from the equipment at some technological processes, with combustion plant steam gases.

Additionally during NPP operation wastes in form of big unassembled elements of worn equipment may form (steam generators, reinforcement frames, pipelines with big diameters, etc) that can not be disintegrated or packed into barrels. Place of storage for these wastes and their disposal order are determined individually. These big-size wastes are transported to the storage place according to special protection rules (covering with polyethylene film, special fixing solutions, etc)

Getting of radioactive substances into the environment must be excluded.

Table 36 gives approximate information about radioactive wastes for reclaiming and storing on the territory of NPP [14].

Table 36 –Amount of SRW passing to reclaiming and further storing in 0UKS building from two plants

Waste		Place of formation	Amount of waste from two plants passing to 00UKS building, m^3/year (at normal operation, maintenance and repairing, at accidents)	Note
1 Low-active SRW				
1.1	Combustible	Controlled access area buildings	220 (110/110)	
1.2	Incombustible pressed	Controlled access area buildings	130 (65/65)	
1.3	Metal	Controlled access area buildings	20 (5/15)	50 % for disintegrating
1.4	TEN	PO	1,0 (1/-)	50 % for disintegrating
1.5	Filters			
1.5.1	Incombustible pressed	Controlled access area buildings	32	Once in two years
1.5.2	Combustible	Controlled access area buildings	36	Once in two years
1.5.3	Hardened waste	Normal operation technological and control system buildings and special water purification buildings	9,4	
2 Medium-active SRW				
2.1	Metal	Controlled access area buildings	10 (10/-)	90 % for reclaiming
2.2	Other waste			
2.2.1	Combustible	Controlled access area buildings	23 (11.5/11.5)	90 % for reclaiming

Table 36 (continued)

Waste		Place of formation	Amount of waste from two plants passing to 00UKS building, m^3/year (at normal operation, maintenance and repairing, at accidents)	Note
2.2.2	Incombustible	Controlled access area buildings	54 (54/-)	90 % for reclaiming
2.3	Filters			
2.3.1	Incombustible	Controlled access area buildings	75	Once during the operation period (50 years)
2.3.2	Combustible	Controlled access area buildings	87	Once during the operation period (50 years)
2.4	Hardened waste	Normal operation technological and control system buildings and special water purification buildings	25.7	
2.5	Hardened waste from special washing rooms and combustion installation	Building of RW reclaiming and storing	16.8	
3 High-active SRW				
3.1	Interior reactor detectors	RW	1.0	
3.2	Detecting units	RW	1.0	
Final volume of solid radioactive waste (after reclaiming and not intended for reuse) doesn't exceed 50 m^3/g from one plant.				

7.5.5 Storage of solid radioactive waste

SRW storage unit cells in 00UKS building are designed for storage of low, medium and high-active SRW. For disposal and storage of high-active SRW at present there is a “Equipment set for storage of solid radioactive waste of activity group III” developed by LJS “Atommasheksport”. Low and medium-active SRW are stored in cells of ferroconcrete protective irrevocable containers NZK-150-1,5P.

Until now worked-our RW has not been removed outside the ground and are placed in temporary storage places. With introducing NZK as packing it will become possible to keep RW on the NPP ground for 50 years. This solution facilitates mode order of RW storing process and reducing the potential RW danger (due to reducing of activity by natural decay).

7.6 Impact and estimate of noise, electric field, oil equipment influence

7.6.1 Impact and estimate of noise influence

For evaluation of noise impact on the environment the following initial data was adopted:

- evaluation of noise sources impact appearing with putting the energy unit into operation;

- because of absence of the personnel on the site, outside the industrial buildings and constructions, working places evaluation of noise impact is carried out only inside these buildings and constructions;

- because of absence of public or administrative building with constant staying of people (not personnel) within the controlled area, for evaluation of noise impact special values limiting sound pressure on the personnel working places were set by State Standard 12 .1.003-83.

In industrial buildings and constructions of NPP the source of noise impact on the personnel is rotating equipment (turbine aggregate, pumping aggregates, diesel generators, ventilation installations) and reduced equipment.

List of buildings and constructions of PWR-1000 with equipment which is the source of noise is given in Table 37.

In most of these industrial buildings (list positions 5, 6, 7, 8, 9…) production process is fully automated and they don't contain constant personnel. During operation there is no personnel there; or they may be there periodically or for short time (inspectors).

Table 37 – List of buildings and constructions with equipment that is constant noise source

Building or construction	Equipment	Operation mode
1 Main building. Reactor part	Main circulating pumps. Other pumping aggregates	Constant Constant
2 Main building. Turbine compartment	Turbo aggregate Pumping aggregates РОУ 14/6; 14/3 БРУ-К, БРУ-СН	Constant Constant Constant Periodical
3 Main building. Deaeration compartment	Feeding electro pumps. Other pumping aggregates. Ventilation equipment	Periodical Constant Constant
5 Solid radioactive waste storage (SRWS). Reclaiming complex	Pumping equipment Ventilation plants Press	Periodical
6 Diesel generating electric power plant of energy unit No.2	Diesel generator with auxiliary equipment Compressor Technical water pumps of "B" group	Periodical Constant Constant
7 General plant diesel generating electric power plant	Diesel generator with auxiliary equipment	Periodical
8 Plant pumping station of technical water supply system No.2	Pumping aggregates	Constant
9 RCCAS CP. Diesel generating station	Diesel generator	Periodical

In separate buildings and constructions personnel working places are in control board special rooms or in other rooms with sound-insulating constructions. Calculated level of noise load in the rooms with sound-insulating constructions corresponds to the requirements of GOST 12.1.003-83 "Labor safety standards system.

Noise. General safety requirements" and for control rooms doesn't exceed permitted value given in Table 38.

For other personnel working places the same standard requirements to noise load on constant working places are applied what is a conservative approach as the personnel is at these places periodically or for short time.

Table 38 - Permitted levels of noise level in control rooms and laboratories

	Octave bands with center frequencies, Hz								
	31.5	63	125	250	500	1000	2000	4000	8000
Permitted level of noise load, dB	93/96*)	79/83	70/74	63/68	58/63	55/60	52/57	50/55	49/54
Integral noise level, dBA	60/65								

* In the Table the numerator shows values for control rooms, the denominator – for the laboratories

According to technical documentation for the equipment that is noise source in rooms of list positions 1-3 noise load at distance of 1 m from the source should not exceed values restricted by State Standard 12.1.003-83 for constant working places (Table 39); that is why for these rooms the State Standard requirements are met.

Table 39 – Permitted levels of noise load

	Octave bands with center frequencies, Hz							
	63	125	250	500	1000	2000	4000	8000
Permitted level of noise load, dB	99	92	86	83	80	78	76	74
Integral noise level, dBA	85							

7.6.2 Impact of electric field and its estimate

Electro equipment installed in NPP buildings is not the source of harmful outputs, radio gamming or noise.

Sources of harmful impact on the environment can be HL-330 kV and high-volt equipment including transformers, reserve auxiliary transformers, communication autotransformers, linear reactors.

According to sanitary norms population protection from impact of electric field of air electro transmission lines with voltage of 220 V and lower meeting the requirements of "Electro installations norms", is not required.

On the territory of the Belarusian NPP the following HL-330 kV are considered:
- from energy unit No.1 transformer to DEED-330 kV;
- from reserve auxiliary transformer No. 1 to DEED-330 kV;
- from reserve auxiliary transformer No. 2 to DEED-330 kV;
- from DEED-330 kV to communication autotransformer.

Providing permitted voltage levels of flexible communications electric fields is achieved by following normative sizes – minimum distances of HL over the surface at which EF permitted possible voltage levels up to 5 kW/m are provided – Table 40.

Time of presence for the personnel in EF with voltage of to 5 kW/m is not limited. Permitted time of staying in EF with voltage higher than 5-20 kW/m is determined by calculations according to “Norms of the personnel protection from electric field impact”.

Table 40 – Minimum distances of HL-330 kV cables over the ground

HL span placement	Minimum distance of HL cables over the ground, m at HL rated voltage, kV	
	330	
	According to the norms	According to the project
In unpopulated areas (NPP territory)	7.5	25 (17)*
On cross-roads	8.5	25-17(10-25)

* Values considering maximum dips are given in brackets.

Flexible communications HL-330 kV supports are made of galvanized metal. All lines have lightning protection cables and discharger for protection from excess voltages. HL supports are grounded.

Repairing and operating of HL-330 kV must be carried out according to the regulations developed by Belarusian NPP.

At designing of PDD-330 kV a typical PDD-330 kV with three switches per two circuits with metal ports will be used.

Application of aerial disconnectors in GDD will reduce area for 48 % in comparison with typical PDD with support disconnectors.

Equipment installation height is chosen considering required PED distances to insulation and busses with dips, the possibility of installation of cable boxes, and safety regulations for carrying out repairing works and for personnel protection from electric shock.

To protect the personnel from electric shock PDD has stationary protection means:

- caps set over working places neat terminal boxes, drives, aggregate and distribution boxes;
- vertical screens between cells switches, additional switches screens.

For protection from electric shock at PDD insulation distortions there is a protective grounding circuit connected with all energized parts of equipment.

Air transmission facilities 330 kV leading off PDD are made considering the requirements of “Sanitary norms and regulations of population protection from the impact of electric field created by commercial frequency alternative current transmission facilities”

7.6.3 Impact of oil-filled equipment and its estimate

On the territory of Belarusian NPP from the side of turbine compartment row oil-filled transformers will be installed. They include plant transformer of 3xORTs-

417000/750/3 type, auxiliary transformers of 2xTRDNS-63000/35 type, and energy unit reserve auxiliary transformers of 2xTRDNS-63000/330 type.

To prevent leakage of oil and spreading fire each transformer and reactor has an oil receiver counted for full volume of oil and water at fire extinguishing with drainage to oil collector.

All transformers and reactors are equipped with wet automatic sprinkle systems.

For service of oil-filled equipment NPP has a centralized oil sector equipped with reservoirs for oil storage and recycling, pumps, oil purifying and regeneration installations, portable oil-purifying sets, containers for oil transportation.

8 NUCLEAR FUEL HANDLING

Nuclear fuel handling system is designed to provide reactor core with enough fuel to keep the required power level, to take spent fuel from the core and its removal from NPP territory.

Nuclear fuel storage and handling system provides:

– receiving, storage and handling with fresh (unirradiated) including its transition to the reactor part;

– core refueling;

– handling and storage near reactor of spent (irradiated) nuclear fuel (WNF);

– removing of WNF from the territory of the station.

At all stages of works on refueling, transportation and storage of nuclear fuel the personnel biological protection is provided.

The system project is designed according to the following solutions and positions:

– core includes 163 fuel elements;

– refueling of reactor core is carried out one time in 18 months, at that about ¼ core FE are replaced – 41 pcs maximum;

– loading (unloading) of nuclear fuel to (from) reactor is carried out through the transport hatch along the trstle;

– delivery of frest fuel elements to the reactor, refueling атв removing of spent fuel is carried out when the energy unit doesn’t operate;

– fresh fuel elements are delivered to the station with absorbers bundles;

– refueling is carried out by fuel-handling machine according to the special program under protective water later providing radiation protection;

– spent fuel elements are cooled in boron water with concentration of 16 to 20 g/dm3 and maiximal temperature of 50 to 70°C;

– during refueling it is necessary to control the hermiticity, level and composition of fuel elements removed from the reactor.

According to the requirements [49] fresh fuel storage room is constructed as storage class 1, that is, the project excludes the possibility of getting water into FFS what is provided by the complex of following measures (item 4.1.1 NP-061-05):

- fresh fuel is delivered to the NPP by special rail transport according to the special schedule depending on the quantity of nuclear fuel required for the station normal operation;

- fresh fuel packed into the containers is delivered to the station in special B-60SK carriages;

- fresh fuel is delivered to the reactor in packing sets on a special platform with freight capacity of 50 tons;
- spent nuclear fuel unloaded from the reactor is kept in energy unit reactor within the hermetic area;
- all main operations on refueling are carried out by fuel-handling machine;
- spent cassettes are moved-out from the reactor to the cooling pond thickening stands where they are kept (at least 3 years to reduce activity) until they are moved-out from the territory of the station.

Cooling pond capacity allows keeping spent fuel elements for ten years including placing of defect fuel elements in hermetic boxes and the possibility of refueling of the whole reactor core in any moment of NPP operation.

Cooling pond has four compartments- three compartments for storage of spent fuel and FC-13 container fueling compartment for spent fuel elements.

At removal of spent nuclear fuel FC-13 is delivered to the operative mark of reactor hall for and loaded through the hatch. Shock absorbers reduce loads on the container in case of its falling to the loads equivalent to loads at it falling from 9 m height to the firm foundation.

During refueling cooled spent nuclear fuel is taken from the nuclear plant ground to fuel regeneration plant. WNF is carried by special rail echelon consisting of several FC-13.

The project includes annual timely arrival of transport echelon for WNF removal. Building for storage of spent nuclear fuel is not planned.

Refuel and fuel storage systems elements are extremely important for the safety and are planned according to the requirements of special norms and regulations of the Russian Federation.

Functional diagram of nuclear fuel handling is given in Figure 37 [14].

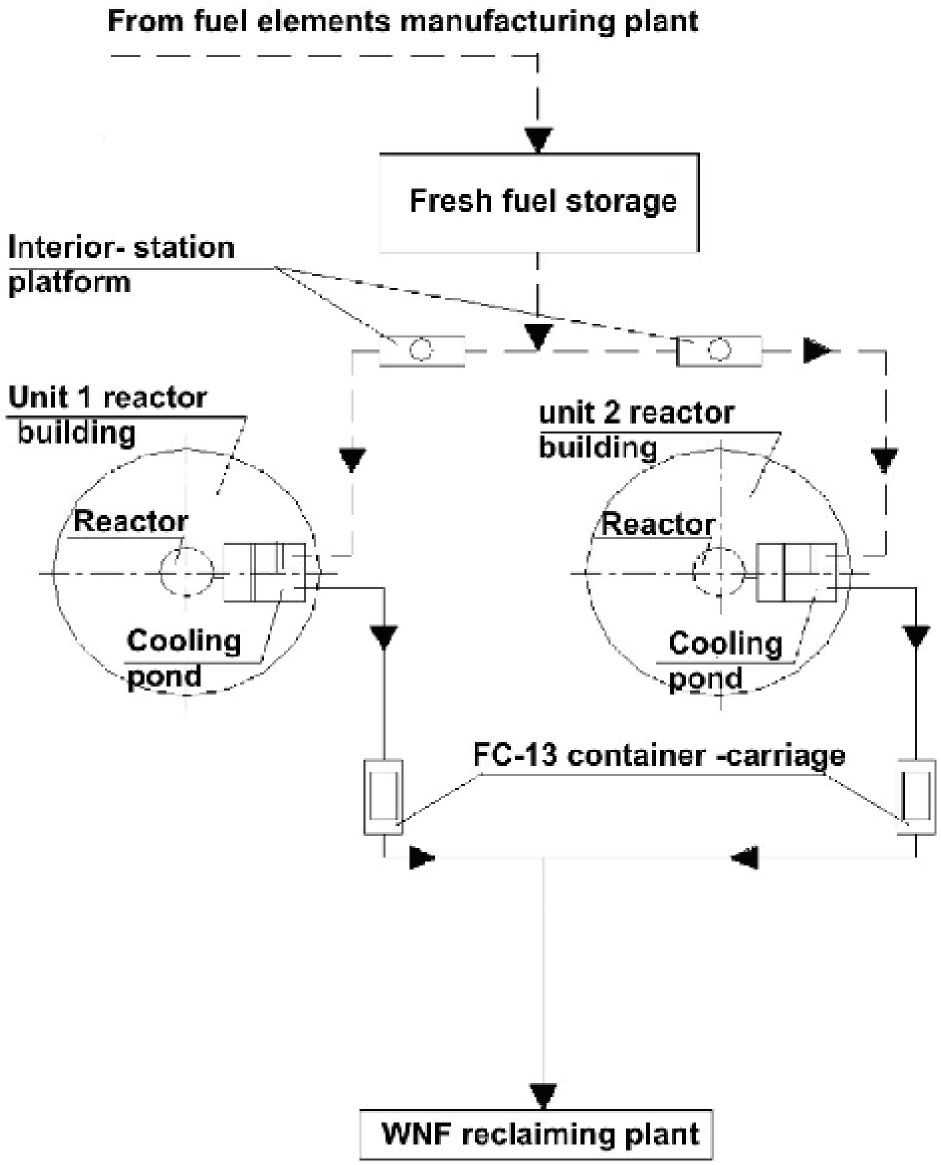


Figure 37 - Functional diagram of nuclear fuel handling

9 RADIATION PROTECTION

9.1 Radiation safety control

According to NRB-2000 the main purpose of radiation safety is health protection including health of the personnel from harmful impact of ionizing radiation by following main radiation safety norms and principles without unreasonable limitation of useful activity using radiation in industrial branches, science and medicine.

Radiation safety of the personnel and population is provided in the conditions of following the main radiation safety principles (reasonability, optimization, normalization) and meeting radiation safety requirements set by the Law of the Republic of Belarus in January, 5, 1998 No. 122-3 “About radiation safety of the population” Of NRB-2000 and valid sanitary regulations.

The main concept of radiation safety is providing in all operation modes including accidents of radiation that is currently proved as secure for the NPP personnel and for the population living in the redistrict of NPP placing. Levels of permitted radiation impact are reflected in normative documentation defining NPP operation safety.

Requirements of modern normative documents related to radiation safety fully correspond to the main International safety norms oa protection against ionizing radiation and secure handling of sources of its radiation [50]. Carrying out the main task of radiation safety is based on the principles of radiation safety. In short, these principles can be rendered as follows: practical activity which leads or can lead to irradiation must be used only in cases if it brings to irradiated people or to the society use largely exceeding harm caused by it (that is practical activity must be reasonable); individual doses include combination of irradiation from all corresponding types of activities must not exceed set dose limits.

9.2 Main criteria and radiation safety limits

The project considers the following sanitary hygienic safety criteria (Table 41):

- at normal NPP operation according to NRB-2000 the personnel effective dose should not exceed 20 mSv/year for any sequent 5 years, but not much than 50 mSv/year.

- in biological protection design permitted radiation levels in working rooms must be restricted by values regulated OSP-2002.

Table 41 – Regulation radiation levels at design protection from external exposure (according to OSP-2002)

Category of irradiated people	Places and territories	Duration of irradiation, h/year	Project equivalent dose power, μSv/h
Personnel	Rooms with constant presence of the personnel	1700	6.0
	Rooms of temporary presence of the personnel	850	12

There are categories of works [51.52] for preventive measures in case of nuclear catastrophe to prevent appearance of stochastic effects (Table 42):

Table 42 – Criteria for preventive measures

Criteria		Protective measures
Thyroid gland irradiation dose	50 mSv for first 7 days	Blocking thyroid gland
Total effective dose	100 mSv for first 7 days	Shelter, evacuation, deactivation, restrictions of food products

9.3 Main measures of providing radiation safety

General radiation safety of the NPP is provided by constructive – technological and organizational measures directed to avoid radioactive substances leakage outside operation circuits and/or their localization in case of leakage. Besides, in relation to the personnel project solutions are directed to maximum reducing of penetrating radiation field and to organize works of NPP site service so that to reduce dose loads on the personnel by reducing time or increasing MD values.

First of all providing NPP radiation safety is connected with project solutions directed to provide general safety and RI safety and NPP equipment and with safety reserved safety systems (emergency stop of the reactor, emergency heat sink system, filters, bubble devices, etc).

The main technical means of direct providing radiation safety of NPP are:

- physical barriers on the way of possible spreading of radioactive substances (fuel matrix, fuel elements cover, closed hermetic circuits system with localizing reinforcement, hermetic spaces systems including hermetic barrier in the form of double ferroconcrete cover with controlled intermediate clearance, etc) and radiation (biological protection system including equipment bodies walls, bridges and other construction elements carrying out functions of protective screens);
- systems of localizing of radiation impact sources and protection of personnel, population, environment in normal operation conditions, disturbances of normal operation, project and beyond design basis accidents;
- system of radiation control means of radiation danger sources (radiation levels, environments activity, admixture content in the rooms' atmosphere, in NPP waste and outputs, etc), physical barrier condition control;
- ventilation systems of controlled access area keeping required conditions in working rooms and providing permitted concentrations of radioactive substances in the atmosphere of these rooms;
- removal ventilation air and technological relief gases into the atmosphere with purifying them before it;
- system of collecting, reclaiming and storage of radioactive waste in special storages;

Project solutions taken while development of equipment, constructions, biological protection and radioactivity localization means have the purpose to reduce the possible radiation dose power in rooms, reduce radionuclide output into the environment and to keep all radiation parameters on reasonable low level according to ALARA principles.

Nuclear plant's radiation safety is kept by the complex of measures and activities considered in the project and controlled by the NPP administration; they include:

- dividing buildings and rooms of NPP into areas with different operation modes (areas of controlled and free access), dividing controlled area rooms into categories;

- organization of radiation and dosimetry control service on the NPP fixing of dose loads of each person whose working place is connected with occupational radiation risk;

- setting regulations for all technological processes in the NPP considering ALARMA principles;

- providing the personnel with individual protection means;

- setting and carrying out radiation safety rules in rooms, on the station ground and on the adjacent territories;

- developing plans oa personnel and population protection in case of accident;

- organization of system of training personnel in the field of radiation safety and protection;

- organization of control (radiological monitoring carried out by RCACS in the area of NPP observation optimal sizes of which are set by the project;

- periodical carrying out of medical preventive inspection of the personnel.

9.4 Project foundations and main project approaches to radiation safety

Conceptual approach to designing of complex radiation safety system is a sequential carrying from the principle of deeply-echeloned protection.

This strategic principle implies using of sequential physical barriers on the way of possible spreading of ionizing radiation and/or radioactive substances into the environment and of system of technical and organization measures of their (barriers) protection, keeping their efficiency. Carrying out the principle in the project includes prevention of spreading of radioactive substances and/or penetrative radiation in normal operation conditions and limiting consequences after the accident.

The system of NPP physical barriers includes:

- barriers directly related to RI (fuel elements matrixes, fuel elements covers, hermetic boundaries of the first circuit);

- barriers included into NPP design sphere (hermetic circuit boundaries, hermetic barrier of protective cover, barriers against circuits' pressure,).

- complex biological protection;

Project requirements to NPP physical barriers include:

- not exceeding of operational limits of fuel elements damages in the conditions of normal operation;

-not exceeding operation safety levels of fuel elements damage at design basis accidents;

- not exceeding amounts of project leakages between circuits (in steam generators, heat exchangers cooling the first circuit environment) and reducing to minimum (minimum control) of unorganized leakages amounts;

- reducing to permitted levels of penetrating radiation with help of multicomponent biological protection.

- providing of project characteristics of reliability and hermetic safety of barriers in the conditions of design basis accidents and considered by the project internal and external impacts including degrees of maximum project leakages of protective covers;

- choice of solutions determining barriers construction, used materials on the base of norms and regulations considering experience in operation and creation of analogues and prototypes, conservative model of NPP operation, analysis of project and beyond design basis accidents;

- diagnosis of barriers conditions including continuous operative control of fuel elements sealing of the first circuit boundaries and adjacent circuits, protective cover;

- forming a complex of systems providing fulfillment of requirements of effectiveness and reliability of physical barriers;
-prevention of barriers failures on general reasons including fires.

9.5 Validation of NPP radiation safety

Put into the project principles of radiation safety provided by certain engineering and organization solutions guarantee minimum radiation impact on the personnel in case they carry out behavior rules at operation and occupational activities.

The project guarantees radiation protection of the personnel and population at servicing all procedures and processes carried out in NPP at all service cycles of the NPP in all operational conditions – at handling with fresh and spent nuclear fuel (refueling and storage), at handling with RW of all types and categories of activity (transporting, conditioning, storage), at working with operating equipment and carrying out repair works.

Calculated predicted dose impact of project outputs on the region population will not exceed dose quota.

At carrying out NPP-2006 project safety analysis impact at project and beyond design basis accidents; the project determined sizes of areas where on the basis of predicted calculated radiation consequences at beyond design basis accidents protection measures for predicted doses prevention are possible.

Experience of operating nuclear energy objects completely proves reasonability of project approaches and solutions providing radiation safety of NPP operation.

Values of collective and middle individual radiation doses for NPP personnel and subcontractors are given in Table 43 [45].

Table 43 – Radiation doses

NPP	Number of controlled persons (personnel)		Collective radiation area, man-Sv	Average individual radiation dose, mSv
NPP with PWR-1000 and PWR-440 types reactors				
Novovoronezh	NPP Personnel	2429	6.43	2.65
	Subcontractors	847	1.26	1.49
	Total	3276	7.69	2.4
Kolskaya	NPP Personnel	1594	1.8	1.13
	Subcontractors	700	0.84	1.2
	Total	2294	2.64	1.15
Rostov	NPP Personnel	1118	0.04	0.03
	Subcontractors	620	0.09	0.16
	Total	1738	0.13	0.08
Balakovo	NPP Personnel	2381	1.27	0.53
	Subcontractors	1202	1.13	0.94
	Total	3583	2.4	0.67
Kalinin	NPP Personnel	2724	1.76	0.64
	Subcontractors	1612	0.58	0.36
	Total	4336	2.34	0.54

Table 43 (continued)

NPP	Number of controlled persons (personnel)		Collective radiation area, man-Sv	Average individual radiation dose, mSv
NPP with HPCR-1000 type reactors				
Kursk	NPP Personnel	4371	13.13	3.01
	Subcontractors	1432	2.39	1.73
	Total	5803	15.52	2.7
Leningrad	NPP Personnel	3691	7.07	1.92
	Subcontractors	1212	3.85	2.35
	Total	4903	9.92	2.02
Smolensk	NPP Personnel	3303	8.9	2.7
	Subcontractors	1249	2.51	1.86
	Total	4652	11.41	2.45
NPP with AHP-100 and AHP-200 and PV-600 types reactors				
Beloyarsk	NPP Personnel	1304	0.95	0.7
	Subcontractors	284	0.25	0.87
	Total	1588	1.20	0.76
NPP with EGP-6 type reactors				
Bilibino	NPP Personnel	509	2.14	4.2
	Subcontractors	188	0.4	2.1
	Total	697	2.54	3.64

There were no cases of personnel exceeding control levels (CL) set in the NPP and dose limits (DL) of 20 mSv set by the Federal law of the Russian Federation "About radiation safety of the population".

10 NPP DECOMMISSIONING

10.1 Conceptual approach to the problem of NPP decommissioning

Plant decommissioning is a complex problem including a number of questions starting with termination of NPP operation to its complete liquidation and returning the site into the initial condition ready for being used in other purposes, that is complete removal of radioactive wastes formed during NPP operation. [53 – 55].

At that ecological consequences for the territory of NPP both at putting NPP into operation and at its disposal should be minimum.

Radioactive wastes including solid radioactive wastes are formed during energy units operation in normal modes (hardened wastes, filters, sorbents, etc), during repairing works (technological equipment, sensors, tools, special clothes, etc), during emergencies.

During energy unit operation radioactive fission products and activation are formed; at that 99.9 % of fission products storeв in nuclear fuel remain in spent fuel elements; these are high-radioactive wastes. After temporary storage in the NPP cooled spent nuclear fuel is directed to reclaiming.

According to the definition [56] energy unit disposal is a process of carrying out a complex of activities after unloading nuclear fuel excluding its use as energy source and providing personnel and environment safety.

Stopping of energy unit operation will be only after the end of project service life of its main equipment equal to 60 years if the decision about NPP operation term prolongation is not taken.

Energy unit decommissioning according to OPB-88/97 should be preceded by complex inspection by special committee and final decision is taken on the base of its conclusion.

To carry out energy unit disposal it is necessary to develop project plan of the process confirmed by the corresponding authorities.

The project is made approximately 5 years before the end of the energy unit service life considering the results of preliminary inspection of its condition, experience of energy units with similar reactors decommissioning and must be the main document on base of which all main stages of disposal are carried out.

By the beginning of designing of this project it is necessary to carry out the following scientific-research and experimental-constructive works:

– researches on optimal variant of energy unit disposal with analysis of alternatives and engineering justification of adopted project;

– research and registering of the rooms and equipment;

– analysis of radiation situation and radionuclide composition of coolant and contaminated equipment;

– determining of equipment activity values by calculations and experimentally;

– evaluation of total amount and categories of radioactive wastes formed at decommissioning;

– development of normative documentation regulating project works of disposal;

– development of radiation and ecological control means during deactivation and dissembling of the equipment;

– development of radiation protection and dosimetry control system of technological decommissioning process;

– radiological researches, development of methods and mathematical models for evaluation of personnel collective irradiation dose during disposal, calculation of supposed expenses on carrying out the main technological operations;

– research and development of creation methods for working areas, pressurization of rooms and boxes at dissembling of badly contaminated and activated constructions;

– development of handling methods for radioactive wastes formed during disposal and complex technological systems of reclaiming, removal, storage and disposal of radioactive wastes, transition of low-active wastes into category without limitations;

– development of technological means for technological operations of deactivation, fragmentation, soldering, compacting of metal and non-metal radioactive wastes;

– development of organizational and engineering principles, nomenclature of special equipment and special tools for dissembling of high-active constructions, systems and big equipment (reactor vessel, reactor installation interior vessel devices, steam generator, etc) including remote complexes;

– development of staged dissembling system for reactor equipment and reactor sector rooms;

– development plan of measures of personnel and population protection fin case of accident during decommissioning works and documents (instructions) set for the personnel carrying out dissembling works at accidents;

While developing energy unit disposal project all systems, equipment, transport means, protective and sanitary-hygienic barriers must be maximally used.

This includes:

– systems of electric power supply, heating, drainage, water supply, radiation control, sanitary barriers, ventilation system with filters, transport means and freight-lifting mechanisms;

– transport – technological means proving carrying out the operations with nuclear fuel and radioactive units of reactor installation;

– radioactive equipment deactivation ponds and deactivation solutions preparation systems;

– systems of collecting, concentrating, hardening and disposal of liquid and solid radioactive wastes, systems of removal and disposal of ventilation system aerosol filters;

– two-way radio search telephone communications;

– information about impact on the systems and equipment during plant operation data about which is kept in NPP archives;

To carry out works on NPP energy unit disposal after the end of set service life with small labor expenses the following technical solutions were be taken in the project also directed to reducing of dose loads on the personnel:

– shortest routes of radioactive wastes and equipment removal;

– closed transport bridges for transportation of “contaminated” equipment and assemblies with help of floor-level transport;

– use of protective containers and equipment for collecting, sorting, transporting, and reclaiming of radioactive wastes;

– system and equipment providing radiation control on the construction ground and within NPP controlled area;

– arrangement of all buildings and constructions must provide placement of main and auxiliary equipment, reinforcement and pipelines during energy unit decommissioning within freight-lifting means action providing lifting and moving of the equipment (aggregate or its compounds) from the site to transport means with minimum loads;

– repairing and operation ventilation systems and recirculating aggregates;

– two-way radio search and telephoney communications;

– places for installation of containers for collecting and removal of radioactive wastes;

– decontamination solutions preparation Unit and special transport and protective containers deactivation areas and portable means and equipment for deactivation;

– information about impacts on systems and equipment during energy unit operation must be registered and stored in NPP archive;

– possibility of working areas creation;

– the project considers the possibility of the following variants of energy unit disposal:

a) liquidation (liquidation of the energy unit after its conservation for ~ 30 years);

b) unit disposal.

10.2 Environmental safety of energy unit at disposal

Conservation of NPP energy unit is provided by pressurizing of hatches, doors of all rooms of energy unit through which radioactive substances can spread outside the controlled area and excluding of unauthorized access of the personnel.

Environmental safety of disposed energy unit is provided by the following measures:

– reactor shut-off, nuclear chain reaction stop and transition from power operation to removing of remained heat and spent fuel elements from reactor core situated in reactor storage. Heat sink from the reactor core is provided by normal and emergency cooling system which is based on passive operation principle;

– moving spent fuel from the reactor;

– transportation of spent and cooled fuel to the reclaiming;

After removal of cooled spent fuel from the energy unit nuclear danger in it is eliminated and radiation safety is provided by strict following the requirements of normative and technical documentation which is valid at the moment of NPP energy unit disposal using special ventilation and special drainage systems.

Disposal of buildings and constructions may consist of the following stages:

– equipment dissembling, if necessary its decontamination, delivery either to conditioning and storage or to reclaiming for industrial reuse;

– building constructions dissembling, their delivery either to conditioning and storage or to reclaiming for industrial reuse;

Special ventilation and special drainage systems dissembling must be carried out after disposal of main engineering equipment.

Control of carrying out radiation safety norms at the stage of unit cooling during its disposal is provided as at operation period by means of radiation control system which collects and processes information about radiation control parameters and sends it to control posts.

According to its functions radiation control system is divided into 4 interrelated systems:

– of radiation technological control;

– of radiation dosimetry control;

– of individual dosimetry control;

– of environmental radiation control in the region of NPP.

11 RADIOLOGICAL PROTECTION OF POPULATION AND ENVIRONMENT

11.1 NPP operation in normal operation conditions and disturbances of normal operation

These operation modes are project and according to the requirements of normative documents minimum radiation impact on population and environment is guaranteed in these modes. Limit of individual risk of anthropogenic irradiation of a person according to NRB-2000 is 5M10^{-5} per year. Level 10^{-6} per year determines sphere of risk.

Bin normal operation conditions predictable effective irradiation dose of restricted number of population according to NRB-99, NRB-2000 must not exceed the limit of 1 mSv a year during any sequent 5 years, but not more than 5 mSv/year.

Recently a high level of safety has been achieved in operating NPP and really small population irradiation level (less than 10 μSv/year). This fact may be proved by the following words:

Leading expert of the International Strategic Relations institute (France) Jan-Bensan Brisse said [57]: - "Many courtiers of the world start developing nuclear power industry, increasing atomic powers and increasing terms of their operation. The reason is that resources that become less and less in number are consumed in the world. Nuclear power industry is reliable in comparison with other sources. Besides, it is more ecologically secure. For example, the USA government declared about their intention to develop nuclear power industry as one of “green” technologies – if they want to achieve lower level of CO2 emission they need to find new sources of clean energy. Nuclear power industry is one of such sources. This situation is not atomic resonance but evolution in energy use. This process has always been developing, for hundreds of years we burnt wood, later we started burning coal, then mineral fuel and petrol, now we have come to use of uranium and plutonium because we need more energy sources which become rare”.

Similar point of view was said by the Director of Nuclear Reactors Institute of Russian scientific centre “Kurchatovsky Institute” Jury Semchenkov: “Let’s remember that in Bulgaria, in Kozloduy there were 6 reactors on a river bank. Now there are only two of them but there are any problems, and the Danube is flowing along the whole Europe. Today in Russia safety justification includes all peculiarities of both operation and position. Anotherк example is Tyanvan NPP that is situated on the Yellow Sea coast in a very beautiful resort area. And the Chinese are happy to have a station – ecologically secure but not coal. Construction gives positive effect on their lives. With the beginning of construction working vacancies will increase, infrastructure will improve. Social and economic parameters balance fear of construction. By the way we are also building in India “Kundakulam” station units in very beautiful places in the very southern point of Hindustan peninsula on the ocean coast. And Sri-Lanka famous for its resorts is situated further. And nobody is afraid of problems with NPP” [58].

Touching upon the question about dose loads Deputy Director of Institute of Nuclear power industry Secure Development Problems of RSA, professor of physics and mathematics Rafael Arutunian said the following: “There are radiation – hygienic passports of territories annually issued by Rospotrebnadzor, a state supervisory body, for all cities, all regions, independent of existence of NPP on this territory. In them it reports about radiation doses of population and its sources – medicine, natural phone, any abject – from hospitals to nuclear plants. These values are annually published confirmed by Chief Sanitary Doctor of the country. The values are obvious and official. Nothing has changed for recent several years in these passports: population irradiation doses caused by nuclear plants are 10000 times lower than caused by impact of natural phone or medicine. Today if you want to learn NPP output you must find very up-to-date devices and it will be rather difficult. Not numbers but doses got by people are important. If natural phone dose is one or even 10 mSv a year, for NPP this number is 1 or 19 mSv a year that is 10000 times lower. System of strict norms in our country causes panics. Russian limits violations, as a rule, are not noticed abroad. When we say “irradiation limit for population” of for example 1 mSv in this case from the point of view of nuclear objects impact is thousands of times less. Words “limit”, “permitted limit” are so understood by the people that if a person gets more he will immediately die. It is not so. In Russia for example in Altai republic natural phone due to radon is almost 10 mSv, in Finland – 7.5 mSv, in Belgium – 6. Science knows that such phone doesn’t influence on a person. In any case Russia has supervisory bodies independently controlling phone and publishing their data, finally there is a site where all data is shown in relation to the natural phone. Even if the value is five times higher it will not have any impact” [59].

11.2 Radiation consequences of accidents on energy units

11.2.1 International nuclear events scale (INES)

International nuclear events scale (*IAEA and OECD/NEA, 2001*) was created to simplify the possibility of quick interaction with mass media in characterizing danger level on different types of nuclear plants connected with civil nuclear production including events connected with use of radioactive sources and radioactive materials transportation. Giving real state of event INES makes realizing of accidents in NPP easier (Table 44). It is reported about events estimated as level 2 or higher and about events attracted international interest.

Events having nuclear or radiological impacts are classified according INES scale divided into eight levels. Industrial events without nuclear or radiological impacts are off the scale. Example of off-scale event is a fire without radiological danger. Predicted operation events are referred to INES level 0.

Among 5 levels that have been chosen by their off-ground impact the heaviest is level 7. Such incident would cause a great output of nuclear materials from NPP core. The lowest level is 3; it includes a dose equivalent approximately to one tenth of annual extreme dose for population. Events with impact inside the ground are considered lower than level 3.

At events from level 1 (deviation) to level 3 (serious event) civil protection measures are not required. Accident without big risk outside the ground is classified as INES level 4. these levels are determined by doses for critical group. Consequences of accidents estimated as level 5 are limited outputs which probably would lead to partial emergency activities in order to reduce possibility of impact on health. INES levels 6-7 are classified as accidents at which civil protection measure are necessary. Last levels are determined by outputs radiologically equivalent to given value in TBq of iodine-131 isotope.

Most events about which mass media report are lower than level 3.

Table 44 - International nuclear events scale (INES) (IAEA and OECD/NEA, 2001)

Level/attribute	Events' nature
INES 0 Expected events	Deviations from normal operation modes can be classified as INES level 0 where operation limits and conditions are not exceeded and are controlled by adequate procedures. Examples include: accidental single failure in reserve system revealed during periodical inspections and testing, plan reactor shut-off and slight spreading of contamination inside the controlled space without consequences for safety culture.
INES 1 Deviation	Abnormal deviation from permitted mode but at corresponding depth protection. It can happen because of equipment failure, personnel error or procedure inadequacy; it may happen within the scale in such spheres as installation operation, radioactive materials transportation, handling of fuel and radioactive wastes storage. Examples are: disturbance of technological regulations or transportation rules and slight defects of pipelines.
INES 2 Incident	Includes incidents with great safety measures disturbance but with sufficient protection in depth to resist additional failures. Events leading to exceeding of set extreme annual dose for personnel or case causing great amounts of radiation in fields not considered by the project and requiring correction activities.

Table 44 (continued)

Level/attribute	Events' nature
INES 3 Major incident	Radioactivity output resulting in one tenth of extreme permitted annual value of Sv of critical population group irradiation. At such incident protective measures outside the grout can be required. Events on the ground causing such dose of personnel irradiation which leads to serious diseases and/or great spreading of contamination. Further safety systems failure can lead to accident.
	Such incident happened in Paksh NPP, Hungary in 2003. During planned repairing fuel assemblies were put into the bottom of deep water pond in separate cleaning equipment. Because of the error in equipment design circulating cooling system was damaged and fuel assemblies were overheated. It resulted in output of radioactive gases and a small amount of iodine into the reactor hall. Off-ground output was small; radiation levels on the ground and on the nearest territories didn't exceed normal phone levels. People were not injured, personnel radiation dose was maximum 10 % of annual extreme dose.
INES 4 Accident without great risk outside the ground	Radiation output causing irradiation dose of critical population group of about several Sv. Necessity of protective activities outside the ground is not likely. Serious damage of installation on the ground. One or more workers are irradiated as a result of the accident, overirradiation can lead to death. Example of such event was accident connected with overcriticality happened in Japan in nuclear fuel plant in Tokkamura in 1999. Three workers were overirradiated, two of them later died. The plant was in the city which was later evacuated and people were advised to undertake protective measures. Thin walls of the building and container for uranium didn't protect the environment from radiation. Maximum dose for a person was 16 mSv.
INES 5 Accident with risk outside the ground	Output of radioactive materials (in amounts equivalent to 100 – 1000 terra Becquerel of iodine-131). Such output can cause to partial countermeasures considered by the project to reduce possibility of impact on health. Events on the ground lead to serious damage of installations. Such accident may involve most part of core, cause big accident connected with overcriticality or great fire or powerful explosion with output of great amount of radioactivity within the installations. Accident in Three Mile Island, USA in 1979 was of INES level 5. it started because of leakage in the reactor system. Emergency reactor cooling activated but was stopped by the operator. It became the reason of overheating and partial melting of core. In spite of serious damage of the core pressurized reactor vessel and containment prevented output and stayed undamaged. Impact on the environment was small.
INES 6 Heavy accident	Output of radioactive substances (in amounts equivalent to ten thousands of terra Becquerel of iodine-131). Such output is most likely accompanied by counter measure to limit impact on health. Only one INES 6 accident has happened. It was in the Soviet Union (now Russia) in 1957 in recycling plant near the city of Kyshtym. Reservoir with high-active liquid wastes was exploded accompanied by output of radioactive material. Impact on people's health was restricted by countermeasures such as evacuation.

Table 44 (continued)

Level/attribute	Events' nature
INES 7 Major accident	Output of large fractions of radioactive material in bid installation (e.g. nuclear reactor core). It includes mixture of short and long-living radioactive fission products (in amounts more than tens thousands of terra Becquerel of iodine-131). Such output may lead to sharp long-term impact on people' health on big territories of more than one country and have long-tern ecological consequences.
	Only one case of INES 7 has happened – accident in Chernobyl nuclear plant in Soviet Union (present day Ukraine) in 1986. reactor was destroyed by explosion accompanied by burning of graphite which is used as inhibitor in reactor. It caused big output of radioactive materials into the environment. Several workers of the NPP and people taking part in the liquidation of accident consequences died of wounds or radiation. Alienation area of 30 km was marked around the reactor and approximately 135000 people were evacuated.

11.2.2 Referent heavy beyond design basis accident

According to the requirements EUR, (Volume 2 Chapter 1 Safety requirements (Part 1), NPP project will consider off- design basis accidents. Consequences of four types of the beyond design basis accidents (BDBA) will be analyzed:

- accident when coolant gets into the protective cover space of the first circuit. All systems operate normally but there are disturbances in protective cover functioning;
- accident with simultaneous coolant leakages of the first circuit and failures of some emergency cooling systems;
- accident with station discharge and with impossibility of activation of three emergency diesel safety systems during the first day;
- accident with coolant leakages from the first circuit into the second circuit.

Results of analysis of all four types of BDBA showed that the most serious consequences can be caused by BDBA type 3. in this case due to full de-energizing of the NPP cooling of the reactor core stops. It causes serious damages of nuclear fuel but cover keeps its pressurization. By IAEA scale such accident is level 5. at such accident maximum of all types of accident output of cesium-137 occurs and total output power is great. Radioactive substances output at such accident would last for a day..

Detailed analysis of reference BDBA in NPP-2006 is given in the work [60]. The main purpose of NPP safety at BDBA is reaching and keeping secure NPP state at least ia wek after the accident. For this it is necessary to carry out the following functions:

- fragments of core are in solid phase and their temperature is stable or decreasing;
- heat emission of core fragments is led to final heat absorber, fragments configuration is so that Cef is lower than 1;
- pressure In protective cover is so low that in case of full depressurization radiation consequences criteria for the population are met;

- passing of fission products to protective cover space has stopped.

To provide continuity and pressurization of protective cover at heavy BDBA the project considers:

- prevention of early damage of interior protective cove;
- prevention of late failure of protective cover by the corresponding measures such as:
- providing heat sink and localization of melt in the catcher, excluding of direct melt impact on protective cover, foundation, reactor mine concrete;
- prevention of accumulating of potentially dangerous hydrogen concentrations.

Initial events of reference BDBA are:

- distortion of the main circulating pipeline Du 850 in the reactor input with two-way coolant leakage;
- loss of alternative current sources and correspondingly unserviceability of all active safety systems for long period not more than 24 hours, emergency feeding is from batteries.

Process of development of heavy BDBA is shown in Table 45.

Table 45 – Development of heavy BDBA

Event	Time	Comments
Distortion of main circulating pipeline Du 850 in the reactor input. Loss of all sources of alternative current	0,0 s	Initial event
Disconnection of all main circulating pipelines. Deactivation of feeding and blowing system. Prohibition on activation of RI-K.	0,0 s	Refuse: loss of all sources of alternative current including all diesel-generators
Emergency protection activation	1,9 s	At unit de-energizing with delay for 1,9 s
Start of PCAS	8,0 s	First circuit pressure drop lower than 5,9 MPa
SPOT system activation	30,0 s	At de-energizing to feeding sections with delay for 30 s
Activation of GE – 2 ASCS	120,0 s	First circuit pressure drop to 1.5 MPa and delay for system turn
Stop of boron water delivery from GE-1 ASCS	144,0 s	Reducing of level in GE ASCS tanks to the mark of 1.2 m
Steam condensing in SG tubes	3600,0s	Second circuit parameters are lower than first circuit parameters
Stop of boron water delivery from GE-2	30,0 h	Exhausting supply of boron water
Hydrogen generation in AP by oxidizing reaction	44,6 h	T fel > 1000 ^{0}C
Damage of AZ and start of passing destroyed materials of core	47,7 h	
Melting of support grid and passing of fragments to the reactor vessel bottom	51,0 h	T support grid > 1500 ^{0}C
Reactor vessel damage and start of melt passing to ULR	52,0 h	T vessel > 1500 ^{0}C

To minimize consequences of heavy BDBA the following systems are used:

- system of heat sink from pressurized cover (sprinkler system)
- system of emergency and plan first circuit cooling;
- system of hydrogen concentration control and emergency removal;

- system of catching and cooling of core off the reactor.
Purposes of these safety systems are given in Table 46

Table 46 – Result of operation of safety systems at BDBA control

Safety system	Operation period	Purpose
System of emergency hydrogen removal	During the whole period of the accident	Providing hydrogen safety
System of passive heat sink System of hydro containers of stage 2	Till transition to heavy stage	- preventing of early damage of protective cover - providing heat sink from protective cover and fuel
System of catching and cooling of core fragments	After destroying of reactor vessel and accident transition to off-vessel stage	- reaching of NPP secure state - providing of heat sink and localization of melt in the catcher - stop of fission products passing to protective cover space
Sprinkler system System of emergency and plan cooling of the first circuit	Three days after the beginning of the accident	- reaching of NPP secure state - pressure drop in protective cover - providing heat sink from protective cover and fuel - preventing of late damage of protective cover

11.2.3 Radiation consequences of the beyond design basis accident

Calculations of interior and exterior doses given in work showed [61]:

- only at the heaviest accident BDBA of type 3 shelter (in residential houses) may be need in the radius of 6 km of the output centre;

It is necessary to note that such types of accidents are little likely because simultaneous shutoff of three independent safety systems are from the reality. At accidents of other types sheltering of population during passing of output cloud is not required;

- necessity of iodine preventive measures can appear at the distance of not more than 12 kilometers from the NPP only for pregnant women and children. This measure is necessary only in the radius of 4 km from the NPP and only for BDBA of type 3;

- only at accident of this type question about evacuation of children and pregnant women for 2-3 months can arise in the area of not more than 4,7 km;

- in 30-km area restrictions on food consumption may be taken (milk, vegetables). But this type of radiation impact is connected with the fact that iodine-131 can get into the food chain (e.g. soil – grass – milk – human) which decays during several months. That is why after 2-3 months food products can be used;

- only at accident of type 3 some exceeding of radiation dose for winter crops are possible. In this case special protection measures are required to protect milk cows in the radius of 5-7 km from the NPP (transition to paddock food).

Longer (to 1 year) restrictions on contaminated food products produced not far from the NPP and containing zicium-137 can be put in the radius of 11 km along the cloud trace. This restriction is possible only for BDBA of type 3. But trace width according to meteorological, geological peculiarities is not more than 4 km so rural areas in 30-km area can be contaminated.

Within this area waters are relatively protected at all types of beyond design basis accidents because output trace is rather narrow and very small amount of radionuclides can get to the ground waters. Ground wares are mixed with surface waters that is why surface waters – rivers and streams will not also be contaminated.

Even if to drink water from basins without preliminary purification dose increase for 6 % of permitted limit for iodine-131 and zecium-137 content will be three times less than permitted value for drinking water.

Within 5-7 km from the NPP BDBA of types 2 and 3 can have some consequences for animals and plants. But changes are possible only at small area – to 20 km- and in some years they are balanced by natural processes.

Researches on all types of accidents at NPP including the heaviest shows that there is no serious danger for population in the station region. Scenarios of all accidents consider sequence of protective activities.

11.2.4 Radiation control. General

According to valid norms and regulations on all objects where production process can cause contamination of technological environments and air with radioactive substances and personnel can be subjected to ionizing radiation control must be carried out. For this NPP has a system of radiation control.

RCS is designed for:

– providing radiation safety of the personnel and population in the NPP region;

– increasing NPP reliability by means of early revealing of deviations from normal operation mode of technological equipment;

– supervising following measures of radiation control at all stages of NPP service cycle: commissioning, operating and disposal.

RCS consists of automated radiation control system, portable devices, local stationary devices, laboratory equipment for samples' analysis.

Radiation control in the NPP is carried out in the modes of normal operation, deviations from normal operation, project and beyond design basis accidents and at carrying out emergency control measures of personnel and population protection.

In normal operation mode the system provides information about parameters characterizing NPP state and confirming that they do not exceed limits set for normal operation. These parameters include:

– pressurization of protective barriers;

– activity of gas and aerosol and liquid outputs;

– radiation state in the power unit rooms;

– contamination of the rooms, transport and personnel with radioactive substances;

– individual irradiation doses for the personnel;

– content of radionuclides in environmental objects;

– population irradiation doses.

In the mode of deviations from normal operation RCS system sets normal operation parameters exceeding the limits and follows the process of their development. Corresponding organizational and engineering measures are developed to prevent the deviations and to stop their development into design basis accidents. If necessary the system sends signals to control systems to influence on technological systems to prevent output of radioactive substances into the environment.

At design basis accidents the system sets parameters exceeding secure operation level and if necessary gives signals to form control influence on power unit safety systems to prevent output of radioactive substances into the environment. The system evaluates amount of radioactive substances on the protective barriers, predicts radiation conditions on the power unit and estimates personnel and population irradiation doses. On the base of this information corresponding organizational and engineering measures are designed.

At BDBA RCS reveals parameters exceeding extreme levels and gives information for taking some measures according to personnel and population protection activities.

RCS protections provide control of following radiation safety norms at carrying out works on liquidation of accident consequences and evaluates quality and quantity of the work.

Considering multilevel safety system of design NPP RCS measuring channels have structural and functional independence. At that there is the possibility of storing and using information at several levels of measuring channel. The lower level is the less volume of information but the more reliability of its receiving. Depending on initial safety requirements RCS has a number of main parameters whose control is carried out in all operation modes including design basis accidents. These parameters are controlled by several independent measuring channels.

RCS consists of the following subsystems:

– radiation technological control (RTC);
– radiation control of the rooms and production ground (RCRPG);
– radiation control of unspreading of radioactive contamination (RCURC);
– radiation dosimetry control (RDC);
– radiation environment control (REC).

12 SUMMARY

Reasonability of development of nuclear power industry in the republic is proved by the following factors:

- low supply of own fuel resources;
- necessity of diversification of different types of energy carriers and replacement of a part of imported natural resources – natural gas and fuel oil;
- possibility of creation of long-term reserves of nuclear fuel and reducing dependence on imported natural gas;
- possibility of reducing prime cost of electric energy produced by energy system;
- possibility of excess electric energy production for its export;

Including nuclear fuel into the energy balance of the Republic will increase economic and energy safety of the country in the following directions:

−a great part of imported energy resources (to 5.0 million tons of conventional fuel in a year) is replaced and structure of fuel end energy balance of the country changes;

–nuclear fuel is several times cheaper than organic fuel and is not a monopoly of the manufacturing country; there is a possibility of buying in different countries;

– including NPP into the energy balance will reduce the prime cost of produced electric energy by reducing expenses on fuel;

–operation of autonomous nuclear electric power plants is less dependent on supply continuity and fuel prices changes than of organic fuel stations.

Besides, use of organic fuel (natural gas) will decrease output of greenhouse gases into the atmosphere for 7-10 million tons what will give the Republic of Belarus economic profits according to Kioto Protocol of framework convention of the United Nations Organizations about climatic changes dated December, 11. 1997.

Scientific and research works on the choice of site began in 90-s of last century. On the base of their results according to IAEA requirements the most perspective sites are: Bykhov and Shklov-Gorki in Mogilev region and Ostrovets in Grodno region.

On these sites research works were carried out during 2005-2006. Results were discussed with IAEA specialists and subjected to international tests in Russia and Ukraine. Comparative evaluation results show:

- there are no forbidding factors for all alternative sites (no factors/conditions forbidding placing NPP on these sites).

- there is no potential possibility of activation of piping-carst processes in Krasnaya Polyana and Kukshinov sites what is a complication factor and need further studying. Engineering and geological conditions of Kukshinovo site are difficult (uneven lating of soil of different compositions and properties whose level is near the surface to 1.8 m). separate unfavorable factors may be excluded/balanced by the corresponding engineering solutions;

. – by complex of important factors Ostrovets site has advantages over Krasnaya Polyana and Kukshinovo sites.

The main advantage of nuclear power industry in comparison with traditional energy technologies are:

- absence of output of greenhouse gases and harmful chemical substances;

- absence of radioactive substances output at normal operation (output is limited by permitted quotes, radioactive wastes are localized, concentrated and buried), and TPS radioactive wastes contained in carbon black (natural radionuclides – potassium, uranium, thorium and their decay products) are involved into the life cycle;

- small influence of raw coast on produced electric energy cost.

During development of nuclear power industry approaches to its safety have been changed. The reasons were some heavy accidents on NPP: accident in Three Mile Island, USA in 1979 of INES scale level 5 and accident in Chernobyl NPP in the Soviet Union in 1986 (level 7). So the world community could formulate the main IAEA safety principles and requirements to European electric energy producers and modern reactor installations.

As a result of corresponding researches of design limits reactor installations used at present o (generation III) possess high reliability characteristics:

- calculated frequency of core damages is < $1x10^{-6}$ /reactor a year;

- frequency of heavy radiation emissions is <$1x10^{-7}$ /reactor a year.

Reliability characteristics reached in the project correspond to risk values of $1x10^{-6}$.

This NPP safety levels have been reached by implementation of IAEA safety principles and fundamental safety function in the project solutions. For them the project uses combination of active and passive safety systems minimizing "human factor" and providing secure operation of the installations.

This book describes concepts of nuclear and radiation safety of the project "NPP-2006", formulates the general purpose of NPP radiation safety. It gives brief description of engineering, organizational means and measures providing NPP safety.

The book shows the ways of fulfillment of IAEA principles and criteria and EUR requirements providing secure operation of power units. At realization of the project a part belongs to accident control problems including:

- prevention of deviations from normal operation;
- control at deviations from normal operation;
- prevention of development of initial events and design basis accidents;
- off-project control;
- planning of activities of personnel and population protection during accidents.

To achieve design limits of radiation and nuclear safety NPP project considers reasonable combination of active and passive safety systems. Modern projects pay great attention to internal protection. Internal protection of RI is expressed in ability of preventing development of initial events and accidents, limiting their consequences without personnel participation, energy consumption, and external help for a long period of time. This time should be used by the personnel for evaluation of the situation and carrying out correcting measures. Properties of internal self-protection of the reactor should be directed to self-limitation of power and self-shutoff, limitation of pressure and temperature in the reactor, heating rate, first circuit depressurization, fuel damage, keeping vessel undamaged in heavy accidents.

Information given in the book shows that modern project of Russian NPP and conceptual project "NPP-2006" meet the safety requirements:

- at beyond design basis accidents it is necessary to provide limiting of the consequences with heavy damages of the core to protect the population, calculated radius of urgent evacuation area should not exceed 800 m what excludes the necessity of urgent and long-term evacuation. Radius of the area within which population protection measures are required should not exceed 3 km (iodine preventive measures, sheltering, etc);
- evaluated by the project average value of probability of exceeding extreme emergency output according to the total operation conditions (power operation, non-operation modes, etc) and all internal and external initial events should be not lower than $1,0x10^{-7}$ per one year of power unit operation;
- annual emission of liquid radionuclides into the environment at normal operation and deviations from normal operation (excluding tritium) should not exceed 10 GBq;
- annual aerosol emission of inert gases into the environment at normal operation and deviations from normal operation should not exceed 40 TBq;
- annual aerosol and iodine isotopes emission into the environment at normal operation and deviations from normal operation should not exceed 0,8 GBq;
- emission of Cs-137 into the environment at heavy accidents with fuel melting should not exceed 10 TBq.

Reaching these target limits will provide correspondence to the technical normative acts of the Republic of Belarus.