

DEPARTMENT OF ENERGY OF THE REPUBLIC OF BELARUS  
PROJECTING SCIENTIFIC AND RESEARCH REPUBLICAN UNITARY  
ENTERPRISE  
**"BELNIPIENERGOPROM"**

**JUSTIFICATION OF INVESTMENTS INTO NUCLEAR POWER  
STATION CONSTRUCTION IN THE REPUBLIC OF BELARUS**

**BOOK 11**

**EVALUATION OF IMPACT ON THE ENVIRONMENT**

**1588-ПЗ-ОИ4**

**PART 8**

**EIE REPORT**

**Part 8.1. NPS Description**

**EXPLANATORY NOTE**

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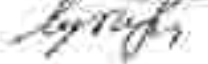
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## 1 TERMS AND DEFINITIONS

**EP (emergency protection)** — safety function of quick transition of the reactor to undercritical mode and keeping it in this mode; security measures system carrying out the function of emergency protection.

**Off-project accident** — an accident caused by events not considered by the project or accompanied by additional multiple security system failures and personnel false actions not considered by the project.

**Project accident** — an accident whose initial data and final conditions are considered by the project and are within its security system providing limitations of the consequences of the accident.

**Active zone** — a part of the reactor which accommodates nuclear fuel, delay mechanism, absorbent, heat carrier, means of influence on reactivity and construction elements carrying out controlled nuclear chain fission reaction and transferring of heat to the heat carrier.

**Activity (A)** — measure of radioactivity and amount of a radionuclide in a definite condition at definite period of time:  $A = dN/dt$ , where  $dN$  — supposed number of spontaneous nuclear transitions from the given energetic condition occurring at a period of time. Activity unit in measuring system is back second ( $s^{-1}$ ), called becquerel (Bq). Off-system activity unit curie (Ci) used earlier is  $3,7 \times 10^{10}$  Bq.

**Alpha radiation** — type of ionizing radiation consisting of a flow of positive particles (alpha-particles) emitted at radioactive decay and nuclear reactions.

**Alpha-particle** — a positive particle emitted by the atomic nucleus during the positive decay. Alpha-particles are helium nuclei; contain two protons and two neutrons.

**Annihilation** — interaction of an elementary particle and antiparticle in the result of which they both disappear and their energy turns to electro magnetic radiation.

**Antiparticle** — elementary particle identical by weight, life time and other characteristics to its “clone” – normal particle with different electrical charge, magnetic moment and some other characteristics.

**NS** — nuclear station.

**ARCCS** — automated radiation conditions control system.

**Atom** — smallest particle of a chemical element carrying its chemical characteristics. An atom consists of a positive atomic nucleus and negative electrons moving in the nucleus' Coulomb field according to the laws of quantum mechanics.

**Atomic mass** — weight of a chemical element's atom given in atomic mass units (a.m.u.). 1 a.m.u. is 1/12 of carbon isotope's mass with atomic mass is 12. 1 a.m.u.  $= 1,6605655 \times 10^{-27}$  kg.

**Nuclear Power Plant (NPP)** — nuclear plant for producing electrical and heat energy in given modes and application conditions situated on a definite site where there is a nuclear reactor (reactors) and complex of systems, equipment and installations necessary for its functioning.

**Atomic energetics — Nuclear energetics.**

**Atomic nucleus** — central positive part of an atom around which electrons are moving and which has almost the whole atom mass. It consists of protons and neutrons.

**Nuclear ship** — a general name of vessels with nuclear power plants.

**Basic load** — part of electrical energy consumption which remains constant for 24 hours; it is approximately equal to minimal daily load.

**Becquerel (Bq)** — measuring system unit of activity of radioactive isotopes, named after French physicists Anry Becquerel, 1 Bq is 1 decay per second.

**Nuclear and radioactive security of a nuclear power station (further – nuclear station security)** — capability of nuclear station at normal operation and normal operation failures including emergencies to limit radioactive impact on the personnel, population and environment.

**Beta-particle** — particle emitted from the atom during radioactive decay. Beta-particles can be both electrons (with negative charges) and positrons.

**Biological protection** — complex of constructions and materials surrounding the nuclear reactor and its units designed to reduce radioactive radiation to biologically safe level. Biological protection is a barrier designed to prevent or limit radioactive impact on the personnel in the conditions of normal operation, failures of normal operation including project emergencies. The main means of biological protection is concrete; different metals can also be protective materials with good absorbing properties.

**Bituminization of radioactive wastes** — hardening of liquid concentrated or dry radioactive wastes by mixing them with fused bitumen and thermal dehydration of the resulted mixture.

**Nuclear power plant unit** — a part of nuclear plant that is a nuclear reactor with generating and other equipment providing functions of nuclear power station in the scale determined by the project.

**FN** — reactor on fast neutrons in which the first and second coolant circuit is sodium, the third coolant circuit is water and steam. In Russia it is used in Beloyarsk NPS.

**Boric company** — period of WMWC reactor operation between fuel overloads (till the moment when boric acid concentration in first coolant circuit is zero).

**Breeder — Breeder-type reactor.**

**Fast neutrons** — neutrons whose kinetic energy exceeds a definite level. This level can be of a wide range and depends on the application (reactors' physics, protection, dosimetry). In reactors' physics this value is usually chosen of 0,1 MV.

**Ram (roentgen-equivalent-man)** — off-system unit of equivalent dose. 1 ram= 0,01 Sievert.

**RSA** — possible security analysis.

**Putting into operation** — process during which systems and components of built nuclear station are activated and their correspondence to the project is evaluated.

**WMWC** — water-moderated water-cooled reactor which uses water as coolant and deterrent. The most spread in Russia reactor type has two modifications — WMWC-440 and WMWC-1000.

**External radiation** — radiation of a body by the outer sources of ionizing radiation.

**Internal radiation** — radiation of a body by the internal sources of ionizing radiation.

**Heavy water (D<sub>2</sub>O)** — type of water in which usual hydrogen (H) is replaced by its heavy isotope-deuterium (D).

**Impact on the environment** — nonrecurrent periodical or constant process resulting in negative changes in the environment.

**Reproducing material** — material containing one or several reproducing nuclides capable of direct or indirect transition to nuclides dividing by means of catching neutrons (uranium – 238 and thorium – 232).

**Secondary nuclear fuel** — secondary nuclear fuel includes plutonium – 239, uranium – 233 formed in nuclear reactors from uranium – 238 and thorium – 232 at absorbing of neutrons.

**Decommissioning** — process when a nuclear station is stopped being used at which the security of the personnel, population and environment is guaranteed.

**Nuclear fuel burn-out** — reducing of concentration of any nuclide in nuclear fuel due to nuclear transformation of the nuclide at the reactor operation.

**Burning out absorbent** — material put into critical system; it intensively absorbs neutrons and compensates excess critical mass of dividing material at the initial stages of its operation and later burns out.

**Highly enriched uranium** — uranium with uranium-235 isotope content of 20 or more per cent.

**Gamma radiation** — electro magnetic radiation with very short wave length (less than 0,1 nm) appearing at radioactive transformations and nuclear reactions, at deceleration, decay and annihilation of particles.

**International Atomic Energy Agency Guarantees** — international system of control adopted in the frames of non-proliferation of nuclear weapons; system of check applied to peaceful use of nuclear energy responsibilities of which were imposed on International Atomic Energy Agency (IAEA) according to the Agency Charter, Agreement on non-proliferation of nuclear weapons and Agreement on prohibition of nuclear weapons in Latin America.

**GW** — gigawatt ( $10^9$  W).

**Genetic consequences of radiation** — undesirable radiation consequences of impact of ionizing radiation on living organisms resulting in changes in its hereditary properties and revealed in descendants of the organism influenced by radiation.

**Hydrometallurgical processing of uranium ore** — extraction of uranium and its compounds out of natural ore with help of chemical reagents' water solutions and further extraction of uranium out of these solutions. It is the main method of chemical enrichment of uranium ore and getting uranium concentrate resulting in changing of minerals' compositions.

**Depth of burning out** — initial number of nuclei of a certain type that have transformed in the reactor under the impact of neutrons (amount of energy got out of fuel mass unit, expressed in MWday/kg U).

**Graphite** — mineral, one of crystal forms of carbon. Nuclear pure graphite (without substances absorbing neutrons) is used as neutrons deterrent in nuclear reactors.

**Gray (Gy)** — unit of measuring of absorbed radiation dose in measurement system, 1 Gy is absorption of 1 joule of energy per 1 kilogram.

**GTP** — gas-turbine plant.

**MCP** — main circulating plant.

**Decontamination** — removal or reducing of radioactive contamination off any surface or environment.

**Deuterium** — "heavy" hydrogen isotope with atomic mass off 2.

**Nuclear fission** — splitting of a heavy nucleus into two parts accompanied by extraction of relatively large amount of energy and as a rule two or three neutrons.

**Fissible material** — material containing one or several fissible nuclides and at definite conditions capable of reaching criticality.

**Fissible nuclide** — nuclide capable of nuclear fission in the result of interaction with slow neutrons. There are three important fissible nuclides that nuclear energetics deals with. One of them (uranium – 235) exists in nature, two other nuclides (uranium – 233 and plutonium – 239) are artificial.

**Detector of ionizing radiation** — sensitive element of a measuring device (means) designed for registration of ionizing radiation.

**Uranium dioxide** — chemical compound which is the basis of nuclear fuel. In the form of powder is used for manufacturing of fuel tablets.

**Spacer grid (SG)** — element of heat-generating assemble designed for attaching of heat-generating elements.

**Annual effective dose (equivalent)** — sum of effective (equivalent) dose of a person's external radiation got by a year and supposed effective (equivalent) dose of internal radiation caused by radio nuclides got into the organism during the same year. Annual effective dose unit is Sievert (Sv).

**Absorption dose** — amount of ionizing radiation energy transmitted to the substance. The energy can be averaged by any definite amount, in this case average dose will be equal to the full energy transmitted to the amount divided to the mass of this amount. In measurement system absorbed dose is measured in joule divided to kilogram and has a special name – grey (Gy).

**Prevented dose** — predictable dose in the result of an emergency that can be prevented by protective measures.

**Equivalent dose** — absorbed dose in an organ or tissue multiplied to the corresponding weight coefficient for this type of radiation.

**Effective dose** — value of impact of ionizing radiation used as a measure of risk of distant consequences of radioactive irradiation of a person's body and its separate organs considering their radioactive sensitivity. It is a sum of products of equivalent doses in organs and tissues and corresponding weight coefficients for definite organs and tissues.

**Collective effective dose** — measure of collective risk of radiation stochastic effects; it is equal to the sum of individual effective doses. Collective effective dose unit is man-sievert (m-Sv).

**Dosimeter** — device for measuring absorption dose or ionizing radiation dose power.

**Dosimetry** — a sphere of applied nuclear physics studying physical processes characterizing impact of ionizing radiation on different objects.

**Natural radiation background** — space radiation and radiation created by natural radio nuclides contained in soil, water, air, other elements of biosphere, in food products, in the organisms of people and animals.

**LRW** — liquid radioactive wastes.

**Unremovable (fixed) surface contamination** — radioactive substances that are not transferred to other objects with contacts and not removed at decontamination.

**Removable (unfixed) surface contamination** — radioactive substances that are transferred to other objects with contacts and removed at decontamination.

**Radioactive contamination** — presence of radioactive substances on the surface or inside a material, in the air, in a human body or in any other place in the amount exceeding the adopted levels.

**Uranium oxide ( $U_3O_8$ )** — compound having several modifications depending on conditions of its preparation, formed at oxidation of uranium dioxide and at burning of any uranium oxide, oxide hydrate or uranium salt and acid.

**Inhibitor** — material for example light or heavy water, graphite used in the reactor for inhibition of fast neutrons by their collision with lighter nuclei to facilitate further fission of nuclear fuel.

**Closed nuclear fuel cycle** — nuclear fuel cycle in which worked out nuclear fuel is unloaded from the reactor and processed for extraction of uranium and plutonium for repeated production of nuclear fuel.

**Burial of radioactive wastes** — safe placement of radioactive wastes without intention of their further usage.

**Protective cover of the reactor** — technical means designed for preventing output of excess amount of radioactive substances out of the nuclear reactor to the environment even in case of accident.

**Protective security systems (elements)** — systems (elements) designed for prevention or limitation of damages of nuclear fuel, fuel elements, equipment and pipelines containing radioactive substances.

**Siewert (Sv)** — equivalent and effective radiation dose unit in measurement system, named after Swiss scientist G. R. Siewert.

**Reproduction zone** — part of nuclear reactor containing reproducing nuclear material and designed for getting secondary nuclear fuel.

**Observation zone** — territory outside the sanitary protection zone where radiation monitoring is carried out.

**Radiation accident zone** — territory where the fact of radiation accident has been proved.



**Isotope** — nuclear form of the element having a definite number of neutrons. Different isotopes of an element have similar number of protons but different numbers of neutrons and different nuclear mass, for example U-235, U-238. Some isotopes are unstable and decay forming isotopes of other elements.

**Inertial radioactive gases (IRG)** — gaseous chemically inert products of nuclear fuel fission in the reactor including radio nuclides of argon, krypton, xenon.

**INES** — international scale of nuclear accidents classification for evaluation of their level and danger. It has 8 levels (zero level and seven danger levels).

**Ion** — atom, electrically charged due to loss or getting electrons.

**Ionization** — formation of positive and negative ions out of electrically charged neutral atoms and molecules.

**Ionizing radiation** — radiation formed at radioactive fission, nuclear transformations, slowdown of charged particles in a substance; that forms ions with different signs at interacting with the environment.

**Research reactor** — nuclear reactor used for fundamental and applied researches and working out of radio isotope products.

**Natural radiation source** — natural source of ionizing radiation included into the norms of radiation security RSN-2000.

**Anthropogenic radiation source** — source of ionizing radiation specially created for useful applications or is a by-product of useful activity.

**Ionizing radiation source** — device or radioactive substance emitting or capable of emitting ionizing radiation.

**Closed radionuclide source** — source of radiation whose structure excludes entrance of radionuclides to the environment while its operation and working out.

**Open radionuclide source** — source of radiation while using of which entrance of radionuclides to the environment is possible.

**Initial material** — material having in its composition uranium or thorium with isotope correlation as in natural uranium and thorium.

**ITER, International Thermonuclear Experimental Reactor** — International Thermonuclear Experimental Reactor that is being built by an international group of scientists under the control of IAEA. It is planned to be prototype of the first thermonuclear station DEMO in the world.

**Channel-type reactor** — nuclear reactor in whose active zone fuel and circulating coolant is contained in separate hermetic technological channels capable to bear high pressure of the coolant.

**Ceramic fuel** — nuclear fuel consisting of high-heat compounds, e.g. oxides, carbides, nitrides.

**Coefficient of set power use (CSPU)** — relation of actual energy production of a reactor plant for the period of operation to energy production at nominal power; it characterizes effectiveness and security of NPS operation.

**Wastes classification** — process of distributing of wastes by special categories adopted to guarantee that wastes are processed in a secure for people and environment way.

**Security classes** — classification of NPP equipment and systems by their roles in providing NPP security (class 1 includes fuel and NS elements, whose failures are initial events of off-project accidents leading to fuel elements damage with exceeding limits of project accidents).

**Containment** — protective concrete hermetic cover of reactor hall.

**Radiation control** — gathering information about radioactive conditions in the organization, environment and about the levels of population exposure to radiation (includes dissymmetrical and radiometrical control).

**Nuclear reactor vessel** — hermetic container designed for active zone and other plants and for organization of nuclear fuel safe cooling by coolant flow.

**Tank reactor** — nuclear reactor whose active zone is in a tank capable to bear heat loads and coolant pressure. High pressure of coolant in light-water reactors that are constructionally vessel require thick-wall steel vessel.

**Space radiation** — energy particles including protons that get to the Earth from the space.

**Reproduction coefficient** — characteristics of chain fission reaction reflecting the correlation of the number of neutrons of a given generation to the number of neutrons of the previous generation.

**Security criteria (levels)** — parameters and (or) characteristics of a NS set by normative and legal acts and (or) state regulative authorities according to which the security of the station is estimated.

**Critical mass** — smallest mass of nuclear fuel in which self-keeping chain fission reaction can occur. It is determined by the construction, active zone composition and other factors.

**Critical condition of the reactor** — stationary condition of a reactor at which the number of neutrons doesn't change (Reproduction coefficient).

**Curie (Ci)** — off-system unit of activity, earlier - activity of 1 g of radium-226 isotope.  $1 \text{ Ci} = 3,7 \times 10^{10} \text{ Bq}$ .

**Light-water reactor** — nuclear energy reactor in which usual (light) water is used as a moderator and a coolant simultaneously. There are two types of these reactors – reactor with water under pressure and reactor with boiling water/.

**Localizing security systems (elements)** — systems (elements) designed for preventing or limiting spreading of radioactive substances and ionizing radiation in the environment at accidents.

**Radiation disease** — general disease with specific symptoms resulted from the impact of ionizing radiation.

**Radiation injury** — pathologic changes of blood, tissues, organs and their functions resulted from the impact of ionizing radiation.

**International Atomic Energy Agency (IAEA)** — International Atomic Energy Agency, international control organ supervising nuclear security and non-proliferation of nuclear weapons in the world.

**Megawatt (MW)** — power unit of  $10^6$  watt. MW(e) is referred to electrical power of the generator, MW(h) – to the heat power of the reactor and heat source (for example full heat power of the reactor is usually thrice as big as the electric power).

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

**IRPC** — International radio ecological protection commission, an independent group of scientists giving consultations on protection of population and personnel of nuclear branch from ionizing radiation.

**“Wet” storage** — storage of nuclear fuel (usually worked-out) using water.

**MOX, Mixed Oxide Fuel** — mixed (usually on the basis of uranium and plutonium) oxide nuclear fuel.

**Monitoring** — systems of regular monitoring according to a certain program for evaluation of the current condition of the object under observation and forecasting its future conditions.

**Dose power** — radiation dose per a time unit: ram/s, Sv/s, mram/h, mSv/h, mcram/h, mcSv/h).

**MPa** — megapaskal ( $10^6$  Pa).

**Population** — all people including personnel when not at work with sources of ionizing radiation.

**Independent systems (elements)** — systems (elements) for which failure of one system (element) doesn't cause failure of another system (element).

**Open nuclear fuel cycle** — nuclear fuel cycle in which worked-out nuclear fuel unloaded from the reactor is not processed.

**Neutron** — Uncharged elementary particle in the nucleus of each atom excluding hydrogen. Single moving neutrons moving with different speeds appear in the result of fission reactions. Slow (thermal) neutrons can cause fission of isotopes' nuclei for example U-235, Pu-239, U-233; fast neutrons can cause fission of "reproducing" isotope nuclei, for example U-238. Sometimes nuclei catch neutrons.

**Unrevealed failure** — failure of a system (element) that is not revealed in the moment of its appearance at normal operation and is not revealed by control means during checks and maintenance.

**Low-activity waste** — radioactive waste that don't require special protection at dealing because of low content of radionuclides.

**Reduced-enrichment uranium** — uranium with uranium-235 isotope content less than 20%.

**Normal operation** — operation of NS in operational limits and conditions determined by the project.

**Nuclide** — type of atom with definite number of protons and neutrons in nucleus characterized by atomic mass and atomic (serial) number.

**Unfissile (threshold) nuclide** — nuclide splitting under the influence of neutrons when their energy exceeds a definite threshold. Natural fissile nuclides are U-238 and Th-232 (they are also called rough or reproducing nuclides).

**Fissile nuclide** — nuclide capable of splitting under the influence of neutrons with any kinetic energy including equal to zero. There is only one natural fissile nuclide. It is isotope U-235. Pu-239 and U-233 are artificial (reproducing) fissile nuclides.

**Nucleon** — general name for proton and neutron – particles of which atomic nuclei consist.

**Depleted uranium** — uranium in which uranium-235 isotope content is lower than in natural uranium (less than 0,7 %), it is by-product in fuel cycle, can be mixed with enriched uranium for production of nuclear fuel.

**Supporting security systems (elements)** — systems (elements) designed to supply security systems with energy, working conditions for their functioning.

**Irradiation** — impact of ionizing radiation on humans.

**Emergency irradiation** — irradiation in the result of radiation accident.

**Medical irradiation** — irradiation of humans (patients) at medical inspections and treatment.

**Natural irradiation** — irradiation by natural sources of radiation.

**Industrial irradiation** — irradiation of the personnel by all sources of anthropogenic and natural ionizing radiation in the process of industrial activities.

**Professional irradiation** — irradiation of the personnel in the process of work with anthropogenic sources of ionizing radiation.

**Anthropogenic irradiation** — irradiation by anthropogenic sources in usual and emergency conditions excluding medical irradiation.

**Uranium (uranium ore) enrichment** — activities of processing mineral raw material with uranium in order to separate uranium from other minerals in the composition of ore with enlarging the correlation of U-235 to U-238. Enrichment process includes reduction and crushing of ore and other activities aimed to separate ore from waste that are called “tails”. Enrichment by leaching includes chemical processes of separating uranium from the solution.

**Enrichment of nuclear fuel** — nuclear fuel in which content of fissible nuclides is more than in initial natural raw material.

**Enriched uranium** — uranium in which uranium-235 (to U-238) is higher than in natural uranium (for 0,7 %). Reactor uranium is usually enriched approximately to 3,5—4 % U-235, and weapon uranium contains more than 90 % of U-235.

**Processing of radioactive waste** — complex of anthropogenic processes aimed to reduce radioactive wastes, to change their composition or to transform them into radionuclide-fixing forms. It includes the processes of hardening, vitrification, calcination, bituminization, cementation and burning of radioactive wastes.

**Disposal of radioactive wastes** — all kinds of activities connected with gathering, transportation, processing, storage and (or) burial of radioactive waste.

**SJR** — report on security justification.

**NSS** — general regulations on providing security of nuclear stations.

**Optimization** — philosophical principle of radiological protection according to which doses and risks of irradiation should be kept as low as reasonably achievable —**ALARA**) considering economical and social factors.

**Operational testing** — stage of putting NS into operation starting with energy activation to adopting into industrial operation.

**Vitrification** — including waste of high level of activity into borosilicate glass with mass of approximately 14 %. Vitrification is designed for fixing radionuclides in insoluble stable matrix ready for burial.

**Hardening of radioactive waste** — processing of liquid radioactive waste in order to transform them into solid substances and fixing them in solid state.

**Failures on general reasons** — failures of systems (elements) appearing due to one failure or personnel mistake, or because of internal or external impact or some other internal reason.

**Worked-out nuclear fuel** — nuclear fuel irradiated in the reactor active zone and removed out of it.

**Starting of reactor** — absorbing of neutrons by a part of nuclei with big absorption cross-section of heat neutron energy (formed by fission of uranium and plutonium) and whose concentration quickly reaches equilibrium value.

**Radioactive gaseous waste** — RGW in the form of aerosol, inertia gases, iodine vapors and iodine compounds.

**Radioactive liquid waste** — RLW in the form of liquids (water or organic) or pulps containing radionuclides in dissolved form or suspensions.

**Radioactive hardened waste** — RHW transformed to solid state.

**Radioactive waste (RW)** — substances in any aggregative state not intended for further use in which content of radionuclides exceeds levels set by radioactive security norms RSN-2000.

**WNF (Worked-out nuclear fuel)** — fuel (fuel assemblies) which after being used in the reactor lost their properties and should be removed for processing or burial.

**“Greenhouse” gases** — carbon dioxide and water vapors absorbing long-wave heat radiation from the Earth’s surface and repeatedly radiate it returning back to the Earth and causing the greenhouse effect.

**Pascal** — pressure and mechanical stress unit in measuring system. 1 Pa – pressure caused by force of 1N equally spread on the surface with area of 1 m<sup>2</sup>.

**Passive security system (element)** — system (element) whose functioning is connected only with the event which it was caused by and doesn’t depend on another active system (element), e.g. control system, energy source etc.

**NSR** — nuclear stations reactor plants security rules.

**First circuit** — circuit with pressure compensation system in which coolant is circulating along the active zone under the operational pressure.

**Overload of active zone (overload)** — яденuclear-dangerous works on the reactor plant on loading, removing and replacing of fuel assemblies (fuel elements),

reactiveness influence means and other means influencing on reactivity in order to repair, replace or disassemble them.

**Reprocessing of worked-out nuclear fuel** — complex of chemical-technological processes designed to remove the fission products out of the worked-out nuclear fuel and regeneration of fissionable material for reuse.

**Reprocessing of RW** — technological operations aimed to changing the aggregate state and (or) physical and chemical properties of radioactive wastes in order to transform them into states eligible for transportation, storage and (or) burial.

**Half-decay period** — period of time during which activity (or number of radioactive nuclei) reduces twice.

**Plutonium** — radioactive chemical element, atomic number 94, mass number of the longest-living isotope 244. Plutonium isotope - plutonium-239 is used in nuclear energetics as nuclear fuel.

**Neutron-absorbing control rod** — movable element of control and protection system made of neutron absorbing material influencing on reactivity and used for nuclear reactor regulation. (**Control rods**).

**Positron** — electron anti-particle with the mass equal to electron's mass but positive electrical charge.

**Limits of secure operation of NPS** — technological process parameter values set by the project deviations from which can cause an accident.

**Annual entrance limit (AEL)** — permitted level of entrance of a certain radionuclide to the organism during a year which at mono-factor impact leads to human's irradiation by the dose equal to the corresponding limit of annual dose.

**Dose limit (DL)** — amount of annual effective and equivalent dose of anthropogenic radiation which should not be exceeded at normal operation conditions. Following the annual dose limit prevents appearance of determined effects and keeps the possibility of stochastic effects at acceptable level.

**Prestarting adjustments** — stage of putting nuclear station into operation at which completed systems and elements of the nuclear station are put into operational readiness with checking their correspondence to the project criteria and characteristics, the stage is completed by readiness to the physical activation of the reactor.

**Natural uranium** — uranium contained in nature with U-235 isotope content of about 0,7%; it can be used as a fuel in heavy-water reactors.

**Fission product** — nuclide formed in the result of fission or further radioactive decay of radioactive nuclide formed in this way.

**Decay product** — stable or radioactive atomic nucleus got in the process of radioactive decay of unstable nucleus.

**Projecting** — process and result of development of concept, detailed drawings, additional calculations and technical conditions for the nuclear station and its equipment.

**Construction documents** — complex of graphical and text documents determining the structure of design project and expenses for its construction.

**Project limits** — parameters and characteristics of systems, elements of the nuclear station set in the project for its normal operation and failures of normal operation including preaccidental situations and accidents.

**Fuel production** — production of nuclear fuel usually in the form of ceramic tablets in the metal tubes which are further gathered into fuel assemblies.

**Commercial operation** — operation of nuclear power station put into operation in the corresponding order whose security and correspondence to the project is proved by tests on the stage of putting the station into operation.

**Industrial reactor** — nuclear reactor designed mainly for production of fissible materials (e.g. plutonium).

**Proton** — positive particle in the atomic nucleus.

**CPS AR** — absorbing rod of control and protection system.

**Accident development** — sequence of conditions of systems and elements of NPS in the process of accident development.

**Rad** — off-system unit of absorbed radiation dose equal to 0,01 Grey.

**Radiation accident** — loss of control over ionizing radiation source caused by failure, damaged equipment, wrong actions of the personnel, natural disasters or other reasons which may lead to excess irradiation of people or radioactive contamination of environment.

**Radioactive security of population** — protection of present and future generations from harmful impact of ionizing radiation.

**Radiation accident** — event at which there is irradiation exceeding set limits for the corresponding categories of people.

**Radiation control** — control over following radiation security norms and main sanitary regulations at work with radioactive substances and sources of ionizing radiation.

**Radiation** — emitting and spreading energy with help of electro magnetic waves or particles.



**Radium** — product of radioactive decay of uranium frequently revealed in uranium ore. It has several radioactive isotopes. Radium-226 forms radon-222 at decay.

**Radioactive substance** — substance in any aggregate state containing radionuclides with activity exceeding levels set by normative acts including technical normative acts.

**Radioactivity** — spontaneous decay of unstable atomic nucleus which causes changes in nucleon composition and radiation process.

**Radioactive waste** — nuclear material and radioactive substances not intended for further use.

**Radioactive source** — view **Source of ionizing radiation**.

**Radioactive material** — material containing radioactive substances.

**Radioactive decay** — spontaneous transformation of nucleus at which gamma-radiation and particles are emitted or X-ray emission or spontaneous nucleus fission occur.

**Radioisotope** — radioactive isotope of any element.

**Radiometer** — device for measuring radionuclides activity in the source or sample (in certain amount of liquid, gas, aerosol, on contaminated surfaces) and measuring flux density of ionizing radiation.

**Radionuclide** — nuclide possessing radioactive characteristics (radioactive atoms of a certain chemical element).

**Radionuclide source** — substance containing radionuclide (radionuclide mixture) in the cover or fixed in some other way inside some material or on its surface and used as a source of ionizing radiation.

**Radioprotectors** — chemical compounds capable of reducing harmful impact of ionizing radiation on human's organism.

**Radiotoxicity** — unfavorable influence of radionuclides on human's health due to its radioactivity.

**Radiochemistry** — part of chemistry studying properties of radionuclides, methods of their emission and concentration, use in different fields of science and techniques.

**Power acceleration** — very fast acceleration of reactor power higher than normal operational level.

**Reactor acceleration** — view **Power acceleration**.

**Separating technologies** — special process and equipment for separating of isotopes (e.g. Uranium-235 and Uranium-238) with help of different speed of movement of gas molecules under centrifugal forces created inside cylinder (rotor) rotating in axial direction; it is used for producing enriched uranium.

**RAW** — abbreviated from **radioactive waste**.

**Expansion of nuclear fuel production** — reproduction of nuclear fuel with conversion coefficient more than 1, that is when there is more fissionable material that is used in the reactor.

**Powerful channel-type reactor (PCTR)** — type of single-circuit energy reactor whose coolant is water and reflector is graphite.

**FNR** — reactor on fast neutrons.

**Breeder** — fast reactor where expanded reproducing of nuclear fuel is carried out.

**Reactor plant** — complex of systems and elements of nuclear station designed for transformation of nuclear energy into heat energy; consisting of the reactor and connected with its systems necessary for its normal operation, emergency cooling, emergency protection and keeping in safe condition by means of carrying out main and auxiliary functions by other systems of nuclear station. Boundaries of the reactor plant are set in for each reactor plant in the project.

**Fission reaction** — view **Nuclear fission**.

**Regenerated uranium** — uranium extracted from worked-out nuclear fuel during radiochemical processing for reuse in nuclear fuel (regenerated fuel).

**Regulation of nuclear reactor** — function of control and protection system of nuclear reactor providing supporting or changing of speed of chain nuclear reaction.

**Control rods** — movable element of CPS made of material absorbing neutrons influencing on reactivity and used for regulating nuclear reactor (view also **Absorbing rods**).

**Control authority** — national authority or system of authorities appointed by the government and having legal rights of control over security of nuclear plants, carry out the process of licensing and in this way regulate security at choosing the construction site, projecting, construction, putting into operation and operation and supervise solving problems related to these items.

**Reserving** — using more than minimally required amount of energy, number of elements and systems in such way that failure of one element or system doesn't lead to the failure of the whole function.

**X-ray** — off-system unit of measuring exposition dose of X-ray and gamma-radiation determined by their ionizing influence on dry atmospheric air:

$$1P = 2,58 \times 10^{-4} \text{ C/kg.}$$

**X-ray radiation** — short-wave electro magnetic ionizing radiation with wavelength  $10^{-7}$  to  $10^{-12}$  m, appearing at interaction of charged particles or photons with electrons.

**Radiation risk** - possibility for a person or his descendants to have some harmful effect in his organism caused by radiation.

**HNR** — reactor on heat neutrons.

**RRC** — regional reacting centre.

**Self-sustained chain reaction** — chain nuclear reaction characterized by value of effective coefficient of neutron reproducing ( $C_{eff}$ ) exceeding 1 or equal to it.

**Sanitary-protective zone** — area round the source of ionizing radiation where at normal operation irradiation level can exceed set limit for irradiation of people. Permanent and temporary residence of people is forbidden in sanitary-protective zone, agricultural activities are restricted and radiation control is constantly held.

**Gathering of radioactive waste** — concentration of RAW specially marked and equipped areas.

**Interaction (fission, absorption, etc) cross-section** — value characterizing possibility of interaction.

**Synthesis** — formation of heavier nucleus of two lighter ones (usually hydrogen isotopes) accompanied by emitting of large amount of energy.

**Control and protection system (CPS)** — complex of means of technical, software and informational support designed to provide safe chain nuclear reaction. Control and protection system is a very important security system combining functions of normal operation and security and consisting of elements of normal operation control systems.

**Systems of disposal of radioactive waste** — technological systems designed for gathering, and (or) storage, and (or) processing, and (or) conditioning, and (or) transporting.

**TASIS** — European Union program on providing assistance to CIS countries that has carried out a number of projects on increasing safety level of nuclear stations.

**Tveg** — fuel element, hermetic tube with fuel tablets of uranium dioxide and burnable absorber – gadolinium oxide.

**Fel** — from “Fuel element”.

**Fuel assembly (FA)** — engineering article containing nuclear materials and designed for getting heat energy in nuclear reactor by means of controlled nuclear reaction.

**Fuel element** — separate assembly unit containing nuclear materials and designed for getting heat energy in nuclear reactor by means of controlled nuclear fission reaction and (or) storage of nuclides.

**Coolant** — liquid or gas used for heat transferring from the reactor active zone to steam generators or directly to turbines.

**Thermonuclear reactor** — reactor where controlled thermonuclear synthesis is carried out to get energy.

**Thermonuclear synthesis** — process of interaction (fusion) of light nuclei at high temperatures with formation of heavier nuclei and heat emission.

**Anthropogenic radiation** — radiation from radiation sources formed in the result of industrial activities.

**Heat company** — number of years of FA operation in the reactor active zone.

**Fuel tablet** — tablet of pressed uranium dioxide that is the basis of nuclear fuel, placed inside fuel elements.

**Thorium** — chemical radioactive element (metal) with atomic number 90 and atomic mass of the most spread and stable isotope 232 (there are eight thorium isotopes in nature).

**Thorium-232** — natural thorium isotope with atomic mass 232, the only widely spread in nature thorium isotope with half-decay period of  $1,4 \times 10^{10}$  years.

**Transmutation** — conversion of atoms of one element into atoms of another element by means of neutron bombing resulting in ceasing neutrons.

**Transport reactor** — nuclear energy reactor used as an energy source for movement of a vehicle (vessel).

**Transuranium element** — radioactive element formed artificially by catching neutrons and with possible further beta-decay. It has higher atomic number than uranium (92). The most spread transuranium elements are neptunium, plutonium, americium, and curium.

**SRW** — solid radioactive waste.

**Turbine** — primary engine with rotary motion of working element (rotor with blades) converting kinetic energy of the working body (steam, gas, water) into mechanical work.

**Heavy-water reactor** — nuclear reactor in which inhibitor is heavy water (e.g. Canadian reactor CANDU).

**HES** — heat electrical station.

**Packing of radioactive waste** — packing set (container) with RAW in it ready for transportation, and (or) storage, and (or) burial.

**Control (absorbing) rods** — rods of material absorbing neutrons with help of which it is possible to inhibit or stop chain reaction in the reactor; a part of CPS system.

**Control systems (elements) of normal operation** — systems (elements) forming and carrying out control over technological equipment of systems of nuclear station unit normal operation according to the set technological aims, criteria and limitations.

**Uranium, U** — chemical radioactive element (metal) with atomic number 92. Natural uranium is a mixture of uranium isotopes with U-235 content of 0,7 %.

**Uranium-233** — artificial uranium isotope with half-decay period of  $1,6 \times 10^5$  years, got in the result of transmutation of thorium-232 after seizing neutrons; is referred to fissible nuclides.

**Uranium-235** — natural uranium isotope with half-decay period of  $7,1 \times 10^8$  years and atomic mass 235; is the only natural fissible material.

**Uranium-238** — natural uranium isotope with atomic mass 238 and half-decay period of  $4,47 \times 10^9$  years; can be used as reproduction material for getting plutonium-239.

**Uranium ore** — ore with rich content of uranium what makes it industrially important.

**Uranium oxide fuel** — nuclear fuel consisting of burnt at high temperature and pressure tablets of uranium dioxide with enriching of uranium-235 isotope for 2 – 4 %; is used in light-water reactors.

**Uranium concentrate** — product got at hydrometallurgical reprocessing of uranium oryx contains up to 70-90 % of uranium in the form of oxides mixture with a general chemical formula  $U_3O_8$ .

**Level of emergency readiness** — set level of readiness of the personnel, civil defense and emergencies control authorities and other involved organs and necessary technical means to protect personnel and population in case of emergency in the nuclear station.

**Interference level** — parameters and characteristics determining radioactive conditions complex of which requires measures on protection of the personnel and population.

**Secure operation conditions** — set in the project minimal limitations of a number of reactor plant characteristics important for security; following these limitations guarantee secure operation of the plant.

**Physical barrier** — engineering installation, technical means or device limiting exit of radioactive substances and ionizing radiation into the rooms of radioactively-dangerous object and to the environment.

**Physical protection of nuclear station** — technical and organizational measures of keeping nuclear materials and radioactive substances in the nuclear station aimed to prevent unsanctioned entrances to the territory of the nuclear station, unsanctioned access to the nuclear materials and radioactive substances and timely revealing and stopping of subversion and terrorist acts threatening the security of the station.

**Physical obstacle** — natural obstacle in the way of spreading of ionizing radiation, nuclear material, or radioactive substance.

**Physical start-up of the reactor** — stage of putting NS into operation including loading of the reactor with nuclear fuel, reaching critical condition of the reactor and carrying out all necessary physical power measurements at which heat removal from the reactor is achieved by natural heat losses (dispersion).

**Storage of radioactive waste** — placement of radioactive waste in special places designed for safe isolation of the waste, including control and possibility of further processing, transportation, and (or) burial of the waste.

**Cementation of radioactive waste** — method of conditioning of liquid and solid radioactive wastes by mixing them with cement and hardening of the resulted mixture.

**Chain nuclear reaction** — sequence of heavy atoms nuclei fission reaction at their interaction with neutrons and other elementary particles in the result of this reaction lighter atoms, new neutrons and other elementary particles are formed, and nuclear energy is emitted. Depending on average number of fission reaction the reaction can be called damped, self-contained, or increasing reactions.

**Decay chain** — row in which every nuclide transforms into the following one during the radioactive decay until a new stable nuclide is formed.

**Zirconium** — chemical element (metal) with weak ability of absorbing heat neutrons; is widely used in atomic machine building.

**CAS** — Chernobyl atomic station.

**EGR** — energy graphite reactor of channel-type with steam overheat; is used in Bilibinsk APS.

**Ecological security** — condition of protectiveness of environment, people life and health from possible harmful influence of industrial and other activities, at natural and anthropogenic emergencies.

**Ecological damage** — evaluation of harmful influences calculated as volume and cost of work on restoring the environment.

**Experimental reactor** — view **Research reactor**.

**Operational limits** — parameters and characteristics of systems, elements of the nuclear station determined by the project for normal operation.

**Operation** — all activities aimed to achieve the purpose of the station by safe means including power operation, start-up, stops, tests, maintenance, inspections during operation and other activities.

**Operational conditions** — determined by the project conditions of quantity, quality, serviceability and maintenance of all systems and elements necessary for normal functionality of the station without exceeding the operational limits.

**Electron-volt (Ev)** – energy unit equal to changes of electron energy at potential difference of 1 volt.

**Energy start-up of atomic station** — stage of putting atomic station unit into operation starting with finishing of physical start-up and till beginning of electroenergy output.

**Energy reactor** — nuclear reactor designed for electrical energy production.

**Nuclear accident** — accident connected with damage of fuel elements exceeding the permitted levels of safe operation and (or) irradiation of the personnel. It can be caused by:

- failure of control of chain nuclear fission reaction in the reactor active zone;
- appearance of criticality at overloads, transportation and storage of fuel elements;
- damage of coolant of fuel elements;
- other reasons leading to damage of fuel elements.

**Nuclear security** — condition of protectiveness of environment and people from possible harmful influence of ionizing radiation of nuclear plant and (or) storage point reached by corresponding operational conditions, disposal of worked-out nuclear materials and (or) operational radioactive waste.

**Nuclear reaction** — conversion of atomic nuclei caused by their interaction with elementary particles and with each other and accompanying by changing of mass, charge or energy condition of the nuclei.

**Nuclear plant** — installations and complexes with nuclear reactor (reactors) including installations and complexes with industrial, experimental and research nuclear reactors, critical and subcritical nuclear assemblies.

**Nuclear energetics** — sphere of modern engineering based on conversion of nuclear energy into other types of energy (heat, mechanical, electrical) and its application in industrial and household purposes.

**Nuclear energy** — internal energy of atomic nucleus connected with motion and interaction of nucleons forming the nucleus. There are two ways of getting nuclear energy: chain nuclear fission reaction of heavy nuclei and thermonuclear reaction of light nuclei synthesis.

**Nuclear fission** — process accompanied by splitting of heavy atom nucleus at interaction with neutrons or other elementary particles; in the result of this process new lighter nuclei and other elementary particles are formed and energy is emitted.

**Nuclear conversion** — conversion of one nuclide into another.

**Nuclear fuel** — substance that can be used in nuclear reactor for carrying out nuclear chain fission reaction of heavy nuclei. Nuclear fuel contains fuel and substances interaction of whose nuclei leads to forming of secondary nuclear fuel.

**Nuclear material** — material containing or capable of reproducing fissionable materials (substances).

**Nuclear reactor** — installation for carrying out controlled chain nuclear reaction.

**Nucleus** — **view Atomic nucleus.**

**NFC** — nuclear fuel cycle, a complex of activities directed to provide functioning of nuclear energetics including the mining and processing of uranium ore, fuel production, its transportation to the station, storage and processing of worked-out nuclear fuel. In case of burial of waste TAC is called open, in case if it will be reprocessed and reused it is called closed.

**NEP** — nuclear energy plant.

**English terms and abbreviations:**

**ALARA (abbreviated from As Low As Reasonably Achievable)** — principle in philosophy of radiological protection at which dose and risk of irradiation are kept low considering economical and social factors.

**BWR (abbreviated from Boiling water reactor)** — tank reactor with boiling water containing heavy water as a coolant and natural uranium as a fuel; reactors of this type are used in Canada.

**EUR** — (European utility requirements) — requirements of European energy companies to AES with light-water reactors.

**IAEA** - International Atomic Energy Agency

**INES** - International Nuclear Events Scale



**ITER** - International Thermonuclear Experimental Reactor

**MOX** - Mixed Oxide Fuel (usually on the basis of uranium and plutonium).

**PWR (ab Pressurized water reactor)** — type of reactors with pressed water, analogue of WMWC reactor.

## 2 INTRODUCTION

Energetics is the basis of successful development of economy and society in the whole.

In October, 8, 1975 on the scientific session devoted to 250-anniversary of Academy of Sciences of the USSR academician Petr Leonidovich Kapitsa who was awarded Nobel Physics Prize three years later made a conception report devoted to different sources of energy. In short views of academician Kapitsa can be rendered as follows: whatever energy source to consider it can be characterized by two parameters:

- energy density – that is its amount in the volume unit;
- and speed of its transmission (spreading).

Product of these values is maximal power that can be got from a surface unit using a definite type of energy.

Development of the world energetics for the recent 34 years has completely approved the views of Kapitsa P. L.

Successful development of reproduced energetics abroad is mainly due to the stable and diverse support of the governments [1]:

- providing tax remissions, tax vocations, free access to general use networks to owners of electro stations on the basis of reproduced energy sources (RES);
- compulsory buying of energy produced by RES by the state by fixed tariffs;
- state financing of NIOKR and other pilot projects in RES sphere;
- participation in construction projects of electrical and heat stations on the basis of RES;
- barren money to the enterprises of the branch.

Heat electrical stations working on coal poison environment so badly that operation term of current HES should be maximally shortened and construction of new ones should be stopped at least until new technologies of operation without waste appear.

Electro stations operating on gas burn not just energy carrier but a very expensive raw from the point of view using gas in chemical industry. We lack of raw for scientific experiments, for creating new materials and substances wasting stores of gas.

Biological fuel is a new suggestion for electro stations but it sounds blasphemous [1]:

- firstly, nobody can guarantee that there will be enough of biological fuel for continuous work of the world energetics or at least for one generation in one country for a long period of time.
- secondly, we are not sure that large territories that are planned to be used for growing of biological fuel will not lead to shortage of food resources.

In his report academician Kapitsa paid especial attention to atomic energetics and said that it had three main problems on its way to become the most important energy source for the mankind:

- problem of burial of radioactive waste;
- critical danger of catastrophes in atomic stations;
- problem of uncontrolled spreading of plutonium and nuclear technologies.

Development of atomic energetics was accompanied by large catastrophes (NPP Three Mile Island in 1979 and Chernobyl NPP in 1986), by signing international agreements on control of nuclear technologies and spreading of weapon plutonium. In spite of a number of unsolved problems the alternative of atomic generation can appear not earlier than in 50 – 100 years. And it is likely to be linked with creation of electro station on the basis of pulse thermonuclear energy reactor.

Currently more than 50 countries reported to IAEA about their intention to develop nuclear energetics in peaceful purposes according to the words of IAEA General Director Mohamed el Baradei to the Organization of Economical Cooperation and Development in Paris (France). IAEA Director marked that 10 years ago future of atomic station was questioned. Now the situation has changed and many developing countries ask IAEA to help them in construction of atomic electro stations.

Today 10 countries including Belarus are working on programs of development of nuclear energetics. In China 6 nuclear reactors are being built. Russia plans to build tens of small and big reactors to 2020. In the world 439 atomic electro stations are working in 30 countries [2].

Today about 20 % of electricity in the USA are produced by atomic energetics. As the number of population and energy consumption increase it is necessary to increase the number of atomic stations to keep the energy production at the same level. If we consider that increase of energy consumption requires the transition to energy sources with low extraction of CO<sub>2</sub>, part of electro energy produced by using atomic generation will be more than 20 %. Atomic energy has a great importance as unlike wind energy and solar energy it is capable of producing a large amount of the main electro energy to which wind and solar contribution can be additional because these energy sources are available. One more profit of atomic energy is that it requires little fuel as compared with coal and natural gas that is why mining and waste are less (1g of uranium produces a million times as much energy as 1g of coal). So uranium mining and disposal of WNF is much less harmful to the Earth [3].

Since very beginning of development of atomic energetics dangerous radiation impact on environment has determined high requirements to the control of environment both in sanitary- protection zone and in observation zone of NPP. Several facts can prove it:

- Kursk atomic station was awarded a prize of Russian Federation Natural Resources Ministry “Best ecological project of the year” in nomination “In harmony with nature”. The name of the project is “Studying biological diversity of anthropogenic landscapes of Kursk NPP ” [4];

- By the decision of organizational committee of IV Russian ecological conference “New priorities of national ecological policy in real economy sector” Balakovsk NPP was awarded honorable title “Leader of nature protection activity in Russia – 2008” for active activities in the sphere of environmental protection and rational use of natural resources. Director of the station Ignatov V. was awarded an honorable medal “For ecological security” and its Chief Engineer – honorable order “Ecological shield of Russia” [5].

Analysis and generalization of information about condition and protection of environment, about behavior in the environment of the contaminating substances from NPP and ecological systems' responses to the impacts accompanying operation of NPP allowed to determine the main ecological conceptions of nuclear energetics [6, 7]:

- NPP is a complex representing NPP itself, its auxiliary and construction organizations and enterprises, energetics' town with enterprises and organizations of social sphere;

- NPP is a source of four types of influence on quality of life of people and on environment – radioactive, chemical, heat and connected with region urbanization;

- at normal operation of NPP all population and environment are protected from radiation influences of NPP, at distortion of normal operation radiation influence can become the main type of influence;

- the main type of influence of normally operating NPP on ecological system is heat impact cooling stack;

- the main types of influence on surface ecological systems are impacts accompanying constructional works, region urbanization and possible chemical impact;

- in NPP region there are groups of population, biogeocenosis, landscapes, species of plants and animals critical by their response to NPP influence.

Considering all facts given above at projecting, construction and operation of NPP much attention must be paid to ecological security. Figure 1 shows an approximate structure of justification of NPP ecological security [8].

Основания для разработки – Justifications for development

Общие характеристики объекта – General characteristics of the object

Строительство – Construction

Источники и факторы воздействия – Sources and factors of influence

Современное состояние исследуемой территории – Current condition of the observed territory

Прогнозируемое состояние ОС – Prognosed Env condition

Состояние приземной атмосферы – Condition of nearest atmosphere

Состояние наземных экосистем – Condition of surface ecological systems

Состояние подземных и поверхностных вод – Condition of underground and surface waters

Медико-демографическая характеристика – Medical and demographical characteristics

Хозяйственное использование территории – Industrial use of the territory

Общая характеристика загрязненности – General characteristics of contamination

Эксплуатация АЭС – NPP operation

Мероприятия по ограничению воздействия – Measures of impact limitation

Радиационное воздействие на ОС – Radiation impact on the Env

Основные нерадиационные факторы воздействия на ОС – Main non-radiation factors of impact on the Env

Нормальная эксплуатация – Normal operation

Влияние градирей – Influence of cooling stack

Аварийные ситуации – Emergencies

Поступление химических веществ – Entrance of chemical substances

Концепция охраны ОС на этапе вывода из эксплуатации ФЭС – Environmental protection conception at the stage of stopping the operation of NPP

Предложения по организации экологического мониторинга – Suggestions  
on the organization of ecological monitoring  
Основные выводы – Main conclusions

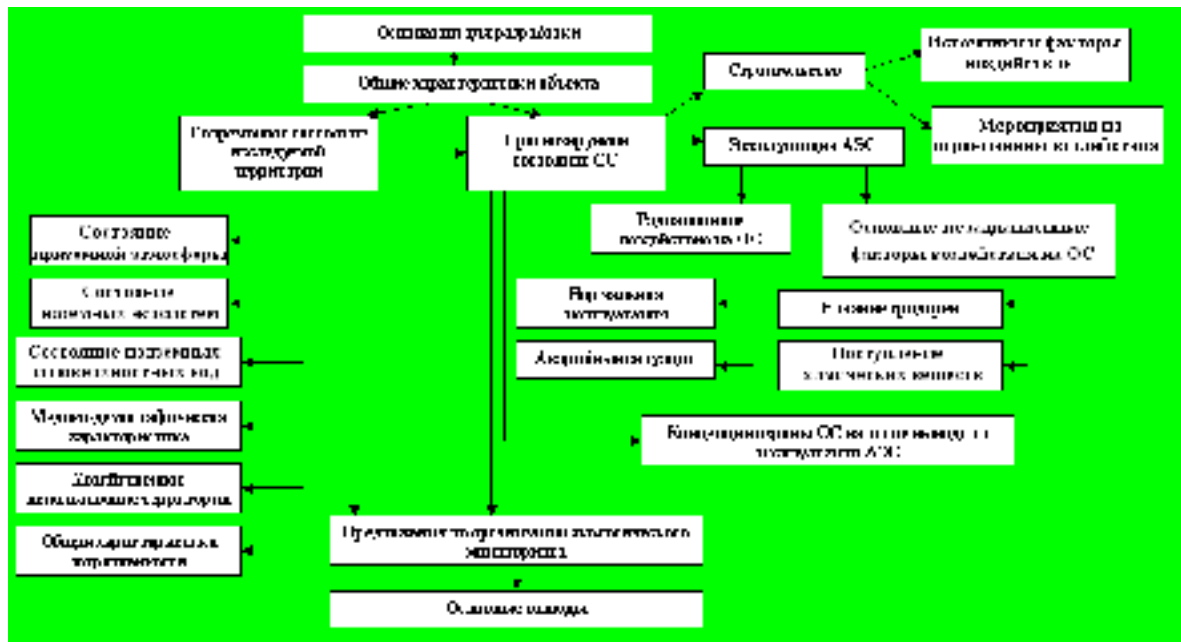


Figure 1 – Structure of justification of AES security

As we can see at the figure at the stage of EIE it is necessary to solve the following main tasks:

- get maximal possible information about the condition of the environment in the place of the station and in its observation zone;
- determine groups of population, biogeocenosis, landscapes, species of plants and animals critical to the impact of NPP;
- develop the suggestions on the organization of the environmental ecological monitoring system.

At development of impact evaluation on the environment of Byelorussian NPP norm documents of the Republic of Belarus [9,10] , international recommendations [11] and materials of EIE of different atomic stations [12-16].

### **3 GENERAL. JUSTIFICATION OF THE NECESSITY OF CONSTRUCTION OF NPP**

The main aim of evaluation of impact on the environment (EIE) is to determine the condition of environmental components in NPP construction region, evaluation of impact and prognosis of possible changes of these components at the process of NPP construction and operation, justification of ecological possibility of NPP construction.

EIE is the main component of justification of investment into construction of atomic electro station in the Republic of Belarus.

The basis for this work is agreement № 551-307-08 dated 12.12.2008 for development of justification of investments into construction of the atomic electro station in the Republic of Belarus between state enterprise "Directorat of atomic electro station construction" and project research republican unitary enterprise "Belnapienergoprom".

Technical brief for EIE and letter-agreement of Ministry of Natural Resources of the Republic of Belarus are given in appendixes A and B.

#### **3.1 Information about documents justifying the construction of Byelorussian NPP**

Works on the byelorussian NPP are held on the basis of a number of government decisions and regulations the main of which are given below:

1 Conception of national security of the Republic of Belarus confirmed by the decree of the President of the Republic of Belarus on July, 7 2001 № 390 (National register of legal acts of the Republic of Belarus 2001, № 69, 1/2852).

2 State complex program of modernization of the main industrial stocks in Byelorussian energetics system, energy saving and increasing of use in the Republic own HER in 2006-2010 confirmed by the decree of the President of the Republic of Belarus dated by 25.08.2005 № 399 «Confirmation of the conception of energetic independence of the Republic of Belarus and State complex program of modernization of the main industrial stocks of Byelorussian energetic system (BES), energy saving and increasing of use of interior fuel and energy resources in 2006-2010 (National register of legal acts of the Republic of Belarus, 2005, №137, 1/6735).

3 State complex program of modernization of the main industrial stocks of Byelorussian energetic system, energy saving and increasing of use of interior fuel and energy resources for the period till 2011 confirmed by the decree of the President of the Republic of Belarus on November, 15 2007 № 575

4 Program of social and economical development of the Republic of Belarus for 2006 -2010 years, confirmed by the decree of the President of the Republic of Belarus on June, 12, 2006 № 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 dated on June,14, 2007 № 3 "Saving and economy are the main factors of economical 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 on the construction of atomic electro station in the Republic of Belarus confirmed by the Decision of the Council of Ministers dated 21.01.09 № 64-2.

#### **3.2 Main normative documents regulating the activities in the**

## **sphere of atomic energetics of the Republic of Belarus**

For regulating the activities in the sphere of atomic energetics a number of normative documents were adopted in the Republic [17 – 20].

Because of the absence of normative basis and due to the fact that Belarusian NPP will be constructed according to the Russian project (AES-2006) a working group has been created that will regulate activities on developing of technical normative acts (TNA) under the direction of Chairman of State standard of the Republic of Belarus. The result of the work of this group was Index of the Main valid normative documents of the Russian Federation regulating secure operation of AS energy plants with WMWC reactors and document put into action on the territory of the Republic of Belarus № ОУП-06/01, confirmed by the Prime-Minister Deputy of the Republic of Belarus Semashko V. I. This decision was adopted on the following reasons:

- impossibility of TNA development in short time because of lack of experience in projecting and operating of nuclear energy plants;
- contradictions in the normative documents of the RF and RB, e.g. in the RF the personnel is divided into two categories;
- Belarusian AES will be designed, constructed and operated with the participation of Russian organizations that is why it is justified to use Russian TNA.

### **3.3 Brief information about the customer, designer and executers of EIE**

According to the Decree of the President of the Republic of Belarus dated from November, 12, 2007 № 565 “About some measures on construction of atomic electro station” the following authorities were created in the Republic of Belarus:

1 State body “Directorat of the construction of atomic electro station” (SA DCAES) to carry out the functions of the customer in performing a complex of preparation and design works on the construction of atomic electro station (further – NPP).

2 Department of nuclear and radiation security to carry out state supervision of providing nuclear and radiation security in the Ministry of Emergencies.

Design research republican unitary enterprise “Belniplerienergoprom” has appointed as the general designer to coordinate the development of construction documents of NPP.

#### **Co-executers of EIE:**

**Republican unitary enterprise “Central scientific-research institution of complex use of water resources” (RUE “CSRICUWR”)** – institute of Ministry of Natural Resources of the Republic of Belarus studying the surface waters. Purpose of the work is to estimate the impact of atomic electro station in the Republic of Belarus on surface waters. Surface waters are quality and quantity characteristics, trans-boundary transition of radioactive contamination.

**SA “Republican Centre of radiation control and monitoring”** – state authority within the Ministry of Natural Resources monitoring environmental objects of the Republic of Belarus (chemical and radioactive contamination). Purpose of work is to develop monitoring system in the observation zone of the byelorussia NPP, estimate the current condition of the environmental objects, set the monitoring in the observation zone for the construction period, determine surface radioactive contamination in normal operation mode and at radiation accident (including heavy off-project acci-

dents) in the byelorussian NPP, transboundary transition of radioactive contamination by air.

**SA “Republican hydro meteorological centre”** – state authority within the Ministry of Natural Resources monitoring environmental objects of the Republic of Belarus. Purpose of work is to characterize the current condition of environment and the climate, conditions of mixtures spreading in the atmosphere, estimate the influence of the belarusian NPP on the air and micro climate.

**SSI “Institute of use of natural resources of the National Academy of Sciences of the RB”** – leading scientific institution of the Republic of Belarus in the field of use of natural resources, environmental protection and hydro technologies, geoecology, geography and paleography, climatology, hydrogeochemistry, hydroecology, geodynamics. Purpose of work is to give characteristics to the current condition of the environment (landscapes, flora and fauna), underground waters (quality and quantity esteems); estimate the influence of the byelorussian NPP on all these factors; give prognosis of transboundary transition of chemical and radioactive contamination by underground waters.

**Scientific research part – main scientific control body of Byelorussian State University (SRP – BSU SCB)** – leading scientific research institution in the sphere of hydroecology of the Republic of Belarus. It has a big experience of work in Naroch nature reserve. Purpose of work is to study the current condition of biological components of water eco systems and processes of formation water quality; to estimate the influence of NPP operation on condition of water eco systems and quality of surface waters.

**RSC “Hygiene”** of Ministry of Health of the Republic of Belarus registers dose loads of the population, estimates risk of people’s health. Purpose of work is to characterize current condition of population health in the site of byelorussians NPP; estimate of radiological impact of NPP on the population (in the mode of normal operation and accidents); estimate the risk of influence of air contamination of different kinds of fuel on the population.

**RNSI “Radiology Institution”** - leading scientific research institution of the Republic of Belarus in the sphere of agricultural radiology. Purpose of work is to describe the current condition of the agriculture in the region of NPP; evaluate the radiation impact on the agricultural ecological systems in the result of planned activities; give recommendations on agricultural activities in case of contamination at accidents.

**SRI “Fire safety and emergencies” of Ministry of Emergencies of the Republic of Belarus** – specialized institution on the esteem of emergency risks and connected with them problems. Purpose of work is to evaluate the influence of emergencies on atomic station, to plan the measures of accident elimination on byelorussian NPP.

### **3.4 Engineering and economical prerequisites for development of nuclear energetics in Belarus**

Detailed evaluation of technical possibility, commercial and economical reasonability of investments into the construction of NPP with alternate variants is given in work [21].

Predictive data for engineering and economical calculations was adopted on the basis of “State complex program of modernization of the main industrial stocks of Byelorussian energetic system (BES), energy saving and increasing of use of interior

fuel and energy resources in 2006-2010 years” and according to the predictions of social and economical development of the country. The calculations considered variants of energy system development with and without construction of atomic electro station.

Calculations for each scenario determined optimal schedule of putting new units into operation providing minimal expenses for production of electro energy by the whole system. For each scenario the main part of production of electro energy is carried out by existing HES and HES. The main conclusions of the calculations are:

1 Reasonability of development of atomic energetics in the republic has been proved. Different scenarios of balancing predicted electrical power deficits show that putting into operation a source on nuclear fuel leads to reducing of costs for electro energy production but the most profitable is a scenario with using of natural gas and nuclear fuel.

Considering different scenarios of balancing predicted electrical power deficits show that putting into operation a source on nuclear fuel leads to reducing of costs for electro energy production but the most profitable is a scenario with using of natural gas and nuclear fuel.

2 Each scenario has an optimal graphic of putting new units into operation with minimal expenses on producing electrical energy by the whole energy system. For each scenario the main part of production of electro energy is carried out by existing HES and HES.

3 It is proved that optimal variant of development of atomic energetics in Belarus is putting energy plants into operation with total electrical power of about 2 GW. It is supposed that NPP part in electrical energy production by 2020 year will be 27 – 29 %.

4 Including atomic energetics into fuel and energy balance of our country will make possible to carry out diversification of HER use, to keep valuable energy resources, firstly oil and gas for their raw use, to reduce output of greenhouse gases of heat electro stations HES), and to increase economical effectiveness of fuel and energy complex (FEC). It will also allow to develop use of non-traditional energy sources requiring power reserving and to provide stable development of economy and society in the whole.

### **3.5 Heat and energy budget of the Republic of Belarus till 2020**

Table 1 shows preliminary power and energy balance of Byelorussian energy system by prediction of average electrical energy consumption increase in Belarus.

Advance increase of electric energy consumption in comparison with increase of gross energy resources consumption for 5-10% occurs in all countries of the world. For the Republic of Belarus in the considered period this tendency is kept at one level, and for heat energy it is twice as low as gross energy resources consumption. It is connected with the fact that the Republic has a large energy saving potential in heat energy saving.

As we can see from the table the basic power loads will be taken by NPP power, at that the number of regulating power in HES structure will increase, total annual operation time of HES will decrease. But putting NPP into operation will influence not only on the operational modes of the energy resources but on the structure of heat and energy balance as well (table 2). Increasing to 2020 nuclear fuel consumption along with other structural changes in the heat and energy balance will allow com-



compensating increase of gas consumption and greatly stabilize its consumption at a stable level.

In future it is possible to stop electro energy import and transition of energy system to self-balance as in most countries of the world. But for economical reasonability and providing energy security and stability it is necessary to consider the possibility of restarting of electro energy import.

According to the tendencies of industrial development HER use as industrial raw in chemical, petrochemical and other non-fuel industries will increase.

Heat and energy balance considers increasing of use of coal for production of construction materials and in energetics and nuclear fuel by NPP construction.

Including coal into heat and energy balance is caused by the necessity of diversification of countries supplying coal. Coal supply by comparable prices can be carried out not only from the Russian Federation but also from Poland, the Ukraine and other countries.

It is considered to include nuclear fuel in heat balance as soon as possible as it is the best resource for increasing energy security of the republic. It can be supplied by different manufacturers without big transportation expenses, it is possible to create stores with little storage expenses, predicted costs are lower than costs on any other kind of energy resources. By its ecological factors the influence of nuclear fuel on the environment is the least.

Volumes of use of local fuel kinds (oil products, associated gas, peat, firewood, brown coal), non-traditional and restored fuel types (wind, sun, phytomass, geothermal sources, biological fuel, hydro energy resources, etc) are set according to limited potential stores, economical and ecological reasonability of the expenses on their production and use.

To achievement of predicted fuel and energy balance along with other activities of energy security there is NPP construction with power of about 2GW and including 2,5 – 5,0 mln tons of conditional nuclear fuel into the balance.

**Table 1 - Preliminary balance of Byelorussian energy system till 2020 according to the predictions of average increase of electrical energy**

Parameter	Measuring unit	Years			
		2005	2010	2015	2020
Total demand in electro energy	billion.kW/h	35,0	39,3	42,5	47,1
Pure import	billion.kW/h	4,04	5,1		
Output of energy system	billion.kW/h	30,96	34,2	42,5	47,1
Set power of AES and others	MW	7900	8900	9700	9900
Set power of AES	GW	-	-	-	2
Total set power	MW	7900	8900	9700	11900
Peak power	MW	5871	7012	7814	8970
Required power considering reserve 20 per cent	MW	7525	8939	10551	12400

**Table 2 – Demands of the Republic in different types of energy and energy resources at maximal increase of GDP and minimal decrease of its energy intensity**

Types of energy resources	Years							
	2005		2010 predictions		2015 predictions		2020 predictions	
	mln t	Per cent	mln t	Per cent	mln t	Per cent	mln t	Per cent
Natural gas (according to the balance of a union country)			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	0,30	1,0	0,27	0,8	0,26	0,7	0,22	0,5
as a raw and for transportation	1,52	5,1	1,80	5,3	3,00	8,1	3,00	7,1
Condensed gas	0,35	1,2	0,39	1,2	0,38	1,0	0,38	0,9
NR 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 coke breeze	0,21	0,7	1,22	3,6	2,7	7,4	3,0	7,2
Gross HER	37,08	41,6		45,9		52,4		
Окончание таблицы 2								
Heat energy, mln Gcal	73,5	77,9		81,8		87,5		
Including secondary heat energy resources (SHR) in the equivalent of	0,8	1,0		1,3		1,9		
Electro energy, billion kW/h	35,00	39,9		44,0		50,3		
Local types of fuel (LFT) considering WER	4,56	6,48		8,46		9,72		
						-		
						9,92		
LFT part in CIF consumption without raw		16,8	20,5		25,0		26,6-29,1	

General characteristics of most energy system stations is high increasing physical and moral wearing-out of the main and auxiliary equipment, energy transport communications. Wearing-out of the main electro generating equipment of electrical and heat networks is about 60 % what proves the necessity of modernization of the main energy system equipment.

According to the "Conception of energy security of the Republic of Belarus" confirmed by the President of the Republic of Belarus 17.09.2007 № 433, the main directions of increasing of security of energy system are:

- advance speed of renewing of the main industrial budgets over speed of wearing-out in order to achieve wearing level not more than 45 % by 2020;
- diversification of fuel types for regenerating sources;
- supporting existing intercommunications with energy systems of neighboring countries and establishing of new main lines of communications.

In order to follow these directions by 2020 State complex program of modernization of the main industrial stocks of Byelorussian energetic system, energy saving and increasing of use of interior fuel and energy resources in 2006-2010, State program of innovation development of the Republic of Belarus in 2007-2010 confirmed by the Decree of the President of the Republic of Belarus in March, 26, 2007 № 136 (National register of legal acts of the Republic of Belarus, 2007, № 79, 1/8435) and other programs consider modernization of electro stations functioning on the basis of steam and gas technologies and including of energy plants automated control systems allowing to decrease fuel expenses on output of heat and electrical energy and to increase production security of electro energy objects.

The main component in increasing of electro energy security of generating sources functioning should be construction of new electro stations with nuclear fuel and coal including:

- NPP with power of about 2000 MW;
- a number of heat electro stations on coal with total power of 800 – 900 MW.

Power high maneuverable sources will be required to regulate NPP energy system loads.

Along with new sources of power small HES in industrial enterprises, in small towns and district centres will be further developed; it will increase safety and stability of energy supply.

According to the predictions of social and economical development of the republic and considering activities directed to energy saving, electrical energy demands in 2020 will be 47,1 billion kW/h, heat energy demands - 84,5 mln Gcal.

Unlike the conditions of State complex program of modernization of the main industrial stocks of Byelorussian energetic system, energy saving and increasing of use of interior fuel and energy resources in 2006-2010 in this period electro energy and peak power will increase but not decrease. It is caused by the growth of GDP production firstly, in the spheres of industry and agriculture.

Advance increase of electric energy consumption in comparison with increase of gross energy resources consumption for 5-10 % occurs in all courtiers of the world. For the Republic of Belarus in the considered period this tendency is kept at one level, and for heat energy it is twice as low as gross energy resources consumption. It is connected with the fact that the Republic has a large energy saving potential in heat energy saving.

Conception of energy security considers construction of NPP with power of about 2 GW and including of 2,5 – 5,0 mln tons of conditional nuclear fuel. Putting NPP into operation will influence not only on the operational modes of the energy resources but on the structure of heat and energy balance as well (table 2).

Nuclear fuel consumption that will be increasing by 2020 along with other structural changes in the heat and energy balance will allow to compensate increasing demands in gas and largely stabilize its consumption.

## **4 ALTERNATE SITES FOR NPP ALTERNATE ENERGY SOURCES**

### **4.1 Alternate sites for construction of NPP**

Initially there were 74 variants of possible sites for NPP. Later 20 of them were excluded because they were within forbidden factors determined by the main requirements to NPP sites. So, 54 sites were analyzed on the basis of budget and archive materials [22, 23].

To make the research works on the sites shorter committee of experts was created which determined on the basis of hydrological, seismotectonic, ecological, air-meteorological, radiological, engineering and geological factors studying three most perspective variants for detailed analysis:

- Bykhov (Mogilev region);
- Schklov-Goretsk (Mogilev region);
- Ostrovetsk (Grodno region).

In 2006-2008 in these points three sites were determined:

- Krasnopolyana site (Bykhov point);
- Kukshinovsk site (Schklov-Goretsk point);
- Ostrovetsk site (Ostrovetsk point).

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

By the results of researches for comparison of sites all data was gathered in tables 3 – 5 [24] for comparison of sites.

**Table 3 – Comparative characteristics of NPP sites**

Characteristics	Competitive sites		
	Kukshinovsk site	Krasnopolyana site	Ostrovetsk site
<i>Seismotectonic conditions</i>			
Area of enlarged sites situated on stable units, km <sup>2</sup>	4,0	2,0	4,5
Distance to the nearest zone of possible earthquake centres (PEC), km(according to IAEA recommendations not less than 5 km).	12 km to Orshansk centre	24km to Mogilev centre	39 km to Oshmyany centre
Soil category by seismic characteristics	II	II	II
Project earthquake (PE), intensity	5	5	6
Maximal counted earthquake (MCE), intensity	6	6	7
<i>Geological and hydrogeological conditions</i>			
Bedrock composition making quaternary deposit	Dolomite, limestone, clay, siltstone, aleurite	Chalk, marl, clay	Siltstone, marl, dolomite
Quaternary deposit thickness, m	68-72	45-55	72-103
Quaternary deposit composition	Mainly drift and lacustrine clays; morainal sand	Mainly interdrift clay; drift clays and clay sands.	Mainly drift clays and sands; morainal sand
Laying of complex of loess-like soil and lake-swamp soil with thickness of 5m and more	No	No	No
Character of first intermorainal waterbearing formation	Forcing	Non-forcing	Forcing – non-forcing
Depth of waterbearing formation first from the surface, v	1,8	10	15
Protectiveness of ground water from surface contamination (existence of upper confining layer)	Good	Satisfactory	good
<i>Hydrological conditions of the sites' water supply</i>			
Natural source of technical water supply	r. Dniepr	r. Dniepr	r. Vilia

Continuation of table 3

Characteristics	Competitive sites		
	Kukshinovsk site	Krasnopolyana site	Ostrovetsk site
Provision of AES with technical water supply (feeding) with demands of 2,54 m <sup>3</sup> /s	12,58 m <sup>3</sup> /s	18,18 m <sup>3</sup> /s	17,3 m <sup>3</sup> /s
<i>Meteorological conditions</i>			
Correspond to normative requirements by placement conditions on all considered sites			
<i>Anthropogenic influence</i>			
Para humidity output gradien:			
In summer	Increase of relative humidity for 0,2% over the background; doesn't influence on the processes of dew, mist and fog formation		
In winter	Increase of relative humidity for 1% over the background; doesn't influence on the processes connected with humidity changes, doesn't cause additional electric lines cables		
Radiation condition on the site under the impact of para humidity output	Slight increase of radioactive aerosol concentration at distance of not more than 1,5 km from the source		
Influence of industrial output on 30-kilometer zone of the site	No	No	No
<i>Influence of off-site accidents</i>			
Transition of radioactive aerosols by fires in forests and peats	Slight	Slight; radiation control is required	Slight
Smoke formation caused by accidents and fires on gas pipeline	Slight	No	Slight
Smoke formation caused by accidents and fires on oil pipeline	Possible	No	No
<i>Radiation contamination</i>			
Natural soil contamination with radionuclides at the beginning of AES operation, Ci/km <sup>2</sup> (norm is not more than 5)			
	up to 0,17	4,99	0,28
<i>Demographical characteristics</i>			
Population density p/km <sup>2</sup> (permitted not more than 100)	34	20	24

Table 4 – Characteristics of construction conditions on competitive sites

Parameters characterizing construction conditions	Competitive sites		
	Kukshinovsk site	Krasnopolyana site	Ostrovetsk site
1 Density and spreading of population in the radius to 25 km: - population density; - centre of population, direction, distance, number of population <sup>1)</sup>	34 p/km <sup>2</sup> ;  - c. Mogilev, south-west, 50 km, 365 thousand people; - t. Gorky, south-east, 15 km, 33,9 thousand people; - t. Schklov, south-west, 28 km, 15 thousand people; - t. Orsha, north-west, 25 km, 130,5 thousand people	20 p/km <sup>2</sup> ;  - c. Mogilev, north-west, 35 km, 367 thousand people; - t. Bykhov, south-west, 30 km, 16,7 thousand people; - t. Chausy, north-east, 25 km, 10,6 thousand people; - t. Slavgorod, south-east, 25 km, 8,3 thousand people; - t. Godylevo, east, 25 km, 1 thousand people	24 p/km <sup>2</sup> ;  - t. Ostrovets, south-west, 19 km, 8 thousand people; - t. Svir, 22 km, north-east, 1,5 thousand people; - c. Vilnius 40km, west, 542 thousand people
2 Foundation conditions of the main buildings	Construction dewatering, strong damp-course, replacement of soil with low strength characteristics are required due to high level of ground pressure water and soft ground. Potential possibility of activization of piping-karstic processes in cavernous and karstic dolomites.	Potential possibility of piping-karstic processes in marl-chalk layers under quaternary sands.	Possibility of construction of the main buildings on natural base (the most economical variant). Dry construction conditions.
3 Project earthquake, PE, density	5	5	6
4 Maximal calculated earthquake, density	6	6	7

Continuation of table 4

Parameters characterizing construction conditions	Competitive sites		
	Kukshinovsk site	Krasnopolyana site	Ostrovetsk site
5 Climatic and airclimatic conditions	Possibility of whirlwinds and squalls	Possibility of whirlwinds and squalls	Possibility of whirlwinds and squalls
6 Relief (average bend of surface) within the main construction site	15 %	14 %	14 %
7 Radioactive contamination of the site	No	Site is in the zone of partial radioactive contamination caused by catastrophe on Chernobyl AES (in the zone of periodical radiation control)	No
8 Necessity of water supply of the main construction objects	2,54 m <sup>3</sup> /s	2,54 m <sup>3</sup> /s	2,54 m <sup>3</sup> /s
9 Length (km) of additional water pipelines for technical water supply and pipe diameter (mm)	Length 39 km; Two lines with diameter of 1600 mm	Length 36 km; Two lines with diameter of 1600 mm	Length 6 km; Two lines with diameter of 1600 mm
10 Technical water supply diagram	Back with cooling stacks	Back with cooling stacks	Back with cooling stacks
11 Length of railway approach, km	4	27	32
12 Length of outer roads, km	4	3	4



Table 5 – Analysis of competing sites correspondence to normative documentation requirements

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
<b>Prohibitive factors for NPP construction (according to TKP-097-2007)</b>						
Site is situated directly on tectonically active faults	Without active faults	Corresponds	Without active faults	Corresponds	Without active faults	Corresponds
Site with whose seismicity is characterized with MCE intensity of more than 9 on MSK-64 scale	Site seismicity PE intensity is 5, MCE intensity is 6	Corresponds	Site seismicity PE intensity is 5, MCE intensity is 6	Corresponds	Site seismicity PE intensity is 6, MCE intensity is 7	Corresponds
AES is situated over water supply sources with ground water stores used or planned to be used for drinking water supply, if impossibility of their contamination with radioactive substances can not be grounded	No water supply sources	Corresponds	No water supply sources	Corresponds	No water supply sources	Corresponds
The region doesn't possess water resources enough to restore 97 % losses in AES cooling systems and with no secure sources for restoring water losses in reactor plant cooling systems important for AES security. Demand is 22.000 m <sup>3</sup> /day	Water drain is provided in the range of 150.000-200.000 m <sup>3</sup> /day considering ecological limitations	Corresponds	Water drain is provided in the range of 150.000-200.000 m <sup>3</sup> /day considering ecological limitations	Corresponds	Water drain is provided in the range of 150.000-200.000 m <sup>3</sup> /day considering ecological limitations	Corresponds

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Territory with a proved fact of active karst possibility of activation of piping-karst processes	No active karst  Potential possibility of activation of piping-karst processes in cavernous and karsted dolomites.	Corresponds  Complication factor	No active karst Potential possibility of activation of piping-karst processes in marl-chalk layers under the quaternary sands.	Corresponds  Complication factor	No active karst or possibility of activation of piping-karst processes	Corresponds
Region of development of active landslide and other dangerous bend processes (fallings, mud torrents)	No dangerous processes	Corresponds	No dangerous processes	Corresponds	No dangerous processes	Corresponds
Territory can be flooded by catastrophe freshets and inundations with frequency of once in 10000 years considering ice jams, wind-induced surges and high and low tides	No danger	Corresponds	No danger	Corresponds	No danger	Corresponds
Territory is potentially subjected to being flooded by braking waves of water storage basins press fronts situated upstream	No danger	Corresponds	No danger	Corresponds	No danger	Corresponds

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Territory within which AES placement is prohibited by nature protection laws	No prohibitions	Corresponds	No prohibitions	Corresponds	No prohibitions	Corresponds
Territory with average population density of 100 p/km <sup>2</sup> and more (including workers and AES personnel)	Population density is 34 p/km <sup>2</sup>	Corresponds	Population density is 20 p/km <sup>2</sup>	Corresponds	Population density is 24 p/km <sup>2</sup>	Corresponds
Unfavorable factors						
Territory with proved facts of modern differentiated movements of the Earth crust (vertical – with the speed of more than 10 mm per year, horizontal – more than 50 mm per year)	Vertical: with speed of less than 10 mm per year, horizontal – less than 50 mm per year	Corresponds	Vertical: with speed of less than 10 mm per year, horizontal – less than 50 mm per year	Corresponds	Vertical: with speed of less than 10 mm per year, horizontal – less than 50 mm per year	Corresponds
Territory with salt soil and salinization and leaching developing on it	There are no areas with salt soil and salinization and leaching developing on them	Corresponds	There are no areas with salt soil and salinization and leaching developing on them	Corresponds	There are no areas with salt soil and salinization and leaching developing on them	Corresponds

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Territory with left mining	No	Corresponds	No	Corresponds	No	Corresponds
Territory contains river floodplains and banks of water basins with the speed of movement of shear lines abrasive bench of more than 1 m per year.	No	Corresponds	No	Corresponds	No	Corresponds
Slopes with bend of 15° and more	No	Corresponds	No	Corresponds	No	Corresponds
Water in the water supply source has a high degree of chemical and biological contamination exceeding the set limits	Chemical and biological contamination of water in water supply source corresponds to the norms	Corresponds	Chemical and biological contamination of water in water supply source corresponds to the norms	Corresponds	Chemical and biological contamination of water in water supply source corresponds to the norms	Corresponds

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Sphere of feeding of the main waterbearing formations	According to the available data the territory of the site is not included into the sphere of feeding of the main waterbearing formations. Final evaluation can be carried out at the following stages of researches	Corresponds	According to the available data the territory of the site is not included into the sphere of feeding of the main waterbearing formations. Final evaluation can be carried out at the following stages of researches	Corresponds	According to the available data the territory of the site is not included into the sphere of feeding of the main waterbearing formations. Final evaluation can be carried out at the following stages of researches	Соответствует
Site with ground waters in the depth of less than 3 m from the planning surface in soil with thickness of 10 m and filtration coefficient of 10 m per day and more and with jointed and fragmental soils and low absorption capability.	Ground waters in the site are in the depth of less than 3 m from the planning surface	Doesn't correspond. Additional dewatering is required.	Ground waters in the site are in the depth of less than 10 m from the planning surface	Corresponds	Ground waters in the site are in the depth of less than 10 m from the planning surface	Соответствует

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Region of structurally and dynamically unstable soils (frozen and permanently frozen soil, forest expensive soil, salinitized and peated soil, loose sand and soil with deformation module less than 20 MPa and others).	Dynamically unstable soil has not been evaluated (is subjected to evaluation at the further research stages). Surface lake-swamp peated soil will be taken off; lake-swamp peated soil in the lower part of quarry sediments with thickness of more than 10 m are spread not everywhere and at the depth of 40-50 m.	Correspond	Dynamically unstable soil has not been evaluated (is subjected to evaluation at the further research stages). Occurring surface forest and lake-swamp peated soil will be removed at planning.	Corresponds	Dynamically unstable soil has not been evaluated (is subjected to evaluation at the further research stages).	Corresponds

Continuation of table 5

Factors considered in site choice	Competitive sites					
	Kukshinovsk site		Krasnopolyana site		Ostrovetsk site	
	Characteristics	Conclusions	Characteristics	Conclusions	Characteristics	Conclusions
Territory is subjected to influence of hurricanes and whirlwinds	There is a possibility of whirlwinds and squalls.	Doesn't correspond. At AES projecting whirlwind danger account is required.	There is a possibility of whirlwinds and squalls.	Doesn't correspond. At AES projecting whirlwind danger account is required.	There is a possibility of whirlwinds and squalls.	Doesn't correspond. At AES projecting whirlwind danger account is required.
Territory on which in the result of planned industrial, water-industrial public construction or development of moistened agriculture unpermitted changes of ground and surface waters mode, their temperature and surface composition are possible.	Changes of ground and surface water modes, their temperature and surface composition are not prognosed. Corresponds	Changes of ground and surface water modes, their temperature and surface composition are not prognosed.	Corresponds	Changes of ground and surface water modes, their temperature and surface composition are not prognosed.	Corresponds	

The results of comparative analyses show that [27]:

- There are prohibition factors in all three competing sites (factors or conditions not permitting NPP placement according to the requirements of the corresponding normative documents);
- In Krasnopolyana and Kukshinovsk sites there is a potential possibility of activation of piping-karts processes that is a complication factor. Engineering-geological and hydrogeological conditions of Kukshonovsk site are complicated (the thickness of different types of soils is uneven, there is press water with piezometral level close to the surface up to 1,5 m).
- According to the totality of important factors Ostrovetsk site has advanges over Krasnopolyana and Kukshinovsk sites.

Considering all facts given above and IAEA recommendations and importance of security factors Ostrovetsk site has been determined as a priority one.

## 4.2 Alternative electro energy sources

Nuclear fuel as non-traditional fuel types is a nonrenewable energy source. Annual industrial consumption of uranium in the world is about 60 thousands tons.

Nuclear Energetics Agency (NEA) of the Organization of economical cooperation and development (OECD) in June, 3, 2008 published a report where it is said that if consumption is kept at the present level world stores of uranium are enough for all reactors for one hundred years. As it was marked in the report considering that cost for production of a kilogram of uranium will be less than 130 USA\$ discovered uranium store whose production is cheaper, is 5,5 mln t, undiscovered – 10,5 mln t [1].

The report says that world amount of electricity production by nuclear energy last year was 372 GW, and by 2030 it is supposed to increase for 80%. OECD NEA thinks that discovered stores of uranium can fully level increase of demand on electricity produced by nuclear energy; with the technologies growth world stores of uranium will be able to fully satisfy the demands of the whole planet for several thousands years ahead.

In the world the average cost of electro energy produced by new NPP is 5 c/kW-h. according to the assessments of WEA\* atomic energetics is profitable at natural gas cost higher than 4,70 \$/mln BHU, and coal cost – 70 \$/t. Economic effect can be larger in case enterprises will pay fines for contamination of the environment. In 2007 439 NPP plants were operating and 34 were being built, atomic energy part was (% of total energy consumption): in France – 39, in Sweden – 30, in Latvia – 24, in Switzerland – 22, in Finland – 20, in the Ukraine and Belgium – 15, In the Republic of Korea – 14, in Japan – 12, in Germany – 10 [1].

According to the public opinion [25,26], in the period to 2020 atomic energetics will be developed on the basis of heat reactors using U-235 as a fuel. At the following stages preparation of heat reactors for transition to thorium-uranium cycle with production of missing U-233 in fast reactors thorium blankets will be started. At storage in them of U-235 with thorium concentration required for heat reactors thorium-uranium fuel production will not require extracting of pure U-235. Besides, works on including of MOX fuel (mixture of weapon plutonium and worked-out AES fuel) in

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\* МЭА – World energy agency.

<sup>1</sup> BHU – British heat unit. 1 BHU = 252 kcal or 1055 J.



heat reactors are being led. Rosatom is carrying out works on construction of intermediate productivity plant for supplying eight reactors of WMWC-1000 type with MOX-fuel. Plant is being projected on the basis of experience, technologies and equipment on MOX-fuel production in t. Hanau, Germany. At production scale of approximately 1 t for plutonium per year cost of MOX-fuel is twice as big as cost of uranium fuel.

So, in spite of the fact that provision of the mankind with uranium is comparable with provision with oil and gas, developed technologies increase nuclear energy resources at least in 60 times that is for 3000 years at present speeds of atomic energy consumption.

### 4.3 Comparative characteristics of different types of fuel, HES and NPP

In order to compare different types of fuel there is a term "conditional fuel". Combustion heat of 1 kg of conditional fuel (c.f.) is 29,3 MJ or 7000 kcal what approximately corresponds to 1 kg of black coal. Table 6 gives characteristics of different types of fuel.

**Table 6 – CHARACTERISTICS OF DIFFERENT TYPES OF FUEL**

Type of fuel	Calorific value, MJ/kg	CO <sub>2</sub> output coefficient	Calorific value of a unit, MJ/kg	% of carbon content, CO <sub>2</sub> 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 WMWC)	3900 GJ/kg			
Natural uranium (in fast reactors)	28000 GJ/kg			

Considering that the mankind possesses maximal stores of uranium and coal it is reasonable to make detailed comparisons of these two types of fuel.

Figure 2 [8] shows comparative characteristics of energy cycle for coal and nuclear fuel.



Сравнительная характеристика угля и ядерного топлива – Comparative characteristics of coal and nuclear fuel

Ядерное топливо – Nuclear fuel

8000 кВт час электроэнергии – electro energy 8000 kW/h

230 г ОЯТ – WNF 230g

Хранение – Storage

30 – 70 кг руды – 30 – 70 kg of ore

Обогащение – Enrichment

30 г топлива – 30 g of fuel

200 г отвал – 200 g bank

30 г ОЯТ – WNF 30 g

20 мл отходов – Waste 20 ml

6 г стекло – glass 6 g

Угольное топливо – Coal fuel

3 т черного угля (или 9 т бурого) – 3 t of black coal (or 9 g of brown coal)

ТЭС – HES

300 кг золы – 300 kg of ash

Газовые и аэрозольные выбросы – Gas and aerosol output

8 тонн  $CO_2$   $SO_2$  и пр. – 8 tons of  $CO_2$   $SO_2$  and others

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

The figure shows that: 30 to 70 kg of uranium ore are required for horsting (230 grams) of dioxide uranium concentrate. In this concentrate (called “natural uranium”) uranium consists of approximately 0,7 % of U-235 of fissible uranium isotope. Natural uranium is used for fueling “CANDU” type reactors produced in Canada widely spread in the world. In the countries using light-water reactors (so-called PWR and BWRs reactors) natural uranium is enriched by U-235 isotope content and from 30 – 70 kg of uranium ore about 30 g of enriched uranium with U-235 content to 3,5 % are made. Worked-out uranium in CANDU reactors contains small amount of nuclear fuel that is processed as waste. Uranium worked-out in light-water reactors contains rather big amount of nuclear fuel and in some countries it is processed for reusing. After secondary fuel processing about 20 ml of liquid highly active waste remain. Such highly radioactive waste occupying not more than 1 cubic centimeter is “vitrified” that is put in special tablets with weight to 6 g and dimensions of a big coin

made of a special type of glass. In the process of operation of nuclear reactors other wastes are also formed but they have much smaller value [28].

Given data shows a number of advantages of atomic energetics over traditional energy technologies:

- absence of output of greenhouse gases and harmful chemical substances;
- absence of output of radioactive substances at normal operation of NPP (output is limited by permitted quotas, radioactive wastes are localized, concentrated and buried) while at HES radioactive wastes (natural radionuclides potassium, uranium, thorium and their decay products) are involved in biological life cycle;
- small influence of raw cost on cost of produced electro energy.

#### 4.4 Description of alternate variants

At present atomic energetics is one of the main world sources of electro energy, its part is 17 % of the total amount of produced electro energy in NPP in Russia. Ecological and economical advantages of atomic energetics allow it good perspectives in future. Such qualities of atomic energetics as competitiveness with energy plants on limited fuel, replacement of nonrenewable resources, absence of demands in transportation and practically absence of output of harmful substances into the atmosphere including carbon dioxide that is closely connected with greenhouse effect of the planet create favorable conditions for its further development.

Alternative variants suggested by different public ecological organizations for covering regional energy resources in perspective are:

- heat electro stations working on organic fuel (coal, gas, fuel oil);
- hydro electro stations of medium and grate power by their possibility of providing with hydro resources;
- wind electro station;
- other non-traditional energy sources (solar plants, hydrogen energetics, fuel elements).

Alternative variants are compared by technical and economical factors (prime cost of produced energy), ecological factors (influence on the environment) and factors of assessment of total production prime cost including ecological effects for fuel chain and influence on occupation of the population and society in local, regional and global scales.

Comparison of full cost of electro energy production considering external and social expanses for compared technologies of energy production including ecological effects on fuel chain and influence on occupation of the population and society in local, regional and global scales is given in table 7 [29].

**Table 7 – Total cost of electro energy production. Prices are given in Eurocents per kW/h**

Technology	External expanses (expanses on cycle)	ex- (ex- panses on fuel cycle)	Financial expanses	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
Hydro energy	0,22		4,5	4,7
Nuclear energy	0,04		3,5	3,5

Assessment of the resource base of heat electro stations shows the following picture.

Perspective aim is reducing of specific part of consumption of natural gas in comparison with coal.

Wind energy plants also have a definite perspective which should be assessed according to a complex of technical and geographical factors.

A very important factor for comparison of suggested in the project and alternative variants means of covering perspective electrical loads is a factor of guaranteed output of electro energy.

It is determined by the value of energy source set power use coefficient (ESSPUC).

Project ESSPUC of the AES is less than 90 %, ESSPUC of HES 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 responsibilities for covering of a part of loads belongs to HES. Refusal from NPP will lead to increase of average ESSPUC for HES.

HES ESSPUC can be up to 50 %, and ESSPUC of wind plants and solar energy sources is less than 50 %. So to be equal in electric energy supply safety with other sources whose ESSPUC 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 ecological security by the atmospheric outputs of NPP and alternative sources at different fuel types including stages of electro energy production and operation is given in table 8 [30,31].

**Table 8 – Atmospheric outputs from different fuel cycles including stages of electro energy production and operation y(kW-h)**

Type of output	Fuel cycle			
	NFC	Coal	Oil	Natural gas
SO <sub>x</sub>	1,500	12,500	8,300	13,700
NO <sub>x</sub>	0,400	3,000	4,500	3,400
CO	0,010	0,240	0,610	0,060
CH <sub>4</sub>	0,005	0,050	1,250	0,010
CO <sub>2</sub>	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 Kiotsk agreement are CO<sub>2</sub> and CH<sub>4</sub>.

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

Brief comparison of NPP and HES by ecological security shows that 1 GW of NPP set power allows to save annually 5,9·10<sup>6</sup> tons of coal or 2,2·10<sup>6</sup> tons of fuel oil or 2,6·10<sup>9</sup> m<sup>3</sup> of gas. Besides it prevents output of great amount of gases formed at burning of organic fuel and formation of solid wastes – 8,3·10<sup>5</sup> tons/year (for coal). Heat electro station puts into the atmosphere more radioactivity than NPP of the same power. It has been experimentally proved that individual radiation doses in the region of HES 5-10 times more than in the region of NPP.

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

Atomic branch 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 mcSv 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 electro stations into the atmosphere in natural money values  $\beta$  per unit of produced electro energy for European part of the RF**

Electro stations	$L/10^6$ , years / (kW-h)	$N_{x,6}/10^6, 1/(\text{kW-h})$	$N_{\text{дн}}/10^6, 1/(\text{kW-h})$	$\beta$ , roub/ kW-h
Operating HES: on natural gas on coal	0,03	0,01	3	0,03
	0,44	0,14	50	0,50
Design HES on coal	0,20	0,06	20	0,20
NPP (WMWC-1000)	$1,0 \cdot 10^{-4}$	-	-	$3,0 \cdot 10^{-5}$

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

## 5 POSSIBLE VARIANTS OF CARRYING OUT PROJECT SOLUTIONS

Nuclear energetics is energetics technology based on using of heat energy emitted at fission of heavy uranium and plutonium nuclei. Amount of energy emitted at one fission act is about 200 MV or  $3,2 \cdot 10^{-11}$  J. At abstracted consideration energy of 200 MV is very small. But considering masses of participating particles this amount of energy is rather big. For example to get 1 MW of heat energy a day (produce 1 MW of heat energy or 0,33 MW of electrical energy a day) only 1,24 g of uranium - 235 are required. Equivalent amount of coal considering its combustion heat of 30230 kJ/kg is 2860 kg/day. Relation of amount of coal to uranium-235 for production of the same amount of energy is 2300000:1 [35].

Heat energy emitted in active zone at carrying out controlled chain reaction of heavy nuclei fission is carried to heat exchanger by the coolant where it is used for production of steam activating turbo generator for electricity production (similar to heat electro stations).

Most of nuclear plants in the world are reactors with water coolant (LWR- light water reactor). In these reactors water is used for keeping chain reaction and for heat transferring from the reactor active zone. It is also used as neutrons inhibitor. There are two types of reactors:

- BWR – boiling water reactor;
- PWR – pressurized water reactor.

Besides, there are two types of reactors with other inhalants:

- HWR – pressurized heavy water reactor;
- Channel-type power reactor CTPR – graphite is used as an inhalant. We will not consider this type of reactors because their construction is not being planned.

In spite of diversity of types and dimensions 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 **WMWC 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 active zone.

#### **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 WMWC reactor has similar design and history. Currently there are 53 reactors of this type in 7 countries of the Eastern Europe. Third modification of WMWC reactors of 1000-320 type was greatly changed; it has a greater power (up to 1000 MW).

Second most spread 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 active zone what leads to instability of the active zone. 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 evolutionary models developed on the base of reactors of the second generation with changes on the basis of innovative approaches. According to the data of 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 active zone;
- minimal 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 2004b) 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 Atomenergoprojekt and Hydropress developed an advanced WMWC-1000. The main representatives of advanced small and medium reactors are AP-600 (American company Westinghouse) and WMWC-640 (Atomenergoprojekt 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 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 AES Kasivazaki Kariva.

#### *Heavy water reactor*

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

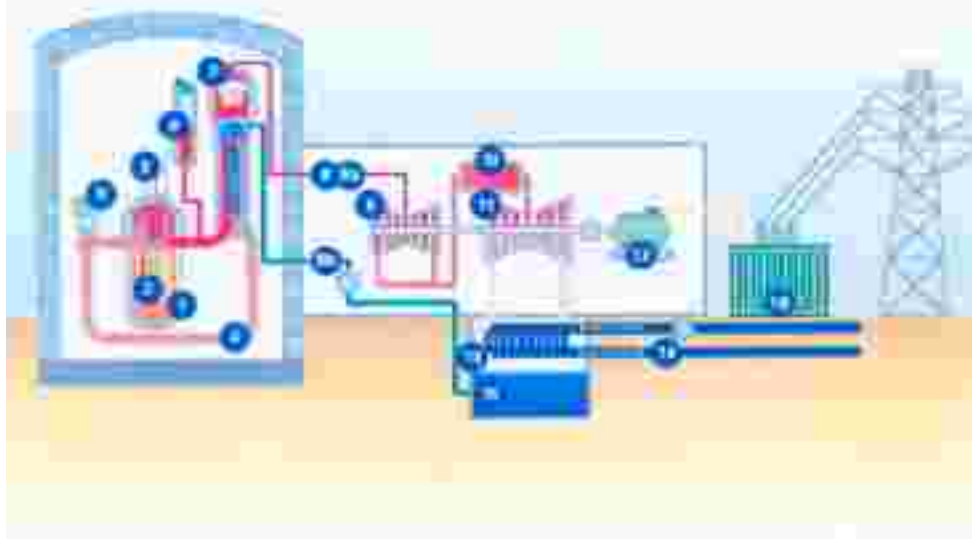
## **5.1 Pressurized water reactor (PWR)**

It is the most spread type of commercial energy reactor in the world. About 60% of currently operating NPP use reactors of this type.

As a fuel they use uranium dioxide  $UO_2$  with 3-5 % enrichment of uranium-235 that is situated in tubes of zirconium with length of 3,5-4 m. Pressurized water carries out functions of an inhibitor and as a coolant transfers in the steam generator heat from the active zone; at that water in the second circuit is heated to produce steam which is used for turbine activation (figure 3).

In order to increase boiling point and to make heat transition more effective coolant in the first circuit is under great pressure (16 MPa). Passing through the active zone the coolant reduces the heat emitted at fission of uranium-235 nuclei and at that is heating to the temperature of 300-330 °C. In the steam generator it gives its heat to pressurized (7,8 MPa) coolant of the second circuit. The second circuit coolant heats in the steam generator to the temperature of 290 °C and is delivered to the turbo generator. Heat effectiveness coefficient of PWR NPP is АЭС ББЭР – 32-37 %.

Reactor and the main equipment of the first circuit are located in the containment designed to keep integrity at interior impact (disruption of the pipeline of the first circuit or possible explosion of detonating mixture formed during operation of the reactor) and external impact (earthquake, collapse of a big aircraft or terrorist act).



(1) reactor, (2) active zone, (3) absorbing rods, (4) first circuit, (5) main circulating pump, (6) pressure capacitor (7), steam generator, (8) second circuit, (8a) steam for the turbine, (8b) water for the steam generator, (9) high pressure cylinder, (10) steam overheater, (11) low pressure cylinder, (12) generator, (13) capacitor, (14) water circuit for capacitor cooling, (15) condensate, (16) transformer.

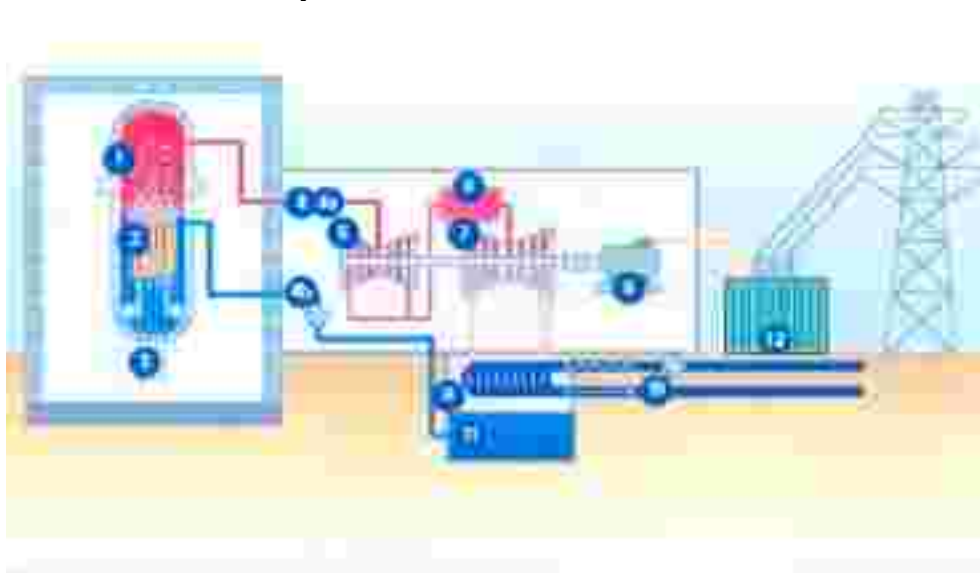
**Figure 3 – Main elements of AES with pressurized water reactor**

## **5.2 Boiling water reactor (BWR)**

BWR reactor is one-circuit reactor without steam generator (figure 4) in which water is circulating through the active zone carrying out the functions of inhibitor and coolant. Reducing heat emitted in the active zone water heats to the temperature of about 300 °C, boils and produces steam at pressure of about 7,0 MPa. About 10 % of water turns into steam and transferred to steam turbines. After condensation pumps return water to the active zone and completes circulation cycle. Fuel is similar to PWR but special volume power (energy per a unit of active zone volume) is half



less with lower temperature and pressure. It means that for the equivalent heat production BWR body is more than PWR body but absence of steam generator and lower pressures of the systems allow smaller protective cover. Essential drawback of this power unit is the possibility of dirtying of the whole circuit with radioactive fission products in case of depressurization of fuel elements and the necessity to account radioactive corrosive contamination of cooling circuit internal surfaces during planning-preventive maintenance and repairing works. At lower pressures (7,0 MPa) and temperatures heat efficiency coefficient of NPP BWR is 30-35 %.



(1) reactor, (2) active zone, (3) absorbing rods, (4) first circuit, (4a) steam for the turbine, (4b) water for the reactor, (5) high pressure cylinder, (6) steam overhead, (7) low pressure cylinder, (8) generator, (9) capacitor, (10) cooling water circuit, (11) condensate, (12) transformer.

**Figure 4 – Main elements of AES with boiling water reactor (BWR)**

### 5.3 Pressurized heavy water reactor (CANDU)

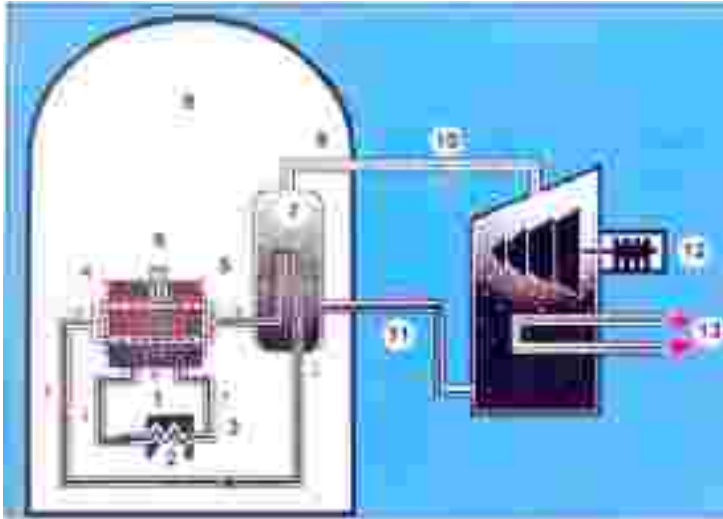
Reactor CANDU uses deuterium oxide (as a special form of water) as a heat carrier and inhibitor. It allows using low-enriched or natural uranium ( $UO_2$ ), located in zirconium tubes as a fuel. Construction of CANDU reactor is similar to PWR but instead of firm body the fuel elements are put into hundreds of horizontal tubes (channels) under working pressure of the heat carrier. The tubes are cooled by heavy water which takes heat out of the active zone as in the case with PWR. Pressurized tubes are in a big body or calander containing separate inhalant of heavy water at low pressure (figure 5).

Average special of volume power of the reactor CANDU is equal to one tenth of PWR power density what explains bigger sizes of the protective cover in comparison with PWR of the same power.

CANDU fuel differs from PWR and BWR fuel as it is much shorter with several bundles of fuel elements (usually 12,50 cm each) situated end-to-end in fuel channel. Position of fuel tube/fuel elements bundle means that fuel of CANDU reactors can be changed during the operation (without stopping the reactor) what increases use coef-

ficient of the set power. The first circuit is usually operated at the pressure of 1 MPa and temperature of 285 °C, what provides heat efficiency coefficient of about 30%.

Advanced CANDU reactor - ACR is a hybrid technology of PWR and CANDU. This type of reactor uses slightly enriched fuel and light water as a heat carrier. It allows increasing power density and fuel combustion what permits to decrease the reactor's dimensions and decrease the amount of worked-out fuel in comparison with its natural equivalent.



(1) reactor, (2) heat exchanger, (3) inhibitor, (4) fuel channels, (5) fuel, (6) control rods, (7) steam generator, (8) protective cover, (9) steam, (10) steam line, (11) pump, (12) turbo generator, (13) water for capacitor cooling.

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

#### 5.4 Comparison of reactor types by the main parameters

Table 10 gives comparison of described above reactor types.

**Table 10 - Main parameters of different types of reactors**

Reactor type, heat energy conversion diagram	Used fuel	Heat carrier	Working pressure, MPa	Temperature at the output from active zone, °C	Specific volume power related to PWR	Efficiency coefficient, %	Containment	Notes
PWR, two-circuit	Low-enriched uranium, 3 – 5 % <sup>235</sup> U	water	16	300 -330	1,0	32 - 37	yes	Second circuit is not radioactive. All equipment of the first circuit is protected with containment.
BWR, One-circuit	Low-enriched uranium, 3 – 5 % <sup>235</sup> U	water	7,0	about 300	0,5	30 - 35	Only reactor	The whole circuit is radioactive. High dose loads at carrying out repairing works. Big dimensions as compared with PWR.
CANDU, hybrid, two-circuit	Natural uranium	Heavy water	12	285	0,1	30	yes	Second circuit is not radioactive. All equipment of the first circuit is protected with containment. Big dimensions as compared with PWR.

As we can see from table 10 PWR have a number of advantages over other types of reactors:

- most power density in the active zone and consequently the least dimensions per power unit;
- two-circuit NPP circuit allows to localize all radioactive equipment (first circuit) in the protective cover;
- minimal dose loads at carrying out repairing works.

These advantages make wide use of this reactor type in electro energy production reasonable (about 60 % of world production).

The main world producers of atomic stations with PWR reactor plants are Westinghouse-Toshiba (USA - Japan), Atomstrojexport (Russia), Areva NP (France - Germany) (view table 11).

**Table 11 – Designs of reactors being under consideration for Byelorussian AES**

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

These NPP correspond to valid norms of IAEA, EUR requirements and national norms of nuclear and radiation security. Table 12 gives the main characteristics of security of atomic stations under consideration.

**Table 12 – Security of atomic stations**

AE type	Heavy damages of active zone, 1 reactor per year	Frequency of limit emergency radiation outputs out of the plant, 1 reactor per year
AP - 600	$< 1,0 \times 10^{-7}$	$< 1,0 \times 10^{-8}$
AP - 1000	$< 2,4 \times 10^{-7}$	$< 3,7 \times 10^{-8}$
AЭC - 2006	$< 5,8 \times 10^{-7}$	$< 1,0 \times 10^{-8}$
EPWR	$< 3,9 \times 10^{-7}$	$< 6,0 \times 10^{-8}$

From the projects given above (table 12) in current century the following projects have been implemented:

- projects AP-600 and AP-1000 are only in development, not being built;
- project EPWR - France is building first NPP for last 15 years in Finland and France;
- project NPP - 2006. Russia is the only country that has been actively building NPP with PWR-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 “Taiwan” – in 2007. The nearest prototype of AES-2006 project was put into commercial operation in 2007 in China (two energy plants). 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 plant of "Taiwan NPP". Operation of both power plants is stable with power of 1060 MW, have high technical and economical 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 security level	
a) security systems	active and pasive
b) calculated value of the possibility of active zone damages by the initial events	not more than $10^{-5}$ reactor <sup>-1</sup> H year <sup>-1</sup>
b) calculated possibility of reaching of limit emergency output at off-project accident	less than $10^{-7}$ reactorHyear <sup>-1</sup>
Low sensitivity to human factor (errors, wrong decisions of the personnel)	$5,6 \times 10^{-8}$

## 6 DESCRIPTION OF THE AES. TECHNOLOGICAL SYSTEMS AND TECHNICAL SOLUTIONS

### 6.1 Main technical and economical characteristics of NPP -2006

The main technical and economical characteristics of NPP -2006 are given in table 14 [38].

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

Characteristics		Measuring unit	Parameter value
1 General parameters of the unit			
1.1	Rating heat power of the reactor	MW	3200
1.2	Rating electrical power	MW	Ø 1170
1.3	Effective number of use of rating power	hour/year	8400
1.4	AES service life	years	50
1.5	Seismic resistance		
1.5.1	Maximal calculated earthquake (MCE)	g	0,25
1.5.2	Project value (PV)	g	0,12
1.6	Number of TVS in the active zone	pieces	163
1.7	Time of fuel presence in the active zone	years	4 - 5
1.8	Depth of fuel burning, maximal	MW day/kg U	up to 60 (in perspective up to70)
1.9	Maximal linear energy density of fuel elements	W/cm	420
2 Main parameters of the first circuit			
2.1	Number of circuit loops	pieces	4
2.2	Heat carrier expanses through reactor	m <sup>3</sup> /hour	85600 ± 2900

Continuation of table 14

Characteristics		Measuring unit	Parameter value
2.4	Heat carrier temperature at the exit from the reactor	<sup>0</sup> C	329 ± 5
2.5	Rating pressure of stationary mode in the exit from the active zone	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	<sup>0</sup> 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 project accident	MPa	0,5
4.1.4	Calculated temperature	<sup>0</sup> 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 evolitional project on the base of NPP with series reactor plant B-320 (table 15).

**Table15 – NPP with RP B-320 in operation**

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

Operating time of prototypes of NPP energy plants with RP B-320 is more than 120 reactor/years. During this period of atomic stations operation the main specific

characteristics, safety and stability of operation both of systems and separate equipment units of RP B-320 put into initial technical project have been proved.

By the results of operation of separate equipment units and RP systems measures of increasing security 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 RP 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 № 5 of Balakov NPP, NPP "Kudankulam" in India, "Taiwan" in China, "Belene" in Bulgaria, "Busher" in Iran). Besides, in these projects RP equipment is constructionally advanced what allows to increase safety and reliability of the RP and to improve service conditions and operation of the equipment.

## **6.2 Information about directions and conditions of the project development of new generation Russian NPP**

Specific characteristics of the project NPP – 2006 is a new reactor plant (RP) and additional security systems:

- new characteristics of the RP;
- system of passive heat leading (PHLS);
- system of reset and cleaning of the cover;
- cooling system of fuel melting catcher (corium) at off-project accident (OPA).

The project considers principle of overcoming and control of off-project 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 security system providing principle (passive and active) fulfillment of critical security functions allowing essentially (in 500 – 1000 times) decrease the possibility of heavy damages of the reactor active zone and at the same time to decrease (in 5 – 7 times) sensitivity of the NPP to the personnel mistakes;

- combining the functions of normal operation and security 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 active zone emergency cooling and worked-out fuel ponds cooling.

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

In the 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 zone and zone of limited access for servicing;
  - double cylinder reinforced concrete cover with a distance of 1,8 – 2,0 m;
  - position of important security systems in the foundation part and in accessory constructions of the cover on the same base of seismic risibility 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 °C (parameters for PA – 0,5 Mpa, 150 °C).
- All mentioned technical solutions show their progressivity and aiming to reaching

### **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 Atomic Energetics of the Russian Federation in the frames of comparison of security 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 security 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 security systems and adequate security analysis".

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

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

Club EUR (EUROPEAN 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 plants for further development of atomic energetics in Europe on the base of NPP modern security and economy conception 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 security 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 AES-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 security 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;
- active zone 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 worked-out 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 plant. 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 plants with PWR-100/428 in China has been completed. In the period from 1995 to 1999 IAEA expertises were carried out on materials of project NPP with PWR-1000/428 for CDR. Results of the expertises 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 for Tianwan NPP, Systems, 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 for 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 for Tianwan NPP, COTAINMENT INTEGRITY 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 for 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 for 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 maximal 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 RP 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 project- NPP analogue 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 electrical power of 100 MW is determined by its high economical characteristics and the level of nuclear and radiation security corresponding to the external international requirements. The main aim of creating of new generation NPP is making a unified comparable NPP project corresponding to modern security 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 security and to recommendations of IAEA, international advisory group of regulating security INSAG and others.

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

Apart from the procedure of licensing in Russian supervising authorities in order to prove its correspondence to the world criteria and security 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:

- a) increasing of security level by:
  - improvement of characteristics of nuclear fuel and the main equipment of the reactor plant;
  - creating of advanced security systems with active and passive systems;
  - decreasing sensibility of the NPP to the personnel mistakes;
  - increasing of the NPP equipment operational reliability;
  - maximal use of experience in creating and operating of plants with reactors of PWR-440 and PWR-1000 types;
- б) improvement of technical and economical 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 active zone 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, nodes, 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-plant NPP.



**Figure 6 – Overall view of one-plant NPP**

Здание турбины – Turbine building

Паровая камера – Steam chamber

Реакторное отделение – Reactor compartment

Вспомогательное отделение – Auxiliary compartment

Здание безопасности – Security building

Дизельная – Diesel building

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

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

Nonnuclear part combines technologies of conversing heat energy into electrical energy.

Electro technical part provides output of electro energy to energy system and provides electro 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 plant is situated; it includes:

- 1) reactor;
- 2) steam generators;
- 3) pressure capacitor;
- 4) main circulating pumps and main circulating pipes;
- 5) passive part of active zone emergency cooling, in the protective cover there is equipment for operations with nuclear fuel, systems of passive heat leading, system of localization active zone melting and other systems;

– security building containing equipment and pipelines of active zone 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” electro 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” zone, 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 turbo plant and turbo generator and auxiliary systems providing their functionality in all modes.

## **6.5 Functional diagram of the NPP. Composition of the main equipment**

### **6.5.1 Functional diagram of the NPP**

Functionally all objects of the atomic station can be divided into main objects and auxiliary and service objects.

The main objects include:

- the main buildings and constructions of energy plant 1;
- the main buildings and constructions of energy plant 2;
- electro technical buildings of 330 kV;
- cable channels and tunnels of energy plants 1 and 2 on the territory of industrial site;
- trestle bridges and channels for technological pipelines on the industrial site;
- technical water supply buildings.

The rest objects are included into auxiliary and service part.

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

Heat diagram of RP is two-circuit.

Energy plant includes reactor plant and one turbo plant.

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 heat neutrons. Heat carrier 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 atomic station of 50 years.

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

Heat carrier of the first circuit passing through the active zone 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 heat carrier 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 plant is shown in figure 7.

Ёмкость CAO3 – SAOZ capacity

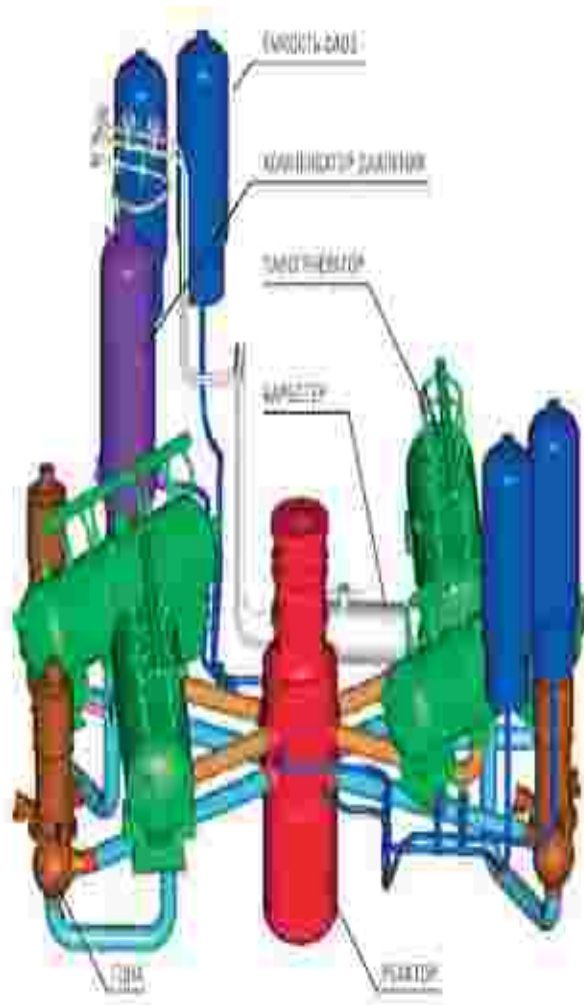
Компенсатор давления – Pressure canceller

Парогенератор – Steam generator

Барботер – boron tank

ГШНА – GSHNA

Реактор – Reactor



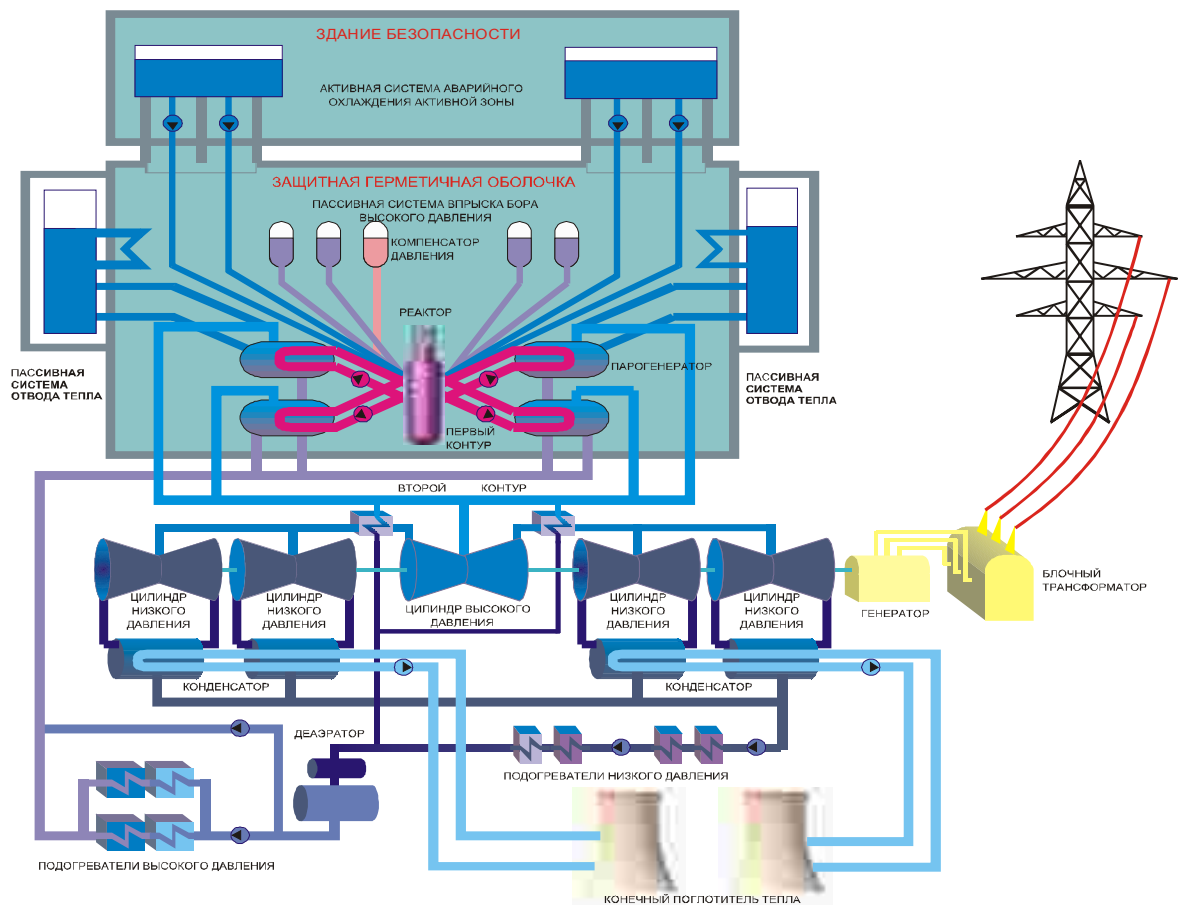
**Figure 7 - Arrangement of reactor plant**

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 heat energy into mechanical energy of turbine rotor rotation. Generator set on the same shaft with turbine rotor converts mechanical energy of rotor rotation into electrical energy.

Functional technological diagram of NPP -2006 energy plant is given in figure 8.



**Figure 8 – Functional technological diagram**

Здание безопасности – Security building  
 Активная система аварийного охлаждения активной зоны – Active system of active zone emergency cooling  
 Защитная герметичная оболочка – Protective hermetic cover  
 Пассивная система впрыска бора высокого давления – Passive system of high pressure boron injection  
 Компенсатор давления – Pressure canceller

Реактор – Reactor  
 Пассивная система отвода тепла – Passive system of heat leading  
 Первый контур – First circuit  
 Парогенератор – Steam generator  
 Второй контур – Second circuit  
 Цилиндр низкого давления – Low pressure cylinder  
 Цилиндр высокого давления – High pressure cylinder  
 Генератор – Generator  
 Емкостной трансформатор – Transformer  
 Конденсатор – Capacitor  
 Деаэратор – Deaerator  
 Подогреватели низкого давления – Low pressure heaters  
 Подогреватели высокого давления – High pressure heaters  
 Конечный поглотитель тепла – Final heat absorber

### 6.5.2 Composition of the main NPP equipment

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

**Table 16 – List of the main equipment**

Name	Quantity
<b>Main equipment of normal operation systems</b>	
<i>Main equipment of the first circuit</i>	
Reactor B-491	1
GNHA-1391	4
Steam generator PGV-1000MKP	4
Pressure canceller	1
<i>Main equipment of the second circuit</i>	
Turbine of K-1200-6,8/50	1
Condensing plant:	1
- one-stroke two-flow capacitor	4
- hermetic capacitor system:	
main water-jet injector	4
water-jet injector of circulating system	2
water-jet injector of steam thickening capacitor	1
First stage capacitor pumps	3
Second stage capacitor pumps	3
Vertical, two-stage jalousie separator-steam overheater	4
Feeding electro pump	5



Continuation of table 16

Auxiliary feeding electro pump	2
High pressure deaerator	1
Turbo aggregate lubrication system: - oil box - lubrication system pump - lubrication system pump (emergency) - oil cooler	1 2 1 3 (is being detailed in the project)
Regulation oil supply system: - oil box - regulation system pump	1 2

Creation of PWR-1200 RP is based on evolutionary modernization approach and including proved and reliable systems and equipment checked at PWR RP operation in active AES. The main RP 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 RP considering its service life of 60 years.

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

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

RP includes the following main components:

- first circuit and systems connected with it;
- reactor main equipment;
- second circuit within protective cover and systems connected with it;
- transportation and technological part of the RP;
- complex of systems of control, check, regulation, protection, blocking, signaling and diagnostics forming ACS in RP part;
- heat isolation of RP equipment and pipelines;
- fixing elements of equipment and pipelines;
- equipment and systems for assembly and adjustment works;
- equipment for repairing and maintenance of RP;
- set of control systems for equipment and pipelines metal;
- complex of systems and control means for of-project accident and decreasing consequences including system of warning and active zone melting cooling.

The main parameters in rating mode and technical characteristics of the RP are given in table 17.

**Table 17- The main parameters and technical characteristics of the RP**

Names and units	Value
Heat rating power, MW	3200*
Steam productivity of one steam generator (at feeding water temperature of 225 °C and continuous blowing of 15 t/h), t/h	1600+112***
Heat carrier expanse through the reactor in the rating mode, m <sup>3</sup> /h	85600±2900**
Rating pressure of stationary mode at the exit from active zone (absolute), MPa	16,2±0,3
Temperature of heat carrier in active zone in rating mode, °C – at the entrance – at the exit	298,6 <sup>+2</sup> <sub>-4</sub> ** 329,7±5**
Names and units	Value
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
Maximal linear energy intensity of fuel elements, W/cm	420
Feeding water temperature in rating mode, °C	225±5
Time of fuel presence in active zone, year	4-5
Depth of fuel burning, maximal, 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 active zone, pieces	163
<p>* during project design on the base of planned researches it is possible to increase RP heat power to 3000 MW by implementation of tabulators, lowering conservatism of calculated codes and methods, optimization of fuel cycle.</p> <p>** Is being detailed at RP technical design.</p> <p>*** Maximal deviation caused by differences in SG heat powers.</p>	

## 6.6 Arrangement of reactor plant equipment

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

Development of RP 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 active zone melting outside the reactor vessel at heavy off-project accidents.

The arrangement considers the possibility of RP 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 heat neutrons. Heat carrier 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.

Heat carrier is given by circulating pumps through four input connecting branches, lowered along the ring clearance between the vessel and mine of the active zone and passes to NVC through the perforation in the bottom and mine support tubes.

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

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

Neutron-physical characteristics of active zone and reactivity control systems are chosen according to the initial project security requirements.

Reactor includes:

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

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

RP equipment and reactor active zone 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.

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

Active zone 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 active zone, keeping power on the set level and its transition from one level to another, equalizing of energy emitting field to active zone height, preventing and suppressing of xenon fluctuations.

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

Reactivity coefficients characterizing changes of the active zone reactivity at changes of parameters of fuel, heat carrier, boron concentration, are negative in normal operation modes, in modes of irregular operation and at project 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 project limits for fuel and power range.

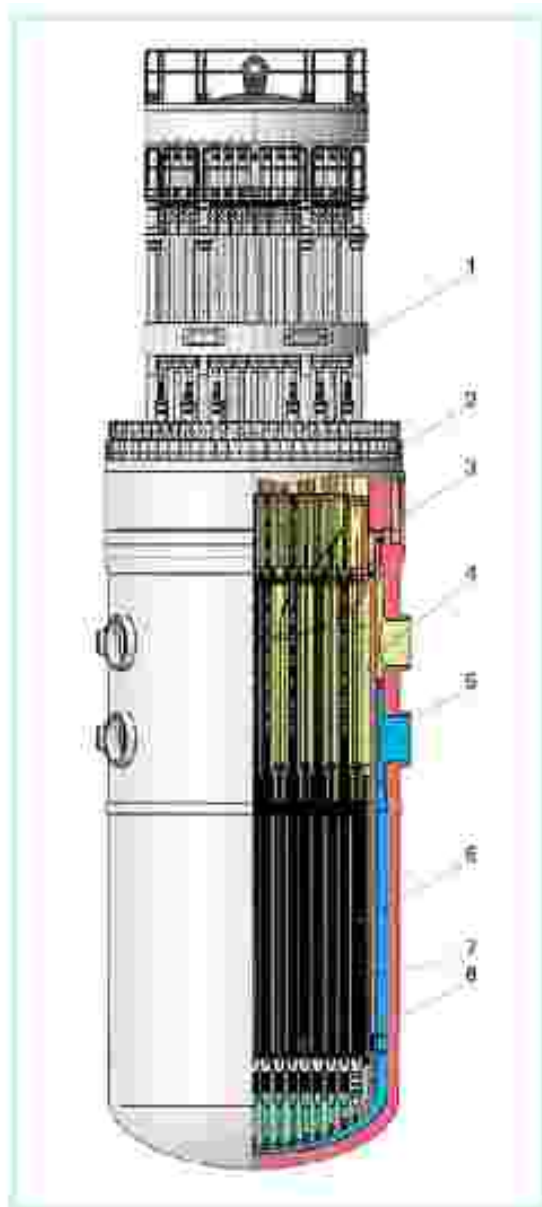
PWR-1200 reactor construction was developed on the base of experience in projecting and operating of PWR type reactors in the Russian Federation, CIS countries and abroad.

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

PWR-1200 reactor as PWR-100 series reactors has a loop heat carrier leading system with two-row branch Du 850 position on the reactor vessel, thickening of the main distributor, organization of heat carrier leading to the active zone, 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 heat carrier and providing possibility of vessel interior decontamination. Longitudinal plan of the reactor is shown in figure 9.



- 1 - блок верхний
- 2 - привод ШЭМ-3М
- 3 - каналы датчиков ВРК
- 4 - шахта внутрикорпусная
- 5 - блок защитных труб
- 6 - выгородка
- 7 - сборка тепловыделяющая
- 8 - корпус

**Figure 9 – Longitudinal plan of the reactor**

- 1 – блок верхний – upper unit
- 2 – привод ШЭМ-3М – PM drive
- 3 – каналы датчиков ВРК – VRK sensors channels
- 4 – шахта внутрикорпусная – interior vessel mine
- 5 – блок защитных труб – protective tubes unit
- 6 – выгородка – reflection shield
- 7 – сборка тепловыделяющая – fuel assembly
- 8 – корпус – vessel

Vessel length is 300 mm more due to lengthening support shell. Enlarging vessel length allows to make active zone 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 active zone 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 active zone increases – it is important at accidents connected with heat carrier 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 zone 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 CPS 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 RP B-320) to 141 (upper unit of RP of Novovoronezh NPP, plant 5 of Balakov 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 Active zone**

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

Construction of reactor active zone includes fuel assemblies and CPS regulating devices (to 121 pieces). Spacer grids and guide channels of the active zone are made of zirconium. Increasing of economical parameters is achieved by fuel overload cycle with periodicity of 10 to 24 months and increasing of fuel burning depth to 70 MW day/kg U.

TVS-2M construction (figure 10) has been chosen as prototype for NPP -2006 as meeting all FA requirements. The main requirements to RP active zone are given in table 18.

**Table 18 – Main requirements of RP to the active zone**

Parameter	PWR-1000	PWR-1200*
1 Rating heat power of the reactor, MW	3000	3200/3300*
2 CSPU	0,78	0,92*
3 Heat carrier pressure at the output from active zone, MPa	15,7	16,2
4 Heat carrier temperature at the reactor input, °C	290	298,6
5 Heat carrier temperature at the reactor output °C	319,6	329,7
6 Maximal linear heat flow, W/cm	448	420
7 Fuel cycles	3x350; 3x1,5; 4x1; 5x1	4x1; 3x1,5; 5x1; 2x2*
8 Maximal fuel burning in FA, MW*day/kgU	68	70*
9. Operation mode with power changes, maximal. Speed	Base mode 3 % Nrat /min	Base + maneuver modes 5 % Nrat/min
10 Number of regulated FA	61	121
11 Position of measuring channel	central	shifted
12 Maximal lengthening of active zone, mm	150	200 - 250
13 Relative position of lower fuel edges, mm, rating	52,5	0 *

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

- reliability;
- security;
- economical parameters (CSPU, etc).

Modern level of security is provided by meeting the following requirements to FA and CPS constructions:

- using of best proved technical solutions with evolutional approach to modernization;
- using technical solutions providing maximal 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 heat carrier parameters.

Safety of the active zone 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 economical characteristics are determined by meeting the following requirements to FA:

- providing minimal possible fuel load in FA to achieve high CSPU;

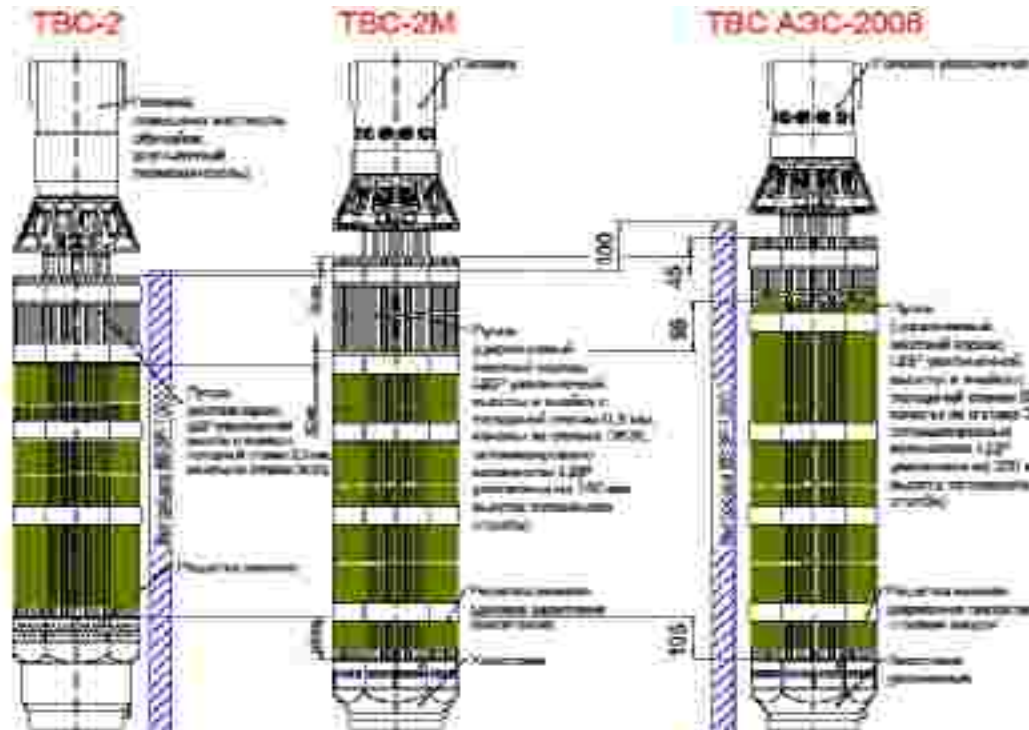
- maximal possible fuel enrichment (to 5%);
- providing fuel cycles with maximal fuel burning to 70 MW day/kg U.

Among FA currently existing these requirements are most completely met by FA-2M which is now being industrially tested in plant 1 of Balakov NPP. Its prototype – 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 exploitation in AES. FA-2 proved its high geometry stability and quality of technological and design solutions.

FA-2M construction provides possibility of maximal 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**

Головка, повышена жесткость обечайки, улучшенный термоконтроль – Head, increased shell firmness, improved thermocontrol

Пучок (жесткий каркас, ЦДР увеличенной высоты и ячейка с толщиной стенки 0,3 мм, каналы из сплава Э635) – Bundle (firm carcass, increased height of CDP with wall thickness of 0,3 mm, channels of E635 welding)

Решетка нижняя – Lower grid

Головка – Head

Пучок (циркониевый жесткий каркас, ЦДР увеличенной высоты и ячейка с толщиной стенки 0,3 мм, каналы из сплава Э635, оптимизировано количество ЦДР увеличена на 150 мм высота топливного столба) – Bundle (zirconium firm



carcass, increased height of CDP with wall thickness of 0,3 mm, channels of E635 welding, increased number of CDP, heat column height is increased for 150 mm)

Решетка нижняя (цанговое закрепление твэлов/твэгов) – Lower grid (collet attachment of fuel elements)

Хвостовик – Shank end

Головка укороченная – Shortened head

Пучок (циркониевый жесткий каркас, ЦДР увеличенной высоты и ячейка с толщиной стенки 0,3 мм, каналы из сплава Э635, оптимизировано количество ЦДР увеличена на 200 мм высота топливного столба) – Bundle (zirconium firm carcass, increased height of CDP with wall thickness of 0,3 mm, channels of E635 welding, increased number of CDP, heat column height is increased for 200 mm)

Решетка нижняя (закрепление твэлов/твэгов с осевым зазором) – Lower grid (fuel elements attachment with axial clearance)

Хвостовик (укороченный) – Shank end (shortened)

FA-2M construction (considering developed solutions on reducing its KGS to UFA level) provides heat technical reliability and increasing of RP 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**

Реактор	ТВС	Ø таблетки, мм/Ø отверстия, мм	Высота топливного столба, мм	Масса топлива, кг в твэле/ в ТВС/ в активной зоне/	Процент увеличения, %	Зерно, мкм
ВВЭР-1000	ТВС-2	7,57 1,4	3530	1,575 491,4 80098	-	10
	ТВС-2М	7,6 1,2	3680	1,671 521,3 84973	6,1	10
	ТВС-2М	7,8 0,0	3680	1,805 563,1 91793	-	20-30
ВВЭР-1200	ТВС-1200 I этап	7,6 1,2	3730	1,694 528,4 86128	7,5	10
	ТВС-1200 II этап	7,8 0,0	3730	1,829 570,8 93 040	16,2	20-30
	ТВС-1200 III этап	7,8 0,0	3780	1,854 578,5 94 287	17,7	45-60

Реактор – Reactor

ТВС – FA

Ø таблетки, мм/Ø отверстия, мм – tablet diam, mm, hole diam, mm

Высота топливного столба, мм – Fuel column height, mm

Масса топлива, кг в твэле/ в ТВС/ в активной зоне – Fuel mass, kg in fuel element/ in FA/ in active zone

Процент увеличения, % - Per cent of increasing, %

Зерно, мкм – Grain, mcm

ВВЭР-1000 – PWR-1000

ВВЭР-1200 – PWR-1200

ТВС-2 – FA-2

ТВС-2М – FA-2М

ТВС-1200 I этап – FA-1200 stage I

ТВС-1200 II этап – FA-1200 stage II

ТВС-1200 III этап – FA-1200 stage III

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 expands on utilization of replaced elements are not required (figures 13, 14).



**Figure 13 – Head and collet node**

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.



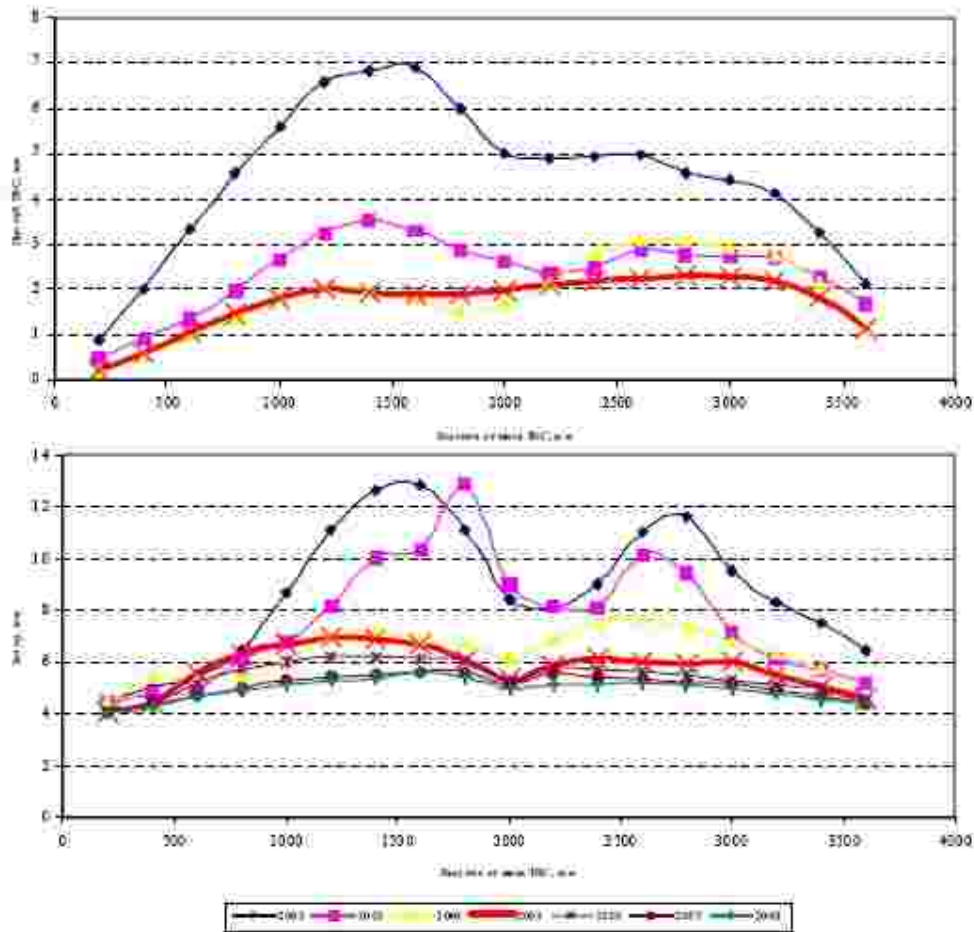
FA-2M construction has been proved for emergency and seismic loads, it better (in comparison with UFA) bears these loads.

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 AES). FA-2M construction is aimed to TTC with speed to 4 m/min.

**Figure 14 – Collet node 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 Balakov 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.

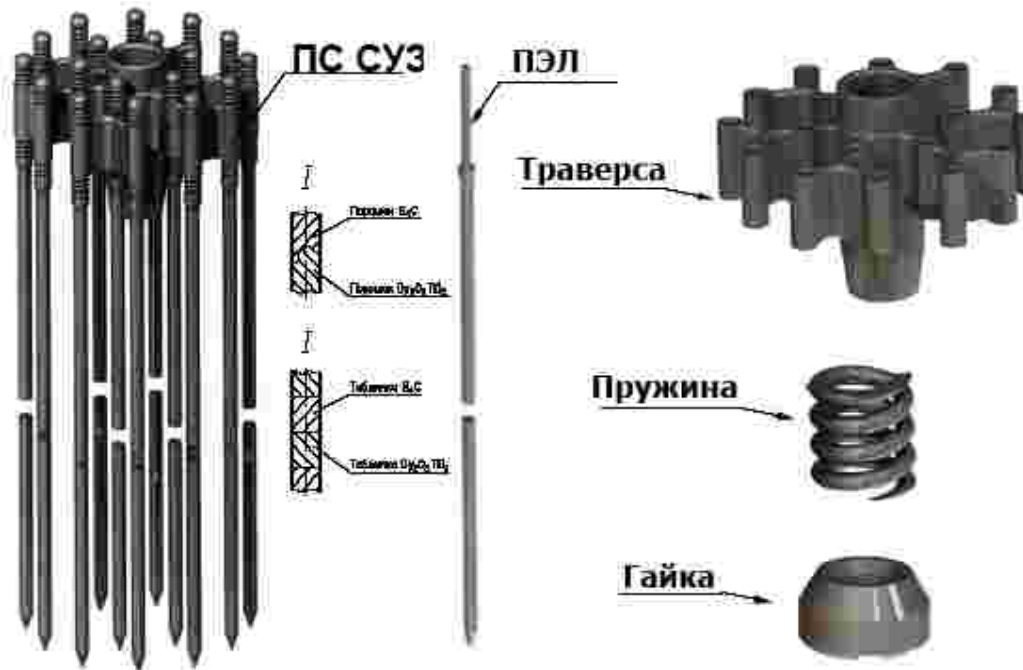
In the result of FA-2 exploitation the active zone has been rectified and inter cassettes clearances have reduced to the project values (figure 15). FA-2 construction has proved to be highly reliable – only one failure during all operating time since 2003.



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

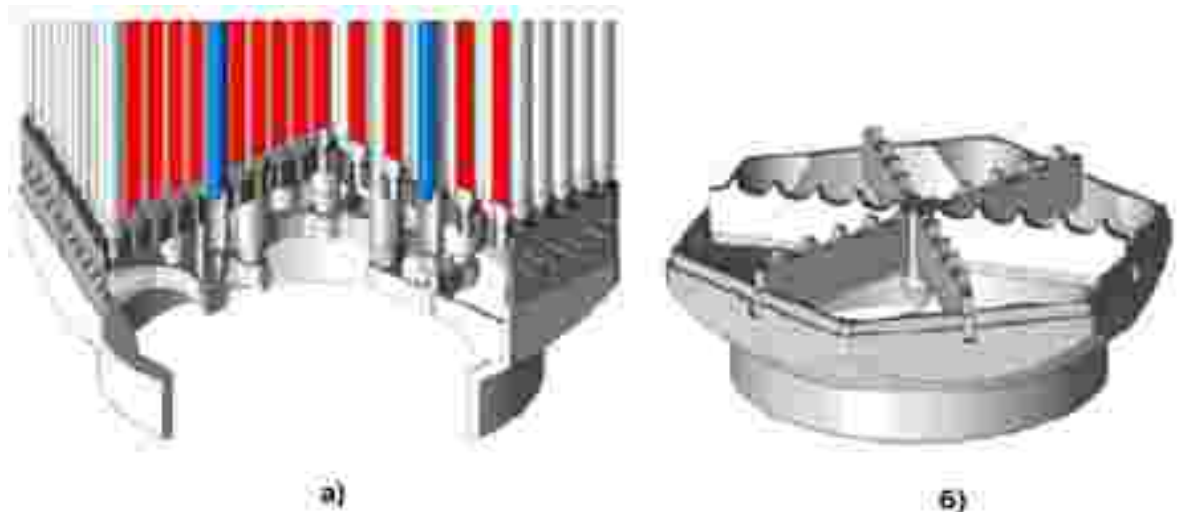
The main FA-2M elements (head, shank end, NK) have been recognized as the most successful and adopted for NPP -2006 FA construction.

By NPP -2006 RP CPS and its elements are similar to PWR-1000 CPS construction (figure 16).



**Figure 16 – CPS PS**  
 ПС СУЗ – CPS PS  
 Траверса – Traverse  
 Пружина – Spring  
 Гайка – Nut

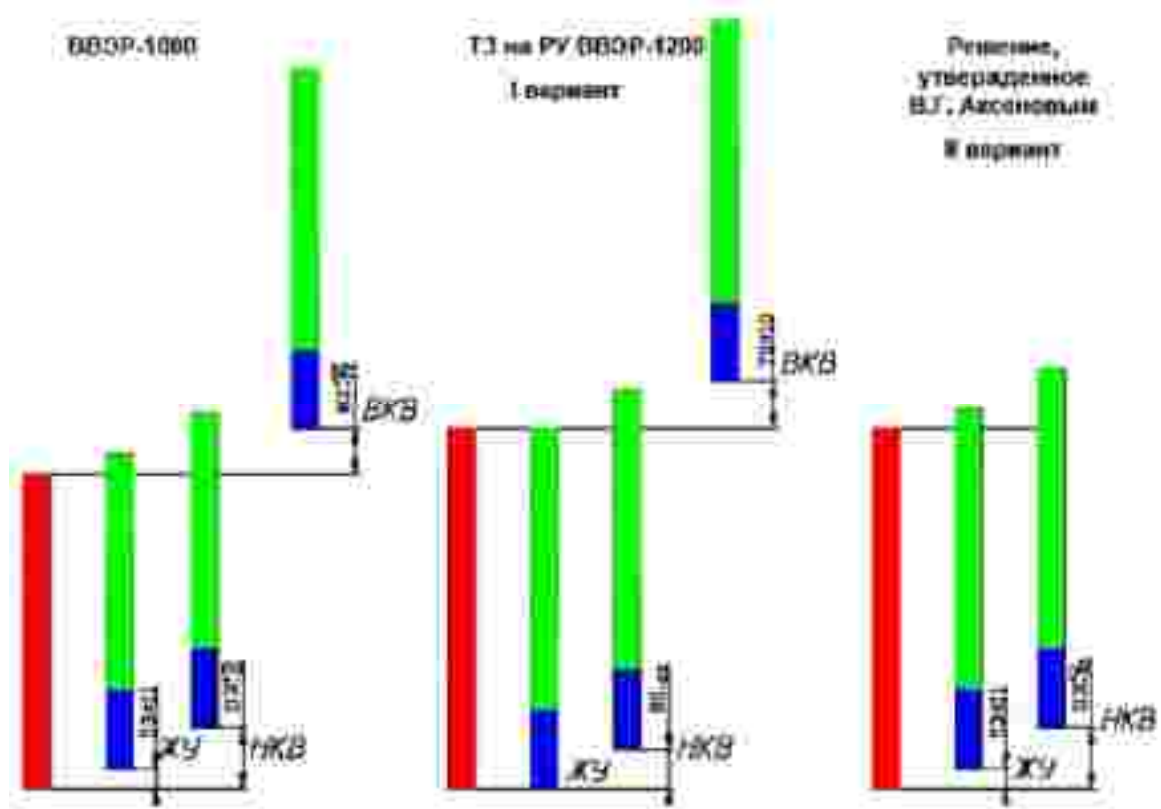
FA-2M shaft end construction allows fulfilling the requirement of FL in RP in bridging of fuel column by absorber when CPS RS are on firm supports. For this NK is attached on special grid allowing to lengthen them lower than fuel elements attachment level. This solution complicates the technology but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



**Figure 17 – Shank end with long NK a) 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 active zone. Considering the fact that for NPP -2006 RP active zone uncovered area is smaller (in comparison with PWR-1000) it was decided to use FA-2M shaft end in AES-2006 RP construction.

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



I вариант – variant I

II вариант – variant II

Решение, утвержденное В.Г. Аксеновым III вариант – decision confirmed by Aksionov V. G. Variant III

**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 CPS OP the number of drives in active zone has been expanded to 121 (figure 19).

**Figure 19 – Diagrams of CPS positions for PWR-1200 a) and PWR-1000 б)**

The main stages of NPP -2006 active zone elements development are given in figure 20

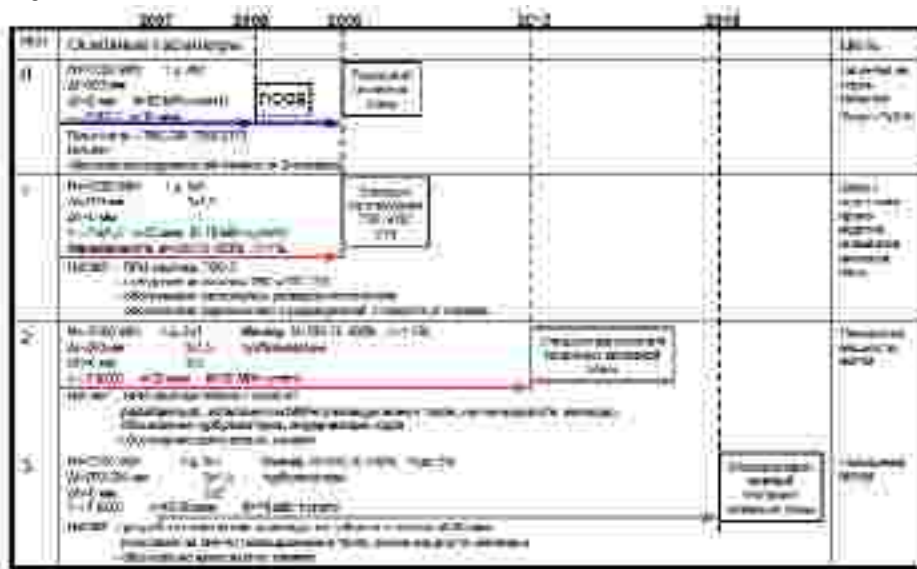


Figure 20 – Stages of development of NPP -2006 RP active zone elements

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

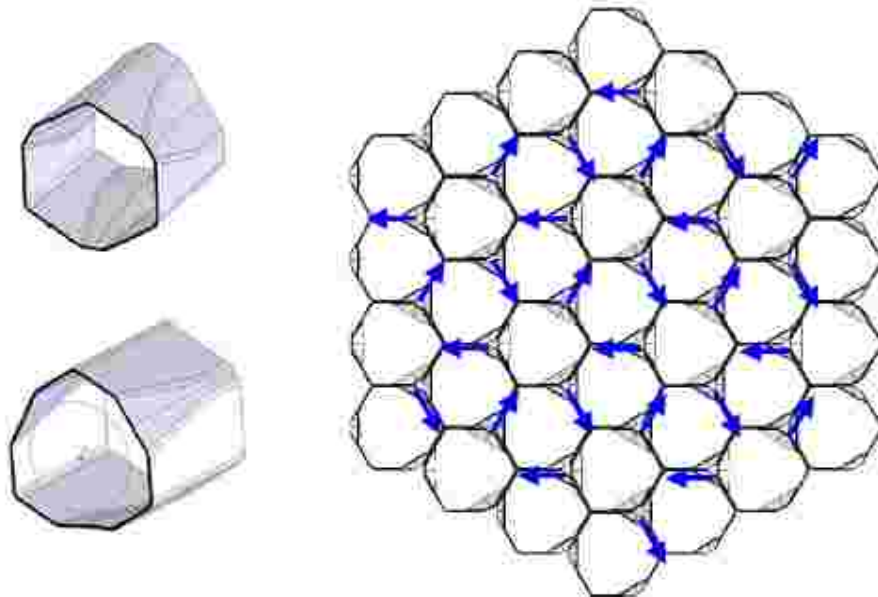
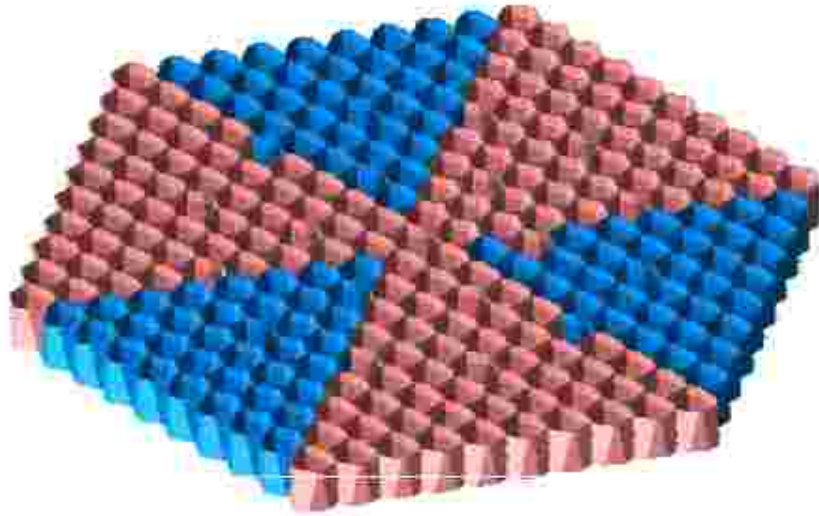


Figure 21 – Cells and a part of mixing grid of “cyclone” type.



**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 heat carrier and finally, increasing reactor power. At that FA carcass doesn't interfere with heat carrier 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 RP. 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 RP active zone on base of FA-2M [39].

### **6.6.3 Drives**

For RP a modernized drive SHEM-3 of CPS 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 minimal clearance between the tubes is 6,0 mm what is actually equal to minimal 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 Balakov NPP, Nivovoronezh 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 RP and is 60 years.

Патрубок пара – Steam branch

Коллектор питательной воды – Feeding water collector

Вход питательной воды – Feeding water input

Выход теплоносителя – Heat carrier output

Вход теплоносителя – Heat carrier input



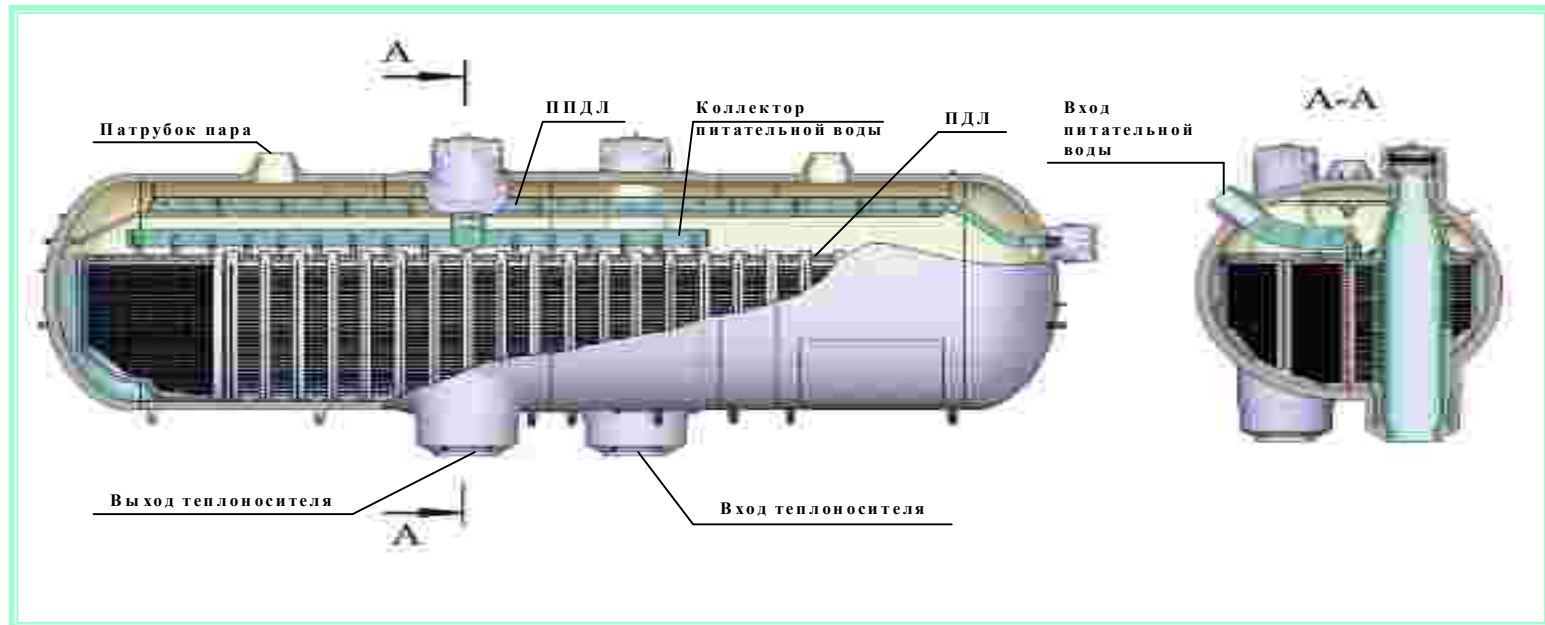


Figure 23 – Longitudinal section of a steam generator

### **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 nodes 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 tribo-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 nodes 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 exploitation experience in the composition of MCPA -195M in AES (whose mean time to failure is 70590 hours);

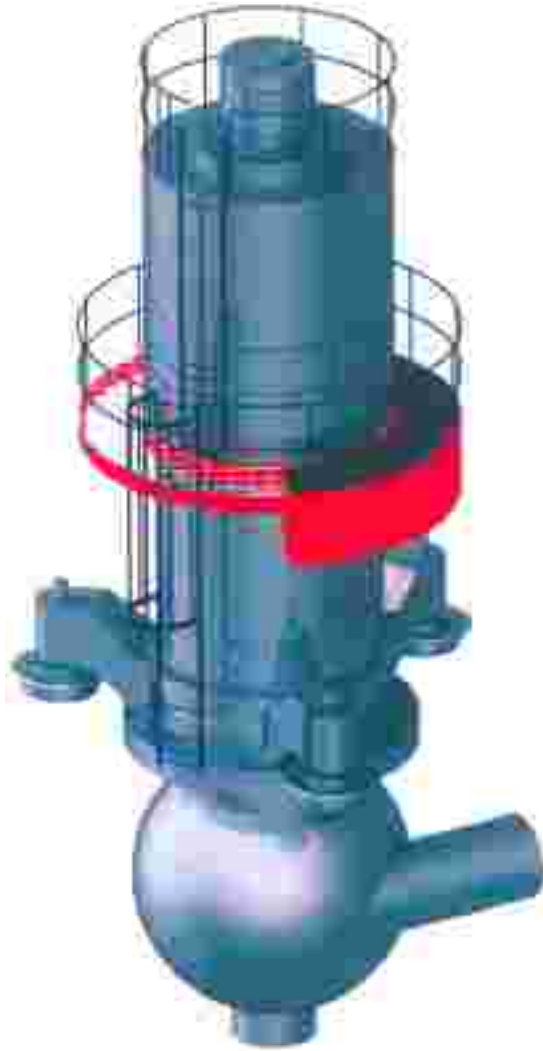
interpolator MCPA -1391 is completely similar to series interpolator MCPA -195M, whose mean time to failure is 70590 hours, what validates its reliable operation in MCPA -1391;

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 plant 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 RP projects of AES under construction (Novovoronezh NPP, plant 5 of Balakov NPP, NPP "Kundalkulam" in India, NPP -2, "Taiwan", "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 turbo plant 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 alternate 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;

- capacitors 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 HES 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 the 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 conception 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 t 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 decentring. 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 zone 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 electrical 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 project limits

Safety criteria and project 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 – Project limits on effective irradiation dose**

Name	Effective dose, mcSv/year
Population, lower limit at AES 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 project 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 off-project 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 plant of 1000 MW (el) at working during the whole project operation period	<5000 0,5 manSv/year
Целевой годовой предел для персонала на БПУ при рассматриваемых в проекте авариях	25000
- Unlike RF RS-99 RS-2000 doesn't divide personnel of the AES into categories A and B.	

At normal operation and deviations from normal operation annual liquid radionuclides output from the energy plant into the environment (excluding tritium), annual aerosol output of inertial gases, aerosols and iodine isotopes must correspond to the requirements of "sanitary norms of projecting and operating of atomic stations" 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 active zone 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 heat carrier: - 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 active zone for project 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 off-project accident considering all initial events, 1 react/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 off-project 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 (jumble 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 energy plants exploitation 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 I 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 plant, project accidents, off-project 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 plants produced in our country and foreign NPP with PWR (ALARA principle – providing irradiation at reasonably achievable low level).

At project 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 off-project accidents it is necessary to provide limitation of consequences of accident with heavy damages of active zone in order to protect the population; calculated radius of urgent evacuation zone must not exceed 800 m what excludes the necessity of urgent evacuation and long-term migration of the population. Radius of the zone 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 zones must be calculated for the worst weather conditions.

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

Purpose of providing radioactive 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 than  $1,0 \times 10^{-7}$  per one year of energy plant 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 plants with prevention of failures;

- low frequency of initial events disturbing normal operation;

- probability of heavy damages of active zone 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 zone with radius of 800 m, less than  $10^{-7}$  per reactor a year;

- increasing reserve time for personnel controlling off-project 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 security systems**

At development of security 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 plant including conditions at stopped reactor.

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



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

- it must include active and passive channels (elements) in relation to the main security functions;
- actions of active and passive SS channels (elements) must be considered totally both at project accidents and at off-project accidents; contribution of all elements of SS must be considered at security justification;
- in order to provide functional and economical advantage it is recommended to use the principle of joint functions of normal operations and security by the same active mechanisms;
- structure of active and passive security systems channels must be directed to achieving of optimal characteristics of functional properties and of minimal 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 projecting, 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 security 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 and engineering studying of the problem, exploitation experience, probability security 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 security characteristics are:

- preventing of deviations from normal operation which require security 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 security systems activation;
- maximal possible reducing of general purpose failures and dependent failures by means of choosing the corresponding constructive and arrangement solutions, security function doubling;
- existence of multifunctional system of reactor emergency cooling based on multiple approaches to carrying out of the security functions, interconnection of active and passive channels; such system provides probability rate of active zone damage over the set limits for project accidents not worse than  $10^{-6}$  per one reactor a year;
- application of system of localization of accident products based on containable of keeping accident products without exceeding the value of permitted output by main dose-forming nuclides at heavy accidents;
- decreasing 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 security and operation purposes or only security purposes. Diagram of deep protection echeloning is shown in figure 25.

Эшелонирование в глубину – Deep echeloning

Барьеры предотвращающие выход продуктов деления в окружающую среду – Barriers preventing output of fission products into the environment

Топливная матрица – Fuel matrix

Предотвращение выхода продуктов деления под оболочку тепловыделяющего элемента – Prevention of output of fission products under the fuel element cover

Оболочка тепловыделяющего элемента – Fuel element cover

Предотвращение выхода продуктов деления в теплоноситель главного циркуляционного контура – Prevention of output of fission products to the main circulating circuit fuel elements

Главный циркуляционный контур – Main circulating circuit

Предотвращение выхода продуктов деления под защитную герметичную оболочку – Prevention of output of fission products under the protective hermetic cover

Система защитных герметичных ограждений – Hermetic barriers protection system

Предотвращение выхода продуктов деления в окружающую среду – Prevention of output of fission products into the environment

## ЭШЕЛОНИРОВАНИЕ В ГЛУБИНУ

БАРЬЕРЫ ПРЕДОТВРАЩАЮЩИЕ ВЫХОД ПРОДУКТОВ  
ДЕЛЕНИЯ В ОКРУЖАЮЩУЮ СРЕДУ



Figure 25 – Deep echeloning protection

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 plant in the project;
- providing high quality at all stages of NPP creation (designing, constructing, equipment manufacturing, assembling, and operating);
- security barriers control during the operation.

The second level of deep echeloned protection is provided by:

- interior characteristics of security 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 security systems – protective, control, localizing and support which are considered by the project to prevent the progress of failures and personnel mistakes at project accidents and the progress of project accidents into heavy accidents and to keep the radioactive materials inside localizing systems.

The fourth level – off-project 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 security requirements the project considers security system consisting of active and passive parts, each of them capable of carrying out the corresponding security requirements.

### 6.8 Security systems. Project principles and project solutions

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

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

**Table 24 – Main security systems**

Safety functions	Security 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 active zone (AZECS) and supply systems	System of passive heat sink (PHSS). System of passive water delivery to active zone
2.3 Heat sink from worked-out 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 security system includes active and passive parts each of them capable of independent carrying out of main security functions. Figure 27 gives list of security functions included into SS active and passive parts.

Two atomic stations are being constructed according to project-2006:

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

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

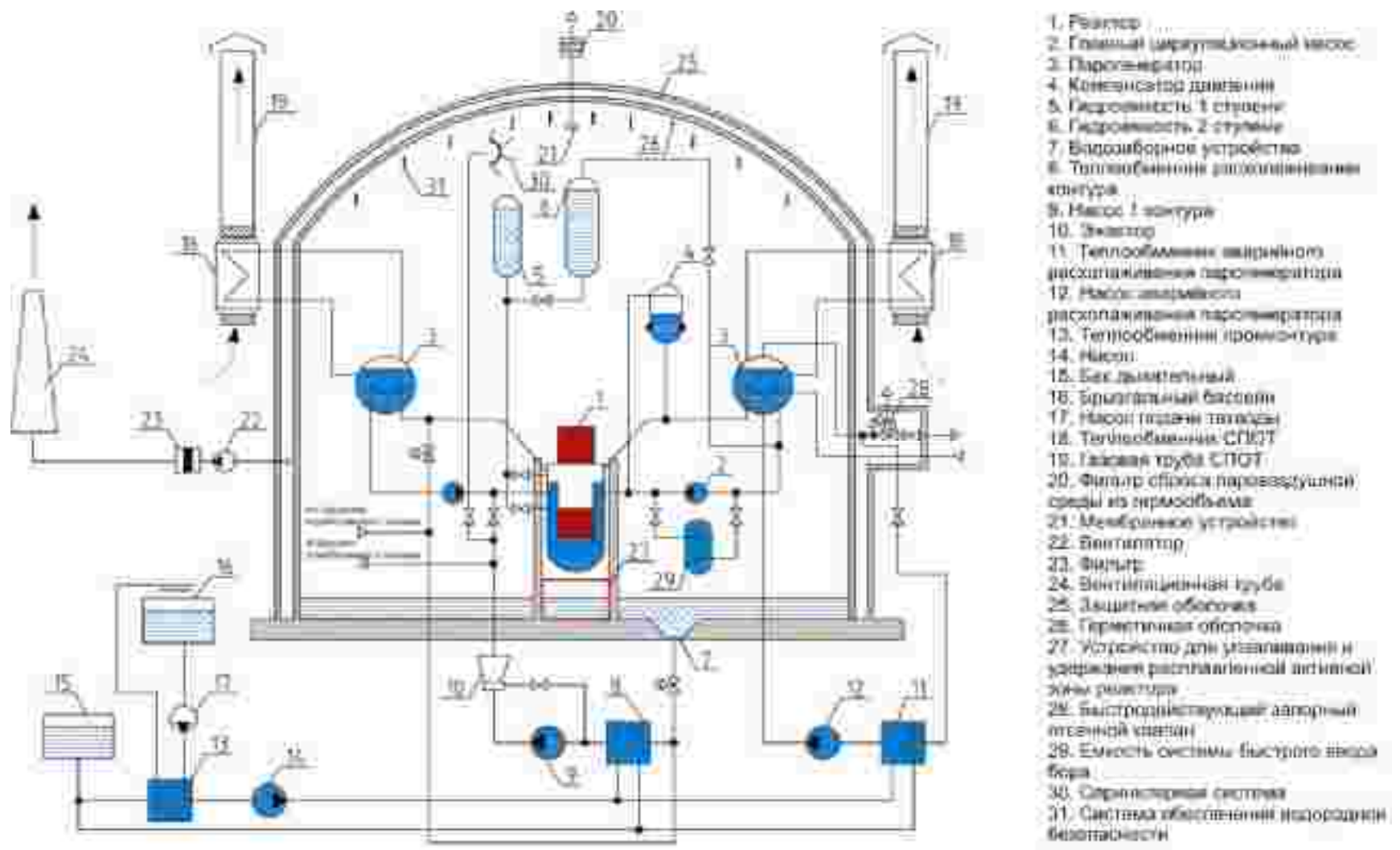
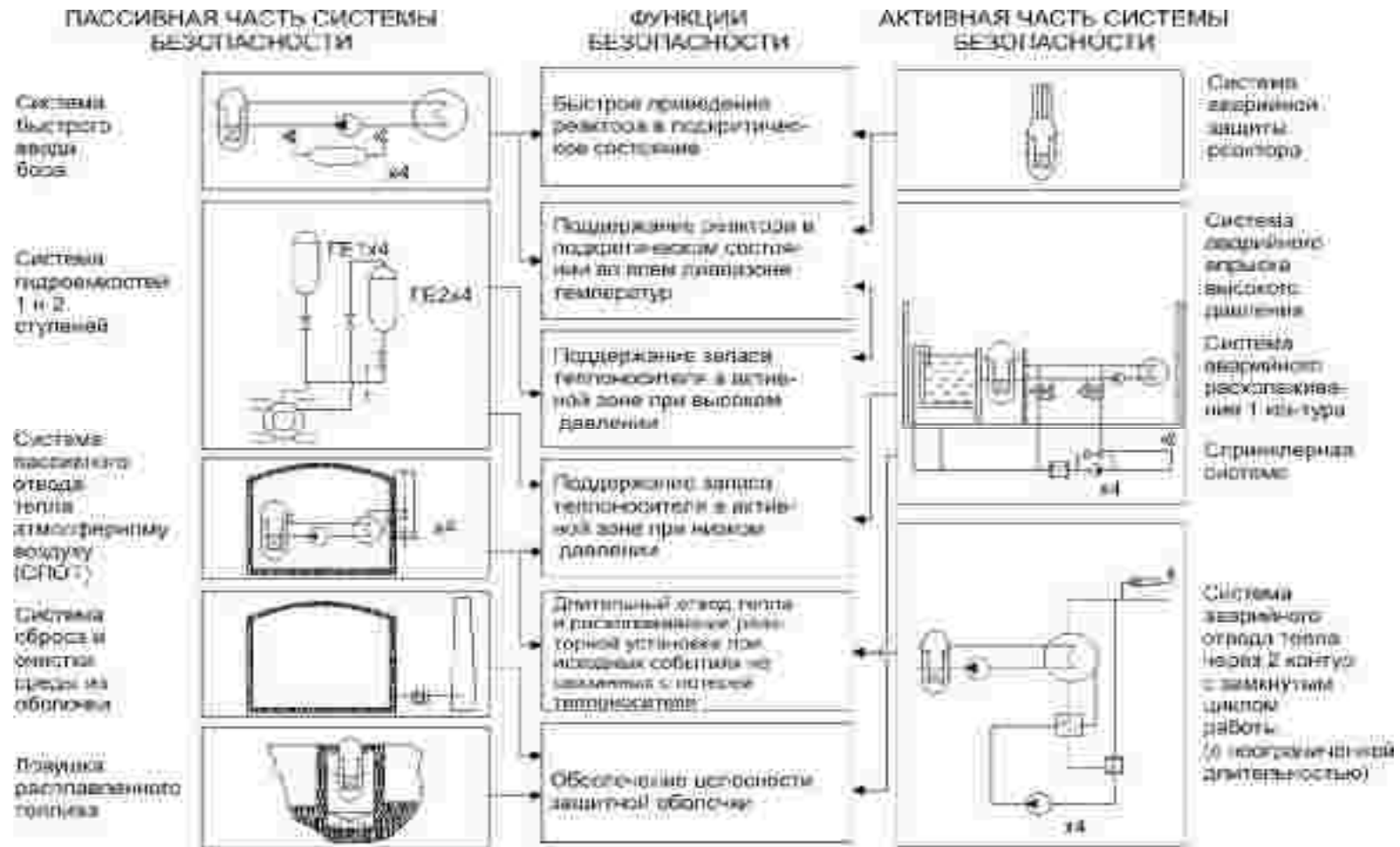


Рисунок 26 – Принципиальная схема систем безопасности энергоблока

1. реактор – reactor
2. главный циркуляционный насос – main circulating pump
3. парогенератор – steam generator
4. компенсатор давления – pressure capacitor
5. гидроемкость 1 ступени – stage 1 accumulator
6. гидроемкость 2 ступени – stage 2 accumulator
7. водозаборное устройство – water intake
8. теплообменник расхолаживания контура – circuit cooling heat exchanger
9. насос 1 контура – circuit 1 pump
10. эжектор – injector
11. теплообменник аварийного расхолаживания парогенератора – steam generator emergency cooling heat exchanger
12. насос аварийного расхолаживания парогенератора – steam generator emergency cooling pump
13. теплообменник промконтура – operating circuit heat exchanger
14. насос – pump
15. бак дыхательный – breathing tank
16. брызгальный бассейн – spray pond
17. насос подачи техводы – technical water input pump
18. теплообменник СПОТ – PHSS heat exchanger
19. газовая труба СПОТ – PHSS gas pipe
20. фильтр сброса паровоздушной среды из гермообъема – filter of steam-air sink from hermetic volume
21. мембранное устройство – membrane device
22. вентилятор – ventilator
23. фильтр – filter
24. вентиляционная труба – ventilation tube
25. защитная оболочка – protective cover
26. герметичная оболочка – hermetic cover
27. устройство для улавливания и удержания расплавленной активной зоны реактора – device for catching and keeping of reactor melted active zone
28. быстродействующий запорный отсечной клапан – fast-acting stop shut-off valve
29. емкость системы быстрого ввода бора – quick boron input container
30. спринклерная система – sprinkler system
31. система обеспечения водородной безопасности – hydrogen security provide system





### Figure 27 – Principle solutions on providing security functions in project NPP -92

Пассивная часть системы безопасности – Passive part of security

Система быстрого ввода бора – Quick boron input system

Система гидроемкостей 1 и 2 ступеней – Stages 1 and 2 accumulator systems

Система пассивного отвода тепла атмосферному воздуху (СПОТ) – System of passive heat sink to the atmosphere

Система сброса и очистки среды из оболочки – System of cover output and cleaning

Ловушка расплавленного топлива – Melted fuel catcher

Функции безопасности – Security functions

Быстрое приведение реактора в подкритическое состояние – Quick transition of the reactor into subcritical condition

Поддержание реактора в подкритическом состоянии во всем диапазоне температур – Keeping the reactor in subcritical condition at all temperature range

Поддержание запаса теплоносителя в активной зоне при высоком давлении – Keeping of fuel element store in the active zone at high pressure

Поддержание запаса теплоносителя в активной зоне при низком давлении - Keeping of fuel element store in the active zone at low pressure

Длительный отвод тепла и расхолаживание реакторной установки при исходных событиях не связанных с потерей теплоносителя – Continuous heat sink and reactor plant cooling at initial events not connected with heat carrier losses

Обеспечение целостности защитной оболочки – Providing continuity of protective cover

Активная часть системы безопасности – Active part of security system

Система аварийной защиты реактора – System of reactor emergency protection

Система аварийного впрыска высокого давления – System of emergency high pressure input

Система аварийного расхолаживания 1 контура – System of emergency cooling of the first circuit

Спринклерная система – Sprinkler system

Система аварийного отвода тепла через 2 контур с замкнутым циклом работы (с неограниченной длительностью) – System of emergency heat sink through the second circuit with closed operation cycle (unlimited operation)

**Table 25 – Security 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 t/hour carrying out all required functions in the whole regulation range – one is in operation, two are in reserve	Feeding: two pumps x 60 t/hours for "large" boron regulation and heat carrier leakage compensation. Three pumps x 6,3 t/hours for "flexible" regulation and leakages compensation.
AZECS active part	Combined two-channel high and low pressure system with reserving of 2 x 200 % and internal reserving of 2 x 100 %	Separate four-channel systems of high and low pressure with channel reserving of 4 x 100% each
System of emergency boron acid input	Two-channel system with channel reserving of 2 x 100 % and internal channel reserving of 2 x 50 %	Four-channel system with channel reserving of 4 x 50 %
Emergency feeding water system	Absent	Four-channel system with channel reserving of 4 x 100 % with storage tanks of emergency feeding water
System of SG emergency cooling	Closed two-channel system with reserving of 2 x 100 %	
System of passive reflooding of active zone (GE-2)	Passive four-channel system with channel reserving of 4 x 33 % and two containers in each channel	Absent
System of passive heat sink (PHSS).	Passive four-channel system with channel reserving of 4 x 33 % and two heat exchangers cooled with air in each channel	Passive four-channel system with channel reserving of 4 x 33 % with 18 heat exchangers cooled by water in each channel
<b><i>Security systems (for providing free lance operation modes of the energy plant)</i></b>		
Active part of active zone emergency cooling system	Combined two-channel high and low pressure system with reserving of 2 x 200 % and internal reserving of 2 x 100 %	Separate four-channel systems of high and low pressure with channel reserving of 4 x 100% each
System of emergency boron acid input	Two-channel system with channel reserving of 2 x 100 % and internal channel reserving of 2 x 50 %	Four-channel system with channel reserving of 4 x 50 %
Emergency feeding water system	Absent	Four-channel system with channel reserving of 4 x 100 % with storage tanks of emergency feeding water
System of SG emergency cooling	Closed two-channel system with reserving of 2 x 100 %	Absent
System of passive reflooding of active zone of stage 2	Passive four-channel system with channel reserving of 4 x 33 % and two containers in each channel	Absent
Passive heat sink system	Passive four-channel system with channel reserving of 4 x 33 % and two heat exchangers cooled with air in each channel	Passive four-channel system with channel reserving of 4 x 33 % with 18 heat exchangers cooled by water in each channel

Melting localization device	<p>The system is designed for keeping of liquid and solid fragments of destroyed active zone, parts of reactor body, interior body devices at heavy accidents with melting of active zone. The device carries out the following protective functions:</p> <ul style="list-style-type: none"><li>- receiving and placing inside of liquid and solid elements of active zone and reactor constructive materials;</li><li>- heat transmission from melting to cooling water;</li><li>- keeping the reactor bottom at its breaking off;</li><li>- preventing of melting coming out of the boundaries of its localization set by the project;</li><li>- providing subcriticality of the melting in concrete mine;</li><li>- providing cooling water input to the device and steam sink off the device;</li><li>- providing minimal output of radioactive substances into the hermetic cover space;</li><li>- minimization of hydrogen output;</li><li>- proving of not exceeding of maximal permitted voltages in constructions situated in under-reactor room of the concrete mine;</li><li>- providing the fulfillment of its functions with minimal operator's control.</li></ul>
Protective covers system	<p>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 project 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.</p>

### **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 active zone materials may cause destruction of the reactor body 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 m<sup>2</sup> (Order No. 99117898 with priority dated 12.08.1999).

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 active zone materials melt, interior body devices and reactor body to full crystallization. At that the following points are provided:

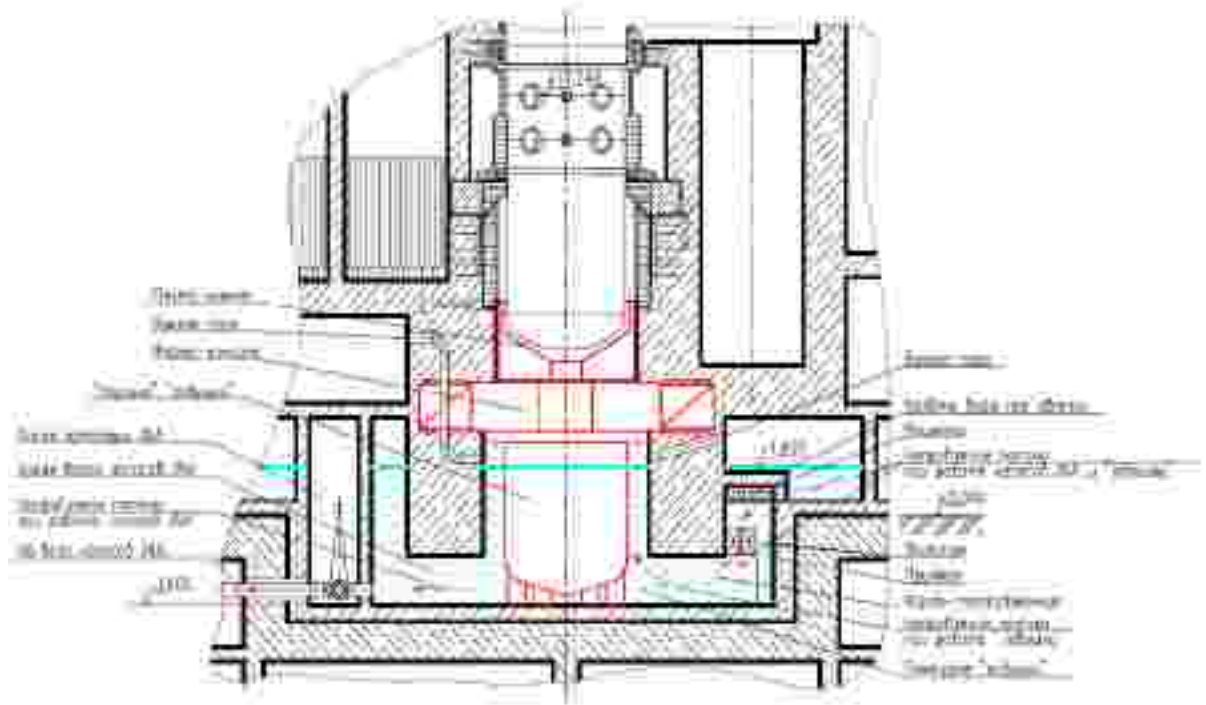
- keeping the reactor body bottom at its breaking-off or plastical deformation;
- not exceeding maximal permitted voltages in constructions carrying out melt cooling and construction;
- subcriticality of melt;
- minimization of output of radioactive substances into the hermetical space;
- minimization 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 active zone and in melt localization device with the possibility of distant control by the operator from control panel.

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

Figure 28 gives schematic arrangement of the active zone melt localization device.



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 Hermetic 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 hermetic enough considering pressure and temperature loads at guillotine break of circuit 1 pipeline or steam pipes;
- interior design cover pressure considers store more than maximal calculated cover pressure;
- pressure under cover is decreased more than for 50% of maximal pressure during 24 hours after the postulated accident;
- cover stands maximal pressure drop in the result of unintendent 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 off-project 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 security category 1 (ПИНЭЭ-5.6) and of seismic-resistance category 1 (НП-031-01). All shut-off valves in the protective cover shut-off system are made according to the 2L security 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 AES 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 security systems and equipment used in NPP project**

Design equipment and security systems of NPP is referred to RP B-320 line being exploited at NPP and an NPP built in China, being built in India, Iran, Bulgaria, Czech Republic and Russia (project of completing plant 5 of Balakov NPP, NVAES-2).

Adopted in the project technical solutions allow to provide the required level of RP reliability and security by balanced number of active and passive security systems and by measures directed to prevention and limitation consequences of accidents including heavy ones.

NPP project uses the following active and passive security systems implemented and operating with B-320 reactor plant 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 security 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 security systems are used partially or fully in the projects of AES being built in China (AES “Taiwan”), Iran (AES “Busher”), India (AES “Kudankulam”), Russia (project of completion of plant 5 of Balakov AES, 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 SS use

Figure 29 shows the results of improvements of passive security systems

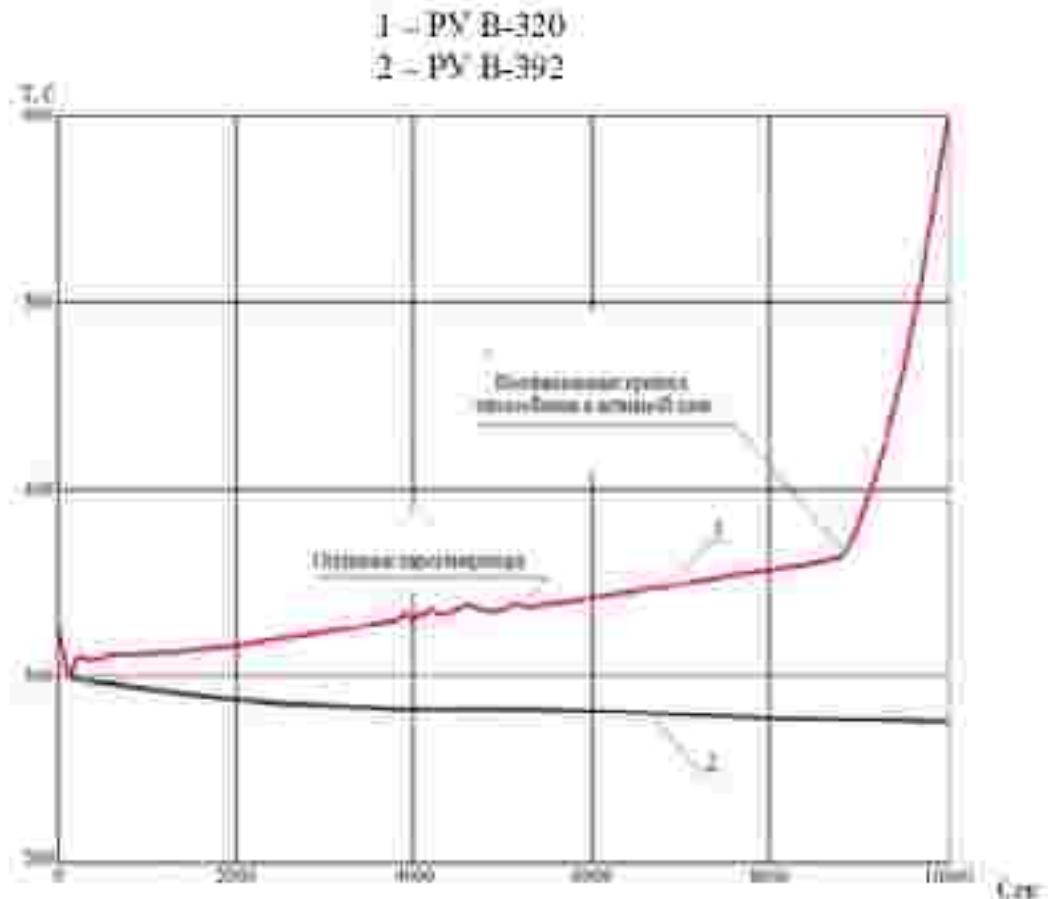


Figure 29 – Maximal temperature of fuel element cover at full loss of alternate current sources

Возникновение кризиса теплообмена в активной зоне – Appearance heat exchange crises in the active zone  
 Осушение парогенератора – Steam generator drying

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 active zone 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**

Жилпоселок – Residential area  
 Расчетный радиус зоны планирование мероприятий по экстренной эвакуации – Calculated radius of planning zone for urgent evacuation  
 Расчетный радиус зоны планирование защитных мероприятий (укрытия, йодная профилактика) – calculated radius of planning zone for protective measures (shelters, iodine preventive measures)  
 Площадка АЭС – NPP site  
 600 м – расчетный радиус санитарно-защитной зоны – 600 m- calculated radius of sanitary –protection zone



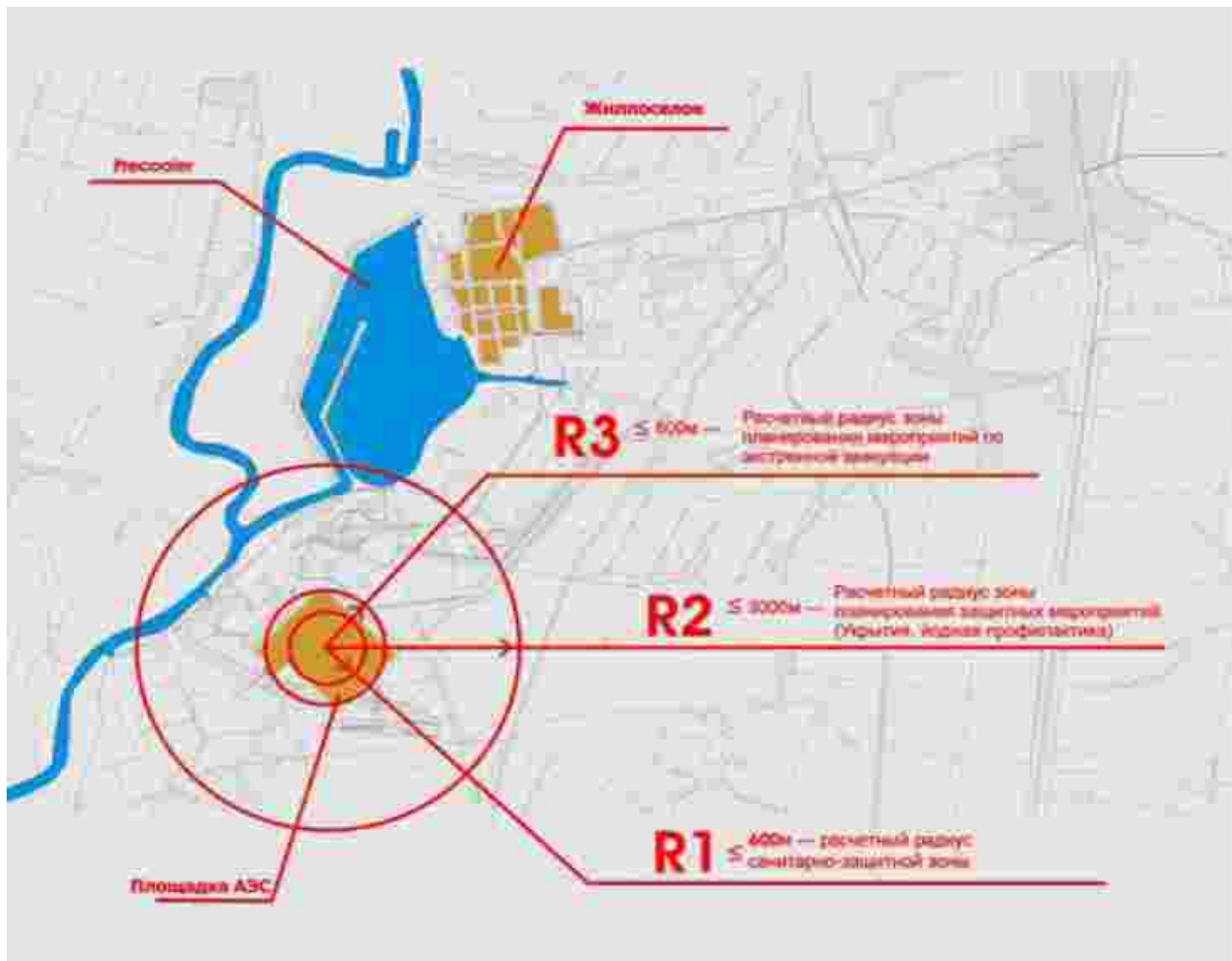


Figure 30 shows calculated values of radiuses for different zones where different activities at accidents are planned; so the calculated radius value of planning urgent evacuation zone doesn't exceed 800 m; this fact proves the absence of practical need in such activities.

Project NPP -2006 successfully combines reference qualities and positive experience of equipment and systems exploitation in operating NPP, great progress in technology allowing to rise at high level of security and at the same time to reach economical 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 electro 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  $N_{rat}$ . SPUC at energy plant operation in base mode is not less than 90%. Effective use at reactor operation with rating 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 plant with water-moderated energy reactor with pressurized water and turbine plant. Heat diagram is two-circuit.

The first circuit is radioactive and consists of heterogenous reactor on heat neutrons, four main circulating loops, steam pressure capacitor, and auxiliary equipment. Each circulating loop includes: steam generator, main circulating pumping aggregate, main circulating pipeline Du850.

Fuel is low-enriched uranium dioxide. Heat carrier of the first circuit heated at passing through the reactor active zone 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 Byelorussian will include two energy plants with PWR-1200 RP.

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 electrical power output.

The following requirements were considered at general plan arrangement:

- providing maximal autonomy of energy plants (nuclear part);
- module principle of the construction site with unified modules-energy plants;
- 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 zone is situated in the centre of the site and includes unit modules-energy plants united into one construction unit. Each module includes:

- reactor building;
- transport hatch estacade;
- steam chamber;
- security building;
- auxiliary building;
- control building;
- new fuel and solid radioactive wastes reservoir;
- nuclear service building with service rooms of controlled access zone;
- turbine building;
- normal operation electro supply building;
- heating building;
- water preparation building with chemical water cleaning auxiliary tanks;
- And separate construction:
  - a) ventilation tube;
  - b) building of reserve diesel electro station of emergency electro 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 electro station 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 minimal distances from the reactors buildings. Each unit has two pumping consumers stations with switching chambers.

Main buildings and energy plants site will be fenced. Two road approaches are planned.

Personnel passage from check post of free-access zone service building to energy plants buildings is along pedestrian tunnel.

Two evaporation cooling stacks with turbine building consumers pumping stations are situated on the industrial site from the side of turbine buildings.

The following general station buildings and constructions are planned in industrial site from the side of the first plant:

- free access zone 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 zone waste water and other auxiliary buildings.

General station buildings and constructions zone is arranged considering the possibility of enlarging objects for NPP second construction stage (for plants 3 and 4).

NPP electrical power output to the energy system will be carried out through complex distribution gas-insulated of 330 kV (KRUE-330 kV).

Territory KRUE includes:

- KRUE – 330 kV building;
- KRUE-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 zone AES project considers free access zone 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 plants fencing will be installed around nuclear part.

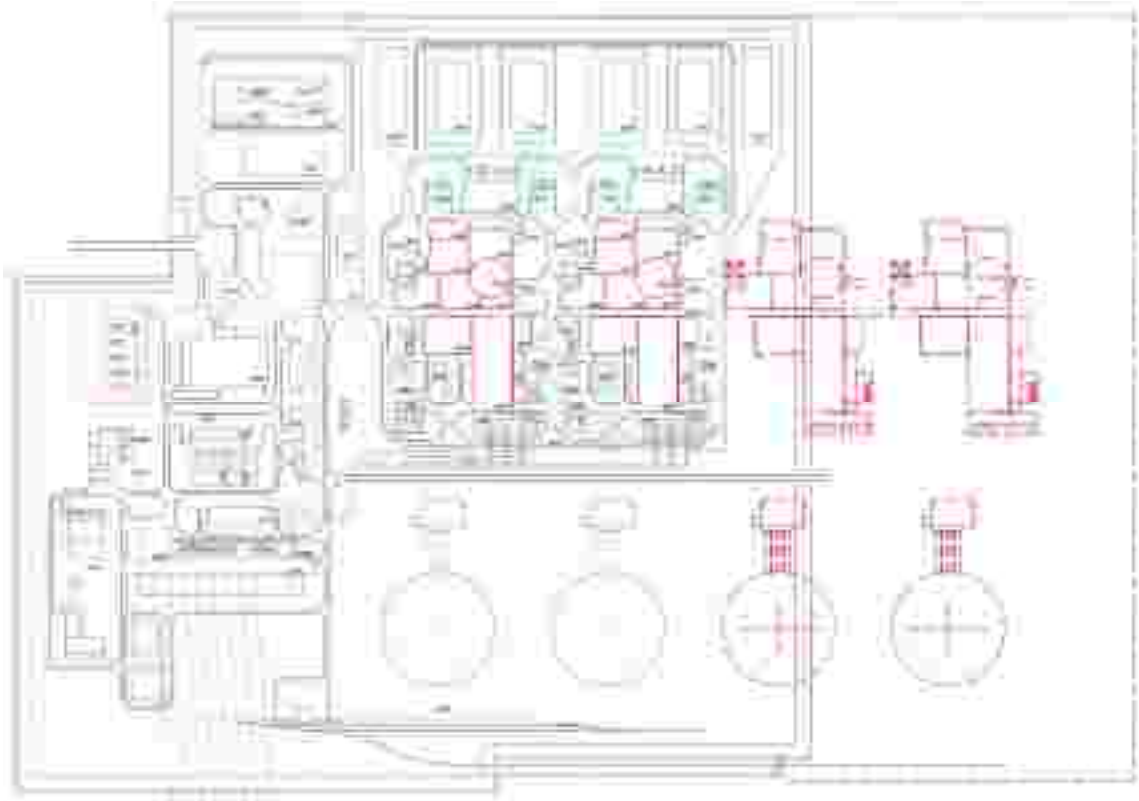
There are three drives to the industrial site: automobile – from the side of the first plant neat the main check post and from the side of the second NPP plant where there will be rail and automobile drives with check posts, according to GO the third drive from the site is required.

Within the site fence NPP railway station will be designed mainly for removing of worked-out fuel and receiving of new fuel. The station will also have an open station refueling node.

For organization of security means the NPP will have a complex of physical protection buildings situated in the zone 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 zone and behind the second energy plant.

General plan of NPP -2006 is given in figure 31.



**Figure 31 – General plan of NPP -2006**

Approximate appearance of byelorussian NPP is given in figure 32.



**Figure 32 – Approximate appearance of byelorussian NPP**

## **7 CHARACTERISTICS OF BYELORUSSIAN 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 mortality - 10 – 15 years;
- mortality with preliminary stage of conserved energy plant par t-
  - 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 Construction of atomic station

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 inertia 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**

<b>Main materials used in construction</b>	<b>Hard-to remove waste and looses, thous. m<sup>3</sup></b>
<b>Central-mixed concrete</b>	<b>13,3</b>
<b>Ready mixture</b>	<b>0,35</b>
<b>Roll hydro isolation and roofing materials, thous m<sup>3</sup></b>	<b>0,05</b>
<b>Mineral wool articles, thous m<sup>3</sup></b>	<b>1,06</b>
<b>Paint-and-lacquer materials and bitumen compounds</b>	<b>0,1</b>
<b>Saw timber</b>	<b>0,31</b>
<b>Unrecycled tara and package</b>	<b>9,00</b>
<b>Unconsidered waste</b>	<b>0,73</b>
<b>Total construction waste</b>	<b>24,90</b>
<b>Total domestic waste</b>	<b>7,1</b>

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 zone (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 Byelorussian NPP – Nizhegorodsk NPP [14].

All material used on the site can be divided into three groups:

- road-construction material (360 pcs with total power of 25500 kW);
- road transport (482 pcs);
- diesel plants (13 pcs with total power of 440 kW).

**Table 27 – Maximal concentration of substances in working area MCD parts in atmospheric air in the construction site at simultaneous work of all material**

Substance	Maximal concentration in MCD doses	MCD, mg/m <sup>3</sup>	Danger class
CO	0,35	20	4
NO <sub>2</sub>	0,79	5	2
NO	0,13	5	3
CH	<0,01	900	4
C	0,13	4	3
SO <sub>2</sub>	0,02	10	3
NH <sub>3</sub>	<0,01	20	4
CH <sub>2</sub> O	<0,01	0,5	2
Benzpyrene	<0,01	<sub>4</sub> 1,5·10 <sup>-</sup>	1
Summation group (NH <sub>3</sub> + CH <sub>2</sub> O)	<0,01	-	-
Summation group (NO <sub>2</sub> + SO <sub>2</sub> )	0,80	-	-

**Table 28– maximal concentration dose of substances for population in the air at the nearest population centre (2 km from the construction ground) at dangerous speed of wind (0,5 m/s) by types of simultaneously working material**

	Maximal concentration in MCD doses				M CD, mg/m <sup>3</sup>
	road-construction material	Road transport	Diesel plants	All material	
CO	0,15	0,13	0,81	0,98	5
NO <sub>2</sub>	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	<sub>5</sub> 0,1
SO <sub>2</sub>	0,08	0,05	0,01	0,14	0,5
NH <sub>3</sub>	<0,01	<0,01	<0,01	<0,01	0,2
CH <sub>2</sub> O	-	-	0,02	0,02	<sub>35</sub> 0,0
Benzpyrene	-	-	0,01	0,01	<sub>0<sup>-6</sup></sub> 1·1
Summation group (NH <sub>3</sub> + CH <sub>2</sub> O)	-	-	-	0,02	1
Summation group (NO <sub>2</sub> + SO <sub>2</sub> )	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<sub>2</sub> substances and summation group (NO<sub>2</sub>+ SO<sub>2</sub>) from HCS output by working road-construction material 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 maximal waste volume is 385 tons/month	Approximate maximal waste volume is 740 tons/month
Remained waste water		
Concrete sediments		
Plumbeous batteries		
Soil contamination		
Used oil	730 000 m <sup>3</sup>	1 400 000 m <sup>3</sup>
Remained paint		
Drinking and unprocessed water - drain after processing	20 000 m <sup>3</sup> /month as maximal volume	40 000 m <sup>3</sup> /month as maximal 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 maximal 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 plant 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 constructional 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.

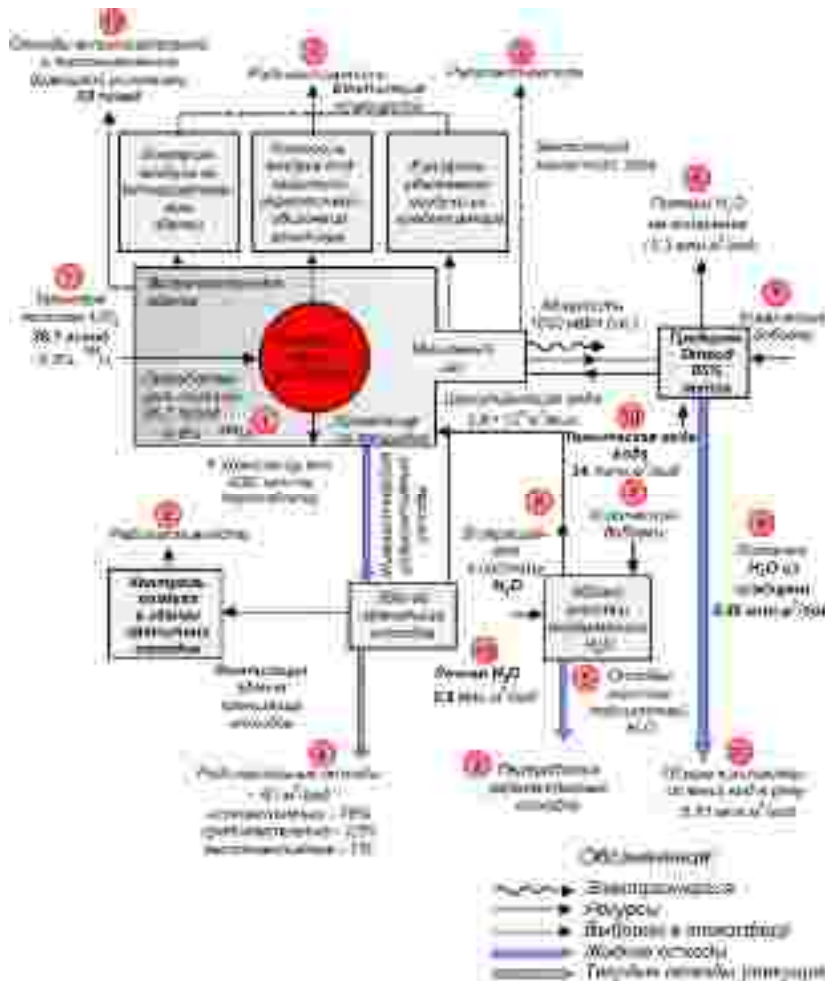
Organization of works on linear constructions (roads and railroads, technical water supply channels, pipelines) considers maximal use of linear construction spots for drives.

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 List and brief characteristics 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 nodes of impact on the environment**

Отходы вспомогательной и дополнительной дизельной установки 53 т/год  
 – Waste of auxiliary and additional diesel plant 53 t/year

Радиоактивность – Radioactivity

Вентиляция помещений – Rooms ventilation

Контроль воздуха во вспомогательном помещении – Air control in auxiliary rooms

Контроль воздуха под защитной герметичной оболочкой реактора – Air control under protective hermetic cover of the reactor

Контроль удаляемого воздуха из конденсатора – Control of the air removed from the capacitor

Вентиляция машинного зала – Machine hall ventilation

Урановое топливо 26,7 т/год – Uranium fuel, 26,7 t/year

Вспомогательное здание – Auxiliary building

Отработавшее топливо 26,7 т/год – Worked-out fuel, 26,7 t/year

Контеймент реактора – Reactor containment

Хранилище на площадке – Storage on the ground

Машинный зал – Machine hall

Мощность 1000 мВт (эл.) – Power 1000 MW (el)

Градирня. Отвод 65 % тепла – Cooling stack. Sink of 65 % sink

Химические добавки – Chemical supplements

Циркулирующая вода  $2,6 \cdot 10^3 \text{ м}^3/\text{мин}$  – Circulating water  $2,6 \cdot 10^3 \text{ м}^3/\text{мин}$   
 К хранилищу вне АЭС или на переработку – To the storage outside NPP or for recycling  
 Жидкие/твердые радиоактивные отходы – Liquid/solid radioactive waste  
 Возвращаемая в систему H<sub>2</sub>O – H<sub>2</sub>O returned to the system  
 Остатки H<sub>2</sub>O из градирни 5,45 млн.м<sup>3</sup>/год – Remains of H<sub>2</sub>O from cooling stack of 5,45 mln m<sup>3</sup>/year  
 Контроль воздуха в здании хранилища отходов – Air control in waste storage building  
 Вентиляция здания хранилища отходов – Ventilation of waste storage building  
 Здание хранилища отходов – Waste storage building  
 Здание очистки подпиточной H<sub>2</sub>O – Feeding H<sub>2</sub>O cleaning building  
 Речная H<sub>2</sub>O 0,5 млн.м<sup>3</sup>/год – River H<sub>2</sub>O 0,5 mln m<sup>3</sup>/year  
 Отходы очистки подпиточной H<sub>2</sub>O – Feeding H<sub>2</sub>O cleaning waste  
 Радиоактивные отходы 60 м<sup>3</sup>/год – Radioactive waste 60 m<sup>3</sup>/year  
     низкоактивные – 76 % - low-active  
     среднеактивные – 23 % - medium-active  
     высокоактивные – 1 % - high-active  
 Переработка радиоактивных отходов – Radioactive waste processing  
 Общее количество сливных вод в реку 6,81 млн.м<sup>3</sup>/год – Total amount of water drain to river of 6,81 mln m<sup>3</sup>/year  
 Обозначения – Markings  
     электроэнергия – electro energy  
     ресурсы – resources  
     выбросы в атмосферу – output to atmosphere  
     жидкие отходы – liquid waste  
     твердые отходы (текущие) – solid waste (current)

Critical by their impacts on the environment nodes are marked with circles on the figure. These nodes 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 stacks with natural air thrust using river water. The following critical nodes are marked with numbers:

Node 2. Uranium demand and worked-out fuel placement. For active zone fueling 80 tons of fuel are required - UO<sub>2</sub>. 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 worked-out fuel after that is kept in NPP in worked-out fuel cooling ponds. Activity of worked-out fuel after unloading is about  $10^{20} \text{ Bq}$ .

Node 2 (figure 33). Annual permitted output of radioactive gases and AS aerosols are rated as SP AS-03. For PWR reactors the following values of extreme annual outputs are determined:

- IRG -  $6,90 \times 10^{14} \text{ Bq}$ ;
- <sup>131</sup>I (gas + aerosol forms) –  $1,8 \times 10^{10} \text{ Bq}$ ;
- <sup>60</sup>Co -  $7,4 \times 10^9 \text{ Bq}$ ;
- <sup>134</sup>Cs -  $0,9 \times 10^9 \text{ Bq}$ ;
- <sup>137</sup>Cs -  $2,0 \times 10^9 \text{ Bq}$ .

Besides, annually NPP outputs about  $2,3 \times 10^{11} \text{ Bq}$  of <sup>14</sup>C and about  $3,0 \times 10^{13} \text{ Bq}$  of <sup>3</sup>H. The reason of gaseous outputs in AES is leakage through fuel elements

noncompactness and getting of gaseous fission products into first circuit heat carrier. These gases are removed from the heat carrier 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.

Node 3. Liquid radioactive waste of corrosion products and tritium with activity of  $4,44 \times 10^9$  and  $1,12 \times 10^{13}$  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 worked-out liquids for reuse.

Node 4. Predicted activity of low-active solid radioactive waste (including remains after liquid waste evaporation) is about  $1,96 \times 10^{14}$  Bq/yaer.

Nodes 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  $302800 \text{ m}^3/\text{year}$ . 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  $15,14 \text{ mln m}^3/\text{year}$ . 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  $3,785 \text{ mln m}^3/\text{year}$  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 cromium are used for these purposes.

5) Water used in cooling stocks (items 3 and 4) in amount of about  $19 \text{ mln m}^3/\text{year}$  comes directly from rivers.

Node 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 differ depending on quality of used water.

Node 12. Organic fuel combustion products are formed even at nuclear station. Relatively small amounts of  $\text{SO}_2$ ,  $\text{NO}_x$ , 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 electrical 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 mortality 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;
- electro magnetic 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 stacks with counter-flow movement of air and water heat carrier as energy plants turbine equipment coolant for byelorussian NPP. Evaporating cooling stack 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 stack 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 AES ground atmosphere boundary layer.

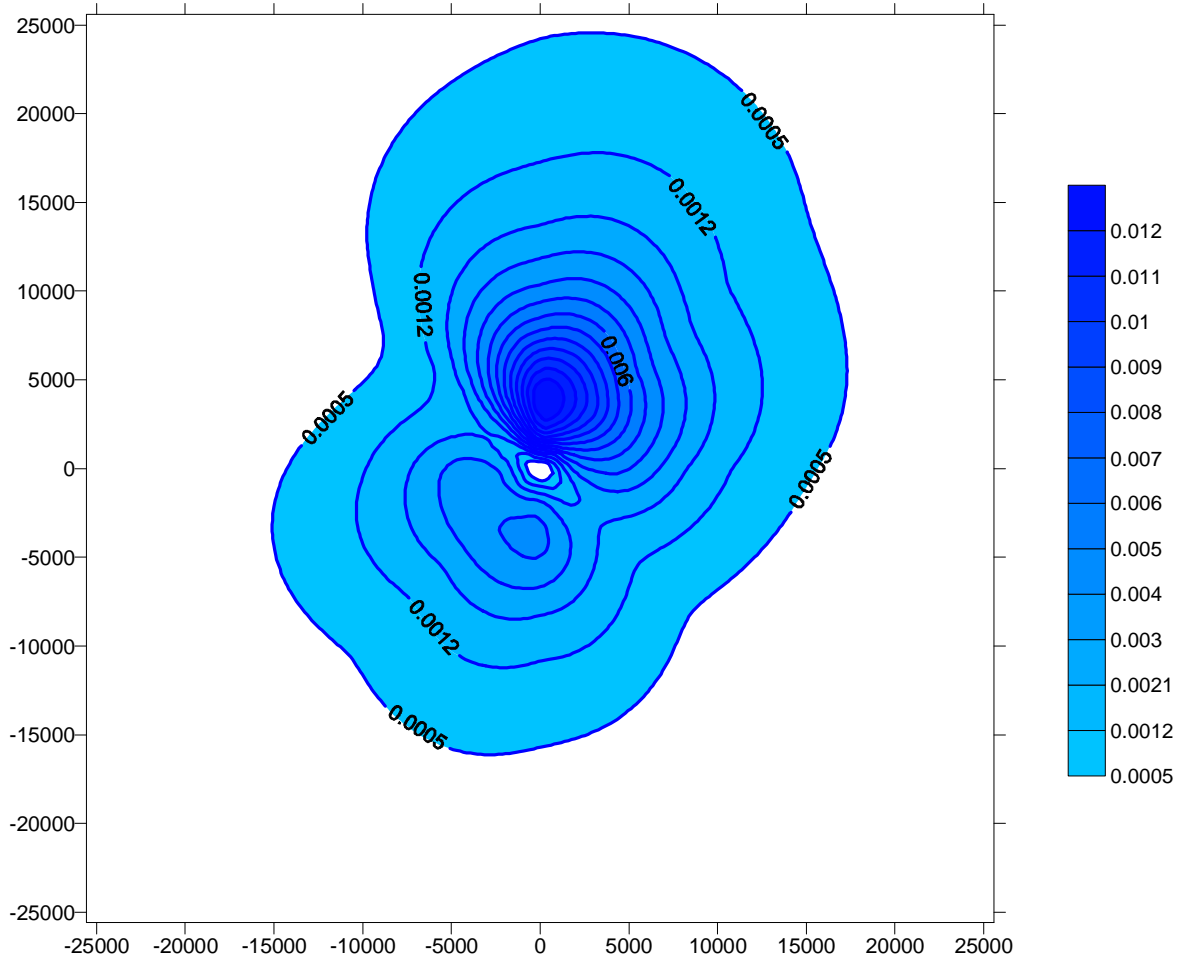
As an example for putting into operation and mortality stage of byelorussian NPP let's take estimation of impact of atmospheric outputs by evaporating cooling stacks at Nizhegorodsk NPP on the micro climate of nearby areas.

It is suggested to use tower evaporating cooling stack on energy plant with rating power of 1200 MW; the cooling stack calculated heat load is 1717 Gcal/h and it has the following parameters:

- a) geometrical parameters of cooling stack:
  - tower height -170 m;
  - tower mouth diameter – 86,8 m.
- b) expanse of air through the tower mouth:
  - in summer – 21300 m<sup>3</sup>/s;
  - in winter – 22750 m<sup>3</sup>/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 maximal annual values of ground humidity and temperature increase can reach 0,0129 g/kg and 0,0133 °C correspondingly at distance of 3360 to 4490 m from cooling stacks at southern wind direction.

Figure 34 shows distribution of calculated increases of ground specific humidity around Nizhegorodsk NPP cooling stacks [14].



**Figure 34 – Distribution of calculated increases of ground specific humidity (g/kg) around Nizhegorodsk NPP cooling stacks. Point with coordinates (0,0) is the place where cooling stacks are situated. Distance from the cooling stacks (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. Maximal 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 stacks in Nizhegorodsk AES 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 Nizhegorodsk NPP. Average annual air temperature in the ground region is 4,3 °C. On the base of this we can make a conclusion that cooling stacks 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<sup>2</sup>, 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 stack 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 stacks and complex calculations with use of hydrodynamic model of forming steam and moisture torch in the region of cooling stacks showed:

- circulating water supply system with tower cooling stacks is satisfactory from the point of view of environment protection;
- cooling stacks influence on the environment mainly through steam and moisture torch;
- application of modern highly-effective polymer catchers in cooling stacks allows to reduce droplet entrainment from 0,6% (without water catcher) to 0,002% and minimize negative influence of cooling stacks on the environment;
- region of cooling stacks influence on microclimate is restricted by industrial site with a slight (not more than 150-200 m) outside it;
- temperature and humidity changes created by cooling stacks heat and steam and moisture outputs are slight and reach maximal values of 6 – 8 °C (for air temperature) and 5 – 6 % for relative humidity;
- maximal values of water remain intensity on the surface by gravitation sedimentation of water drops through the tower output section and formed in the atmosphere in the 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”.

Расчеты башенной градирни для белорусской АЭС будут проведены на этапе архитектурного проекта.

### **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 in the 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 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 zone 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	Disbalancing 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 discharge протечек	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 industrial ground	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%

Continuation of table 30

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 industrial grounds 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 <sub>x</sub> , SO <sub>2</sub> , CO, V <sub>2</sub> O <sub>5</sub> , carbon
2 Oil-fuel oil sector	Periodically	Kerosene, carbon vapors
3 Diesel-generator stations	Periodically	NO <sub>x</sub> , SO <sub>2</sub> , CO, carbon
4 Centralized repairing workshop	Periodically	Mg, welding aerosol, abrasive metal dust
5 Repairing and construction sector	Periodically	Inorganic dust with SiO <sub>2</sub> content of less 20 to more than 70 %, wood dust, NO <sub>x</sub> , SO <sub>2</sub> , CO, carbon black
6 Road transport	Periodically	NO <sub>x</sub> , SO <sub>2</sub> , CO, carbon black, naoil products vapors, petrol, kerosene and others.
7 Housing and communal control	Periodically	CO, NO <sub>x</sub> , wood dust, welding aerosol, oil products vapors
8 Complex of solid radioactive waste recycling	Periodically	CO <sub>2</sub> , NO <sub>x</sub> , SO <sub>2</sub> , 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 stacks;
- sludge water after cleaning grid and disk filters and ultra filtration installation membranes (FIM);
- concentrate from installation of stage 1 back osmius;
- 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 plant of byelorussian 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 <sup>3</sup> /hour	2322	73.5	14,6	62.9	2473
Input mode	Constant	Constant	Периодический	Constant	
Weighted substances, mg/l	12,4	0	9	175,3	11,7
Water temperature, °C	Зима -27.2	25	30	25	27,1
	Лето – 37.7				37,0
Mineralization, mg/l	679	1513	728	387	697
pH	8,25	7,51	7,5	7	8,19
Calcium . Ca <sup>2+</sup> (mg/dm <sup>3</sup> )	116,74	253.4	65	63,71	119,1
Magnum. Mg <sup>2+</sup> (mg/dm <sup>3</sup> )	31,96	68,13	19	17,13	32.58
Sodium. Na <sup>2+</sup> (mg/dm <sup>3</sup> )	10,08	35,76	94,89	7,75	11,28
Potassium. K <sup>+</sup> (мг/дм <sup>3</sup> )	4,66	9,49	2,5	2,5	4,74
Ferrous general (mg/dm <sup>3</sup> )	0,06	0,2	0,095	0,05	0,064
Manganese. Mn <sup>2+</sup> (mg/dm <sup>3</sup> )	0,02	0,2	0,100	0,098	0,028
Aluminum. Al <sup>3+</sup> (mg/dm <sup>3</sup> )	0,042	0,2	0,453	0,05	0,049
Zinc . Zn <sup>2+</sup> (mg/dm <sup>3</sup> )	0,026	0,052	0,013	0,013	0,0264

Continuation of table 32

Phosphates. $\text{PO}_4^{3-}$ (mg/dm <sup>3</sup> )	0,238	0,4	0,103	0,103	0,238
Chlorides $\text{Cl}^-$ (mg/dm <sup>3</sup> )	24,86	68,17	17,18	17,18	25,9
Sulfates. $\text{SO}_4^{2-}$ (mg/dm <sup>3</sup> )	37,8	229,2	330,9	57,47	45,7
Бикарбонаты (мг- экв/дм <sup>3</sup> )	428,7	779,1	166	197	432
Кремний. $\text{SiO}_3^{2-}$ (mg/dm <sup>3</sup> )	14,86	35,8	9,3	9,21	15,3
Аммоний. $\text{NH}_4^+$ (mg/dm <sup>3</sup> )	0,08	2,26	0,6	0,6	0,161
Нитраты. $\text{NO}_3^-$ (mg/dm <sup>3</sup> )	0,80	29,79	7,8	7,8	1,88
Нитриты. $\text{NO}_2^-$ (mg/dm <sup>3</sup> )	0,012	0,14	0,074	0,074	0,0177
Нефтепродукты	0,016	0,02	0,013	0,013	0,0160
СПАВ	0,002	0,01	0,05	0,05	0,0037

### 7.3.4 Characteristics of chemical outputs

Buildings situated on the industrial ground of byelorussian NPP are the source of periodical impacts on the environment in the 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 plant 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 crash. 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 inertia 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**

AES	IRG	I-131	Co-60	Cs-134	Cs-137
	TBк (% of PO)	MBк (% of PO)			
<b>NPP with PWR-1000 and PWR-440</b>					
Novovoronezh	110 (16)	1700 (9,4)	350 (4,7)	41 (4,6)	140 (7)
Kolsk	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)
Balakov	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 disbalanced station water from the controlled access zone (CAZ) is dumped. 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 plant operation in normal mode is shown in figure 36.

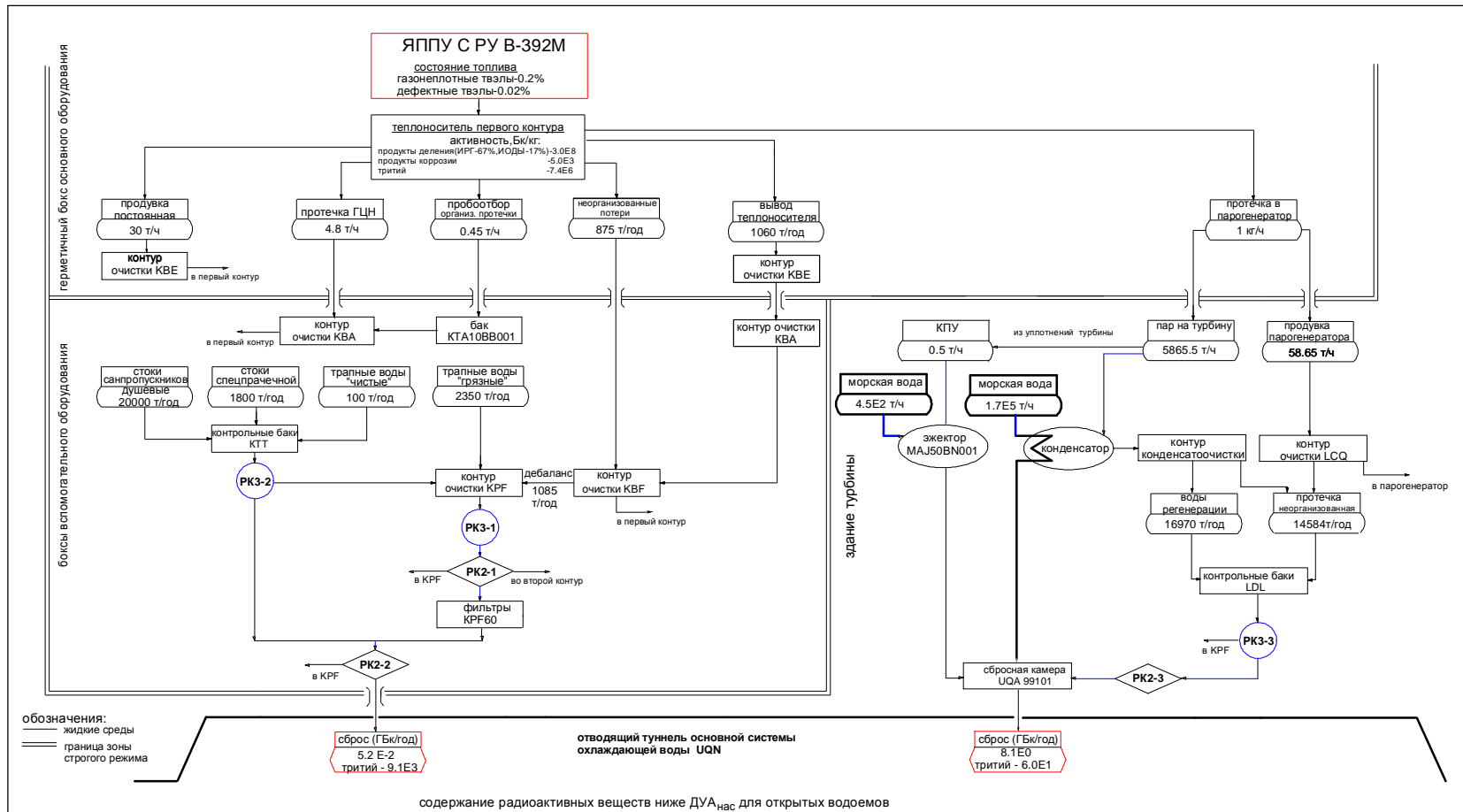


Figure 36 – Output of radioactive substances into the environment with liquid non-radioactive dumps at plant operation in normal mode.



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**  
**водоемы**

AES	Volume of dumped water, m <sup>3</sup>	Radionuclides passing to water basins, % of PO
<b>NPP with PWR-1000 and PWR-440 reactors</b>		
Novovoronezh	51000	18,9
Kolsk	16102	0,01
Rostov	NPP uses circulating water supply	—
Balakov	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 (Novovoronezhsk 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 minimal 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 AES 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). Security of waste disposal function is based on energy plant 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 than 10
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 exploitation is its classification according to gamma-radiation power level at distance of 0,1 m from the surface:

- low-active – 1 mcSv/h to 300 mcSv/h;
- medium-active – 0,3 mcSv/h to 10 mcSv/h;
- high-active – more than 10 mcSv/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 “security 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 (worked-out 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 active zone (heat carrier, construction materials), in neutron radiation field.

Through leakages in fuel elements covers active products can pass to first circuit heat carrier. Mixtures of radionuclides activation products also pass there in the result of construction materials corrosion; besides, radionuclides in the heat carrier 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, worked-out 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 in the result of fuel elements leakages into the heat carrier, 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 security requirements given in main normative documents [46 – 48].

Согласно основным технологическим схемам обращения с РАО, обращение с РАО трех агрегатных состояний (жидкие, твердые, газообразные) в упрощенной форме может быть описано следующим образом:

### **7.5.2 Solid RW**

Solid waste is formed in controlled access zone buildings (most part of solid RW 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 disassembled for transportation. Medium-active SRW are transported to the storage and reclaiming building in protective containers.

- high-active wastes whose range is determined include worked-out RP 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 t/h. in the 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 worked-out 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 burial 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 centres 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<sup>3</sup>/year, what is less than in operating NPP with PWR-1000 in Russia.

Dering 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 station systems and is 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 zones; in the atmosphere of these buildings a slight amount of radioaerols 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 capacitor barometer relief gases passed through hydrogen burning system. Auxiliary operation thread cleans relief gases from heat carrier 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<sup>3</sup>, 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 AES [14].

**Table 36 –Amount of SRW passing to reclaiming and further storing in 00UKS building from two plants**

Waste	Place of formation	Amount of waste from two plants passing to 00UKS building, m <sup>3</sup> /year (at normal operation, maintenance and repairing, at accidents)	Note
<b>1 Low-active SRW</b>			
1.1 Combustible	Controlled access zone buildings	220 (110/110)	
1.2 Incombustible pressed	Controlled access zone buildings	130 (65/65)	
1.3 Metal	Controlled access zone 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 zone buildings	32	Once in two years
1.5.2 Горючие	Controlled access zone 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	
<b>2 Medium-active SRW</b>			
2.1 Metal	Controlled access zone buildings	10 (10/-)	90 % for reclaiming
2.2 Other waste			
2.2.1 Combustible	Controlled access zone buildings	23 (11,5/11,5)	90 % for reclaiming

Continuation of table 36

2.2.2	Incombustible	Controlled access zone buildings	54 (54/-)	90 % for re-claiming
2.3	Filters			
2.3.1	Incombustible	Controlled access zone buildings	75	Once during the operation period (50 years)
2.3.2	Combustible	Controlled access zone 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 <sup>3</sup> /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-out 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 plant into operation;
- because of absence of the personnel on the industrial ground, 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 sanitary protection zone, 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 POY 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 electro station of energy plant No.2	Diesel generator with auxiliary equipment Compressor Technical water pumps of "B" group	Periodical Constant Constant
7 General plant diesel generating electro station	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 State Standard 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 jamming 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 byelorussian NPP the following HL-330 kV are considered:

- from energy plant 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 – minimal 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 deter-



mined by calculations according to “Norms of the personnel protection from electric field impact”.

**Table 40 – Minimal distances of HL-330 kV cables over the ground**

HL span placement	Minimal distance of HL cables over the ground, m at HL rating voltage, kV	
	330	
	According to the norms	According to the project
In unpopulated places (AES territory)	7,5	25 (17)*
On cross-roads	8,5	25-17(10-25)

\* Values considering maximal 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 Byelorussian AES.

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 alternate current transmission facilities”.

### **7.6.3 Impact of oil-filled equipment and its estimate**

On the territory of byelorussian NPP from the side of turbine compartment row Goil-filled transformers will be installed. They include plant transformer of 3xOПЦ-417000/750/3 type, auxiliary transformers of 2xTPДHC-63000/35 type, and energy plant reserve auxiliary transformers of 2xTPДHC-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 active zone with enough fuel to keep the required power level, to take worked-out fuel out of the active zone 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;
- active zone refueling;
- handling and storage near reactor of worked-out (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:

- active zone includes 163 fuel elements;
- refueling of reactor active zone is carried out one time in 18 months, at that about  $\frac{1}{4}$  active zone FE are replaced – 41 pcs maximum;
- loading (unloading) of nuclear fuel to (from) reactor is carried out through the transport hatch along the tristle;
- delivery of fresh fuel elements to the reactor, refueling and removing of worked-out fuel is carried out when the energy plant 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;
- worked-out fuel elements are cooled in boron water with concentration of 16 to 20 g/dm<sup>3</sup> and maximal 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 НП-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-60CK carriages;
- fresh fuel is delivered to the reactor in packing sets on a special platform with freight capacity of 50 tons;
- worked-out nuclear fuel unloaded from the reactor is kept in energy plant reactor within the hermetic zone;
- all main operations on refueling are carried out by fuel-handling machine;

- worked-out 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 worked-out fuel elements for ten years including placing of defect fuel elements in hermetic penals and the possibility of re-fueling of the whole reactor active zone in any moment of NPP operation.

Cooling pond has four compartments- three compartments for storage of worked-out fuel and FC-13 container fueling compartment for worked-out fuel elements.

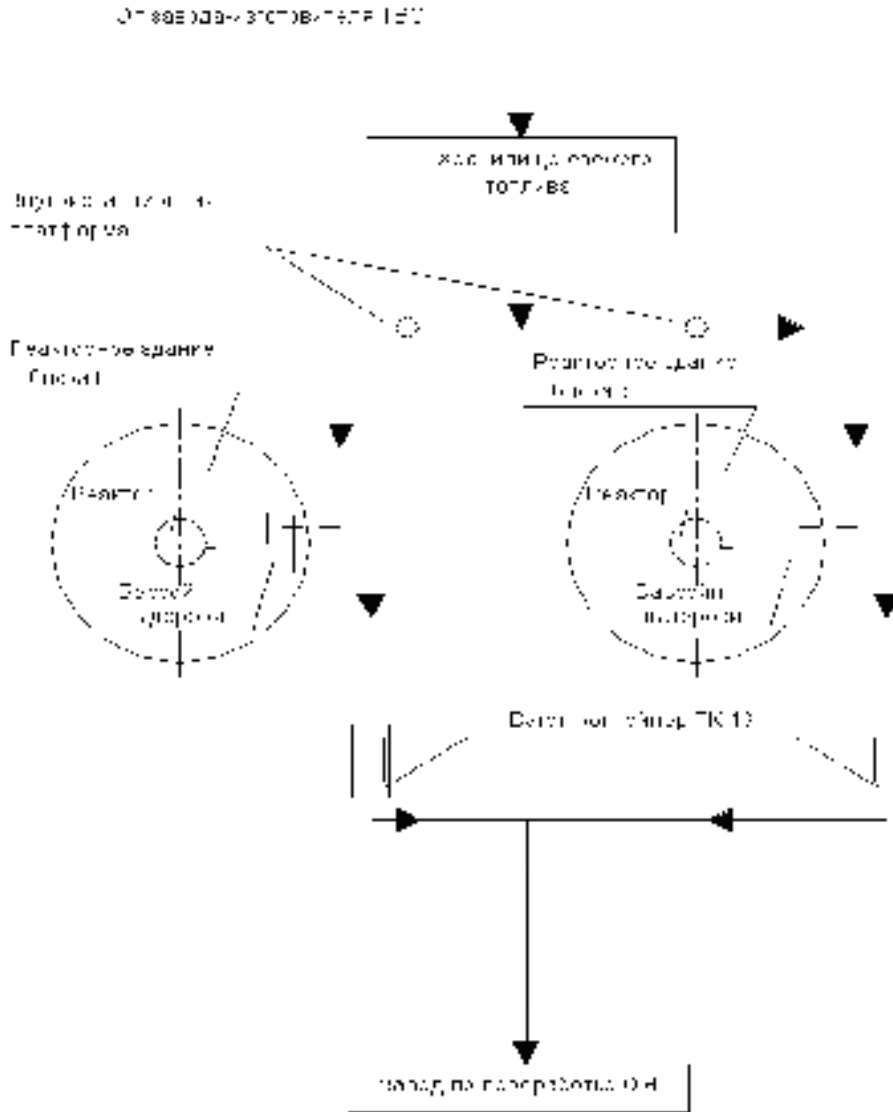
At moving-out of worked-out nuclear fuel FC-13 is delivered to the operative mark of reactor hall for and loaded through the hatch. Shock absorbers reduce loads on the container in case of its falling to the loads equivalent to loads at it falling from 9 m height to the firm foundation.

During refueling cooled worked-out nuclear fuel is taken from the atomic station 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 moving-out. Building for storage of worked-out nuclear fuel is not planned.

Refuel and fuel storage systems elements are extremely important for the security 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**

От завода-изготовителя ТЭС – From fuel elements manufacturing plant

Хранилище свежего топлива – Fresh fuel storage

Внутристанционная платформа – Interior- station platform

Реакторное здание блока 1 – Unit 1 reactor building

Реакторное здание блока 2 – unit 2 reactor building

Реактор – Reactor

Бассейн выдержки – Cooling pond

Вагон-контейнер ТК-13 – FC-13 container -carriage

Завод по переработке ОЯТ – WNF reclaiming plant

## 9 RADIATION PROTECTION

### 9.1 Radiation security control

According to NRB-2000 the main purpose of radiation security is health protection including health of the personnel from harmful impact of ionizing radiation by following main radiation security norms and principles without unreasonable limitation of useful activity using radiation in industrial branches, science and medicine.

Radiation security of the personnel and population is provided in the conditions of following the main radiation security principles (reasonability, optimization, normalization) and meeting radiation security requirements set by the law of the Republic of Belarus in January, 5, 1998 No. 122-3 "About radiation security of the population" Of NRB-2000 and valid sanitary regulations.

The main conception of radiation security 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 security.

Requirements of modern normative documents related to radiation security fully correspond to the main International security norms on protection against ionizing radiation and secure handling of sources of its radiation [50]. Carrying out the main task of radiation security is based on the principles of radiation security. 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 security limits

The project considers the following sanitary hygienic security 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 projecting protection from external radiation (according to OSP-2002)**

Category of irradiated people	Places and territories	Duration of irradiation, h/year	Project equivalent dose power, $\mu\text{Sv/h}$
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
Throid gland irradiation dose	50 mSv for first 7 days	Blocking throid gland
Total effective dose	100 mSv for first 7 days	Shelter, evacuation, deactivation, restrictions of food products

### 9.3 Main measures of providing radiation security

General radiation security 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 maximal reducing of penetrating radiation field and to organize works of NPP industrial ground service so that to reduce dose loads on the personnel by reducing time or increasing MD values.

First of all providing NPP radiation security is connected with project solutions directed to provide general security and RP security and NPP equipment and with safety reserved security systems (emergency stop of the reactor, emergency heat sink system, filters, bubble devices, etc).

The main technical means of direct providing radiation security 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 off-project 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 zone keeping required conditions in working rooms and providing permitted concentrations of radioactive substances in the atmosphere of these rooms;

- moving-out 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.

AS radiation security is kept by the complex of measures and activities considered in the project and controlled by AS administration; they include:

- dividing buildings and rooms of NPP into zones with different operation modes (zones of controlled and free access), dividing controlled zone 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 professional 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 security rules in rooms, on the station ground and on the adjacent territories;
- developing plans on personnel and population protection in case of accident;
- organization of system of training personnel in the field of radiation security and protection;
- organization of control (radiological monitoring carried out by RCACS in the zone 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 providing radiation security**

Conceptual approach to designing of complex radiation security system is a sequential carrying out of 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 RP (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 security levels of fuel elements damage at project accidents;
- not exceeding amounts of project leakages between circuits (in steam generators, heat exchangers cooling the first circuit environment) and reducing to minimum (minimal 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 security of barriers in the conditions of project accidents and considered by the project internal and external impacts including degrees of maximal 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 exploitation, analysis of project and off-project accidents;

- diagnosis of barriers conditions including continuous operative control of fuel elements hermiticity 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 Justification of aes radiation security

Put into the project principles of radioactive security provided by certain engineering and organization solutions guarantee minimal radiation impact on the personnel in case they carry out behavior rules at operation and professional 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 worked-out 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 security analysis impact at project and off-project accidents; the project determined sizes of zones where on the basis of predicted calculated radiation consequences at off-project accidents protection measures for predicted doses prevention are possible.

Experience of operating atomic energy objects completely proves reasonability of project approaches and solutions providing radiation security of NPP exploitation.

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 zone, man-Sv	Average individual radiation dose, mSv
<b>NPP with PWR-1000 and PWR-440 types reactors</b>				
Novovoronezh	NPP Personnel	2429	6,43	2,65
	Suncontractors	847	1,26	1,49
	Total	3276	7,69	2,4
Kolsk	NPP Personnel	1594	1,8	1,13
	Suncontractors	700	0,84	1,2
	Total	2294	2,64	1,15
Rostov	NPP Personnel	1118	0,04	0,03
	Suncontractors	620	0,09	0,16
	Total	1738	0,13	0,08
Balakov	NPP Personnel	2381	1,27	0,53
	Suncontractors	1202	1,13	0,94
	Total	3583	2,4	0,67
Kalinin	NPP Personnel	2724	1,76	0,64
	Suncontractors	1612	0,58	0,36
	Total	4336	2,34	0,54



Continuation of table 43

<b>NPP with HPCR-1000 type reactors</b>				
Kursk	NPP Personnel	4371	13,13	3,01
	Suncontractors	1432	2,39	1,73
	Total	5803	15,52	2,7
Leningrad	NPP Personnel	3691	7,07	1,92
	Suncontractors	1212	3,85	2,35
	Total	4903	9,92	2,02
Smolensk	NPP Personnel	3303	8,9	2,7
	Suncontractors	1249	2,51	1,86
	Total	4652	11,41	2,45
<b>NPP with AHP-100 and AHP-200 and PV-600 types reactors</b>				
Belojarsk	NPP Personnel	1304	0,95	0,7
	Suncontractors	284	0,25	0,87
	Total	1588	1,20	0,76
<b>NPP with EGP-6 type reactors</b>				
Bilibinsk	NPP Personnel	509	2,14	4,2
	Suncontractors	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 Federal law of the Russian Federation "About radiation security of the population".

## 10 NPP MORTALITY

### 10.1 Conceptual approach to the problem of NPP mortality

Plant mortality is a complex problem including a number of questions starting with stopping of NPP operation to its complete liquidation and returning the industrial ground into the initial condition ready for being used in other purposes, that is complete moving-out 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 minimal.

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 plant operation radioactive fission products and activation are formed; at that 99,9% of fission products stored in nuclear fuel remain in worked-out fuel elements; these are high-radioactive wastes. After temporary storage in NPP the cooled worked-out nuclear fuel is directed to reclaiming.

According to the definition [56] energy plant 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 security.

Stopping of energy plant exploitation 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 plant mortality 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 plant 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 plant service life considering the results of preliminary inspection of its condition, experience of energy plants with similar reactors mortality 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 plant disposal with analysis of alternative variants and engineering justification of adopted project;
- research and registering of the rooms and equipment;
- analysis of radioactive conditions and radionuclide composition of heat carrier and contaminated equipment;
- determining of equipment activity values by calculations and experimentally;
- evaluation of total amount and categories of radioactive wastes formed at mortality;
- 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 mortality 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 zones, 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, moving-out, storage and burial 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 plant 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 in case of accident during mortality works and documents (instructions) set for the personnel carrying out dissembling works at accidents;

While developing energy plant disposal project all systems, equipment, transport means, protective and sanitary-hygienic barriers must be maximally used.

This includes:

- systems of electro 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 plant;

- radioactive equipment deactivation ponds and deactivation solutions preparation systems;

- systems off collecting, concentrating, hardening and burial of liquid and solid radioactive wastes, systems of moving-out and burial 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 plant disposal after the end of set service life with small labor expenses the following technical solutions were taken in the project also directed to reducing of dose loads on the personnel:

- shortest routes of radioactive wastes and equipment moving-out;

- closed transport testles for transportation “contaminated” equipment and its nodes 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 sanitary protection zone;

- arrangement of all buildings and constructions must provide placement of main and auxiliary equipment, reinforcement and pipelines during energy plant mortality within freight-lifting means action providing lifting and moving of the equipment (aggregate or its compounds) from the site to transport means with minimal loads;

- repairing and operation ventilation systems and recirculating aggregates;

- two-way radio search and telephony communications;

- places for installation of containers for collecting and moving-out of radioactive wastes;

- decontamination solutions preparation node 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 zones creation;

- the project considers the possibility of the following variants of energy plant disposal:

- a) liquidation (liquidation of the energy unit after its conservation for ~ 30 years);

- b) unit burial.

## 10.2 Ecological security 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 zone and excluding of unauthorized access of the personnel.

Ecological security 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 worked-out fuel elements from reactor active zone situated in reactor storage. Heat sink from the reactor active zone is provided by normal and emergency cooling system which is based on passive operation principle;

- moving worked-out fuel from the reactor;
- transportation of worked-out and cooled fuel to the reclaiming;

After removal of cooled worked-out fuel from the energy unit nuclear danger in it is eliminated and radiation security is provided by strict following the requirements of normative and technical documentation which is valid at the moment of AES 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 security 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 minimal 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  $5 \cdot 10^{-5}$  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 security has been achieved in operating NPP and really small population irradiation level (less than 10 mcSv/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 atomic energetics, 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. Atomic energetics is reliable in comparison with other sources. Besides, it is more

ecologically secure. For example, the USA government declared about their intention to develop atomic energetics as one of “green” technologies – if they want to achieve lower level of CO<sub>2</sub> emission they need to find new sources of clean energy. Atomic energetics 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 Chief of Nuclear Reactors Institute of Russian scientific centre “Kurchatovsky Institute” Jury Semchenkov: “Let’s remember that in Bulgaria, in Kozloduj 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 security justification includes all peculiarities of both operation and position. Another example is Taiwan 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 economical 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”

Touching upon the question about dose loads Deputy Chief of Institute of Atomic Energetics 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 Rospotrebadzor, 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 object – from hospitals to atomic stations. 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 atomic stations 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, OK let it be 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 violation 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 atomic 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 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 exploitation 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 active zone. 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 amounts of by outputs radiologically equivalent to given value in terra-becquerel of iodine-131 isotope.

Most events about which mass media report are lower than level 3.

**Table 44 - International nuclear events scale (INES)  
(IAEA b 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 security culture.
INES 1 Deviation	Abnormal deviation from permitted mode but at corresponding depth protection. It can happen because of equipment failure, personnel mistake 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 security 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.
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 out-

	side 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 security systems failure can lead to accident.
Continuation of table 44	
	Such incident happened in Paksh AES, Hungary in 2003. During planned repairing fuel assemblies were put into the bottom of deep water pond in separate cleaning equipment. Because of the mistake 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 in the 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. Maximal 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 active zone, 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 Mail 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 active zone. In spite of serious damage of the active zone 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.
INES 7 Major accident	Output of large fractions of radioactive material in bid installation (e.g. nuclear reactor active zone). 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 atomic station in Soviet Union (present day the 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 AES and people taking part in the liquidation of accident consequences died of wounds or radiation. Alienation zone of 30 km was marked around the reactor and approximately 135000 people were evacuated.

### **11.2.2 Referent heavy off-project accident**

According to the requirements EUR, (Volume 2 Chapter 1 Security requirements (Part 1), AES project will consider off- project accidents. Consequences of four types of off-project accidents (OA) will be analyzed:

- accident when heat carrier 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 heat carrier 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 security systems during the first day;
- accident with heat carrier leakages from the first circuit into the second circuit.

Results of analysis of all four types of OA showed that the most serious consequences can be caused by OA type 3. In this case due to full de-energizing of the NPP cooling of the reactor active zone stops. It causes serious damages of nuclear fuel but cover keeps its pressurization. By IAEA scale such accident is level 5. At such accident maximal 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 OA in AES-2006 is given in the work [60]. The main purpose of NPP security at OA is reaching and keeping secure NPP state at least a week after the accident. For this it is necessary to carry out the following functions:

- fragments of active zone are in solid phase and their temperature is stable or decreasing;
- heat emission of active zone fragments is led to final heat absorber, fragments configuration is so that  $C_{ef}$  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 OA the project considers:

- prevention of early damage of interior protective cover;
- 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 OA are:

- distortion of the main circulating pipeline Дy 850 in the reactor input with two-way heat carrier leakage;
- loss of alternative current sources and correspondingly unavailability of all active security systems for long period not more than 24 hours, emergency feeding is from batteries.

Process of development of heavy OA is shown in table 45.



**Table 45 – Development of heavy OA**

Event	Time	Commentaries
Distortion of MCT Ды 850 in the reactor input. Loss of all sources of alternate current	0,0 s	Initial event
Disconnection of all MCT. Deactivation of feeding and blowing system. Prohibition on activation of RP-K.	0,0 s	Refuse: loss of all sources of alternate 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 °C
Damage of AZ and start of passing destroyed materials of active zone	47,7 h	
Melting of support grid and passing of fragments to the reactor vessel bottom	51,0 h	T support grid > 1500 °C
Reactor vessel damage and start of melt passing to ULR	52,0 h	T vessel > 1500 °C

To minimize consequences of heavy OA 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 active zone off the reactor.

Purposes of these security systems are given in table 46.

**Table 46 – Result of operation of security systems at OA control**

Security system	Operation period	Purpose
System of emergency hydrogen removal	During the whole period of the accident	Providing hydrogen security
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	After destroying of reactor vessel and accident	- reaching of AES secure state - providing of heat sink and

of active zone fragments	transition to off-vessel stage	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 AES 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 OA

Calculations of interior and exterior doses given in work showed [61]:

- only at the heaviest accident OA 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 security systems are out of 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 AES only for pregnant women and children. This measure is necessary only in the radius of 4 km from the AES and only for OA 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 zone of not more than 4,7 km.

- in 30-km zone 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 OA of type 3. But trace width according to meteorological, geological peculiarities is not more than 4 km so rural areas in 30-km zone can be contaminated.

Within this zone waters are relatively protected at all types of off-project 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 OA 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 security 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: putting into operation, 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 off-project accidents and at carrying out antiemergency 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 project 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 project accidents the system sets parameters exceeding secure operation level and if necessary gives signals to form control influence on power unit security 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 OA 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 security norms at carrying out works on liquidation of accident consequences and evaluates quality and quantity of the work.

Considering multilevel security 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 security requirements RCS has a number of main parameters whose control is carried out in all operation modes including project 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 atomic energetics 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 electro energy produced by energy system;
- possibility of excess electro energy production for its export;

Including nuclear fuel into the energy balance of the republic will increase economical and energy security of the country in the following directions:

–a great part of imported energy resources (to 5,0 mln 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 electro energy by reducing expenses on fuel;

–operation of autonomous atomic electro stations 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 mln tons what will give the Republic of Belarus economical profits according to Kiot protocol of frame convection 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-Goretsk in Mogilev region and Ostrovetsk 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 the Ukraine. Comparative evaluation results show:

- there are no forbidding factors for all competitive sites (no factors/conditions forbidding placing NPP on these sites).

- there is no potential possibility of activation of piping-carst processes in Krasnopolyana and Kukshinovsk sites what is a complication factor and need further studying. Engineering and geological conditions of Kukshinovsk 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 Ostrovetsk site has advantages over Krasnopolyana and Kukshinovsk sites.

The main advantage of atomic energetics 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 HES 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 electro energy cost.

During development of nuclear energetics approaches to its security 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 security principles and requirements to European electro energy producers and modern reactor plants.

In the result of corresponding researches of project limits reactor plants used at present o (generation III) possess high reliability characteristics:

- calculated frequency of active zone damages is  $< 1 \times 10^{-6}$  /reactor a year;
- frequency of heavy radiation outputs is  $< 1 \times 10^{-7}$  /reactor a year.

Reliability characteristics reached in the project correspond to risk values of  $1 \times 10^{-6}$ .

This NPP security levels have been reached by implementation of IAEA security principles and fundamental security function in the project solutions. For them the project uses combination of active and passive security systems minimizing “human factor” and providing secure operation of the installations.

This book describes conceptions of nuclear and radiation security of the project “NPP -2006”, formulates the general purpose of NPP radiation security. It gives brief description of engineering, organizational means and measures providing NPP security.

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 project accidents;
- off-project control;

- planning of activities of personnel and population protection during accidents.

To achieve project limits of radiation and nuclear security NPP project considers reasonable combination of active and passive security systems. Modern projects pay great attention to internal protection. Internal protection of RP 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 projects of Russian NPP and conceptual project "NPP -2006" meet the security requirements:

- at off-project accidents it is necessary to provide limiting of the consequences with heavy damages of the active zone to protect the population, calculated radius of urgent evacuation zone should not exceed 800 m what excludes the necessity of urgent and long-term evacuation. Radius of the zone 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  $1,0 \times 10^{-7}$  per one year of power unit operation;

- annual output of liquid radionuclides into the environment at normal operation and deviations from normal operation (excluding tritium) should not exceed 10 GBq;

- annual aerosol output of inertia gases into the environment at normal operation and deviations from normal operation should not exceed 40 TBq;

- annual aerosol and iodine isotopes output into the environment at normal operation and deviations from normal operation should not exceed 0,8 GBq;

- output of Cs-137 into the environment at heavy accidents with fuel melting should not exceed 10 TBq.

Reaching of these target limits will provide correspondence to engineering normative acts of the Republic of Belarus.