Implementation of Safety Design Criteria in the Large Power Size Sodium Cooled Fast Reactor BN-1200 Design

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INTRODUCTION (1/3)

- Federal Target Program (FTP) “Nuclear power technologies of a new generation for the period of 2010-2015 and with outlook to 2020”, adopted in Russia, aims at the development and creation of new technological platform for nuclear power based on transition to closed nuclear fuel cycle (CNFC) with Generation-IV fast reactors.
- Fast reactors with sodium coolant (BN-1200 project) and lead coolant (BREST-OD-300 project) are considered as the Generation-IV fast reactors within this FTP.
- The development of the basic design of the BN-1200 reactor facility was carried out within the FTP.
- At the international level, the Generation-IV International Forum (GIF) is organized to consolidate and coordinate efforts to develop advanced Generation-IV nuclear energy systems (NES) with participation of the Russian Federation represented by the State Corporation “Rosatom” together with other countries.

INTRODUCTION (2/3)

- GIF consolidates efforts of all interested countries to carry out R&D in support of the Generation-IV NES for six different reactor technologies, including sodium-cooled fast reactors (SFR). It should be noted that SFR is the most developed and mastered reactor technology within the GIF framework. Russia actively participates in the GIF activities on SFR.
- The global GIF technology goals defined in four aspects of reactor technologies (sustainability, proliferation resistance and physical protection, safety and reliability, and economics), which should be pursued by the developers of the Generation-IV NES, are of a general nature and it is difficult to apply them for evaluation of specific designs. Therefore, activities aimed at detailed elaboration of the GIF global goals into more specific criteria and requirements are very important.
- In particular, 26 metrics are developed for evaluation of the Generation-IV SFR within the GIF framework, those take into account in detail all aspects of the reactor technology. A self-assessment of the BN-1200 concept done by the Russian Federation in accordance with these metrics confirmed its compliance with the requirements to the Generation-IV SFR.

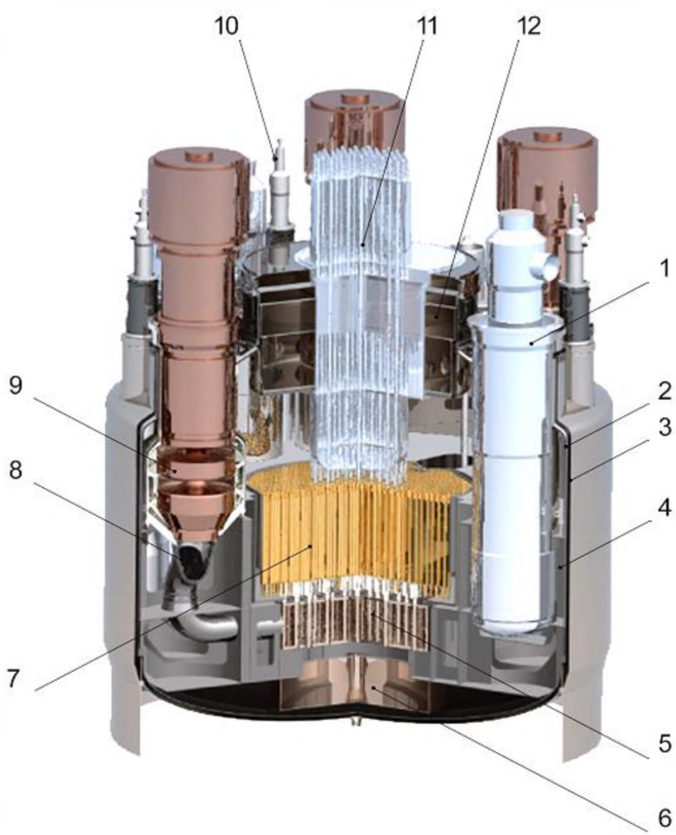
INTRODUCTION (3/3)

- Safety is, of course, the highest priority aspect of reactor technologies. Therefore, considering only the GIF global safety goals for evaluation of the Generation-IV NES safety is not sufficient. It was recognized necessary to elaborate the safety design requirements for the Generation-IV NES. Moreover, it was decided to begin development of these safety requirements for SFR. With this purpose, the GIF Task Force was created for development of safety design criteria (SDC) for the Generation-IV SFR.
- This GIF Task Force has developed SDC for the Generation-IV SFR on the base of the IAEA document, regulating specific safety requirements for light water reactors. The new document additionally included requirements considering the specific properties of sodium coolant and SFR on the whole. After revision of the IAEA document SSR-2/1 in 2016 by including, in particular, lessons learned from the Fukushima Dai-ichi NPP accident, an appropriate updating the GIF Report on safety design criteria for the Generation-IV SFR has been carried out.
- This report provides an analysis of compliance of safety requirements used in development of the BN-1200 design with safety design criteria for the Generation-IV SFR developed by the SDC TF.

MAIN PARAMETERS OF BN-1200

Parameter	Value
Rated thermal power, MW	2800
Electric power, MW	1220
Load factor, %	90
NPP efficiency, %: gross net	 43.5 40.7
Number of primary loops	4
Number of secondary loops	4
Design lifetime of nonreplaceable equipment, year	60
Primary circuit coolant flowrate, kg/s	15784
Secondary circuit coolant flowrate, kg/s	12776
Primary circuit coolant temperature (IHX outlet/inlet), °C	410/550
Secondary circuit coolant temperature (SG outlet/inlet), °C	355/527
Tertiary circuit parameters: live steam pressure, MPa live steam temperature, °C feedwater temperature, °C type of intermediate steam reheating	 17.0 510 275 Steam
Fuel	Nitride, MOX

VIEW OF BN-1200 REACTOR VESSEL

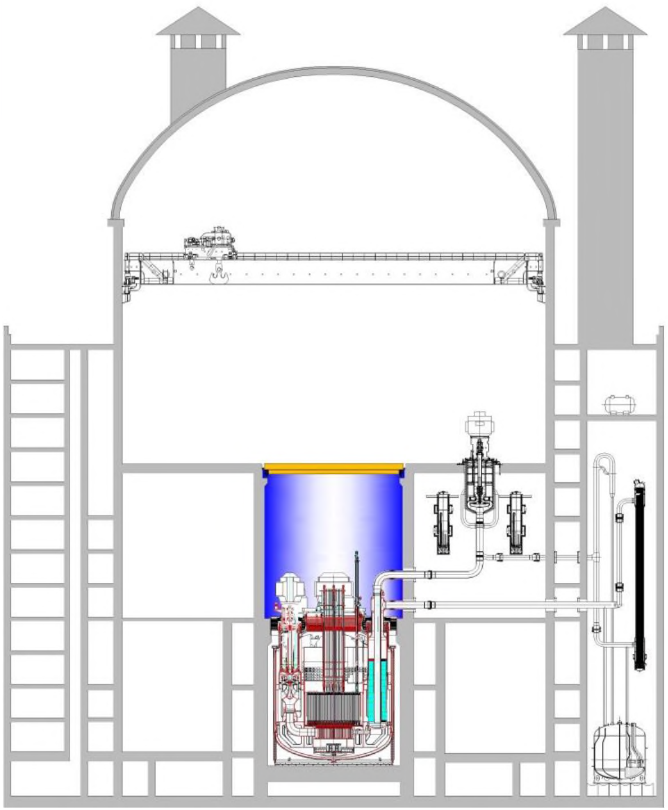


1 – IHX; 2, 3 – main and guard vessels respectively; 4 – supporting structure; 5 – inlet plenum; 6 – core catcher; 7 – core; 8 – pressure pipeline; 9 – MCP-1; 10 – DHX; 11 – CRDM; 12 – rotating plugs

The most important new conceptual technical and design decisions accepted for the BN-1200 design are as follows:

- Pool type arrangement of the primary circuit with location of all sodium systems including cold traps and chemical-engineering control systems within the reactor vessel;
- Simplification of the refuelling system by exception of intermediate storage drums of fresh and spent FSAs and organization of a capacious in-reactor vessel storage (IVS) of spent FSAs (SFSAs), providing direct unloading of SFSAs (after their exposure in the IVS) from the IVS into washing cells and further into an exposure pool;
- Transition from sectional-modular SG scheme to integral one based on application of straight-tube large-capacity modules;
- Maximum enhancement of inherent safety features of the reactor facility and application of safety systems based on passive principles of functioning.

VIEW OF BN-1200 REACTOR BUILDING



Besides, the BN-1200 design envisages the following design decisions:

- Traditional three-circuit design of the power unit;
- Each primary loop contains one IHX and one MCP-1;
- Each secondary loop contains one IHX, one MCP-2 and one SG;
- One turbine unit per power unit;
- Steam reheating;
- Operation of the NPP at the stable (mainly, rated) power level with load factor equal to at least 0.9.

Safety approach applied to the BN-1200 design (1/2)

- The BN-1200 design was developed in accordance with requirements of existing Russian regulatory documents in the field of NPP safety. Accordingly, approach to substantiation of the BN-1200 safety is dictated by these documents.
- The most important of these documents are:
  - Federal Standards and Rules in the Field of Use of Atomic Energy ”General Safety Assurance Provisions for Nuclear Power Plants” (NP-001-15), Moscow, 2015;
  - Federal Standards and Rules in the Field of Use of Atomic Energy “Nuclear Safety Rules for Reactor Installations of Nuclear Power Plants” (NP-082-07), Moscow, 2008.
- In accordance with paragraph (p.) 1.2.4 of the NP-001-15, the BN-1200 safety is ensured due to consistent implementation of the Defence in Depth (DiD), which provides for developing the NPP design documentation on the basis of a conservative approach with inherent safety features of the reactor facility (RF) and measures aimed at elimination of the cliff edge effect.
- As mentioned above, the BN-1200 design focuses on maximum enhancement of inherent safety features of the RF and application of safety systems based on passive principles of operation in order to ensure a high level of safety (p. 3.1.10 of the NP-001-15). In particular, in case of failure of standard emergency protection systems, the design provides for two independent passive reactor shutdown systems based on different operational principles:
  - Passive shutdown system based on hydraulically suspended absorbing rods;
  - Passive shutdown system self-actuated due to increase of the reactor core outlet coolant temperature above a certain value.
- A passive decay heat removal system (DHRS) through air-sodium heat exchangers (AHX) that is directly connected to the reactor vessel is applied in the BN-1200.
- Deterministic and probabilistic safety analyses are applied for the BN-1200 safety analysis (p. 1.2.9 of the NP-001-15).

Safety approach applied to the BN-1200 design (2/2)

- In order to mitigate of consequences of a severe beyond-design basis accident (BDBA), the following solutions and requirements were implemented in the BN-1200 design:
  - In accordance with p. 3.4 of the Appendix to the NP-082-07 reactivity coefficient values in terms of temperature and power of the reactor as well as a total coefficient of reactivity in terms of the coolant and fuel temperature are provided negative over the entire range of the reactor parameter changes during normal operation and anticipated operational occurrences including design basis accidents. For beyond design basis accidents, the permissible range of the sodium void reactivity effect (SVRE) is substantiated;
  - Sodium cavity over the reactor core is designed to reduce SVRE in case of sodium boiling in the core.
- As mentioned above, pool type arrangement of the primary circuit with location of all sodium systems including cold traps and chemical-engineering control systems within the reactor vessel is applied in the BN-1200 design. The reactor vessel is surrounded by a guard vessel. This design practically eliminates a risk of radioactive sodium release outside the reactor vessel and its fire.
- The pipelines of the secondary loops are surrounded by safety jackets that mitigates consequences of sodium leaks in the secondary loops.
- In case of the core damage:
  - Core catcher is located at the bottom of the reactor vessel to eliminate release of failed core fragments outside the reactor vessel boundaries;
  - A volume of the room located above the reactor is used as a containment analogue to localize radioactive products and to eliminate their release into the environment.

Analysis of compliance of safety requirements used in development of the BN-1200 design with safety design criteria for the Generation-IV SFR

- The safety design criteria developed by the SDC TF for the Generation-IV SFR are divided into the following categories:
  - General criteria related to management of safety in design (Criteria 1-3);
  - Principal technical criteria (Criteria 4-12);
  - Set of criteria related to general plant design which is divided into five subsets:
    - Design basis (Criteria 13-28);
    - Design for safe operation over the lifetime of the plant (Criteria 29-31);
    - Human factors (Criterion 32);
    - Other design considerations (Criteria 33-41);
    - Safety analysis (Criterion 42);
  - Group of criteria related to design of specific plant systems:
    - Overall plant system (Criterion 42bis);
    - Reactor core and associated features (Criteria 43-46);
    - Reactor coolant systems (Criteria 47-53);
    - Containment structure and containment system (Criteria 54-58);
    - Instrumentation and control systems (Criteria 59-67);
    - Emergency power supply (Criterion 68);
    - Supporting systems and auxiliary systems (Criteria 69-76);
    - Other power conversion systems (Criterion 77);
    - Treatment of radioactive effluents and radioactive waste (Criteria 78-79);
    - Fuel handling and storage systems (Criterion 80);
    - Radiation protection (Criteria 81-82).

Management of safety in design

Management of safety in designing Russian NPPs is regulated by provisions of the NP-001-15 obliging all organizations involved in activities on development the NPP design to be responsible for its compliance with all applicable safety requirements **(Criterion 1)**.

JSC "OKBM Afrikantov", being chief designer of the BN-1200 reactor facility, has established and implemented a management system for ensuring that all safety requirements established for the design of the plant are considered and implemented in all phases of designing the BN-1200 and that they are met in the final BN-1200 design **(Criterion 2)**. In particular, it should be noted that JSC "OKBM Afrikantov" is a developer of the BN-600 and BN-800 RF designs and, thus, it took into account the gained experience of designing and operation of these facilities for developing the BN-1200 RF design.

In the Russian Federation, JSC "Concern Rosenergoatom" is the operating organization for all NPPs, which thoroughly worked out the procedure of establishing formal system for ensuring the continuing safety of the plant design throughout the NPP lifetime **(Criterion 3)**. Supervision of proper safety assurance of the NPP by the operating organization and registration of all necessary licenses is carried out by the Federal Environmental, Industrial and Nuclear Supervision Service of Russia "Rostechnadzor".

Principal technical criteria (1/3)

The requirement to perform fundamental NPP safety functions **(Criterion 4)** is formulated in p. 3.1.2 of the NP-001-15:

- "3.1.2. The NPP shall have safety systems intended for fulfilling the following main safety functions:
  - Reactor scram and maintaining it in subcritical state;
  - Emergency removal of heat from the reactor;
  - Confining radioactive substances within the predetermined boundaries".

Compliance with **Criterion 5**, concerning radiation protection in design, is ensured by implementation of p. 1.2.3 of the NP-001-15:

- "1.2.3. Permissible exposure dose rates for NPP personnel and allowable limits of exposure doses for population for normal operation and anticipated operational occurrences including accidents, values of maximum permissible radioactive releases to atmospheric air and permissible discharge of radioactive substances into water objects shall be specified in compliance with regulatory legal acts.
- Exposure doses as a consequence of releases and discharges of radioactive substances from the NPP shall be below the predetermined levels and as low as reasonably achievable".

BN-1200 design was developed in such a way that the plant and items important to safety have the appropriate characteristics to ensure that safety functions can be performed with the necessary reliability, that the plant can be operated safely within the operational limits and conditions for the full duration of its design life, and that impacts on the environment are minimized **(Criterion 6)**. Here it is possible to refer to use of previous SFR experience in the BN-1200 design and to implementation of provisions of p. 1.2.2 of the NP-001-15:

- "1.2.2. NPP safety is achieved due to high-quality design, construction and manufacture of equipment, NPP siting, construction and operation through compliance with Federal laws, Federal regulations and rules in the field of use of nuclear power, through formation and maintenance of safety culture, as well as taking into account operational experience and the current level of development of science, technology and industry".

Principal technical criteria (2/3)

The requirement for implementation of the defence in depth principle **(Criterion 7)** is determined in p. 1.2.4 of the NP-001-15:

- "1.2.4. NPP safety shall be ensured due to consistent implementation of the defence in depth based on the application of the system of physical barriers on the path of release of ionizing radiation and radioactive substances into the environment and a system of technical and administrative arrangements on protection of barriers and maintaining their effectiveness as well as on protection of personnel, population and environment.
- The system of physical barriers of the NPP unit shall include: reactor coolant circuit boundary, confining structures of the RF and biological shield as well as, as a rule, fuel matrix, fuel pin cladding.
- The system of technical and administrative measures shall provide five levels of defence in depth and include the following levels:
  - Level 1. NPP siting conditions and prevention of anticipated operational occurrences.
  - Level 2. Prevention of design basis accidents by systems of normal operation.
  - Level 3. Prevention of design extension conditions by safety systems.
  - Level 4. Management of design extension conditions.
  - Level 5. Emergency planning: preparation and implementation of action plans for protection of personnel and population on the NPP site and outside its boundaries.
- ...All reasonably achievable measures should be taken to ensure independence of DiD levels from each other".

The need to take into account interfaces of safety with security and safeguards **(Criterion 8)** in order to eliminate their adverse impact on each other is determined in p. 1.2.29 of the NP-001-15:

- "1.2.29. Technical and administrative measures for ensuring physical protection and fire safety of the NPP shall be envisaged in the NPP design.
- Measures to ensure physical protection shall not impair the conditions of providing the NPP safety neither during normal operation nor in anticipated operational occurrences including accidents".

Principal technical criteria (3/3)

The implementation of **Criterion 9** on proven engineering practices shall be achieved by implementation of provisions of p. 1.2.2 of the NP-001-15 mentioned above.

Note that use of the experience gained in designing, construction and operation of the BN-600 and BN-800 for development of the BN-1200 design provides implementation of **Criterion 11** in addition to **Criterion 9**. Paragraph 1.2.7 of the NP-001-15 also states about necessity of application of the experience:

- "1.2.7. Technical and administrative decisions made for ensuring the NPP safety shall be well proven by the previous experience, tests, investigations, operating experience of prototypes. Such approach shall be applied not only in development of equipment and design of the NPP but also in manufacture of equipment, construction and operation of the NPP, its reconstruction and reconditioning of its systems and elements, as well as the NPP decommissioning".

As part of development of the BN-1200 design, a Safety Analysis Report (SAR) is prepared, where in accordance with the requirements of p. 1.2.9 of the NP-001-15 deterministic and probabilistic analyses of the BN-1200 safety are performed for all operating states of the NPP and taking into account all existing locations of nuclear materials, radioactive substances and radioactive waste at the NPP site, where anticipated operational occurrences could occur. The development of such a document at the design stage allows for the fulfillment of **Criterion 10** on safety assessment.

In accordance with p. 3.8.4 of the NP-001-15:

- "The NPP design shall envisage means for treating radioactive waste providing collection, sorting, processing, conditioning and storage of radioactive waste during normal operation of the NPP and anticipated operational occurrences including design basis accidents". This paragraph along with p. 5.2 of the NP-001-15, which requires that "the NPP design shall envisage measures for safe decommissioning of the NPP unit", ensures implementation of **Criterion 12**.

Design basis of general plant design (1/7)

The following categories of the plant states are considered in the BN-1200 design **(Criterion 13)**:

- Normal operation;
- Anticipated operational occurrences;
- Design basis accidents;
- Design extension conditions, including postulated severe accidents with reactor core damage.

The implementation of the design basis for items important to safety **(Criterion 14)** is provided by compliance with requirements described in pp. 3.1.8 and 3.1.17 of the NP-001-15:

- "3.1.8. Systems and elements important to safety shall be capable of performing their functions within the scope specified in the design with allowance for external natural impacts (earthquakes, hurricanes, tornadoes, floods and other phenomena possible in the region of the NPP site), external man-induced impacts peculiar to the NPP site and (or) under postulated hydraulic, mechanical, thermal, chemical and other impacts resulting from accidents which require operation of these systems and elements".
- "3.1.17. The NPP Safety Analysis Report shall include reliability analyses of functioning of systems important to safety as well as reliability indices of elements important to safety. The reliability analysis shall be conducted with account of common cause failures and personnel errors".

Design basis of general plant design (2/7)

Criterion 15 related to design limits and **Criterion 28** associated with operational limits and conditions for safe NPP operation correlate with requirements of p. 3.1.18 of the NP-001-15 that says:

- "3.1.18. The NPP design shall establish and justify and the NPP Safety Analysis Report shall reflect operational limits and conditions, safe operation limits and conditions for all operational states of the NPP including reactor operation on power level, shutdown state, refuelling state". In accordance with this requirement, the BN-1200 design contains operational limits and conditions, safe operation limits and conditions for all operational states of the BN-1200.

The fulfillment of **Criterion 16** is ensured by p. 1.2.14 of the NP-001-15:

- "1.2.14. List of initiating events presented in the NPP Safety Analysis Report shall include all possible internal and external events those violate normal operation of the NPP and are not eliminated on the basis of inherent safety features of the reactor and its design principles. Combinations of failures of systems (elements) of the NPP, personnel errors, internal or external impacts are considered as a part of the specified list of initiating events in cases provided by requirements of Federal regulations and rules in the field of use of nuclear power".

Design basis of general plant design (3/7)

The implementation of **Criterion 17** on identification and evaluation of internal and external hazards is provided by pp. 1.2.14 and 3.1.8 of the NP-001-15 mentioned above.

Criterion 18 on engineering design rules appreciably correlates with Criterion 9 on proven engineering practice and it is covered by p. 1.2.2 of the NP-001-15.

The conditions for implementation of **Criterion 19** on design basis accidents are defined in pp. 1.2.15 and 1.2.9 of the NP-001-15:

- “1.2.15. Tentative lists of initiating events for analysis of design basis accidents specified for each type of reactor shall be established in Federal regulations and rules in the field of use of nuclear power. The final lists of initiating events for analysis of design basis accidents shall be presented in the NPP SAR”.
- “1.2.9. ... Deterministic analyses of design accidents shall be performed on the basis of a conservative approach...”.

Design basis of general plant design (4/7)

Paragraphs 1.2.16, 1.2.18 and 3.1.3 of the NP-001-15 meet **Criterion of 20** on design extension conditions:

- "1.2.16. Tentative lists of design extension conditions specified for each type of reactor shall be established in Federal regulations and rules in the field of use of nuclear power. The final lists of design extension conditions (including severe accidents) shall be presented in the NPP SAR. They shall include representative scenarios for defining measures on management of such accidents. Representativeness of the scenarios shall be ensured by taking into account the levels of severity of the NPP state and, besides, possible states of serviceability or non-serviceability of safety systems and special technical means for managing design extension conditions".
- "1.2.18. If estimation of the probability of large emergency release does not confirm the implementation of paragraph 1.2.17 of these General provisions (not exceeding total probability of large emergency release for each NPP unit during interval of one year equal to 10^{-7}), it is necessary in the NPP design to provide additional technical solutions (including special technical means for management of design extension conditions) with purpose of decreasing the probability of occurrence of accidents and mitigation of their consequences".
- "3.1.3. The NPP design shall provide for special technical means for management of design extension conditions".

Design basis of general plant design (5/7)

Criterion 21 on physical separation and independence of safety systems meets the requirement stated in p. 3.1.2 of the NP-001-15:

- “3.1.2. ... The mutual influence of safety systems which could prevent the proper performance of their safety functions shall be eliminated. This is achieved in such ways as physical separation and functional independence”.

Classification of systems important to safety regulated by **Criterion 22** is established in Section 2 of the NP-001-15 “Classification of systems and elements”.

This section indicates that all systems and elements of the NPP vary in their designation and their relation to safety. In accordance with relation of the NPP elements to safety, four safety classes are identified. Any element which possesses attributes of different safety classes at one time it shall be assigned to a higher class.

The requirement to reliability of systems important to safety **(Criterion 23)** is subject to requirement defined in p. 1.2.10 of the NP-001-15:

- “1.2.10. Design and reliability of systems and elements important to safety … shall be the subject of activities relating to quality assurance at all stages of the full life cycle of the NPP”, in particular at the design stage.

Design basis of general plant design (6/7)

As regards Criterion 24 on common cause failures, it corresponds to p. 3.1.9 of the NP-001-15:

- "3.1.9. In the NPP design measures on protection of safety systems and elements as well as systems and elements of special technical means for management of accidents from common cause failures by implementation of principles of diversity, redundancy and independence shall be reviewed and justified".

The single failure criterion **(Criterion 25)** is identical to "the single failure principle" used in the NP-001-15. Paragraph 1.2.12 of the NP-001-15 requires that the single failure principle shall be applied to each safety system incorporated in the NPP design:

- "1.2.12. The established limits for design basis accidents shall not be exceeded during anyone of initiating events considered in the NPP design with simultaneous occurrence – according to the principle of single failure – of a failure independent on the initiating event of anyone of the following safety systems elements: an active element or a passive element having moving mechanical parts, or a passive element without moving parts but having a probability of failure of a safety function of 10^{-3} or more, or one personnel error independent on the initiating event.

  In addition to one failure independent on the initiating event of anyone of the above elements, all the failures shall be taken into account those are resulting from this single failure, including the failures resulting from the initiating event, as well as failures of elements affecting the development of the accident that are not detectable during the NPP operation..."

Design basis of general plant design (7/7)

The principle of fail-safe design **(Criterion 26)** is somewhat similar to the principle of safe failure used in the NP-001-15, according to which it is recommended to design the NPP and RF systems:

- "3.1.10. The NPP and RF systems (elements) shall be designed with priority given to systems (elements) design of which has been based on the passive principle of action and inherent safety features (self-control, thermal inertia, natural circulation and other natural processes), as well as the implementation of the principle of safe failure".

In accordance with p. 3.7.1 of the NP-001-15 "the necessary support safety systems performing functions of supplying safety systems with working fluid, energy and creating the required conditions for their functioning, including heat transfer to an ultimate heat sink shall be provided in the NPP design". The support safety systems shall be classified into four classes as the other safety systems depending on their relation to safety. In addition, "support safety systems shall have reliability indices of functions performance sufficient for achieving along with the corresponding indices of safety systems which they support the necessary reliability of the latter, specified in the design" (p.3.7.2). Thus, it is possible to say that conditions of **Criterion 27** related to support service systems are implemented.

Design for safe operation over the lifetime of the plant (1/3)

With regard to **Criterion 29** on conditions of maintenance of systems important to safety, it is necessary to refer to p. 3.1.1 of the NP-001-15, containing general requirements to designing systems important to safety:

- "3.1.1. Systems and elements important to safety shall be designed and constructed in accordance with principles of these General provisions and in compliance with other Federal regulations and rules in the field of use of nuclear power".

The principles of these General provisions, which shall guide the design of systems important to safety, are disclosed in pp. 3.1.6 and 3.1.14 of the NP 001-15:

- "3.1.6. The NPP design shall envisage devices and accessories for:
  - Confirmation of serviceability of systems and elements (including devices located inside the reactor), replacement of the equipment exceeding its service life;
  - Systems testing to assure their compliance with design parameters;
  - Checking sequence in transmission of signals and actuation of equipment (including transition to emergency power sources);
  - Control of the state of metal (including welded joints) of equipment and pipelines;
  - Metrological verification of measuring means and measuring channels of measuring systems for compliance with design requirements".
- "3.1.14. The NPP systems and elements important to safety shall be subjected usually to direct and full checks to assure their compliance with the design characteristics in commissioning, after repair and periodically during the whole lifetime of the NPP. Should performance of direct and (or) full checks not be possible which shall be validated in the NPP design, indirect and (or) partial checks shall be carried out. Adequacy of indirect and (or) partial checks shall be validated in the NPP design. The NPP design shall provide for possibility of diagnostics (examination) of state of safety systems, special technical means for management of design extension conditions, as well as normal operating elements important to safety and referred to safety classes 1 and 2, and their representative tests".

Design for safe operation over the lifetime of the plant (2/3)

The qualification of equipment and systems important to safety to verify capability of performing their intended functions when necessary, and in the prevailing environmental conditions, throughout their design life is regulated by **Criterion 30**. The requirements to qualification of equipment and systems important to safety are formulated in pp. 4.1.6 and 4.1.9 of the NP-001-15, and conditions in which they have to perform their functions are defined in p. 3.1.8 (mentioned above):

- "4.1.6. To maintain safety systems in operable state and prevent failures in systems important to safety their maintenance, repair, tests and checks shall be conducted.

  The operating organization shall ensure development of the technological regulations for maintenance, repair, tests and checks involving developers of the NPP and RF in compliance with the NPP design and the NPP Safety Analysis Report".
- "4.1.9. The operating organization shall ensure development and performance of the program for systems and elements important to safety to confirm implementation of requirements of p. 3.1.8 of these General provisions".

Design for safe operation over the lifetime of the plant (3/3)

Ageing management regulated by **Criterion 31** is subject to p. 4.1.17 of the NP-001-15:

- "4.1.17. In accordance with established procedure every 10 years a periodic assessment of the NPP unit safety shall be provided for the NPP having license for operation during more than ten years, taking into account changes in the NPP site characteristics, ageing processes of the NPP elements (including equipment, building structures), reconstructions implemented, operating experience, the current level of science, technology and industry, as well as changes in the requirements of regulatory documents in order to confirm the possibility of continuation of the safe NPP operation".

Human factors

Paragraphs 3.4.2.3 and 3.4.5.1 of the NP-001-15 are dedicated to consideration of human factors **(Criterion 32)** aimed at ensuring the design for optimal operator performance:

- “3.4.2.3. In the design of the unit control room (UCR) problems of «man-machine interface» shall be solved by optimal way. The NPP parameters to be controlled from the UCR shall provide personnel with unambiguous information indicating that NPP safe operation limits and conditions are met as well as indicating automatic response and functioning of safety systems”.
- “3.4.5.1. The operator information support system shall provide personnel of the UCR with generalized information on the NPP parameters characterizing the state of safety functions”.

Other design considerations (1/3)

Criterion 33 defining that each unit of a multiple unit NPP shall have its own safety systems and shall have its own safety features for design extension conditions fully correlates with requirement of p. 3.1.13 of the NP-001-15:

- "3.1.13. …The safety systems of one unit of a multiple unit NPP shall be independent from safety systems of another unit of the same NPP.
- Sufficiency of special technical means for management of design extension conditions in case of simultaneous occurrence of accidents in all units of a multiple unit NPP shall be ensured".

Criterion 34 relates to requirements for design of the NPP systems those may contain fissile material or radioactive material. These systems shall be designed as to:

- prevent the occurrence of events that could lead to an uncontrolled radioactive release to the environment;
- prevent accidental criticality and overheating;
- ensure that radioactive releases are kept below authorized limits on discharges in normal operation and below acceptable limits in accident conditions, and are kept as low as reasonably achievable;
- facilitate mitigation of radiological consequences of accidents.

The above requirements are taken into account in section 3.8 of the NP-001-15 dedicated to nuclear fuel and radioactive waste storage systems, in particular in pp. 3.8.2, 3.8.3, and 3.8.5:

- "3.8.2. The possibility of reaching criticality in storages of fresh nuclear fuel and spent nuclear fuel (SNF) during its location and transportation shall be eliminated due to providing the appropriate characteristics of storages and transportation means".
- "3.8.3. Provision shall be made for reliable decay heat removal systems to an ultimate heat sink to prevent damage of nuclear fuel and release of radioactive substances to the NPP premises or environment beyond limits established in the NPP design…"
- "3.8.5. The NPP design shall provide for technical and administrative measures to prevent formation of explosive concentrations of hydrogen-containing mixtures in the storages of nuclear fuel and radioactive waste, as well as necessary means of control of hydrogen-containing mixtures".

Other design considerations (2/3)

The NP-001-15 does not contain any special requirements to the NPP used for cogeneration of heat and electric power (such as for district heating) and/or for water desalination to prevent processes leading to transport of radionuclides from the NPP to the desalination unit or the district heating unit **(Criterion 35)**.

- In this regard, we will emphasize that the BN-1200 design does not provide for its application for other purposes not related to electricity production. Nevertheless, it should be noted that there is the relevant experience of application of the BN-600 and BN-800 power units for district heating in the city of Zarechny and, if necessary, it can be applied for the BN-1200 design.

The NP-001-15 does not contain any specific requirements related to the provision of escape routes from the plant for events stipulated in the NPP design **(Criterion 36)**. However, the implementation of such measures is envisaged in accordance with requirements determined in pp. 4.1.5, 4.5.4 and 4.5.5 of the NP-001-15:

- “4.1.5. Based on the technological regulations and the NPP SAR, the NPP administration makes arrangements for elaboration, issue and maintenance of guidelines and manuals determining personnel actions on ensuring safety under anticipated operational occurrences, including the guideline on elimination of design basis accidents and the manual on management of design extension conditions, in particular severe accidents”.
- “4.5.4. Emergency planning procedures developed for the purpose of personnel and population protection shall be elaborated, approved and provided with the necessary resources”.
- “4.5.5. The plan of arrangements on protection of personnel in the event of an accident at the NPP shall be elaborated by the NPP administration in accordance with requirements of Federal regulations and rules in the field of use of nuclear power”.

Other design considerations (3/3)

The availability of the effective means of communication at the NPP **(Criterion 37)** is provided by pp. 1.2.30 and 4.5.8 of the NP-001-15:

- "1.2.30. Communication and annunciation means shall be provided in the NPP design including redundant ones for planning NPP control during normal operation modes, under design basis accidents and design extension conditions".
- "4.5.8. Prior to delivery of nuclear fuel to the NPP protected points of emergency actions control shall be set up and maintained in constant readiness; they shall be provided with the necessary equipment, instrumentation and communication means…"

Criterion 38 on control of access to the plant and **Criterion 39** on prevention of unauthorized access to, or interference with, items important to safety are related to physical protection items and they are not analysed in this report. However, consideration of these items in the NPP design is regulated by appropriate documents.

Criterion 40 dedicated to prevention of harmful interactions of systems important to safety as well as **Criterion 41** on interactions between the electrical power grid and the plant are covered by requirements of p. 3.1.8 of the NP-001-15 mentioned above.

Safety analysis

The safety analysis of the NPP design **(Criterion 42)** with application of the methods of both deterministic and probabilistic analyses is required in p. 1.2.9 of the NP-001-15:

- "1.2.9. Deterministic and probabilistic safety analyses shall be presented in the NPP SAR. Safety analyses should be performed for all operational states of the NPP and take into account all existing locations of nuclear materials, radioactive substances and radioactive waste at the NPP where abnormal operation events may occur. Deterministic analyses of the design basis accidents should be carried out on the basis of a conservative approach. Probabilistic safety analyses should include an assessment of the probability of large emergency release. Safety analyses should be accompanied by estimates of errors and uncertainties of the results obtained. Software applied for the safety analysis should be certified".

Overall plant system (1/2)

Criterion 42bis regulates consideration in the NPP design of the following specific characteristics of the SFR:

- The reactor core is not in its most reactive configuration under normal operating conditions. This could lead to a positive reactivity insertion due to an unfavourable change in reactor core geometry;
- The sodium void reactivity may be positive in the central region of the reactor core. This could lead to a positive reactivity insertion due to sodium boiling or gas entrainment;
- The high boiling temperature of sodium at standard atmospheric pressure enables the reactor coolant system to operate at low pressure with a large margin to boiling;
- The high thermal conductivity and heat transfer coefficient of sodium, the large temperature gradient in the reactor core, and the decrease of sodium density with increasing temperature enable decay heat removal by natural circulation of the coolant;
- Sodium is chemically active and opaque, and it is solid below 98 ºC;
- Some mist and vapour of sodium can deposit on the components.

All these specific SFR characteristics reflected in Criterion 42bis are considered in the BN-1200 design.

Overall plant system (2/2)

In particular, analysis of severe accidents performed in the framework of the BN-1200 design has demonstrated that massive sodium boiling can occur in the core only due to failure of emergency protection systems. In this regard, the BN-1200 design provides for additional shutdown systems based on the passive principles of operation – hydraulically suspended absorbing rods that are naturally inserted into the core due to decrease of sodium flowrate through the core below a certain value, as well as a passive shutdown system based on the temperature principle of operation when sodium temperature at the core outlet exceeds a certain threshold value. Thus, large-scale sodium boiling in the core can occur only in case of extremely unlikely severe accident with postulated failure of all available reactor emergency protection and shutdown systems.

Analysis of postulated severe accidents that can be accompanied by sodium boiling in the core shows that coolant boiling begins in the upper part of the core. Due to sodium cavity located over the core sodium boiling in its upper part causes negative SVRE. It leads to decrease of the reactor power and intensity of coolant boiling consequently although all the shutdown systems are failed.

As noted above, coolant natural circulation is applied as a standard mode of operation of the DHRS in the BN-1200.

Reactor core and associated features (1/3)

The requirements related to operation of fuel pins and FSAs, those are regulated by **Criterion 43**, correlate with pp. 2.2.7 and 2.2.14 of the NP-082-07:

- "2.2.7. The core and its components' (including fuel pins and fuel subassemblies) design and implementation shall be such that during normal operation and anticipated operational occurrences, including design basis accidents, the corresponding fuel damage limits would not be exceeded considering:
  - RF design operational modes, their number and design course;
  - force (mechanical), thermal and radiation impact to the core components;
  - physical and chemical interaction of the core structural materials and coolant;
  - limiting deviations from design, process characteristics and process parameters;
  - shock and vibration impacts, thermal cycling, radiation and thermal creep and material ageing;
  - influence of the coolant fission products and admixtures on strength and corrosion resistance of fuel rods;
  - other factors that degrade mechanical properties of the core structural materials and integrity of the fuel pin cladding".
- "2.2.14. The FSA design shall be so that changes in shape of fuel pins and other FSA components, which are possible during normal operation, anticipated operational occurrences and design basis accidents, do not lead to blocking of FSA flow area resulting in fuel damage in excess of the corresponding limits and do not disrupt normal performance of CPS rods".

Reactor core and associated features (2/3)

The above cited p. 2.2.14, p. 2.2.11 of the NP-082-07, and p. 3.2.2 of the NP-001-15 correspond to **Criterion 44** on structural capability of the reactor core:

- "2.2.11. During normal operation and anticipated operational occurrences including design basis accidents the possibility for unanticipated movements and(or) deformations of the core components inducing reactivity growth and degrading of heat removal which lead to fuel pins damage over the relevant design limits shall be excluded".
- "3.2.2. The core shall be designed in such a way as to ensure during normal operation and anticipated operational occurrences including design basis accidents absence of deformations of the core components impairing normal functioning of means acting on reactivity and reactor scram or impeding cooling of fuel pins exceeding established design fuel pin damage limit".

Requirements related to control of the reactor core **(Criterion 45)** are defined in pp. 2.2.1 and 2.2.10 of the NP-082-07:

- "2.2.1. The reactor core shall be designed such that any reactivity changes during normal operation and anticipated operational occurrences, including design basis accidents, do not lead to violation of the relevant fuel pins damage limits".
- "2.2.10. The RF design shall demonstrate that in case of unanticipated movement of the rod of the highest worth or a group of CPS rods the fuel rods are not damaged to result in violation of the safe operation limits considering the EP actuation without one CPS rod of the highest worth".

Reactor core and associated features (3/3)

Requirements concerning reactor shutdown **(Criterion 46)** are set out in pp. 2.3.1.4 and 2.3.1.5 of the NP-082-07:

- "2.3.1.4. The RF design shall provide for, at least, two reactor shutdown systems, each one being capable independently from the other of rendering the reactor subcritical and maintaining it in this state considering single failure criterion or human error. These systems shall be designed in accordance with the diversity, independence and redundancy principles".
- "3.2.1.5. During normal operation, anticipated operational occurrences including design basis accidents at least one of the reactor shutdown systems (which does not perform the EP function) shall have:
  - efficiency that is sufficient for rendering the reactor subcritical and maintaining it as such, considering possible reactivity release;
  - response time sufficient for rendering the reactor subcritical without violation of design fuel pins damage limits established for design basis accidents (taking into account performance of the emergency core cooling systems)".

Reactor coolant systems (1/4)

Requirements to the design of reactor coolant systems **(Criterion 47)** are defined in p. 3.3.1 of the NP-001-15, as well as in pp. 2.5.3 and 2.5.9 of the NP-082-07:

- “3.3.1. The equipment and pipelines of the reactor coolant circuit shall withstand without destruction static and dynamic loads and temperature effects arising in their any parts (with allowance for actions of protection safety systems and their probable failures as per p. 1.2.12 of these General provisions) during anticipated operational occurrences including design basis accidents…”.
- “2.5.3. The design shall demonstrate that the strength of the reactor vessel is ensured during normal operation and anticipated operational occurrences including design basis accidents throughout the NPP power unit service life”.
- “2.5.9. The RF design shall provide for leak limiters in the piping running from the main circulation pipeline. A waiver to install leak limiters shall be justified in the RF design”.

With regard to the BN-1200 design, it should be repeated that the all primary coolant including all auxiliary systems is located inside the reactor vessel, in turn, surrounded by the guard vessel that practically eliminates a risk of radioactive sodium leaks in the BN-1200.

Reactor coolant systems (2/4)

Overpressure protection of the reactor coolant pressure boundary **(Criterion 48)** is regulated by p. 3.3.2 of the NP-001-15 and by p. 2.5.8 of the NP-082-07:

- "3.3.2. The operation of the devices for pressure decrease to protect the coolant reactor circuit against overpressure shall not result in the primary coolant release outside the RF confinement system".
- "2.5.8. The RF design shall provide for the means of automatic protection against impermissible overpressure in the primary circuit during normal operation and anticipated operational occurrences including design basis accidents".

Control of coolant level in the reactor vessel **(Criterion 49)** is provided in accordance with p. 3.3.6 of the NP-001-15:

- "3.3.6. The NPP design shall provide for the technical means of controlling coolant level in the reactor".

Reactor coolant systems (3/4)

The availability of reactor coolant purification systems **(Criterion 50)** is regulated by p. 2.5.11 of the NP-082-07 and p. 3.3.5 of the NP-001-15:

- "2.5.11. The RF and NPP designs shall establish the coolant quality indicators; its chemical composition and permissible content of radionuclides during operation; the design shall envisage engineered features and organizational measures for their maintaining and monitoring. Technical solutions and organizational measures to ensure the coolant quality, as well as those related to methods and means of its monitoring, shall be justified in the RF and NPP designs".
- "3.3.5. Reactor coolant purification systems from radioactive contamination shall be designed to operate up to safe operation limit for fuel pin damage to ensure the NPP operation at radioactivity level in circuit of reactor coolant as low as reasonably achievable".

The BN-1200 design provides for purification systems of the primary sodium from corrosion products and other impurities, which are located inside the reactor vessel.

Reactor coolant systems (4/4)

Availability of the decay heat removal system from the reactor core and heat transfer to an ultimate heat sink in the NPP design **(Criteria 51 and Criteria 53)** are obliged by above mentioned p. 3.1.2 of the NP-001-15 and p. 2.6.1 of the NP-082-07:

- “2.6.1. The RF and NPP designs shall provide for the emergency core cooling systems. A composition, structure and characteristics of the emergency core cooling systems shall be justified in the RF and NPP designs”.

  The functions of emergency core cooling and decay heat removal to an ultimate heat sink are combined in the SFR. As noted above, DHRS with AHXs directly connected to the reactor vessel is applied in the BN-1200 design, which is based on passive principles of operation with natural circulation of sodium and air in the DHRS heat removal circuits.

Containment structure and containment system (1/2)

The availability of the containment system for the reactor **(Criterion 54)** is regulated by pp. 3.6.1 and 3.6.2 of the NP-001-15:

- "3.6.1. Provision shall be made for localizing safety systems confining radioactive substances and ionizing radiation under an accident within the boundaries specified in the NPP design".
- "3.6.2. The reactor and RF systems and elements containing radioactive substances shall be accommodated entirely within the limits of the RF leak proof compartments for localizing radioactive substances released during design basis accidents..."

The issue of control of radioactive releases from the containment **(Criterion 55**) is considered in pp. 3.6.2 and 3.6.6 of the NP-001-15:

- "3.6.2. ... Controlled release of radioactive substances outside the boundaries of the RF confinement system is allowed under severe accidents only for the purpose of prevention of the confinement system destruction provided that measures for ensuring radiation safety of the population are taken (by means of application of the release filtration system, shelter, evacuation of the population or other measures)".
- "3.6.6. The amount of allowable loss of integrity by the confinement system shall be proved in the NPP design. Compliance of actual leak tightness with the design value shall be confirmed prior to the first reactor loading and verified in a process of operation with periodicity established in the NPP design.

  Tests of the confinement system in the NPP unit commissioning shall be conducted at design pressure, subsequent tests shall be carried out at pressure specified in the NPP design…"

Containment structure and containment system (2/2)

Requirements to isolation of the containment **(Criterion 56)** are formulated in p. 3.6.5 of the NP-001-15:

- "3.6.5. All lines intersecting boundaries of the confinement system through which release of radioactive substances outside the confinement system is possible shall be equipped with isolating elements in compliance with requirements of Federal regulations and rules in the field of use of nuclear power".

Regulatory documents analysed in this report do not contain special requirements to control of the access to the containment **(Criterion 57)**. Nevertheless, this issue is being considered within the framework of the BN-1200 design.

Control of containment conditions **(Criterion 58)** shall be provided in accordance with the conditions of p. 3.6.4 of the NP-001-15:

- "3.6.4. In those cases when for preventing pressure rise inside the confinement system systems for heat removal with active elements (or passive elements with moving parts) are to be provided, these systems shall include several independent channels".

As noted above, the volume of the room located above the reactor is used as the containment analogue in the BN-1200 design, which ensures localization of radioactive products to limit radioactivity release into the environment under severe accident conditions.

Instrumentation and control systems (1/3)

Pp. 3.4.1.1 and 3.4.3.2 of the NP-001-15 determine that the NPP shall include:

- *Instrumentation: for determining the values of all the main variables that can affect the fission process, the integrity of the reactor core, the reactor coolant systems and the containment at the NPP; for obtaining essential information on the plant that is necessary for its safe and reliable operation; for determining the status of the plant in accident conditions; and for making decisions for the purposes of accident management* ***(Criterion 59)****;*
- *control systems for maintenance and limitation of the relevant process variables within the specified operational ranges* ***(Criterion 60)****;*
- *protection system that has the capability to detect unsafe plant conditions and to initiate safety actions automatically to actuate the safety systems necessary for achieving and maintaining safe plant conditions* ***(Criterion 61)****.*
- "3.4.1.1. For control of process equipment relating to normal operating systems and safety systems at each NPP unit provision shall be made for:
  - Unit control room (UCR);
  - Emergency control room (ECR);
  - Normal operation control systems (NOCS);
  - Control safety systems (CSS);
  - Operator information support system;
  - Autonomous means for data recording and storage".
- "3.4.3.2. Normal operation control systems shall include:
  - Means for collection, processing, recording and storage of information sufficient to ensure the possibility of timely and unambiguous identification of initiating events preceding anticipated operational occurrences including accidents, their evolution, establishing the actual algorithm of operation of safety systems and elements important to safety, including control and monitoring systems, deviations from stationary algorithms, personnel actions;
  - Means for detecting leakage of the primary coolant exceeding the value established in the NPP design and its location;
  - Means of automated control of radioactivity of the primary coolant and (or) other technological media of the primary circuit".

Instrumentation and control systems (2/3)

Requirements to reliability and testability of instrumentation and control systems **(Criterion 62)** including application of computer-based equipment in systems important to safety **(Criterion 63)** are determined in pp. 3.4.3.3 and 3.4.4.7 of the NP-001-15 and p. 2.4.6 of the NP-082-07:

- "3.4.4.3. The NOCS of the NPP unit shall provide automatic and (or) automated diagnostics of status and operating conditions including technical means of the NOCS themselves (in particular, the technical means using the software)".
- "3.4.4.7. The CSS shall allow for:
  - Continuous automatic self-diagnostics of control systems serviceability;
  - Periodic technical diagnostics of status of CSS trains and process equipment from unit and emergency control rooms as per p. 3.1.14.

In case of failures of hardware and software and malfunctions in the CSS, signals shall be generated to UCR and ECR, as well as actions aimed at ensuring the NPP safety shall be triggered".

- "2.4.6. Diagnostics of normal operation control systems (NOCS) and controlling safety systems (CSS) shall be provided for".

Separation of protection systems and control systems **(Criterion 64)** is dictated by pp. 3.1.2 and 3.4.4.5 of the NP-001-15:

- "3.1.2. ... The mutual influence of safety systems which could prevent the proper performance of their safety functions shall be eliminated. This is achieved in such ways as physical separation and functional independence".
- "3.4.4.5. The CSS shall be separated from the NOCS to such a degree that malfunction or putting out of operation of any element or train of the NOCS could not affect the CSS capability of performing its functions".

Instrumentation and control systems (3/3)

The availability of the unit control room **(Criterion 65)** and the supplementary (emergency) control room at the NPP **(Criterion 66)** is determined in p. 3.4.1.1 of the NP-001-15 mentioned above.

Requirements to the UCR and ECR are formulated in pp. 3.4.2.1, 3.4.2.2 and 3.4.2.7 of the NP-001-15:

- "3.4.2.1. The UCR shall ensure opportunity for operational personnel to control systems (elements) of normal operation (including control of operational limits and conditions), safety systems (elements) and special technical means for management of design extension conditions within the scope specified in the NPP design during normal operation and anticipated operational occurrences including accidents".
- "3.4.2.2. Adequacy of measures provided shall be proved in the NPP design to ensure survivability, habitability and normal functioning of the UCR in all normal operation modes as well as under anticipated operational occurrences including design basis accidents and design extension conditions".
- "3.4.2.7. Both the UCR and the ECR shall perform the following actions:
  - control of safety systems;
  - bringing the reactor core to subcritical state and maintaining the reactor core in subcritical state;
  - removal of heat from the reactor and from SNF storage pool to an ultimate heat sink;
  - control of state of the RF and SNF storage pools".

The establishment of emergency response service and appropriate facilities on the NPP site **(Criterion 67)** is prescribed by p. 4.5.8 of the NP-001-15:

- "4.5.8. Prior to delivery of nuclear fuel to the NPP protected points of emergency actions control shall be set up and maintained in constant readiness; they shall be provided with the necessary equipment, instrumentation and communication means to ensure in case of accident management by implementation of plans in accordance with pp. 4.5.6 and 4.5.7 of these General provisions".

Emergency power supply

The availability of the emergency power supply system in the NPP design **(Criterion 68)** is ensured by p. 2.4.25 of the NP-082-07:

- "2.4.25. The NOCS and CSS shall be provided with reliable power supply during normal operation and anticipated operational occurrences including design basis accidents (including the power unit blackout) in the scope justified in the RF design".

Supporting systems and auxiliary systems (1/2)

Criteria 69-76 contain requirements to supporting systems and auxiliary systems:

- Criterion 69 on performance of supporting systems and auxiliary systems;
- Criterion 70 on heat transport systems;
- Criterion 71 on process sampling systems and post-accident sampling systems;
- Criterion 72 on compressed air and gas systems;
- Criterion 73 on air conditioning systems and ventilation systems;
- Criterion 74 on fire protection systems;
- Criterion 75 on lighting systems;
- Criterion 76 on overhead lifting equipment;
- Criterion 76bis on sodium heating systems;
- Criterion 76ter on sodium chemical reaction prevention and mitigation.

Criterion 69 requires that the design of supporting and auxiliary systems shall be such as to ensure that the performance of these systems is consistent with the safety significance of the system or component that they serve at the NPP. Compliance with this requirement is ensured by the classification of the NPP elements in accordance with the NP-001-15 into four safety classes depending on the degree of their impact on the NPP safety, so that “more stringent requirements to quality assurance shall be applicable to a higher safety class” (p. 2.10 of the NP-001-15).

Russian regulatory documents discussed in this report do not contain a specific list of supporting and auxiliary systems that should be provided as part of the NPP. Such a list is defined in the framework of a specific NPP design. It should be noted that the BN-1200 design provides for all the above-mentioned supporting and auxiliary systems.

Supporting systems and auxiliary systems (2/2)

However, the requirements to some of these systems are determined in the NP-001-15. In particular, implementation of **Criterion 71** is provided in accordance with pp. 3.1.5 and 3.3.6 of the NP-001-15:

- “3.1.5. The NPP design shall ensure the technical means for control of the RF and the NPP state in terms under accident conditions including severe accidents, as well as means for post-accident monitoring. The scope of control of the RF and the NPP provided for in the NPP design shall be sufficient for accident management”.
- “3.3.6. The NPP design shall ensure: the technical means for control of the primary coolant activity and (or) other technological media of the first circuit”.

The need of availability of the fire protection systems throughout the NPP site **(Criterion 74)** is required in pp. 1.2.29 and 3.7.1 of the NP-001-15:

- “1.2.29. Technical and administrative measures for ensuring physical protection and fire safety of the NPP shall be envisaged in the NPP design…”
- “3.7.1. The NPP design shall provide for necessary support safety systems performing functions of supplying safety systems with working fluid, energy and creating the required conditions for their functioning, including heat transfer to an ultimate heat sink. Support safety systems may also include fire protection systems that ensure necessary conditions for safety systems functioning in the event of a fire or prevention of fire spreading to safety systems”.

Other power conversion systems

Criterion 77 is aimed at restriction of the possible adverse influence of equipment and systems of the power conversion system (for example, steam supply system, feedwater system or NPP turbine generators) on the primary circuit systems and equipment and prevention of exceeding relevant design limits for them in operational states or accident conditions.

Appropriate general requirements are defined in p. 3.3.1 of the NP-001-15:

- “3.3.1. The equipment and pipelines of the reactor coolant circuit shall withstand without destruction static and dynamic loads and temperature effects arising in their any parts (with allowance for actions of protection safety systems and their probable failures as per p. 1.2.12 of these General provisions) during anticipated operational occurrences including design basis accidents…”, based on the fact that all possible failures in power conversion systems are considered mandatory in the list of anticipated operational occurrences.

Regarding the BN-1200 design, we recall that availability of the secondary intermediate sodium circuit practically eliminates direct influence of the tertiary circuit on the systems and equipment of the primary circuit.

Treatment of radioactive effluents and radioactive waste

Requirements for treatment of radioactive waste **(Criterion 78)** and liquid and gaseous radioactive effluents at the NPP **(Criterion 79)** are regulated by p. 3.8.4 of the NP-001-15:

- "3.8.4. …The NPP design shall envisage means for treating radioactive waste providing collection, sorting, processing, conditioning and storage of radioactive waste during normal operation of the NPP and anticipated operational occurrences including design basis accidents.

  The NPP design shall ensure storages for solid and liquid radioactive waste, systems for treatment of gaseous radioactive waste, as well as justify volumes and terms of storing non-conditioned and conditioned radioactive waste in storages.

  The NPP design shall provide for purification systems of gaseous media prior to release into the atmosphere, as well as water purification systems prior to discharge into water objects".

Fuel handling and storage systems

Availability of fuel handling and storage systems at the NPP **(Criterion 80)** is provided in accordance with p. 3.8.1 of the NP-001-15 and p. 2.7.1.1 of the NP-082-07:

- “3.8.1. Storages of fresh nuclear fuel, SNF and radioactive waste shall be available at each NPP. The capacity of SNF storage at each NPP unit shall be designed such as to provide the possibility of full discharge of fuel from the core at any moment of operation of the NPP unit”.
- “2.7.1.1. The RF design shall justify and describe the refuelling equipment and the requirements they are subject to, fulfillment of which ensures safe handling of FSAs and other core components during refuelling and also in case of failures and damages to the refuelling equipment”.

Radiation protection (1/2)

The implementation of **Criterion 81** on design of radiation protection for ensuring that doses to operating personnel at the NPP will be maintained below the dose limits is stated in p. 1.2.1 of the NP-001-15:

- "1.2.1. The NPP meets safety requirements if the following conditions are met:
  - the radiation influence of the NPP on personnel, population and environment during normal operation and anticipated operational occurrences including design basis accidents does not lead to exceeding exposure doses established for personnel and population, permissible rates on releases and discharges;
  - the radiation influence of the NPP on personnel, population and environment is limited under design extension conditions…"

Radiation protection (2/2)

Requirements for ensuring that there is adequate radiation monitoring in operational states and design basis accident conditions and, as far as is practicable, in design extension conditions **(Criterion 82)** are set out in pp. 4.4.3, 4.4.4 and 4.4.5 of the NP-001-15:

- “4.4.3. The NPP design shall provide for the radiation control system which shall ensure measurements of controlled parameters characterizing radiation conditions at the NPP site and its premises as well as in the safe area and in the surveyed area within the predetermined scope under any operating conditions of the NPP, design basis accidents and design extension conditions including the NPP decommissioning.
- 4.4.4. The NPP design shall envisage continuous measurements in the safe area and in surveyed area of ionizing radiation dose rates, wind velocity and other meteorological parameters as well as periodic measurements of density of radioactive precipitation for assessment and prediction of radiation situation in the surrounding area during normal NPP operation and anticipated operational occurrences including design basis and design extension conditions. Technical provisions for implementing these assessments and predictions shall be envisaged.
- 4.4.5. The NPP administration provides keeping account of exposure doses received by the NPP personnel and personnel from other organizations involved in maintenance, repair and testing of the NPP systems and elements, development and implementation of other arrangements to reduce personnel exposure to as low as reasonably achievable level”.

CONCLUSION

- Comparison of safety requirements used in development of the BN-1200 design with safety design criteria for the Generation-IV SFR developed by the SDC TF demonstrates their compliance.
- This leads to the conclusion that the BN-1200 design meets the safety design criteria for the Generation-IV SFR.

SSC RF – IPPE

Thank you for your attention !