Russian Regulatory Approaches for VVER-1200 Designs

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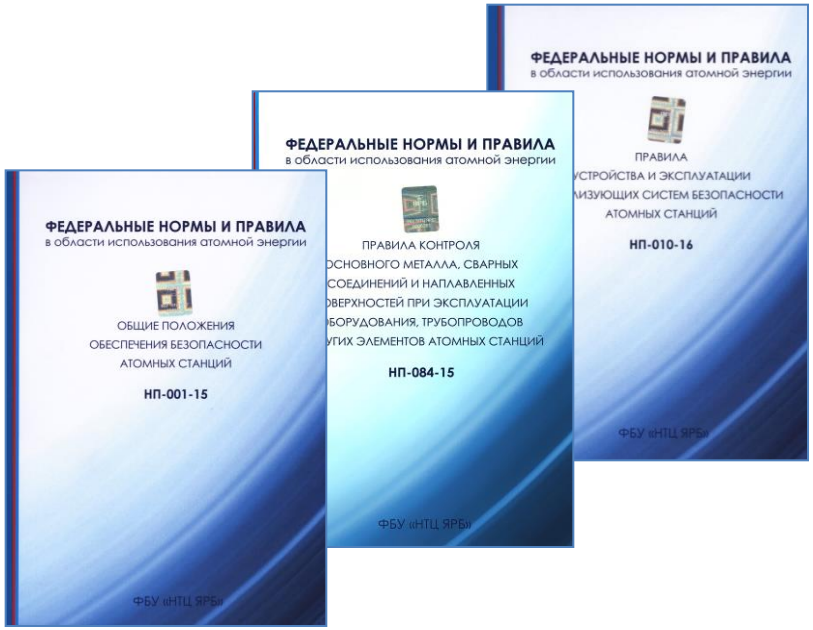
Federal Safety Rules and Regulations related to NPPs (1/2)

- NP-001-15 “General safety provisions for nuclear power plants”
- NP-082-07 “Nuclear Safety Rules for Reactor Facilities of Nuclear Power Plants”
- NP-095-15 “Basic requirements to probabilistic safety analysis of a nuclear power plant unit”
- NP-006-16 “Requirements for the content of safety analysis report for nuclear power plants with VVER type reactors”
- NP-031-01 “Design Standards for Aseismic Nuclear Power Plants”
- NP-064-17 “Accounting of external natural and man-induced impacts on nuclear facilities”
- NP-089-15 “Rules for design and safe operation of equipment and pipelines of nuclear power installations”
- NP-010-16 “Rules for arrangement and operation of nuclear power plant confining safety system”
- NP-026-16 “Requirements to the Control Systems Important for Nuclear Power Plants Safety”



Federal Safety Rules and Regulations related to NPPs (2/2)

- NP-032-01 “Siting of nuclear power plants. Main safety criteria and requirements”
- NP-015-12 “Standard Content of Action Plans for Personnel Protection in the Event of Accident at a Nuclear Power Plant”
- NP-002-15 “Rules for the Safe Management of Radioactive Waste from Nuclear Power Plants”
  - *NP-019-15 “Collection, Processing, Storage and Conditioning of Liquid Radioactive Waste. Safety Requirements”*
  - *NP-020-15 “Collection, Processing, Storage and Conditioning of Solid Radioactive Waste. Safety Requirements”*
  - *NP-021-15 “Management with Gaseous Radioactive Waste. Safety Requirements”*
- NP-061-05 “Safety Rules for Storage and Transportation of Nuclear Fuel at Nuclear Facilities”
- NP-090-11 “Requirements to Quality Assurance Programs for Nuclear Facilities”
- NP-096-15 “Requirements to Resource Management of Equipment and Pipelines of Nuclear Power Plants”
- some others

Assessment and selection of site for NPP location

Para 3.1, 3.2 Section 3 "Basic criteria and requirements for the safe disposal of nuclear power plants" NP-032-01:

Exclusion factors for NPPs siting:

- places where the siting of nuclear plant is not allowed;
- places that are unfavorable to the siting of nuclear plant.

Para 2.7, 2.8 NP-064-17 (Accounting of external impacts):

DBA caused by:

- natural factors with the recurrence frequency: **$\geq 10^{-4}$ 1/year**;
- man-induced factors with the recurrence frequency: **$\geq 10^{-6}$ 1/year**.

BDBA's caused by external events:

- with an intensity exceeding the intensity of events accounted in the NPP design basis, as well as a combination of these impacts

NPP safety targets

Para 1.2.17 NP-001-15

Non-exceedance of integrated probability of:

- Severe accidents for each NPP unit **of 10^{-5} per year**;
- Large emergency release for each NPP unit **of 10^{-7} per year**;
- Severe accidents for NPP fuel storages (with do not make up the NPP units) **of 10^{-5} per year**

Large accident release probability > 10^{-7} per year:

NPP design shall provide for additional technical features (including special technical means for BDBA management) to manage accidents with the purpose of decreasing the probability of accidents and mitigating their consequences

Defense in depth

Paras 1.2.4, 1.2.5 NP-001-15

- Level 1. Conditions of NPP siting and prevention of operational occurrences
- Level 2. Prevention of DBA by normal operation systems
- Level 3. Prevention of BDBA's by safety systems
- Level 4. BDBA's management *(use of special technical means)*
- Level 5. Emergency planning

Physical barriers: Reactor coolant circuit boundary, Containment and Biological shielding, fuel matrix and cladding

Requirements based on Fukushima lessons learned:

- independence of the DiD levels from each other, as far as this practically possible *(especially for Level 3&4);*
- prevention of a barrier damage due to the damage of other barriers as well as several barriers damage resulting from the similar impact;
- measures aimed at excluding the «Cliff-edge effect» *(Level 1)*

Designing and safety substantiation

Paras 1.2.7, 1.2.9 NP-001-15

- Safety related decisions shall be well proven by the previous experience or tests, investigations, operating experience of prototypes;
- Safety substantiation of systems operability shall be confirmed by experimental studies, operational experience and (or) calculations;
- Computer programs used for calculations shall be verified and certified

Para 3.1.10 NP-001-15

- While designing the systems (elements) of NPP, it is necessary to give preference to the systems (elements) with design based on the **passive principle** of functioning

Safety related systems and safety systems

Para 3.1.9 NP-001-15

All safety systems shall be designed and protected to tolerate common cause failures by applying of:

- diversity principle,
- redundancy principle,
- independence principle

Principles can be applied to combination of active and passive systems

Para 4.2.4 NP-001-15

- Confirmation of actual characteristics of safety related systems is performed during the Unit commissioning

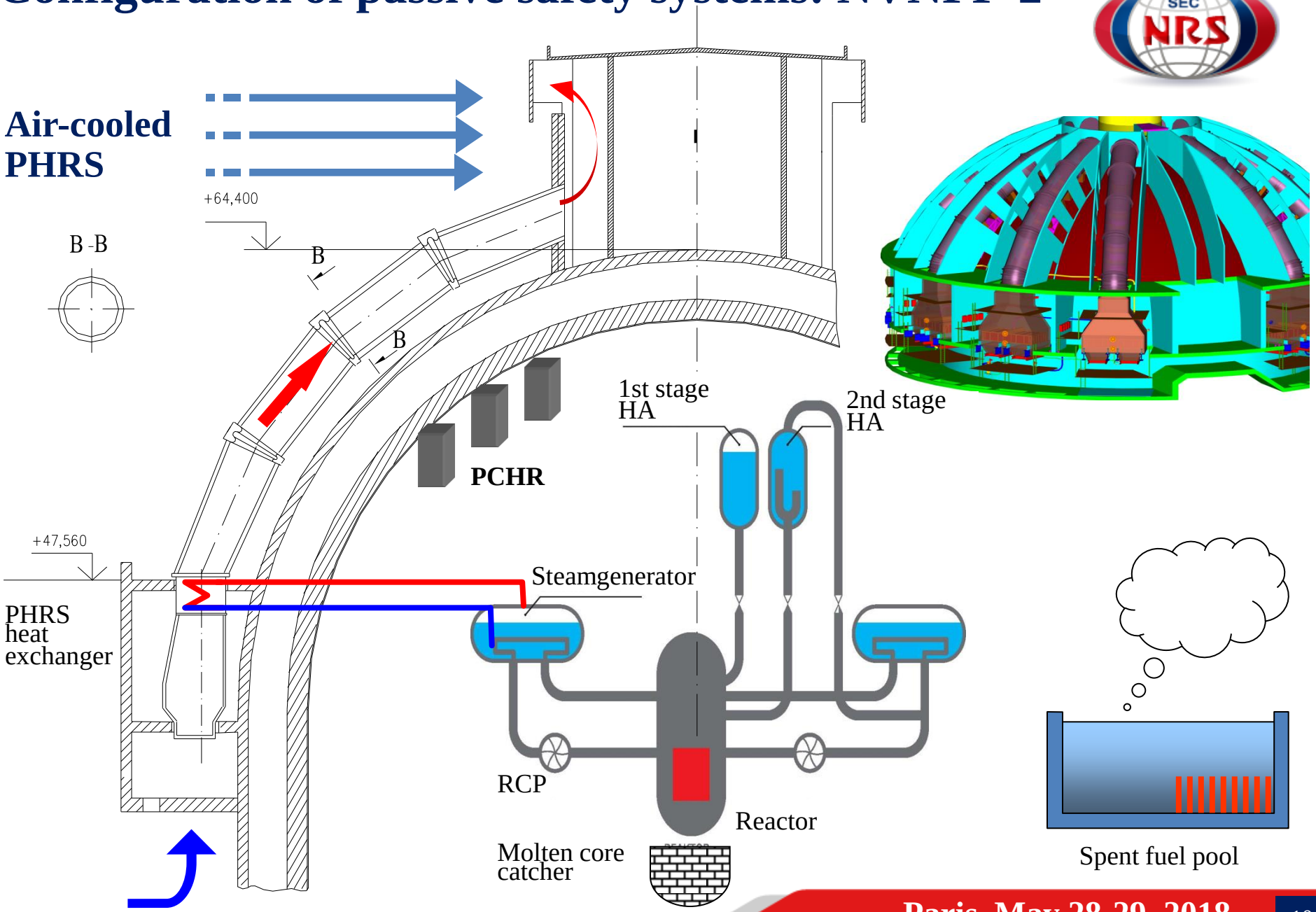
Differences in VVER-1200 design solutions for safety systems

Leningrad NPP-2	Novovoronezh NPP-2
Active systems	
➢ 4x100% («typical» structure of safety systems)	➢ 2x100%, 4x50% (2-trays, some - with redundancy of separate elements inside train)
Passive systems	
➢ Double-walled containment	➢ Double-walled containment
➢ Hydroaccumulators of ECCS (stage 1)	➢ Hydroaccumulators of ECCS (stage 1)
➢ Emergency hydrogen removal system	➢ Emergency hydrogen removal system
➢ Passive heat removal system (PHRS) from SG (water-cooled)	➢ Passive heat removal system (PHRS) from SG (air-cooled)
➢ Passive heat removal system from Containment	➢ Hydroaccumulators of ECCS (stage 2)

➢ Molten core catcher (in case of severe accidents)

➢ Mobile equipment

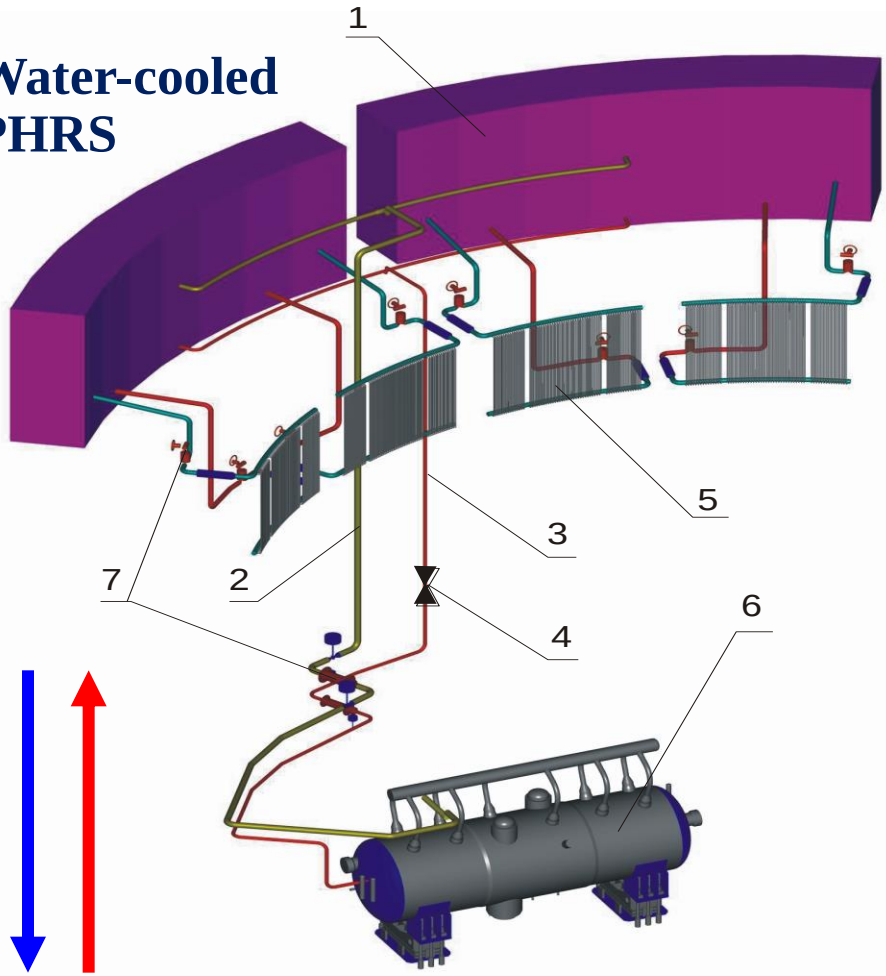
Configuration of passive safety systems: NVNPP-2

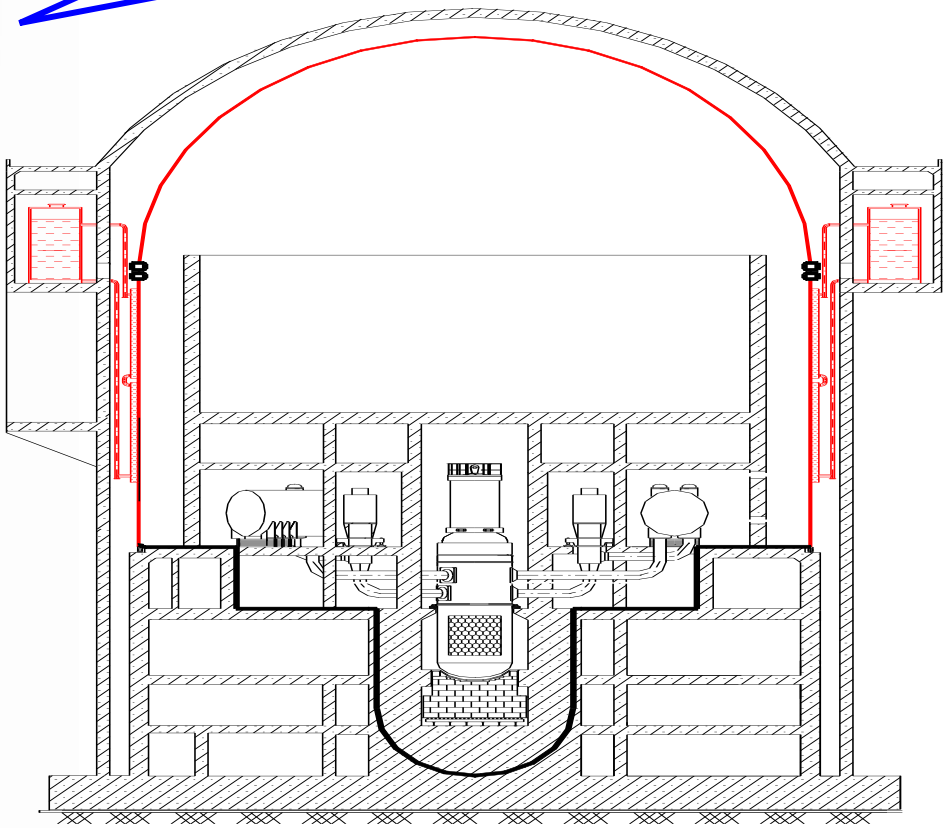


Configuration of passive safety systems: LNPP-2

Heat is removed with evaporating water from the tanks to the atmosphere

Water-cooled PHRS





1 – tank; 2 – steamlines; 3 – condensate lines; 4 – SG PHRS valve;
5 – containment PHRS heat exchangers; 6 – steam generator;
7 – cut-off valves

Regulatory approaches to evaluation of PHRS (1/2)

Safety review of substantiation of PHRS:

- sufficiency of heat removal from reactor:
  - ✓ with no time limitation or the providing explanation for time limitation 24, 72 or more hours *(for water-cooled PHRS: the measures on inventory make-up are to be envisaged)*
  - ✓ in any weather condition *(for air-cooled PHRS: temperatures or wind speed)*
- potential interactions of active and passive systems or/and different passive systems foreseen to operate simultaneously:
  - ✓ potential negative interactions i.e. interactions worsening their reliability
- possible delays in systems activation caused by various reasons (such time interval shall not exceed time period when the accidents' evolving into the severe condition is being prevented because of natural processes related to coolant heating and boiling-off (in SGs, in primary circuit)
- possible negative effects of non-condensable gases (measures to prevent collection of them into the heat exchangers)

Regulatory approaches to evaluation of PHRS (2/2)

App 3 to NP-006-16

- When safety function can be fulfilled by either active or passive safety system the SAR (Chapter 15) should contain substantiation for both cases:
  - ✓ when only active systems are in operation;
  - ✓ when only passive systems are in operation.
- False actuation (starting) of passive system should be evaluated as one of initiating event (as a rule the false actuation of PHRS SG is considered)

Para 3.1.14 NP-001-15

Passive safety systems should be tested, including their active components, during commissioning and in operating plants

- Direct and full checks are preferable
- If performance of direct and/or full checks not be possible indirect and/or partial checks shall be carried out

Adequacy of indirect and/or partial checks shall be validated in the NPP design

Design-basis accidents (DBA)

Paras 1.2.14, 1.2.15 NP-001-15:

- List of initiating events for analysis of DBA shall include all possible internal and external events that lead to NPP operational occurrences and are not exempted due to inherent safety features of the reactor and principles of its arrangement
- Combinations of NPP systems (elements) failures, human errors, internal or external impacts shall be taken into account

✓ *Internal events with probability of 10^{-6} or less per year may not be included*

- Tentative lists of DBA initiating events are established in NP-006-16 (Requirements for the content of SAR)
- Final lists of DBA initiating events shall be presented in the NPP SAR

Beyond-design-basis accidents (BDBA) (1/3)

Para 1.2.16 NP-001-15

Tentative lists of BDBA initiating events are established in Annex 9 to NP-006-16 (requirements for the content of SAR).

BDBA list shall include, in particularly,

- external natural impacts
- external man-induced impacts
- combination of these external impacts
- **severe accidents** (in operation and in shut down states of reactor with a non-heated primary circuit)

With an intensity exceeding those considered in the design of NPP

- ✓ Long-term NPP blackout

  leading to the dehydration of the SG and the boiling-off of the primary coolant

- ✓ The range of leaks in the primary circuit inside the Containment area with the failure of the active elements of ECCS

  leading to severe damage to fuel elements in the core.

- ✓ The range of leaks from the primary circuit to the second one with the failure of the active elements of the ECCS

  leading to severe damage to the fuel elements in the core.

Beyond-design-basis accidents (BDBA) (2/3)

Para 1.2.16 NP-001-15

Final lists of BDBA (including severe accidents) shall be:

- presented in the NPP SAR;
- include representative scenarios for identification of measures for managing such accidents

The representativeness of the BDBAs scenarios to define measures on such accidents management is to be provided through accounting of severity levels of a nuclear plant conditions and, besides that, the possible conditions of availability and non-availability of safety systems and special engineering means for the BDBAs management

Taking into account of this conception:

- **Safety Guideline RB-102-15 "Recommendations to the Structure and Content of BDBAs Management Guideline (including Severe Accidents)"** brought in force in 2015;
- **Safety Guideline "Recommendations on the development of BDBA list to be considered in the design of NPP with VVER-type reactors"** planned to put in force in 2018

Beyond-design-basis accidents (BDBA) (3/3)

Para 1.2.11 (i. 2) NP-001-15

Technical and organizational measures in NPP design:

- limitation of consequences of BDBAs by means of technical measures for BDBA management and any other applicable technical means regardless their intended purpose and by means of organizational measures

Para 1.2.19 NP-001-15

Measures on the BDBAs management are to be developed regardless of the probability of accident origination:

- additional engineering means - in case the large-scale emergency release probability exceeds the 10^{-7};
- administrative measures on the BDBAs management - **for all cases**

Special technical means used for BDBA management (1/3)

Paras 3.1.3, 3.1.4 NP-001-15

Providing basic safety functions for the following BDBA's:

- failure of normal operation systems and safety systems removing heat from the reactor and nuclear fuel storage facilities to the UHS;
- failure of normal operation power supply systems accompanied by failure of the emergency power systems

Para 2.5 NP-001-15

- Special technical means for BDBA management within 72 hour shall be classified as safety related equipment

✓ ***in the initial 72 hours*** *failure of BDBA management means makes a significant contribution to the probability of the large-scale emergency release and the total probability of severe accidents (it is assumed that recovery of the failed NPP equipment and external support provision are limited during this period).*

✓ ***after the 72 hours period*** *- the accident response tools are prepared and deployed and the failed equipment for BDBA management means can be replaced.*

Special technical means used for BDBA management (2/3)

Substantiation of reliability and operability under BDBA conditions within and beyond the 72 h

- *including SA conditions*

Protection measures against external events or accident induced impacts

- *safe locations for mobile pumps, means, etc.*
- *points for connection of the special technical means with the operating equipment should be defined in the NPP design and protected from hazards initiating the necessity of its use*
- *availability and protection of transportation routes (beyond and on site of NPP)*

Sufficiency of special technical means for BDBA management in case of a simultaneous accident at all units of a multiunit NPP, combined with damage to infrastructure beyond the NPP site, including availability of:

- necessary quantity and composition of NPP staff
- vehicles that provide transportation of special technical means

Take into account:

- ✓ plant states considered for each unit may be different;
- ✓ design of some units may have differences - old and modern units in one site

Special technical means used for BDBA management (3/3)

Operation procedures for special technical means for BDBA management:

- special engineering means which require human interaction for their start-up (or operation) shall be checked for appropriateness of human-machine interface issues;
- possible human errors affected on the special engineering means operability should be carefully checked and necessary countermeasures should be taken;
- possible delays in the actuation or operation of the special engineering means due to a variety of reasons should be taken into account in the design of NPP;
- start-up time for special engineering means should take into account the time interval required for:
  - ✓ organization of personnel transfer to the location of the mentioned systems (equipment);
  - ✓ the necessity to clear the transportation routes
  - ✓ time period for equipment transportation to the deployment and connection place
- fuel and water supply - prolonged time periods for heat removal from nuclear fuel;

PSA

Para 8, 9, 10 NP-095-15.

- PSA level 1: total probability of SA in one year for one unit for all initial events, all modes of normal operation, all locations of nuclear materials available on NPP unit.
- PSA level 2 : the total probability of a Large emergency release in one year for one unit for all initial events, for all normal operation modes, for all locations of nuclear materials, radioactive substances and radioactive waste on NPP unit.

Para 12, 13 NP-095-15.

Take into account:

- initial events:
  - ✓ related to the failure in the system (element) of the NPP, error of NPP staff or mistaken staff decision;
  - ✓ due to internal impact;
  - ✓ caused by external impact of natural and made-man origin.
- all possible operating conditions of the NPP unit, including power operation, shut-down, cooling, nuclear fuel transfer, maintenance and repair of systems (elements), heating, start-up.

SAR

Para 1.2.8 NP-001-15

- Technical and organizational measures to ensure the safety of NPPs, the design basis of systems and elements related to safety, should be presented in SAR

App 4 to NP-006-16

- Safety related systems, including passive systems and special technical means for BDBA management should be described in SAR at the same level of detail
- Sufficient substantiation of systems operability by calculations, experimental studies and (or) operational experience);
- Applicability of thermo-hydraulic computer programs (codes) used for safety justification, including information about their verification and certification

Para 3.1.17 NP-001-15

- Reliability analyses of fulfillment of functions by the **safety related systems**
  - ✓ ***Regulatory guide RB-100-15 "Recommendations in order of execution reliability analysis of systems and components of nuclear power plants important to safety and their functions"***

Para 4.2.6 NP-001-15

based on the results of commissioning, a final version of the FSAR should be developed (contains information on the results of the carried out tests, including the refined information of the systems).

Current state (1/2)

https://www.seogan.ru/novosti/stroyashiesya-aes/

Novovoronezh VNPP-2
Unit 1 - OL
Unit 2 - CL

Leningrad NPP-2
Unit 1 OL
Unit 2 - CL
Unit 3 - SL
Unit 4 - SL

NVNPP-2 Unit 1 - OL
24.03.2016 First fuel assembly
20.05.2016 First criticality
05.08.2016 Connection to grid
27.02.2017 Commercial operation

NVNPP-2 Unit 2 - CL
22.03.2018 Activity on turbine generator installation

LNPP-2 Unit 1 - OL
08.12.2017 First fuel assembly
06.02.2018 First criticality
09.03.2018 Connection to grid

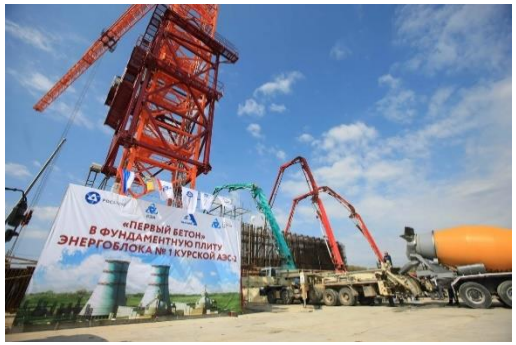
LNPP-2 Unit 2 - CL
24.04.2018 Assembling the containment dome

Current state (2/2)

https://www.seogan.ru/novosti/stroyashiesya-aes/

Kursk NPP-2
- Unit 1 - CL
- Unit 2 - CL

Smolensk NPP-2
- Unit 1 - SL
- Unit 2 - SL



Kursk NPP-2 Unit 1 - CL
29.04.2018 First concrete

Thank you for your attention !