



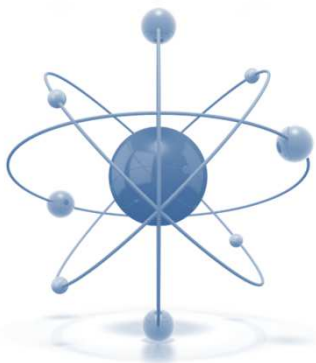
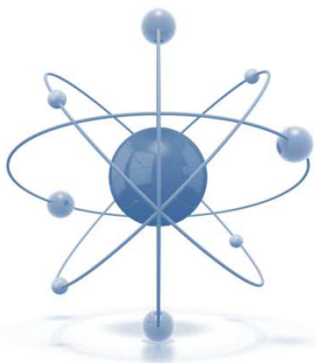
Application of the Defense-in-Depth Concept in the Projects of New-Generation NPPs Equipped with VVER Reactors

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Content



General information about the new VVER NPP designs

DiD concept in Russian Regulatory Documents

An evolution of the approach to DiD for new NPPs

Brief description of new VVER NPPs in the light of DiD

Main objectives in designing new VVER NPPs

AES 2006 → VVER-TOI

The new evolutionary designs of NPPs equipped with VVER reactors developed in JSC “Atomenergoproekt” are presented by AES-2006 (NVNPP-2) and VVER-TOI projects

Lower Construction period



Achievement of low Risk level



High Performance Indicators

UP-to-date technologies, complex information model



Optimization of the design solutions



Basic characteristics of new VVER plants (1/2)

	AES 2006	VVER - TOI
Electrical Power of the Unit	1 198 MWt	1 255 MWt
Thermal Power of the Unit	3 200 MWt	3 300 MWt
Design life time	50 a	60 a
Efficiency Factor	37,4 %	37,9 %
Availability Factor (18 months operating period)	91 %	93 %
Cycling mode	100-75-100	100-50-100
Autonomy time in BDBA	24 h	72 h

Basic characteristics of new VVER plants (2/2)

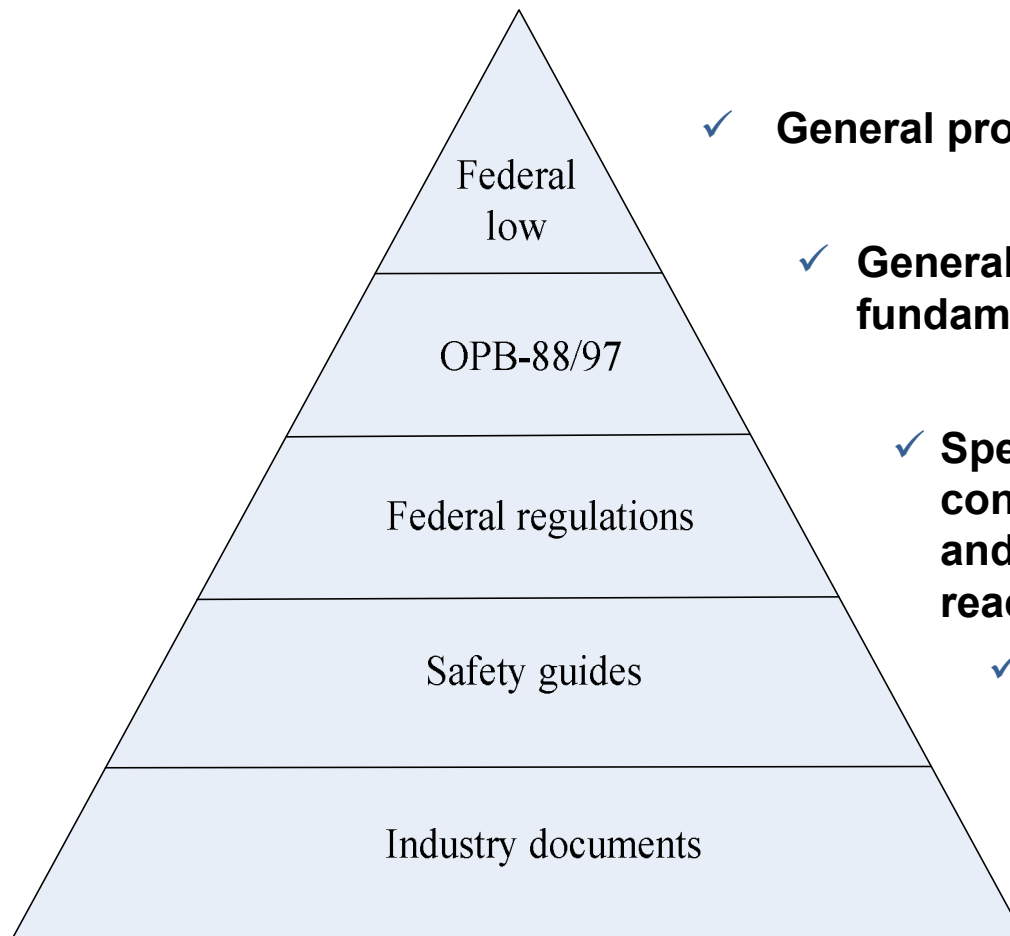
	AES 2006	VVER - TOI
OPE / SSE	6/7 points	7/8 points
Option: SSE (Customer requirement)	-	9 points
Airplane (design)	5,7 t	20 t
Commercial airplane (BDBA)	—	400 t
Construction period	54 m	48 / 40 m
Auxiliaries	7 %	6,47 %

General plant layout

Specific area – 200 м2/MWt



General structure of regulatory type documents in Russia



- ✓ **General provisions in use of Atomic Energy**
- ✓ **General provisions in Nuclear Safety (Safety fundamentals)**
- ✓ **Specific Safety requirements (i.g. SAR content and format, requirements for siting and design, nuclear safety regulations of reactor unit, etc.)**
 - ✓ **Guides in specific areas of safety (i.g. PSA)**
- ✓ **Others**

DID concept in Russian regulatory documents (1/4)

Basic definitions (OPB-88/97):

- ✓ **Initiating event** – a single event (component failure, human fault or external event) that cause termination of normal operation and may lead to exceeding safety limits or (and) breach of safety technical specifications;
- ✓ **Design Basis Accident** – an accident that assumes corresponding (established in the design) initiating event (PIE) and end states, for which safety systems implemented in the design with account for single failure criterion provide bounding its consequence within design limits;
- ✓ **Single Failure Criterion** – the rule, in accordance to which safety system should perform its function in the case of any IE that requires its operation and given single independent failure of any active component or passive component with mechanically moving parts;
- ✓ **BDBA** – an accident that occurs as result of event, not considered in the design or characterized by bigger number of independent failures (in comparison to SFC);
- ✓ **Severe accident** – BDBA with fuel damage that exceed design limits, which may result in LR .

DID concept in Russian regulatory documents (2/4)

Basic provisions (OPB-88/97):

- ✓ i.1.2.3 Nuclear safety shall be guaranteed by means of gradually implemented DiD concept which is based on implementation of set of physical barriers on the way of propagation of radioactivity to the environment, and set of technical and organizational measures aimed to protect barriers and maintain their effectiveness as well as measures on radiation protection of plant stuff and population
- ✓ These barriers include the following:
 - ✓ Fuel matrix
 - ✓ Claddings of fuel rods
 - ✓ Reactor vessel, pipelines, and other equipment containing the coolant in the reactor unit
 - ✓ Containment
 - ✓ Biological shielding.

DID concept in Russian regulatory documents (3/4)

Basic provisions (OPB-88/97):

- ✓ **System of technical and organizational measures shall form 5 levels of DiD aimed to:**
 - ✓ **Level 1 Prevention of anticipating transients during normal operation**
 - ✓ **Level 2 Bringing plant into normal operation in the case of anticipating transient conditions, preventing their transfer to PIE or BDBA**
 - ✓ **Level 3 Prevention of transfer PIEs to DBA and DBA to BDBA. Providing achievement of Safe state by means of Safety Systems operation in case of DBA**
 - ✓ **Level 4 Prevention of transfer BDBAs to severe accidents. Containment protection in the case of BDBA. Return to the stable state, mitigating accident consequences**
 - ✓ **Level 5 Radiation protection of population**

Basic provisions (NP-082-07):

- ✓ **i.2.1.8 The lists of PIEs of DBAs and BDBAs shall be established and documented in the designs of Reactor Unit and NPP. DBAs and BDBAs shall be classified on the basis their frequencies and severity of consequences. The list of BDBA shall include severe accidents**

DID concept in Russian regulatory documents (4/4)

Basic provisions:

- ✓ i.1.2.12 The technical and organizational measures should be implemented in the design aimed to prevent DBA occurrence and limiting their consequences and which guarantee achievement of safety state in any PIE with account for SFC.
- ✓ The breaches of vessels that manufactured and operated in accordance with requirements of high quality established in Federal regulations can be excluded from list of PIEs if it is shown that probability of such events is less than $1E-7$ per year.
- ✓ In some specific cases, where high level of components reliability mentioned in SFC as well as systems which they belong to is justified, these components can not be subjected to requirements i.1.2.12.
- ✓ Same is true for the time when components are taken from the operation for the maintenance within AOT, established in the design on the basis of reliability approach.

DiD concept in Russian regulatory documents generally corresponds to the traditional approach adopted in international standards (IAEA, SSR-2/1). Requirements for the BDBA are not specified at detail level

EUR approach to DiD (1/2)

EUR 2.1.3 (DBC) SS design shall based on DiD concept, e.g:

- ✓ Establishing in the design comprehensive list of internal IEs and assigning them into categories according to their frequencies (from 2nd to 4th)
- ✓ Applying conservative design rules for SS
- ✓ Considering loads resulting from combinations of normal conditions and postulated hazards
- ✓ Use of a number of deterministic conventions (in particular SFC and acceptance criteria)

EUR 2.1.4 (DEC):

- ✓ The DEC shall be selected by the designer with the basis aim of meeting all probabilistic safety objectives (CDF, frequency to exceed CLI)
- ✓ DEC shall include Complex sequences (failures beyond SFC but not result in core melt) and Severe accidents
- ✓ Complex sequences shall include ATWS, SBO, some containment bypass scenarios, may include CCFs
- ✓ These sequences in general, to be determined using probabilistic methods
- ✓ Severe accidents to be considered as a part of DEC and shall meet CLI criteria
- ✓ Corresponding sequences are mainly identified on the PSA basis

EUR approach to DiD (2/2)

EUR 2.1.5 (Hazards):

- ✓ Risk from hazards to be commensurate with probabilistic targets
- ✓ Use “standard plant design conditions” for DBS, provide an assessment of their impact
- ✓ Effect of hazards to be considered with the most adverse NO conditions and with account for SFC
- ✓ SFC may not be applied for sequences involving hazards of very low frequency
- ✓ DBC for hazards to be specified on the basis of combination of engineering and probabilistic judgments
- ✓ An assessment to be made to demonstrate no sudden increase in risk for hazards, which intensity exceeds DBC parameters, considering design margins
- ✓ Intentional aircraft crash shall be considered deterministically, but as a DEC part

DiD based requirements to the Design in EUR follows general concept, are formulated at detail level, including requirements to DEC. For this part the main target is to prevent core damage and limit the release with CLI targets. PSA plays important role in DEC analysis

Finding for DID concept raised from Fukushima and other accidents (1/3)

- ✓ **External event** may result in a single internal IE or in a set of internal IEs, that occur simultaneously or one after another in relatively short time
- ✓ These secondary internal IEs could act in a longer time than it specified in the design
- ✓ These IEs can be combined with multiple SS component failures (e.g. CCF in support systems, dependent failures in front line and containment components)
- ✓ Cumulative effect need to be considered (not only by load)
- ✓ External event may be also intentional
- ✓ As a result – the enhance of traditional DiD approach based on SFC to a more stringent requirements is necessary
- ✓ Frequencies of External events and their direct consequences need to be assessed properly (e.g. with account for their duration, justified screening criteria, etc.)



DID concept in WENRA position papers (1/2)

WENRA position (main statements):

- ✓ **New reactor designs and associated evolution of the defence-in-depth levels**
 - ✓ Level 3 DiD is subdivided into two sublevels 3a and 3b;
 - ✓ Sublevel 3a: Safety systems, accident procedures, postulated single initiating events, SFC, stringent acceptance criteria;
 - ✓ Sublevel 3b: Additional safety features (together with SS if available), accident procedures, postulated multiple failure events, less stringent criteria;
- ✓ **Independence of the levels of Defence-in-Depth**
 - ✓ There shall be independence to the extent reasonably practicable between different levels of DiD;
 - ✓ The adequacy of the achieved independence shall be justified by an appropriate combination of deterministic and probabilistic safety analysis and engineering judgement
- ✓ **Multiple failure Events**
 - ✓ Multiple failure events to be considered at the design stage :
 - ✓ a postulated CCF or inefficiency of all redundant trains of SS aimed to cope with AOO or PIE;
 - ✓ a postulated CCF of SS to fulfill NO functions

DID concept in WENRA position papers (2/2)

WENRA position (main statements):

- ✓ **Provisions to mitigate core melt and radiological consequences**
 - ✓ The off-site radiological impact of accidents with core melt only leads to limited protective measures in area and time (no permanent relocation, no long term restrictions in food consumption, no need for emergency evacuation)
- ✓ **Practical elimination**
 - ✓ To identify accident sequences that have the potential to cause a large or early release, deterministic assessment, probabilistic risk assessment and/or engineering judgment should be used;
 - ✓ An examples of events to be practically eliminated - rupture of major pressure retaining components (e.g. reactor vessel), internal hazard leading to severe core degradation (heavy load drops), etc.
- ✓ **External hazards**
 - ✓ External Hazards considered in the design should not lead to a core melt accident (level 3 DiD);
 - ✓ Accident sequences with core melt resulting from external hazards which would lead to ER or LR should be practically eliminated (level 4 DiD)
- ✓ **Intentional crash of a commercial airplane should not lead to core melt**

WENRA papers: Conclusion

In general requirements are closed to EUR

Show further evolution of DiD concept.

Emphasize mainly on deterministic principles

Provide response to challenges from recent accidents

Include more stringent requirements to new Designs in some areas (e.g. multiple event consideration, DiD levels independence)

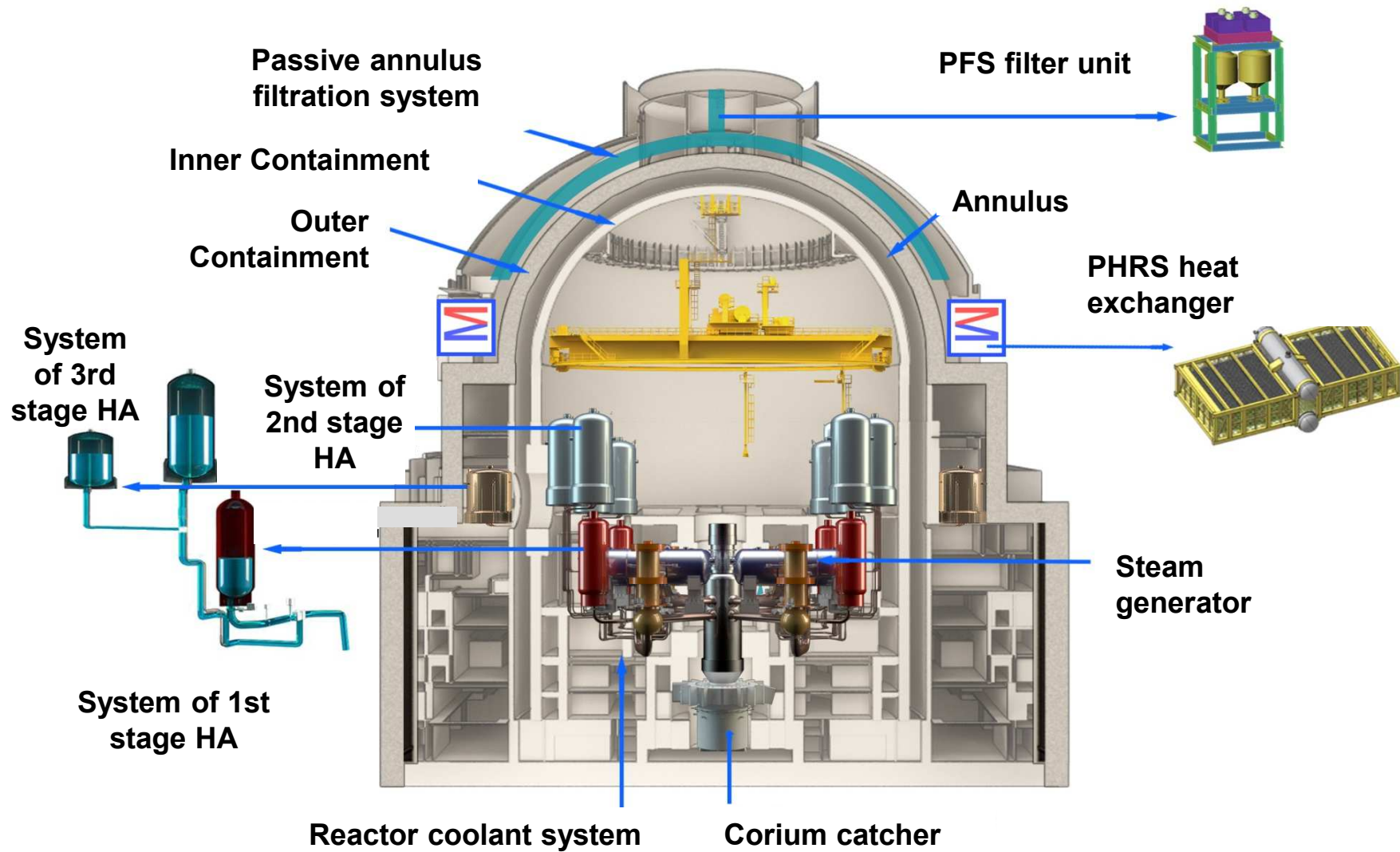
In the Technical Assignment for AES-2006/VVER-TOI projects

EUR and partially WENRA requirements were used in addition to Russian regulatory documents

Structure of safety systems adopted in the new VVER projects and protection against CCF

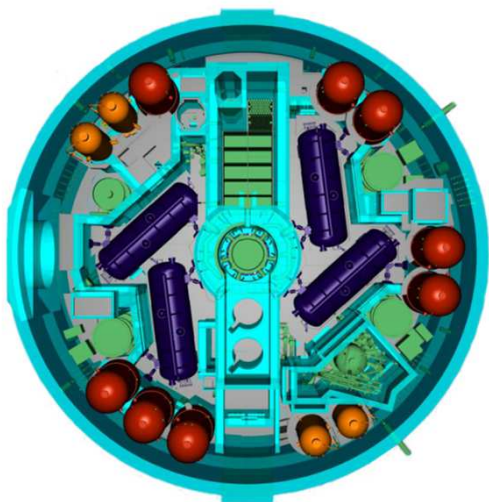
NAME OF SAFETY SYSTEM	SYSTEM STRUCTURE
High-Pressure ECCS	An active two-train system (2x100% trains)
Emergency and Planned Cooldown System (EPCS)	An active two-train system (2x100% trains)
Emergency Boron Injection System (JND)	An active two-train system (2x100% trains)
SG Emergency Cooldown System (ECS)	A closed-loop active two-train system (2x100% trains)
ECCS Passive Hydroaccumulators (HA1)	A four-train passive system
Supplementary Passive Core Flooding System (HA2)	A four-train passive system
Passive Heat Removal System (PHRS)	A four-train passive system) fitted with air-cooled heat exchangers
Passive Annulus Filtration System (PAFS)	A four-train passive system

The main design solutions on safety systems

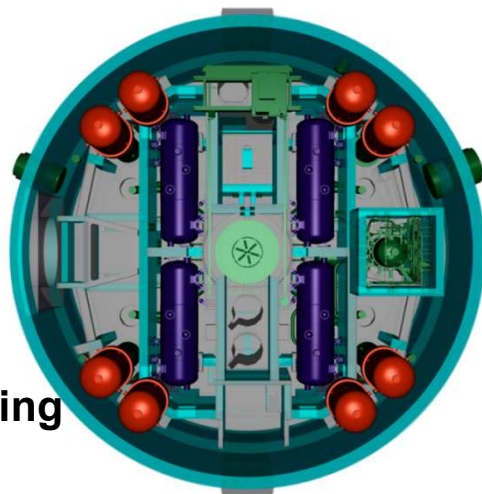


Reactor building solutions- layout optimization and protection against internal hazards

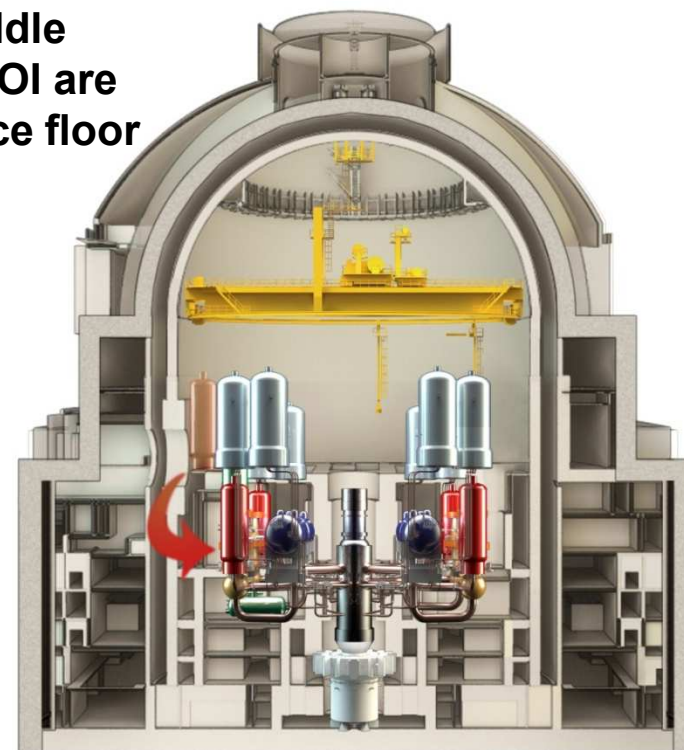
AES-2006



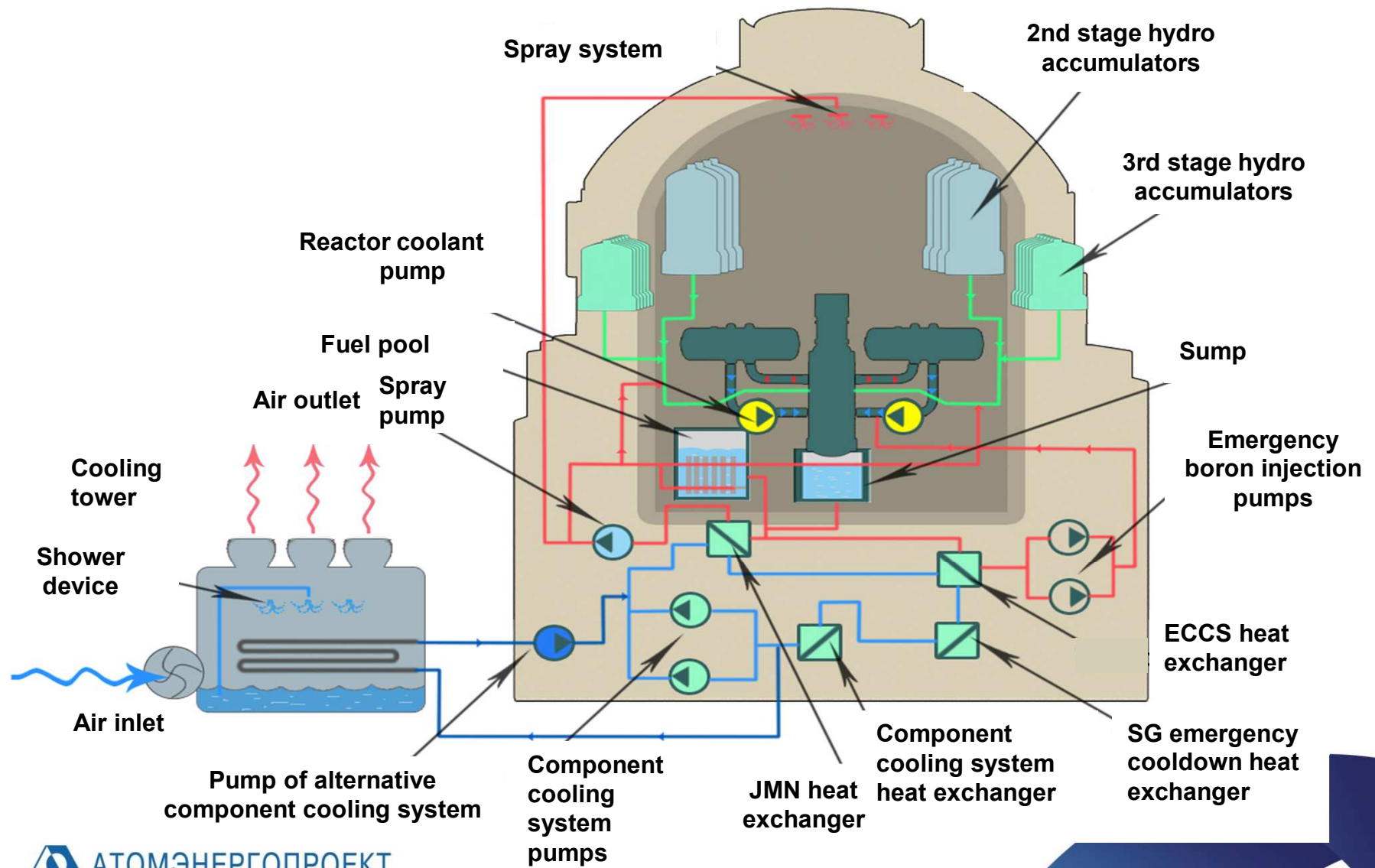
SS rooms are placed from each side of Containment. Middle pressure HAs for VVER-TOI are placed under maintenance floor



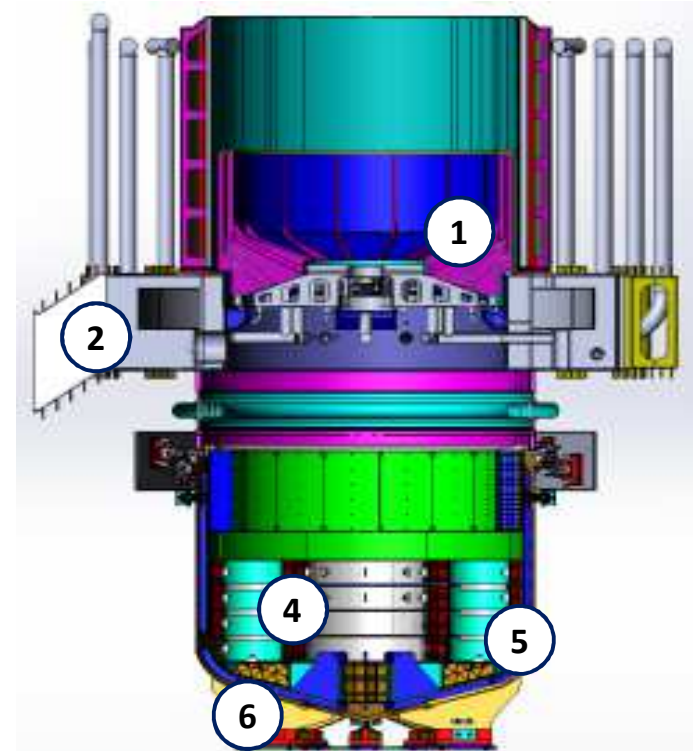
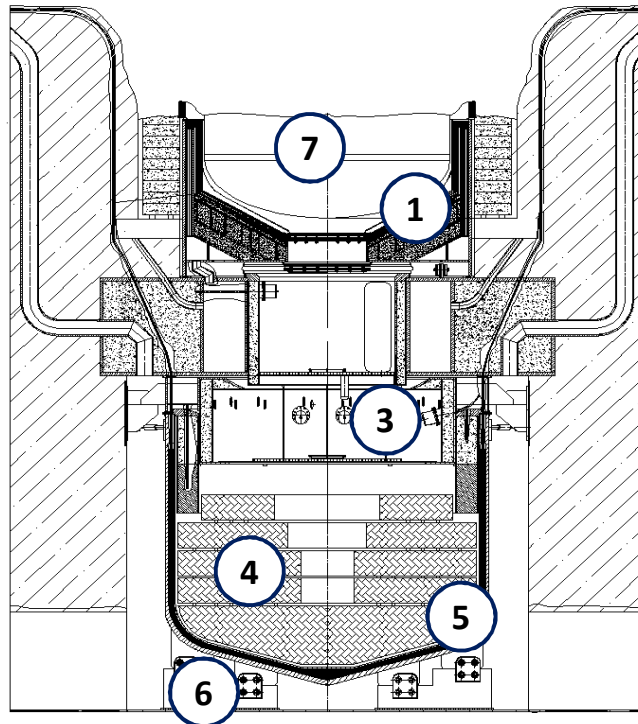
VVER-TOI – «mirror symmetry» approach in Containment building



Supplementary Safety features for external hazards






AES-2006 (VVER-TOI) Core Catcher and DiD level 4

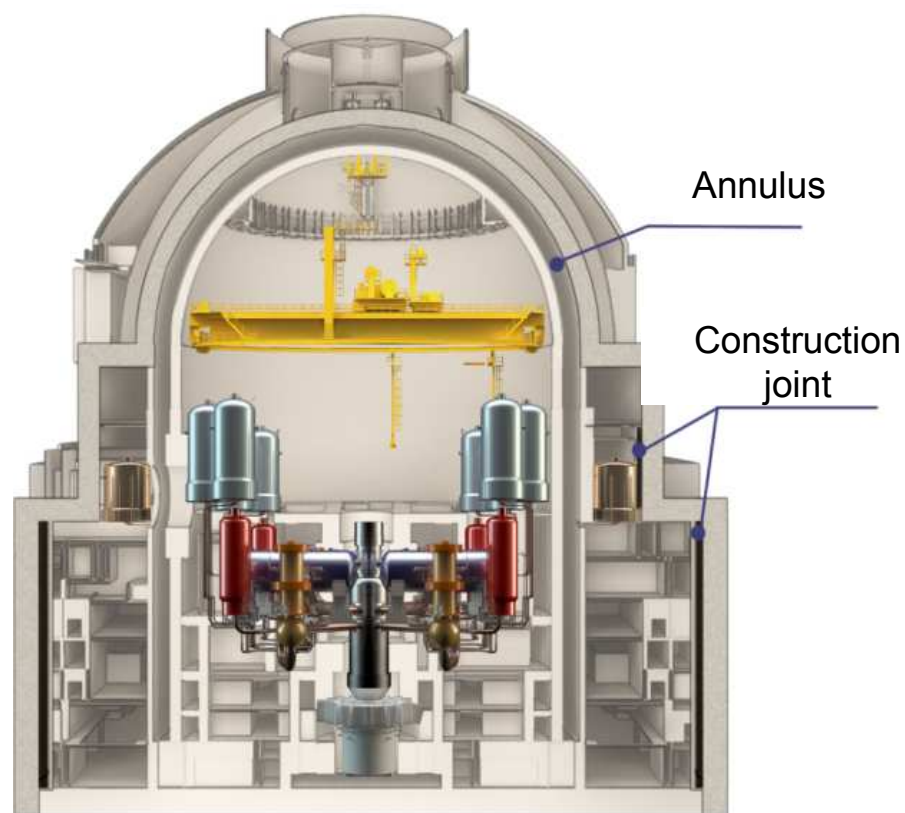


The Core catcher is placed in the lower part of Containment in reactor shaft. The Core catcher provides molten core retention and cooling by water in sump in severe accidents and together with other safety features (passive hydrogen recombiners, alternative heat removal unit) serves for preventing Containment failure

1 – bottom plate; 2 – truss-cantilever; 3 – service platform; 4 – filling agent;
5 – casing; 6 – casing support; 7 – reactor vessel

Protection against aircraft crash

Mass, t	Velocity, m/s	Impact spot, m ²	
<i>LearJet 23 (considered in the NVNPP-2 project)</i>			
5.7	100	12	
<i>Phantom RF-4E – a design-basis initiating event</i>			
20	215	7	
<i>Boeing 747-400 – a beyond design-basis initiating event</i>			
400	150	50+50	



New VVERs against requirements followed current practice and new DiD concept evolution (1/2)

DBC, Level 3a DiD

- ✓ **The comprehensive list of PIEs are classified in the design in accordance with their frequency (above $1E-6$ 1/y) and corresponding acceptance criteria were defined. IEs with very small frequency (about $1E-6$ 1/y and less) were considered as a part of complex sequences study. IEs with extremely small frequency (e.g. Reactor vessel rupture) were not considered deterministically**
- ✓ **SSC in new VVERs are designed to cope with PIEs in conservative way, supported by calculations and experiments (including traditionally considered external hazards), which cover all operating states of NPP**
- ✓ **SSs are presented in the design by active (traditional) and passive systems**
- ✓ **Active SSs are of two-train structure with inner redundancy, this meets SFS for all PIEs and all operating states**
- ✓ **Passive systems work together with active and if latter failed, may themselves maintain cooling reactor at least in 72h (24h for AES-2006)**
- ✓ **This also provides an effective protection against CCF**

New VVERs against requirements followed current practice and new DiD concept (2/2)

Complex sequences, Level 3b DiD:

- ✓ Include both rare events of different origin and CCFs
- ✓ Because of active/passive diversity, CCF postulated in any system does not result in core damage
- ✓ Support system functions (CCS, SW, EPS) are doubled by means of PHRS function, which in transients at power may work for a long time
- ✓ To exclude CCF in I&C, the special decisions in I&C design are implemented. In addition, a complementary I&C and batteries that supply the most critical components are implemented
- ✓ For rare IEs including long-term initiators, caused by beyond design hazards the complementary safety features are used to prevent core/fuel pull damage
- ✓ Intentional commercial aircraft crash is considered in the design

Severe accidents, Level 4 DiD:

- ✓ Core Catcher
- ✓ Passive annulus filtration
- ✓ Passive hydrogen recombiners
- ✓ Complementary active safety features (to protect containment against late overpressure)

Results of Leve1 PSA

CDF Frequency	VVER-TOI	AES-2006 (Novovoronezh-2)
Power, internal IEs	1,31 E-07 1/ a	1,58 E-07 1/a
All shutdown states, internal IEs	1,60 E-07 1/ a	2,58 E-07 1/a
Internal Fires/Flooding	-	9,04 E-09 1/a
External hazards	-	3,89 E-08 1/a
Total	2,91 E-07 1/ a	4,68 E-07 1/a

Conclusion:

The decisions implemented in the design for new VVERs allowed meeting requirements raised from up-to-date DiD concept with account for its further evolution.

On this basis the high level of safety (quantitatively expressed by low CDF value) is shown

PLEASE, READ PAPER FOR MORE DETAILS



Application of PSA in Designing New Third-Generation NPPs Equipped with VVER Reactors

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Further tasks



Licensing

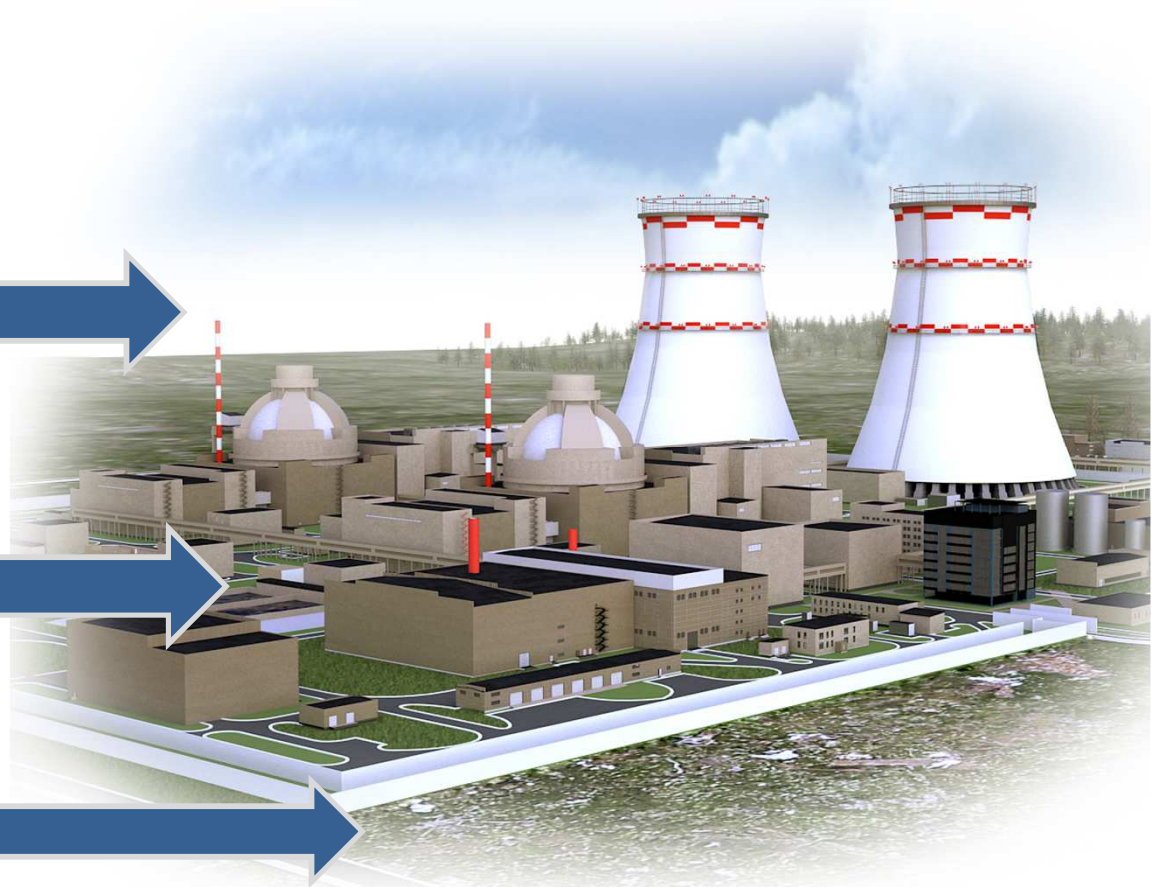


Certification, Expertise



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Design Promotion



Thank you for the attention

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