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Course: Fundamentals of AES-2006 technology

Module 05: VVER (AES-2006) Safety Systems

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Training Objectives

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- Terminal Training Objectives:

1. To list the safety systems used to carry out functions for DBC and DEC-A conditions
2. To list the AES-2006/E safety systems used in Hanhikivi-1 NPP

- Enabling Training Objectives:

1. To familiarize trainees with the basic requirements and nuclear safety approaches implementation in the AES-2006/E
2. To describe the defence-in-depth concept implementation for AES-2006/E
3. To list the VVER safety systems
4. To describe the principles of safety system operation of the NPP with VVER

Content

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Safety Fundamentals for NPPs

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Definition of «Safety»

I. ***Safety*** is the state of being "safe" (from French sauf), the condition of being protected from harm or other non-desirable outcomes. Safety can also refer to the control of recognized hazards in order to achieve an acceptable level of risk. [Wikipedia]

II. ***"Safety"*** means the protection of people and the environment against radiation risks, and the safety of facilities and activities that give rise to radiation risks. *"Safety"* as used here and in the IAEA safety standards includes the safety of nuclear installations, radiation safety, the safety of radioactive waste management and safety in the transport of radioactive material; it does not include non-radiation-related aspects of safety. [IAEA]

III. ***[Nuclear] safety***

The achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards. [IAEA]

Definition of «Safety»

IV. ***Safety*** – the condition of being protected from or unlikely to cause danger, risk, or injury. [Oxford dictionary]

V. ***Safety*** is a property of nuclear power plants to provide reliable protection of personnel, the public and the environment from the unacceptable radiation exposure in accordance with federal norms and rules in the use of atomic energy. [www.rosatom.ru]

VI. ***Safety*** – the use of nuclear energy must be safe; it shall not cause injury to people, or damage to the environment or property. [Finland, Nuclear Energy Act 11.12.1987/990. Section 6 – Safety]

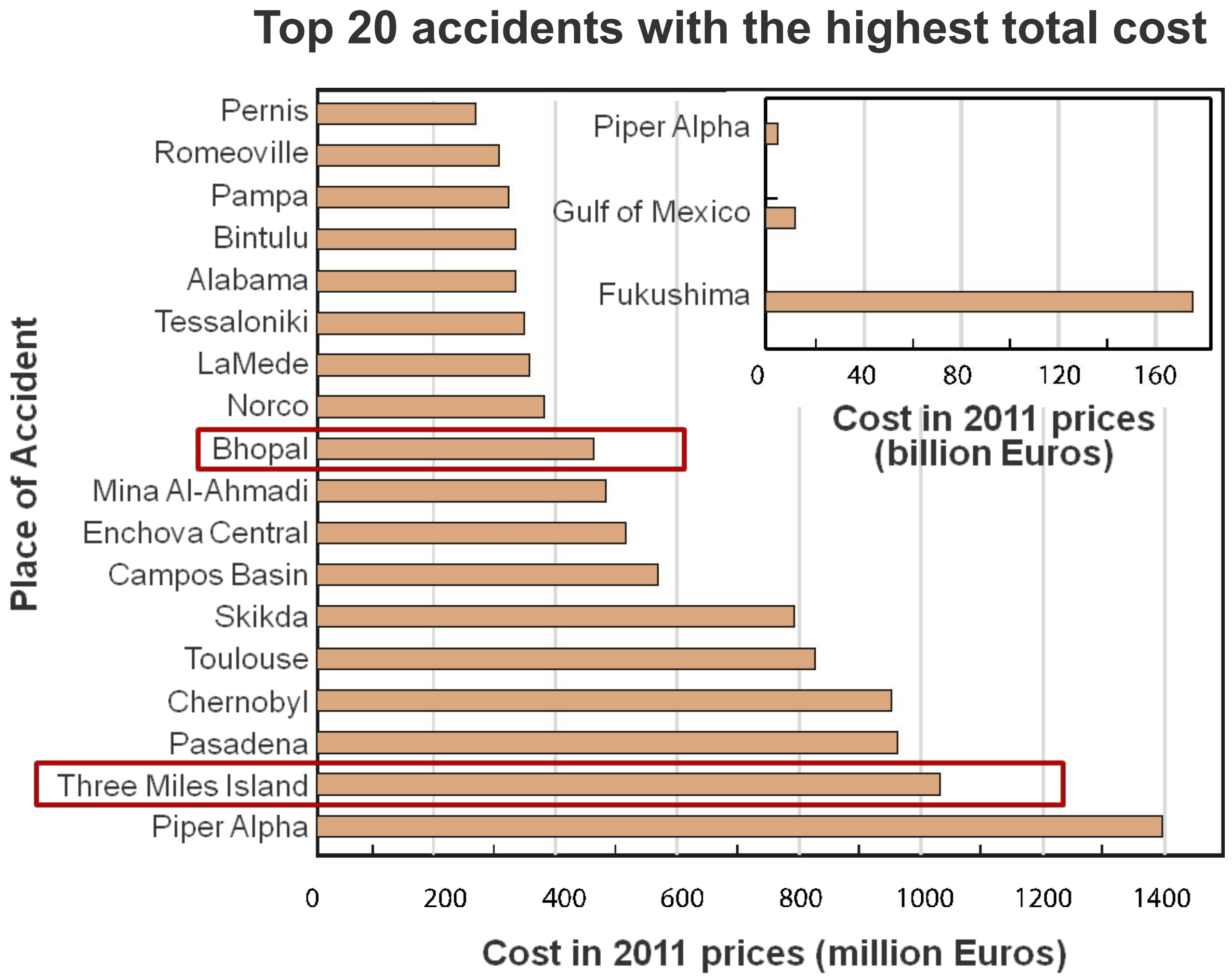
Major Industrial Disasters

Bhopal, 1984

An accident at the pesticide plant in Bhopal, India, released at least 30 tons of a highly toxic gas. The plant was surrounded by shanty towns, leading to more than 600,000 people being exposed to the deadly gas cloud that night

Deaths: At least 3,787; over 16,000 claimed

Non-fatal injuries: At least 558,125



www.ariquemesonline.com.br/noticia.asp?cod=302779&codDep=24

Pasadena, 1989

Devastating series of explosions and fire in Pasadena, US. The initial blast registered 3.5 on the Richter scale, and the conflagration took 10 hours to bring under control. Twenty-three employees were killed and 314 injured

Responsibility

- The organisation operating a nuclear power plant shall be responsible for the plant's safe operation under all operational states and accident conditions
- Personnel shall be encouraged to perform responsible work, and to identify, report, and eliminate factors endangering safety. Personnel shall be given the opportunity to contribute to the continuous improvement of safety
- SAHARA principle – safety as high as reasonably achievable

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Design and Safety Functions

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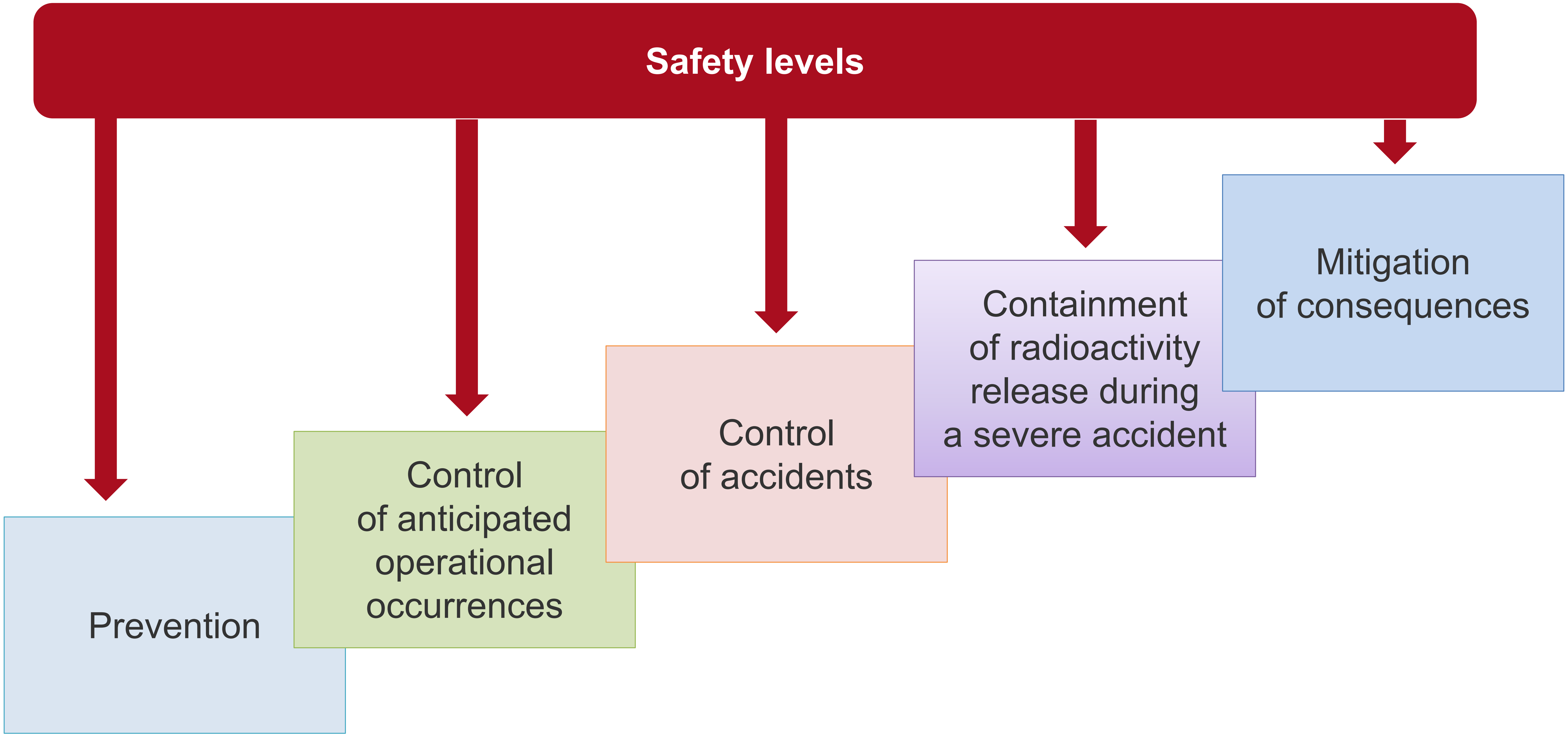
Defense-in-Depth: Five Successive Levels of Protection



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Physical barriers system

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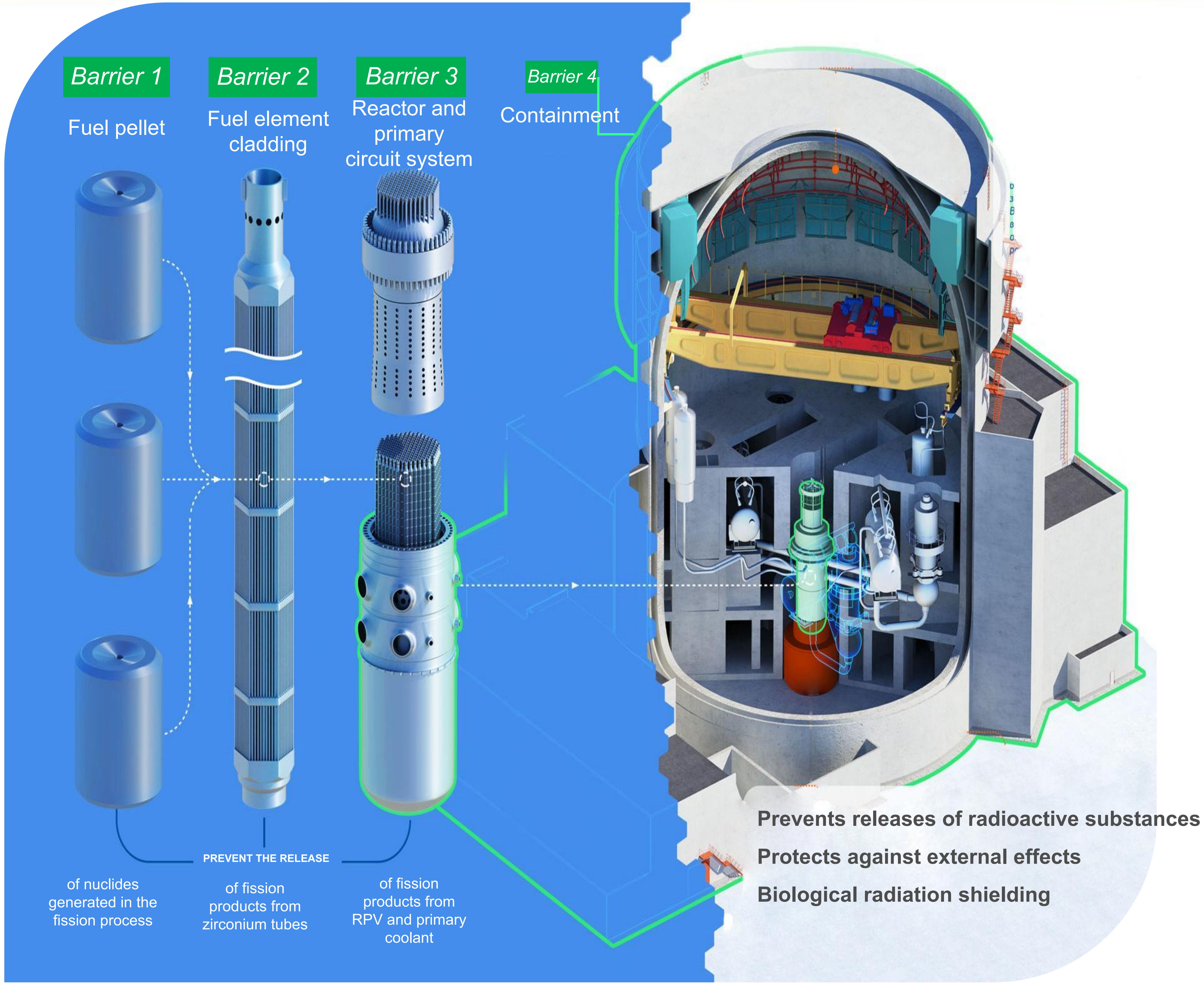


rosatom.ru/about-nuclear-industry/safety-russian-npp/index.php?sphrase_id=145794

DiD Principle

Defense-in-depth is a philosophy
to ensure nuclear safety

Organizational and technical measures

- Level 1. Prevention of abnormal operation and failures
- Level 2. Control of abnormal operation and detection of failures
- Level 3. Control of accidents

Physical barriers

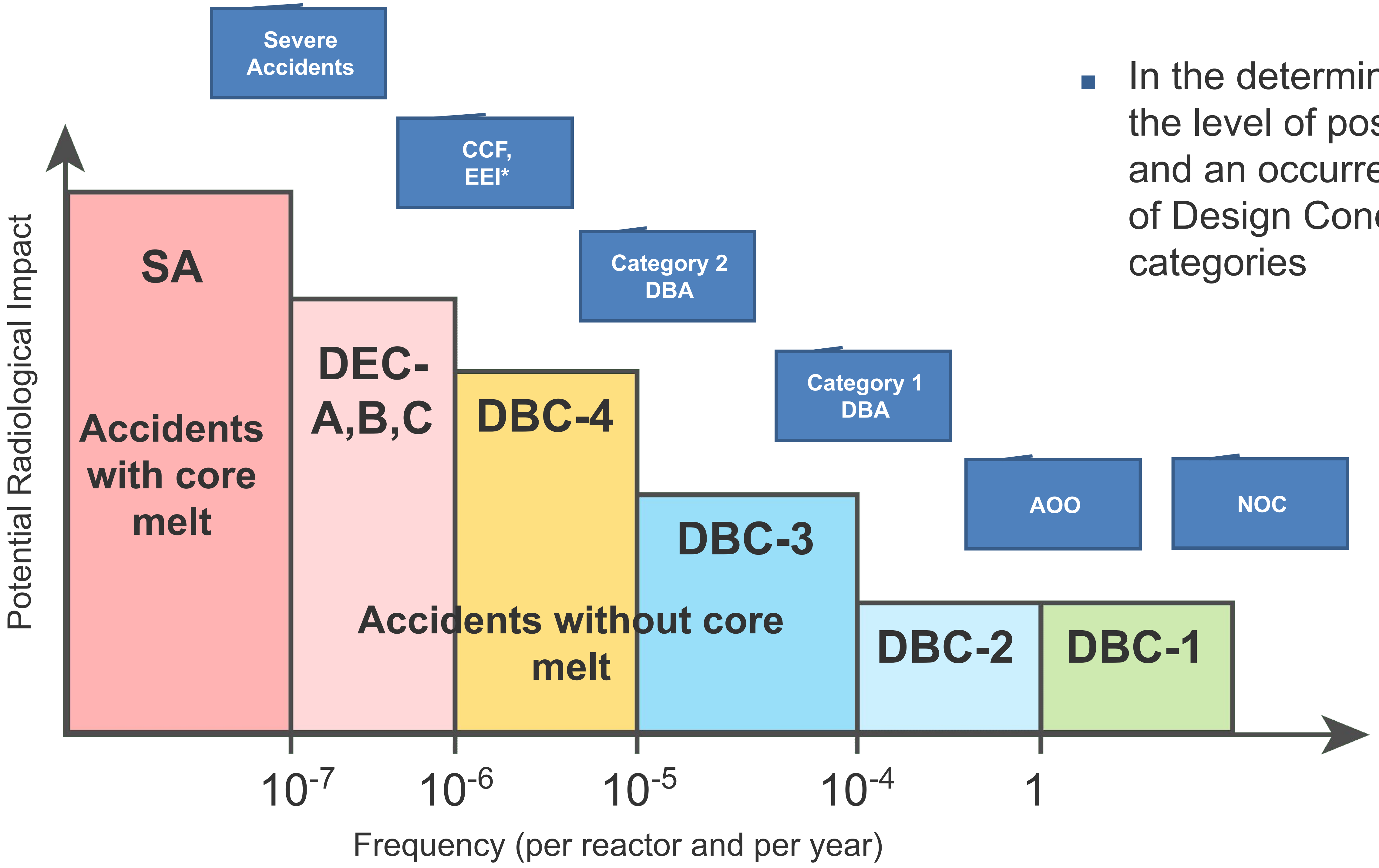
- Fuel matrix (pallets)
- Fuel rod cladding
- Reactor coolant system boundary
- Containment

New safety requirements

- Level 4. Severe accident management
- Level 5. Emergency planning

Population and environment protection

Design Basis Conditions (DBC) and Design Extension Conditions (DEC)



- In the deterministic safety analysis, as per the level of possible negative consequences and an occurrence probability, the list of Design Conditions is divided into several categories

*) DBA – Design Basis Accident
CCF – Common Cause Failure events
EEI – Extremely External Impacts

- Acceptance criteria for each category of design conditions
- Safety analysis to justify the acceptance criteria

www.iaea.org/INPRO/7th_Dialogue_Forum/Rosatom_1.pdf

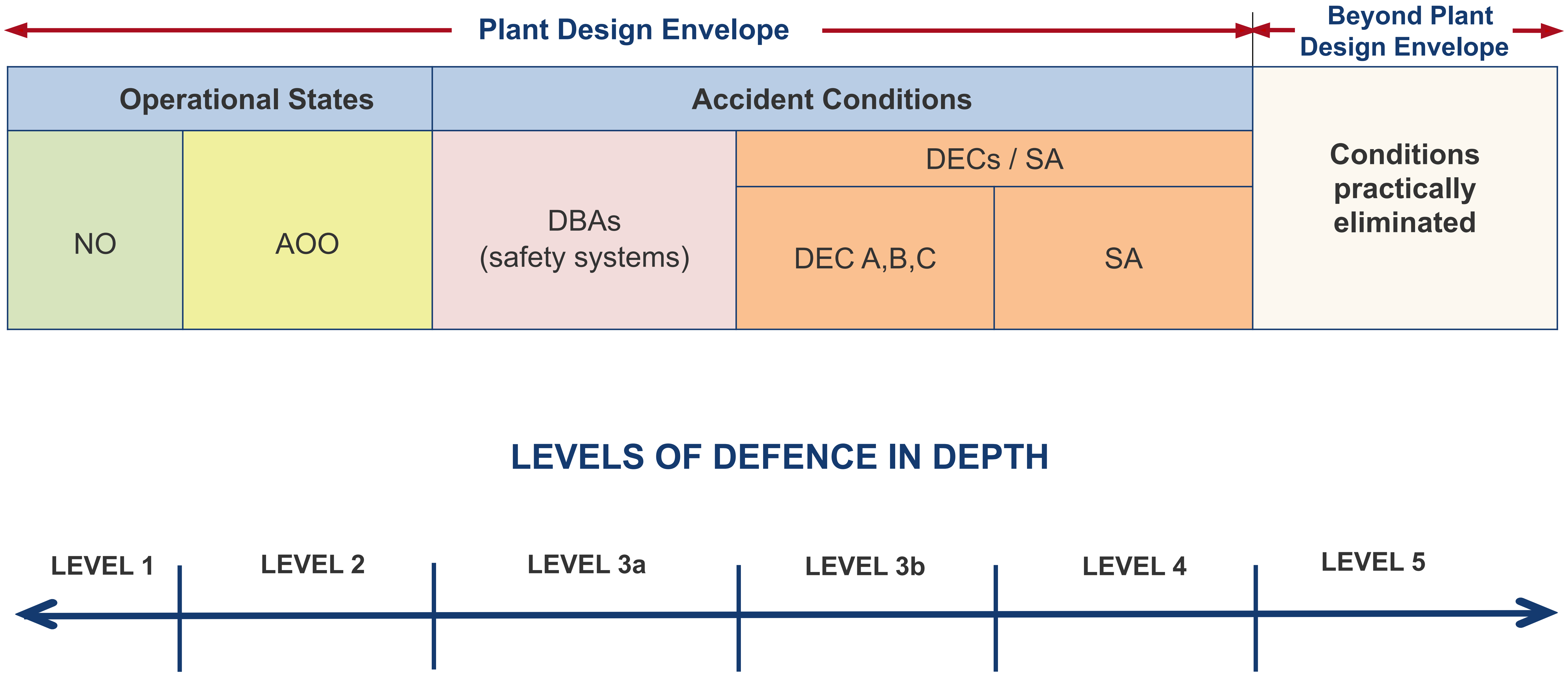
Acceptance Criteria

- Activity release into containment atmosphere under LOCA accidents is ever determined by presence of damaged fuel cladding in the core. The following acceptance criteria are justified in the design:
  - For DBC-3 – the number of damaged fuel rods shall not exceed 1% of the total number of fuel rods in the core
  - For DBC-4 –the number of damaged fuel rods shall not exceed 10% of the total number of fuel rods in the core

- In accordance with Gov. Decree 717/2013 (and then YVL C.3) in case of accidents the expected annual irradiation dose of the critical group of population shall be limited with:
  - DBC-3 – effective dose below 1 mSv
  - DBC-4 – effective dose below 5 mSv
  - DEC – effective dose below 20 mSv

- Severe accidents:
  - Not more then 100 TBq for atmospheric releases of Cs-137. No *large scale protective measures for the population nor any long-term restrictions on the use of extensive areas of land and water* are required. Evacuation of people living in close proximity to the NPP is not required

Plant States & Design Basis / Envelope as Consequence of the Requirement of Practical Elimination



Fundamental Safety Functions

Condition s

Operational plant states	During and after any design basis accident	In emergency conditions arising in the case of beyond design basis accidents

Functions

- Control of reactivity
- Removal of heat from the reactor
- Confinement of radioactive material, shielding against radiation and control of planned radioactive releases, as well as limitation of accidental radioactive releases

VVER Safety Systems

DiD level 3

Level 3 is divided into levels 3a and 3b:

Level 3a includes systems ensuring execution of safety functions during accidents of classes 1 and 2 (DBC-3 and DBC-4)

Level 3b includes systems ensuring execution of safety functions under the conditions when level 3a systems cannot perform their functions as a result of common-cause failures, external effects or other complex accident sequences

Accident management

Accident management strategy includes:

- bringing the NPP to the controlled state
- bringing the NPP to the safe state

Controlled state is the state when the fission chain reaction stops and residual heat is removed from the fuel

Safe state is the state when the fission chain reaction stops, residual heat is removed from the fuel and there is no excessive pressure within physical barriers 3 and 4

Safety Functions

Basic safety functions	A. Reactivity control	B. Heat removal from nuclear fuel	C. Localization of activity
	AA: Fission reaction termination	BA: Maintenance of primary coolant inventory	CA: Limitation of pressure inside the containment, heat removal from the containment
	AB: Reactor power limitation	BB: Heat removal from primary coolant	CB: Localization inside the containment
	AC: Subcriticality assurance	BC: Primary circuit integrity assurance	CC: Localization outside the containment
		BD: Secondary circuit integrity assurance	CD: Localization in SG
		BE: Cooling of spent fuel	CE: Localization in auxiliary systems
			CF: Fuel handling
			CG: Radioactive waste handling

Design principles of safety systems

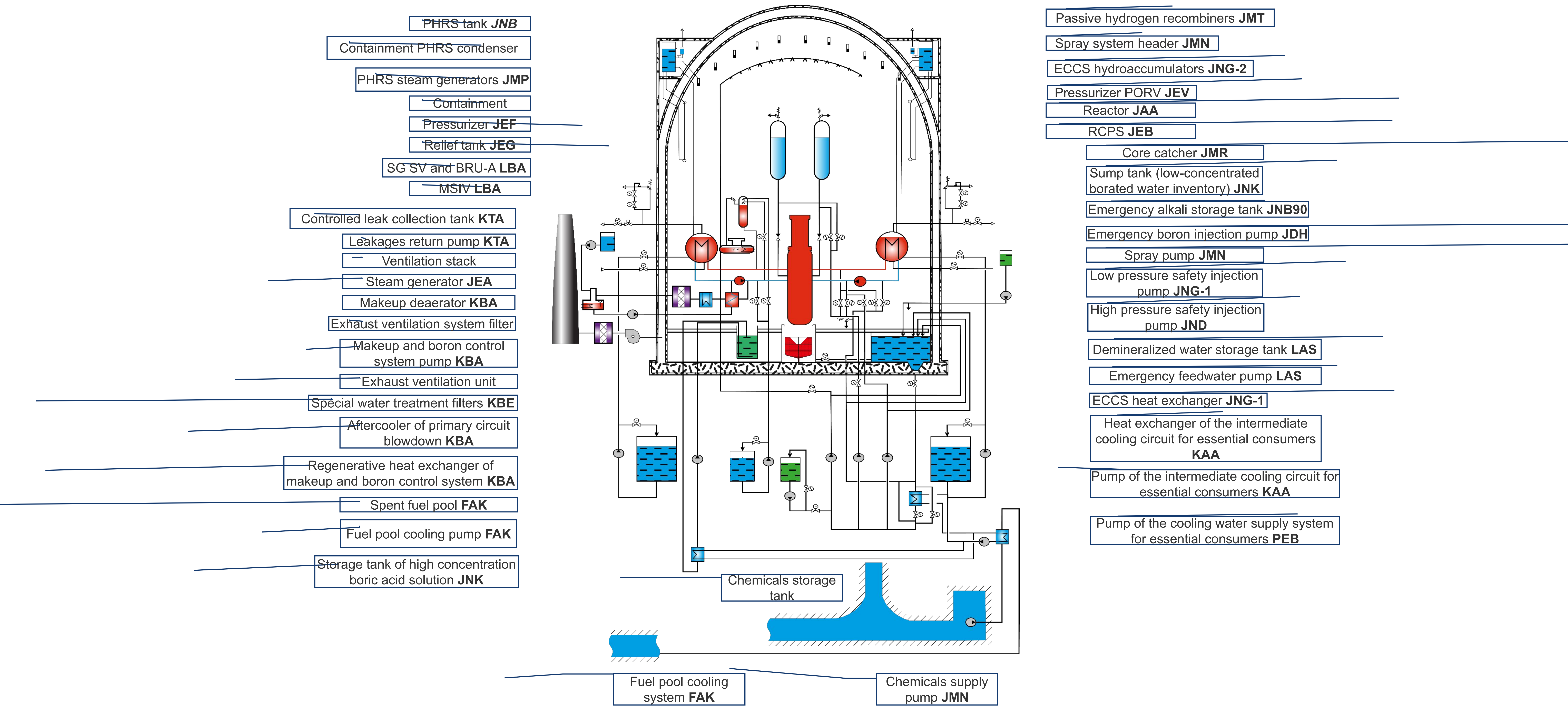
Safety systems are designed in accordance with the principles ensuring their reliability and failure tolerance:

- Redundancy principle
  - system redundancy – application of multi-train systems
  - component redundancy – component and equipment redundancy within system trains
- Independence principle
  - physical separation
  - functional separation
- Diversity principle
  - application of means based on different principles of operation
  - different physical variables
  - different operating conditions
  - different equipment manufacturers

Reliability of safety systems and equipment is provided by the quality of their design, manufacturing and maintenance. It is expressed by their safety class

Монтажеру: выделить все обозначенные узлы на словах лектора про many safety systems, чтобы показать что их много

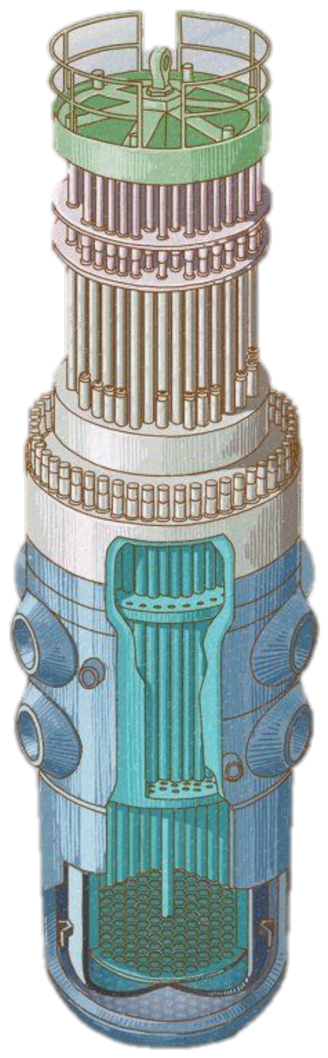
General diagram of safety systems and means



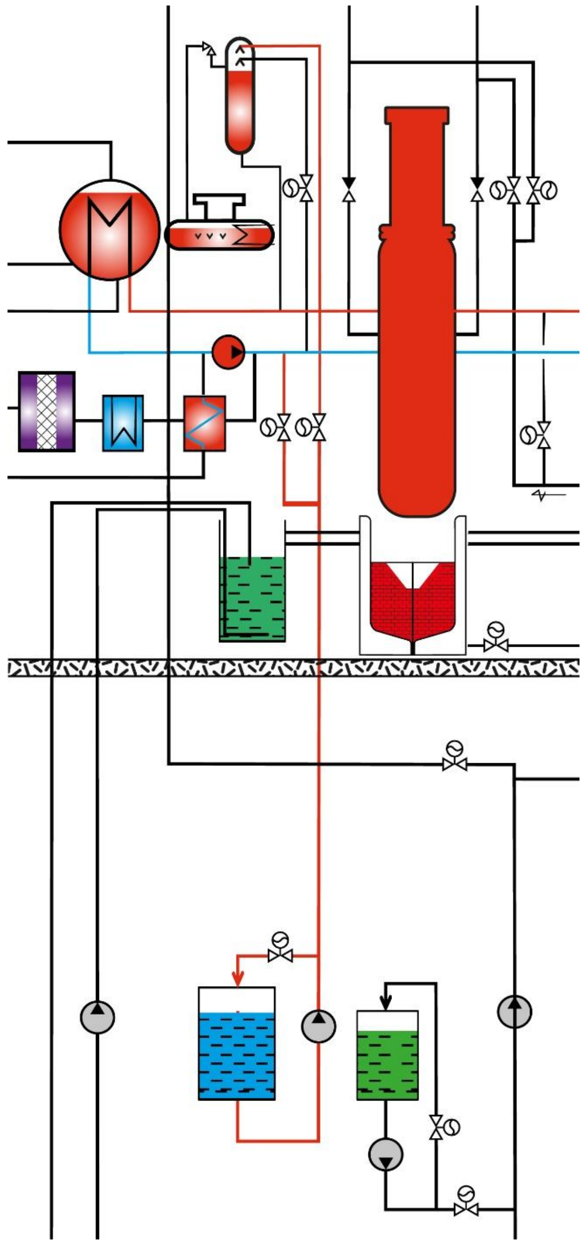
A. Reactivity control

Reactivity control

The NPP design provides for the following means to ensure reactivity control and core subcriticality:



- **CPS rods** – *under emergency conditions CPS rods are transferred into the lower position in response to EP signals and in case of power output loss*



- **Emergency boron injection system JDH** *is designed to bring the core to the subcritical state under conditions relating to CPS CR failure (ATWS)*

edu.strana-rosatom.ru/glava-4-atomnyie-stanczii/

Emergency Injection System

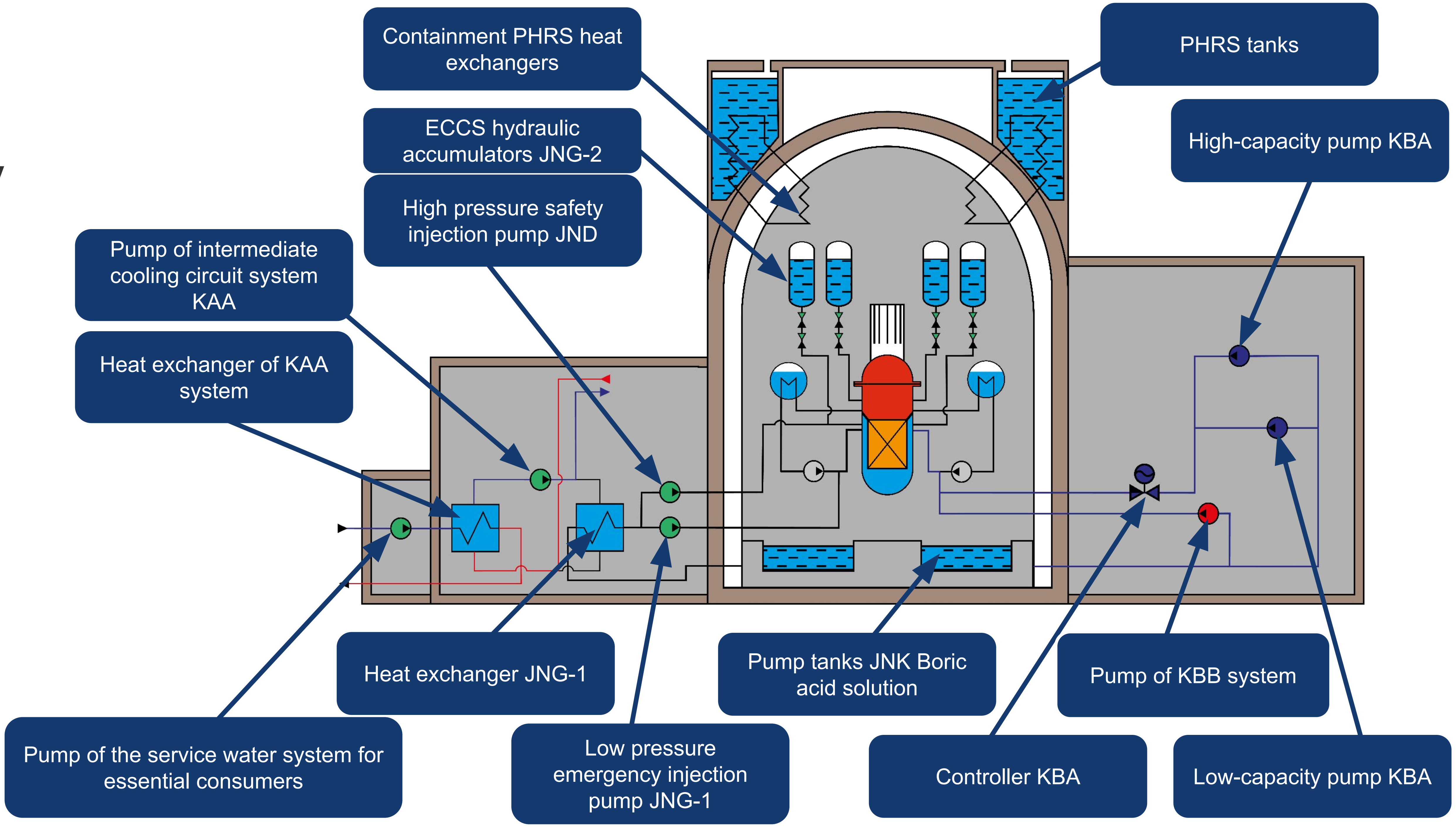
- Supplies boric acid solution with the concentration of 40 g/kg and temperature of at least 20 °C at any pressure in the primary circuit within the range of 0.098 ÷ 24.5 MPa
- The system is has a four-train structure. System performance functioning is:
  - *4x33% - functioning in ATWS (DEC)*
  - *4x50% - functioning in PRISE (DBC4)*
- The system includes the following:
  - *plunger pumps*
  - *valves*
  - *pipelines*
- JNK system stores boric acid solution inventory with the concentration of 40 g/l. The design provides for 4 tanks with the operating capacity of 50 m^3

B. Heat removal from nuclear fuel

BA: Maintenance of primary coolant inventory

The design provides for the following systems and means to maintain the coolant inventory and to make up the primary circuit:

- *High pressure safety injection system JND*
- *Low pressure safety injection system JNG-1*
- *ECCS hydraulic accumulators JNG-2*
- *KBB system pumps*

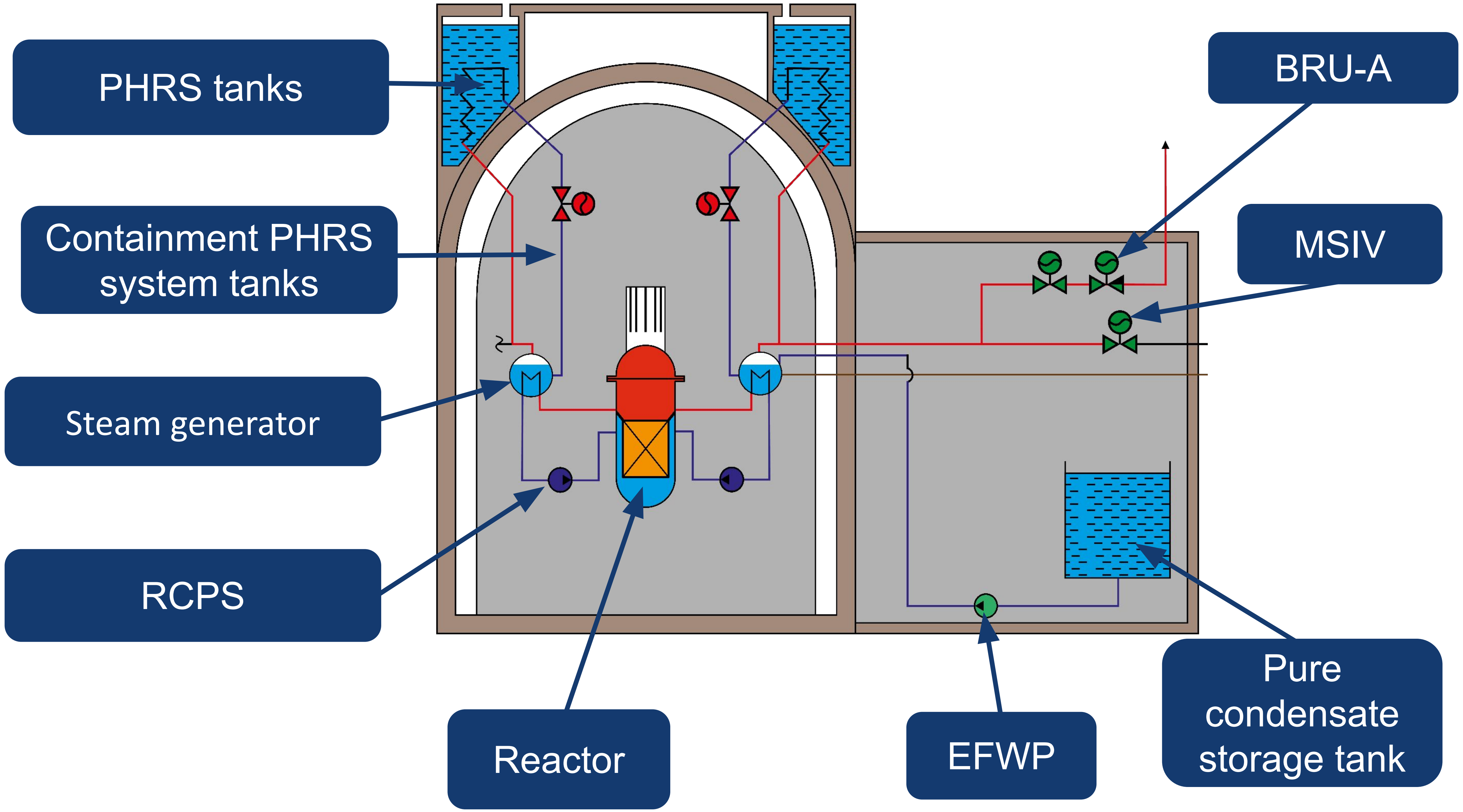


Arrangement of the main systems and means ensuring coolant inventory maintenance and NPP primary circuit makeup

BB: Heat removal from primary coolant

Means ensuring heat removal from the core and RP cooldown to 130 °C:

- *BRU-K+AFWP*
- *BRU-A+EFWP*
- *SG PHRS*



Arrangement of the main equipment ensuring RP cooldown to 130 °C

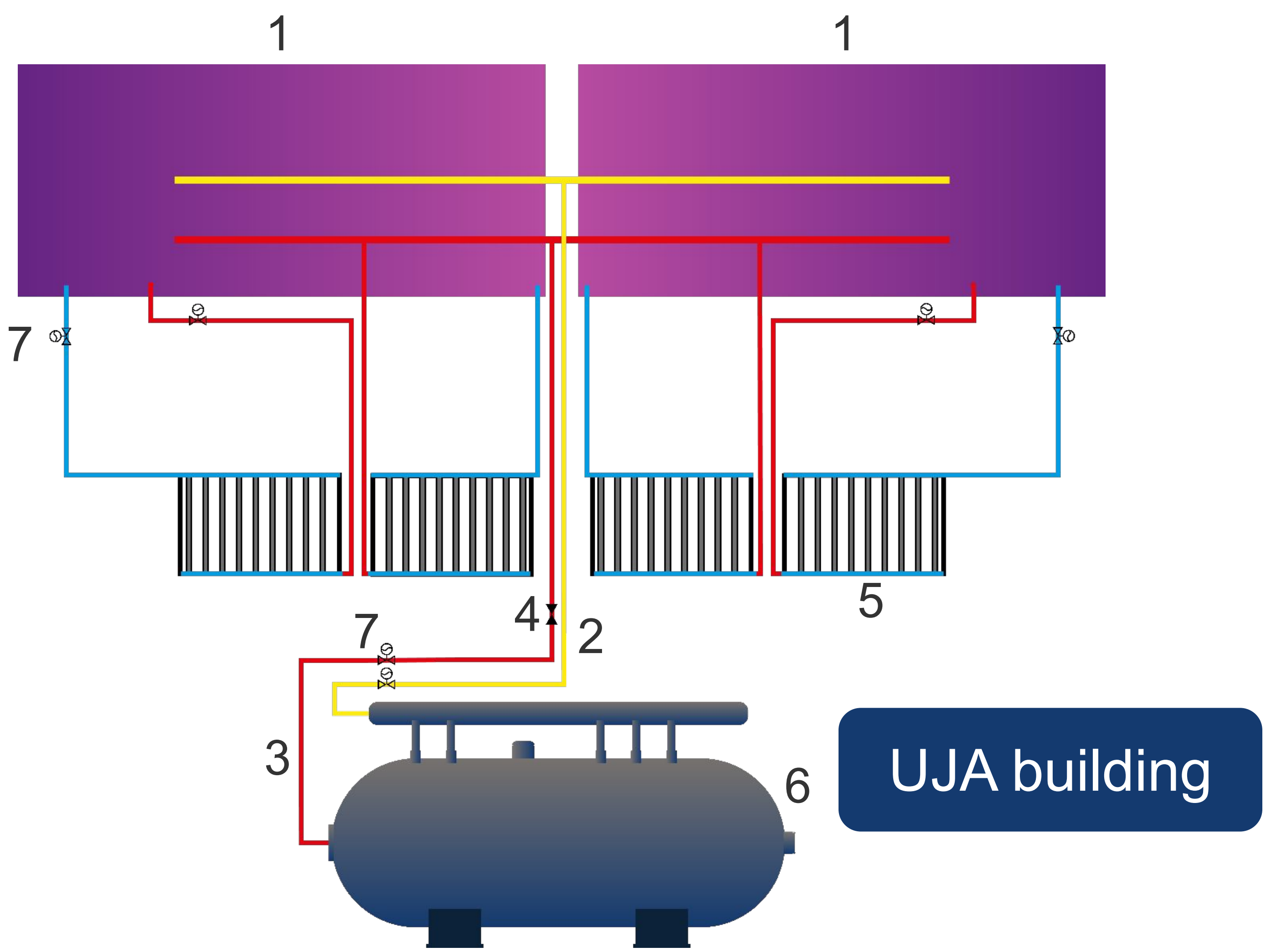
System for passive heat removal through steam generators

The system for passive heat removal through steam generators is designed to continuously remove residual heat from the core and cool down the RP to 130 °C in DEC conditions (level 3b).

The system operates for 72 hours without operator participation during accidents with full blackout and SG feedwater failure.

Heat is removed passively through steam lines to EHRT tanks.

The system has a four-train structure.
System functioning efficiency is 4x33 %



1 – emergency heat removal tanks (EHRT)

2 – steam lines

3 – condensate pipelines

4 – SG PHRS valves

5 – containment PHRS heat exchangers-condensers

6 – steam generators

7 – isolation valves

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BC and BD: Primary and secondary circuit integrity assurance

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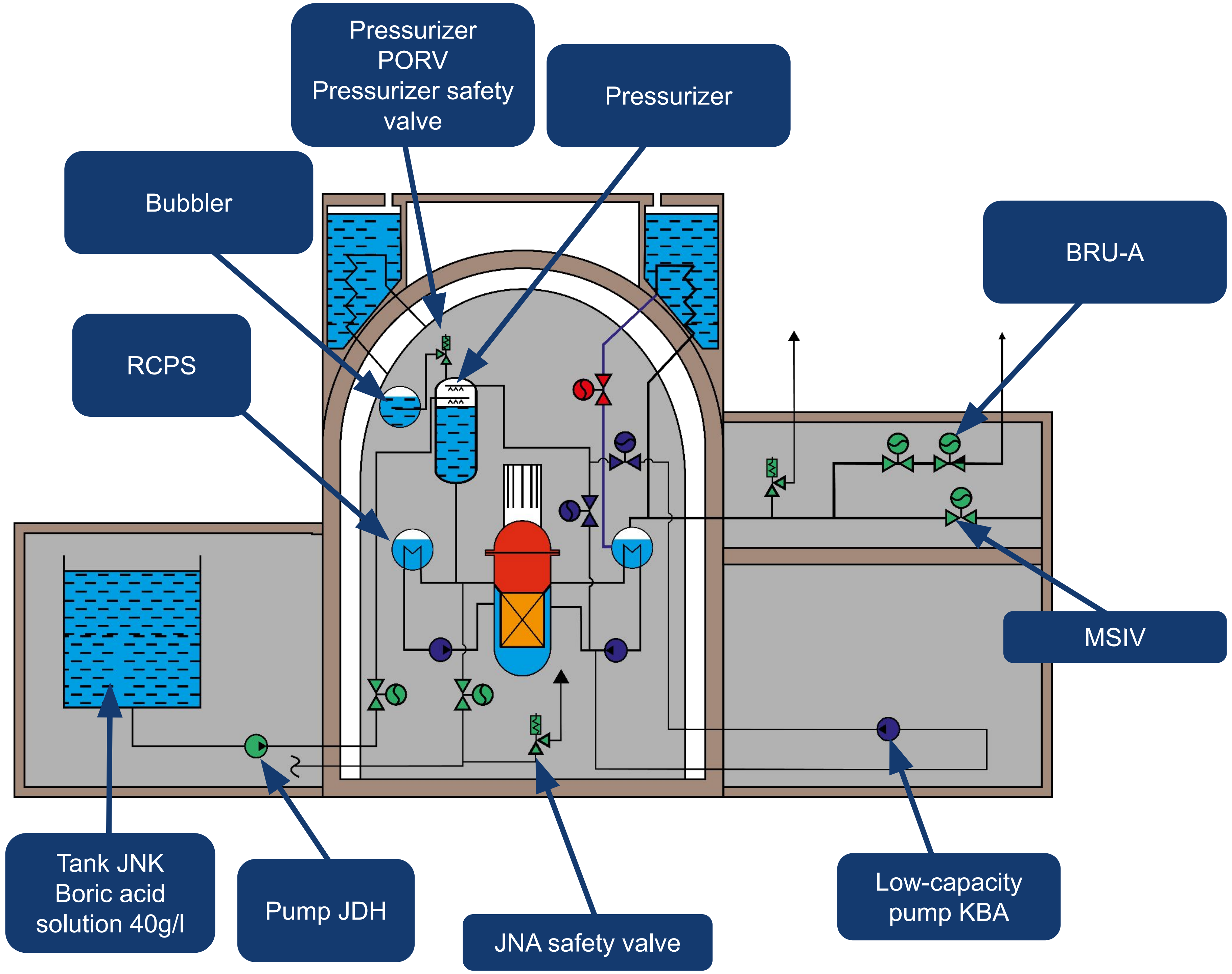
Pressure is reduced in the primary circuit by condensation in the vapor space of the pressurizer by means of injection:

- *from RCPS head*
- *from head of pumps of the makeup and boron control system (KBA)*
- *by the pump of the emergency boron injection system*

The following hardware is provided in the design for pressure relief:

- *safety valves of pressurizer and SG*
- *BRU-A*
- *safety valves in the residual heat removal system*



Pressurizer relief devices

The primary circuit overpressure protection system includes three pilot-operated relief valves, each consisting of the following:

- *main valve*
- *relief valves with pipelines*
- *cutoff valve*
- *spring setting valve*
- *additional control line with three successive valves*

PORV 1 control – actuation pressure: 18.11 MPa.

PORV2, PORV3 operating – actuation pressure: 18.6 MPa.

Steam is discharged into bubbler JEG

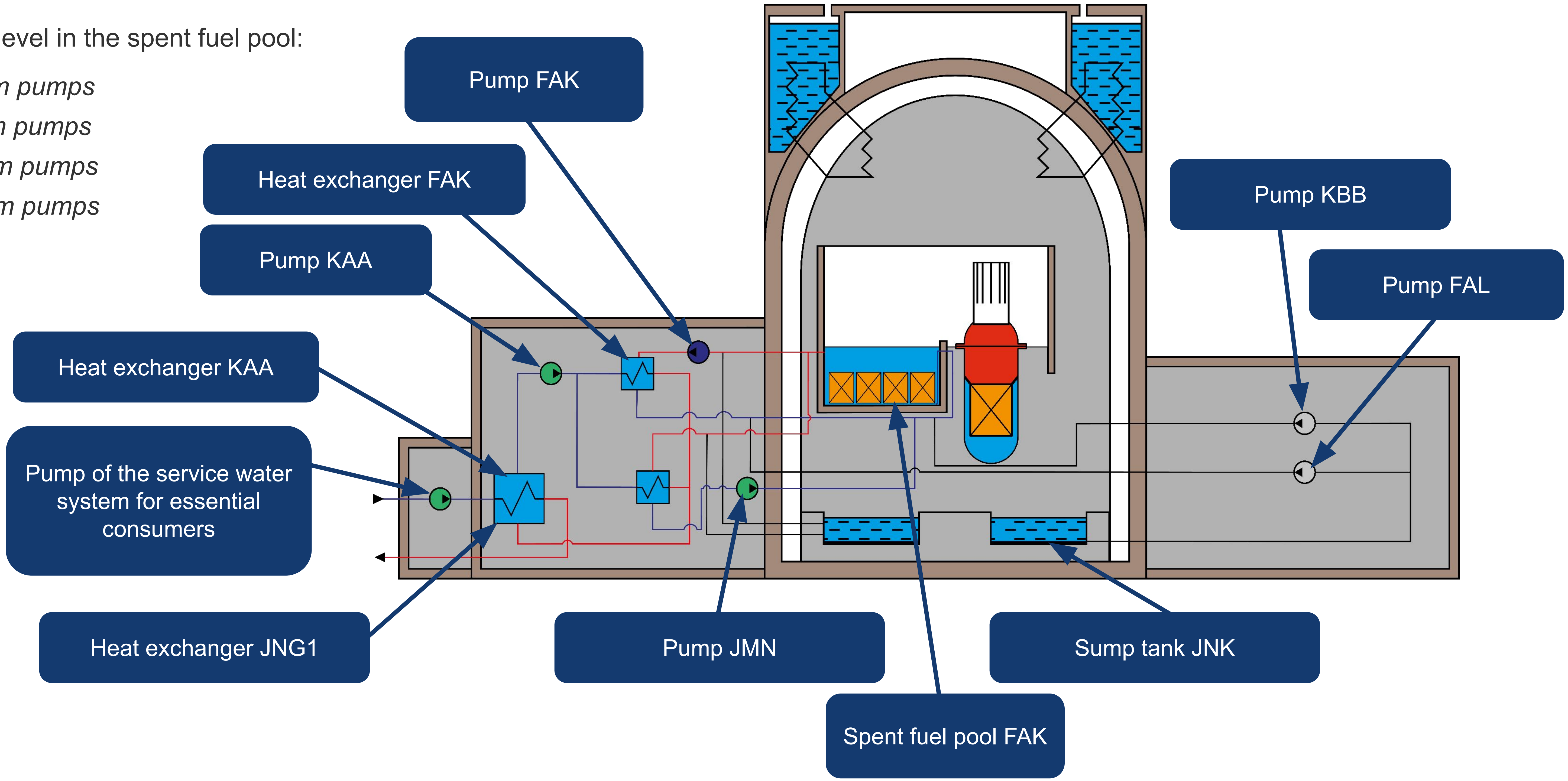
BE: Spent fuel cooling

The following systems are provided for in the design to remove heat from spent fuel assemblies stored in the spent fuel pool:

- *Fuel pool cooling system (FAK)*
- *JMN/JNG/JNA system*

For maintaining water level in the spent fuel pool:

- *FAK system pumps*
- *FAL system pumps*
- *KBB system pumps*
- *JMN system pumps*

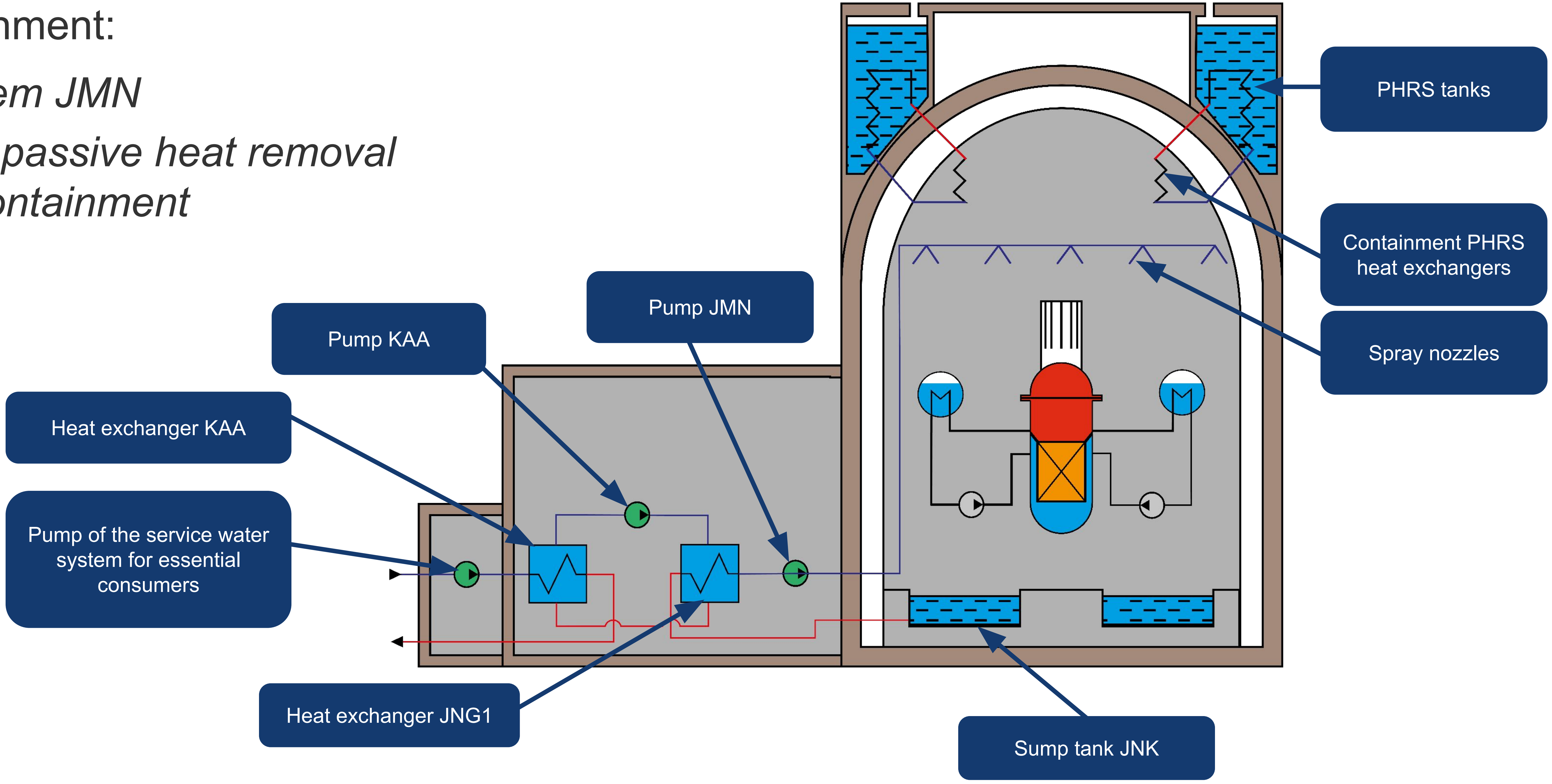


C. Localization of activity

CA: Limitation of pressure inside the containment, heat removal from the containment

The following means are provided in the design for heat removal from the containment:

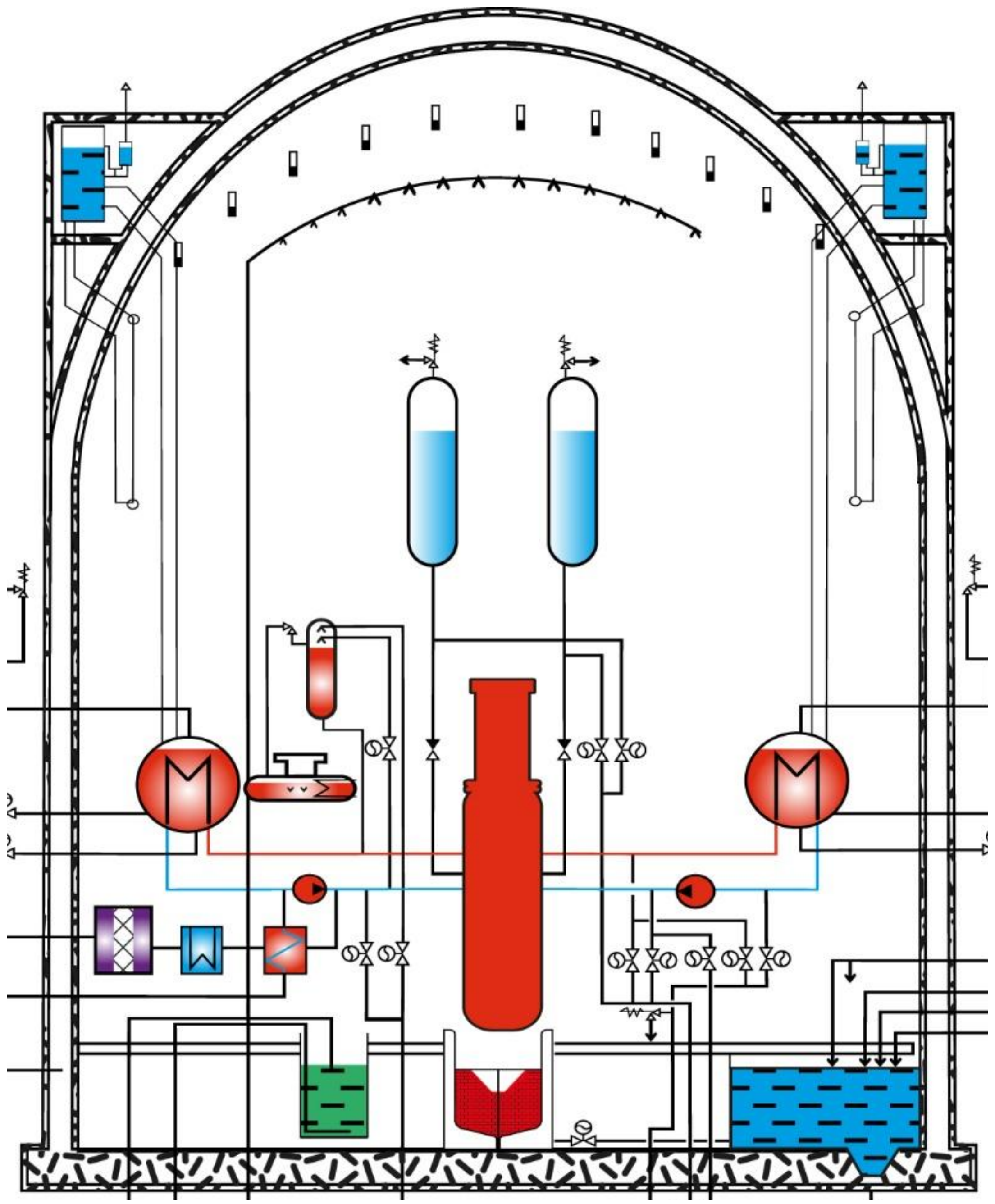
- *spray system JMN*
- *system for passive heat removal from the containment*



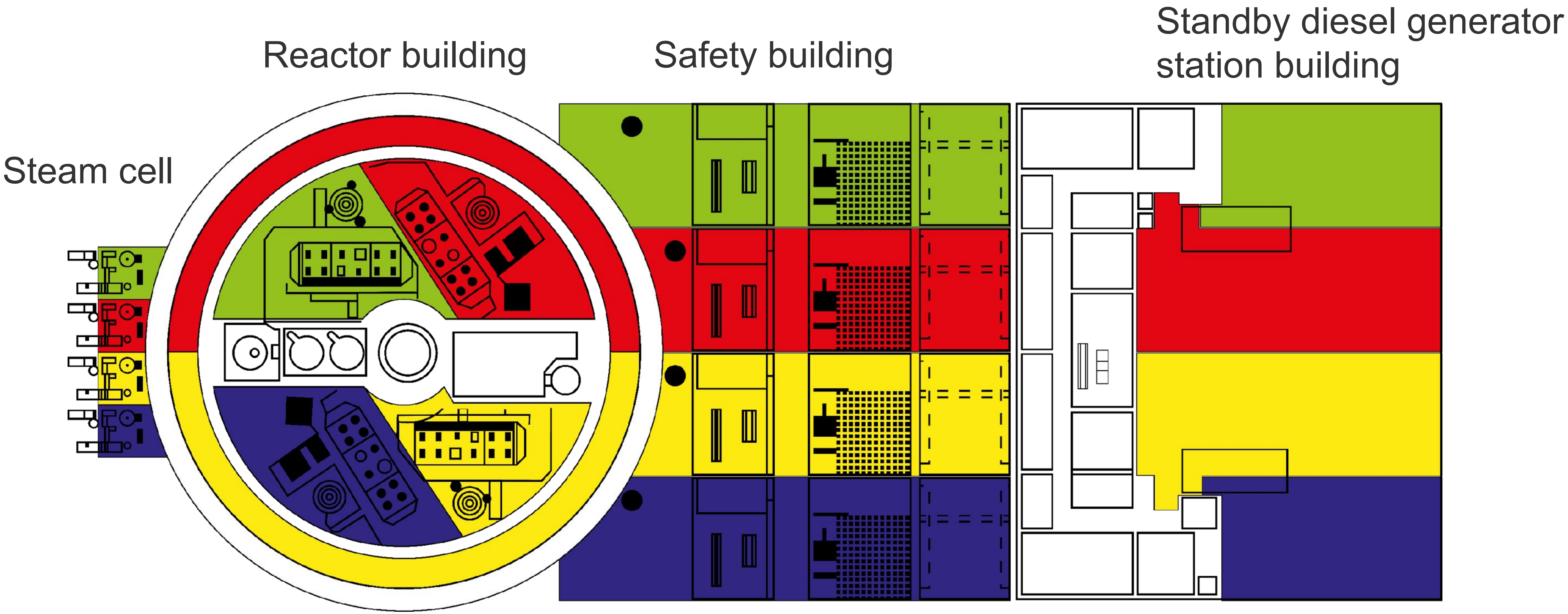
Accident localization system

Containment system:

- leak-proof steel liner
- reinforced concrete enclosing structures
- manholes, locks
- penetrations
- isolating devices



AES-2006/E Layout



Thank you for your attention!