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International Standards of Safety and the Modern Projects of Nuclear Power Stations

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Outline

- Development of safety standards for Generation III Nuclear Power Plants
- Development of Russian nuclear safety regulations
- Main safety features characterizing Generation III NPPs
- Examples of Generation III safety features as implemented in VVER-1200 design

Development of safety standards for Generation III Nuclear Power Plants (1)

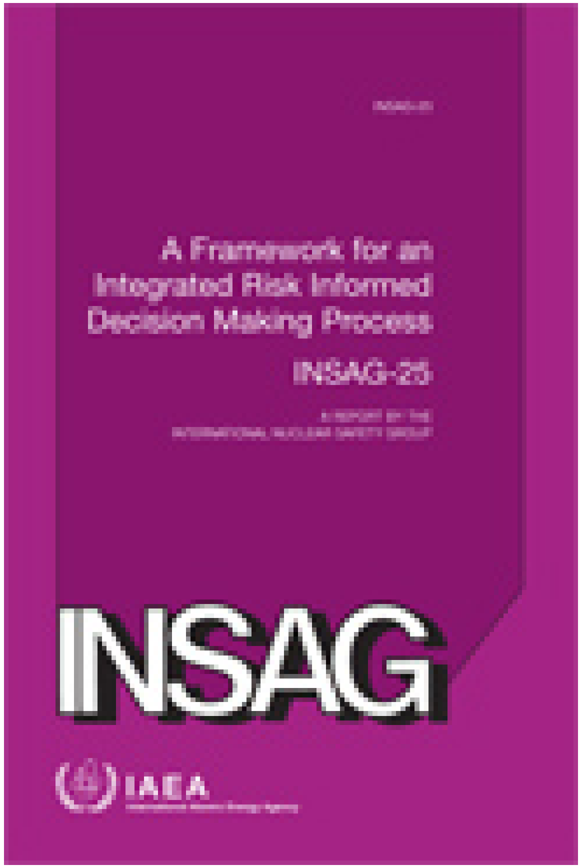
Global co-operation to develop general design principles for new safer nuclear power plants was started after the Chernobyl accident in the INSAG group that had been established only a few months earlier in 1985.

INSAG group consisted of 13 highly appreciated nuclear safety experts – they had been invited by the IAEA Director General.

Development of safety standards for Generation III Nuclear Power Plants (2)

INSAG group issued several reports that showed the direction for Generation III plants:

- INSAG-3 Basic safety principles for nuclear power plants, 1988
- INSAG-5 The safety of nuclear power, 1992
- INSAG-10 Defence in depth in nuclear safety, 1996
- INSAG-12 Basic safety principles for nuclear power plants (rev of INSAG-3), 1999



http://www-pub.iaea.org/books/IAEABooks/Series/40/INSAG-Series

Development of safety standards for Generation III Nuclear Power Plants (3)

Unfortunately, the IAEA Safety Standard *Safety of Nuclear Power Plants: Design,* issued in 2000, did not yet take a clear step towards Generation III.

This IAEA Safety Standard at start of the new century was still close to the thoughts that gave basis for the Generation II plants.

Nevertheless, new INSAG principles for enhanced safety were incorporated into some of the national safety requirements, especially in Europe.

Development of safety standards for Generation III Nuclear Power Plants (4)

WENRA, a group established by the heads of the European nuclear regulatory bodies, initiated in 2007 its first pilot study aiming to develop common safety objectives for new NPPs. This work was based very much on the INSAG ideas.

The common objectives were agreed after three years of work in November 2010 in the WENRA meeting held in Bratislava.

In a joint statement all European regulators have committed to promote the common safety objectives in their countries.

Development of safety standards for Generation III Nuclear Power Plants (5)

The WENRA safety objectives provide now a good reference for the plans to revise the EU Nuclear Safety Directive.

WENRA safety objectives and a report elaborating their application were key reference also for the group that drafted the revised IAEA Safety Standard *Safety of Nuclear Power Plants: Design,* issued in 2012.

Development of Russian nuclear safety regulations (1)

Active contribution to the INSAG work gave the emerging Russian nuclear safety community first hand information on nuclear safety principles defined in different countries.

The Russian *General Regulations on Ensuring Safety of Nuclear Power Plants (OPB 88/97)* were already in the 1990's written to be consistent with the INSAG visions on safer future plants.

The VVER-1200 plants currently being built, also called AES-2006, have been designed to meet OPB 88/97.

The VVER-1200 plants are thus designed in parallel with the global development of the nuclear safety principles and are representing state-of-the-art of the Generation III nuclear power plants.

Development of Russian nuclear safety regulations (2)

This year the Russian *General Regulations on Ensuring Safety of Nuclear Power Plants* have been revised after a thorough discussion in the Russian nuclear community and are now called OPB 88/12.

These new safety regulations cover all requirements of the IAEA Safety Standard *Safety of Nuclear Power Plants: Design,* issued in 2012.

In addition, the OPB 88/12 includes new requirements that are based on the lessons learned from Fukushima, as identified

- in the “stress tests” conducted jointly by the European nuclear regulators,
- in the reports of the IAEA’s “Fukushima meetings”, and
- in the “stress tests” conducted in Russia.

The new VVER plants being offered in the market are designed to meet OPB 88/12 requirements.

Main safety features characterizing Generation III NPPs

There is no general definition of what is meant by a Generation III nuclear power plant but I would suggest the following characteristics:

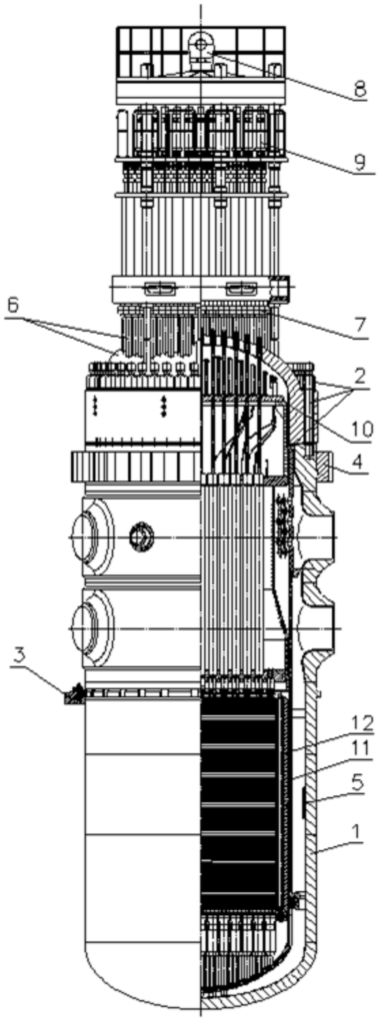
- improved assurance of primary circuit integrity for the extended lifetime,
- significantly strengthened protection against natural and manmade external hazards, such as major earthquakes and floods and crash of a large passenger airplane,
- digital control and protection systems that improve accuracy of plant monitoring and control, and provide reliable automatic protection against complicated accidents,

Main safety features characterizing Generation III NPPs (cont.)

- lay-out that provides credible physical separation of redundant systems and subsystems,
- diverse and redundant safety systems that can be used in a flexible manner to manage accidents going beyond the traditional design basis accidents, such as long-term loss of all AC power and loss of the primary heat sink,
- capability to contain even a molten reactor core after a possible severe reactor accident without significant radioactive releases,
- advanced approaches to fire protection.

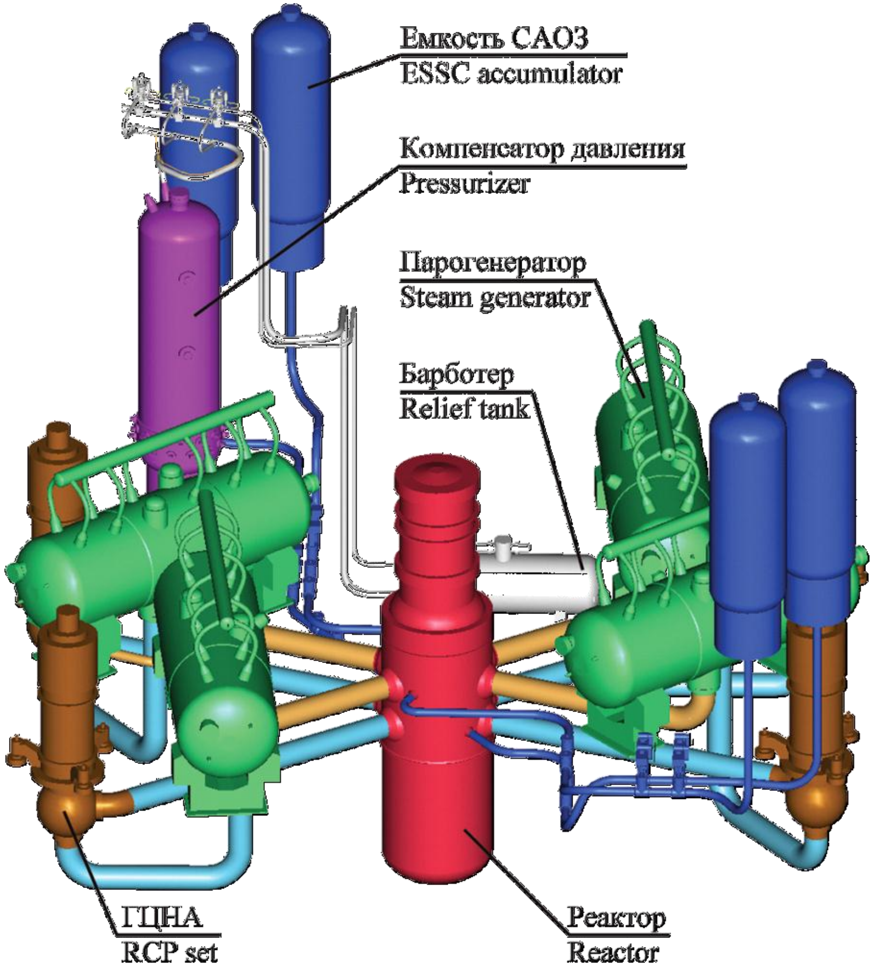
Improved assurance of VVER-1200 primary circuit integrity for 60 years operation

- Reactor vessel materials and structure
  - less impurities in base metal and welds, less nickel in welds, increased vessel diameter in order to reduce neutron irradiation of the vessel;
  - according to extensive research the material maintains its ductility even in lowest possible temperatures after 60 years of operation at full power;
  - small material embrittlement by neutron irradiation can be confirmed by investigating material samples placed in optimum way on vessel wall.



Improved assurance of VVER-1200 primary circuit integrity for 60 years operation

- Steam generator structure and operating conditions
  - improved removal of corrosive products, avoiding copper in secondary side materials, new type of water chemistry in secondary side
- Reactor coolant piping meets all necessary conditions of the “leak-before-break” concept
  - material properties, stress analysis, in-service inspections, leak monitoring



Protection of VVER-1200 against natural hazards

Seismic design against Safe Shutdown Earthquake (SSE)

- Russian sites are chosen so that an earthquake causing horizontal peak ground acceleration (pga) 0,125g (specified intensity of SSE) is not estimated to occur more often than once in 10 000 years.
- Nevertheless, **vital systems and components are designed to withstand an earthquake intensity of 0,25g**. This gives **an opportunity** to offer foreign sites an optional SSE **up to 0,41g** without changes in plant spaces or lay-out.
- Strength of **buildings and concrete structures** of exported plants can be designed for site specific conditions **as requested by customer**.
- Seismic analysis is done with conservative models, as defined in international standards; in addition a verification analysis is made with realistic models and 40 % higher intensity to demonstrate adequate margin of design.
- Response of structures is studied for several different frequency spectra.

Protection of VVER-1200 against manmade external hazards

Air plane crash

- **Design basis** air plane crash evaluated with conservative models and assumptions is crash of a small private air plane (**weight 5,7 tons**).
- **Design extension** air plane crash evaluated with realistic models and assumptions is a large commercial air plane (**weight 400 tons**) hitting the plant with maximum conceivable speed.
- Protection shall **provide elimination** of
  - radioactive releases as **direct consequence** of impact
  - an accident sequence due to loss of decay heat removal capability, which could be either a consequence of **direct damage to safety systems**, indirect damage due to induced **vibrations in equipment**, or indirect damage due to a kerosene (fuel) **fire**.

Modern digital protection systems of VVER-1200 plants

- VVER plants **can be offered** with
  - digital protection systems that are designed and qualified initially for nuclear applications and **proven with extensive experience** at the 24 French plants (1300 MW series) since 1983 – at equipment level the technology is modernized in line with todays' state-of-the-art
  - digital systems for controlling **normal operation and limitation functions**, purchased **from a different contractor** to ensure diversity and independence
  - **hardwired** analog I&C systems as **back-up** for main parts of the digital protection systems

Lay-out of VVER-1200 plants

Lay-out provides systematic separation of diverse safety systems and of redundant subsystems of safety systems

- Separation is based on placing diverse systems and redundant subsystems to **different buildings or different building compartments** so that a fire, flood or any other internal or external threat cannot cause loss of an entire safety function.

Diverse and redundant safety systems of VVER-1200 plants (1)

General design principle

All **fundamental safety functions can be provided both with active** systems that have reliable AC power supply **and with passive systems** that do need electrical power:

1. **Control of reactivity**
   - preventing uncontrolled reactor power increase
   - ensuring fast safe shutdown of the reactor when needed,
2. **Removal of decay heat to the ultimate heat sink**
   - cooling of shutdown reactor
   - cooling of used nuclear fuel
3. **Confinement of radioactive materials**
   - preventing significant radioactive releases to the environment

Diverse and redundant safety systems of VVER-1200 plants (2)

Control of reactivity

- VVER-1200 plant reactor has a unique safety feature when compared with other pressurized water reactors:
  - If the control rods are inserted to the core the reactor will **stay in shutdown state also in low temperatures**
- VVER-1200 plant reactor has also reliable boron injection systems that can add liquid with high boron concentration to the reactor coolant
  - Even in the event that the control rods would not drop to the reactor core, the boron induced shutdown is so fast that no fuel damage would occur – this is **more efficient protection against ATWS (Anticipated Transient Without Scram) than found in most other reactors**

Diverse and redundant safety systems of VVER-1200 plants (3)

Removal of decay heat to the ultimate heat sink

- Active systems can remove decay heat to
  - the heat sink used by the condenser coolant system (e.g. sea, river, cooling tower) or to a separate "spray pond" used by the safety systems as an alternative heat sink
  - the atmosphere – feed and bleed from steam generators.
- **Passive systems can remove the decay heat from steam generators directly to the atmosphere**.

Passive system for decay heat removal at Leningrad-2 plant (1)

1 – emergency heat removal tanks (EHRT) outside containment ; **heat is removed by boiling of water in EHRTs in atmospheric pressure**

2 – steam lines

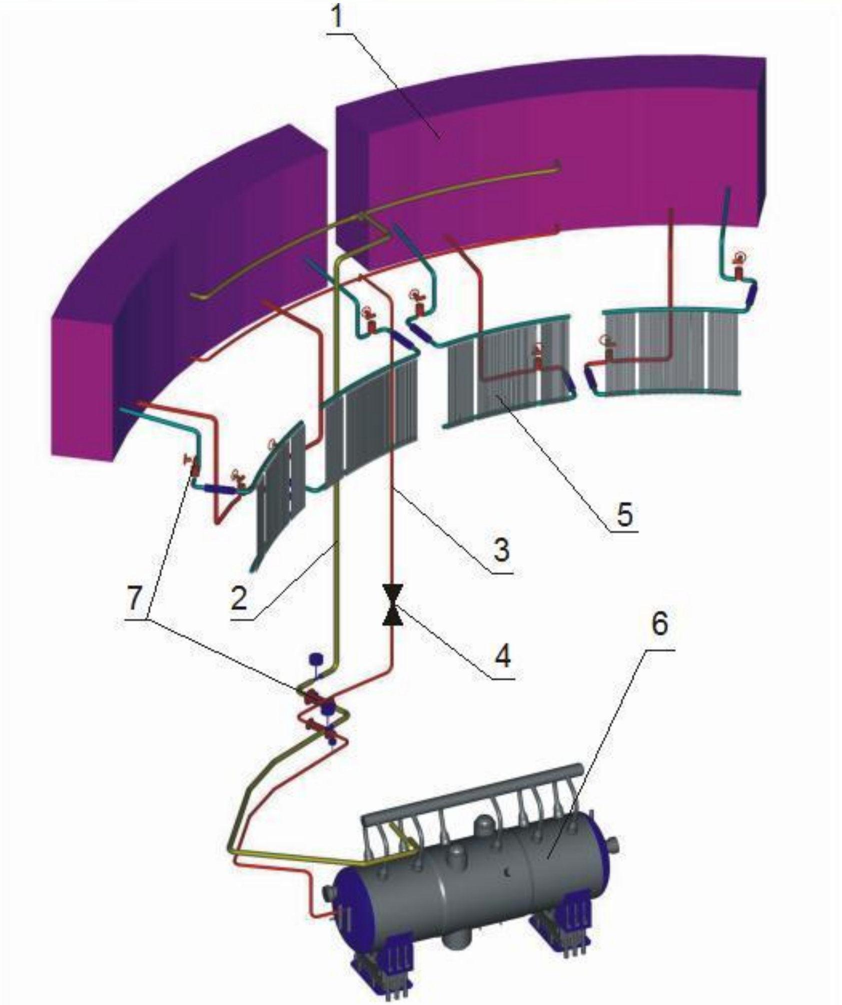
3 – condensate pipelines

4 – PSHR-SG valves

[**5** – heat exchangers of containment heat removal system PSHR-C; *it is a separate system but uses same EHRTs*]

6 – steam generators

7 – cutoff valves



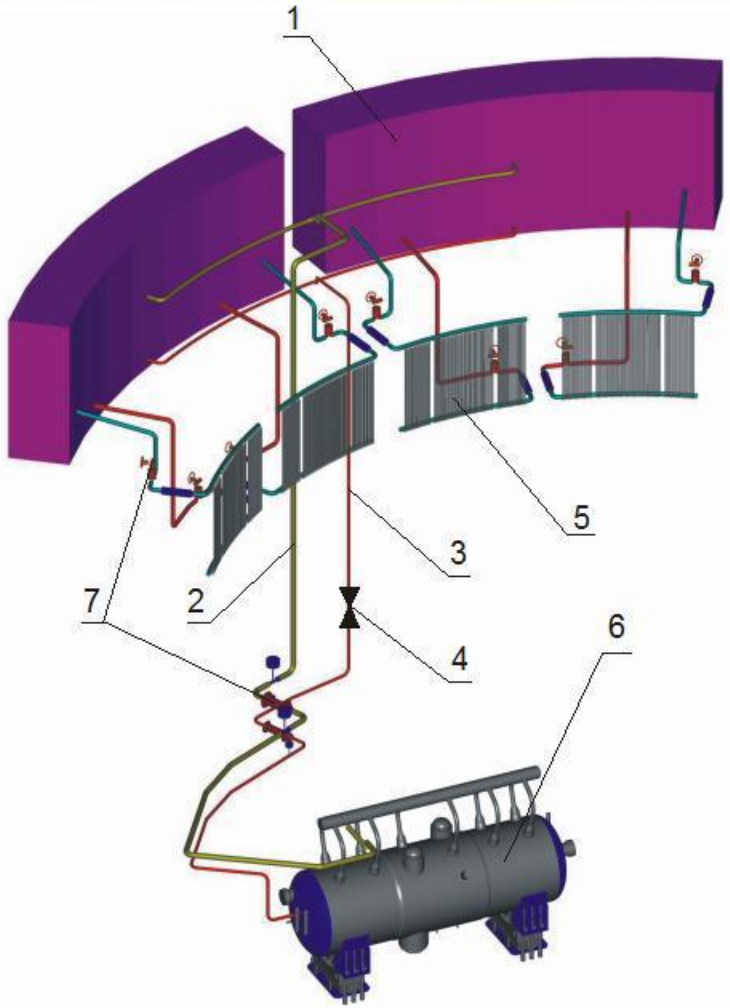
Passive system for decay heat removal at Leningrad-2 plant (2)

Operation of 3 out of 4 EHRT tanks provides **cooling** for 24 hours, all 4 tanks **for 72 hours**. All tanks can be connected as communicating vessels and then all water is available.

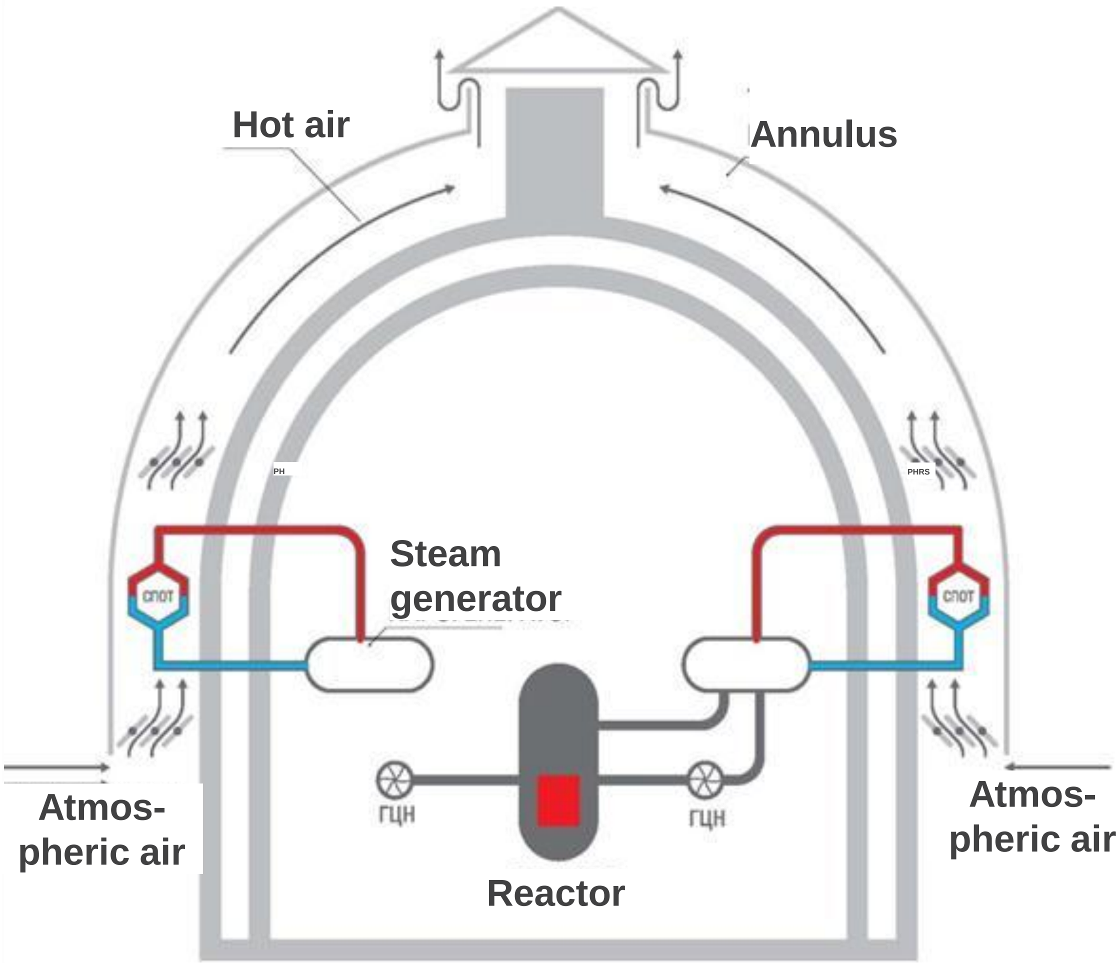
A fixed battery driven pump was added to design that **can refill the EHRT tanks and spent fuel pools from a separate storage tank, batteries have a capacity for 72 hours.**

Also, connections were made for transportable small diesel generator for dedicated **recharging of batteries** and thus for providing water without time limit.

Furthermore, connections were made for two transportable **diesel driven pump** units that can also refill EHRT tanks and spent fuel pools.



Passive syste for decay heat removal at Novovoronesh-2 plant

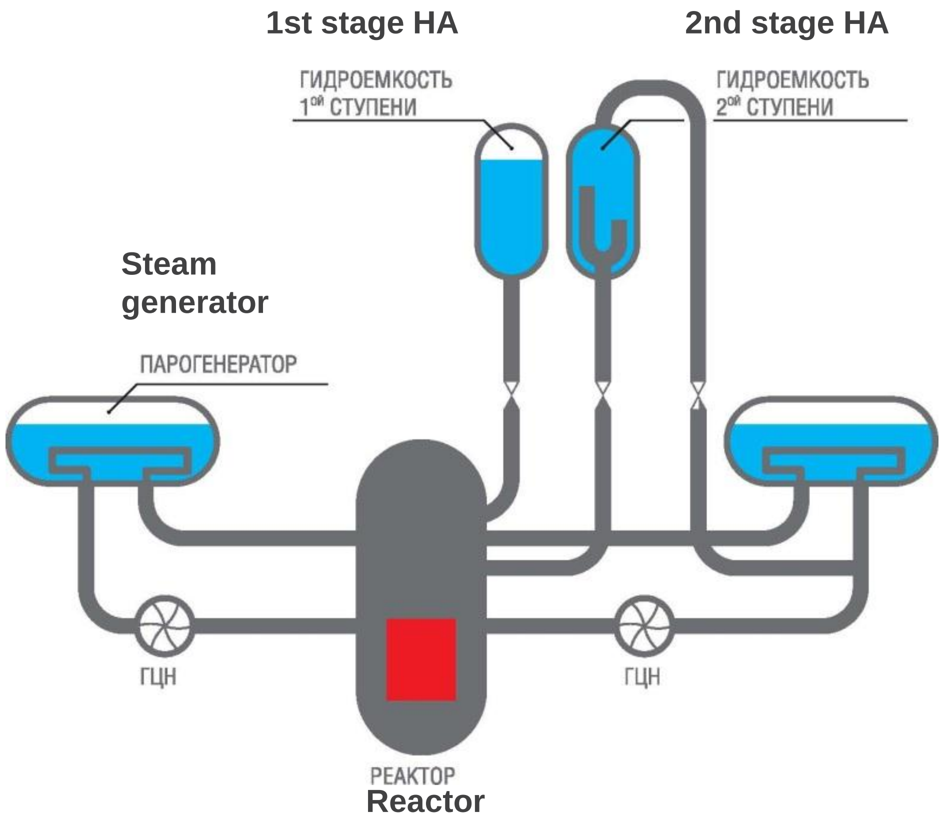


- The passive heat removal system operates with natural circulation in closed loops, by condensing steam in coolers
- No need to add any water and thus no time limit for operability
- Passive devices control the air flow rate to provide cooling of primary circuit at proper rate

Passive system for core cooling after loss of coolant accident at Novovoronesh-2 plant

The 1st stage Hydro Accumulators are intended for fast flooding of the reactor core during large-break leaks of the reactor coolant circuit. The system operates automatically when the pressure in the reactor coolant system drops below 5.9 Mpa.

The **2nd stage Hydro Accumulators** are intended for passively flooding the reactor core in emergency by boric acid solution when the pressure in the reactor coolant system drops below 1.5 MPa. It can keep the reactor flooded with water for at least 24 hours even after largest possible pire break without operator actions.



Loss-of-coolant-accident scenarios analysed for Novovoronesh-2 (failure of the active ECCS)

Leak size, equivalent pipe diameter mm	Start of HA1 operation, s (h)	End of HA1 operation, s (h)	Start of HA2 operation, s (h)	End of HA2 operation, s (h)	Time for reaching the design limit 1200^{0}C, s (h)
850	7,4	194	115	94760 **(26,3)**	110563 (30,7)
70	1037 (0,29)	2853 (0,79)	2870 (0,8)	97268 **(27)**	158000 (43,9)
50	2010 (0,56)	6460 (1,8)	3780 (1,05)	102100 **(28,3)**	169000 (47)
25	3398 (0,94)	10070 (2,8)	9576 (2,66)	~190000 **(52,8)**	259200 (72 h)
10	5004 (1,39)	25212 (7)	138090 (38,36)	**~280 h**	–

Containing severe reactor accidents without significant radioactive releases (1)

- A clear target was set already after Chernobyl accident:
  - **Independent dedicated systems** have to be developed for the new generation of VVER plants **for protecting the reactor containment after possible core meltdown accident.**
- Protection of the reactor containment even in connection with a core meltdown accident has been one of the original design principles used for VVER-1200 plants
  - respective experimental research has been done for more than 20 years.

Containing severe reactor accidents without significant radioactive releases (2)

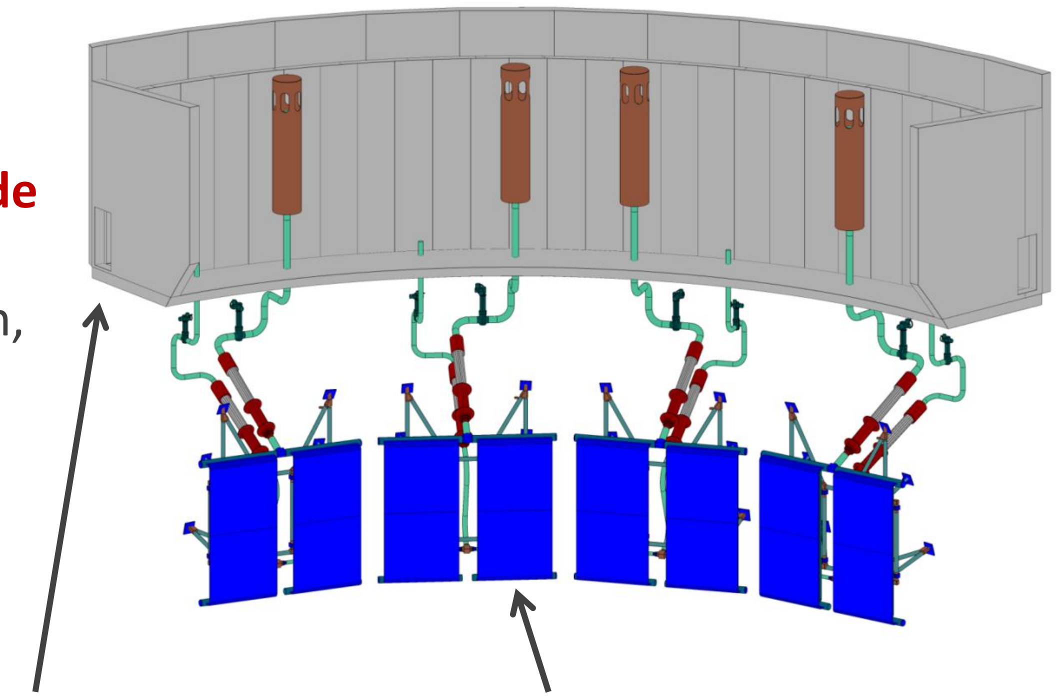
- The strategy for protection of the VVER-1200 containment after possible reactor core meltdown is that **all physical phenomena that could occur in connection with core meltdown** and endanger the containment integrity **are taken into account** and dedicated means are provided to ensure containment integrity.
- **Protection** of the VVER-1200 containment integrity against all those physical phenomena **is based on systems that are completely independent and separated from the systems that are intended to prevent a severe reactor core damage.**

Containing severe reactor accidents without significant radioactive releases (3)

The physical phenomena to be eliminated in the AES-2006 design include:

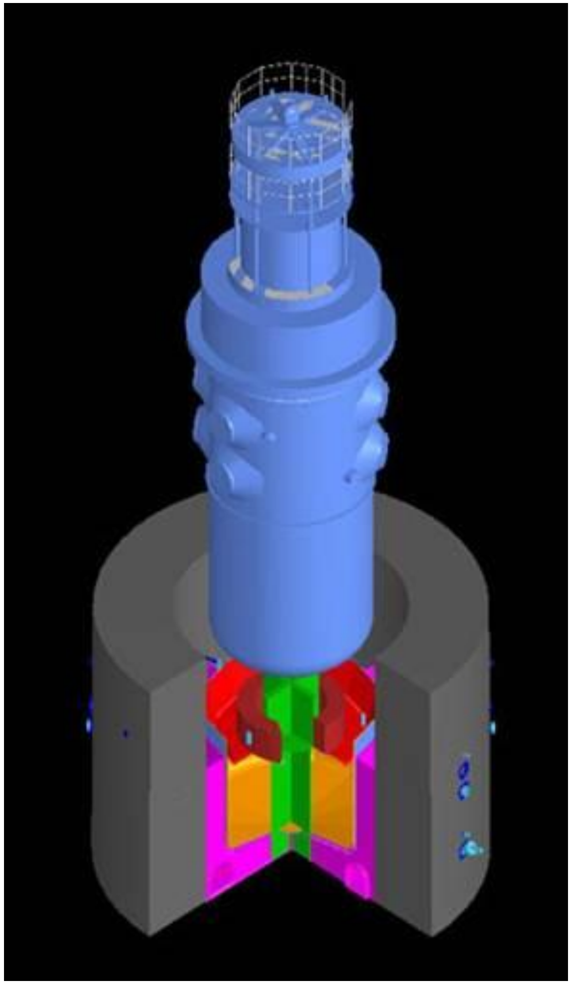
- reactor core **meltdown in high primary** circuit pressure,
- containment **overpressure** due to the steam generated inside the containment,
- accumulation of **hydrogen inside the containment** and consequent hydrogen explosion,
- **steam explosion,**
- **penetration** of the molten reactor core through the containment bottom, and
- **recriticality** of the molten reactor core

Containment overpressure protection system at Leningrad-2



Molten core catcher to be installed in all new VVERs, already installed in China and India

- Placed below the reactor vessel to **protect the containment structures** against impact of molten core (very high temperature of more than 2000°C).
- Retains and cools core melt and solid fragments of the core, parts of the vessel and reactor internals resulting from core damage.
- Transfers passively the heat to cooling water surrounding the “core melt pot” and thus **ensures long term cooling** and solidification of the molten core.
- Molten core is mixed with neutron absorbing material placed inside the “core melt pot” to ensure that no chain reaction can start in the mixed materials inside the core catcher.
- Core catcher decreases significantly the hydrogen generation and radionuclides transfer into the containment.



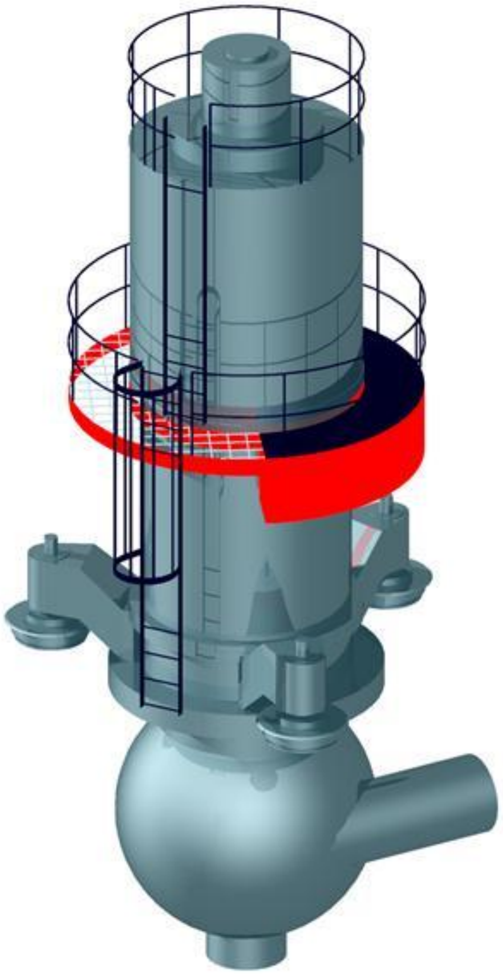
Advanced approaches to fire protection at VVER-1200 plants

Reduction of fire hazards

- Primary circuit main circulations pumps and their motors have **water cooling and water lubricated bearings**; this eliminates the risk of large fire inside the reactor building and is a unique feature when compared with most PWR plants in operation today or being offered in the markets.

Reliable and safe fire suppression

- For suppressing oil and electrical fires there are water based ”high fog” systems that have been effective in suppressing fires in many real fire accidents at different facilities; these systems involve no use of poisonous or suffocating materials and thus their use is not hazardous to operating staff or environment.



Conclusions

- New safety principles for design of new power plants have been developed as a worldwide co-operation already after Chernobyl accident but in most countries they have not been taken as requirements.
- Fukushima Daiichi accident has changed the situation and only advanced "Generation III" plants are now considered acceptable in most countries.
- Requirements for new Russian NPPs were developed and implemented already in the first 10 year period after the Chernobyl accident.
- New VVER-1200 plants have been designed to meet the most advanced safety principles and requirements that are available today.