EMERGENCY HEAT REMOVAL IN THE INTEGRAL WATER COOLED ABV-6 REACTOR FOR THE VOLNOLOM FLOATING NUCLEAR POWER PLANT

Yu.D. BARANAEV, Yu.I. OREKHOV,
Yu.A. SERGEEV, I.M. SHVEDENKO
Institute of Physics and Power Engineering,
Obninsk, Kuluga Region

Yu.P. FADEEV
OKB Mechanical Engineering,
Nizhny Novgorod

V.M. VOROBYEV
CDB Baltudoproject,
St. Petersburg

Russian Federation

Abstract

Several independent active and passive safety systems are employed in the design of integral WCR in order to provide together with the reactor inherent safety features realization of the emergency heat removal function:
- active primary coolant clean-up system transmitting heat to the tertiary and then to the forth circuit,
- passive emergency heat removal through steam generator to the atmosphere,
- reactor cavity flooding system providing heat transfer from the reactor vessel to the reactor metal-water shielding tank,
- high and low pressure make-up system using water from the special storage tank.

Operation of the systems under LOCAs and accidents with normal heat removal systems failure is considered in the paper. Special emphasis is done to the description of systems characteristics, systems interaction and modes of operation which are influenced by the reactor integral design.

Emergency heat removal (EHR) is one of the major safety functions that should be provided by the design of reactor safety systems.

Under the design of the ABV-6 reactor designated for the floating NPP "Volnolom" the following specific features of the reactor were taken into account:
- Integral reactor design (Fig.1)
- Low reactor capacity (38 MWt)
- High reactor heat accumulation capability (~1.8 s per °K)
- Natural convection in the reactor primary circuit

- High margin in the strength characteristics of the primary circuit equipment (tolerable pressure of 31 MPa is ~2 times higher than the nominal design pressure)
- Employment of metal-water shielding tank containing 26 m^3 of water
- High thermal conductivity of reactor fuel made of uranium-aluminum alloy.

These features of the ABV-6 reactor strongly influence the solution of the EHR issues.

1. The integral arrangement of the primary circuit results in exclusion of big primary pipelines as well as a larger primary coolant inventory in the reactor pressure vessel (RPV). These result in long period before it is necessary to start coolant supply to the RPV under LOCAs, since reactor core uncovery in the case of reactor make-up system failure would take place only several hours after the beginning of the accident. Besides, there is a possibility for the EHR through steam-generator in integral reactor design and this also enlarges the grace period.

2. The relative portion of heat dispersed to the surroundings is higher at small reactor capacity. This allows decrease in the time required for the EHR systems to operate.

3. The high reactor heat capacity allows reduction of the EHR system capacity compared with the residual heat rate. The excess of extracted heat is accumulated in the reactor primary coolant and structures in the first stage of the accident without unacceptable reactor temperature and pressure rise.

4. Natural convection ensures reliable heat removal from the reactor core with sufficient departure from nucleate boiling margin during transient and accident conditions.

5. Large margins in the strength of the primary circuit together with high heat capacity of the reactor ensure tightness of the primary circuit under accidents with failure of all EHR trains for a long period of time. For some beyond the design basis sequences this time is unlimited.

6. The metal-water shielding tank is an effective heat sink. The amount of water in the tank is sufficient to provide the EHR for 3 days.

The ABV-6 reactor plant is equipped with the following systems that can be used for the EHR:
- Active two trains system supplying water to the steam generator (SG) from the feed water storage tank (48 m^3) by the emergency feed water pumps with a flow rate up to 15 m^3/h each (Fig.2).
- Passive two trains system supplying water to the steam generator from pressurized storage tanks containing 4 m^3 of water (Fig.3).
- Active primary coolant purification system with pump and heat exchanger designed to remove 1370 kW (3.3% of reactor rated power) of heat directly from the primary water (Fig.4).
- Active two trains emergency core cooling system (ECCS) supplying water to the reactor vessel by 3 high-pressure (head 17 MPa, flow rate 1.2 m^3/h each) and 2 low-pressure (head 3.5 MPa, flow rate 20 m^3/h each) pumps (Fig.5).

ABV-6 reactor

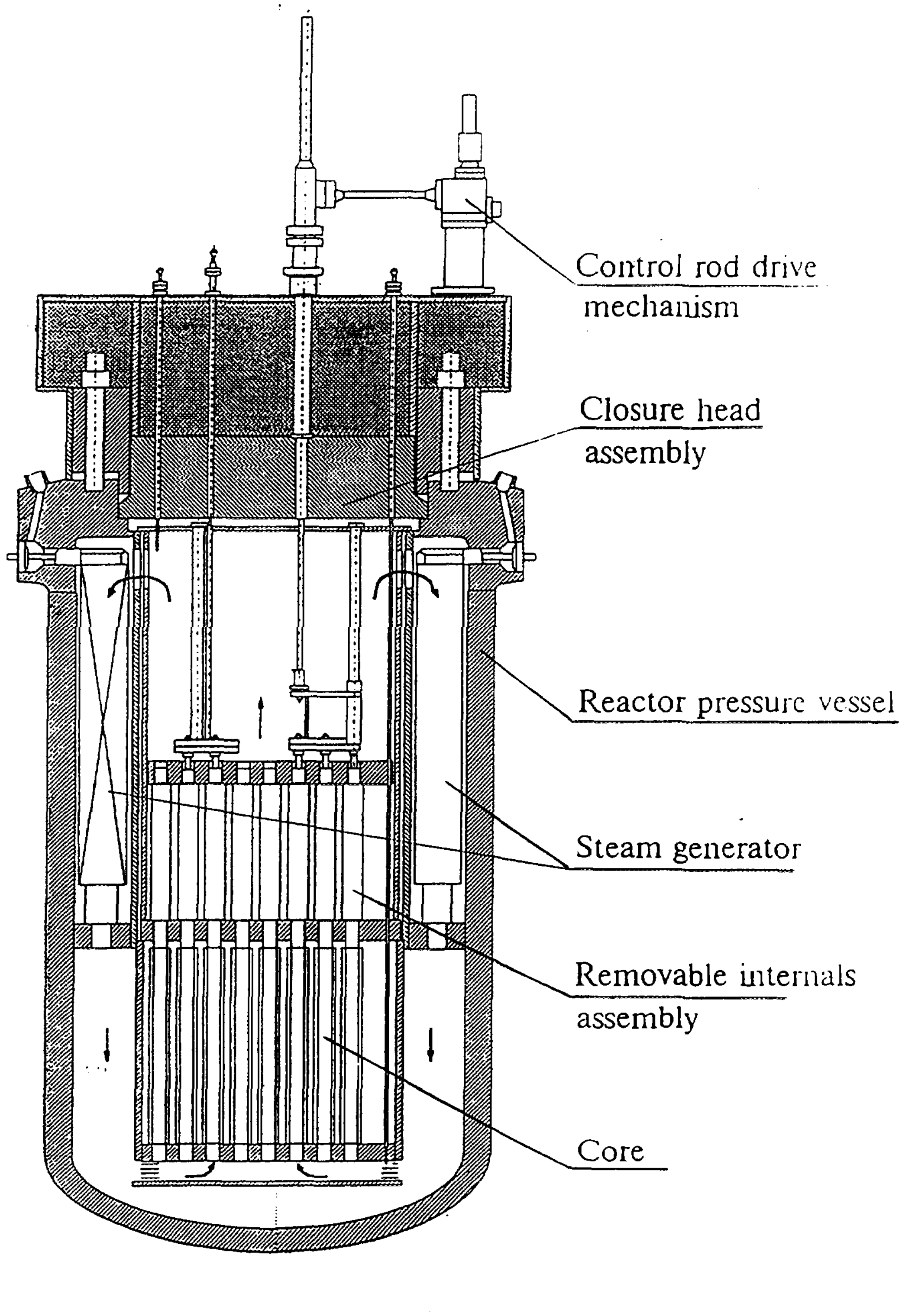

Fig. 1.

Engineered emergency residual heat removal system

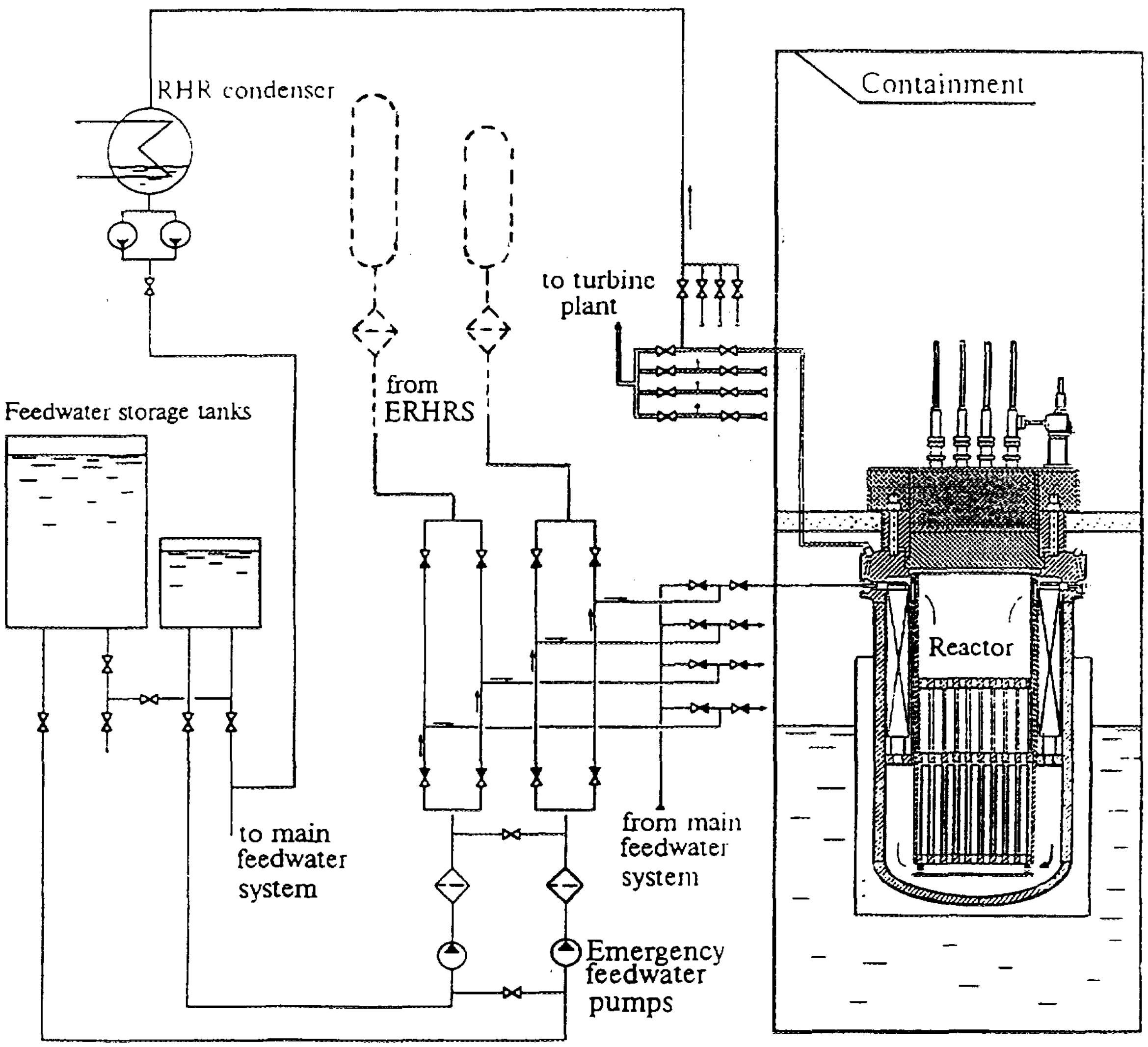

Fig. 2.

Passive emergency residual heat removal system

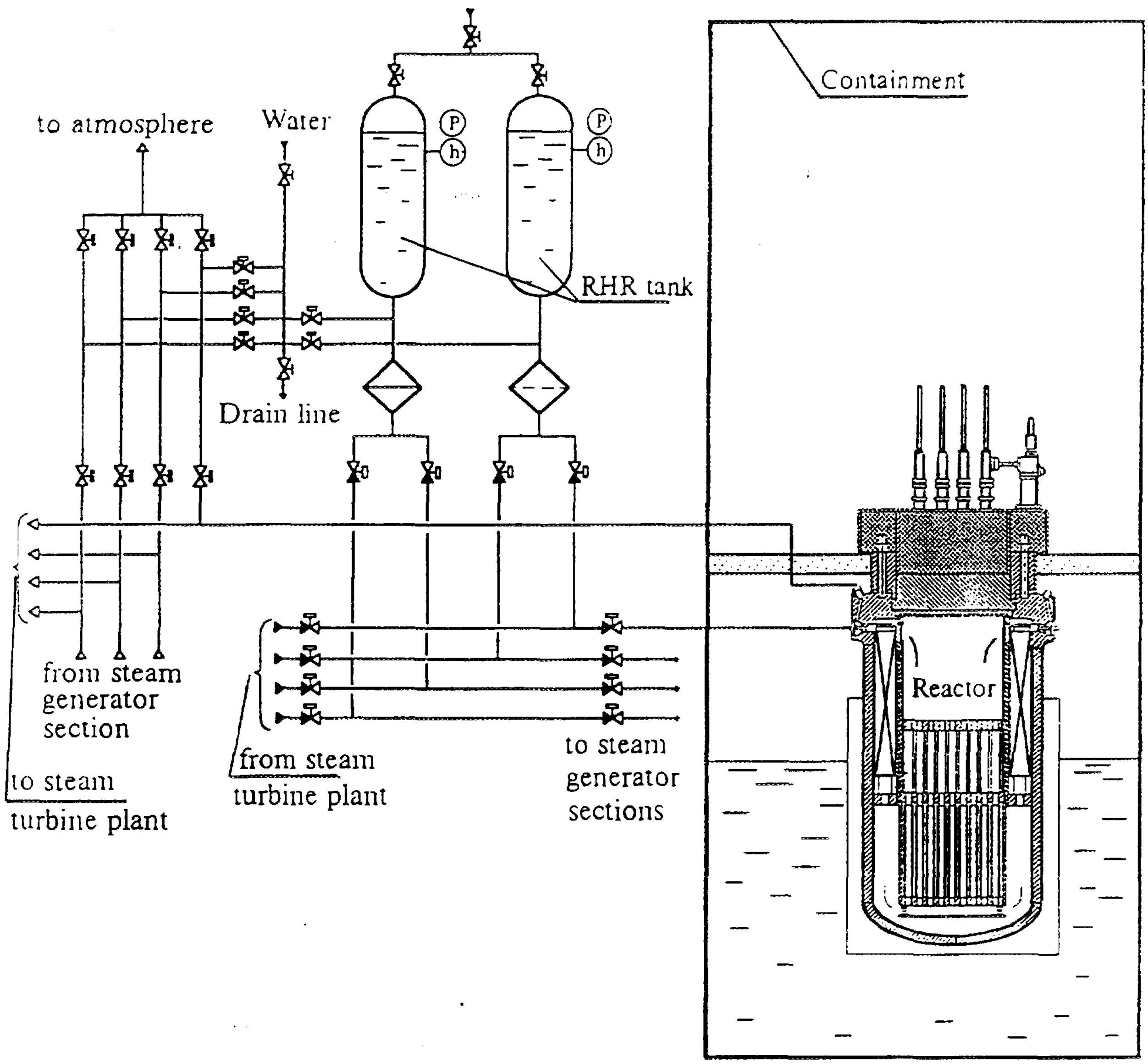

Fig. 3.

Channel for heat removal throught purification system cooler

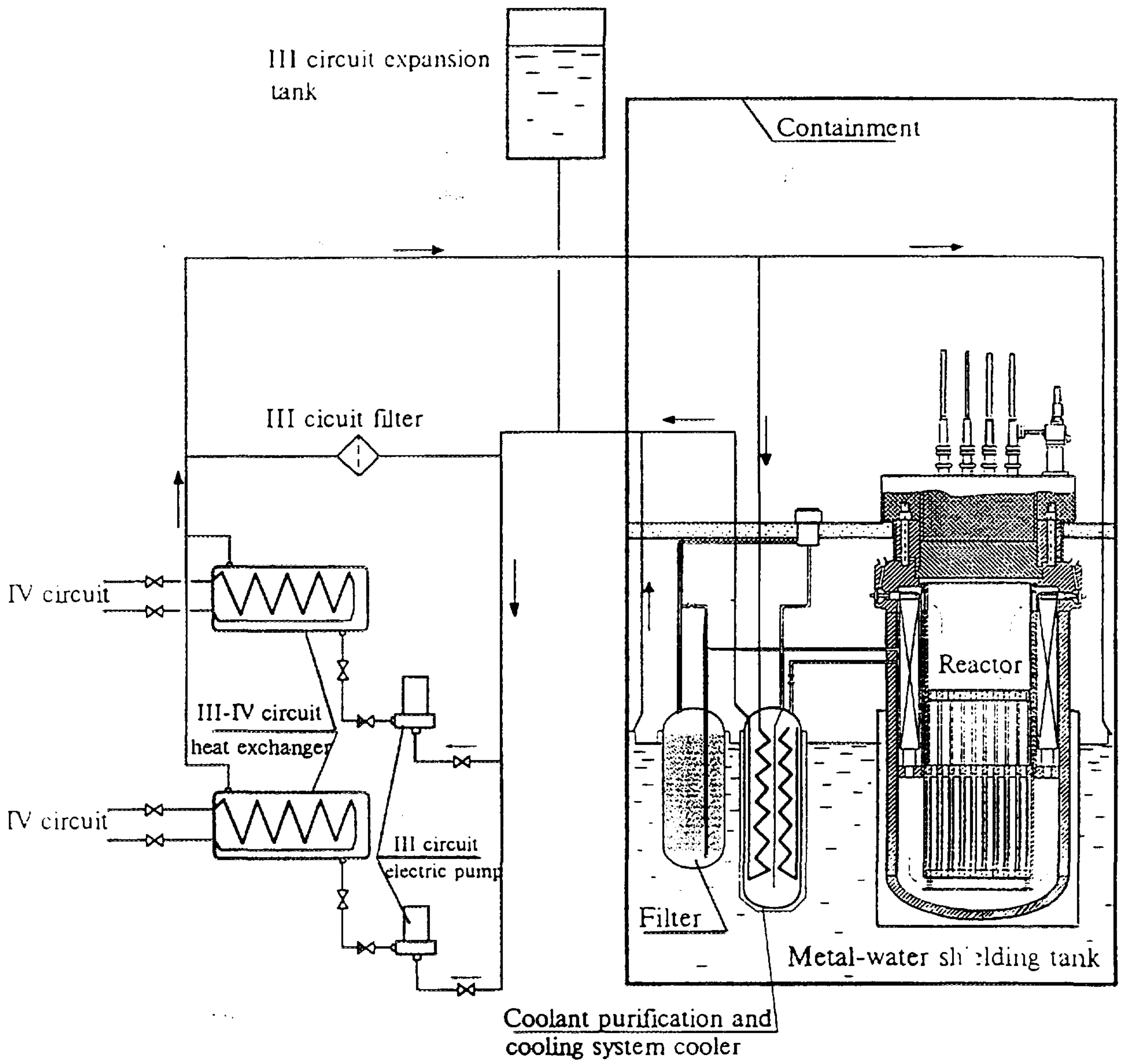

Fig. 4.

Emergency core cooling system

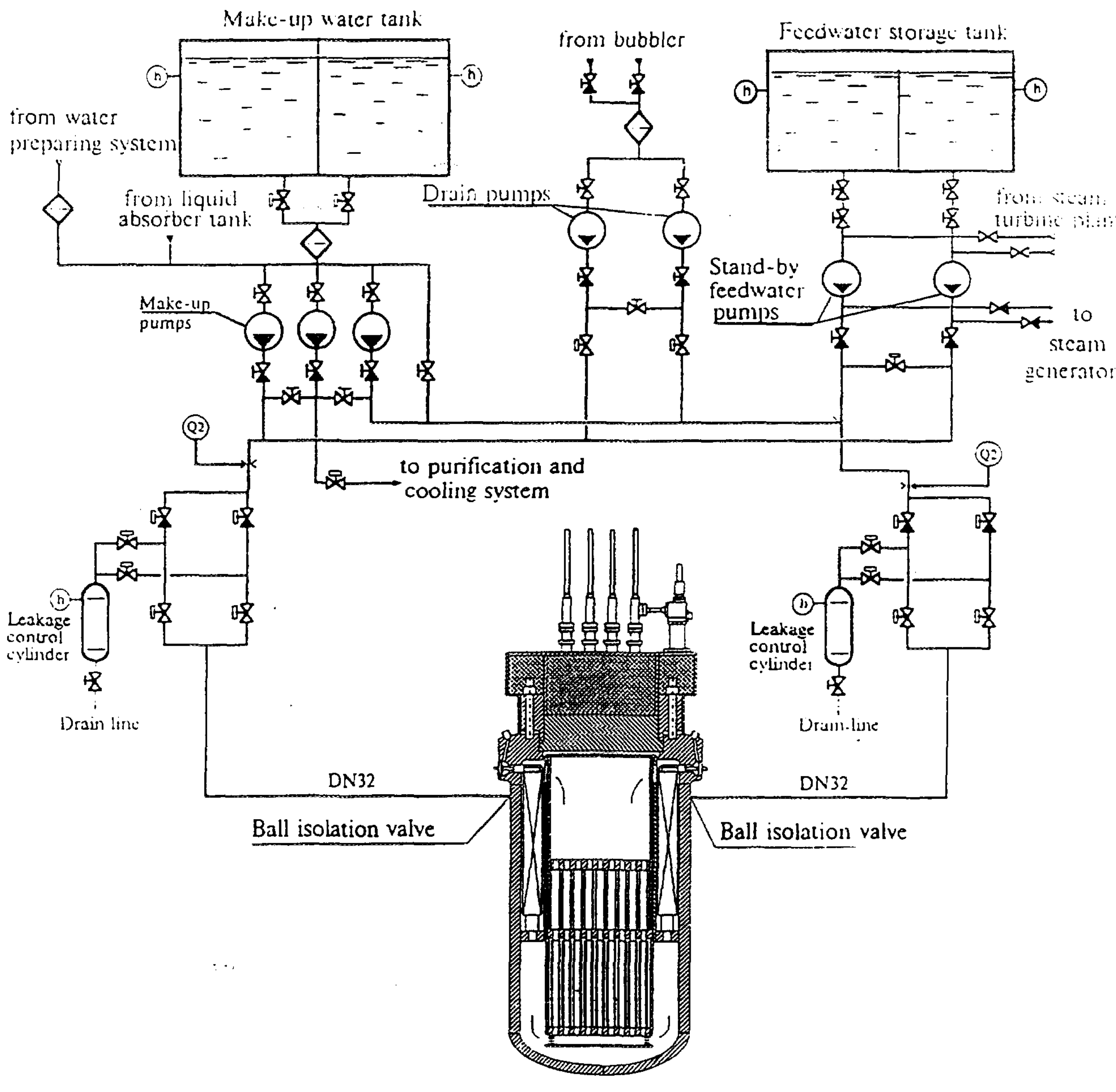

Fig. 5.

Reactor vessel emergency cooling system

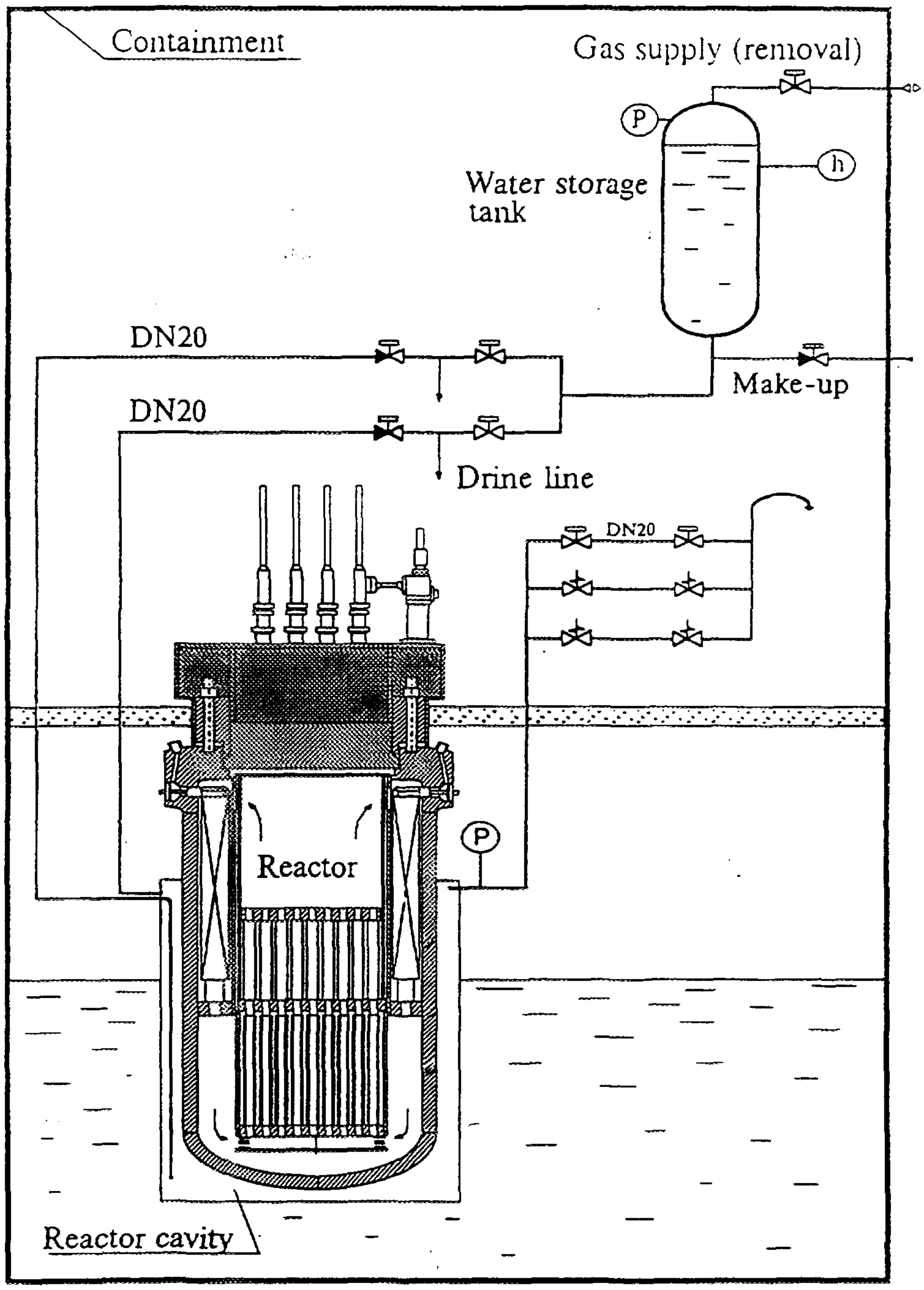

Fig. 6.

Table

ABV-6 REACTOR SAFETY CHARACTERISTICS UNDER BDBA

Initial event	Safety systems failure	Accident characteristics
Black-out	One train of passive EHR failure	Reactor pressure drops from 15.4 MPa to 13.5 MPa by the moment (3.5 h) of depletion of hydroaccumulator. Further on the pressure increases up to 25 MPa in 36 h and then it goes down thanks to dispersion of heat to surroundings. The tightness of primary circuit is kept.
	Two trains of passive EHR failure	Reactor pressure goes up reaching the primary circuit strength limit (31 MPa) in 5 h. Without operator actions control rod drive sealing failure takes place.
	Scram failure	Negative feedback shut the reactor down. Passive EHR system starts to operate in 2 min at the pressure of 18.7 MPa. By the moment of the pressurized water tanks depletion (3.5h) the primary pressure drops to 15.7 MPa and then increases up to 29.2 MPa in 27 h. The tightness of primary circuit is kept.
Pressurizer pipeline break	One train of the ECCS failure	One high pressure pump is sufficient to prevent core uncovery. Minimal water volume above the core is 1 m^3 even in case of only high pressure pump operation and is 2 m^3 if low pressure pump operates.
	Two trains of the ECCS failure + failure of heat removal through the SG	Core uncovery in 3 h. Beginning of FP release from the fuel in 4.5 h. Core melt in 7.2 h. Maximal RPV temperature does not exceed 710 °C if the reactor cavity flooding is provided during the core melt. If not, the RPV temperature reach 1200-1300 °C. The RPV melt through is prevented anyway. If the EHR through the SG takes place core uncovery starts in 10 h and all further processes go slower.

- Passive reactor cavity flooding system with a pressurized water tank up to 7 MPa containing 1.2 m^3 of water (Fig.6).

Safety analysis for all initial events considered has demonstrated a high level of reactor safety system effectiveness and sufficiency under design and beyond the design basis sequences. Some results of the safety analysis are shown in the Table.

It is reasonable to add that according to the PSA, the frequency of black-out with simultaneous failure of two passive EHR system trains does not exceed 10^{-10} per reactor-year. Cumulative frequency of core melt was assessed as $2.5*10^{-7}$ per reactor-year.

The above information allows the conclusion that the integral design concept provides broad range of opportunities to enhance reactor safety with reliance on clear and simple design solutions. This concept looks rather promising at least for small water-cooled reactors.