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Design features of water-cooled research reactors

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Abstract

Brief review of the design, specific features of thermal hydraulics of reactor cores and circulation loops of pool-type research reactors is given. Principal distinguishing features of research reactors as compared with industrial power reactor units are outlined. Design of reactor units is examined using the example of two research reactors VVR-M (Gatchina) and VVR-ts (Obninsk). Direction of coolant circulation constitutes the feature of research reactor installations which is of key importance. In contrast to power reactor units, propagation of coolant in research reactors is arranged in downwards direction, i.e. from core top to bottom. In connection with the above, particular design features of reactor support grids are discussed in the present study. A set of data is presented on the values of preset values of alarm and emergency protection triggering thresholds. The issue of modernization of the reactor core implemented by developing the family of fuel assemblies (FAs) of the new type is discussed separately using the example of modernization of the VVR-M reactor. It is demonstrated that by changing the FA design it is possible to significantly increase the neutron flux density and per unit power of reactor units. Tables containing main technical characteristics of different FAs for nuclear reactors of the IRT type are presented. Certain circuit engineering solutions for coolant circulation loops and characteristic design of research loops aimed at the solution of different research tasks are discussed.

Keywords: Research reactor; Turbulence; Thermal hydraulics; Heat transfer in nuclear reactor; Fuel assembly; Reactor safety; Pool-type research reactor; VVR-M2; VVR-M3; VVR-M5; VVR-ts fuel assemblies.

Introduction

Research nuclear reactors occupy important place in the development of nuclear power generation. Substantiation of safety of commercial NPP operation is impossible without implementation of wide program of fundamental and applied studies conducted on research nuclear reactors (RNR). Studies in the field of nuclear and neutron physics, solid state physics, nuclear and radiation chemistry, material studies, biology, medicine, testing fuel pins of power reactors under design and structural materials for reactor building are conducted in RNR cores [1,2].

Despite the lower power levels and, correspondingly, smaller amounts of radioactive substances generated as the result of RNT operation, potential hazard of these reactors for public and environment remains nevertheless to be high because of a number of their special features:

- High repeatability of transients during operation (reactor start and shutdown operations, variation of power levels);
- Frequent core reshuffling and continuous transfers of irradiated items;
- High repeatability of load cycles on the main equipment of cores and first cooling loops of reactors;
- High neutron flux density in reactor cores;
- Presence of high-enrichment fuel;
- Smaller, as compared with commercial power reactors, number of physical protective barriers preventing dispersion of fission products;
- Location of the majority of RNR in large cities with large population.

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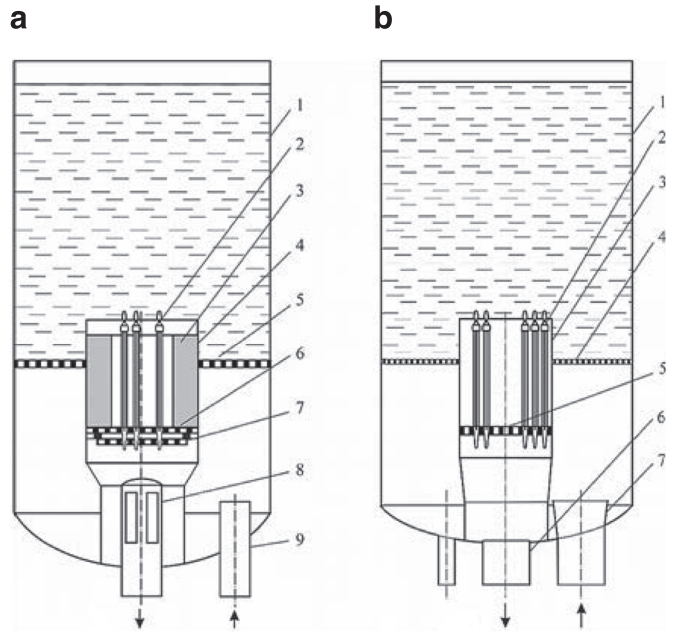

Fig. 1. (a) RNR VVR-M: 1 – tank; 2 – FA; 3 – beryllium reflector; 4 – reactor vessel; 5–7 – baffle, guiding and support grids; 8, 9 – suction and pressure pipelines. (b) RNR VVR-ts: 1 – tank; 2 – FA; 3 – reactor vessel; 4, 5 – baffle and support grids; 6, 7 – suction and pressure pipelines.

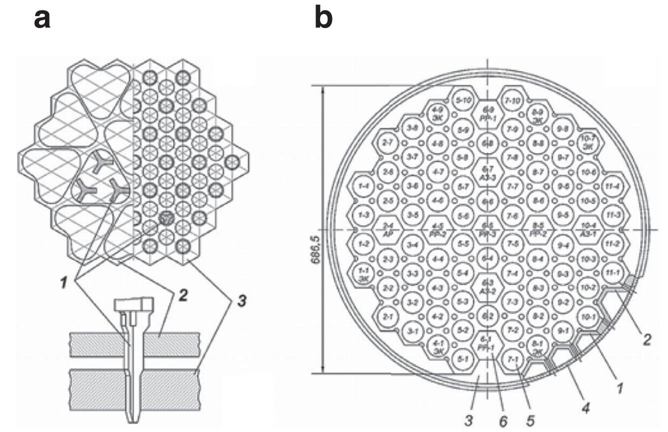

Fig. 2. (a) Shapes of grids and layout of installation of FA supports in the VVR-M reactor lattice: 1 – FA support; 2, 3 – guiding and support reactor grids. (b) Support grid of the VVR-ts reactor: 1, 2 – segment; 3 – support grid; 4 – shell ring; 5 – FA cell; 6 – CPS moving element cell.

Let us note that the present study, although it is of a review nature, does not claim, however, that comprehensive description of pool-type RNR will be provided and does not offer the solution of one of the most important issues outstanding at the present moment, namely, the use in RNRs of FAs loaded with low-enrichment fuel.

Design features of research nuclear reactor installations and the main circulation loop

In the most general case pool-type reactor represents a cylindrically shaped tank with height equal to 5.5–8.5 m and with internal diameter equal up to 3.0 m. Wall thickness of the tank varies within the range of 12–20 mm. Spherical or flat bottom with wall thickness equal to 20–35 mm is welded to the lower part of the tank. Upper lid of the tank is flat with wall thickness equal up to 35 mm. Shell ring consisting of two cylindrical parts having larger and smaller diameters is welded in the lower part or the reactor vessel to its bottom (Fig. 1(a) and (b)).

Cylindrical parts are connected with each other using conical insert. Separator representing a hollow cylinder to the lower part of which either one grid (support grid) or two grids (guiding and support grids) are welded, is installed in the upper part of the larger diameter cylinder. The main purpose of the guiding and support grids is to ensure rigid fixation of FAs, reactor CPS rods and vertical experimental channels. Guiding and support grids of the RNR VVR-M reactor are shown in Fig. 2(a), and support grid of the RNR VVR-ts reactor is shown in Fig. 2(b).

Organization of coolant circulation in the reactor core (r.c.) constitutes the principal distinguishing feature of pool-type reactor units. In contrast to power reactor units coolant moves in the RNR core in the direction from top to bottom, i.e. the downwards movement takes place, while in commercial power reactor coolant movement is organized in upward direction. RNR type of organization of coolant flow completely excludes buoyancy of FAs under the effects of approach flow, which allows simplification of the reactor core due to the possibility to design the reactor core without the use of FA anchorage in its upper part and makes it easier accessible for installation of diverse experimental devices.

Baffle grid intended for leveling the coolant velocity and temperature fields and excluding penetration of unwanted objects on the bottom is installed between the cylindrical shell ring of larger diameter and the reactor tank. Installation of FAs in the reactor core is implemented either manually using a shaft, or using automatic loading mechanism. Extraction of FAs from the reactor core into the cooling pool is achieved only using automatic loading mechanism.

Analysis of process circuit flow diagrams for pool-type RNR demonstrates that, despite the diversity of engineering solutions in the choice of configuration and equipment of primary circulation loops (PCL) there exist general principles of construction while the features of hydraulic circuits (application of dedicated equipment) are dictated, in the first place, by the specifics of the RNR intended use and design configuration.

Typical conceptual engineering diagram of pool-type RNR is shown in Fig. 3(a). Let us note that this diagram is not exhaustive and many details are not shown in it.

Presence of experimental loop installations (EPI) applied for solving different experimental tasks is the typical feature of all RNRs. Conceptual engineering diagram of low-temperature EPI is shown in Fig. 3(b) as an example.

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