THERMAL STRATIFICATION OF SODIUM IN THE BN 600 REACTOR

Obmelukhin J.A., Obukhov P.I., Rinejskij A.A.,
Sobolev V.A., Sherbakov S.I.

Abstract

The signs of thermal stratification of sodium in the BN 600 reactor upper plenum revealed by the analysis of standard temperature sensors' readings are defined. The initial conditions for existence of different temperature sodium layers are given

Two approaches for realizing on a computer of equations describing sodium motion in the upper plenum of the reactor are presented.

The BN 600 reactor put on power on April 8, 1980, operates as a component of the third unit of Belojarskaja nuclear plant named after I.V. Kurchatov. Its rated thermal power of 1470 MW is transferred to three once-through modular steam generators producing 660 tons of steam per hour at 550°C and 14 MPa each. The steam generators supply with steam three turbogenerators of 220 MWe unit power.

Reactor operation at 100% power in December 1981 was a result of three succeeding power stages.

The first stage: reactor operation at 30% of rated power to carry out field-adjustment and research work including adjusting of steam generators' water chemistry and unit controllers.

The second stage: reactor operation at 40 - 70% of rated power to continue the first stage efforts at elevated power, check emergency condition algorithms, determine reactivity effects etc.

The third stage: reactor operation at 80% of rated power with check of long-term equipment operation at rated circuit parameters.

The signs of thermal stratification of sodium in the upper reactor plenum appeared at the very beginning of reactor operation on power. Differencies in thermocouples' readings (Fig. 1) were noted in flow transition zone and at intermediate heat exchanger

(IHX) inlets. At 80% power the discrepency for the most of IHXs amounted to approximately 20°C and at 100% power the difference in readings of the thermocouples was reduced to 10°C.

Thermocouples placed at IHX inlets had practically the same readings at sodium temperature 250 - 300°C with reactor at isothermal condition. During operation on power the thermocouples' readings differed. Nonuniformity of thermal stratification roun the azimuthal ordinate is due to eccentricity of central rotati column (CRC), (Fig. 2).

The sodium temperatures near thermocouples' junctions locat in the flow transition zone and at IHX inlet differ from averag mixed sodium temperatures at reactor outlet. This is evidenced by the absence of balance of thermal powers calculated for the three plant circuits.

The initial condition for existence of thermal stratificati of sodium in the BN 600 reactor is a sodium temperature differen at core, radial blankets' and storage fuel assemblies' outlets. At rated power operation the difference in sodium temperature a fuel and blanket assemblies' outlets is of 126 to 79°C depending on time from the first start of the reactor. Sodium temperature at storage fuel assemblies' outlets can differ from core outlet temperature by 134 - 199°C.

The great radial thermal gradient in the region of blankets with no flow control through fuel assemblies hinders temperature equalization and thereby does not allow to eliminate the source of thermal stratification of sodium in the upper reactor plenum.

As the model experiments show [I] the considerable equalization of temperature, velocity and pressure distributions in the sodium flow occurs at distance of 4 - 5 zone diameters. Such conditions, however, are realized in no one BN type reactors.

Sodium temperature and velocity fields' investigations for the upper reactor plenum were done analytically with the use of computer. During the mathematical models development there were used two approaches for computer realization of motion equations in the form of Navie -Stokes and energy equations.

The first mathematical approach used a set of dimensionless equations in Boussinesq approximation in the variables: vorticity - flow function. The approach is commonly accepted and suggests equations' discretization in a differential form.

The second approach used a mathematical model consisting of fluid motion and energy equations for two-dimensional and axisymmetrical geometry of a region under calculation in a conservative form. This suggested to use the integral motion equation in the form of energy conservation law of value Ω, representing the vortex lines' volumic density:

$$\rho \frac{\partial\tilde{\Omega}}{\partial\tau} + \iint\limits_{(S)} \rho \vec{V} \Omega \, d\vec{S} = \oint\limits_{(r)} d\vec{r} \left[\rho \vec{g} + \mu_{eq} \nabla^2 \vec{V} \right] \tag{1}$$

$$\iint\limits_{(S)} \rho \vec{V} d\vec{S} = 0 \tag{2}$$

$$v\tilde{\Omega} = \oint\limits_{(r)} d\vec{r} \left[\vec{V} \right] \tag{3}$$

$$\rho = \rho(T) \tag{4}$$

where ρ - fluid density, $\vec{V}$ - velocity vector, $\vec{g}$ - gravitational constant, μ_{eq} - equivalent viscosity with account of turbulence, v, $\vec{S}$ and $\vec{r}$ - integration volume, its surface and closed circuit limiting volume projection onto the solution plane, respectively. Values in square brackets are upper plenum depth and space free for flow averaging. The averaging sign above $\tilde{\Omega}$ is set to differentiate volume-averaged value in (3) from a local one in (1).

Temperature distribution in fluid as well as in solid structural elements is determined at given boundary conditions through solution of thermal energy balance equation :

$$v c_p \frac{\partial\tilde{T}}{\partial\tau} + \iint\limits_{(S)} \rho \vec{V} c_p T \, d\vec{S} - \iint\limits_{(S)} \lambda_{eff} \nabla T \, dS = q v \tag{5}$$

where c_p - heat capacity, T - temperature, λ eff - effective thermal conductivity coefficient with account to turbulence, q - heat source (sink) volumetric density.

The numerical solution of equation system (I) - (5) in terms of corresponding boundary conditions was carried out for four reactor upper plenum radial sections differing in the degree of obstruction to sodium rise between the CRC and the tubes of radial shielding (Fig. 2).

Calculations did not show the existence of a great temperature gradient at IHX inlet and of narrow transition zone of convective interaction between cold and hot sodium. However, the differencies in temperature and velocity fields for each calculated sector suggests potential sodium interleakage between the sectors so that the results of calculation obtained in two-dimensional approximation can be distorted to a considerable extent.

The similar results were obtained with the use of the first mathematical model with numerical integration of equations in a differential form. The calculation was also carried out in two-dimensional approximation but for one average reactor upper plenum section.

For verification of thermal stratification pattern of sodium in the BN 600 reactor upper plenum at steady-state power levels at present is thought to undertake sodium temperature measurements by non-standard multijunction thermocouples. The thermocouples will be inserted into penetrations provided in the reactor roof (principally into hermetic sheaths of standard thermocouples).

The start-up of BN 600 reactor showed the greater degree of thermal stratification of sodium for the integral reactor primary equipment layout with mixing chambers of great volume. Thereby the importance of present investigations of sodium stratification is verified.

REFERENCIES:

1. Opanassenko A.N., Shangin N.N. Hydrodynamics of Nuclear Power Plant Mixing Chambers", J. "Atomnaja Energija", v. 52, issue 6, July 1982, p.385.

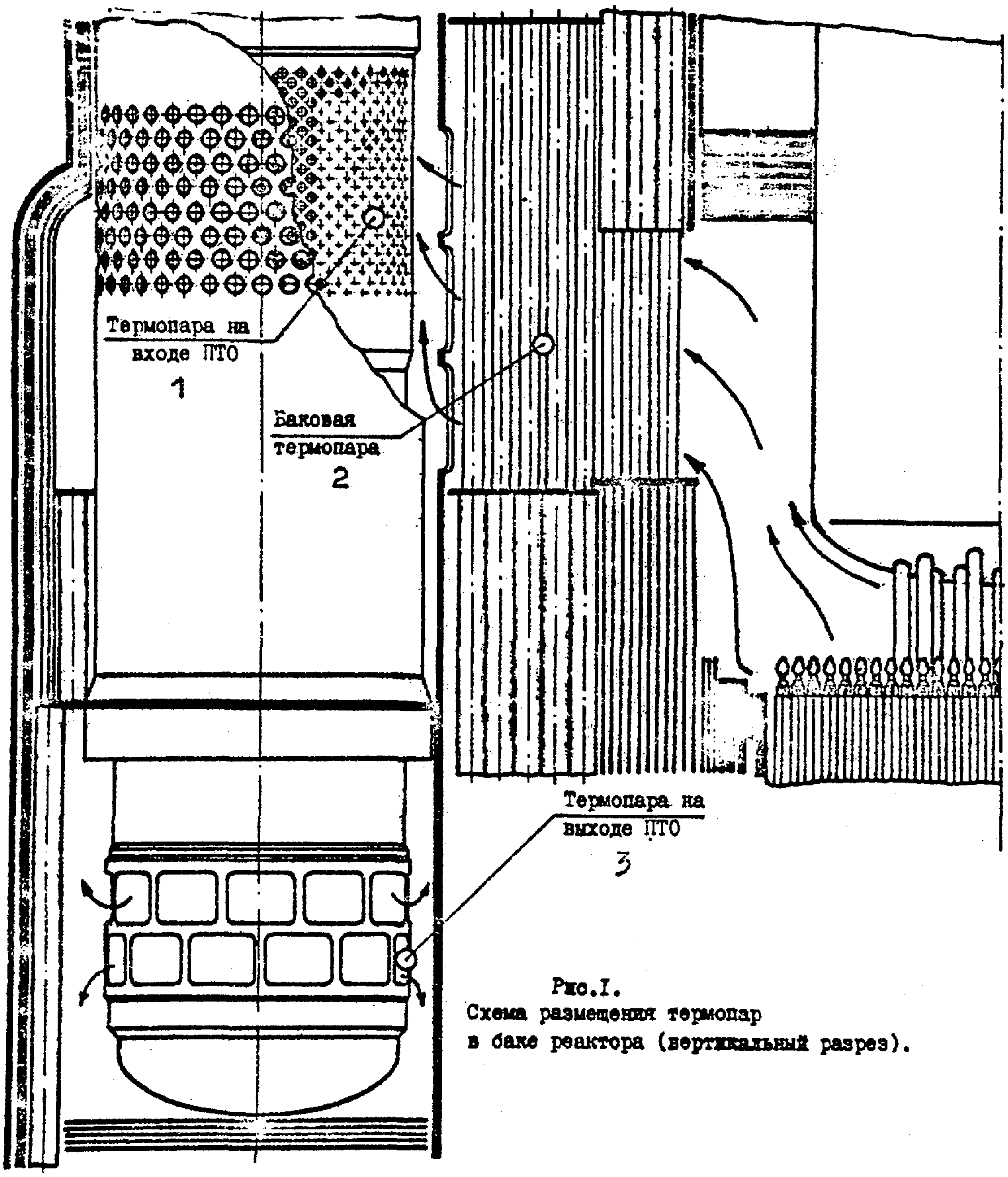

Рис.I.
Схема размещения термопар
в баке реактора (вертикальный разрез).

Fig. 1. Thermocouples' Location Scheme in the Reactor Vessel (Elevation View).

1. thermocouple at IHX inlet; 2. in-vessel thermocouple; 3. thermocouple at IHX outlet.

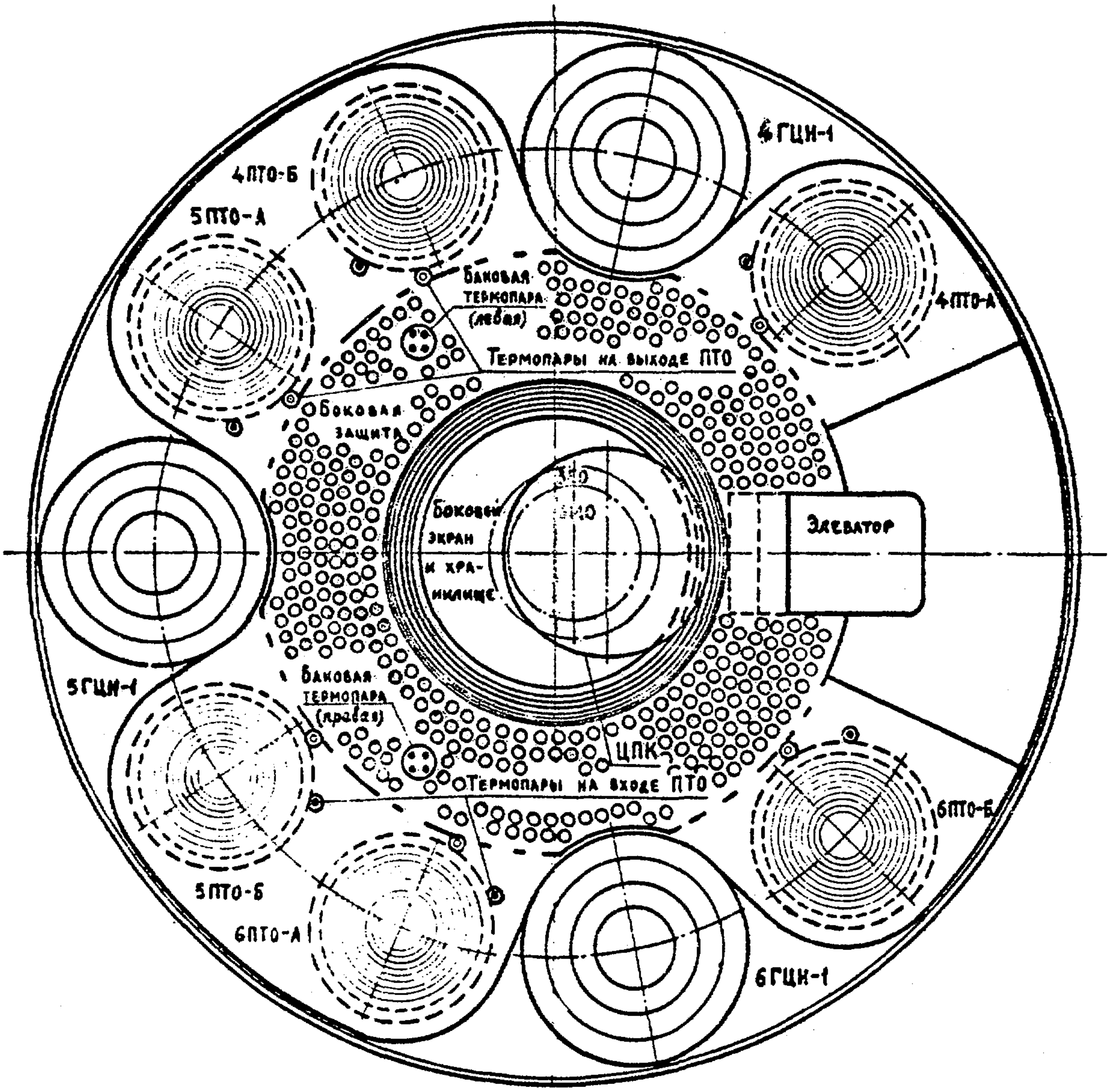

Fig. 2. Thermocouples' Location Scheme in the Reactor Vessel (Cross-Sectional View)

ГЦН - main circulating pump;
ЗБО - high enrichment zone;
ЗМО - low enrichment zone;
ЦПК - central rotating column.