COMPARISON OF DECAY HEAT EXCHANGERS PLACING IN THE PRIMARY CIRCUIT OF POOL TYPE FAST REACTOR

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Abstract

Description of two alternative arrangements of decay heat exchangers (DHXs) in the fast reactor tank is presented: in "hot" cavity and in "cold" cavity. The results of calculation for the two alternative arrangements as regards static and dynamic parameters in the primary circuit on 1-D program are given.

1. DESCRIPTION OF ALTERNATIVE ARRANGEMENTS OF DHXS IN THE REACTOR TANK

One of main objectives when developing the new generation reactor plants (RPs) is the creation of principally more reliable decay heat removal system (DHRS) with the probability of the entire system failure of not more than 1E-7 1/demand. Such reliability can be attained only using passive principles of DHRS action requiring no external energy sources to provide its function.

In BN-1600M RP there are four independent DHRS channels. Each channel consists of equipment assuring the necessary conditions for the development of natural convection:

1) autonomous sodium-sodium heat exchangers immersed into the reactor tank;
2) sodium-air heat exchanger equipped with air gates;
3) vent stack for provision of air draught through sodium-air heat exchanger;
4) sodium pipes.

DHRS channels are serviced by auxiliary systems for indication of sodium impurities, for purification, filling, drainage, electric heating.

DHRS actuation is effected by initial events associated with non-possibility of decay heat removal via the steam generators:

1) loss of external energy supply;
2) failure of feed water supply system;
3) seismic impact.

The BN-1600M DHRS has only one active element, namely sodium-air heat exchanger gates. In the mode of waiting for cooling down the sodium-air heat exchanger gates are partly closed assuring the flow of air through the heat exchanger about 10% of nominal. Transition of DHRS into cooling down mode is done by full opening of the gates. In case of the gates non-actuation from electric drives and difficulties with their manual opening a passive emergency drive is envisaged. The action is based on natural processes: force of gravity, transition of material from one state into another or on shape memory by metal at temperature variation. The passive drive can be installed in the reactor tank or in expansion tank of sodium-air heat exchanger. The drive actuates when the temperature of sodium in the reactor tank reaches 600°C.

The choice of design power removed by DHRS is done with account of primary sodium and reactor metal structures heat capacity. The ultimate temperature of reactor vessel is set at 650°C at which with account of time limitations its operability is preserved. The capacity of one DHRS channel is 27.5 MW.

Two DHRS variants are studied distinguished by the arrangement of DHXs in the reactor tank. In the first variant (Fig.1) the DHXs are arranged in "hot" cavity of the tank and suspended from upper stationary reactor shielding. DHX upper inlet holes are under primary sodium level in such a way that in case of reactor vessel depressurization accident the possibility of circulation through DHXs is preserved.

Primary sodium circulation in the cooling down mode is as follows. Hot sodium comes from the upper part of reactor tank into DHX, cools down and comes out from DHX draining into the power part of "hot" cavity onto the thermoliner. A part of sodium cooled down in DHX enters from underneath into the space between FAs and cooles them from outside. Other part of the cooled sodium mixes on the level of FAs heads with flows of sodium coming from the gaps between FAs and from FAs themselves. From the volume above the core the sodium enters intermediate heat exchangers (IHX) and from there goes into the "cold" cavity of the tank and then through main circulation pumps (MCPs) to the core inlet.

In the second variant (Fig.2) the DHXs are arranged in boxes of "hot" cavity by analogy with boxes of main circulation pumps. For this arrangement of in-vessel part of the DHRS the sodium enters DHX from "cold" cavity having gone through IHXs.

For this variant the circulation of sodium in the reactor tank depends on the RP operation mode. For the most characteristic RP operation modes, namely nominal power and decay heat removal through DHRS the sodium circulation in the reactor tank proceeds as follows.

At RP nominal power operation the DHRS is in waiting mode for cooling down what is assured by natural circulation of air through sodium-air heat exchanger and of sodium in the intermediate circuit. In the primary circuit the natural circulation of sodium through DXH is also established. Sodium enters DHX from "cold" cavity and issues into the same cavity mixing with sodium from IHXs. Thereafter the coolant comes to the pumps and through pipes to core inlet.

At decay heat removal through DHRS there is no heat removal through IHXs and the primary and secondary pumps do not operate. In this mode of reactor operation the coolant leaving the core goes into the "hot" cavity and through IHXs comes to the "cold" cavity. Since there is no heat removal in IHXs the temperature of coolant entering the "cold" cavity is close to its temperature at core outlet and above the temperature of coolant which is in the "cold" cavity. As a result, the coolant coming from IHXs tends to occupy the upper part of the "cold" cavity in which there are DHX inlet holes, cools down in DHX and drops into the lower part of the "cold" cavity. From the "cold" cavity it goes to the pumps and then to the core inlet.

The feature of this DHRS variant is the dependence of the temperature of the coolant coming to the core inlet on the mode of reactor operation what results in considerable variation DHRS parameters' during transition from one mode to another. One of the consequences of the feature of this variant is the reduction of heat losses through DHRS in the mode of waiting for cooling down compared with the first variant.

2. CALCULATIONAL SUBSTANTIATION OF EMERGENCY HEAT REMOVAL SYSTEM VARIANTS

DHRS calculational substantiation is done in three stages. On the first stage the calculation of the RP static parameters was performed when using DHRSs. In these calculations the DHRS thermohydraulic parameters were determined versus intensity of decay heat which is completely removed through sodium-air heat exchangers into the environment. This allowed to choose initial parameters of equipment and DHRS layout. In addition, the data obtained were used as input conditions when performing the dynamic calculations.

On the second stage the RP dynamic calculations were performed for modes requiring DHRS actuation. For performing the calculations the program was based on one-dimensional approximation of motion and energy equations of all units included into circulation circuit. The difficulty of performing the calculations by this program consists in the modelling of units such as "hot" and "cold" reactor cavities by 1-D analogues. For the development of calculation technique the experimental data obtained in the BN-600 reactor including those for the mode of natural circulation in primary and secondary circuits were used.

The third stage is to calculate dynamic processes in the reactor primary circuit using two-dimensional program. For reducing the program volume the region under calculation is restricted by primary circuit and external systems (intermediate sodium circuit and air circuit) are set as boundary conditions. At present the calculations concerning the third stage are not yet completed.

The calculation scheme for reactor cooling down with arrangement of DHX in "hot" cavity is shown in Fig.3. For the analysis the loss of energy supply following the reactor scram is chosen. A conservative prerequisite of the absence of heat removal in IHXs after coastdown of the circulation pumps in the secondary circuit is additionally accepted. The cooling down proceeds at natural circulation in all DHRS circuits. The coastdown of primary and secondary pumps is 100 s and 300 s respectively. The results of static parameters calculations are given in Fig 4. Fig.5 and Fig.6 show the results of dynamic calculations. Sodium at core outlet and at DHX outlet is assumed for both cases to mix on the level of FAs heads.

On the basis of static parameters calculation it can be infered about the acceptable level of natural circulation in the primary circuit assuring non-exceeding temperature restrictions for the core. But the dynamic calculations showed that sodium flow through the core falls down practicully to zero and the core heat is removed mainly by the sodium flowing in gaps between the FAs. 1-D model for the estimation of FAs central fuel elements temperature does not fit, therefore, it is envisaged to carry out the calculations of temperature fields in a separate FA to 2-D and 3-D programs.

Unfavorable results of the variant of DHRS calculation with DHX arrangement in "hot" cavity obtained to 1-D dynamic program initiated the search of other engineering solutions concerning the DHX arrangement. One of them is the DHX arrangement in "cold" cavity. In this case the cold sodium coming from DHX will not flood the reactor "hot" cavity what is namely the main cause of sodium flow reduction through core FAs.

The analysis was made for same operation mode as in the previous case. The calculation scheme and calculation results are shown in Fig 7, 8, 9, 10. The results obtained demonstrate that the DHX arrangement in the "cold" cavity considerably improves the transient run and makes it possible to have successful operation of this variant of DHRS in other RP operation modes. To take final decision for the DHRS variant more detailed calculations are required.

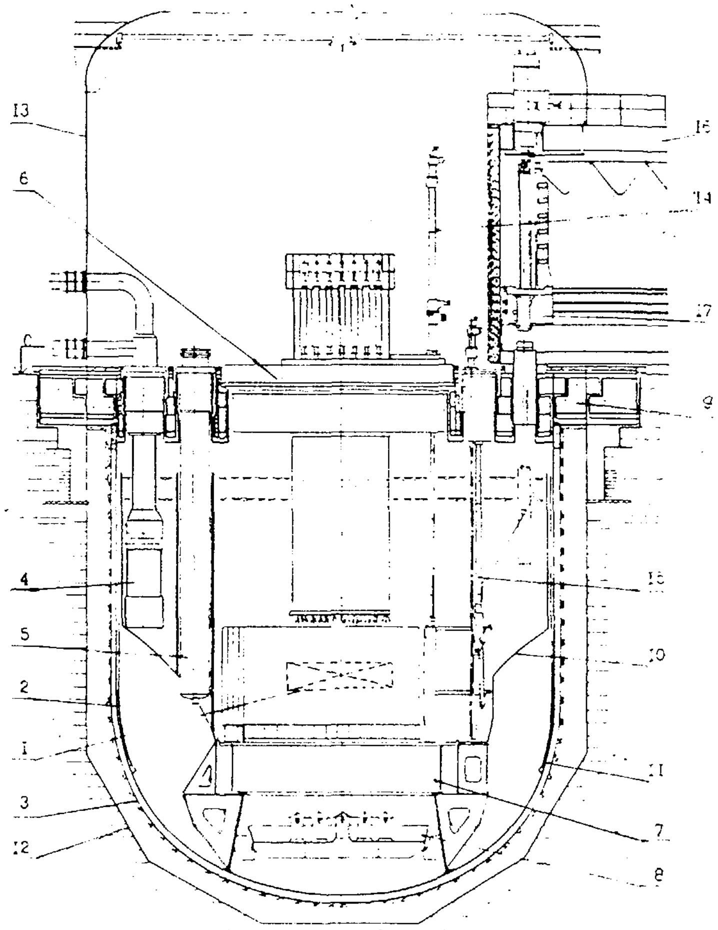

Fig 1 BN-1600 reactor with primary circuit equipment

1-core; 2-main vessel; 3-safety vessel; 4-immersed heat exchanger; 5-cold filter-trap; 6-rotating shield; 7-diagrid; 8-core catcher; 9-upper stationary shield; 10-"hot" inner tank; 11-thermal insulation baffle; 12-well liner; 13-containment; 14-refuelling machine; 15-elevator; 16-fuel transfer cell; 17-fuel transfer mechanism

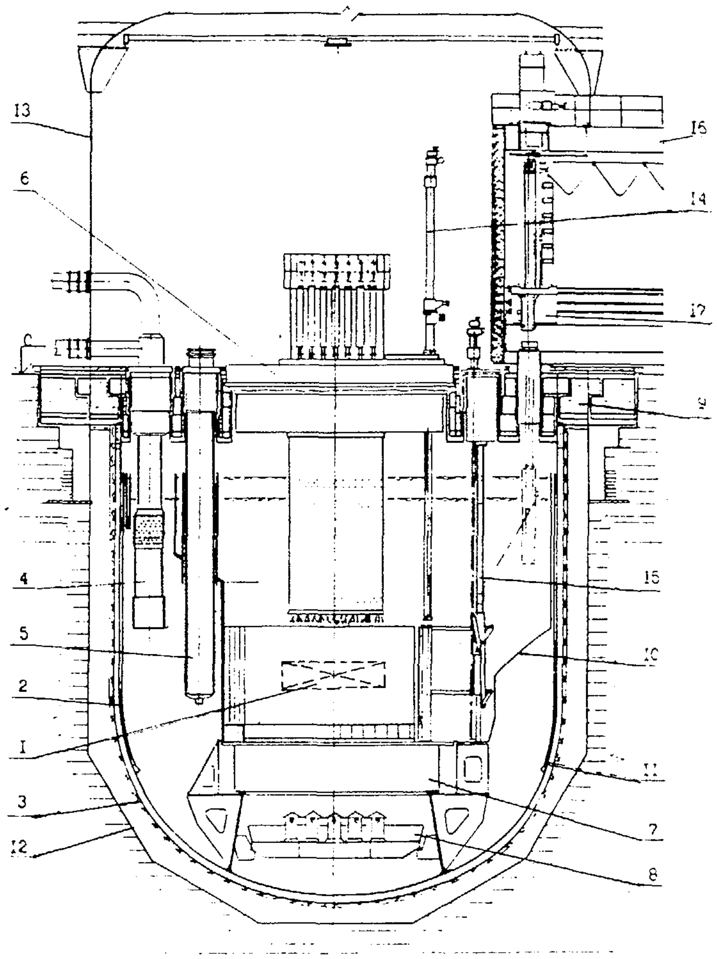

Fig. 2 BN-1600 reactor with primary circuit equipment

1-core; 2-main vessel; 3-safety vessel; 4-immersed heat exchanger; 5-cold filter-trap; 6-rotating shield; 7-diagrid; 8-core catcher; 9-upper stationary shield; 10-"hot" inner tank; 11-thermal insulation baffle; 12-well liner; 13-containment; 14-refuelling machine; 15-elevator; 16-fuel transfer cell; 17-fuel transfer mechanism

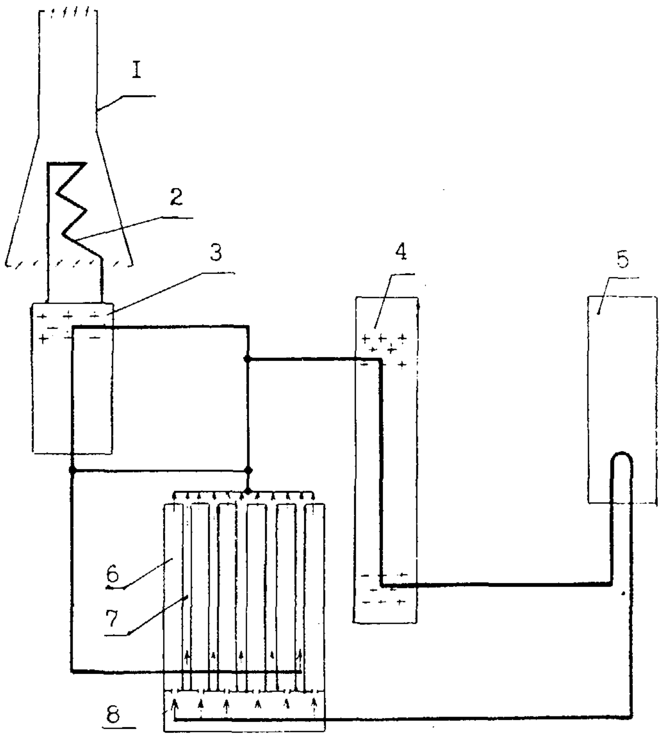

Fig.3. Scheme for parameters calculation of DHX arrangement in "hot" cavity
1-stack, 2-sodium-air exchanger, 3-DHX, 4-IHX, 5-primary pump, 6-FA, 7-space between FAs, 8-core inlet plenum

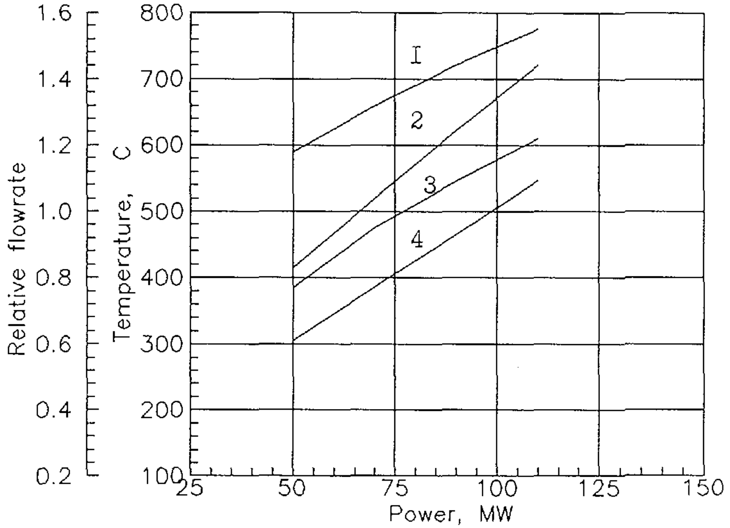

Fig. 4. Primary Circuit Temperatures and
Flowrates versus reactor power with
account of flowrates through gas between FAs
(DHX in hot cavity)

1– flowrate in gaps between FAs
2– sodium temperature at the core outlet
3– flowrate through the core
4– temperature of sodium in the reactor tank

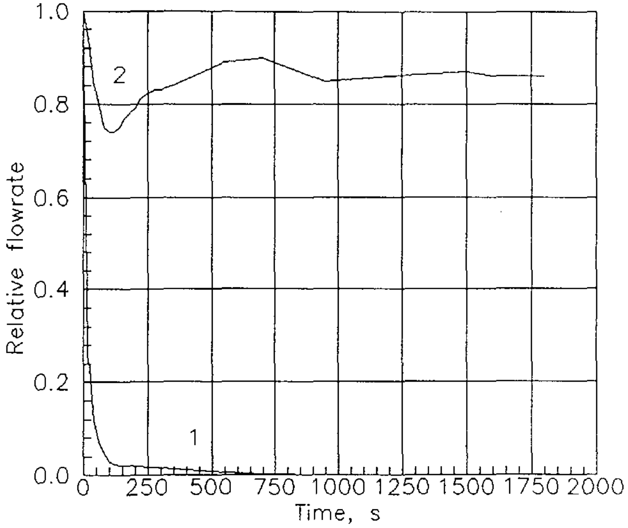

Fig.5. Coolant Flowrate in the Primary Circuit
(DHX in hot cavity)

1– flowrate through the core
2– flowrate through the DHX

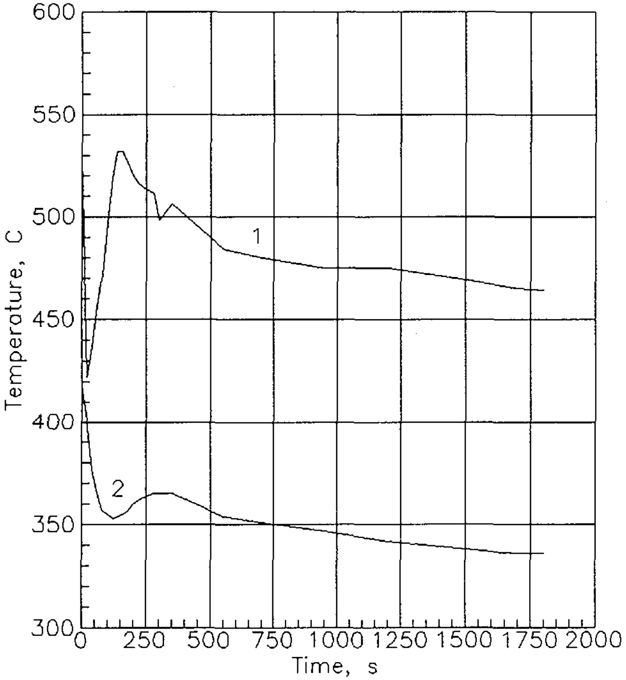

Fig.6. Coolant Temperatures in the Primary Circuit (DHX in hot cavity)

1– coolant temperature at the core outlet
2– coolant temperature at the DHX outlet

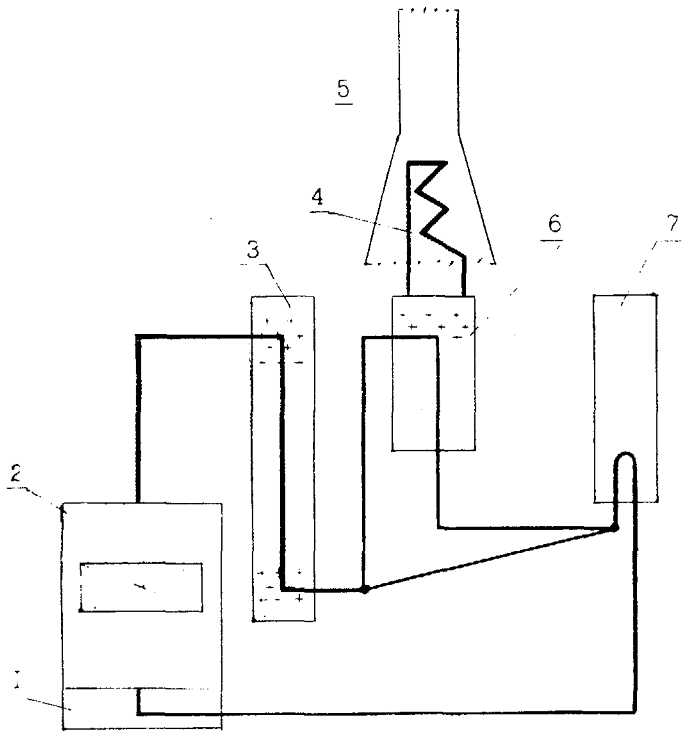

Fig.7. Scheme for parameters calculation of DHX arrangement in "cold" cavity
1-core inlet plenum, 2-core, 3-IHX, 4-sodium-air exchanger, 5-stack, 6-DHX, 7-primary pump

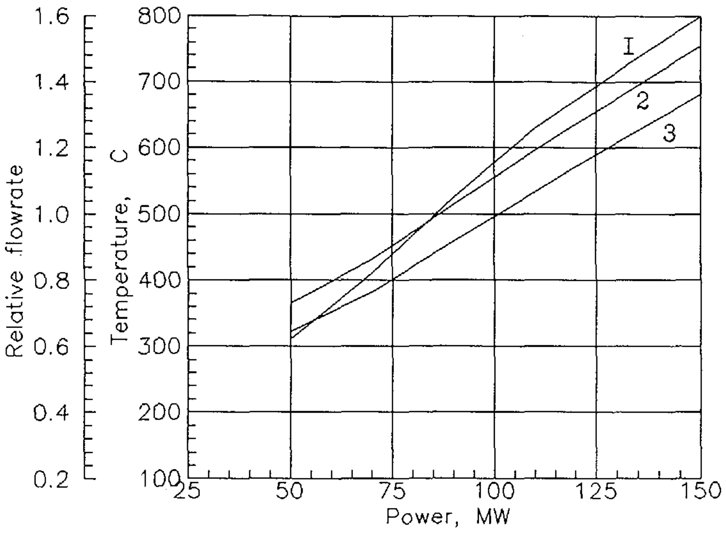

Fig. 8. Primary Circuit Temperatures and Flowrates versus reactor power (DHX in cold cavity)

1– flowrate through the core
2– sodium temperature at the core outlet
3– temperature of sodium in the reactor tank

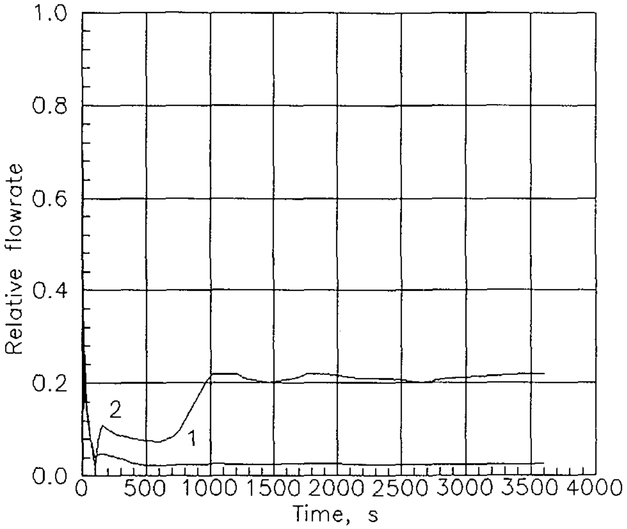

Fig.9. Coolant Flowrate in the Primary Circuit (DHX in cold cavity)

1– flowrate through the core
2– flowrate through the DHX

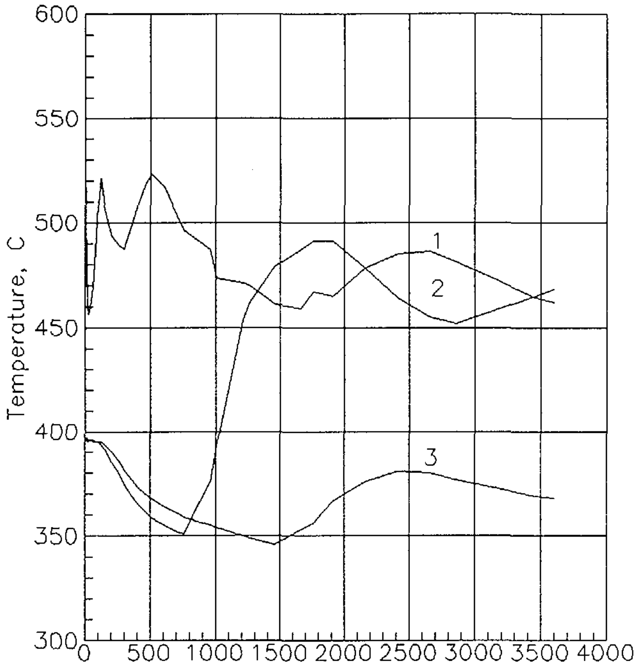

Fig.10. Coolant Temperatures in the Primary Circuit
(DHX in cold cavity)

1– coolant temperature at the core outlet
2– coolant temperature in the mixing chamber
at the DHX inlet
3– coolant temperature at the core inlet