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Preliminary Design of the Active Residual Heat Removal System and a Circulation Pump in the Research Reactor

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1. Introduction

The main purpose of a research reactor is to use a neutron flux in a reactor core. Open pool type research reactor is widely designed in consideration of the heat removal of the core, reactor operation and accessibility. Reactor structure assembly is generally placed at the pool bottom as shown in Fig. 1. Primary cooling system (PCS) circulates the coolant from the reactor core to the heat exchanger. Therefore the heat generated from the reactor core is removed continuously. PCS is designed based on the required thermal design flow rate of the reactor core assembly and the operation characteristics of equipment and measuring instruments.

Primary coolant is dumped into the pool and goes to the reactor core through the flow guide structure. The fission heat generated from the fuel assembly is transferred to the primary coolant, and then heated primary coolant goes to the PCS equipment room in order to remove the heat by the heat exchanger. The PCS inlet pipe is connected to the outlet nozzle of the reactor structure assembly as shown in Fig. 1.

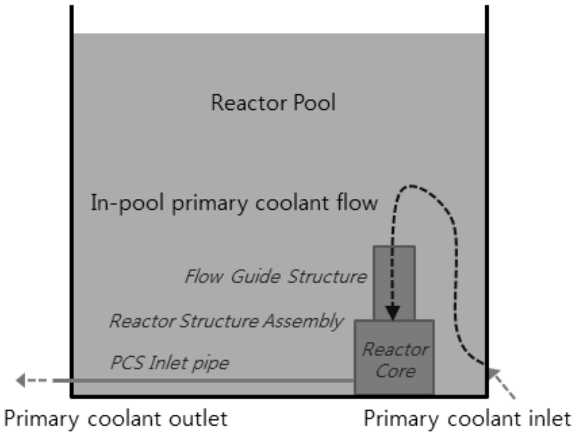

Fig. 1. Schematic diagram of the open-pool type research reactor and the flow path of the coolant.

There is also an active residual heat removal system (ARHRS) designed to provide the core downward flow to remove the residual heat. The ARHRS boundary is depicted as shown in Fig. 2. Main inlet pipe line is connected to the PCS pipe and by-pass pipe line comes from the reactor pool directly. By-pass line is connected to the main inlet pipe line at upstream pump. Outlet pipe line goes back to the reactor pool.

In the reactor operation, the decay heat is removed by the coastdown flow of the PCS pump just after the PCS pump stop. As the pump coastdown flow decreases slowly, ARHRS pump start to operate and maintain the core downward flow and remove the residual heat in sufficient time. The core residual heat is transferred to the reactor pool water considered the ultimate heat sink by the ARHRS circulation pump.

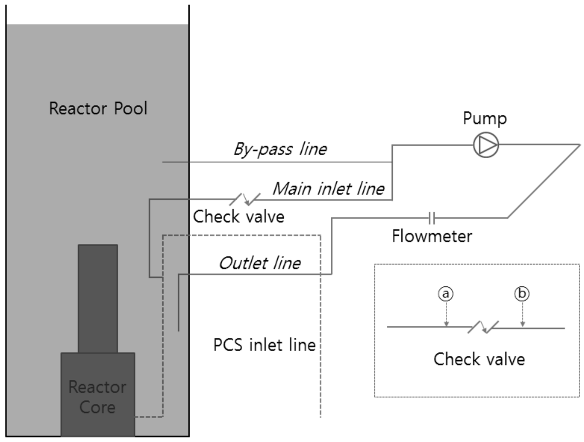

Fig. 2. Schematic diagram of the ARHRS.

2. ARHRS Design

The ARHRS is required and designed to fulfill the following functions.

(a) Provide an adequate downward flow through the reactor core to remove the residual heat.
(b) Abnormal operation of the ARHRS pump shall not affect the normal operation of the PCS and integrity of the ARHRS pump assembly shall be maintained.

The required flow rate is determined based on the reactor core and safety analysis. An ARHRS pump capacity is calculated from this flow rate and system requirements.

The check valve is installed on main inlet pipe as shown in Fig. 2 and closed by gravity when PCS and ARHRS pumps stop because hydrostatic pressure of the point ‘a’ and ‘b’ are the same. It also keeps the closed status while the PCS pump is in normal operation and whether or not the ARHRS pump is in operation because of the differential pressure across the check valve and the performance characteristic of the ARHRS pump. Static pressure of point 'a' is decreased due to the pressure drop while the PCS pump is in operation. And the shut-off pressure of the ARHRS pump is lower than the differential pressure across the check valve. This operation constraint shall be applied to the pump design.

3. Pump Design

In the preliminary design stage of the pump, rated head, flow rate and $NPSH_A$ are already calculated as initial design values in the system design stage. Then, pump is conceptually designed by using these design variables. Generally, $NPSH_R$, type, size and rpm are evaluated in this design stage. Conceptual design results of the pump are given in Table 1.

Table 1. Preliminary design of the ARHRS Pump

Case	n_s	d_s	N_{margin}	H_{ratio}	Type
Case 1	1.45	2.55	5	1.4	Radial
Case 2	1.94	2.15	4	1.7	Radial
Case 3	2.91	1.74	3	2.2	Mixed

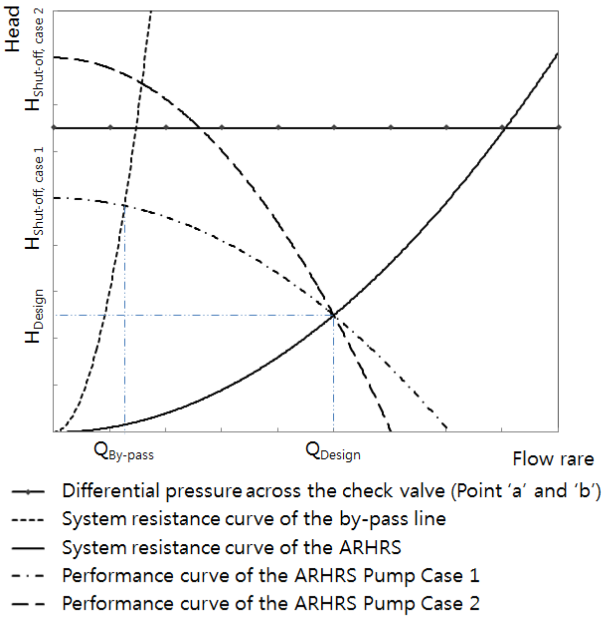

Fig. 3. Relationship between the system resistance curve and the pump performance curve.

3.1 Cavitation

Cavitation of the pump makes the mechanical damage of the impeller, strong vibration and loud noise. In order to maintain the normal operation of the pump without cavitation, the $NPSH_A$ shall be larger than the $NPSH_R$. Operation margin related to cavitation is generally expressed as a ratio of the $NPSH_A$ and $NPSH_R$. Pump used in the nuclear plant requires a NPSH margin of 2. All pump design cases satisfy this design constraint as described in Table 1.

3.2 Pump operation

In ARHRS pump of Case 1, Flow path through the main inlet pipe line shall not be established while the PCS pump is in normal operation because the differential pressure across the check valve is larger than the ARHRS pump shut-off head as shown in Fig. 3. Therefor ARHRS pump operation does not disturb the PCS operation.
ARHRS pump will runs with the by-pass flow rate through the by-pass pipe line in order to protect pump, equipment and piping of the ARHRS.
But, it's impossible to accept the pump design of Case 2 and 3 because pump shut-off head is larger than the differential pressure across the check valve. In this case, PCS flow rate will be changed and Reactor will be in abnormal operation.

4. Conclusions

ARHSR is designed based on the required flow rate and system constraints. And, centrifugal pump of Case 1 with a non-dimensional specific speed of 1.45 [-] and specific diameter of 2.55 [-] is chosen as the preliminary design of the ARHRS pump based on the system operation.

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Nomenclature

d_s	Specific diameter, $D\cdot(g\cdot H_d)^{0.25}/Q_d^{0.5}$, [-]
g	Acceleration of gravity, 9.81[m/s^2]
n_s	Specific speed, $\omega\cdot Q_d^{0.5}/(g\cdot H_d)^{0.75}$, [-]
D	Diameter of the impeller outlet, [m]
H_d	Pump head at the design point, [m]
H_{ratio}	$H_{shut-off}$ / H_d, [-]
$H_{shut-off}$	Pump head at the zero flow rate(shut-off head), [m]
N_{margin}	$NPSH_A$ / $NPSH_R$, [-]
NPSH	Net Positive Suction Head, [m]
$NPSH_A$	Available NPSH, [m]
$NPSH_R$	Required NPSH, [m]
Q_d	Flow rate at the design point, [m^3/s]
ω	angular velocity of the impeller, [rad/s]