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Uncertainty Evaluation for Core Thermal Power in a Research Reactor

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1. Introduction

Research reactors should incorporate the measurement system for the core power to control and regulate the reactor power. The Jordan Research and Training Reactor (JRTR) also has three separated and independent channels of the neutron detectors to measure the core power. To calibrate these detectors, the thermal power of Primary Cooling System (PCS) which cools down the heat generated in reactor core is used as calibration reference. The core thermal power can be estimated by the measured values of the mass flow rate, core inlet temperature, and core outlet temperature of coolant in the PCS. In general, the uncertainty of the core thermal power is required to be controlled below a certain value. To meet this requirement, the uncertainty of core thermal power should be evaluated based on the uncertainty of the measured parameters.

In this paper, the uncertain evaluation is conducted with variation of the uncertainty of the measured parameters such as mass flow rate, core inlet temperature, core outlet temperature. In addition, the numbers of inlet and outlet temperature are considered to get a higher allowable uncertainty of temperature sensors.

2. Method and Results

2.1 System Description

Fig. 1 shows the schematic diagram of the system discussed in this paper. The PCS pump circulates water to remove the heat produced in the reactor core. The heat is transferred to the cold water of Secondary Cooling System (SCS) through the PCS heat exchanger. The inlet and outlet temperatures were measured with resistance temperature detectors (RTDs) located in the inlet and outlet pipes of the PCS. The water mass flow rate was measured using venture-type mass flow meter. With these instruments, the core thermal power can be readily calculated by using the difference between the water inlet and outlet temperature and the flow rate.

2.2 Method of Uncertainty Evaluation

The core thermal power is a function of core inlet temperature ($T_{in.w}$), core outlet temperature ($T_{out.w}$), and mass flow rate ($\dot{m}_w$) as shown in equation (1).

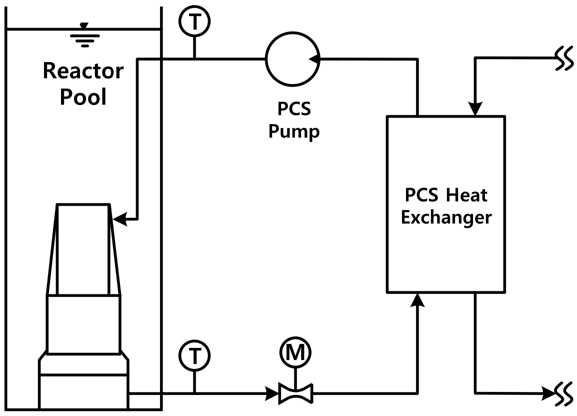

Fig. 1. Schematic diagram of system.

$$Q = \dot{m}_w C_{p.w}(T_{out.w} - T_{in.w})$$

$$= f_n\ (\dot{m}_w, T_{in.w}, T_{out.w}) \quad (1)$$

The calculated uncertainty is obtained from the uncertainties of the measured parameters according to the law of propagation of uncertainty [1]. Eq. (2) presents the calculated uncertainty of the core thermal power.

$$U_Q = \sqrt{\left(\frac{\partial f_n}{\partial \dot{m}_w} U_{\dot{m}_w}\right)^2 + \left(\frac{\partial f_n}{\partial T_{in.w}} U_{T_{in.w}}\right)^2 + \left(\frac{\partial f_n}{\partial T_{out.w}} U_{T_{out.w}}\right)^2} \quad (2)$$

$$where, U_x = uncertanty\ of\ x, has\ the\ same\ unit\ as\ x$$

2.3 Input Data

Table 1 shows the parameter ranges used as input data in Eq. (2). Various values and uncertainties were assumed for design purpose. However, in this paper, one set of value and several uncertainties for each parameter were described to obtain approximately 5% of uncertainty for core thermal power.

Table 1: Assumed parameter ranges

	Value	±Uncertainty
Core inlet temperature, $T_{in.w}$(℃)	34	0.22, 0.23, 0.24, 0.25, 0.26
Core outlet temperature, $T_{out.w}$(℃)	40	0.22, 0.23, 0.24, 0.25, 0.26
Mass flow rate, kg/s	615	13.6, 16.0, 18.4

Table 2: Results

Uncertainty of mass flow rate, kg/s	Uncertainty of core inlet/outlet temperature, ℃	Uncertainty of core thermal power, %
16	0.22	4.60
	0.23	4.74
	0.24	4.89
	0.25	5.03
	0.26	5.18
13.6	0.22	4.39
	0.23	4.53
	0.24	4.68
	0.25	4.84
	0.26	4.99
18.4	0.22	4.84
	0.23	4.97
	0.24	5.11
	0.25	5.25
	0.26	5.39

2.4 Results

The parametric uncertain evaluation was conducted for various input of the measured parameters and the results are shown in Table 2. In general, the uncertainty of core thermal power is required to be controlled below a certain value. For example, to meet 5% of core thermal power uncertainty requirement, 0.24℃ of RTD uncertainty is required with 16 kg/s of mass flow meter uncertainty in Table 2. In the same manner, for 13.6 kg/s and 18.4 kg/s of the mass flow meter uncertainty, the allowable RTD uncertainty should be 0.26℃ and 0.23℃, respectively.

But the problem is that it is not easy to find the RTD sensor with reasonable price which guarantees 0.23, 0.24, or 0.26℃ in nuclear field considering all the parameters like radiation effect, drift effect, etc. To get higher accuracy, more RTDs should be added at each inlet and outlet pipe. Eq. (3) and (4) show how to calculate the uncertainty for core thermal power with (n) number of RTDs

$$Q = \dot{m}_w C_{p.w}\left(\sum_{1}^{n}\frac{T_{out.w.n}}{n} - \sum_{1}^{n}\frac{T_{in.w.n}}{n}\right)$$

$$= f_n\ (\dot{m}_w, T_{in.w,1}, \dots, T_{in.w.n}, T_{out.w,1}, \dots, T_{out.w,n}) \quad (3)$$

$$U_Q = \sqrt{\begin{gathered}\left(\frac{\partial f_n}{\partial \dot{m}_w} U_{\dot{m}_w}\right)^2 + \left(\frac{\partial f_n}{\partial T_{in.w.1}} U_{T_{in.w.1}}\right)^2 + \cdots \\ + \left(\frac{\partial f_n}{\partial T_{in.w.n}} U_{T_{in.w.n}}\right)^2 + \left(\frac{\partial f_n}{\partial T_{out.w.1}} U_{T_{out.w.1}}\right)^2 \\ + \cdots + \left(\frac{\partial f_n}{\partial T_{out.w.n}} U_{T_{out.w.n}}\right)^2\end{gathered}} \quad (4)$$

Table 3: Results with 5 sets of RTDs

Uncertainty of mass flow rate, kg/s	Uncertainty of core inlet/outlet temperature, ℃	Uncertainty of core thermal power, %
13.6	0.39	4.92
16.0	0.37	4.91
18.4	0.35	4.95

With 5 sets of RTDs, the allowable RTD uncertainty are 0.39, 0.37, and 0.35℃, respectively, for 3 different flow rate uncertainties as shown in Table 3.

3. Conclusions

The core thermal power uncertainty has been valuated according to measuring parameters such as mass flow rate, temperatures, and number of RTDs. In this parametric study, allowable uncertainties for measuring devices have been obtained to guarantee 5% of the core thermal power uncertainty. In addition, to obtain more accurate thermal power, the effect of the number of RTDs has been discussed as well.

REFERENCE

[1] Taylor, B.N., and Kuyatt, C.E., Guidelines for evaluating and expressing the uncertainty of NIST measurement results, NIST Technical Note 1297, 1994 edition, U.S. Department of commerce, 1994.