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# Advanced On-Line Isothermal Temperature Coefficient Measurement for A Physics Test

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## 1. Introduction

The Isothermal Temperature Coefficient (ITC) is the change in the reactivity per unit change in the fuel and moderator temperature (ANSI/ANS-19.6.1-2005)[1]. ITC measurements are performed during HZP (Hot Zero Power) reactor physics tests to determine if the measured ITC is consistent with the calculated value. The slope method or the endpoint method can be used to measure ITC. These methods require the tester to increase or decrease the RCS temperature by 3 to 10°F at 10 to 20°F/h, then stabilize it to within 0.3°F for at least 5 min. Particularly, the slope method requires a continuous linear change of the RCS temperature to ensure accuracy and reliability of the measurement. These requirements can delay the test time, which is burdensome for operators. In this paper, an on-line ITC measurement system is developed to reduce the test time for ITC measurements. In addition, ITC measurement uncertainty is evaluated and the range for a 95% level of confidence is calculated in a continuous manner.

## 2. Methods

The analog signals of the RCS temperature and ex-core detector flux are measured and converted into digitalized data automatically during ITC measurements. The reactivity is calculated from the measured ex-core detector flux signal via the following in-hour equation.

$$\rho = \frac{\ell^*}{T} + \bar{I}\sum_{i=1}^{6}\frac{\bar{\beta}_i}{1+\lambda_i T}$$

$\rho$ : reactivity, $\ell^*$: prompt neutron lifetime,

$T$: reactor period, $I$: delayed neutron importance factor

$\bar{\beta}_i$: delayed neutron fraction , $\lambda_i$: decay constant

The on-line ITC measurement system calculates the reactivity change as a function of the temperature change and plots a reactivity-versus-temperature curve. The slope of the curve is equal to the ITC.

$$\mathrm{ITC} = \Delta\rho/\Delta\mathrm{T}$$

$\Delta\rho$ : reactivity change, $\Delta$T : temperature change

The on-line ITC measurement system calculates the slope (ITC) using the least square linear regression method and monitors its variation every one second.

$$\begin{bmatrix} b_0 \\ b_1 \end{bmatrix} = \begin{bmatrix} m & \sum x_i \\ \sum x_i & \sum x_i^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum y_i \\ \sum x_i y_i \end{bmatrix}$$

$$b_1 = \frac{m\sum y_i x_i - \sum x_i \sum y_i}{m\sum x_i^2 - \left(\sum x_i\right)^2}, \quad b_0 = \frac{\sum y_i - b_1 \sum y_i}{m}$$

$$y = b_0 + b_1 x$$

The standard deviation and standard uncertainty of the calculated ITC are evaluated and the range of the given confidence level (95%) is determined from a t-table and from the standard deviation of the mean.

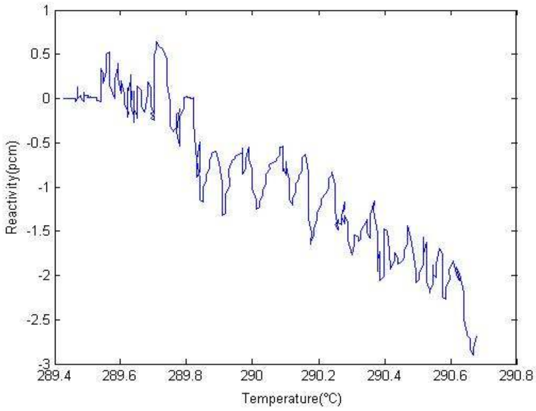
$$\bar{x} - t\cdot s_{\bar{x}} \le \mu \le \bar{x} + t\cdot s_{\bar{x}} \ (\mathrm{CL})$$

$\bar{x}$ : average, $t$ : t − table value,
$S_{\bar{x}}$ : standard deviation of the mean

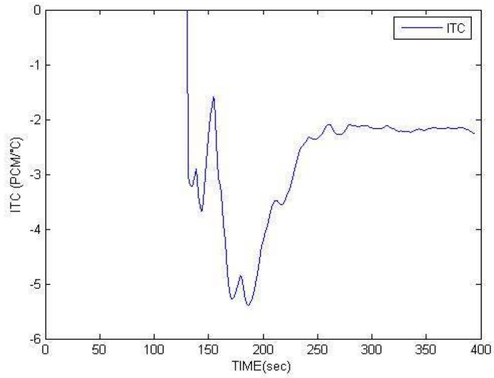
In the first measurement stage, the dispersion of the measurement is large due to statistical perturbations and on account of the rare sample population for the measurement. As the number of samples increases, the ITC value converges to an ideal value. The on-line ITC measurement system calculates the ITC every one second and evaluates the uncertainty in the ITC value continuously. The ITC measurement is terminated if the calculated ITC is within the acceptance criteria with a preset confidence level [2].

## 3. Results

ITC measurement data from physics test of KHNP plants were used to verify advanced ITC method. The measured temperature and calculated reactivity are shown in Fig. 1. Hunting of the reactivity is severe as shown in Fig 1. This creates difficulty in finding the slope. The measured ITC value vs. the time is shown in Fig.1 (b). This figure shows that the ITC can be obtained in approximately 10 minutes.




(a) reactivity-versus-temperature curve




(b) ITC-versus-time curve

Fig.1. Reactivity vs. Temperature (a) and On-line ITC vs. Time (b)

To demonstrate the validity and accuracy of the developed system, several cases of ITC measurement were compared with the results of the conventional method being used in PWRs. Table 1 shows that the developed system can determine the ITC with a high level of accuracy and a shorter time compared to the conventional method. The calculation typically required approximately 30 minutes with the conventional endpoint method and more than 1 hour when using the slope method. The use of the conventional endpoint method contains the risk of unknown reactivity source perturbation while the slope method requires time for the adequate gradual change of the temperature to calculate the slope of the temperature change more accurately. The improved ITC measurement method calculated the slope with least square method; any undesired reactivity perturbations will increase the uncertainty of the measurement, preventing the ITC from converging (Fig. 2).

Table 1. Comparison of the On-line ITC Measurement Results with the Predicted Value and Endpoint Method Result from the Physics test

| | Endpoint Method | | Adv. ITC Method | | Predicted ITC |
|---|---|---|---|---|---|
| | **ITC** | **Time(s)** | **ITC** | **Time(s)** | |
| Case 1 | -2.23 | 2422 | -2.54 | 480 | -3.43 |
| Case 2 | -1.99 | 1014 | -2.32 | 435 | -2.6 |
| Case 3 | -1.10 | 2207 | -1.03 | 746 | -1.59 |
| Case 4 | -1.5 | 2506 | -1.3 | 418 | -2.03 |
| Case 5 | -2.11 | 1414 | -2.26 | 393 | -1.18 |

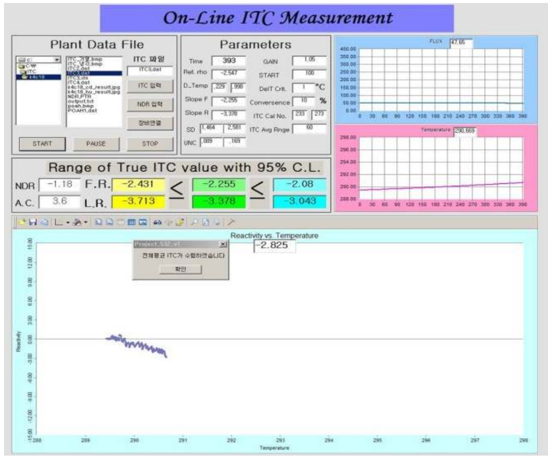



Fig.2. System View

## 4. Conclusions

Advanced on-line ITC measurement system is developed for an accurate ITC measurement and statistical treatment of measured data to evaluate uncertainty and confidence level of ITC. The benefits of using the on-line ITC measurement system are the faster ITC measurement process and an accurate ITC result with a high confidence level. Those benefits are directly related with the safety and economy of Nuclear Power Plant operation. In addition, the advanced ITC measurement method can be applied to the continuous reactivity monitoring of an operating reactor, and for EOL MTC measurements, BOL from a zero power to a full power reactivity change measurement procedure.

## REFERENCES

[1]ANSI/ANS-19.6.1-2005,"Reload Startup Physics Tests for **Pressurized Water Reactors**", American Nuclear Society,(2005).

[2]ANSI/NCSL Z540-2-1997,"U.S. Guide to the Expression of Uncertainty in Measurement", American Nuclear Society,(1997).