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Point-In-Time Measurement Uncertainty Recapture for RCS Flow

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1. Introduction

In nuclear power plants, RCS flow measurement uncertainty plays an important role in the establishment of flow acceptance criteria [1, 2]. The narrow band of acceptance criteria based on the design limiting uncertainty of the measured RCS flow may lead to a point-in-time violation of acceptance criteria in a situation where the measured flow is too close to the upper limit of allowable RCS flow operating band [2]. Also the measured RCS flow may approach the lower limit of the acceptance criteria as operating cycle proceeds. Several measurement uncertainty recapturing methods for RCS flow are attempted to be applied in a point-in-time situation failed to meet the acceptance criteria. Also a combination of these recapturing methods can be utilized to establish a design limiting measurement uncertainty.

2. Uncertainty Recapture Method for RCS Flow Measurement

In this section some of the possible methods are described to recapture the RCS flow measurement uncertainty. The methods include use of all available redundant channels (temperature measurements), reduced instrumentation drift, reduced thermal stratification correction uncertainty and uncertainty calculation based on measured operating data.

2.1 Uncertainty Variable Sensitivity

The RCS flow is measured indirectly using the following measurement equation.

$$W = \frac{Q}{h_H - h_C} \tag{1}$$

Where Q is reactor thermal power, h_H, hot leg fluid enthalpy and h_C, cold leg fluid enthalpy. The RCS flow measurement equation has four independent uncertainty variables: RCS pressure, hot leg fluid temperature, cold leg temperature and reactor thermal power.

The main idea for the measurement uncertainty recapture for the RCS flow is gained by noting that the temperature variables show higher sensitivity and are dominant contributors to the flow measurement uncertainty as shown in Table I.

It is noted that hot leg temperature has 17% larger sensitivity to the unit uncertainty of temperature than cold leg temperature because of its larger temperature derivative of enthalpy.

Table I: Sensitivity and contribution to RCS flow measurement uncertainty

Uncertainty Variable	Sensitivity	Standard Uncertainty
RCS pressure	0.011 Mlbm/hr/psi	0.031%
Cold temperature	3.39 Mlbm/hr/Δ°F	0.670%
Hot temperature	3.97 Mlbm/hr/Δ°F	1.427%
Reactor thermal power	0.048 Mlbm/hr/MW	0.747%

* Based on the calculation condition of the design measurement uncertainty.

2.2 Use of All Available Redundant Temperature Measurement Channels Groups

The groups of available redundant measurement channels are used straight forward to recapture the RCS flow uncertainty. The standard uncertainty of averaged value of the redundant measured values can be obtained using the following equation as described in the guideline [3, 4]:

$$u^2(x) = \frac{\sum_i N_i \, u^2(x_i)}{\left(\sum_i N_i\right)^2} \tag{2}$$

N_i is the number of redundant channels and $u(x_i)$, standard uncertainty of measured value, x_i of redundant group, *i*.

Other groups of redundant temperature measurement channels can be utilized in addition to the groups used in the design uncertainty calculation.

2.3 Reduced Instrumentation Drift Based on Calibration Interval

Instrumentation drift depends on the data provided by the instrument vendors. Generally used drifts are maximum values accumulated for up to 5 years for resistance temperature detectors (RTDs) and 22.5 months for transmitters (designated durations in the instrument manual). However, instrument calibrations are periodically performed at a specified interval and the accumulated instrument drifts are supposed to be cleared. A measurement uncertainty recapture is possible when based on 2.5 year calibration interval instead of 5 year according to the calibration schedule for hot and cold leg temperature instruments.

2.4 Reduced Thermal Stratification Correction Uncertainty

The hot leg temperatures measured with the installed RTDs show a shift from the real temperature due to the thermal stratification phenomena in the hot leg pipe [1]. The degree of shift is reported to range from 0 to 0.5 Δ˚F [1] and the measured temperatures need to be corrected as much. The associated uncertainty of the correction was conventionally taken to be as much as 0.3 ~ 0.5 Δ˚F which is same as the shift and considered to be too conservative [1, 2].

The ISO and KRISS Guides [3, 4] present a methodology for evaluating a standard uncertainty for an estimate of a quantity that has not been obtained from repeated observations (Type B Evaluation). The thermal stratification correction uncertainty belongs to this category. Fig. 1. shows three distributions which can be considered to determine a standard uncertainty.

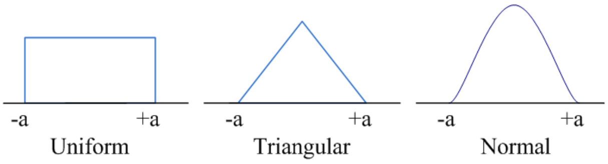

Fig. 1. Distribution for Type B evaluation of standard uncertainty.

Table II shows a standard uncertainty determined using the methodology described in the references [3, 4]. It is noted that a triangular or normal distributions is more reasonable than uniform rectangular distribution.

Table II: Standard uncertainty for Type B (a = 0.5 Δ˚F)

Assumed Distribution	Standard Uncertainty (Δ˚F)
Reference	0.5
Uniform	0.289
Triangular	0.204
Normal	0.167

2.5 Uncertainty Based on Measured Condition

A design measurement uncertainty of RCS flow is determined based on the postulated temperature derived from the design maximum RCS flow (e.g., 115 %W_D). In this process the determined design uncertainty becomes greater due to the reduced hot leg temperature derived from the design maximum flow. In reality, the RCS flow measured is well below the limiting flow and the measured temperature is different from that derived from design maximum flow. The increased hot leg temperature gives an uncertainty reduction because of the reduced sensitivity coefficient of the hot leg temperature.

2.6 Sample Results

RCS flow measurement uncertainties were calculated in the 4 ways for recapturing the RCS flow uncertainty as follows:

Table III: RCS Flow Uncertainty Recaptures

Recapture Method	Standard Uncertainty (%)	Recapture (Δ %)
Reference	1.745	-
Redundant Channels	1.649	0.096
Drift Reduction	1.679	0.066
Thermal Stratification*	1.335	0.410
Measured Condition**	1.624	0.121
Total Combined	1.060	0.685

* Thermal stratification band is a = 0.5 Δ˚F with normal distribution.

** When the measured flow is 110 %W_D.

The maximum recapture is shown to be exploited from the thermal stratification correction uncertainty. The next probable recaptures are from measured condition and redundant channels. The total uncertainty recapture is shown to be 0.685 % with all 4 methods combined in this sample calculation.

3. Conclusions

To recapture the RCS flow measurement uncertainty, possible and practical methods are proposed to be utilized in a point-in-time situation failed to meet the acceptance criteria. These methods can be used as a design basis methodology to establish the design limiting uncertainty.

It is worthy to note that the hot and cold leg temperatures have an additional redundancy such as wide range instrument channel. The measured operating condition for RCS flow has potential for more recapture. With those recapturing ways more applied, the uncertainty recapture can be improved.

REFERENCES

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