Comparative Studies on Uncertainty of the RCS Leak Rate

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1. Introduction

Reactor coolant system (RCS) leak rate calculations are routinely conduced at nuclear power plants to measure the amount of coolant that is leaking from RCS. And RCS leak rate must be monitored via a leak rate calculation. The calculation results are compared to the plant specific technical specification (TS) limits to ensure that the leak rate does not exceed the plant's design specification.

The new plant monitoring system including RCS leak rate calculation program was installed for Kori 4 August 2004. The RCS leak rate program using a snapshot approach [1] is capable of calculating the RCS leak rate only at the very stable condition, and the fluctuating calculation results could not be relied on sometimes. Recently, at Virginia Power's Surry Power Station, the RCS leak rate program using a linear regression approach was developed [3]. And, it was reported that the method enhanced the leak rate accuracy in comparison with snapshot calculation [2, 3]. However, the quantitative analysis of an uncertainty was not carried out.

The study accomplishes the quantitative analysis of an uncertainty for both approaches, snapshot approach and linear regression approach. This uncertainty analysis is expected to provide one of the backgrounds for the decision making in selecting the calculation method.

2. Methods and Results

2.1 Snapshot Approach

Snapshot approach is based on a sliding time average for raw data points. Time interval for average is 60 seconds.

The fundamental sliding time average used is:

$$AvgL_{VCT}(\%) = \frac{\sum_{i}^{N} L_{VCT}^{i}}{N} \qquad (1)$$

Where, L^i_{VCT} is a raw data of VCT level for any time, i. N are a number of data points for fixed time interval (60seconds).

Figure 1 shows the volume control tank (VCT) level variations over about 1.5 hours period. Sliding time average has reduced the fluctuation of the VCT level in comparison with raw data points.

2.2 Linear Regression Approach

Linear regression approach is widely accepted statistical method of developing a straight-line equation for correlated data points.

This equation more stably describes the change of the variables over the leak rate measurement period. The start and stop points in this equation can be used for in the leak rate calculation, while in snapshot approach actual data at start and stop points were used.

2.3 Unidentified leak rate

Unidentified leak rate used is as follows

$$UNIDLR = \Delta VCT - \Delta PRT - \Delta RCDT \qquad (2)$$

Where, ∆ VCT, ∆ PRT, ∆ RCDT are volume control tank, pressurizer relief tank, and reactor coolant drain tank level variation respectively.

Figure 2 typically shows the calculated unidentified leak rate with snapshot and linear regression approaches during normal power operation. It shows that linear regression approach does not fluctuate the leak rate, whereas much fluctuation in snapshot approach.

Figure 3 shows the calculated unidentified leak rate with snapshot and linear regression approaches during normal power operation, however, including data points characterized by measurement system trouble. In this case, the unidentified leak rate of linear regression approach was lower than that of snapshot approach due to erroneous data.

2.4 Uncertainty Analysis

The fundamental uncertainty used is:

$$U^2 = \left(\frac{\delta U}{\delta L_{VCT}}\right)^2 (tS_{VCT})^2 + \left(\frac{\delta U}{\delta L_{PRT}}\right)^2 (tS_{PRT})^2 + \left(\frac{\delta U}{\delta L_{RCDT}}\right)^2 (tS_{RCDT})^2 \qquad (3)$$

Where, t is Student parameter determined by confidence level, and S_{VCT}, S_{PRT}, and S_{RCDT} are standard deviation for VCT, PRT, and RCDT water level.

Using this equation, uncertainties with 95% confidence level can be calculated based on t-distribution.

Standard deviations, S, are as follows for snapshot approach and linear regression approach, respectively.

Snapshot: $$\sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{N-1}} \quad (4)$$

Linear regression: $$\sqrt{\frac{\sum_{i=1}^{n}\left(Y_i - (mX_i + b)\right)^2}{N-2}} \quad (5)$$

Where, the numerator in equation (5) is related with linear regression equation $Y = mX + b$, and subscript i means individual data point.

Figure 4 shows the calculated uncertainty with snapshot and linear regression approaches. It shows that the linear regression approach do not always follow that improved in comparison with snapshot approach.

For case of figure 3, the uncertainty of linear regression approach must be lager than that of snapshot approach because of erroneous data. Thus, in the viewpoint of on-line monitoring, linear regression approach is not always appropriate.

3. Conclusion

This study shows that linear regression approach does not enhance the uncertainty in comparison with snapshot approach, even though the linear regression approach provides more stable results. And, in the viewpoint of on-line monitoring, linear regression approach cannot be appropriate, especially for the case that the data domain contains fatal erroneous data. Thus, linear regression approach may need some additional complements.

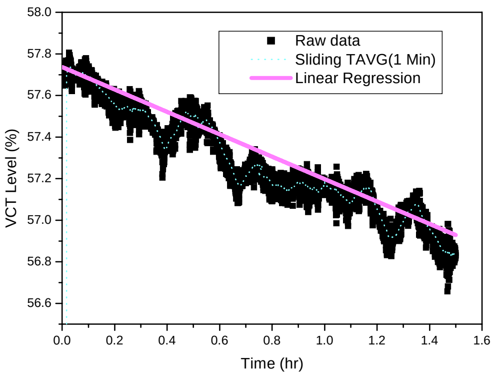

Figure 1. VCT Level

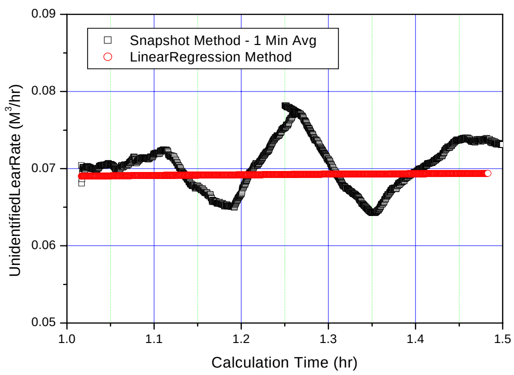

Figure 2. Unidentified Leak Rate

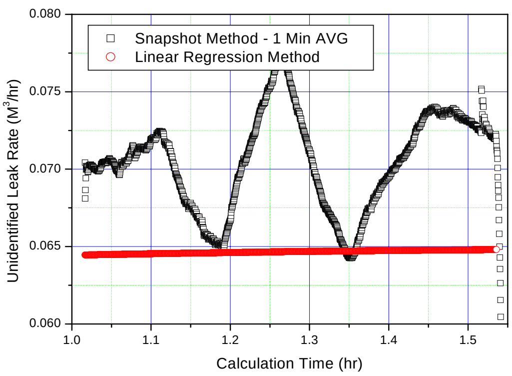

Figure 3. Unidentified Leak Rate Using Some Erroneous Data

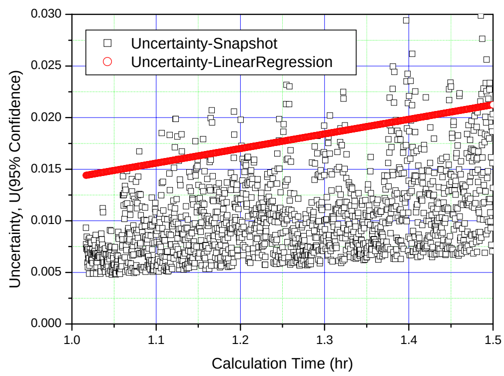

Figure 4. Uncertainty of the Unidentified Leak Rate

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