Real-Time Neutron Flux Monitoring using Rh Self-Powered Neutron Detector

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1. Introduction

Rhodium (Rh) self-powered neutron detectors (SPNDs) are widely used for on-line monitoring of local neutron flux. Its signal is slower than the actual variation of neutron flux owing to a delayed β^- decay of the Rh activation product, but real-time monitoring is possible by solving equations between the neutron reaction rate in the detector and its signal. While the measuring system is highly reliable, the accuracy depends on the method solving the equations and accuracy of the parameters in the equations. The uncertain parameters are the contribution of gamma rays to the signal, and the branching ratios of Rh-104 and Rh-104m after the neutron absorption of Rh-103.

Real-time neutron flux monitoring using Rh SPNDs has been quite successful for neutron transmutation doping (NTD) at HANARO[1]. We revisited the initial data used for the verification of a real-time monitoring system, to refine algorithm for a better solution and to check the parameters for correctness. As a result, we suggest an effective way to determine the prompt parameter.

2. Algorithm for Solution

The abundance of Rh-103 is 100%. It becomes Rh-104 or Rh-104m after a neutron absorption. The Rh-104m decays to Rh-104 by an isomeric transition, and Rh-104 decays to Pd-104 by emitting the β^-. As the activity of Rh-104 constitutes a majority of signal, numerical solutions for following equations are needed:

$$\dot{n}_m = k_m R - \lambda_m n_m \qquad (1)$$

$$\dot{n} = kR + \lambda_m n_m - \lambda n , \qquad (2)$$

where n, k and λ are the Rh-104 number, branching ratio after a neutron capture of Rh-103, and the decay constant, respectively, subscript m means Rh-104m, and R is the (n,γ) reaction rate of Rh-103. We converted above equations into an integral form. For an example, Eq.(1) becomes following:

$$n_m(t) = \int_{-\infty}^{t} k_m R(\tau) e^{-\lambda_m (t-\tau)} d\tau \qquad (1\text{-}1)$$

We measure the SPND signal with a time interval of Δ, and assume the variation of R from t to $t+\Delta$ linear;

$$R(t+x) = R(t) + \alpha x \qquad (3)$$

The SPND signal I basically consists of β^- rays and recoil electrons due to Rh-104 activity, and recoil electrons due to prompt gamma rays from the neutron capture of Rh-103 and the background. There may be a few other minor contributions, but they can be neglected. The effect from the signal cable is also neglected because we are using SPNDs with compensation lines.

$$I(t) = \lambda n(t) + k_p R(t) , \qquad (4)$$

where k_p is a constant between the prompt signal and reaction rate, corresponding to the delayed signal represented by the activity of Rh-104. The α is calculated from the measured $I(t)$ and $I(t+\Delta)$ using difference equations. $R(t+\Delta)$ is then obtained by $R(t)+\alpha\Delta$. By repeating these measurements and calculations, the real-time monitoring of Rh-103 reaction rate is achieved.

3. Sensitivity of Parameters

42.3 s and 4.34 min half lives, and 92.3% and 7.7% branching ratios (k and k_m) for a thermal neutron reaction are used for Rh-104 and Rh-104m, respectively. The k and k_m vary with the neutron energy. As the thermal neutron quality at the SPND position of HANARO NTD hole is good, we chose the thermal neutron data. Experiments in Arkansas Nuclear Unit 2[2] suggested 6.5±0.5%/(1 - 0.065) for k_p, but the basis of this is questionable. From an experiment by Kophazi, et al[3], in a research reactor, we estimated k = 0.942, k_m = 0.058, and k_p = 0.14. However, they depend on the SPND design and neutron spectrum.

The SPND signals are sampled every 1 s, and reactor power signal and control rod position data at the same time interval are gathered from the reactor operation computer. Cross-correlations between R and the reactor power signal showed that the clock for SPND signal sampling was 1.2 s earlier than the reactor operation computer.

Fig. 1 compares R variations for a few k_p values with the reactor power signal, when the power steps down. While the variation of R is amplified for a small k_p, it becomes slow for a larger k_p. After power step down, R does not follow the power variation exactly for any k_p, because the flux at the SPND position is more sensitive than the reactor power signal for the control rod movement.

To minimize the effect of the control rods to the flux, auto-correlations (ACs) at a steady state are compared as shown in Fig. 2. The ACs of R match with those of the reactor power signal when k_p = 0.085 for time intervals of 0, 1, 4 and 5 s.

The effect of k_p is also compared in Fig. 3 while the NTD rig is inserted into the NTD hole, irradiated and withdrawn. The change of control rod position due to the insertion of the NTD rig is negligible as shown in the figure. When the NTD rig reaches its irradiation position and stops vertical movement, R should become almost constant. The figure shows an over shoot and damping for k_ps of smaller and larger than 0.085, respectively.

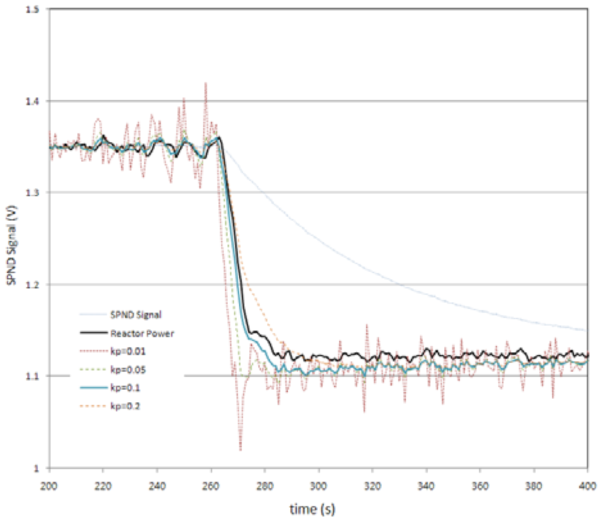

Fig. 1. Variation of R depending on k_p during a power step down

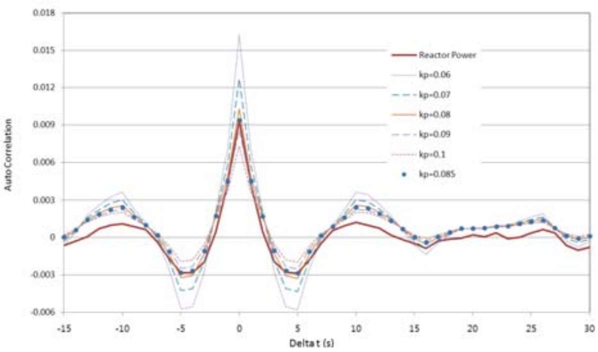

Fig. 2. Comparison of auto-correlations

(AC – Avg.^{2} of normalized signal to 24 MW)

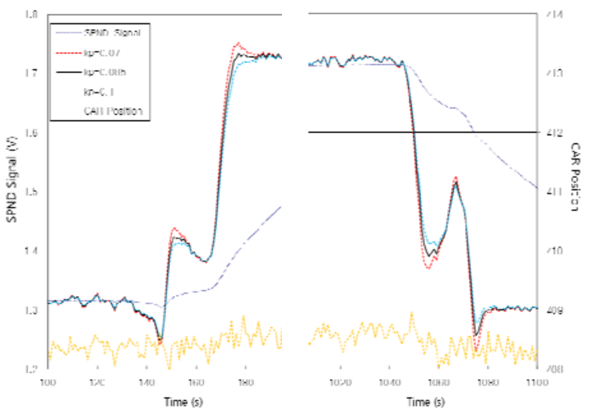

Fig. 3. Comparison of R variation during NTD rig insertion (left) and withdrawal (right)

Fig. 2 also shows that, except for 0, 1, 4 and 5 s, ACs of R are not too sensitive to k_p, and they are a little larger than those of the reactor power signal, especially for a longer time interval than 6 s. This indicates that R has larger delayed correlations than the reactor power signal. However, reasonable changes of k and k_m or addition of a term for the gamma ray contribution from an isomeric transition of Rh-104m did not give a noticeable influence to the ACs.

4. Conclusions

We determined the prompt parameter for the real-time monitoring of a neutron flux using an Rh SPND signal, which matches the ACs with those of the reactor power signal, during a steady state. The accuracy in the calculation of Rh-103 reaction rate during a transient is sensitive to the prompt term, but only slightly sensitive to the delayed terms. Therefore, an accurate real-time flux monitoring is possible using the prompt term determined by this method and the delayed terms for thermal neutrons.

REFERENCES

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