Assessment the Scaling Factor of ^{129}I in the Primary Coolant of CANDU Reactor

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1. Introduction

In Korea, four CANDU type reactors are currently in operation and are required to assess the difficult-to-measurable (DTM) radionuclides, specifically ^{129}I, in LILW. Therefore, the development of scaling factor (SF) evaluation methodology and computer program is progressing. The objective of this study is focused on the introduction of the developed theoretical evaluation methodology for concentrations and SFs of DTM radionuclides, especially ^{129}I.

2. Methods and Results

In this section, theoretical evaluation method is introduced and preliminary results for SF in primary coolant of CANDU reactor are shown.

2.1 Modeling and computational method

The related modeling study is based on the Lewis model for the long-lived ^{129}I coolant activity $A_c(t)$, which is given by Eq. (1) [1]. This model is based on the well-known release mechanism: diffusional release from the defective fuel and recoil release from the tramp uranium.

$$A_c(t) = xF_f y\mu\left[\frac{1-e^{-\phi\tau}}{\phi} + \frac{3}{\psi}\left(\frac{e^{-\psi\tau}-e^{-\phi\tau}}{\psi-\phi}\right)[1-\sqrt{\psi}\cot\sqrt{\psi}] + 6\psi\sum_{n=1}^{\infty}\frac{e^{-\phi\tau}-e^{-n^2\pi^2\tau}}{n^2\pi^2(n^2\pi^2-\psi)(n^2\pi^2-\phi)}\right] + \frac{Cy\mu}{\phi}(1-e^{-\phi\tau}) \quad (1)$$

where $\mu = \lambda / D', \psi = v / D', \tau = D't, \phi = \overline{\beta}_p / D', C = \frac{1}{2}F_t$ and $\beta_p = f_p\varepsilon / M$. x is the number of defective fuel rods, F_f is the average fission rate per defective rod (fission/s), y is the fission yield, λ is the radioactive decay constant (s^{-1}), D' is the diffusivity (s^{-1}), β_p is the coolant purification rate (s^{-1}), f_p is the cleanup system flow rate (kg/s), ε is the removal efficiency, and M is the mass of water in the PHTS (kg), v is the gap escape rate constant (s^{-1}), t is the fuel residence time(s), F_t is the fission rate in the tramp uranium (fission/s).

The model parameters for ^{129}I can be derived by the regression method from the short-lived radioiodine, which is given as a R/y ratio [1].

$$\left(\frac{R}{y}\right) = \left(\frac{v}{\lambda+v}\right)3xF_f\sqrt{\frac{D'}{\lambda}}H + C = \left(\frac{v}{\lambda+v}\right)\frac{A}{\sqrt{\lambda}}H + C \quad (2)$$

where $A = 3x\sqrt{D'}F_f$. R is the release rate (atom/s). H is the correction factor for precursor-diffusion effect.

The object function χ^2, that is, the target for minimization in regression method is set up.

$$\chi^2(\mathbf{a}) = \sum_{i=1}^{5} f_i^2 = \sum_{i=1}^{5}\left(\frac{(R/y)_{Mea,i}-(R/y)_{Cal,i}}{(R/y)_{Mea,i}}\right)^2 \quad \text{for } ^{131}\text{I}\sim^{135}\text{I} \quad (3)$$

where a is a candidate set of model parameter (v, A and C in Eq. (2)). $(R/y)_{Cal,\ i}$ and $(R/y)_{Mea,\ i}$ are the calculated R/y from a candidate set of model parameter and measured R/y for each short-lived radioiodine i, respectively.

The hybrid method combining simplex simulated annealing (SSA) method with LM method is used as a regression method. [2, 3].

For the evaluation of ^{137}Cs activity, related model parameters are determined by relating to those of ^{129}I in Lewis model. However, their relationship are too simplified (as $v_{Cs}=3v_I$, $D'_{Cs}=D'_I$ and $\varepsilon_{Cs}=0.1\varepsilon_I$). First, the value of v_{Cs} is overestimated compared with that of v_I because the volatility of iodine in gap is higher than that of cesium, and the dominant release mechanism is the dissolution of deposited CsI by the ingressed water vapor. Thus the same value of v is assumed in this study. Second, for the reflection of the different diffusion behavior with fuel temperature, the power-dependent diffusivity of ^{137}Cs is approximated from the known PWR data base [4] by relating with power-dependent diffusivity of ^{129}I in CANDU reactor [1]. The available range of $\varepsilon_I/\varepsilon_{Cs}$ is given as (0.01~1.0) from the reference data and assumed limit values, because the value of ε_{Cs} is highly dependent on the service life of purification resin. And, the optimal ratio of ε is estimated from the measured ^{137}Cs by relating to predicted one based on reference ratio of ε (0.01 or 1). The resultant relation in this method is given by ($v_{Cs}=v_I$, D'_{Cs}/D'_I = 0.32~0.6 and $\varepsilon_{Cs}/\varepsilon_I$ =0.01~1).

The suggested method is applied to the measured data in foreign CANDU reactor (i.e., Ontario Power Generation (Darlington Nuclear Generating Station (DNGS)) and the results of comparison (based on different relationship with model parameter for each method) are summarized in Fig. 1 and 2, respectively [5].

Figure 1 shows the resultant R/y with decay constant for each short-lived radioiodine. Figure 2 shows the Comparison of the measured and the predicted ^{137}Cs coolant activity. The range of resultant activity ratio (that is, SF) is same as:

1) Previous correlation: 1.9×10^{-8} ~3.4×10^{-8}
2) This study (when $\varepsilon_{Cs}/\varepsilon_I$=0.01): 4.1×10^{-9} ~6.2×10^{-9}
2) This study (when $\varepsilon_{Cs}/\varepsilon_I$=0.05): 2.0×10^{-8} ~3.1×10^{-8}

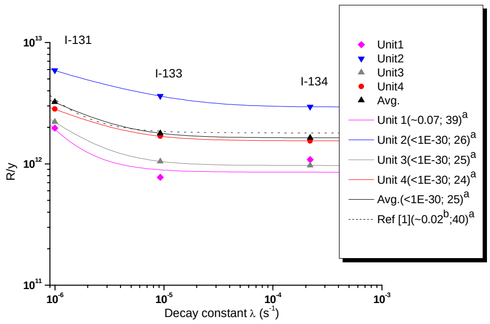

Figure 1. *R/y* versus decay constant for short-lived radioiodines

[a] object function ; Estimated P(in kw/m)

[b] deduced from result

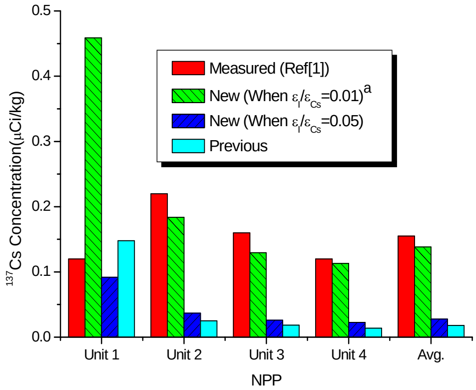

Figure 2. Comparison of the measured and the predicted ^{137}Cs coolant activity

[a] Derived optimal ratio of removal efficiency in this case

2.2 Results

This method shows reliable results in regression analysis, and its prediction for the ^{137}Cs shows relatively better agreements than the previous. Although the values of v and D' for ^{137}Cs are relatively smaller than those suggested by Lewis, the resultant SFs for ^{129}I in this case are relatively smaller than those of previous method because they is highly dependent on relative ratio of ε, and they also correspond to the lower bounds of SF in foreign RCS sampling results[5]. However, further study is needed for the discrimination of SF in coolant and spent resin generated from the primary coolant, especially based on the RCS data in Korean NPPs.

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