A Study on the Method for Dual Analysis and Internal Dose Assessment of Beta Emitters in Korean Nuclear Power Plants

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1. Introduction

Internal radiation exposure at pressurized heavy water reactors (PHWRs) accounts for approximately 20~40% of total radiation exposure; most internal radiation exposure is attributed to tritium. Carbon-14 is not a dominant nuclide from the radiation exposure of workers, but it is one potential nuclide to be necessarily monitored. At PHWRs, carbon-14 is generally produced by the irradiation of oxygen present as impurities in the moderator system from $^{17}O(n,\alpha)^{14}C$ reaction. Because carbon-14 release from PHWRs takes place mostly as carbon dioxide, in the case of carbon-14 release to the work area, it is easily inhaled into the body of radiation workers. Most inhaled carbon-14 is rapidly exhaled from the worker's body, but a small amount of carbon-14 remains inside the body and is excreted by urine. Internal dose assessment for carbon-14 is conducted using the liquid scintillation counting results of carbon-14 in urine samples of radiation workers since carbon-14 is a low energy beta emitter. In this study, the method of dual analysis of tritium and carbon-14 in urine samples was developed with the use of Liquid Scintillation Counters (LSCs) at the Wolsong nuclear power plants (NPPs). In addition, methods for determination of intake and internal dose assessment were established based on the measurement results of carbon-14 and its excretion rate data.

2. Dual Analysis of Tritium and Carbon-14

Liquid scintillation counting is generally used to measure the radioactivity of carbon-14 in urine samples of radiation workers. The effective urine analysis method that is commonly used is to set the lower and upper energy channels of the LSC to rise and to fall, respectively, for detection of liquid scintillation released from only carbon-14 within a specific channel interval. Carbon-14 measurement is conducted with tritium simultaneously and a one minute count is appropriate for detection. In development of the method of dual analysis of tritium and carbon-14, measurement and analysis were performed with LSC and both artificial and real urine samples of radiation workers [1]. Tritium has a continuous spectrum with a maximum energy of 18.6keV, but after measurement of tritium spectrum using an LSC, it was found that 86.5% of total spectrum is distributed lower than 4.0keV. In addition, 95.6% of total counts for tritium are distributed within 12.0keV. Thus, for tritium measurement, determination of channel from 0 to 4.0keV is more effective to reduce the backgrounds despite the small decrease in efficiency compared with that of channel from 0 to 12.0keV. On the other hand, carbon-14 has a maximum energy of 156keV and, after measurement, it was found that 95.6% of total counts are distributed within 42keV. If the upper channel is set from 0 to 60.0keV, 99.7% of total counts are measured. The effective channels of LSC were determined through the optimization process, which maximizes the counting efficiency and reduces the Minimum Detectable Activity (MDA). First, for determination of the lower channel, the upper channel was fixed at Channel 200 and then the lower channel was increased gradually by one channel from Channel 1 to optimize counting channels. Here, one channel is a unit that has 0.5keV. On the other hand, for determination of the upper channel, the lower channel was fixed at Channel 1 and then the upper channel was decreased gradually by one channel from Channel 200 to optimize counting channels similar to the previous process. In this process, the effective channels were determined using the spectrums of both tritium and carbon-14, in order to maximize the counting efficiency and minimize the MDA. As a result, the effective channels were set from Channels 1 to 9 for single and dual analysis of tritium, from Channels 4 to 85 for single analysis of carbon-14, and both from Channels 30 to 85 or Channels 40 to 85 for dual analysis of carbon-14.

3. Internal Dose Assessment for Carbon-14

The dose rate (rem/d) to a tissue of mass m (g) resulting from radioactivity Q (μCi) of carbon-14 is given by Eq. 1 [2,3]. Here, E (MeV) is the mean energy of the beta emission. The committed effective dose (rem) resulting from an initial radioactivity Qo (μCi) is described in Eq. 2.

$$Committed\ Dose = \frac{51.2 \times E \times Q}{m}\ \text{[rem/day]} \qquad \text{(Eq. 1)}$$

$$Committed\ Dose = \frac{(51.2 \times E \times Q_O)}{m} \int_0^{50years} R(t)\ \exp(-0.693t/T_{1/2})\ dt\ \text{[rem]} \qquad \text{(Eq. 2)}$$

Inhaled carbon-14 is distributed throughout all soft tissues of the body. Thus, the committed effective dose, resulting from the mean energy 0.049 MeV and the soft tissue mass of Reference Man 63,000 g, is given by Eq. 3. For a urine sample of concentration C (Bq/L) obtained at time t after single or acute intake, the intake can be estimated by Eq. 4. Here, "1.4 L" is the nominal daily excretion of urine. The final committed effective dose is then given by Eq. 5.

$$Committed\ Dose = 5.0 \times 10^{-5} \times Q_O\ \text{[rem]} \qquad \text{(Eq. 3)}$$

$$Intake = \frac{1.4 \times 3.7 \times 10^4 \times C}{IRF(t)} = \frac{5.2 \times 10^4 \times C}{IRF(t)} \qquad \text{(Eq. 4)}$$

$$Committed\ Dose = 5.2 \times 10^4 \times 6.2 \times 10^{-15} \frac{C}{IRF(t)} = 3.2 \times 10^{-10} \times \frac{C}{IRF(t)}\ \text{[mSv} \cdots\text{]} \qquad \text{(Eq. 5)}$$

4. Conclusion

In this study, a method for dual analysis of beta emitters especially, tritium and carbon-14 in urine samples of NPP workers was developed. Dose calculation of carbon-14 activity were also provided based on the experiment and investigation results. It is expected that the developed technology can make the internal dose assessment for carbon-14 possible and contributed to the radiation protection of workers at NPPs.

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