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Assessment of long-term trend for environmental radioactivity around Wolsong nuclear power plant in Korea

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ABSTRACT

The radiological environment around Wolsong NPP site has been monitored since Wolsong Unit 1 started commercial operation in 1983, as required by regulations in Korea. As a result of the periodic safety review on Wolsong Unit 3 & 4 in 2011, the regulator recommended that an assessment on the long-term accumulation trend of environmental radioactivity around Wolsong Unit 3 & 4 should be performed. In response to this, the assessment was performed based on environmental monitoring data and non-parametric statistical tool (i.e., Mann–Kendall Test). The environmental monitoring data included indicator organisms, soil and marine deposit which were usually monitored for verification of the typical radioactivity level. Most results of the assessment showed no trend and only a few results showed a slight increase. It was concluded that the radioactivity accumulation due to the operation of the plant was insignificant and thus no concern has been raised regarding any effect on the safety and health of the residents around Wolsong NPP site. It is expected that the result of this study could be utilized to establish the plan and policy for environmental monitoring at other NPP sites.

1. Introduction

The Korean nuclear operator Korea Hydro & Nuclear Power Co. (KHNP) is committed to protecting the environment and residents around their plants. Part of this effort involves the periodic environmental monitoring of any radioactivity resulting from plant operations in compliance with Notice No. 2012-5 of the Korea Nuclear Safety and Security Commission (NSSC), which requires the operators to assess the long-term trends of environmental radioactivity around their plants, including short-term changes due to any unexpected effluent of radioactive materials from the plants. For Wolsong nuclear power plant, KHNP has performed this type of monitoring since Wolsong Unit 1 started commercial operation in 1983.

In Korea, 23 reactors are in operation in total and they are fall into one of the following six reactor types or models: the Westinghouse W model, the CE model, the Framatome model, the CANDU type, the OPR-1000 model or the APR-1400 model. In perspective of the safety, KHNP performs a periodic safety review (PSR) every 10 years based on the operating license authorized from the regulator. During the PSRs for Wolsong Unit 3 and 4 in 2010, the regulator proposed a safety improvement item which required the operator to assess the long-term trend of the environmental radioactivity around these units. Although Wolsong Unit 3 and 4 started its commercial operation in 1998 and 1999, respectively, Korean regulatory body (Korea Institute of Nuclear Safety) asked operator to assess all the available environmental data measured around the Wolsong site including Wolsong Unit 1 and 2, which started its commercial operation in 1983 and 1997, respectively. For Wolsong Unit 3 and 4, the results of the assessment performed from July to October of 2012 were submitted to the regulator in November of 2012.

The trend analysis method for long-term environmental radioactivity investigates long-term and continual trends of monthly and annual changes to quantify the environmental radioactivity changes using real measurement data. This statistical treatment method verifies whether or not changes exist quantitatively by comparing them with past data or with data from a reference point. Even if the results meet the regulatory standards, the trend analyses showing an increase or a decrease within the regulatory standard range can be useful for upgrading the reliability in terms of environmental radioactivity management and determining environmental radiation monitoring methods.

Methods for trend analysis are mainly classified into parametric method and nonparametric method. A typical parametric method is the linear regression method. The linear regression method

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evaluates the measurement data according to the degree of inclination with a suitable linear equation in order to judge whether the trend of measurement data are monotonically increasing or monotonically decreasing. A corresponding level in the form of a linearly regressing straight line is shown as the coefficient of determination, but this method cannot deal with volume data and outliers.

Generally in the case of normal distribution, the skewness (level of asymmetry), which shows the degree of lean to one direction, becomes close to 0 and the kurtosis, which shows the level of concentration toward the median value (or mean value) approaches 3.

A nonparametric test is suitable when the parent population distribution is unknown such as environmental monitoring data. For a long-term trend analysis of the environmental radioactivity, a generalized methodology has not been established. Thus, trend analyses were performed using the Mann–Kendall verification method, which is widely used in various analysis fields such as water quality of surface layer water, underground water levels, electric conductivity, water temperature, floodgate and long-term temperature changes (Lee et al., 2002, 2006; Yue et al., 2002; Gadgil and Dhorde, 2005; Coen et al., 2007; Chang, 2008; Zhang et al., 2008). The Mann–Kendall verification method relies on the signs of differences between each data and checks the distribution of the signs. Volume data and outliers can be suitably assessed with this method because the observed values are not used directly. Instead, the ranks of the observed values or degree of variation inclination are used.

In order to improve the reliability of trend analysis, long-term environmental investigations should be performed in advance. Therefore, the environmental radioactivity data measured since 1977, before the operation of Wolsong Unit 1, were put into a database and the trends of radioactive nuclides which have radioactivity over the MDA (Minimum Detectable Activity) were analyzed.

2. Analysis method and monitoring items

2.1. Analysis method

The basic principal of the Mann–Kendall verification method uses the values of an increase (1), a decrease (−1) and equality (0) for comparing each observed value (Mann, 1945; Kendall, 1975). If an observed value at a certain time i is x_i, then in total N $x_j - x_i$ $(j > i)$ differential pairs exist. This can be expressed as follows while calculating the sign of these differences.

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases}$$

The Mann–Kendall statistical quantity is calculated as follows:

$$S = \sum_{u-1}^{n-1} \sum_{j-i-1} \operatorname{sgn}(x_j - x_i)$$

If it is normalized as a dividing statistical quantity S by the number of observed value pairs (i.e., $n(n-1)/2$), then it is located between +1 and −1. We call this the τ coefficient.

$$\tau = \frac{S}{n(n-1)/2}$$

The probability for the hypothesis, which supposed that there was no increase trend, can be obtained with the number of observations (n) and Mann–Kendall statistical quantity (S). In the case of a decreasing trend, sign of S will show the opposite trend. When n is greater than 10, the following equation is used while assuming a normal distribution.

$$Z = \begin{cases} \frac{S-1}{[Var(S)]^{1/2}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{[Var(S)]^{1/2}} & \text{if } S < 0 \end{cases}$$

The maximum value of the probability, i.e., the maximum value of the first-class error, which selects the alternative hypothesis incorrectly when in fact the null hypothesis is true, is the significance level, normally expressed as α (alpha). At the significance level α, if $|Z| > Z_{(1-c/2)}$, then the null hypothesis is rejected. In this case, $Z_{(1-c/2)}$ is the value of standard normal distribution which has the probability exceeding $\alpha/2$. A positive Z value means an increasing trend and a negative Z value means a decreasing trend. Generally, α is set to be 0.05. It can be judged from the p value whether the trend of an 'increase' or a 'decrease' is a meaningful value in the statistics. If the significance level is 0.05, a p value below 0.05 confirms the existence of trend and the trend is a meaningful value statistically.

The size of the trend was suggested by Sen, and it is anticipated using a nonparametric median which was extended by Hirsch (Sen, 1968; Hirsch et al., 1982).

$$\beta = \text{Median}\left[\frac{x_j - x_i}{j - i}\right] \text{ for all } i < j$$

In the equation above, β is the inclination of the trend showing a straight line, which is expressed as a linear equation. This represents a median of inclinations between each observed value pairs. The intercept is calculated by the linear regression method using the pairs and inclinations. The long-term trend is judged as showing an 'increase', a 'decrease' and 'no trend'. Among these, 'no trend' means that it is not effective in the statistics and there is no consistent direction even if a trend exists.

2.2. Monitoring items

The environmental radioactivity around NPPs is monitored to check the short-term changes and long-term accumulation trend. The important items are as follows:

- o Radiation dose
  - *Dose rate:* Estimate the external exposure dose and check the short-term changes of environmental radiation
  - *Accumulative dose:* Estimate the accumulated external exposure dose
- o Environmental radioactivity concentration
  - *Air:* Evaluate the internal exposure dose by inhalation
  - Ground water, Agricultural products and Seafood: Evaluate the internal exposure dose by ingestion
  - *Indicator organisms:* Check the radioactivity level and accumulation trend of radioactivity
  - *Soil and Sub-marine sediment:* Check the accumulation trend of radioactive materials
  - *Sea water:* Check the radioactivity level and estimate the postulated internal expose value from seafood

A radioactivity analysis was performed on indicator organisms, soil and sub-marine sediment as the representative monitoring items for checking the levels and long-term accumulation trend of radioactivity. The monitoring of radioactivity around NPPs has been implemented by classifying the three nuclide types of monitoring nuclides, reference nuclides and natural nuclides during the normal operation of NPPs. Monitoring nuclides could be released