METHODOLOGY FOR DETERMINATION OF ALARM AND WARNING SET-POINTS FOR RADIOACTIVE EFFLUENT MONITORS IN KOREAN PRESSURIZED WATER REACTORS

by

***Tae Young KONG* *, Siyoung KIM, Youngju LEE, and Jung Kwon SON**

Central Research Institute, Korea Hydro & Nuclear Power Co., Ltd., Yuseong-gu, Daejeon, Republic of Korea

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All radioactive gaseous and liquid effluents discharged from Korean nuclear power plants are monitored by effluent monitors to prevent effluent releases to the environment under uncontrolled conditions. This paper provides the methodology and parameters used in the calculation of alarm (high) and warning (low) set-points for gaseous and liquid effluent monitors in Korean pressurized water reactors. Alarm set-points are determined to assure compliance with the Korean regulatory limits of concentration of radioactive effluents. Even though warning set-points are not required by the regulatory body, Korean pressurized water reactors determine the warning set-points of effluent monitors not only to take an active management of effluent discharge but also to keep radiation doses to members of the public living around nuclear power plants as low as reasonably achievable.

Key words: nuclear power plant, pressurized water reactor, effluent control limit, effluent monitor, alarm set-point, warning set-point

INTRODUCTION

Radiation monitoring systems in nuclear power plants (NPP) are generally classified into three types according to purpose. First, a process monitor, for monitoring leaks of radioactive materials in the system. Second, an area monitor, for monitoring radiation levels in the radiation-controlled area. Third, an effluent monitor, used for monitoring radioactive effluents discharged from NPP to the environment. Radioactive effluents are normally regarded as radioactive waste regardless of their concentration and controlled by regulation to protect the environment and members of the public living around NPP [1, 2]. It is also commonly accepted that doses estimation for members of the public originates from the release of radioactive effluents from nuclear facilities [1]. Thus, it is important to control the release of radioactive effluents from nuclear facilities for keeping the public dose as low as reasonably achievable. Korean pressurized water reactors (PWR) operate gaseous and liquid effluent monitors to monitor the instantaneous concentration in radioactive effluents. These monitors provide an early warning of increased concentration and prevent effluent releases exceeding effluent control limits (ECL), the regulatory limits of concentration of radioactive materials [3]. Particularly, alarm (high) and warning (low) set-points of radioactive effluent monitors assure compliance with the ECL of the Nuclear Safety and Security Commission (NSSC), the Korean regulatory body [2, 4]. Exceeding these warning or alarm set-points will trigger an investigation, according to the NPP corrective action program. For example, if the concentration of radioactive effluents exceeds the warning set-points, the NPP decreases the release rate to restore the concentration to within the requirements in the plant procedures or sometimes blocks the discharge. If the alarm set-points have been exceeded, the NPP promptly terminates release of radioactive effluents via this pathway and notifies the NSSC within four hours. The NPP also prepares and submits to the NSSC within 60 days a special report that ascertains the cause for exceeding the alarm set-points. In addition, it also describes the immediate corrective actions that have been taken to reduce the releases and the suggested corrective actions to be taken to assure that subsequent releases will be in compliance with the requirements [5].

SET-POINTS OF GASEOUS EFFLUENT MONITORS

Alarm set-points

Alarm set-points of gaseous effluent monitors are determined to ensure that the concentration of gaseous effluents discharged from Korean PWR to the environment is limited to the NSSC ECL. Assuming that a member of the public inhales or ingests the

* Corresponding author; e-mail: eagertaeyoung@khnp.co.kr

radionuclide continuously all year round, the ECL are defined as the derived radionuclide concentration to give an individual a 1 mSv effective dose [2]. The NSSC provides gaseous and liquid ECL that take into account exposure pathways, the routes of individual exposure to radioactive effluents.

In general, radioactive effluents discharged from NPP include multiple radionuclides, not a single radionuclide. Thus, the sum of the ratios of the concentrations of individual radionuclides to the ECL of corresponding radionuclides should be less than 1, so as not to exceed the dose limit for members of the public [2]. The concentration in radioactive effluents, which include multiple nuclides, at the boundary of an unrestricted area, can be described by the following equations

$$\frac{C_1}{ECL_1} \quad \frac{C_2}{ECL_2} \quad \cdots \quad \frac{C_i}{ECL_i} \quad 1 \tag{1}$$

$$_i \, \frac{C_i}{ECL_i} \quad 1 \tag{2}$$

where C_i is the concentration of radioactivity of radionuclide i [Bqm^{-3}] and ECL_i – the gaseous ECL limit of radionuclide i [Bqm^{-3}]. The sum of the concentration of gross activity of all radionuclides, $_iC_i$ [Bqm^{-3}], discharged from NPP over the limit of the concentration of radioactivity, L [Bqm^{-3}], at the boundary of the unrestricted area should be less than or equal to 1; this sum can be expressed as following eqs.

$$\frac{_iC_i}{L} \quad 1 \tag{3}$$

$$L \quad \frac{_iC_i}{_i \, \frac{C_i}{ECL_i}} \tag{4}$$

$$L \quad \frac{\chi}{Q} M \tag{5}$$

where χ/Q [sm^{-3}] is the atmospheric dispersion factor and M [Bqs^{-1}] – the maximally permissible discharge rate of gross activity in gaseous effluent at a stack. Substituting eq. (4) into eq. (5), the maximally permissible discharge rate of gross activity in gaseous effluent can be written as the following eqs

$$M \quad \frac{L}{\frac{\chi}{Q}} \tag{6}$$

$$M \quad \frac{_iC_i}{\frac{\chi}{Q} \quad _i \, \frac{C_i}{ECL_i}} \tag{7}$$

If the average flow rate F [m^{3}s^{-1}] of gaseous effluents is assumed at a stack, the alarm set-point of a gaseous effluent monitor at a single stack, $SP_{\mathrm{Alarm\text{-}single}}$ [Bqm^{-3}], can be expressed as eq. (8)

$$SP_{\mathrm{Alarm\ \ single}} \quad \frac{M}{F} \quad \frac{1}{F \, \frac{\chi}{Q}} \quad \frac{_iC_i}{_i \, \frac{C_i}{ECL_i}} \tag{8}$$

In Korea, multiple reactors are in operation at a single NPP site. Thus, the alarm set-point of gaseous effluent monitor SP_{Alarm} [Bqm^{-3}], considering multiple discharge points, can be written as eq. (9)

$$SP_{\mathrm{Alarm}} \quad \frac{1}{N} \frac{1}{F \, \frac{\chi}{Q}} \quad \frac{_iC_i}{_i \, \frac{C_i}{ECL_i}} \tag{9}$$

where N is an administrative allocation factor to allow for multiple gaseous effluent releases from different reactor discharge points at a single NPP site. For example, the number of reactors in operation at the Hanbit NPP site is six [6]. This number is used as an administrative allocation factor for the alarm set-point of gaseous effluent monitors at the Hanbit NPP site. However, most reactors have not a single discharge point but several points for gaseous effluent release. Furthermore, some gaseous effluent monitors installed at specific discharge points have three detector channels to monitor particulate material, iodine, and gas [7]. Thus, the current alarm set-point of gaseous effluent monitors in Korean PWR does not include factors regarding multiple discharge points in a reactor and detector channels of effluent monitors. Since gaseous effluent monitors detect the instantaneous concentration in radioactive effluents, it is not allowed to discharge gaseous effluent with the concentration of the alarm set-point continuously over the course of a year [8]. In addition, the concentration in radioactive effluents reaches the warning (low) set-points before reaching the alarm (high) set-points, and this warning pushed plant operator to take corrective action, such as blocking of effluent discharge. Thus, the current administrative allocation factor is determined based on these considerations.

Warning set-points

In order to control radioactive effluent discharge more strictly, Korean PWR apply warning set-points, which are lower than alarm set-points, to effluent monitors. Although warning set-points are not required by the regulatory body, Korean PWR voluntarily establish warning set-points of effluent monitors to undertake active management of effluent discharge [8]. The current warning set-points in Korean PWR are determined by taking into account Article 16, 'Prevention of Hazards to Environment', of NSSC Notice 2017-36. This article provides dose standards that are applied to

Table 1. Dose standards to control releases of radioactive effluents discharged from nuclear facilities (at the boundary of the unrestricted area)

Effluents	Category	Annual limits per unit	Annual limits per site
Gaseous	Air absorbed dose for gamma ray	0.1 mGy	
	Air absorbed dose for beta ray	0.2 mGy	Under the operation of multiple reactors at a single site
	Effective dose for external exposure	0.05 mSv	
	Skin equivalent dose for external exposure	0.15 mSv	· Effective dose: 0.25 mSv
	Organ equivalent dose for radioiodine and particulates (including ^{3}H and ^{14}C)	0.15 mSv	
Liquid	Effective dose	0.03 mSv	· Thyroid equivalent dose: 0.75 mSv
	Organ equivalent dose	0.1 mSv	

the design of facilities concerned, in order to keep radiation doses to members of the public living around NPP as low as reasonably achievable, which are summarized in tab. 1 [2]. Particularly, an annual effective dose of external radiation exposure by gaseous effluents at the boundary of an unrestricted area is limited to 0.05 mSv per reactor. Thus, the warning setpoint of the gaseous effluent monitor, SP_{Warning} [Bqm^{-3}], can be expressed as eq. (10)

$$SP_{\text{Warning}} \quad 0.05\,N\,SP_{\text{Alarm}} \tag{10}$$

where 0.05 is a safety factor considering the NSSC dose standard due to gaseous effluent discharge, N is the number of reactors in operation at a single NPP site, and SP_{Alarm} is the alarm set-point of the gaseous effluent monitor. In particular, the reason why the number of reactors at a single NPP site is multiplied in eq. (10) is that the dose standard, 0.05 mSv per year, is based on a single reactor. For instance, since the number of reactors in operation at Hanbit NPP site is six, the warning set-points of gaseous effluent monitors are calculated as 30 % of the alarm set-points (0.05 6 reactors = 0.3). In addition, the safety factor 0.05 originates from the annual effective dose for external exposure, as indicated in tab. 1. This value is not consistent with the afore-mentioned assumption that a member of the public inhales or ingests gaseous effluents, which corresponds to internal exposure. However, the value 0.05 is used as a safety factor for the warning set-point of the gaseous effluent monitor regardless of types of exposure to radiation: internal and external since the value 0.05 is more conservative than the value 0.15 of annual organ equivalent dose for radioiodine and particulates from all pathways.

SET-POINTS OF LIQUID EFFLUENT MONITORS

Alarm set-points

The determination of alarm set-points of liquid effluent monitors is based on the NSSC liquid ECL [2]. Since the radionuclide concentration in liquid effluents for discharge is controlled using dilution water, the alarm set-point of the liquid effluent monitor, SP_{Alarm} [Bqm^{-3}], can be written as eq. (11)

$$SP_{\text{Alarm}} \quad \frac{F \quad F_E \quad F_C \quad F_S}{F} \quad \frac{{}_i C_i}{{}_i \dfrac{C_i}{ECL_i}} \tag{11}$$

where C_i [Bqm^{-3}] is the concentration of radioactivity of radionuclide i, ECL_i [Bqm^{-3}] – the liquid ECL of radionuclide i, F [m^{3}s^{-1}] – the average discharge flow rate of effluent, F_E [m^{3}s^{-1}] – the flow rate of essential service water, F_C [m^{3}s^{-1}] – the flow rate of circulating water, and F_S [gpm] – the flow rate of seawater bypass. Unlike the alarm set-points of gaseous effluent monitors, eq. (11) does not include an administrative allocation factor to allow for multiple liquid effluent releases from different reactor discharge points at a single NPP site. Generally, in the case of liquid, when mixed with other liquids, the volume is increased, and the concentration is averaged [3]. For example, when two solutions with concentrations of 1 Bqm^{-3} each are mixed together, the volume of mixed solution is increased to 2 m^3 and the concentration is maintained at 1 Bqm^{-3}.

Warning set-points

Similar to the case of gaseous effluent monitors, Korean PWR voluntarily established warning set-points for liquid effluent monitors by taking into account Article 16, 'Prevention of Hazards to Environment', of NSSC Notice 2017-36 [2, 3]. According to the article, annual effective dose to members of the public living around NPP by liquid effluents at the boundary of an unrestricted area is not to exceed 0.03 mSv per reactor. Thus, the warning set-point of the liquid effluent monitor, SP_{Warning} [Bqm^{-3}], can be written as eq. (12)

$$SP_{\text{Warning}} \quad 0.03\,N\,SP_{\text{Alarm}} \tag{12}$$

where 0.03 is a safety factor considering the NSSC dose standard for liquid effluent discharge, N – the number of reactors in operation at a single NPP site, and SP_{Alarm} is the alarm set-point of the liquid effluent monitor. Since the dose standard, 0.03 mSv per year, is based on a single reactor, the number of reactors at a single NPP site is multiplied in eq. (12). For example, the warning set-points of the liquid effluent monitors at the Hanbit NPP site, which has six operating reactors at a single site, are calculated as 18 % of the alarm set-points (0.03 6 reactors = 0.18).

DISCUSSION AND CONCLUSION

Alarm set-points of radioactive effluent monitors in the Korean PWR are determined to comply with the NSSC ECL. The ECL values are equivalent to the radionuclide concentrations that would produce an effective dose of 1 mSv for members of the public if inhaled or ingested continuously over the course of a year. Since radioactive effluents discharged from NPP normally contain various radionuclides, alarm set-points of effluent monitors are determined such that the sum of the ratios of the concentration of individual radionuclides to the ECL of corresponding radionuclides should be less than 1, so as not to exceed the dose limit for members of the public, 1 mSv per year, due to a radioactive effluent discharge. Particularly, the Korean PWR use the number of reactors in operation at a single site as an administrative allocation factor for alarm set-points of gaseous effluent monitors, considering multiple gaseous effluent releases from different reactor discharge points at a single NPP site. In addition to alarm set-points, warning set-points of effluent monitors are established by the Korean PWR to control radioactive effluent discharge more rigorously, even though warning set-points are not regulatory requirements.

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AUTHORS' CONTRIBUTIONS

The literature research and the theoretical analysis were conducted by all authors. Furthermore, all authors analyzed and discussed the results.

REFERENCES

[1] Kong, T. Y., *et al*., Radioactive Effluents Released from Korean Nuclear Power Plants and the Resulting Radiation Doses to Members of the Public, *Nuclear Engineering and Technology, 49* (2017), 8, pp. 1772-1777
[2] ***, NSSC, Standards for Radiation Protection, *etc*., Nuclear Safety and Security Commission, Notice No. 2017-36, Seoul, Korea, 2017
[3] ***, KHNP, Current Status of the Application of set-points to Radioactive Effluent Monitors at Pressurized Water Reactors, Korea Hydro & Nuclear Power, 2017-50003339-Jeong-0859TC, Gyeongju, Korea, 2017
[4] Kong, T. Y., *et al*., Regulations on Radioactive Effluents Released from Korean Nuclear Power Plants, *International Journal of Environmental Studies, 75* (2018), 1, pp. 154-159
[5] ***, NSSC, Reporting and Disclosure Regulations for Accidents and Failures of nuclear Facilities, Notice No. 2014-17, Seoul, Korea, 2014
[6] ***, KHNP, Nuclear Power Plant Status [Online], Korea Hydro & Nuclear Power, Available: http://www.khnp.co.kr/eng/content/529/main.do?mnCd=EN03020101,[Accessed: 07-Dec-2017]
[7] ***, KHNP, Radioactive effluent monitors at Korean pressurized water reactors, Korea Hydro & Nuclear Power, 2017-50003339-Jeon-0690TC, Gyeongju, Korea, 2017
[8] ***, MOST, Assessment of Unplanned Effluent Releases from On-Site Facilities and Determination of Standard Parameters for Off-Site Dose Calculation, Ministry of Science & Technology, Seoul, Korea, 2004

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Тае Јоунг КОНГ, Сијоунг КИМ, Јоунгђу ЛИ, Ђуенг Квон СУН

МЕТОДОЛОГИЈА ОДРЕЂИВАЊА НИВОА АЛАРМА И УПОЗОРЕЊА МОНИТОРА РАДИОАКТИВНИХ ЕФЛУЕНАТА У КОРЕЈСКИМ НУКЛЕАРНИМ РЕАКТОРИМА СА ВОДОМ ПОД ПРИТИСКОМ

Током рада Корејских нуклеарних електрана врши се мониторинг свих гасовитих и течних радиоактивних ефлуената како би се спречило њихово ослобађање у животну средину под неконтролисаним условима. У овом раду приказана је методологија и параметри коришћени за прорачун нивоа аларма (висок ниво) и нивоа упозорења (низак ниво) монитора за праћење гасовитих и течних радиоактивних ефлуената током рада Корејских рекатора са водом под притиском. Нивои аларма су подешени тако да задовољавају критеријуме концентрација радиоактивних ефлуената постављене од стране регулаторног тела. Нивои упозорења на мониторима корејских рекатора са водом под притиском, иако нису захтевани од стране регулаторног тела, успостављени су како би се узела активна улога у управљању испуштања ефлуената и ради одржавања доза за становништво које живи у околини нуклеарних електрана на што је могуће нижем нивоу.

Кључне речи: нуклеарна електрана, реактор са водом под притиском, контрола граница ефлуената, монитор ефлуената, ниво аларма, ниво упозорења