OPERATIONAL EXPERIENCE OF A TWO-DOSIMETER ALGORITHM FOR BETTER ESTIMATION OF EFFECTIVE DOSE AT KOREAN NUCLEAR POWER PLANTS

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Two dosimeters are provided to radiation workers participating in tasks where high radiation exposure is expected during maintenance at nuclear power plants. At Korean nuclear power plants, two dosimeters are currently provided for tasks where exposure rates exceed 1 mSv/hr, the difference of equivalent dose to specific parts of the body is more than 30% and an exposure of more than 2 mSv is expected in a single task. These conditions for the provisioning of two dosimeters are based on previous field test results, and it is recommended that the dosimeters be worn on the chest and back. It was also found that the workers felt it was more convenient when they wore two dosimeters on chest and back rather than on chest and head. After the application of previous field test results to practice, it was found that the calculated effective dose for workers during radiation work was lower than the maximum dose of chest or back dosimeter by approximately 10%–30%. This performance is regarded not only to meet the international guideline but also to provide convenience for workers during radiation work.

Keywords : Operational Experience, TLD, Two-dosimeter Algorithm, Effective Dose, NCRP (55:50) Algorithm

1. INTRODUCTION

Radiation workers can be exposed to a high level of radiation during the maintenance of reactor coolant pumps, pressurizers, and the water chambers of steam generators in nuclear power plants (NPPs) despite short exposure times, as dose rate gradients are high near such equipment. Generally, the radiation dose rate is high and the radiation field is inhomogeneous; hence, if radiation workers use only one thermoluminescent dosimeter (TLD) on their chest, the amount of exposure to radiation cannot be monitored precisely [1,2]. Therefore, additional dosimeters are provided to workers who work in an inhomogeneous radiation field in NPPs. Two dosimeters are typically provided; one on the chest and the other on the head [3–5]. In this way, the radiation dose to the entire body can be determined from the higher of the two doses recorded by the two dosimeters. This represents a conservative method of evaluating the degree of exposure to radiation.

In response to previous field test results, current procedure has been updated so that two dosimeters are now routinely provided to radiation workers at Korean NPPs for tasks where the dose rate is expected to exceed 1 mSv/hr, the difference of equivalent dose to specific parts of the body is expected to exceed 30% and an exposure of more than 2 mSv is expected during a single task. In such cases, radiation workers wear one dosimeter on the chest and another on the back [6,7]. After the task, the effective dose of the radiation worker is calculated using the National Council on Radiation Protection and Measurements (NCRP) (55:50) algorithm for two dosimeters [6–9].

In this paper, the operational experience of using two dosimeters for high radiation exposure tasks during maintenance periods at Korean NPPs is described. Relevant results of previous studies are briefly introduced, and improvements in effective dose estimation resulting from the use of two dosimeters and a two-dosimeter algorithm are discussed.

2. PREVIOUS TEST ON TWO-DOSIMETER ALGORITHM

In previous studies, the application of a two-dosimeter system together with its algorithm and a test of its use in an inhomogeneous high-radiation field were conducted [6,7,9]. The goal of these studies was to develop an

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improved method for effective dose estimation during maintenance periods at Korean NPPs. The use of the two-dosimeter algorithm in Korean and international NPPs, including plants in the USA and Canada, was also investigated. The algorithms used by the Canadian corporation Ontario Power Generation, the American National Standard Institute (ANSI) N13.41, the NCRP, the Electric Power Research Institute (EPRI), Dr. Lakshmanan and Dr. Kim by Texas A&M University were extensively analyzed as two-dosimeter algorithms [6,7]. These seven two-dosimeter algorithms are summarized in Table 1. The possibility of their application to NPPs was also explored by evaluating the results of feeding each algorithm data from two-dosimeter results collected in an inhomogeneous high-radiation field during maintenance periods at Korean NPPs.

The application of seven two-dosimeter algorithms developed by different nuclear regulatory agencies and facilities to Korean NPPs was investigated to analyze problems that might arise. Three dosimeters were provided to radiation workers, who wore a TLD on the head, chest, and back simultaneously for high-radiation work during a maintenance periods at the Yonggwang NPP No. 2 and the Ulchin NPP No. 2 in order to analyze the outcome of applying the two-dosimeter approach at Korean NPPs [6,7]. After the radiation work, the seven two-dosimeter algorithms were applied to two-dosimeter readouts and the effective doses were calculated. The calculated effective doses were very similar to one another, with the exception of those calculated using Lakshmanan's algorithm. Thus, it was concluded that regardless of which algorithm was applied to Korean NPPs, the procedure used for estimating levels of exposure to radiation would be improved [6–8].

Previous testing has shown that wearing one dosimeter on the chest and one dosimeter on the back rather than one on the chest and one on the head reduces the potential for overestimations or underestimations of the effective dose [6,7,10,11]. In addition, as the Nuclear Regulatory Commission (NRC) and NCRP recommend that a radiation worker wear dosimeters on the chest and back, it is feasible for Korean NPPs to follow international standards and trends regarding the use of two dosimeters. After interviews with the radiation workers, it was also found that they reacted positively to wearing dosimeters on the chest and back rather than on the chest and head [6]. Thus, it was concluded that wearing one dosimeter on the chest and one dosimeter on the back is suitable for a radiation worker. Finally, the NCRP (55:50) algorithm was regarded as the optimal two-dosimeter algorithm in an inhomogeneous radiation field as the algorithm does not require a high degree of specificity and the results it gives do not significantly vary, regardless of the location of the radiation source. Moreover, the use of two dosimeters, when worn on the chest and back, reduces the risk of underestimating an effective dose [11].

In this field test, the deep dose equivalents were measured by the readouts of TLD on the chest, the head, and the back for radiation workers participating in tasks at NPPs. The effective doses were calculated by two-dosimeter algorithms using these deep dose equivalents. However, the ICRP first introduced the protection quantity for the effective dose equivalent. Regarding the effective dose equivalent, the ICRP updated this concept with the quantity for effective dose. The effective dose cannot be measured directly in the body. Therefore, the International Commission on Radiation Units and Measurements

Table 1. Two-dosimeter Algorithms.

Developer	Algorithm
Ontario Power Generation (OPG)	$H_E(estimate) = 0.11H_P(10)_{head} + 0.89H_p(10)_{torso}$
American National Standard Institute (ANSI)	$H_E(estimate) = \sum_C W_c H_{P,C}(10)$
National Council Radiation Protection and Measurements (NCRP)	$H_E(estimate) = 0.70H_P(10)_{front} + 0.30H_p(10)_{back}$ $H_E(estimate) = 0.55H_P(10)_{front} + 0.50H_p(10)_{back}$
Electric Power Research Institute (EPRI) & Nuclear Regulatory Commission (NRC)	$EDE_{ex} = \frac{1}{2}(Hi + Mean) = \frac{3}{4}Hi + \frac{1}{4}Lo$
Lakshmanan	$H_E(estimate) = \frac{[H_p(10)_{front} + H_p(10)_{back}]}{1.5}$
Kim (Texas A&M University)	$H_E(estimate) = h(H_E)[0.58H_P(10)_{front} + 0.42H_p(10)_{back}]$ where, $h(H_E) = \frac{0.9H_E(AP)}{0.58H_{front}(AP) + 0.42H_{back}(AP)}$

(ICRU) has developed a set of operational dose quantities for individual monitoring, which is the personal deep dose equivalent, Hp(d). This quantity can provide a conservative estimate under nearly all irradiation conditions [12].

3. SOURCE GEOMETRY OF STEAM GENERATOR

Yonggwang NPP No. 2 and Ulchin NPP No. 2 are Korean Standard Nuclear Power (KSNP) plants equipped with Combustion Engineering type steam generators. The radiation field in a steam generator channel head depends on many factors. However, the radiation source term is dominated by ^{60}Co and ^{58}Co, which contribute approximately more than 90% of the total radiation dose rate [13,14].

This source term is originated from the upper U-tubes in a steam generator, which have a photon radiation field. In a steam generator, the dose rate is non-uniform and its gradient varies from high to low. The dose rate normally exceeds a few mSv/hr and its gradient for the chest varies by more than 50%. The space inside the steam generator is very narrow and limited. The source geometry of such a steam generator is shown in Fig. 1 [15,16].

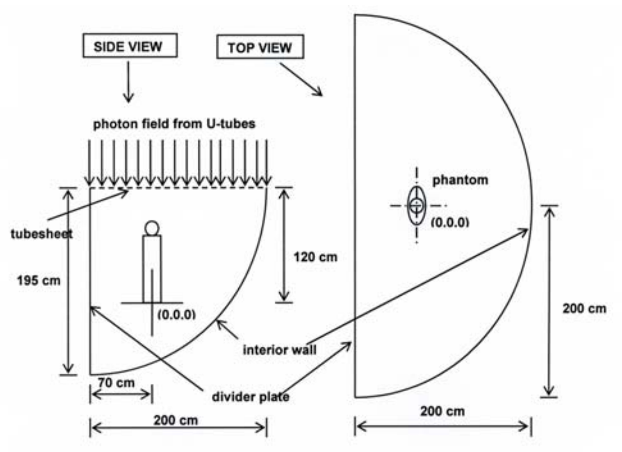

Fig. 1. Source geometry of steam generator.

Steam generators at Korean NPPs differ slightly according to manufacturer. However, it is common that the water chamber of a steam generator is narrow and has a low ceiling. Furthermore, the source geometry of such steam generators, including the source term inside the water chamber of the steam generator, is similar.

4. OPERATIONAL EXPERIENCE OF NCRP (55:50) ALGORITHM

The two-dosimeter algorithm selected in previous study, the NCRP (55:50) algorithm, was reflected in the standard procedures of Korean NPPs at the end of 2005 [6–8]. As a result, this algorithm was applied extensively in all Korean NPPs in 2006. Doses received during the installation of a steam generator nozzle dam, a penetration test of a reactor head, the plugging and nozzle dam removal of a steam generator and during the ultrasonic test of feeder pipe at Kori NPP No. 1, Yonggwang NPP No. 1, and Wolsong NPP No. 1 were analyzed [10,17]. The results are shown in Figs. 2–6.

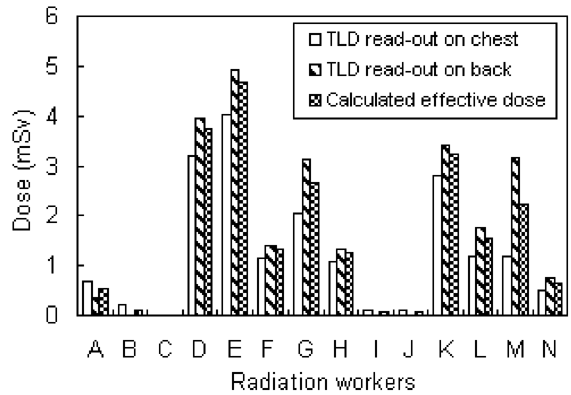

Fig. 2. TLD readouts for the installation of a steam generator nozzle dam at Kori NPP No. 1.

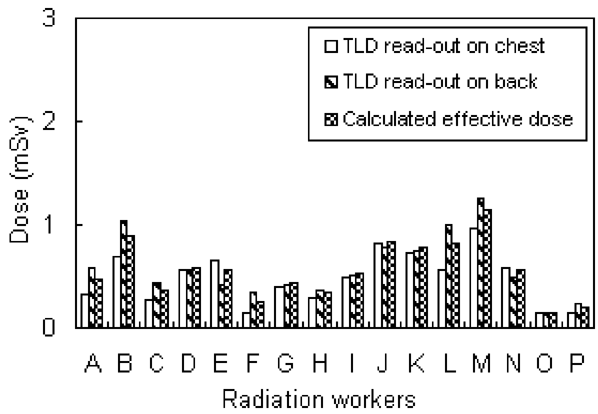

Fig. 3. TLD readouts for the penetration test of a reactor head at Kori NPP No. 1.

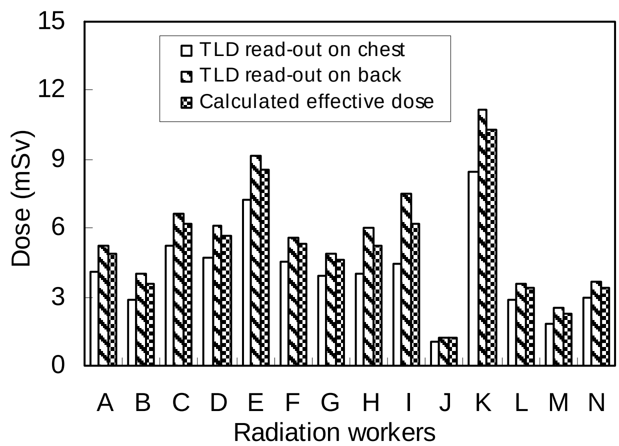

Fig. 4. TLD readouts for the installation of a steam generator nozzle dam at Yonggwang NPP No. 1.

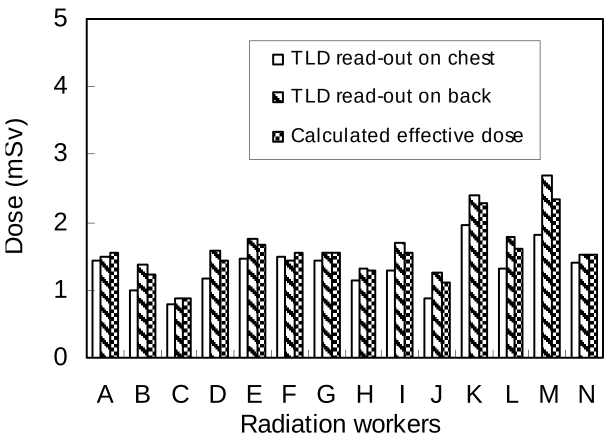

Fig. 5. TLD readouts for the plugging and nozzle dam removal of steam generator at Yonggwang NPP No. 1.

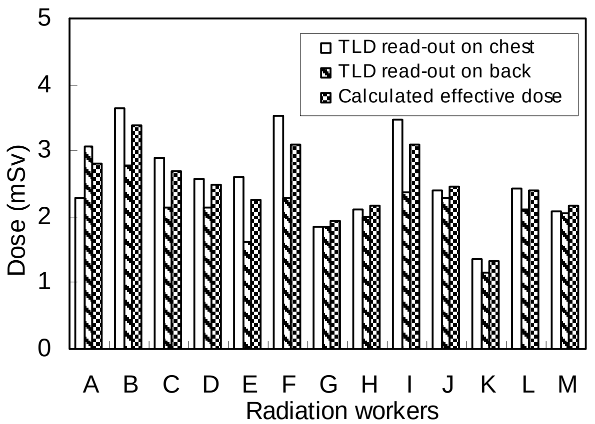

Fig. 6. TLD readouts for the ultrasonic test of feeder pipe at Wolsong NPP No. 1.

To compare the differences among the maximum dose of chest or back dosimeter, minimum dose of chest or back dosimeter, and calculated effective doses using the NCRP (55:50) algorithm, each result from these tests is displayed in Figs. 2–6. After an analysis of the data from all Korean NPPs, the results were found to be mostly similar to the earlier results of previous application tests [6,7,10,17]. That is, the calculated effective dose was lower than the maximum dose on the chest or back dosimeter by approximately 10%–30%. The summary of dose distribution and difference in Figs. 2–6 is demonstrated in Table 2.

For radiation exposure sustained while inside the water chamber of a steam generator, which has a narrow and limited area, the average dose from the back was higher than that from the front. On the other hand, for radiation exposure sustained while conducting an ultrasonic test of feeder pipe, which is conducted in an open environment, the average dose from the front was higher than that from the back. These results were similar to previous field test results [6,7]. Thus, the validity of the two-dosimeter algorithm for use with dosimeters placed on the chest and back was again confirmed through this application test.

Table 2. Summary of Dose Distribution and Difference.

NPP	Items of Radiation Work	General Trend of Dose Distribution[a]	Dose Difference[b]
Kori No. 1	Installation of Steam Generator Nozzle Dam	Chest < E < Back	10–30%
Kori No. 1	Penetration Test of a Reactor Head	Chest < E < Back	5–15%
Yonggwang No. 1	Installation of Steam Generator Nozzle Dam	Chest < E < Back	10–30%
Yonggwang No. 1	Plugging and Nozzle Dam Removal	Chest < E < Back	10–30%
Wolsong No. 1	Ultrasonic Test of Feeder Pipe	Back < E < Chest	5–15%

[a]Chest = TLD readout on the chest, back = TLD readout on the back, E = calculated effective dose
[b]Dose difference = (maximum dose on the chest or back – minimum dose on the chest or back) / calculated effective dose

5. CONCLUSION

In a previous study, an application test was conducted to increase the accuracy of effective dose calculation and to enhance convenience for radiation workers at Korean NPPs. As a result, the NCRP (55:50) algorithm was selected as the optimal method of effective dose calculation and it was recommended that for convenience the two dosimeters worn by radiation workers be placed on the chest and back. In a 2005 application of these previous results, Korean NPPs provided new guidelines to calculate effective doses using the recommended algorithm and to begin to have workers wear two dosimeters in the prescribed manner. These new guidelines have been applied to all Korean NPPs since 2006.

This study provides an analysis of the results of widespread implementation of these guidelines. It was found that implementation of the new guidelines reduces the overestimation and prevents the underestimation of effective doses for radiation workers who participate in tasks expected to result in high radiation exposure. The calculated effective dose was lower than the maximum dose on the chest or back dosimeter by approximately 10%–30%. Moreover, interviewed radiation workers remarked on the increased convenience resulting from changing the position of the dosimeters from the head and chest to the chest and back. In short, the new procedures for the estimation of effective doses at NPPs using two dosimeters are working smoothly, and have met with a favorable reaction from radiation workers.

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REFERENCES

1. Institute of Nuclear Power Operation (INPO). Guidelines for Radiological Protection at Nuclear Power Stations, INPO 91-014 Revision 01, 1995.
2. World Association of Nuclear Operations (WANO). Guidelines for Radiological Protection at Nuclear Power Plants, WANO GL 2004-01, 2004.
3. American National Standards Institute (ANSI). An American National Standard Criteria for Performing Multiple Dosimetry, Report No. HPS N13.41, 1997.
4. Personal Communication with Arif Khan and Dave Whillans of OPG. Summary of Changes to the Method of Assigning Dose from Multiple TLD Badges, 2002.
5. International Commission on Radiation Units and Measurements (ICRU). Measurements of Dose Equivalents from External Photon and Electron Radiation. ICRU Report 51, 1992.
6. Kim HG, Kong TY. A Study on the Application of Two-dosimeter Algorithm to Estimate the Effective Dose in an Inhomogeneous Radiation Field at Korean Nuclear Power Plants. Journal of Radiation Protection 2008 December;33(4):151-160.
7. Kim HG, Kong TY. Application of Estimating Effective Dose from External Radiation using Two Dosimeters during Maintenance Periods at KNPPs. Journal of Nuclear Science and Technology 2008 June;(5):151-154.
8. Korea Hydro and Nuclear Power Co. Ltd. Standard Procedure of Occupational Radiation Dose Assessment, 2006.
9. Korea Electric Power Research Institute (KEPRI). Application of Two-dosimeter Algorithm for Better Estimation of Effective Dose Equivalent to Inhomogeneous Radiation Field at NPPs. TM.105 NJ14.P2006.072, KEPRI, 2006.
10. Cha SC. Current Status of use of a Two-dosimeter. In: Proceedings of ALARA Symposium, 2008.
11. National Council on Radiation Protection and Measurements (NCRP). Use of Personal Monitors to Estimate Effective Dose Equivalent and Dose to Workers for External Exposure to Low-LET Radiation. NCRP Report No.122, Bethesda, 1995.
12. International Commission on Radiological Protection (ICRP). The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, 2007
13. Korea Electric Power Research Institute (KEPRI). Development of Technology for Reducing Radiation Exposure in Primary System at Nuclear Power Plants. KRC-90N-J04, KEPRI, 1993.
14. Electric Power Research Institute (EPRI). Techniques for Controlling Radiation Exposure. Nuclear News (February), 43-47, 1993.
15. Korea Electric Power Corporation (KEPCO). Final Safety Analysis Report for the Yonggwang Nuclear Power Plant Unit No. 3 and 4, 2000.
16. Korea Electric Power Research Institute (KEPRI). Technical Seminar for Estimation of Effective Dose Equivalent using a Two-dosimeter by Dr. Chan Hyung Kim of Hanyang University, Technical Correspondence, KEPRI, 2004.
17. Yang MK. Experience of Advanced Two-dosimeter Procedure to Korean Nuclear Power Plants. In: Proceedings of 12th Dosimetry Workshop, 2008.