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ARTICLE

An Analysis of Radiation Field Characteristics for Extremity Dosimetry in Nuclear Power Plants

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Workers who maintain the water chambers of steam generators during the maintenance period in Nuclear Power Plants (NPPs) have a higher likelihood of high radiation exposure even if they were exposed for a short period of time. In particular, it is expected that the hands would receive the highest radiation exposure because of its contact with radiation materials. In this study, characteristic analysis of inhomogeneous radiation fields for contact operations was conducted using Thermoluminescent Dosimeter (TLD) readouts from the application tests of two-dosimeter algorithms to Korean NPPs. It was observed that inhomogeneous radiation fields for contact operations in NPPs were dominated by high-energy photons, such as ^{58}Co and ^{60}Co. In addition, field tests for workers who maintained the steam generator during an outage at Ulchin NPPs in 2009 were conducted to analyze the radiation fields and to estimate the extremity dose. As a result, the radiation fields were dominated by high-energy photons while the extremity dose was two times higher than that of the deep dose.

KEYWORDS: extremity dose, extremity dosimeter, radiation field characteristics, TLD algorithm, maintenance on steam generator water chamber

I. Introduction

The International Commission on Radiological Protection (ICRP) published the ICRP Publication 60 in 1990 to revise the previous recommendations for radiation protection.[1)] In 1996, the International Atomic Energy Agency (IAEA) also published the Basic Safety Standards (BSS-96) for radiation protection based on the ICRP Publication 60.[2)] In Korea, the research project for implementing the ICRP Publication 60 in the nuclear industry has been conducted by the Korea Institute of Nuclear Safety (KINS) since 1996. After 2003 the revised Korean atomic law, which reflects the ICRP Publication 60, was enforced.[3)] Korean nuclear power plants (NPPs) also implemented the new guidelines based on the ICRP Publication 60 for radiation protection and dosimetry of NPP workers.[4)]

The effective dose was introduced as a unit of dose calculation in the ICRP Publication 60. The effective dose is the amount of radiation exposure that a human being is exposed to and is calculated by evaluating the product of the radiation weighting factor (W_R), tissue weighting factor (W_T) and equivalent dose. Since the effective dose is a protection quantity of the individual dose and is used for promoting radiation protection, it is not possible to measure the effective dose in practice. Thus, deep dose is alternatively used to measure the effective dose and then the effective dose is estimated by deep dose. According to the notification No. 2008-48 from the Ministry of Education, Science and Technology (MEST), the deep dose is considered to be $H_p(10)$, which is the dose at a depth of 1 cm in the soft tissue of a human being, as defined by the International Commission on Radiation Units and Measurements (ICRU).[4,5)]

In NPPs, Thermoluminescent Dosimeter (TLD) is used for dosimetry of radiation workers. NPP workers should wear TLD to enter the radiation-controlled area and their individual dose is estimated by using TLDs monthly. Approximately 80 % of total radiation exposure is attributed to maintenance that occurred during a maintenance period in NPPs. Those workers who maintained the steam generator water chamber in NPPs has a high likelihood of radiation exposure to the whole body, even if the exposure was for a short period of time, due to the high radiation exposure rates. In particular, it is expected that hands would receive the highest radiation exposure because of its contact with radioactive materials. Thus, workers are required to wear an additional TLD on the back, including a main TLD on the chest, while performing maintenance at inhomogeneous radiation fields, such as steam generator water chambers. In some cases, extremity dosimeter is also worn on the fingers of workers.

In this study, radiation fields in NPPs were analyzed to estimate the extremity dose in workplaces where high radiation exposure is possible. To analyze the radiation fields, studies were made on the dose limits of extremity, the technical standards of extremity dosimetry, the structure of extremity dosimeters, and its radiation response. In addition, the incident radiation fields were analyzed using TLD readouts during the maintenance period of inhomogeneous radiation fields. Field tests where workers wore TLD on the chest and back and wore additional TLD on the wrist and extremity dosimeter on the finger were also conducted. TLD on the wrist and extremity dosimeter on the finger were used to analyze radiation fields and to estimate the extremity dose, respectively.

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II. Extremity Dose Limits and Technical Standards

The annual effective dose limit for radiation workers is 100 mSv per 5 years.[6] The ICRP determines the annual dose limits of 150 mSv for eye lens and 500 mSv for skin as an equivalent dose. For extremities, such as hands and feet, the annual equivalent dose limit is 500 mSv.[1,6] In most countries, a deep dose for the entire body is required to estimate the dose limits to the standards of the atomic law, but an equivalent dose for hands and feet is not demanded to evaluate by the atomic law.

The standard from the American National Standards Institute (ANSI) is mentioned as a representative technical standard for deep dose calculation.[7] This standard is reflected in America's code of federal regulations and is also applied to dosimetry. Notification No. 2008-48 of the MEST in Korea, which regulates the registration of reading business and its audits, is based on the ANSI standards.[7] In terms of extremity dosimetry, the ANSI provides the standard for the performance testing of extremity dosimeters, which is ANSI N13.32-1995.[8] This standard provides the criteria for acceptable performance and standardized testing conditions for personnel extremity dosimetry services. In particular, test categories, irradiation ranges, and acceptable levels of performance are specified in this standard. The reference depth for the dose specification needed for the extremities is 7 mg/cm^2, as recommended by both the ICRP and the ICRU. The standard for performance testing of extremity dosimeters is not yet reflected in both Korean atomic law and American federal regulations.

III. Structure of Extremity Dosimeters

In Korean NPPs, two types of whole body TLD and its reader system, Panasonic and Harshaw, are equipped to estimate the deep dose. For Panasonic TLD, lithium borate ($Li_2B_4O_7$) and calcium sulfate ($CaSO_4$) are used as thermoluminescent materials. Korean NPPs use a UD-802 dosimeter to measure the deep dose. In the case of Harshaw TLD, lithium fluoride (LiF) is used as thermoluminescent materials. Korean NPPs use 8805 dosimeter to measure the deep dose.

For extremity dosimetry, Panasonic and Harshaw extremity dosimeters and their reader systems are also used in Korean NPPs. First, Panasonic adopts the ring type of extremity dosimeter and $^{n}Li_2{}^{n}B_4O_7(Cu)$ is used as the material for the TL chips that are inserted into a ring (**Fig. 1**).[9] This dosimeter can measure the skin dose in a range of 0.1 mSv ~ 10 Sv. The weight of the TL chip is less than 1 g and it is classified as either UD-807AS (without numbers) or UD-807ASN (with visible numbers) depending on whether specified numbers are given or not. After the tasks, the TL chip should be removed from the ring and be inserted into a cardholder to see if there are any extremity dosimeters (**Fig. 2**).[9]

Harshaw extremity dosimeters consist of two types of dosimeters, DXTRAD (ring type) and EXTRAD (strap type). The manufacturer recommends to select one of them based on what the user feel is more convenient.[9] Harshaw DXTRAD is a ring type of small dosimeter, which features individual numbers with a barcode that makes it possible to read and identify each dosimeter by humans and by systems. The DXTRAD is composed of three parts: a ringlet, ring cap, and a finger ring container (**Fig. 3**).[10]

Harshaw EXTRAD is a type of extremity dosimeter that is composed of a strap, which makes it easy to wear on fingers and wrists (**Fig. 4**).[10] The EXTRAD uses a chipstrate, which consists of a Polyamide strip that includes a TL chip and a 5-digit barcode ID, instead of a ringlet from the DXTRAD. This TL chip enables anyone to measure a photon, beta or neutron. The materials of the TL chips are either LiF:Mg,Ti or CaF_2:Mn, which has 3 mm^2 in area and is fixed on an inert substrate.

Fig. 1 Panasonic UD-807 dosimeter

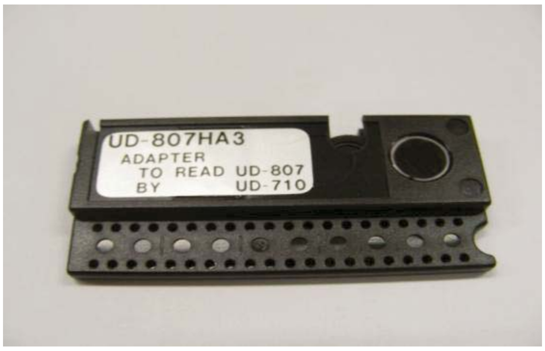

Fig. 2 Panasonic UD-807HA3 card holder

Fig. 3 Harshaw DXTRAD dosimeter

Fig. 4 Harshaw EXTRAD dosimeter

IV. Analysis of Radiation Field Characteristics for Workplaces that have High Radiation Exposure

In a steam generator, most source term originates from the upper U-tubes where the radiation fields are built from high to low locations. In this case, the radiation source term is dominated by ^{58}Co and ^{60}Co, whose exposure rates vary from several tens of mSv/hr to a few hundreds of mSv/hr.[11,12] At this location, workers normally received radiation exposure to inhomogeneous parts of the body depending on the place where they are working.

In 2004, application tests for radiation workers who maintained the steam generator water chamber at Yonggwang NPP Unit 4 during the 7th maintenance period were conducted to determine the optimal two-dosimeter algorithm.[13,14] In these tests, three dosimeters were provided to radiation workers, who wore a TLD on the head, chest, and back simultaneously. As a result of the analysis on the TLD readouts, the NCRP (55:50) algorithm, the two-dosimeter algorithm that 55 % weighting is given to the dose from the chest and 50 % weighting is given to the dose from the back when calculating the effective dose, was selected as the optimal method for deep dose calculation.[13,14)]

In this study, an analysis of radiation field characteristics from a steam generator water chamber was conducted using 4 TLD readouts from previous application tests and TLD algorithm. As a result, the TLD readouts from each element were almost similar; that is, both the deep dose and shallow dose calculated by the TLD algorithm showed the same dose quantity. Thus, it is regarded that the radiation fields for workplaces in NPPs that had high radiation exposure are dominated by high-energy photons, such as ^{58}Co and ^{60}Co. **Table 1** demonstrates a part of the results of the two-dosimeter application tests from the Yonggwang NPPs.

Table 1 TLD readouts of radiation workers that maintained the steam generator nozzle dam at Yonggwang NPPs

Workers	Element 1 (mR*)	Element 2 (mR*)	Element 3 (mR*)	Element 4 (mR*)	Deep dose (mSv)	Shallow dose (mSv)	Wearing position
A	2.45	2.42	2.20	2.30	2.34	2.34	Head
	1.68	1.64	1.75	1.81	1.71	1.71	Chest
	2.12	2.21	2.40	2.26	2.24	2.24	Back
B	3.67	3.55	3.38	3.74	3.57	3.57	Head
	2.76	2.50	2.88	2.81	2.73	2.73	Chest
	4.02	3.60	3.44	3.74	3.69	3.69	Back
C	3.70	3.65	3.28	3.47	3.51	3.51	Head
	2.79	2.47	2.64	2.63	2.62	2.62	Chest
	3.01	2.93	3.01	3.18	3.02	3.02	Back
D	4.11	4.38	4.12	4.37	4.22	4.22	Head
	3.68	3.51	3.81	3.63	3.64	3.64	Chest
	4.71	4.79	4.61	4.63	4.66	4.66	Back
E	1.90	1.77	1.81	2.05	1.88	1.88	Head
	1.34	1.50	1.52	1.42	1.44	1.44	Chest
	1.79	1.72	1.95	1.95	1.85	1.85	Back
F	0.08	0.09	0.16	0.15	0.12	0.12	Head
	0.15	0.18	0.21	0.19	0.18	0.18	Chest
	0.05	0.05	0.13	0.12	0.08	0.08	Back
G	1.36	1.34	1.32	1.25	1.31	1.31	Head
	0.93	0.88	1.06	1.00	0.96	0.96	Chest
	1.05	1.09	1.36	1.25	1.18	1.18	Back
H	2.24	2.12	2.19	2.32	2.21	2.21	Head
	1.59	1.69	1.79	1.76	1.69	1.69	Chest
	2.23	1.99	2.17	2.08	2.11	2.11	Back

Table 2 TLD readouts of radiation workers who wore TLD on the wrist while maintaining the steam generator at Ulchin NPPs

Workers	Element 1 (gU)	Element 2 (gU)	Element 3 (gU)	Element 4 (gU)	Deep dose (mSv)	Shallow dose (mSv)
I	103.0	102.6	100.6	98.0	0.89	0.89
J	251.6	246.2	243.7	236.5	2.19	2.19
K	131.7	134.0	132.9	128.8	1.17	1.17
L	164.0	159.8	160.7	156.2	1.41	1.41
M	154.9	154.3	148.8	144.2	1.36	1.36
N	128.2	126.3	123.3	122.3	1.11	1.11

V. Field Tests for Extremity

In February 2009, field tests for radiation were conducted on workers who maintained the steam generator during a maintenance period at Ulchin NPP Unit 4 to find out the radiation field characteristics of workplaces where there was high radiation exposure.[15)] In the field tests, Harshaw 8805 dosimeters were used as whole body TLDs while the Harshaw EXTRAD dosimeters were used as extremity dosimeters. During the field tests, the workers who wore TLD on the chest and back wore an additional TLD on the wrist and an extremity dosimeter on the finger. The TLDs on the chest and back were commonly used in an inhomogeneous radiation field to measure the effective dose for workers.[13,14)] The TLD on the wrist was intended to unfold the incident radiation field to the fingers since the extremity dosimeter cannot provide the information of incident radiation fields due to its single element. Finally, the extremity dosimeter on the finger was intended to estimate the real extremity dose.

As a result of the analysis of the TLD readouts from the TLD on the wrist, it was discovered that the TLD readouts from each element were almost similar and it was found that the incident radiation field to the fingers was a high-energy photon.[15)] This result is similar to the previous results from the two-dosimeter application tests at Yonggwang NPPs in 2004. Thus, it was concluded that the risk of non-penetrating radiation, such as beta ray, is low for NPP workers because the incident radiation originated from the high-energy photons. **Table 2** displays the results of TLD readouts from TLD on the wrist.

VI. Conclusion

It was found that the incident radiation for workplaces in a steam generator that had high radiation exposure during a maintenance period is high-energy photons, which have high penetration. In addition, it is concluded that the contribution of shallow dose to an extremity dose for radiation workers is low and it is enough to measure deep dose to estimate the radiation exposure of NPP workers. Thus, to simplify the process of dosimetry for NPP workers, it is suggested to estimate the deep dose only instead of the extremity dose for workplaces that had high radiation exposure. It is also necessary to have more flexibility to create conditions for extremity dosimeters.

It is expected that the classification of incident radiation fields for extremity dosimetry will be confirmed by these field tests. Finally, a guide of extremity dosimetry for NPP workers will be suggested after conducting further examination on the field test results.

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References

1) International Commission on Radiological Protection, *1990 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 60, (1991).
2) International Atomic Energy Agency, *Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*, IAEA Safety Series No. 115, Vienna, (1996).
3) Ministry of Education, Science, and Technology. *A notification No. 2008-31: Regulations for radiation protection*, (2008).
4) Ministry of Education, Science, and Technology. *A notification No. 2008-48: Regulations for registration of reading business and its examination*, (2008).
5) International Commission on Radiation Units and Measurements, *Quantities and Units in Radiation Protection Dosimetry*, ICRU Report 51, (1993).
6) International Commission on Radiological Protection, *The 2007 Recommendations of the International Commission on Radiological Protection*, ICRP Publication 103, (2007).
7) American National Standard Institute, *An American National Standard for Dosimetry - Personnel Dosimetry Performance Criteria for Testing*, ANSI N13.11, (1993).
8) American National Standard Institute, *An American National Standard - Performing Testing of Extremity Dosimeters*, ANSI N13.32, (1995).
9) Panasonic Industrial Company, *Brochure for the Panasonic Extremity Dosimeter*, (2008).
10) Thermo Electron, *WinAlgorithms: Dose Calculation Algorithm for DXTRAD & EXTRAD Dosimeters User's Manual*, (2008).
11) Y. H. Yoon, "Shielding Establishment inside Steam Generator," *Proc. Information System on Occupational Exposure*, Asian ALARA Symposium, (2007).
12) H. Ocken, "Techniques for Controlling Radiation Exposure." *Nuclear News,* Feb, 43-47 (1993).
13) H. G. Kim, T. Y. Kong, "A Study on the Application of Two-dosimeter Algorithm to Estimate the Effective Dose in an Inhomogeneous Radiation Field at Korean Nuclear Power Plants," *J. Radiation Protection*, 33[4], 151-160 (2008).
14) H. G. Kim, T. Y. Kong, "An Analysis of Radiation Field Characteristics for Estimating the Extremity Dose in Nuclear Power Plants," *J. Radiation Protection*, 34[4], 176-183 (2009).
15) H. G. Kim, T. Y. Kong, "Application of Estimating Effective Dose from External Radiation using Two Dosimeters during Maintenance Periods at KNPPS," *J. Nuclear Science and Technology*, Supplement 5, 151-154 (2008).