Skin Dose Assessment by Hot Particles in Domestic Nuclear Power Plant

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1. Introduction

Since a contamination event by hot particles happened due to damaged nuclear fuel at a nuclear power plant (NPP) in the 1980's, skin exposure resulted from hot particles has gotten considerable attention from all the radiation workers in the nuclear industry. In particular, contamination incident caused by hot particles which happened at a NPP in Sasquehanna proved that there existed hot particles with the radioactivity of 0.7 GBq, 0.78 GBq, and even 2.78 GBq at maximum. One of these particles was found on a worker's shoe and gave out a dose of 170 mSv[1]. Although there has been no contamination event reported in domestic NPPs which are caused by hot particles, it is hard to conclude that there is no possibility of such contamination for radiation workers. The contaminated samples employed in this study were taken from local NPPs and supposes a case of a worker's skin contaminated by hot particles to evaluate the dose provided to the worker's skin.

2. Materials and Methods

In order to estimate the exposure of hot particles to workers at NPPs, this paper uses hot particles found in the radiation management area of local NPPs. The hot particles used in this research were contaminated particles with higher radioactivity among the samples collected during the overhaul period of four domestic NPPs and are presented in Figure 1[1]. The weight and diameter of UL-3 particle were 0.0627 g and 205.6 μm each. Contained nucleuses were 18 kinds including ^{57}Co, ^{60}Co, and ^{95}Zr, and the radioactivity was ranged from 10^0 Bq to 10^6Bq. The absorbed dose was calculated from the lens, shallow, and deep dose to evaluate the skin dose. In terms of the evaluation condition, the type of source was a point, and in regard of exposure duration, it was considered when the worker was exposed to hot particles at NPP during four working hours in the morning. Absorbed doses for assessment were calculated by use a point kernel code VARSKIN 3 and a Monte Carlo code MCNPX 2.5.0[2,3].

2.1 MCNPX 2.5.0 Code

The conversion electrons and backscattered correction were considered as defaults in estimating the dose rate. In order to simulate the source, the beta energy spectrum from ICRU and ICRP was used[4,5]. The tissue calculation under consideration was performed not for tissue but for water, a compound composed of 88.8 % oxygen and 11.2 % hydrogen and having a density of 1 g/cm^3.

The fluence (particles per cm^2) tally was calculated for an averaged 1 cm^2 area using the DE/DF card. In order to estimate the absorbed dose, the results of the fluence tally were multiplied by the stopping power (MeV·cm^2/g) of water, obtained from NIST's database[6]. The components and weighting percent of the cover material were also obtained from NIST's database. The simulations for the disk-type source were performed using the SDEF card and the SI, SP card. Calculations using MCNPX with the ITS indexing algorithm, also were performed (utilizing the DBCN card switched to 17j)[7]. The ITS style energy indexing algorithm, also called the nearest group boundary treatment, allows one to match (as closely as possible) the MCNPX results.

2.2 Varskin 3 Code

The dose calculation using the VASKIN 3 code was based on the values of Berger's scaled point kernel for water. The effect of internal conversion and auger electron was considered in order to calculate the dose rate as defaults. The source term and the dose assessment options were selected to equally calculate the dose rate in the VARSKIN 3 as well as the MCNPX simulation conditions.

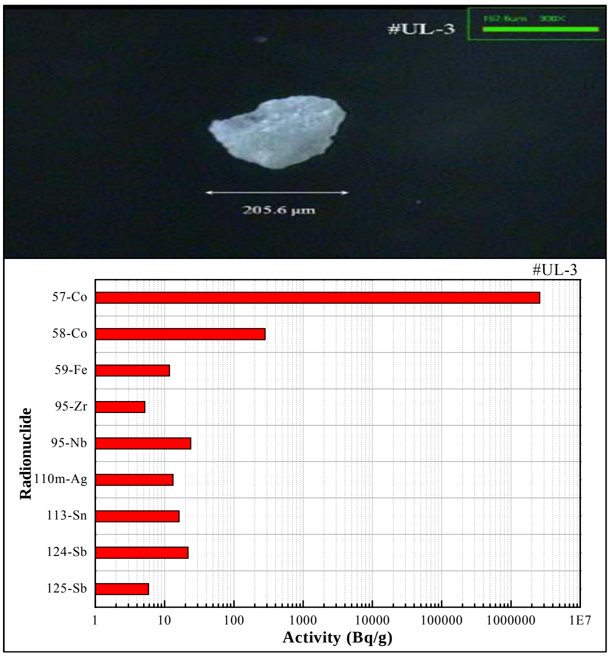

Fig. 1. Microscope image of the particle #UL-3 and its activity content

2. Results

Calculated doses per unit activity with the two codes agreed reasonably well and in the range of 10^{-7}~10^{-3} mGy/h in results. Dose results including Lens of the eye and skin were presented in table 1, 2, and 3. By applying the dose conversion factor to the hottest particle activity, with an assumption that the particle resides on the skin for 4 hours, absorbed dose to different depth of skin were assessed to get 56.7, 0.11, and 2.41 mGy at 0.07, 10, and 3 mm depth, respectively. Table 1. Skin equivalent dose at 3.00 mm depth from a point source of 1Bq on the skin

Table 1. Skin equivalent dose at 3.00 mm depth from a point source of 1Bq on the skin

Nuclide	MCNPX 2.5.0 [mGy/h·Bq]	VARSKIN 3 [mGy/h·Bq]	V/M[a)]
^{57}Co	1.34E-05	1.85E-05	1.381
^{58}Co	1.04E-05	1.47E-05	1.413
^{59}Fe	7.73E-06	7.65E-06	0.990
^{95}Nb	5.27E-06	5.29E-06	1.004
^{95}Zr	5.35E-06	5.12E-06	0.957
^{110m}Ag	-	1.84E-05	-
^{113}Sn	-	5.65E-06	-
^{124}Sb	7.35E-05	6.35E-05	0.864
^{125}Sb	-	6.05E-06	-

a) VARSKIN to MCNPX ratio

Table 2. Skin equivalent dose at 0.07 mm depth from a point source of 1Bq on the skin

Nuclide	MCNPX 2.5.0 [mGy/h·Bq]	VARSKIN 3 [mGy/h·Bq]	V/M[a)]
^{57}Co	9.11E-05	1.03E-04	1.130
^{58}Co	3.59E-04	3.46E-04	0.964
^{59}Fe	6.00E-04	1.12E-03	1.867
^{95}Nb	1.66E-04	2.66E-04	1.602
^{95}Zr	-	1.15E-03	-
^{110m}Ag	-	5.25E-04	-
^{113}Sn	-	3.15E-05	-
^{124}Sb	1.55E-03	1.46E-03	0.942
^{125}Sb	-	6.87E-04	-

a) VARSKIN to MCNPX ratio

Table 3. Skin equivalent dose at 10.0 mm depth from a point source of 1Bq on the skin

Nuclide	MCNPX 2.5.0 [mGy/h·Bq]	VARSKIN 3 [mGy/h·Bq]	V/M[a)]
^{57}Co	4.03E-06	3.38E-06	0.839
^{58}Co	1.86E-06	2.68E-06	1.441
^{59}Fe	1.39E-06	1.40E-06	1.007
^{95}Nb	9.49E-07	9.67E-07	1.019
^{95}Zr	9.35E-07	9.36E-07	1.001
^{110m}Ag	-	3.36E-06	-
^{113}Sn	-	1.03E-06	-
^{124}Sb	2.21E-06	2.02E-06	0.914
^{125}Sb	-	1.11E-06	-

a) VARSKIN to MCNPX ratio

3. Conclusion

This paper calculated the dose from radiation worker when hot particles found in local nuclear power plants contaminated the worker's skin. The result showed that the dose was about to receive from several mGy to tens of mGy. These doses are below the threshold dose for acute deterministic effects to the irradiated tissues. However, in case that such a particle remains on the skin undetected for a few days, the total dose may exceed the threshold dose for erythema to small area of skin. In this respect, being aware of and control of hot particles are needed for successful radiological control in the working environment of NPPs.

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