Reevaluation of Nasal Swab Method for Dose Estimation at Nuclear Emergency Accident

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Abstract. ICRP Publication 66 human respiratory tract model has been used extensively over in exposure dose assessment. It is well known that respiratory deposition efficiency of inhaled aerosol and its deposition region strongly depend on the particle size. In most of exposure accidents, however, nobody knows a size of inhaled aerosol. And thus two default aerosol sizes of 5μm in AMAD for the workers and 1μm in AMAD for the public are given as being representative in the ICRP model, but both sizes are not linked directly to the maximum dose. In this study, the most hazardous size to our health effects and how to estimate an intake activity was discussed from a viewpoint of emergency medicine. In exposure accident of alpha emitter such as Pu-239, lung monitor and bioassay measurements are not the best methods for rapid estimation with high sensitivity, so that an applicability of nasal swab method has been investigated. A computer software, LUDEP, was used in the calculation of respiratory deposition. It showed that the effective dose per unit intake activity strongly depended on the inhaled aerosol size. In case of Pu-239 dioxide aerosols, it was confirmed that the maximum of dose conversion factor was observed around 0.01μm. It means that this 0.01μm is the most hazardous size at exposure accident of Pu-239. From analysis of the relationship between AI and ET1 deposition, it was found that the dose conversion factor from the activity deposited in ET1 region also was affected by the aerosol size. The usage of the ICRP's default size in nasal swab method might cause obvious underestimation of the intake activity. Dose estimation based on nasal swab method is possible from safety side at nuclear emergency, and the availability in quantity should be reevaluated for emergency medicine considering of chelating agent administration.

KEYWORDS: aerosol size, respiratory deposition, nasal swab, dose estimation, emergency accident.

1. Introduction

In an exposure accident at nuclear facilities, nasal swab samples are taken immediately. If radioactivity were detected in it, inhalation intake would be doubted. But the use of sample had been limited because of uncertainty in the detected activity. The quantitative analysis on intake radioactivity has been made with in-vivo and/or in-vitro measurements [1]. But the detection lower limit of a lung monitor and a whole body counter is not always adequate, especially against an alpha emitter such as Pu-239. And it takes long time to take bioassay samples of urine and feces. For prompt administration of a chelating agent, rapid dose estimation is very important even if it had uncertainty with some extent.

When aerosols are inhaled to respiratory tracts, it is well known that the deposition region and the deposition efficiency depend on the physical properties of size, density, shape and so on. Especially, aerosol size is a key parameter to characterize the deposition. In most of emergency accidents, however, nobody knows the properties of inhaled aerosols. Thus it is very difficult to estimate the exposure dose. Therefore, the most probable aerosol size of 5μm is proposed as a default size in ICRP (International Commission on Radiological Protection) human respiratory tract model [2]. In the former ICRP model, 1μm had been given [3]. Then, dose coefficients from intake radioactivity in Bq to committed effective dose in Sv are given in these two sizes of 5μm and 1μm against each radionuclide [4]. However, the value of 5μm is not the most conservative size from a viewpoint of safety side but the most probable size observed in workplace. So to make a decision of medical treatment in nuclear emergency, more discussion should be made. It is worthy of notice that reevaluation study analyzed 15 years of collected data on nose swabs at the Los Alamos National Laboratory (LANL) [5]. It provides a dose factor of 0.8 mSv/Bq for plutonium, which is apparently higher than that tabulated in ICRP Publ.68. In this paper, nasal swab method is reevaluated for emergency medicine.

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2. Evaluation Method

Aerosol deposition within human respiratory tract was based on ICRP Publication 66 model, which is the latest deposition model. In the model, the human respiratory tract is divided into the following five regions: anterior nasal passage (ET1), posterior nasal passage, pharynx and larynx (ET2), bronchial (BB), bronchiolar (bb), and alveolar-interstitial (AI). And also exercise level is assumed to be the following four levels of "sleep", "sitting/rest", "light exercise" and "heavy exercise". As for breathing type in each level, nasal breathing is 100% except heavy exercise consisting of 50% nasal and 50% oral breathing.

Target aerosol in this study is plutonium dioxide that is considered to be the most hazardous at nuclear emergency accident. Particle density of the aerosol is 11.5 g/cm³ and its particle shape factor was assumed to be one, which is a factor for spherical particle. Aerosol size was assumed to be ranged from 0.001 μm to 10 μm in diameter. In the ICRP Publ. 66 model, some parameters on aerosol properties are given as a default. The particle density is 3 g/cm³ and particle shape factor is 1.5. And particle sizes are 5 μm for the occupational workers and 1 μm for the public, respectively.

Deposition efficiency and the resultant committed effective dose was evaluated with numerical simulation using a computer code, LUDEP (Lung Dose Evaluation Programme) version 2.07, developed by the NRPB (National Radiological Protection Board), UK [6]. Aerosol size was described by thermodynamic diameter (TD) for small aerosols ranging from 0.001 μm to 0.5 μm or by aerodynamic diameter (AD) for large aerosols ranging from 0.2 μm to 10 μm. A total of 25 particle sizes ranged from 0.001 μm to 10 μm in diameter were selected at nearly logarithmically equal intervals.

3. Results and discussion

3.1 Dose conversion from the intake radioactivity

From the LUDEP evaluation data, dose conversion factor, DCF\text{intake}, from intake radioactivity in Bq to committed effective dose in mSv was calculated in the ICRP default condition of particle density of 3 g/cm³ and particle shape factor of 1.5 against the occupational workers in the mixed exercise level consisting of light exercise of 68.75% and sitting of 31.25%. Two curves of dose conversion factor in thermodynamic region and aerodynamic region were shown in Fig. 1. When particle density was low, the curves might be roughly united into one by using single conversion factor between the two types of aerosol size. But it is more difficult against aerosols with the higher particle density such as plutonium of our interest, so that the curves were not united to one. Figure 1 showed that the dose conversion factor depended on the aerosol size. The factor corresponded to the dose coefficients tabulated in ICRP Publication 68 [4]. Our results consisted with the ICRP dose coefficients of 0.0083 mSv/Bq for 5-μm-sized aerosol and 0.015 mSv/Bq for 1-μm-sized aerosol for insoluble plutonium at inhalation. Figure 1 indicated two important information for emergency medicine. One is that the curve had a maximum around 0.01 μm. The other is that the maximum value of 0.079 mSv/Bq was higher by approximately 9 times than 0.0086 mSv/Bq in 5 μm. It means that dose estimation would be made in safety side by using a maximum value of dose conversion factor, and that the use of a dose conversion factor of the ICRP default size of 5 μm might cause underestimation of the committed effective dose.

Since aerosol deposition within the respiratory tract is well known to be affected by exercise level, dependence of the dose conversion factor on exercise level was examined. And particle density and particle shape factor were changed from the default physical properties to those of alpha emitter of interest. In this study, Pu-239 dioxide with particle density of 11.5 g/cm³ and particle shape factor of 1 was selected. Figure 2 showed the dependency curves at four exercise levels, comparing with the ICRP default exercise level for occupational workers. In aerodynamic region, the dose conversion factor was strongly affected by the exercise level, and high factors were observed in micrometer-size. On the other hand, the effects caused by exercise level were relatively small in thermodynamic region. The peak aerosol size was slightly changed, but the maximum value of the factors was very stable. They ranged from 0.074 mSv/Bq to 0.086 mSv/Bq, and the scattering from 0.079 mSv/Bq in the default exercise level was within 10%.
3.2 Dose conversion from the deposited radioactivity within ET\textsubscript{1} region

In place of the intake radioactivity, dose conversion factor, D\textsubscript{CFnasal}, from the deposited radioactivity in ET\textsubscript{1} region was calculated. As shown in Fig. 3, the curve of dose conversion factor from deposited radioactivity was similar with that from the intake radioactivity. But the dependency on aerosol size became stronger, and the factors increased clearly in whole size range. The maximum value of the factors increased by approximately 18 times from 0.079 mSv/Bq to 1.4 mSv/Bq. It suggested that the higher factors mean lower sensitivity against contaminant detection, and that the strong dependency on aerosol size means more poor instability against unknown aerosol accident. But the maximum value of 1.4 mSv/Bq is still good for emergency medicine. Since annual dose limit for occupational workers is 50 mSv, at least 36 (=50/1.4) Bq is expected to be detected as radioactivity deposited in ET\textsubscript{1} region. This radioactivity of 36 Bq would be easily detected even if the contaminant were alpha emitter such as Pu-239.

As for dose conversion factor from the deposited radioactivity in ET\textsubscript{1} region, its dependence on exercise level was examined. As shown in Fig. 4, the factor also was strongly affected by the exercise level in the same aerodynamic region as observed in Fig. 2. And moreover in thermodynamic region a marked change was observed at heavy exercise. The reason is oral breathing of 50\%, and thus aerosol deposition in ET\textsubscript{1} region simply reduced almost by half. This side effect at heavy exercise is unavoidable in the nasal swab method measuring radioactivity deposited in ET\textsubscript{1} region. Therefore, more attention should be paid to exercise level in evaluation of the nasal swab data.
Guilmette [5] reported the empirical dose conversion factor of 0.84 mSv/Bq from analysis of 47 inhalation accidents occurred in LANL in USA. When aerosol size is read out from curves in Fig. 4 by substituting the 0.84 mSv/Bq, it located in a range between 0.4μm and 0.6μm as an aerodynamic diameter. The size is not inconsistent with the Guilmette's advocacy that 0.2μm is too small. The maximum value of 2.8 mSv/Bq in the curves of dose conversion factor was adequately higher than the empirical value even if the scattering were considered.

4. Conclusion

To use the maximum value of dose conversion factor against aerosol size provides the maximum dose on the assumption that the most hazardous aerosol might be inhaled at the accident. The dose was obviously high, comparing with that of the ICRP default size of 5μm. The result supports the empirical values of the LANL inhalation accidents. This reevaluation of nasal swab method gives us valuable information on rapid dose estimation for nuclear emergency medicine such as an administration of chelating agent.

On the other hand, instability in accuracy of nasal swab method has been pointed out. Technical problems hereafter in measurements such as wiping and detection efficiencies should be examined and solved.

REFERENCES


