Sensitivity of Inhalation Radiation Dose to Airborne Particle Properties: Focusing on Radioactive Waste and TENORM

Kwang Pyo Kim
Kyung Hee University, Yongin-si, Gyeonggi-do, Republic of Korea
kpkim@khu.ac.kr

1. Introduction

Radiation exposure due to inhalation of radioactive airborne particles is one of the most common intakes in industry associated with radioactive waste and Technologically Enhanced Naturally Occurring Radioactive Material (TENORM).

In 1994, the International Commission on Radiological Protection (ICRP) issued Publication 66, Human Respiratory Tract Model (HRTM) for radiological protection [1]. The model includes morphological, physiological, and radiobiological characteristics of the respiratory tract, deposition and clearance of inhaled particles, and radiation dosimetry. A substantial improvement of this model was ability to explicitly consider particle properties (size, shape, density, and solubility) for radiation dosimetry. The particle properties influence particle deposition and clearance in the respiratory tract and hence influencing radiation dose. The ICRP 66 HRTM recommends that site-specific information on particle physicochemical properties should be measured and then used. In the absence of specific information, ICRP 66 HRTM suggests default reference values. However, the reference values were obtained by pooling data from several studies. In reality, particle properties are widely distributed. Consequently, using recommended default values can potentially skew dose estimates to unrealistic values in individual exposure cases.

The objectives of present study are to to calculate radiation doses for various particle properties and to determine the degree to which uncertainties in particle size, shape, density, and solubility contribute to variations in the effective dose to workers. The results will provide rationale to use site-specific particle properties to reduce uncertainty in the dose assessment.

2. Materials and Methods

The values of 50-year committed effective dose per unit intake were computed for U-238 and Th-230 to workers. Dose computation was performed using Integrated Modules for Bioassay Analysis (IMBA) code (Richland, WA).

Radiation dose was initially calculated using ICRP default particle parameters: activity median aerodynamic diameters (AMAD) are 5 um for workplace and 1 um for the general public, density is 3 g/cm^3, shape factor is 1.5, and solubility is type M for U-238 and type S (for Th-230). After that, radiation doses were calculated for various particle sizes: AMAD, particle density, and shape factor were allowed vary from 0.01 um to 100 um, from 0.7 g/cm^3 to 11 g/cm^3, and from 1 to 2, respectively. Three different absorption types, type F, M and S, were used for dose calculation.

3. Results and Discussion

Figure 1 displays the effective dose due to U-238 and Th-230 particle inhalation. For particle sizes, the inhalation dose generally decreases with increasing particle size. For types M or S, the effective dose due to the inhalation of 0.01 um particles is about an order of magnitude larger than that due to inhalation of 100 um particles. Generally, smaller particles are deposited at deeper region of the respiratory track and stay longer time. This results in higher dose for smaller particles [2].

For particle density and shape, a higher mass density and smaller shape factor results in a higher dose. Particle deposition in the respiratory tract depends on aerodynamic diameter and thermodynamic diameter. The higher density and smaller shape factor decreases the thermodynamic diameter for the same aerodynamic size. This allows for deposition of the particles in deeper region of the respiratory track and hence resulting in higher dose [3].

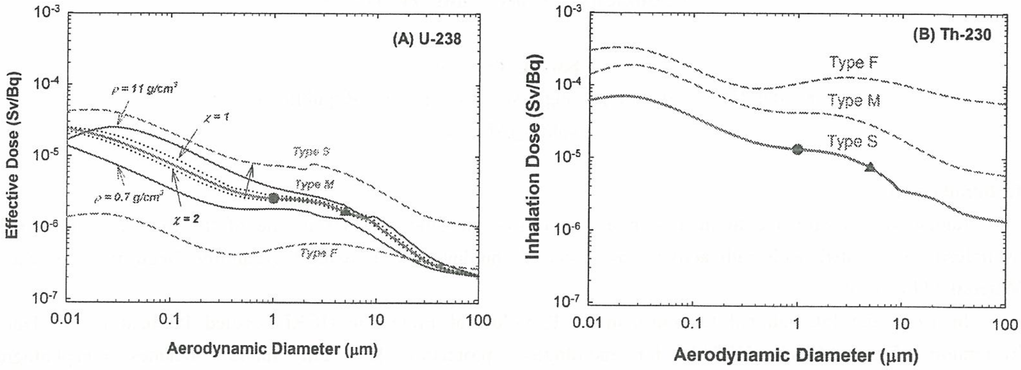

Figure 1. Inhalation dose per unit intake for various particle properties: (A) U-238 and (B) Th-230. Circle and triangle are doses for ICRP reference values for workplace and general public, respectively.

For solubility in lung fluid, type S, type M, and type F material result in the higher dose in that sequence for U-238. In contrast type F result in the highest dose for Th-230. The difference trends can be attributed to different behavior of the radionuclides after absorbed into blood [4]. Type S U-238 materials are slowly absorbed into blood. In other words, they remain within the respiratory tract for longer time and hence resulting in higher dose to lung. After absorbed into blood, they are distributed to internal organs and tissues. However, radiation dose to the organs are much smaller than dose to the lung. As a result, type S results in the highest dose for U-238. While a large fraction of uranium is excreted following its absorption to blood, a large fraction of thorium is taken up within bone and stay there with a considerably longer retention time. Therefore, radiation dose to bone marrow and bone surface for type F Th-230 particles are noted to be significantly higher than doses to the lungs for Type S aerosols of Th-230. Therefore, type F resultd in the higher dose than type S for Th-230 particles

4. Conclusion

This study indicates that the particle size and absorption type are important input parameters for individual and site-specific dose assessments. Conservative assumptions on the size or absorption type can greatly skew dose assessments to unrealistic values by up to an order of magnitude. Therefore, it is highly recommended to measure and then use site-specific information on particle properties for inhalation dosimetry

References

[1] ICRP. Human respiratory tract model for radiological protection. Oxford: Pergamon Press; International Commission on Radiological Protection; ICRP Publication 66; 1994.

[2] Kim K, Wu C, Birky B, Bolch W. Effective dose scaling factors for use with uranium series cascade impactor data: Reassessment using the IMBA code. Health Phys 91:331-337; 2006a.

[3] Kim K, Wu C, Birky B, Nall W, Bolch W. Characterization of radioactive aerosols in Florida phosphate processing facilities. Aerosol Sci Technol 40:410-421; 2006b.

[4] Kim K, Wu C, Birky B, Nall W, Bolch W. Tenorm aerosols in the Florida phosphate industry - Assessment of lung fluid solubility and annual effective dose to workers. Rad Prot Dos 123:41-55; 2007.