Risk assessment of rare metals contained in soil by geo-environmental risk assessment system (GERAS-1)

Yoshishige Kawabe, Yasuhide Sakamoto, Junko Hara, Junko Nishiwaki and Takeshi Komai

Institute for Geo-resource and Environment, National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan, Email y-kawabe@aist.go.jp; sakamoto-yasuhide@aist.go.jp; j.hara@aist.go.jp; junko-nishiwaki@aist.go.jp; takeshi-komai@aist.go.jp@aist.go.jp

Abstract

The exposure rates, the distribution of exposure paths and the risk level of rare metals (antimony, beryllium, barium and vanadium) contained in soil and ground water in Japan have been evaluated by using an originally developed risk assessment model (GERAS-1). The major exposure pathway of these rare metals is the ground water intake. In the case of beryllium and barium, humans also intake them from direct ingestion of soil. The exposure rates and risks were not high for people living in the general environment. The soil contents of the rare metals for the exposure limits are estimated at the following levels: antimony, 34 mg/kg; beryllium, 220 mg/kg; barium, 14000 mg/kg; vanadium, 240 mg/kg.

Key Words

Risk assessment, exposure model, rare metals, soil contamination.

Introduction

Rare metals such as antimony, beryllium, barium and vanadium are widely used for alloy material or electronic devices. Since these materials are easily discarded in landfills or in the subsurface environment, there is a possibility that humans are exposed to these rare metals. Risk and exposure assessment for soil and ground water are important for both aspects for health and environmental protection, as well as making proper decisions about remediation done by engineering activities. Exposure due to hazardous chemicals in the subsurface environment is essential to assess risk level for individual people, especially exposure from the soil and ground water. The exposure assessment model plays an essential role for estimating the exposure or risk level for humans. There are three kinds of exposure models to determine the level and distribution of exposure to individuals: One is screening type model. Two is a site-specific type exposure model. And three is a multimedia type exposure model (Komai, 2002). Because the screening type model is the first step in evaluating the risk level of contamination, it is important to develop it in accordance with the categories and properties of chemicals, and the situation and factors specific to Japan. We have developed the screening type of risk assessment model (Geo-environmental Risk Assessment System; GERAS-1) (Kawabe *et al.* 2003, 2005).

In this study, the exposure rates, the distribution of exposure paths and the risk level of rare metals (antimony, beryllium, barium and vanadium) contained in soil and ground water in Japan have been evaluated by using GERAS-1.

Methods

The risk assessment model used in this study is the geo-environmental risk assessment model for heavy metals (Kawabe *et al.* 2003). It considers both soil properties and exposure factors specific to Japanese situations. In this model the following exposure paths are considered: Ingestion of soil; dermal contact of soil; inhalation of soil; inhalation of indoor air; inhalation of outdoor air; ingestion of ground water; and ingestion of crops (Figure 1).

To input the soil concentration of the rare metals, the cocentrations of rare metals in the pore water and soil air are calculated. Then the concentration of each media, i.e. crops, ground water, indoor or outdoor air, is calculated. Finally, the exposure rates from each path are estimated and then risk is evaluated.

The soil used in GERAS-1 was a loamy sand, which has a high organic carbon content and is a humid soil. The lifetime exposure duration was assumed to be 365 days/year for 70 years (childhood years: 6 years; adult years: 64 years). The body weights of child and adult were 15 kg and 50 kg, respectively. The inhalation rates were 6 m^3/day for a child and 15 m^3/day for an adult, obtained from the estimation using Travis's equation (Travis, 1987). Drinking water intake rates (1 liter/day for a child and 2 liters/day for an adult) and the soil ingestion rates (200 mg/day for a child and 100 mg/day for an adult) were used for the evaluation. The other parameters such as chemical properties have been described in the literature (Kawabe *et al.* 2003).

The endpoints of risk used in this study were the values of the oral reference dose (RfD).

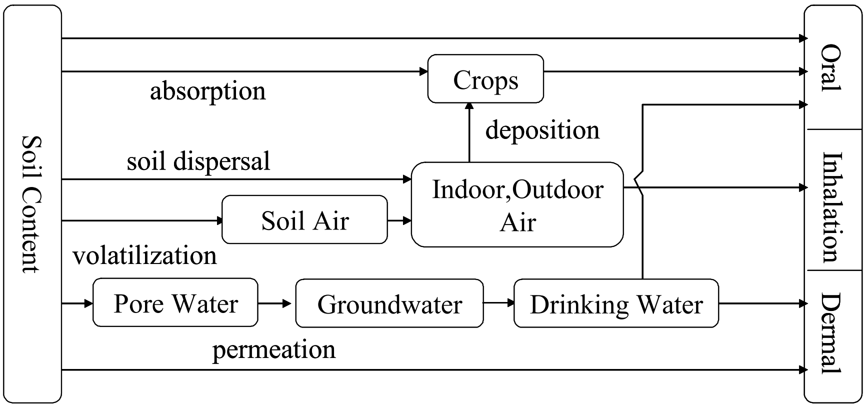

Figure 1. Exposure paths of chemical substance considered in geo-environmental risk assessment model.

Results and discussions

Figure 2 shows the exposure rates and contribution of the different exposure paths during a lifetime (aged 0 to 70) by using GERAS-1. The major exposure pathway is the ground water intake for all rare metals (antimony, 80.4 %; beryllium, 58.3 %; barium, 34.3 %; vanadium, 77.7%). These results indicate that these rare metals easily migrate and are transported to ground water. In the case of beryllium and barium, humans are also exposed to these metals from the direct ingestion of soil (beryllium, 32.4 %; barium, 60.2 %).

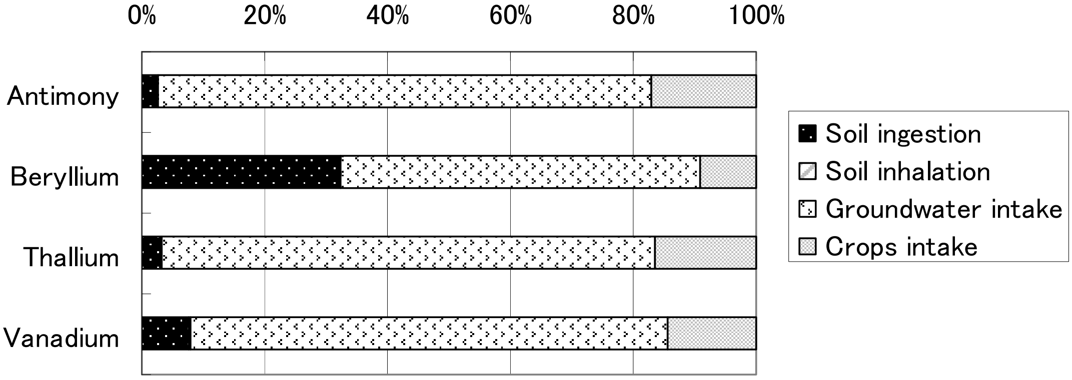

Figure 2. Exposure pathways of rare metals calculated by the GERAS-1.

There are no criteria for soil content of these rare metals. To understand the range of the exposure rates and risks, we estimated exposure rates and risks, assuming that the soil content of these rare metals were Clarke number which is the percent by mass for all elements in the earth surface. Table 1 shows the result of this estimation. The total lifetime exposure rate of antimony is calculated at 5.9 x 10^{-2} μg/kg/day, which corresponds to about 1.0 % of the oral reference dose (RfD).

Table 1. Exposure rates and remediation goal of rare metals, when the soil content of these rare metals were the Clarke number.

	Rare metals	Antimony	Beryllium	Barium	Vanadium
	Clarke number [%]	0.00005	0.0006	0.023	0.015
Lifetime exposure rate [μg/kg/day]	Ingestion of soil	1.5×10^{-3}	1.8×10^{-2}	6.8×10^{-1}	4.5×10^{-1}
	Ingestion of groundwater	4.7×10^{-2}	3.2×10^{-2}	3.9×10^{-1}	4.5×10^{0}
	Inhalation of soil	4.8×10^{-6}	5.8×10^{-5}	2.2×10^{-3}	1.4×10^{-3}
	Crops intake	1.0×10^{-2}	5.1×10^{-3}	6.1×10^{-2}	8.33×10^{-1}
	Total	5.9×10^{-2}	5.5×10^{-2}	1.1×10^{0}	5.7×10^{0}
	Oral RfD [μg/kg/day]	0.4	2	200	9
	Total/RfD [%]	1.0	2.8	0.6	64
	Remediation goal [mg/kg-soil]	34	220	14000	240

According to an estimate by our model, soil content of antimony should be around 34 mg/kg. In the case of the other rare metals, total lifetime exposure rates did not exceed RfD. These results suggest that these rare metals have a low risk for humans living in the general environment. According to an estimate by our model, soil contents of beryllium, barium and vanadium should be around 220 mg/kg, 14,000 mg/kg and 240 mg/kg, respectively.

Conclusion

Risk based assessment makes it possible for a quantitative analysis of environmental risk for health and ecology as well as a cost-effectiveness analysis and a socio-economical analysis. In this study, the exposure rates, the distribution of exposure paths and the risk level of rare metals contained in soil and ground water in Japan have been evaluated by using an originally developed risk assessment model (GERAS-1). Further, research dealing with exposure to the subsurface environment and its risk assessment has just started in Japan. Therefore, many factors and parameters, such as soil properties or exposure factors for the assessment, are needed.

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