Estimation of Radionuclide Biokinetics Dependence on Intake Conditions for Internal Exposure

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Abstract

In a nuclear power reactor accident accompanied by discharge of radioactive iodine or radioactive cesium, internal contamination of the public may occur via some pathways over a long period. In this research, the thyroid retention function of iodine-131 and the whole-body retention function of cesium-137 were calculated based on biokinetic models and the dependence on intake conditions of pathways and period was clarified. As a result of this work, it is suggested that caution is especially required so as not to underestimate or overestimate the internal dose evaluation to the public from continuous intake of iodine-131.

Key Words: Iodine-131, Cesium-137, Biokinetics, Internal dose evaluation

Introduction

When a nuclear power reactor accident occurs which emits a large amount of radioactive material into the environment, not only the workers at the plant but also the general public may be contaminated[1, 2]. Internal contamination especially has several pathways; for example, inhalation of radioactive material in radioactive clouds, inhalation of radioactive material which re-enters the air from the earth's surface, or ingestion of radioactive material in contaminated food or drinking water. Therefore, even after the discharge of the radioactive material from a nuclear installation has subsided, contamination may continue over a long period. Iodine-131, which deposits specifically in the thyroid gland in the early stage after an accident, and Cesium-134 and -137, which are easily distributed over the whole body in a long period after an accident, are important nuclides that may be seen in the aftermath of the Chernobyl accident, the

Fukushima nuclear accident, etc.[3-5] The internal dose from these nuclides is generally evaluated by *in vivo* counting methods, which measure the thyroid residual volume of iodine-131 or the whole body residual volume of cesium-134 and -137 using a thyroid monitor or a whole body counter. Such measured residual volumes in the body are converted to the total intake by the thyroid retention function or by the whole body retention function depending on the biokinetics of the radioactive material taken up by the body, and also are converted to internal dose by the dose coefficient per unit intake activity (Sv/Bq). Since internal contamination of radiation workers mainly takes place by acute inhalation, acute inhalation is also assumed in dose evaluation. On the other hand, since internal contamination of the public can have different intake pathways or periods compared to workers, the thyroid retention function and whole body retention function may change greatly due to the difference in such intake situations. For internal dose evaluation of the public, however, acute inhalation is assumed in many cases, just as for workers, so that the internal dose evaluation may not properly take the intake situation into consideration. Therefore, in this research, the thyroid retention function of iodine-131 and the whole body retention function of cesium-137 based on intake pathway and period are clarified. Moreover, the dependence of these retention functions on internal dose evaluation is discussed. In addition, the whole body retention function of cesium-134 is beyond the scope of this research, although it is the same element and has almost the same biokinetics as cesium-137.

Methods

With reference to the Human Respiratory Tract Model (HRTM)[6], the Human Alimentary Tract Model (HATM)[7] and element specific metabolic models[8] which represent each organ and tissue as some compartments, the thyroid retention function of iodine-131 and the whole body

retention function of cesium-137 were calculated assuming different intake situations. Since iodine-131 might cause child thyroid disease[9], it was targeted at a one-year-old child. Cesium-137 targeted the public adult male. In the HRTM, the Activity Median Aerodynamic Diameter (AMAD) was set to 1μm and the absorption type was set to Type F. Alimentary absorption (f_1 value) was made into the approximate value of 1.0 in the HATM. The conditions of intake pathway were inhalation and ingestion, and those of period were acute intake and continuous intake according to the half-life. The concrete assumption for each condition is shown in Table 1. The retention function for continuous intake was calculated by dividing residual volume by the total intake volume in the period from the start of intake to lapsed days. Moreover, the whole body retention function of cesium-137 was calculated from the sum of the residual volumes in the compartments of the blood and the whole body.

Results

The thyroid retention function of iodine-131 (Figure 1) and the whole body retention function of cesium-137 ranging from the start of intake to 30 days were calculated for four conditions: acute inhalation, acute ingestion, continuous inhalation and continuous ingestion according to half-life.

The thyroid residual rate of iodine-131 after 1, 5, 10, 20, and 30 days from the start of intake is summarized in Table 2 for each of the four conditions. After the thyroid retention function from acute inhalation reaches the highest level of 12.5% in one day, it falls by physical and biological half-life, and is less than 1% in 30 days. In continuous inhalation according to half-life, on the other hand, the intake continues while transferring iodine-131 taken at the time of the start of intake to the thyroid gland over one day. After one day from the start of intake, therefore, there is much radioactivity in the body before it reaches the thyroid gland, so that the

thyroid retention function is less than 10%, which is lower than in the case of acute inhalation. Then, after the thyroid retention function gradually becomes high and exceeds 10% even in five days, it falls gently. A part of the inhaled iodine-131 is emitted by expiration into the environment and the remainder is absorbed into the blood. Meanwhile, ingested iodine-131 is almost all absorbed into the blood. This is the main reason that the thyroid retention function is higher for ingestion than for inhalation. The overall tendency in acute and continuous intake for ingestion is the same as that for inhalation.

The whole body residual rate after 1, 5, 10, 20, and 30 days from the start of intake is similarly summarized in Table 3 for cesium-137. After the whole body retention function from acute inhalation reaches the highest level of 33.7% immediately after intake, it mainly falls according to the biological half-life, and will be 25.8% in 30 days. Although the whole body retention function at the time of continuous inhalation according to half-life also reaches a peak of 33.8% immediately after intake (just as for acute inhalation), the subsequent fall is more gradual and will be 29.8% in 30 days. The whole body retention function for ingestion is higher than that for inhalation, just as it is for I-131. The overall tendency in acute and continuous intake for ingestion is the same as that for inhalation.

Discussion

In the process of internal dose evaluation by *in vivo* measurement methods, when presuming the total intake volume from residual volume in the body, acute inhalation is assumed in many cases. The thyroid retention function of iodine-131 and the whole body retention function of cesium-137 have a range of differences, by about a factor of 3.1 and 1.2 respectively, between acute intake and continuous intake according to half-life at 30 days from the start of intake in case of any intake pathways. Therefore, when acute intake is assumed instead of continuous

intake of iodine-131, there is a possibility of overestimating greatly in presumption of the total intake volume. The reason that a difference is seldom seen by the whole body retention function of cesium-137 is that physical and biological half-life are comparatively long and cesium-137 easily remains in the whole body.

For any conditions of intake period, the thyroid retention function for ingestion is about 2.1 times (iodine-131) and 3.0 times (cesium-137) larger compared to inhalation, not depending on lapsed days and these values are determined by the nuclide. Therefore, when inhalation is assumed instead of ingestion for iodine-131 or cesium-137, the total intake volume is also presumed as 2.1 times or 3.0 times overestimated. On the other hand, the ratios of inhalation to ingestion of committed thyroid equivalent dose coefficients of iodine-131[8, 10] and committed effective dose coefficients of cesium-137[11] are 0.39 times and 0.38 times, respectively. Thus, when internal dose is evaluated using these dose coefficients, the committed thyroid equivalent dose of iodine-131 will be underestimated by a factor of about 0.82 and the committed effective dose of cesium-137 will be overestimated by a factor of 1.1.

The magnifications of evaluated internal dose assuming acute inhalation instead of the correct assumption for each intake condition are summarized for both iodine-131 and cesium-137 in Tables 4 and 5. In the internal dose evaluation of I-131 by thyroid monitor, caution is especially required regarding the overestimation after 20 days from the start of continuous intake. Moreover, there is also a possibility of underestimation within several days after intake start. For continuous intake according to half-life, however, the internal dose evaluated five days after intake start subsides to 0.9 to 1.1 times the value when acute inhalation is assumed. That is, a possibility was suggested that an internal dose minimizing the dependence on intake conditions could be evaluated by taking the timing of *in vivo* measurements into account, also in cases where the details of the intake conditions are unknown. In internal dose evaluation of

cesium-137 by a whole body counter, on the other hand, the dependence on intake conditions is comparatively small (1.3 times at the maximum) in the range examined this time.

Conclusion

Dependence of the thyroid retention function of iodine-131 and the whole-body retention function of cesium-137 was clarified for the conditions of inhalation and ingestion and of acute and continuous intake. Moreover, it was suggested that caution is especially required for underestimations and overestimations by continuous intake of iodine-131 in internal dose evaluation of the public.

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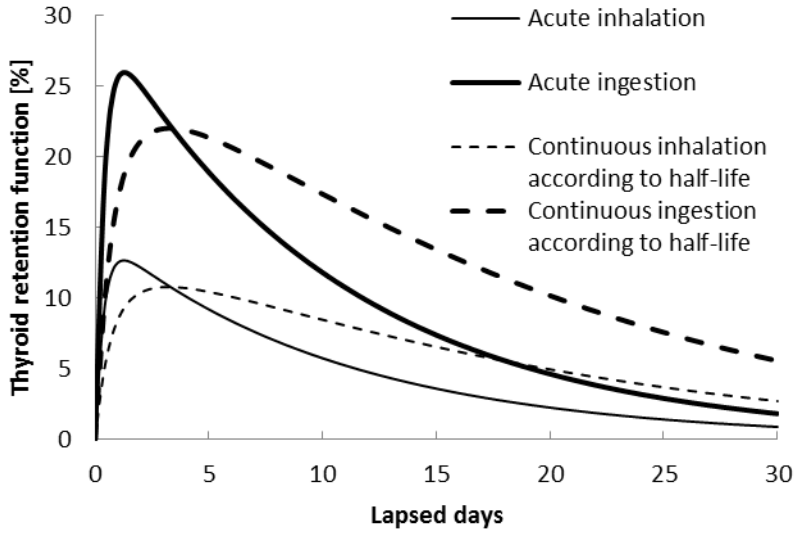

Figure 1 The thyroid retention function of iodine-131 for 30 days for the intake conditions of acute inhalation, acute ingestion, continuous inhalation and continuous ingestion

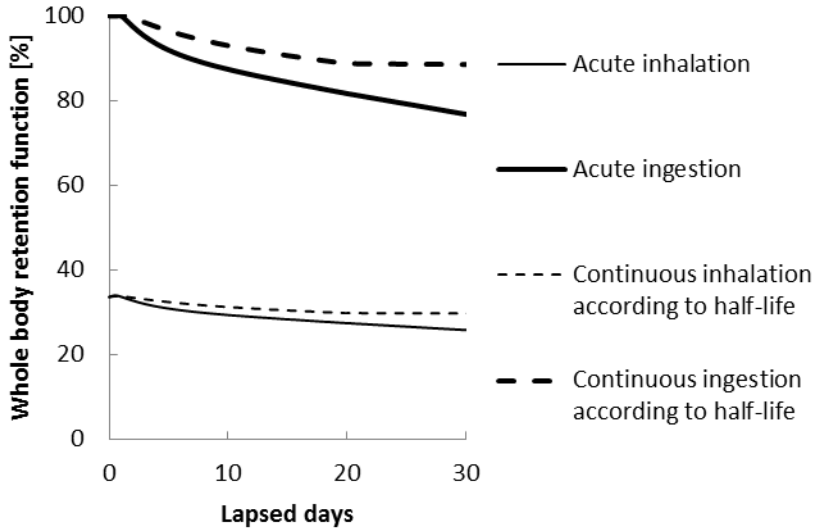

Figure 2 The whole body retention function of cesium-137 for 30 days for the intake conditions of acute inhalation, acute ingestion, continuous inhalation and continuous ingestion

Table 1 The concrete assumption for each condition of intake pathway and period

	Inhalation	**Ingestion**
Acute intake	Assumption of single intake from inhalation	Assumption of single intake from ingestion
Continuous intake according to half-life	Assumption of continuously inhaling the nuclide decreased according to physical half-life	Assumption of continuously ingesting the nuclide decreased according to physical half-life

Table 2 The thyroid residual rate of iodine-131 after 1, 5, 10, 20 and 30 days from intake start [%].

	1 day after	**5**	**10**	**20**	**30**
Acute inhalation	12.5	9.18	5.74	2.25	0.885
Acute ingestion	25.5	18.9	11.8	4.62	1.82
Continuous inhalation according to half-life	8.48	10.4	8.45	4.95	2.71
Continuous ingestion according to half-life	17.0	21.3	17.3	10.2	5.56

Table 3 The whole body residual rate of cesium-137 after 1, 5, 10, 20 and 30 days from intake start [%].

	1 day after	**5**	**10**	**20**	**30**
Acute inhalation	33.7	30.9	29.4	27.5	25.8
Acute ingestion	100	91.9	87.4	81.7	76.8
Continuous inhalation according to half-life	33.8	32.5	31.3	29.9	29.8
Continuous ingestion according to half-life	100	96.4	93	88.7	88.5

Table 4 The magnifications of evaluated internal dose of iodine-131 assuming acute inhalation instead of the correct assumption for each intake condition

	1 day after	5	10	20	30
Acute inhalation	1.0	1.0	1.0	1.0	1.0
Acute ingestion	0.80	0.80	0.80	0.80	0.80
Continuous inhalation according to half-life	0.68	1.1	1.5	2.2	3.1
Continuous ingestion according to half-life	0.53	0.90	1.2	1.8	2.5

Table 5 The magnifications of evaluated internal dose of cesium-137 assuming acute inhalation instead of the correct assumption for each intake conditions

	1 day after	5	10	20	30
Acute inhalation	1.0	1.0	1.0	1.0	1.0
Acute ingestion	1.1	1.1	1.1	1.1	1.1
Continuous inhalation according to half-life	1.0	1.1	1.1	1.1	1.2
Continuous ingestion according to half-life	1.1	1.2	1.2	1.2	1.3