



Optimal Monitoring Intervals and MDA Requirements for Routine Individual Monitoring of Occupational Intakes Based on the ICRP OIR

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ABSTRACT

Background: The International Commission on Radiological Protection (ICRP) has recently published report series on the occupational intakes of radionuclides (OIR) for internal dosimetry of radiation workers. In this study, the optimized monitoring program including the monitoring interval and the minimum detectable activity (MDA) of major radionuclides was suggested to perform the routine individual monitoring of internal exposure based on the ICRP OIR.

Materials and Methods: The derived recording levels and the critical monitoring quantities were reviewed from international standards or guidelines by the International Atomic Energy Agency (IAEA), the International Organization for Standardization (ISO), and the European Radiation Dosimetry Group (EURADOS). The OIR data viewer provided by ICRP was used to evaluate the monitoring intervals and the MDA, which are derived from the reference bioassay functions and the dose coefficients.

Results and Discussion: The optimal monitoring intervals were determined taking account of two requirement conditions on the potential intake underestimation and the MDA values. The MDA requirement values of the selected radionuclides were calculated based on the committed effective dose from 0.1 mSv to 5 mSv. The optimized routine individual monitoring program was suggested including the optimal monitoring intervals and the MDA requirements. The optimal MDA values were evaluated based on the committed effective dose of 0.1 mSv. However, the MDA can be adjusted considering the practical operation of the routine individual monitoring program in the nuclear facilities.

Conclusion: The monitoring intervals and the MDA as crucial factors for the routine monitoring were described to suggest the optimized routine individual monitoring program of the occupational intakes. Further study on the alpha/beta-emitting radionuclides as well as short lived gamma-emitting nuclides will be necessary in the future.

Keywords: Occupational Intakes, Internal Exposure, Routine Individual Monitoring, Minimum Detectable Activity, Internal Dosimetry

Technical Paper

Received February 10, 2020

Revision March 24, 2020

Accepted May 26, 2020

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Introduction

Recently, the International Commission on Radiological Protection (ICRP) has published OIR (occupational intakes of radionuclides) report series for internal dosimetry of occupational intakes [1–3]. In Korea, several nuclear facilities operating nuclear power plants and a research reactor have carried out routine individual monitoring for

radiation workers who are likely to be internally contaminated by radioactive materials with a form of unsealed sources. The individual dosimetry laboratories of the facilities have, however, provided the routine monitoring program of occupational intakes based on the previous ICRP reports [4, 5].

In general, direct measurement methods using whole body counters or thyroid monitors have been used for routine monitoring of concerned gamma-emitting radionuclides which have been produced under normal operation of nuclear facilities. For occupational monitoring of internal exposure, the recording level for routine monitoring in the nuclear facilities has been set at 0.1 mSv in Korea.

The International Atomic Energy Agency (IAEA) and the International Organization for Standardization (ISO) standards suggested to apply the recording level and the investigation level as reference levels for occupational monitoring for intakes of radionuclides [6, 7]. The suggested values on the recording level and the investigation level are set at a value corresponding to an annual dose no greater than 5% and 30% of the annual dose limit, respectively. Therefore, the recording level should be 1 mSv or less than 1 mSv (5% of the annual dose limit) in a year according to IAEA and ISO standards [6, 7]. IAEA suggested a use of the derived recording level (DRL) which is actually measured quantities corresponding to the predetermined recording level. Similarly, General Guidelines for the Estimation of Committed Effective Dose from Incorporation Monitoring Data (IDEAS Guidelines) published by the European Radiation Dosimetry Group (EURADOS) also provided a similar concept with the DRL by application of critical monitoring quantities (M_c) which are the amount of activity retained or excreted at the end of a monitoring period that determines an intake that would result in a committed effective dose of 0.1 mSv in a year [8–10]. In order to perform routine monitoring of DRLs or M_c , the minimum detectable activity (MDA) of the measurement system needs to be less than those values.

In the present study, we derived the optimal monitoring intervals and the MDA of major radionuclides to fulfill the routine monitoring program based on the ICRP OIR reports [1–3] introducing the newly adopted biokinetic and dosimetric models. In addition, the optimized monitoring program based on the ICRP OIR was suggested to practically perform the routine individual monitoring of internal exposure for radiation workers.

Materials and Methods

1. DRL and M_c Values for the Selected Radionuclides

The DRL is measurement values that correspond to the predetermined recording level. The DRLs can be calculated for each radionuclide as a following equation [6]:

$$\text{DRL}_j = \frac{10^{-3}}{N \cdot e(g)_j} m(t_0)_j$$

where, 10^{-3} is a constant representing 1 mSv as an annual committed effective dose, N is the number of individual monitoring performed in a year, $e(g)_j$ is the dose coefficient for inhalation or ingestion of radionuclide j , and $m(t_0)_j$ is the fraction of the intake, called bioassay functions in the ICRP OIR [1], of radionuclide j remaining in the body or in the excretion sample after an elapsed time period t_0 .

The equation of M_c is almost same with the DRL equation. The different value is only the constant to represent the annual dose. The constant used in the M_c equation is 10^{-4} which corresponds to 0.1 mSv in a year. Therefore, the equation to derive the M_c is following [6]:

$$M_c = \frac{10^{-4}}{N \cdot e(g)_j} m(t_0)_j$$

IDEAS Guideline and ISO standard have provided the M_c values for the concerned radionuclides depending on the measurement methods such as whole body measurements, lung measurements, thyroid measurements and urine/fecal measurements [8, 11]. Since the dose coefficients used in both IDEAS Guideline and ISO standard were based on ICRP Publications 68 and 78 [4, 5], the EURADOS addressed that the M_c values need to be updated using the revised data in the ICRP OIR report [8]. In this study, only gamma-emitting radionuclides, ^{59}Fe , ^{57}Co , ^{58}Co , ^{60}Co , ^{137}Cs , and ^{131}I , were considered among the mainly contributable radionuclides to occupational intakes for radiation workers according to the technical basis document of the nuclear facilities in Korea [12]. In the direct measurement methods, all nuclides except for radioiodines such as ^{131}I were measured by a whole body counter, and thyroid measurements were applied only for monitoring of ^{131}I . Table 1 shows the characteristic information including physical half-lives, measurement methods, absorption types, monitoring intervals and M_c for the selected radionuclides provided from IDEAS and ISO reports [8, 11]. As the main pathway of intakes of radiation workers, an inhalation of 5 μm AMAD (activity median aerodynamic di-

Table 1. Characteristic Information for Routine Individual Monitoring Program of the Selected Radionuclides

Radionuclide	Half-life	Measurement method	Absorption type	Monitoring interval (day)	M_c (Bq)
⁵⁹ Fe	44.495 days	Whole body measurement	Moderate	90	400
⁵⁷ Co	217.74 days	Whole body measurement	Slow	180	2,000
⁵⁸ Co	70.86 days	Whole body measurement	Slow	180	500
⁶⁰ Co	5.271 years	Whole body measurement	Slow	180	100
¹³⁷ Cs	8.021 days	Whole body measurement	Fast	180	2,000
¹³¹ I	30.167 years	Thyroid measurement	Fast	15	30

ameter) was used for the calculation of the M_c values. The DRLs of each radionuclide were 10 times greater than M_c values since the DRLs corresponded to a committed effective dose of 1 mSv.

2. Evaluation of Maximum Monitoring Intervals and MDA based on OIR

The monitoring interval is an important factor for the routine individual monitoring program. In order to determine appropriate monitoring interval, intake retention fraction data affected by effective half-lives and biokinetic models of the specific radionuclides need to be taken into account. According to the ISO standard, maximum monitoring intervals shall be determined considering the potential underestimation of intake values below a factor of 3 assuming that a single intake occurred in the middle of the monitoring interval [7]. Therefore, the bioassay function, retention or excretion fraction, at the mid-point of the monitoring interval, $T/2$, needs to be less than three times that after the monitoring interval, T , as shown in a below equation [7]:

$$\frac{m(T/2)}{m(T)} \leq 3$$

In the present work, the bioassay functions of the selected radionuclides were used from the OIR data viewer, a software providing the updated dataset including the dose coefficients and the reference bioassay functions, developed by ICRP. Whole body retention fractions for all selected radionuclides were used except for the case of ¹³¹I, in which a thyroid retention fraction was applied among retention fraction data. Default absorption types recommended from ICRP OIR report series [2, 3] were applied to obtain the reference bioassay functions depending on the type of radionuclides. Then the maximum monitoring intervals, as the firstly required condition, were evaluated to satisfy the requirement for avoiding the excessive underestimation of the intake values.

The MDA is one of the vital parameters to represent the

performance of the direct or indirect measurement system. In general, the MDA of the measurement system is determined by several factors such as counting efficiency, applied measurement time, emission yield of the specific radionuclide and background levels. In this study, the MDA, however, was derived from the minimum detectable dose (MDD) that the individual dosimetry laboratories determined according to their individual monitoring program in the nuclear facilities. Therefore, the MDAs, as the secondly required condition, were calculated using a below equation:

$$MDA_j = \frac{MDD}{N \cdot e(g)_j} m(t_0)_j$$

In this study, the MDDs as the committed effective dose of 0.1, 0.5, 1, and 5 mSv were determined since these dose levels can be applied for the recording levels or the investigation levels in the nuclear facilities. The dose coefficients for the inhalation, $e(g)_j$, and intake retention fraction data, $m(t_0)$, were also used from the OIR data viewer. The whole body retention fractions for all selected radionuclides were used except for the case of ¹³¹I, the same with the firstly required condition.

The optimal monitoring intervals of the each radionuclide were determined taking account of the two requirement conditions. The optimal monitoring interval was limited to be 6 months or less than 6 months (twice in a year) since the ISO standard noted that two measurements, at least, shall be performed annually in a routine monitoring program [7], even though the evaluated maximum intervals satisfying the two requirements were longer than 6 months. Thereafter, the optimal MDA values were suggested based on the MDD of 0.1 mSv applying the MDA requirement value at the end of the optimal monitoring intervals.

Results and Discussion

1. Determination of the Optimal Monitoring Intervals

Fig. 1 shows intake retention fraction data of the selected

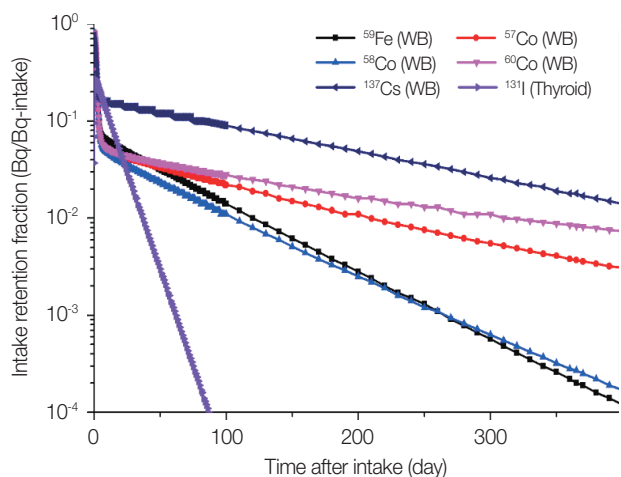


Fig. 1. Intake retention fractions of the selected radionuclides based on the International Commission on Radiological Protection occupational intakes of radionuclides. WB, whole body retention fraction; Thyroid, thyroid retention fraction.

radionuclides as a bioassay function provided from the OIR data viewer. Except for ^{131}I , whole body retention fractions were represented for all the concerned radionuclides, and the thyroid retention fraction was shown only for ^{131}I . Due to the short half-life of ^{131}I , the retention fraction in the thyroid sharply decreased compared with other radionuclides. And the whole body retention fraction for ^{137}Cs showed the highest values during approximately 1 year (12 months) after the initial intake occurred. Applying the equation on the ratio of the retention fraction at the mid-point of the monitoring interval to that at the end of the monitoring interval, the maximum monitoring intervals were evaluated to satisfy the first requirement condition on the maximum potential underestimation of the intake value. The maximum monitoring intervals were evaluated to be longer than 6 months for ^{57}Co , ^{60}Co , and ^{137}Cs satisfying the first requirement condition. The evaluated maximum monitoring intervals for ^{59}Fe , ^{58}Co , and ^{131}I were 130 days, 140 days, and 24 days, respectively. It was noted that in the present evaluation the maximum monitoring intervals for all radionuclides were derived by the consideration of only the first requirement condition on the excessive underestimation.

The optimal monitoring intervals needed to be determined taking account of two requirement conditions, not only avoiding the three times underestimation of the intake but also satisfying the monitoring of the MDA requirement values corresponding to the predetermined recording levels. In the present study, the optimal monitoring intervals were evaluated with a time period of one month (30 days) except

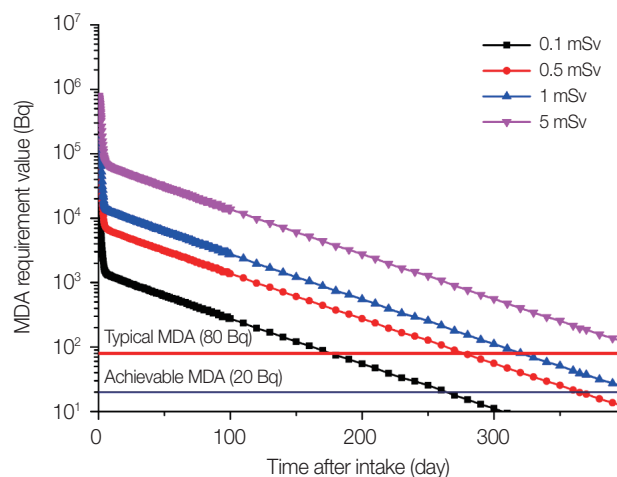


Fig. 2. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{59}Fe (typical MDA=80 Bq; achievable MDA=20 Bq).

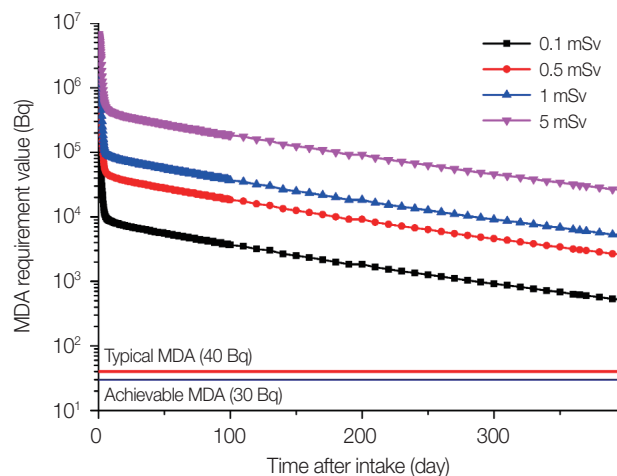


Fig. 3. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{57}Co (typical MDA=40 Bq; achievable MDA=30 Bq).

for ^{131}I . In the case of ^{131}I with the relatively short half-life, a weekly period (7 days) was applied to evaluate the optimal monitoring interval.

Figs. 2–7 represent the MDA requirement values of the selected radionuclides depending on the time after the initial intake. And typical and achievable MDAs provided from IDEAS and OIR reports [2, 3, 8] were also represented in Figs 2–7 to find out when the MDA requirement values were less than the typical or achievable MDAs taking account of monitoring the annual committed effective doses from 0.1 mSv to 5 mSv. In the case of ^{59}Fe , the MDA requirement values for monitoring the annual dose of 0.1 mSv were greater than the

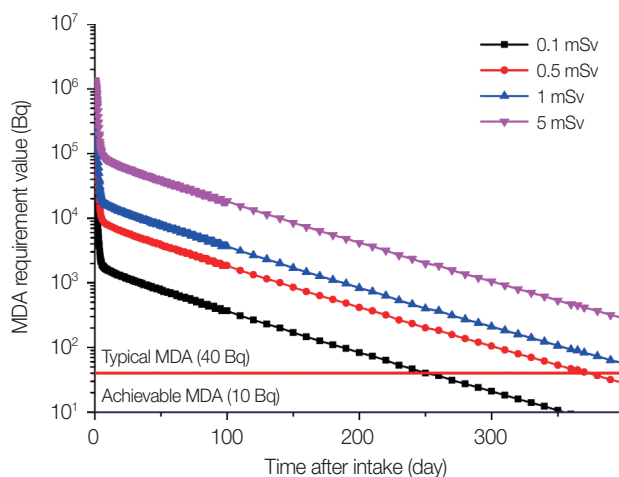


Fig. 4. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{58}Co (typical MDA=40 Bq; achievable MDA=10 Bq).

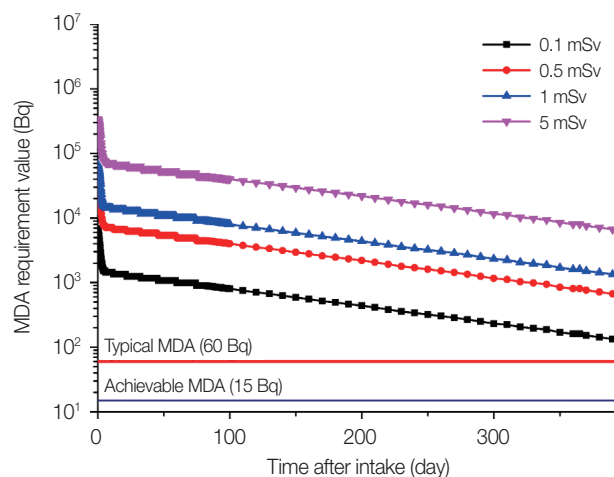


Fig. 6. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{137}Cs (typical MDA=60 Bq; achievable MDA=15 Bq).

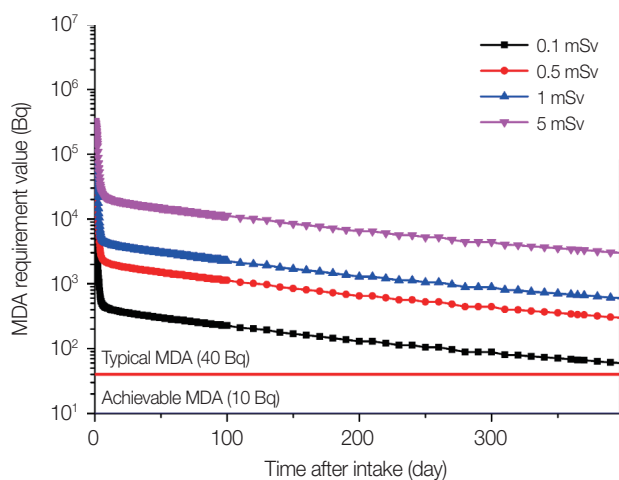


Fig. 5. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{60}Co (typical MDA=40 Bq; achievable MDA=10 Bq).

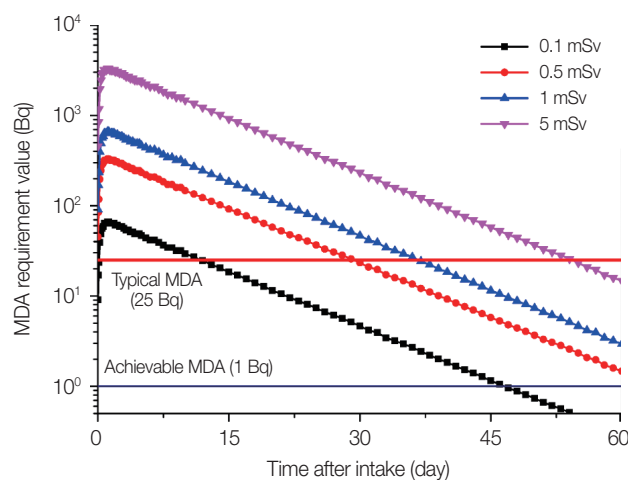


Fig. 7. Minimum detectable activity (MDA) requirement values as a function of the time after the intake depending on the minimum detectable dose from 0.1 mSv to 5 mSv for ^{131}I (typical MDA=25 Bq; achievable MDA=1 Bq).

typical MDA (80 Bq) until 170 days after the intake (Fig. 2). But the maximum monitoring interval was 130 days considering the excessive underestimation due to the rapid decrease of its retention fraction. Accordingly, the optimal monitoring interval of ^{59}Fe in whole body measurements needs to be 120 days (three times per year) to satisfy both two requirement conditions.

In the case of ^{57}Co , ^{60}Co , and ^{137}Cs , the typical MDA (40 Bq for ^{58}Co and ^{60}Co , and 60 Bq for ^{137}Cs) was found to be always less than the MDA requirement values for 1 year after the intake occurred (Figs. 3, 5, and 6) Therefore, the optimal monitoring interval of those three radionuclides were determined

as 180 days (twice per year).

In the case of ^{58}Co , the MDA requirement values for monitoring 0.1 mSv were satisfied within 250 days compared with the typical MDA (40 Bq) (Fig. 4). On the other hand, the maximum monitoring interval of ^{58}Co was 140 days. In order to satisfy both requirement conditions, 120 days (three times per year) were determined as the optimal monitoring interval for ^{58}Co .

In the case of ^{131}I , it was found that the MDA requirement values were not only significantly low, but also rapidly decreased due to its short half-life (Fig. 7). In order to satisfy the MDA requirement for monitoring 0.1 mSv, the thyroid mea-

surement needed to be performed within 12 days after the intake of ^{131}I even though its maximum monitoring interval satisfying the first requirement was 24 days. However, the optimal monitoring interval was determined as 14 days (twice per month) considering the practical application of the routine individual monitoring of internal exposure to the thyroid since monitoring interval of 12 days is practically difficult to maintain. However, more careful consideration should be taken in the case of ^{131}I to determine the optimal monitoring interval due to a rapid decreasing rate of the thyroid retention fraction.

2. Optimized Individual Monitoring Program

The optimal MDA values based on the MDD of 0.1 mSv depending on the type of radionuclides were determined applying the MDA requirement values at the end of the optimal monitoring intervals. Therefore, the optimal MDA values for ^{59}Fe and ^{58}Co were the MDA requirement values at 120 days after the intake. And in the case of ^{57}Co , ^{60}Co , and ^{137}Cs , the optimal MDAs were the MDA requirement values at 180 days after the intake. The optimal MDA of ^{131}I was determined as the MDA requirement value at 14 days after the intake. Table 2 shows the optimized routine individual monitoring program including the optimal monitoring intervals and the optimal MDA values based on the ICRP OIR. In addition, the default absorption types recommended from the ICRP OIR were represented in Table 2.

The routine individual monitoring program depending on the type of radionuclides should be optimized taking a consideration of two important factors such as monitoring intervals and the MDA mainly affected by the bioassay functions and the dose coefficients. And the recording levels should be reviewed and predetermined before the implementation of

routine individual monitoring for occupational intakes. If the low recording level is applied in the monitoring program, the measurement system needs to have sufficiently low MDA to measure the predetermined recording level. Accordingly, the MDA of the measurement system should be analyzed to check if the routine monitoring program applying the MDA achieved from the specific measurement system can monitor the predetermined recording levels. In order to evaluate the recording levels below 0.1 mSv per year, the MDA of the specific measurement system needs to be less than the optimal MDA values. On the contrary, the MDA can be changed to be greater than the optimal values if the individual dosimetry laboratories in the nuclear facilities apply the recording levels exceeding 0.1 mSv per year.

Conclusion

The monitoring intervals and the MDA are crucial factors to properly implement the routine individual monitoring of internal exposure for radiation workers. In the present work, the optimal monitoring program of occupational intakes including the monitoring intervals and the MDA of major radionuclides was described based on the ICRP OIR. Only gamma-emitting radionuclides, however, were taken into account in this work. Accordingly, the monitoring intervals and the MDA using this technical approach can be derived for alpha/beta-emitting radionuclides as well as other gamma-emitting nuclides based on the ICRP OIR. Further ICRP OIR series (Parts 4 and 5) should also be considered in the future. In the case of ^{131}I , more investigation will be required to optimize the routine individual monitoring program of radiation workers who are dealing with the radioiodines. In Korea, whole body counting has been mainly used for individual monitoring of intakes of all gamma-emitting radionuclides for the workers in the nuclear facilities. The recording level of ^{131}I might be adjusted considering the performance characteristics of the applied measurement system since the required conditions on the monitoring interval and the MDA are quite strict compared with other radionuclides.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Table 2. Optimized Routine Individual Monitoring Program based on the ICRP OIR

Radionuclide	Absorption type ^{a)}	Optimal monitoring interval (day)	Optimal MDA value (Bq)
^{59}Fe	Moderate	120	200
^{57}Co	Moderate	180	2,000
^{58}Co	Moderate	120	260
^{60}Co	Moderate	180	150
^{137}Cs	Moderate	180	490
^{131}I	Fast	14	20

ICRP, International Commission on Radiological Protection; OIR, occupational intakes of radionuclides; MDA, minimum detectable activity.

^{a)}Default absorption type recommended for use in the absence of specific material information.

Acknowledgements

This study was supported by a grant of the Korea Institute of Radiological and Medical Sciences (KIRAMS), funded by Nuclear Safety and Security Commission (NSSC), Republic of Korea (No. 50091-2020).

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