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Identification of the Radionuclides that Potentially Contribute to the Internal Dose of Workers at Radiopharmacy Facilities

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Abstract. The optimization principle in radiation protection means that there is a reasonable balance between resources used to monitor exposures and the benefits due to the monitoring program. Programs for the monitoring of workers handling radioactive materials are influenced by numerous factors. Estimation of internal doses due to inhalation or ingestion of radioactive materials is often based on measurements of the activity in the tissues of the body and in excreta, following a given intake. In order to enable dose estimations using the biokinetic models recommended by the ICRP and laboratory data, it is proposed to carry out comprehensive study to identify the main radionuclides that potentially contribute to the internal dose of workers at radiopharmacy facilities. The applied methodology for identification of these radionuclides takes into account criteria set out by the ICRP, IAEA, EPA and Healy. In our country, the monitoring of incorporation is regulated on the basis of Radiation Protection Ordinance, CNEN. The practical purposes to set up this study was to establish a consistent approach to ensure that the dose assessments are as simple as possible and guarantee the necessary quality standards. The result of this study has indicated the requirement of routine measurements for six radionuclides over a range of thirty radioactive material compounds, handled at the radiopharmacy plant of IPEN, avoiding unjustifiable work concerning activity levels that are not relevant for the health of the occupationally exposed persons. The workers subjected to internal exposure, the main intake pathways and the appropriate monitoring frequencies have also been identified. Within this process, the experience gained during the practical application will be taken into account as well as more recent dosimetric information.

KEYWORDS: Radiation Protection, Dosimetry, Bioassay, Individual Monitoring, Internal Exposure.

Topic 3: Dosimetry & Instrumentation

1. Introduction

The optimization principle in radiation protection means that there is a reasonable balance between resources used to monitor exposures and the benefits due to the monitoring program. Programs for the monitoring of workers handling radioactive materials are influenced by numerous factors. Estimation of internal doses due to inhalation or ingestion of radioactive materials is often based on measurements of the activity in the body tissues and in excreta, following a given intake. In order to enable dose estimations using the biokinetic models recommended by the ICRP and laboratory data, it is proposed to carry out comprehensive study to identify the main radionuclides that potentially contribute to the internal dose of workers at radiopharmacy facilities.

2. Methodology

The applied methodology for identification of these radionuclides takes into account criteria set out by the ICRP [1], IAEA [2], EPA [3] and Healy [4]. In our country, the monitoring of incorporation is regulated on the basis of Radiation Protection Ordinance, CNEN [5]. The practical purpose to set up

this study was to establish a consistent approach to ensure that the dose assessments are as simple as possible and guarantees the necessary quality standards.
As a general rule, the radionuclide selection criteria to be included in an internal monitoring program are based on the risk concept. This concept is referred to the attempt to evaluate quantitatively the risk of internal contamination due to a single incorporation of radionuclide.
The specific radionuclide decision factor, d_j, whether individual monitoring is required, is obtained according to the expression (1), for a specific practice in a given installation [2].

$$d_j = \frac{A_j . e(g)_{inh} . F_{fs} . F_{hs} . F_{ps}}{0{,}001} \quad (1)$$

where

A_j is the radionuclide activity accumulated by practice, existing in the work facility along one year, in Bq:
$e(g)_{inh}$ is the dose conversion factor, by AMAD 5 μm inhalation, in Sv/Bq;
0,001 is the conversion factor from sievert to milisievert;
F_{fs} is the safety factor as to the physical form;
F_{hs} is the safety factor for handling; and
F_{ps} is the safety factor for protection.

The factors considered in the d_j expression were extracted from the IAEA [2] for the radionuclides handled in the radiopharmacy plant and were obtained according to the nature of the radioactive material and the type of operation [6].
Table I presents the radioactive compounds that are handled at radiopharmacy plant as well as the annual activities and the decision factors calculated according to the expression (1).
When different radionuclides or compounds are handled in the same workplace the decision factor for all radionuclides are given by:

$$D = \sum_j d_j \quad (2)$$

Then, if $D \geq 1$ an individual monitoring is indicated, otherwise it is not necessary. Furthermore, decisions to conduct individual monitoring for the separate radionuclides may be based on the following criteria:

(i) All radionuclides for which $d_j \geq 1$ shall be monitored;
(ii) When $D \geq 1$, radionuclides or compounds for which $d_j \geq 0.3$ should be monitored
(iii) When $D \geq 1$, radionuclides or compounds for which $d_j << 0.1$ monitoring is unnecessary.

Individual workers should be monitored as a part of routine monitoring programme, for all the nuclides and compounds that meet the presented criteria, if the work is performed continuously. In this case the ICRP recommends a model that the intake of the radionuclide took place in the middle of the monitoring interval of T days. For a given measured quantity, M, obtained at the end of the monitoring interval, the intake, I, is:

$$I = \frac{M}{m\left(T/2\right)} \quad (3)$$

where m(T/2) is the predicted value of the measured quantity (Bq by Bq of intake) at time T/2 after intake, in days.
The monitoring intervals should be established so that, assuming the hypothesis of the incorporation occurrence in the middle of measurement period does not lead to a underestimation of the dose by a factor greater than three.

This factor can be determined by the expressions:

$$R_1 = \frac{E(50)_{t=T-1}}{E(50)_{t=T/2}} \qquad (4) \qquad \text{and} \qquad R_2 = \frac{E(50)_{t=T/2}}{E(50)_{t=1}} \qquad (5)$$

where

$E(50)_{t = T - 1}$ is the committed effective dose calculated for t = T – 1 day before the measurement;
$E(50)_{t = T/2}$ is the committed effective dose calculated for t = T/2 day, or in the middle of the monitoring period; and
$E(50)_{t = 1}$ is the committed effective dose calculated for t = 1 day before the measurement.

and,

$$E(50) = I.\ e(g)_{inh} \qquad (6)$$

where

I is the intake of specific radionuclide, Bq
$e(g)_{inh}$ is the dose coefficient, Sv Bq^{-1}

3. Results and Conclusions

Any radionuclide that can contribute with over 30% in the decision factor for the radionuclides selection will be included in the routine bio-analysis program [2]. In Table I, the decision factor for individual monitoring calculated for specific radionuclides of interest is presented.

Table I. Handling Activity and Decision Factor for Individual Monitoring for each of the Radionuclides of Interest

Compound	Handling Activity A_j (GBq/year)	Decision Factor d_j
• ^{18}F – Fluoro-2-Deoxi-D-Glucose (FDG)	• 5.00.E02	• 2.70.E-02
• ^{32}P –Phosphoric Acid	• 7.40.E01	• 8.14.E-01
• ^{32}P – Sodium Phosphate	• 3.70.E01	• 4.07.E-01
• ^{35}S – Sodium Sulphate	• 3.70.E01	• 2.96.E-01
• ^{35}S – Sulphuric Acid	• 2.00.E00	• 1.60.E-02
• ^{67}Ga – Gallium Citrate	• 1.50.E03	• 4.20.E-01
• ^{45}Ca – Calcium Chloride	• 5.00.E-01	• 1.14.E-01
• ^{201}Tl – Thallium Chloride	• 6.50.E02	• 4.92.E-02
• ^{51}Cr – Chromium Chloride	• 1.00.E02	• 3.60.E-02
• ^{51}Cr – Sodium Chromate	• 5.00.E01	• 1.80.E-02
• ^{51}Cr – Ethylenediamine Tetracetic Acid (EDTA)	• 3.00.E01	• 1.08.E-02
• ^{51}Cr – Human Serum Albumin (HSA)	• 1.00.E00	• 3.60.E-04
• ^{153}Sm – Samarium	• 6.00.E01	• 4.08.E-02
• ^{153}Sm – EDTMP- Ethylenediamine -Tetramethylene -Phosphonic Acid	• 1.50.E03	• 1.02.E00
• ^{153}Sm – Hydroxyapatite	• 2.00.E01	• 1.36.E-02
• ^{99}Mo / ^{99m}Tc –Ipen-Tec Generator	• 9.40.E05	• 3.38.E02
• ^{131}I – Sodium Iodine Capsules	• 3.00.E03	• 3.33.E04
• ^{131}I – Sodium Iodine Solution	• 3.80.E04	• 4.22.E05
• ^{131}I – Iodo-hippurate (Hipp)	• 1.50.E01	• 1.67.E02
• ^{131}I – Lipiodol	• 1.00.E01	• 1.11.E02
• ^{131}I – Human Serum Albumin (HSA)	• 5.00.E02	• 1.11.E01
• ^{131}I – Metaiodo-benzilguanidine (MIBG)	• 1.00.E00	• 5.56.E03
• ^{125}I – Human Serum Albumin (HSA)	• 1.00.E00	• 7.30.E00

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The radionuclides selected for routine individual monitoring, according to the selection criterion are presented in Table II.

Table II. Radionuclides Selected for Routine Individual Monitoring

Compound	Type	Decision Factor d_j
• ^{32}P –Phosphoric Acid	• M	• 8.14.E-01
• ^{32}P – Sodium Phosphate	• M	• 4.07.E-01
• ^{67}Ga - Gallium Citrate	• M	• 4.20.E-01
• ^{153}Sm - EDTMP- Ethylenediamine -Tetramethylene -Phosphonic Acid	• M	• 1.02.E00
• ^{99}Mo/^{99m}Tc – Ipen-Tec Generator	• F	• 3.38.E02
• ^{131}I – Sodium Iodine Capsules	• F	• 3.33.E04
• ^{131}I – Sodium Iodine Solution	• F	• 4.22.E05
• ^{131}I – Iodo-hippurate (Hipp)	• F	• 1.67.E02
• ^{131}I – Lipiodol	• F	• 1.11.E02
• ^{131}I – Metaiodo-benzilguanidine (MIBG)	• F	• 5.56.E03
• ^{131}I – Human Serum Albumin (HSA)	• F	• 1.11.E01
• ^{125}I – Human Serum Albumin (HSA)	• F	• 7.30.E00

The radionuclides that contribute potentially for the internal dose were selected and the measurement methods were established. The compounds and their radionuclides presented in Table II will be those demanding interest for the establishment of a routine dosimetry program for internal contamination. The methods are the in vivo measurement in the thyroid for the iodine compounds and the in vivo measurement in the whole body for gallium-67 and samarium-153. For the phosphorus-32 compounds the in vitro measurement is the method used, with 24 hr. urine collection.
^{99}Mo / ^{99m}Tc – Generator (Sodium Pertecnetate), as it is a radionuclide of short half-life, with a greater potential risk for skin contamination, absorption incorporation and will be considered only as a special monitoring purpose.
Among the radionuclides selected, iodine-131 is considered the most significant radionuclide concerning internal exposition. It was identified that all the other radionuclides listed in Table I, which do not comply with the criteria (ii) should be evaluated by a special monitoring program.
For example, the routine monitoring of iodine-131 compounds at our laboratory are measured by in vivo method in the thyroid, with detection limit of 90 Bq (NaI), established "*a priori*". It was found that the frequency of the routine monitoring based on the minimal detectable dose for this measurement system can be established once a month. However, calculating the values of the ratios R1(3.99) and R2(3.43) with the expressions (4) and (5), and the data of table III, its results in a factor greater than three for the monitoring period of 30 days, and this criteria is not accomplished. The values or R1(0.75) and R2(1.62) calculated for 15 days meet this requirement and it is the recommended monitoring frequency.

Table III: Retention Function in Thyroid and Minimal Detectable Doses for ^{131}I, for Inhalation of Compounds Type F, AMAD of 5µm. (In vivo Measurement)

Days after the incorporation	Retention Function [(1)]	Minimal Detectable Incorporation	
		Incorporation (Bq)	E(50) mSv
• 1	• 1.20.E-01	• 7.50.E02	• 8.25.E-03
• 2	• 1.20.E-01	• 7.50.E02	• 8.25.E-03
• 5	• 9.00.E-02	• 1.00.E03	• 1.10.E-02
• 7	• 7.40.E-02	• 1.22.E03	• 1.34.E-02
• 15	• 3.50.E-02	• 2.57.E03	• 2.83.E-02
• 30	• 8.70.E-03	• 1.03.E04	• 1.13.E-01
• 60	• 5.40.E-04	• 1.67.E05	• 1.84.E00
• 90	• 3.30.E-05	• 2.73.E06	• 3.00.E01
• 180	• 8.10.E-09	• 1.11.E10	• 1.22.E05

Dose coefficient, e(g)inh = 1.10.E-05 mSv/Bq
Limit of detection (thyroid) = 90 Bq

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