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Dose coefficients for natural radionuclides

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DOSE COEFFICIENTS FOR NATURAL RADIONUCLIDES

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Abstract.
Most natural radionuclides are members of a decay series. This implies that most of these radionuclides have radioactive offspring. The conversion from intakes of these decay chain members to the committed dose to workers depends strongly on the way these radioactive daughters are treated. This paper adresses this problem and concludes with a list of recommended dose coefficients for use in the non-nuclear industry.

1. Introduction

The occurance of natural radionuclides in the non-nuclear industry presents radiologial problems.Theoretically the dose due to these radionuclides is highest after inhalation. External irradiation and exposure due to ingested radionuclides play a minor role in this respect. The dose that results from inhalation of radioactive material can only be calculated, not measured. The calculation of the committed dose depends on a large number of factors. The main factors are: the model used for the respiratory tract, the particle size distribution, the solubility of the inhaled particle, the biokinetics of the inhaled element and the treatment of progeny. This last factor pertaines to the way the ingrowth of radioactive daughters is taken into account (e.g. equilibrium, ingrowth in the body) and the subsequent biological behaviour of these daughters (e.g. shared or independent kinetics).
For example, published dose coefficients for inhalation by adults of the natural radionuclide ^{226}Ra range from 0.36 to 9.5 μSv/Bq. However, none of these values is appropriate for the non-nuclear industry, as the applicable combination of factors (solubility, particles size, daughter treatment) is not found in ICRP-publications. This paper deals with this problem.

2. Respiratory tract model

Over the years the model for the inhalation pathway has evolved from a simple two-compartment model to the latest 14-compartment model as recommended by ICRP in its Publication-66 [1]. It is clear that only this last model will give a more or less realistic description of the deposition and clearance of particles in the respiratory tract. This model is therefore used in this paper.

3. Deposition

The ICRP-66-model describes the deposition of particles in the different sections of the airways. The location where the material is deposited depends on the particle size distribution. Usually this distribution is unkown, so in practice a default distribution must be assumed. For workers the value of the main descriptor of the particle size distribution, the Activity Median Aerodynamic Diameter (AMAD), is recommended to be 5 μm. This is a fairly large size, which results in a deposition that is mainly concentrated in the extra-thoracic (ET) part of the respiratory tract (74%), in contrast to a

mere 8% deposited in lung tissue. The effect of this choice is a relatively large dose delivered to extra-thoracic tissues. For many nuclides this inherently means that the ET-dose is greater than the dose to other organs/tissues of the body. As this part of the body has been recently declared a 'remainder'-organ, the contribution of the ET- dose to the effective dose is in this case calculated with a tissue weighting factor of 0.025.

4. Solubility

The ICRP-66-model distinguishes between mechanical and chemical clearance. The mechanical movement of particles (whether intact or partly dissolved) is the same for all chemical compounds. The solubility, however, depends strongly on the chemistry. Most natural radionuclides occur in more or less natural matrices, the solubility of which is usually low. The natural matrix is (by its very existence) known to have survived all kinds of external influences (temperature, weather). Insoluble material is classified in the ICRP-model as class S (Slow). Therefore, the vast majority of natural radionuclides occur in class S chemical compounds. In ICRP publications the recommended solubility class for workers is Class M.

The effect of the classification as 'S' is that the material remains in the airways for extended periods of time. The effective committed dose is therefore dominated by the dose to the respiratory tract. For the single nuclide ^{226}Ra the figures are 41 μSv/Bq for lung tissue, 75 μSv/Bq for ET-tissue and 0.04 μSv/Bq for other organs or tissues (for class S inhalation at AMAD = 5 μm). This means that the biokinetics of the element (here Ra) is not important to the end result.

5. Treatment of radioactive progeny

Radioactive daughters present a variety of problems for the determination of the dose coefficient. The usual procedure for the treatment of radioactive progeny (as applied in ICRP-30 [2]) is as follows: the radionuclide for which the dose coefficient is to be calculated, is assumed to be present at the time of inhalation as a pure radionuclide, i.e. no daughters are assumed to be present at this point in time. The ingrowth of daughters in the body after inhalation is fully taken into account. The kinetic behaviour of these daughters is usually assumed to be the same as that of the mother radionuclide (shared biokinetics). Exceptions to this rule are mentioned seperately, e.g. during the formation of radioactive daughters of the element Rn in bone tissue [2].

Alternatively, it may be assumed that all daughters are present at the time of inhalation. This means that all nuclides of the decay chain are inhaled with an equilibrium activity. The resulting dose coefficient may be applicable to ores or mill tailings. These coefficients may be calculated by taking the sum of the dose coefficients of all decay chain members.

The most sophisticated calculational scheme considers the ingrowth of radioactive daughters in the body, each with its own biokinetic parameters. This method is used in ICRP-71 [3]. In this publication radon istopes in the respiratory tract are assumed to be exhaled at a rate of 100 d^{-1}.

The applicable calculation method depends on the situation encountered in practice.

6. Application to non-nuclear industry

Natural radionuclides in the non-nuclear industry show the following features:

- The inhalation pathway is dominant;
- The solubility is low, i.e. class S applies;
- The dose coefficient is mainly determined by the dose to the respiratory tract;
- Radioactive daughters remain locked in the particle matrix;
- Radioactive daughters are either present in equilibrium or as recent ingrowth.

These parameters make it possible to use the computer programme LUDEP, as developed by NRPB [4]. Version 2.04 of this programme is now available. However, recent biokinetic models for some elements (uranium, radium, lead, ..) that consider recycled material as described in ICRP-67 [5] and ICRP-69 [6] cannot yet be applied in this programme. The same holds for the calculation of the contribution of daughter radionuclides using independent kinetics. In this case this does not seriously influence the end result, as the main dose comes from the respiratory tract. The progamme is well suited for this purpose.

Calculations have been performed for each radionuclide with the following parameters:

- Inhalation, class S, AMAD = 5 μm;
- Single radionuclide at the time of inhalation, ingrowth within the body taken into account or decay chain radionuclides in complete equilibrium;
- Shared ICRP-30-kinetics for radioactive daughters;
- Rn-isotopes remain within the matrix.

Table 1. Dose coefficients for inhalation for single radionuclides and for the (rest of) the decay chain.

Radionuclide (single)	Dose coefficient (μSv/Bq)	Radionuclide (chain)	Dose coefficient (μSv/Bq)
^{234}U	6.8		
^{238}U	5.7	^{238}U + d	65
^{228}Th	33	^{228}Th + d	36
^{230}Th	6.9		
^{232}Th	22	^{232}Th + d	70
^{234}Th	0.006		
^{224}Ra	2.7	^{224}Ra + d	2.7
^{226}Ra	38	^{226}Ra + d	45
^{228}Ra	12		
^{210}Pb	4.6	^{210}Pb + d	7.7
^{210}Po	2.7		

Dose coefficients for the chain are found by summation of the (main) contributors in the chain.

The dose coefficients may be compared with the values obtained for similar circumstances by Silk and coworkers [7]. This comparison shows a good agreement.

It is clear that e.g. the ^{226}Ra-dose coefficients calculated here exceed all values as given by ICRP (range 0.4 to 9.5 μSv/Bq). Dose coefficients for natural radionuclides in slowly dissolvable matrices, as encountered in many sections of the non-nuclear industry, are higher than published in ICRP-documents. The use of ICRP-values underestimates the dose to workers.

References

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[5] ICRP Publication 67, "Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 2 Ingestion Dose Coefficients", Ann ICRP **23**, no 3/4 (1993)

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