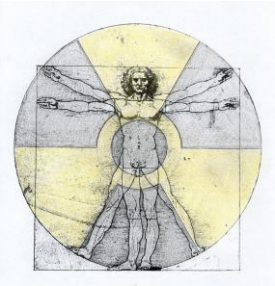

IDEA System

The Expert System for Internal Dosimetry

Newsletter No. 1/2020

IDEAplus

New version of the Expert System for Internal Dosimetry according to the most recent ICRP Recommendations (Publications 134, 137 and 141):

Further improvement of precision and accuracy of internal dose assessment

Background

The 2007 Recommendations of the International Commission on Radiological Protection (ICRP, 2007) introduced changes that affect the calculation of effective dose and implied a revision of the dose coefficients for internal exposure, published previously in the Publication 30 series and Publication 68. In addition, new data are available that support an update of the radionuclide-specific information given in Publications 54 and 78 for the design of monitoring programs and retrospective assessment of occupational internal doses. Provision of new biokinetic models, dose coefficients, monitoring methods, and bioassay data was performed by Committee 2, Task Group 21 on Internal Dosimetry, and Task Group 4 on Dose Calculations.

A new series, the Occupational Intakes of Radionuclides (OIR) series, is going to replace the Publication 30 series and Publications 54, 68, and 78. Part 1 of the OIR series has been issued in 2015, and describes the assessment of internal occupational exposure to radionuclides, biokinetic and dosimetric models, methods of individual and workplace monitoring, and general aspects of retrospective dose assessment.

The following publications in the OIR series (Parts 2–5) will provide data on individual elements and their radioisotopes, including

- information on chemical forms encountered in the workplace
- a list of principal radioisotopes and their physical half-lives and decay modes
- the parameter values of the reference biokinetic model
- and data on monitoring techniques for the radioisotopes encountered most commonly in workplaces.

Reviews of data on inhalation, ingestion, and systemic biokinetics are also provided for most of the elements. Dosimetric data provided in the printed publications of the OIR series include

- tables of committed effective dose per intake (Sv per Bq intake) for inhalation and ingestion,
- tables of committed effective dose per content (Sv per Bq measurement) for inhalation,
- and graphs of retention and excretion data per Bq intake for inhalation.

These data are provided for all absorption types and for the most common isotope(s) of each element. The electronic annex that accompanies the OIR series of reports contains a comprehensive set of committed effective and equivalent dose coefficients, committed effective dose per content functions, and reference bioassay functions. Data are provided for inhalation, ingestion, and direct input to blood.

The second publication in the series (ICRP Publication 134) the above data are presented for the following elements: hydrogen (H), carbon (C), phosphorus (P),sulphur (S), calcium (Ca), iron (Fe), cobalt (Co), zinc (Zn), strontium (Sr), yttrium(Y), zirconium (Zr), niobium (Nb), molybdenum (Mo), and technetium (Tc) (ICRP, 2016). The third publication in the series (ICRP Publication 137) provides the above data for the following elements: ruthenium (Ru), antimony (Sb), tellurium (Te), iodine (I), caesium (Cs), barium (Ba), iridium (Ir), lead (Pb), bismuth (Bi), polonium (Po), radon (Rn), radium (Ra), thorium (Th), and uranium (U) (ICRP, 2017). The fourth publication in the series (ICRP Publication 141) provides the above data for the following elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), actinium (Ac), protactinium (Pa), neptunium (Np), plutonium (Pu), americium (Am), curium (Cm), berkelium (Bk), californium (Cf), einsteinium (Es), and fermium (Fm).

IDEA System has implemented all information provided in the OIR series by now and thus created a new version IDEAplus with improved precision and accuracy.

Features of IDEAplus

More isotopes

The last Version of the IDEA Expert System (Version MV-03.6.7) includes 63 elements with 112 isotopes, the biokinetic functions and dose coefficients of which being based on the ICRP Publication 30 series and Publications 54, 68, and 78.

In the new version IDEAplus the biokinetic functions and dose coefficients of 39 out of these elements have been replaced according to the new ICRP Publications 134, 137 and 141 of the OIR series. In addition, 13 elements have been implemented which were not included in the last version of IDEA, i.e. Praseodynium (Pr), Neodymium (Nd), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Protactium (Pa), Berkelium (Bk), Californium (Cf), Einsteinium (Es) and Fermium (Fm). So, now 76 elements are included in the expert system with in total 601 radionuclides.

For the update the OIR Data Viewer (Version 4.01.04.19) has been used with special authorization of the ICRP. The OIR Data Viewer provides data for the Reference Worker including values of dose per intake coefficients, dose per content functions, and reference bioassay functions for intake by inhalation, ingestion and for direct uptake to the blood.

Table 1: Elements covered by IDEA and IDEAplus (number of available isotopes marked in blue)

Element	Availability of isotopes	
	IDEA	IDEAplus
H	1	1
Be	1	
C	1	2
Na	2	
Mg	1	
P	2	2
S	1	2
Cl	1	
Ca	1	3
K	1	
Sc	1	
Cr	1	
Mn	1	
Fe	2	4
Co	3	9
Ni	2	
Co	1	
Zn	1	7
Ga	1	
Se	1	
Rb	1	
Sr	3	11
Y	2	16
Zr	1	7
Nb	2	15
Mo	1	7
Tc	2	15
Ru	2	6
Rh	1	
Ag	2	
Cd	1	
In	2	
Sn	1	
Sb	3	20
Te	2	21
I	7	18
Cs	2	13
Ba	2	15

Element	Availability of isotopes	
	IDEA	IDEAplus
La	1	12
Ce	2	13
Pr		14
Nd		13
Pm	1	11
Sm	1	12
Eu	3	17
Gd		10
Tb		17
Dy		9
Ho		15
Er		8
Tm		12
Yb	1	9
Lu	1	16
Hf	1	
Ta	1	
Re	1	
Ir	1	20
Hg	2	
Tl	2	
Pb	2	18
Bi	1	14
Po	1	8
At	1	
Ra	3	7
Ac	1	5
Th	4	10
Pa		9
U	4	13
Np	2	11
Pu	5	14
Am	2	14
Cm	5	14
Bk		6
Cf		11
Es		9
Fm		7

Contrary to the previous datasets, the OIR Data Viewer provides biokinetic functions and dose coefficients also for short-lived isotopes with physical half-life values down to 10 min. So, for some elements up to 20 radioactive isotopes are included in the new version of the expert system.

Table 2 shows as an example the availability of isotopes for Iodine. The last version of IDEA covers in total 7 isotopes of Iodine, the half-life of which being typically more than 12 h. There is also one isotope with a shorter half-life (I-132), which has been included because it may be important after nuclear accidents.

The new version IDEAplus includes 10 additional isotopes with a short half-life and one isotope with a longer half-life (I-126) which was missing in the last version. So now any isotope of Iodine is available which could be relevant for internal dosimetry. The same applies also for the other new elements of IDEAplus.

Table 2: Isotopes of Iodine covered by IDEA and IDEAplus

Isotope	Physical halflife	Availability of isotopes	
		IDEA	IDEAplus
I-118	13,7 min		
I-119	19,1 min		
I-120	81,6 min		
I-120m	53 min		
I-121	2,12 h		
I-123	13,2 h		
I-124	4,18 d		
I-125	59,4 d		
I-126	12,9 d		
I-128	24,99 min		
I-129	1,57E07 y		
I-130	12,36 h		
I-131	8,02 d		
I-132	2,295 h		
I-132m	1,387 h		
I-133	20,8 h		
I-134	52,5 min		
I-135	6,57 h		

More organs and tissues

The last version of IDEA provides dose coefficients for the effective dose and for 24 organs and tissues as given in the ICRP Publication 30 series and Publications 54, 68, and 78.

The new version IDEAplus provides in addition dose coefficients for the salivary glands, gall bladder, heart, lymphatic nodes, oral mucosa, and prostate, as given by the OIR series. The upper and lower large intestine (ULI and LLI) given by the ICRP Publication 30 model have been combined to one tissue (colon) in the new model. Thus, the new version IDEAplus provides now all dose coefficients for the effective dose and for 29 organs and tissues (see Table **3**).

Table 3: Organs and tissues covered by IDEA and IDEAplus (marked in blue)

	IDEA	IDEAplus
Effective	■	■
Bone marrow	■	■
Colon (ULI + LLI)	■	■
Lung	■	■
Stomach	■	■
Breast	■	■
Ovaries	■	■
Testes	■	■
Urinary bladder	■	■
Oesophagus	■	■
Liver	■	■
Thyroid	■	■
Bone surface	■	■
Brain	■	■
Salivary glands		■

	IDEA	IDEAplus
Skin	■	■
Adrenals	■	■
ET of HRTM	■	■
Gall bladder		■
Heart		■
Kidneys	■	■
Lymphatic nodes		■
Muscle	■	■
Oral mucosa		■
Pancreas	■	■
Prostate		■
Small intestine	■	■
Spleen	■	■
Thymus	■	■
Uterus	■	■

In the last version of IDEA the dose coefficients are given for the adult worker and for members of the public as well. For the members of the public the dose coefficients are specified for adults and for younger persons in the age of 15 years, 10 years, 5 years, one year and 3 months, respectively. There is no specification with respect to gender, i.e. the dose coefficients are valid for both males and females. In the OIR dataset, however, there are gender-specific dose coefficients for male and female workers.

So, in the new version IDEAplus the dose coefficients are applied in the following way:

- For workers the new dose coefficients are applied as far as available, i.e. for the 39 elements covered by ICRP Publications 134, 137 and 141. In this case the software checks the gender of the worker and allocates the dose coefficients accordingly. For the remaining elements the software applies the available dose coefficients in the same way as in the last version of IDEA.
- For members of the public all dose coefficients are applied in the same way as in the last version of IDEA.

Table 4: Application of dose coefficients

Subject	IDEA	IDEAplus
Worker	Adult	Adult male
		Adult female
Member of the public	Adult	
	15 years old	
	10 years old	
	5 years old	
	1 year old	
	3 months old	

More retention functions

The last version of IDEA provides whole body retention functions and excretion functions for urine and feces for all radionuclides. In addition, some organ retention functions are provided for some selected radionuclides with respect to the interpretation of organ specific *in vivo* measurements (such as thyroid measurement of Iodine, lung measurement of Cobalt, or liver and skeleton measurement of Americium).

The new version IDEAplus provides more organ retention functions allowing for the interpretation of most organ specific *in vivo* measurements. In this context the retention of the alimentary tract is of special importance because it allows for the correction of the contribution from the alimentary tract to the *in vivo* count rates.

The new version IDEAplus provides also excretion functions for all isotopes where in vitro measurements make sense, i. e. isotopes with a biological half-life > 1 h.

Table 5: Retention and excretion functions included in IDEAplus for the 39 new elements

Element	Retention						Excretion[1]	
	Whole body	ALI tract	Lungs[2]	Skeleton	Liver	Thyroid	Urine	Feces
H								
C, S, Ca, Sr, Ba								
P, Fe, Co, Zn, Y, Zr, Nb, Ru, Cs, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ir, Pb, Bi, Po, Ra, Ac, Th, Pa, U, Np, Pu, Am, Cm, Bk, Cf, Es, Fm								
Mo								
Tc, Sb, Te								
I								

Improved time scale

The time scale of the last versions of IDEA is based on a full day scheme: In this scheme the retention functions refer to the body or organ activity at the end of the respective day, whereas the excretion functions refer to the integral urinary or fecal excretion from the beginning until the end of the respective day.

So, in this scheme the first value of any body or organ retention function refers to the body or organ content at the end of the first day. This may give rise for some problems with the interpretation of short-lived radionuclides, such as Tc-99m, where the first value of the whole-body retention function is 5 % of the intake and the second value only 0,2 % (see Figure **1**). So, the retention function starts when most of the activity already has decayed. Thus, the main information about the intake cannot be used for the evaluation of the case.

Figure 1: Whole body retention of ingested Tc-99m

[1] only for isotopes with effective half-life > 1 h
[2] only for inhalation

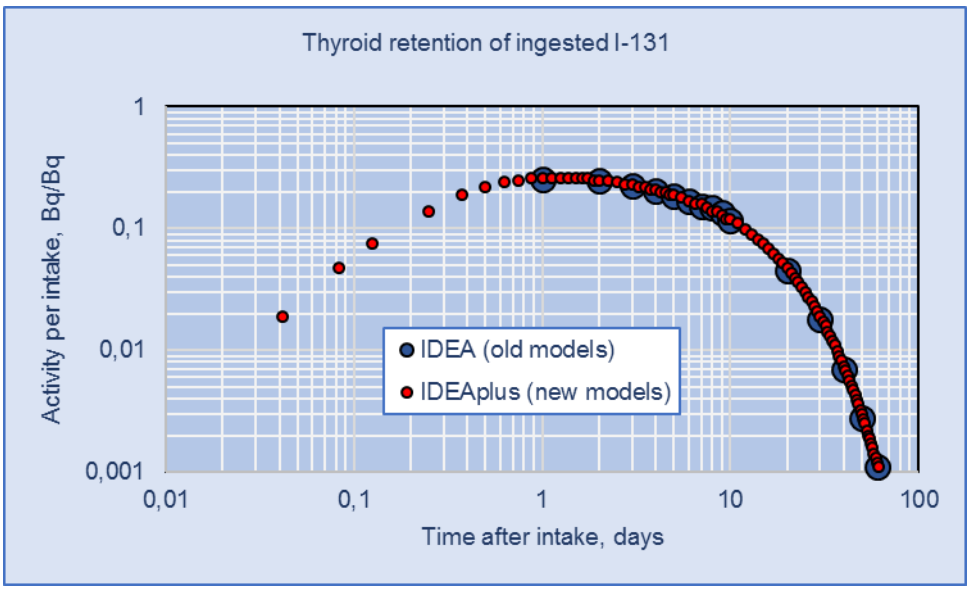

Figure 2: Thyroid retention of ingested I-131

For solving this problem, the new version IDEAplus provides a time scale with a better time resolution. In this new time scale the retention functions starts already at 1 h or 0,042 d, respectively, after intake. The first day is covered now by 10 grid points on a quasi-logarithmic scale. The second day has 8 grid points, the third day 4 grid points, etc. Because of the increased number of grid-points the measured values can be allocated much better to the retention function as before.

So, the new time scale allows for a more precise definition of the time of intake, this being of importance especially for short-lived radionuclides such as C-11, Tc-99m and I-131.

Improved biokinetic models

For many radionuclides, such as Tc-99m and I-131, the new models result in similar biokinetic functions as the old models, the difference between the function values being typically less than 10 %. For some radionuclides, however, there are significant differences between the function values. So, for example, the whole-body retention of Cs-137 after inhalation of type F Cs-137 aerosols is now up to 30 % higher before (see
Figure 3).

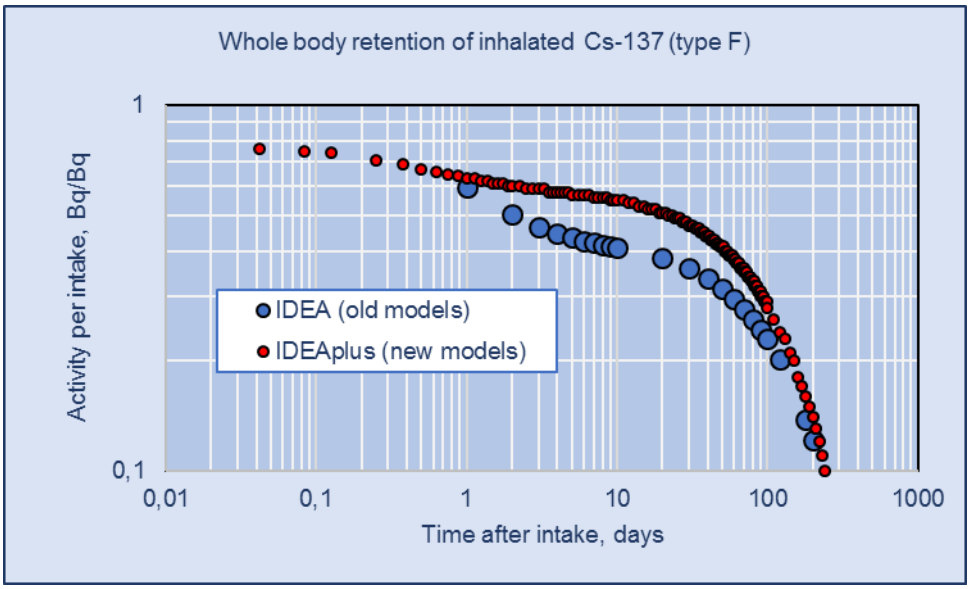

Figure 3: Whole body retention of inhaled Cs-137 (type F, 5 µm AMAD)

The new ICRP recommendations are based on an extensive review of data on inhalation, ingestion, and systemic biokinetics and thus the new models represent in general a better approximation to reality than the previous models. In the case of the whole-body retention of Cs-137 the exposure is overestimated by the old models, and so the assessment result in a conservative dose assessment. The same holds for the excretion of inhaled Th-228 as shown in Figure 4.

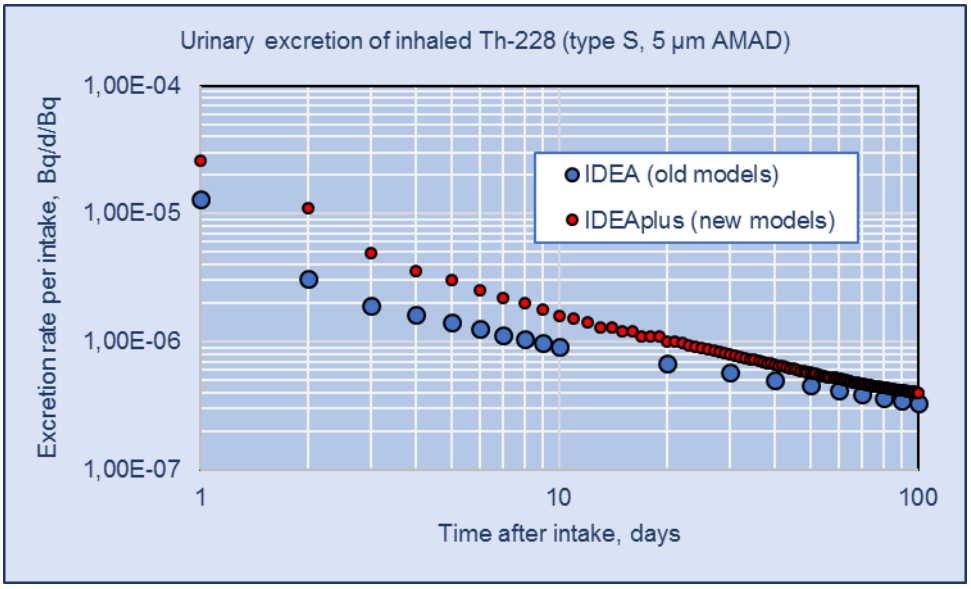

Figure 4: Urinary excretion of inhaled Th-228 (type S, 5 µm AMAD)

There are, however, some other radionuclides where the old models may result in a significant underestimation of the dose. For example, the evaluation of whole-body measurements of inhaled Co-60 (type M, 5 µm AMAD) would result in an underestimation of the intake by about 40 % if the measurement is started only one week after the intake. The underestimation of intake is compensated to some extent by the dose coefficient, but there would be still an underestimation of dose in the order of 15 – 20 %. The situation is similar for some other radionuclides which are measured by lung counting, such as U-235.

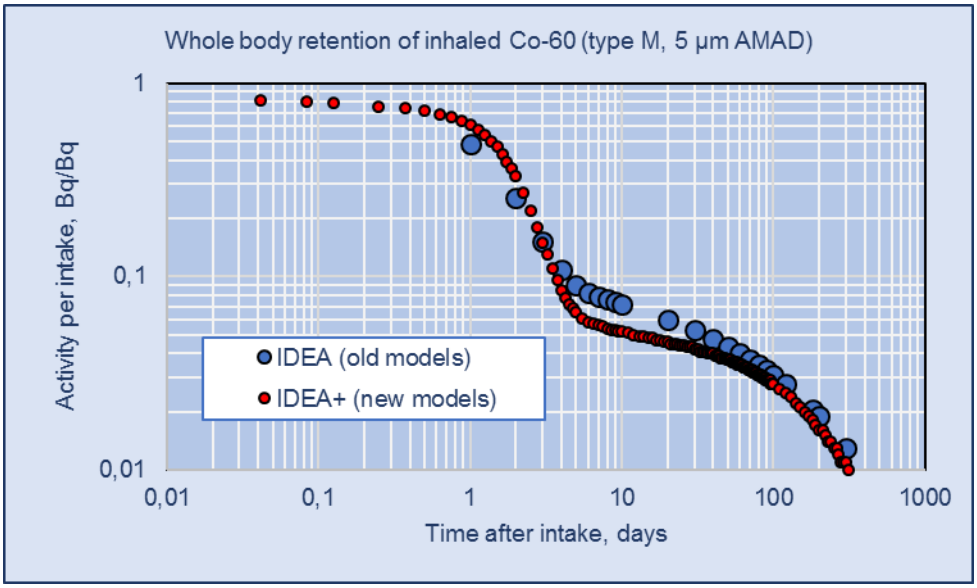

Figure 5: Whole body retention of inhaled Co-60 (type M, 5 µm AMAD)

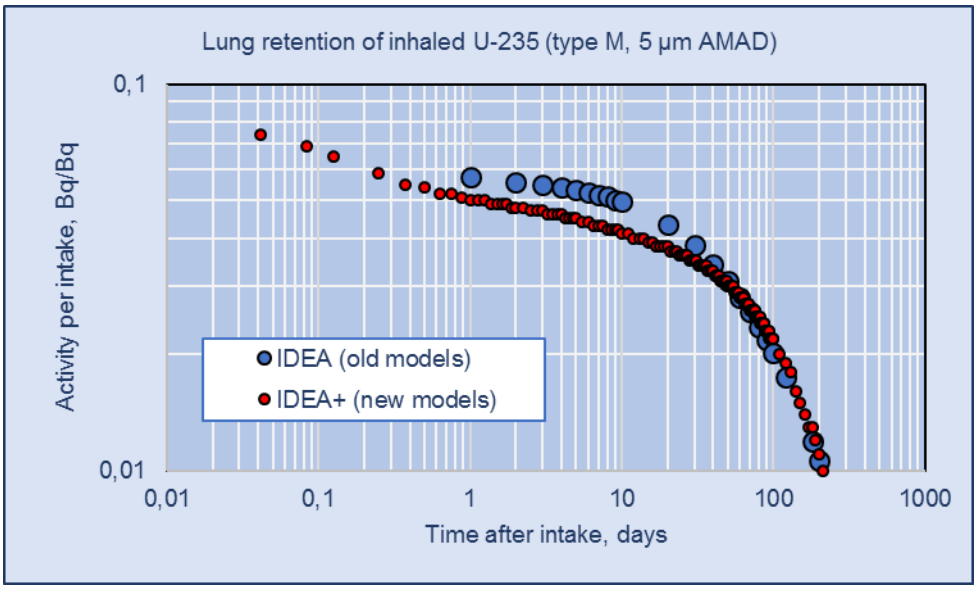

Figure 6: Lung retention of inhaled U-235 (type M, 5 µm AMAD)

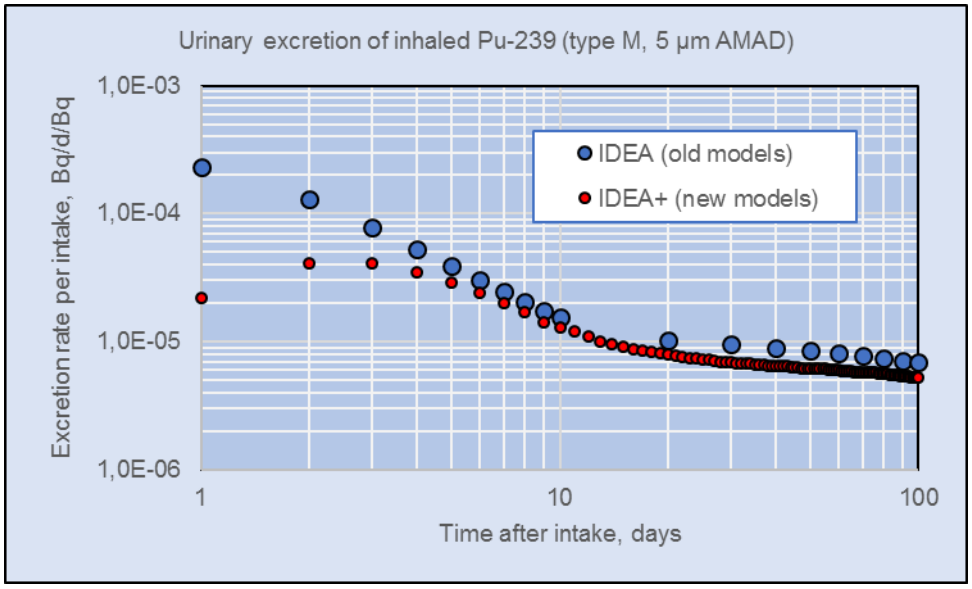

Figure 7: Urinary excretion of inhaled Pu-239 (type M, 5 µm AMAD)

In the case of urinary excretion of inhaled Pu-239 (type M, 5 µm AMAD) there is a significant underestimation of intake especially in the first days after intake. So, a measured Pu-239 excretion rate of 1 mBq/d at the first day would result in an effective dose of 0.14 mSv according to the old models and 0.64 mSv according to the new models, respectively.

Thus, when using IDEAplus the error due to biokinetics can be reduced and thus the accuracy of dose assessment can be improved significantly.

Exploration of new monitoring procedures

Some alpha-emitters, such as Th-228, Th-232 and U-238 have gamma-emitting daughters which can be detected in whole- or partial-body-counters (see Table 6).

Table 6: Examples of alpha-emitters with gamma-emitting daughters for *in vivo* measurement with lung counting techniques

Radionuclide		Principal gamma-emission of daughter		Typical lower limit of detector for lung counting, Bq
Mother	Daugther	Energy, keV	Abundancy, %	
Th-228	Pb-212	238,6	44,6	5
Th-232	Ac-228	911,1	29	5
U-238	Th-234	63,3 + 92,4 + 92,8	9,2	10

IDEAplus provides the retention functions for such daughter nuclides related to the intake of the respective mother nuclide. Figure 7 shows as example the Whole body and lung retention of Pb-212 after inhalation of Th-228 (type S, 5 µm AMAD). The whole-body retention function shows a typical double peak pattern with the first peak being due to the activity in the extra-thoracic air pathways and the second peak due to the activity in the lungs.

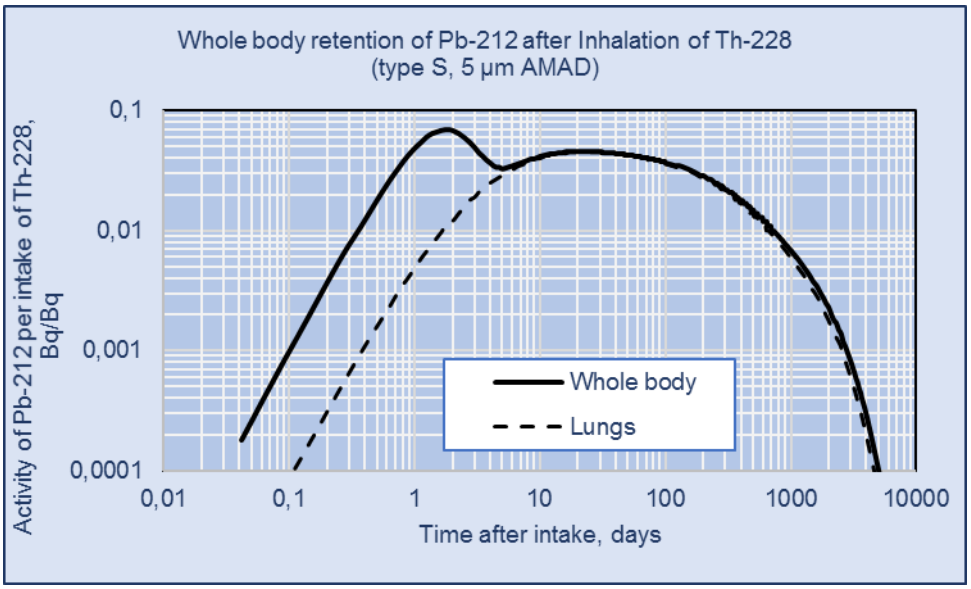

Figure 8: Whole-body and lung retention of Pb-212 after inhalation of Th-228 (type S, 5 µm AMAD)

The figure below shows the lower limit of detection (LLD) of monitoring for inhalation of Th-228 (type S, 5 µm AMAD) based on measurement of Th-228 in urine and measurement of Pb-212 in the lungs, respectively. As can be seen, the measurement of Pb-212 in the lungs is much more sensitive with respect to the dose from Th-228 than the direct measurement of Th-228 in urine. In the range from 10 d to 100 d after intake the LLD of the measurement of Pb-212 in the lungs is close to the required value for routine monitoring (1 mSv), and thus this kind of measurement could be a useful tool for monitoring of type S material. In the case of type M material the situation is vice versa, i. e. the measurement of Th-228 in urine is more sensitive than the measurement of Pb-212 in the lungs, but even here the LLD of the measurement of Pb-212 in the lungs is close to the required level in the mid time range.

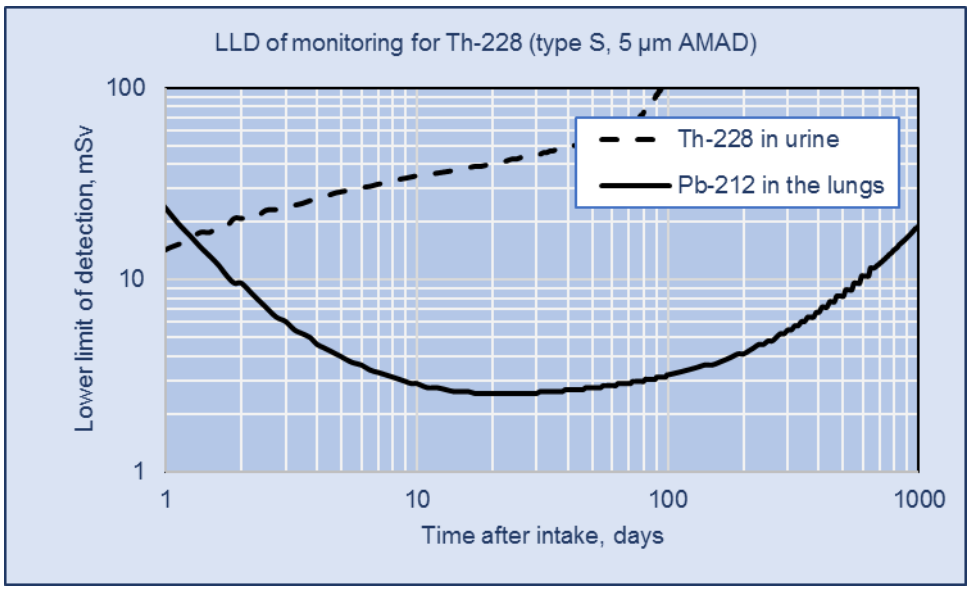

Figure 9: Lower limit of detection (LLD) of monitoring for inhalation of Th-228 (type S, 5 µm AMAD) based on measurement of Th-228 in urine and measurement of Pb-212 in the lungs, respectively

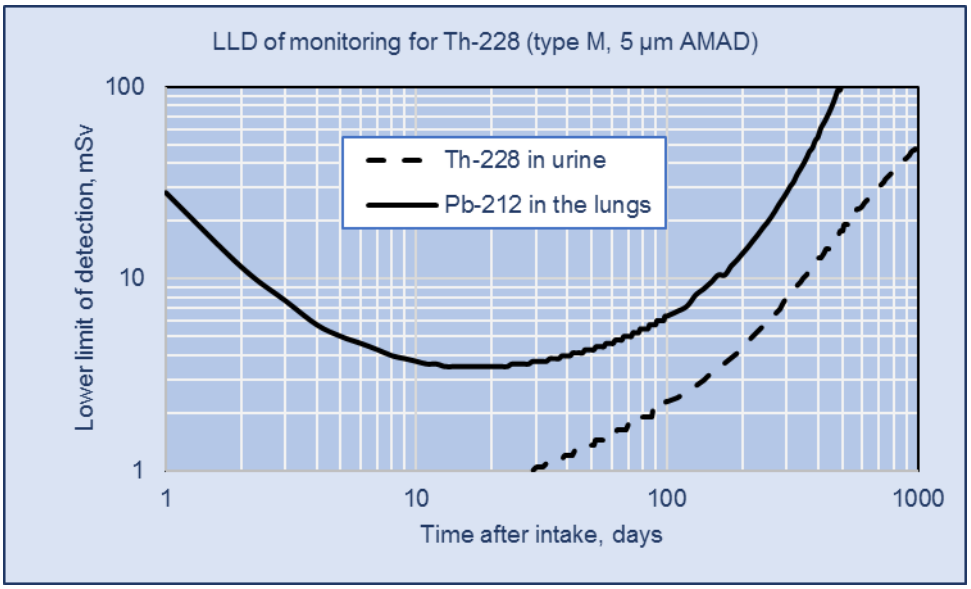

Figure 10: Lower limit of detection (LLD) of monitoring for inhalation Th-228 (type M, 5 µm AMAD) based in measurement of Th-228 in urine and measurement of Pb-212 in the lungs, respectively

This is just an example for the exploration of monitoring procedures using IDEAplus.

Summary

The new version IDEAplus has adopted the most recent ICRP Recommendations as published in the OIR series (ICRP Publications 134 and 137). The application of the new biokinetic models and the respective biokinetic functions and dose coefficients results in a further improvement of both the precision and accuracy of internal dose assessment.

This is achieved by the following innovations according to the ICRP Publications 134 and 137:

- More isotopes
- More organs and tissues
- Gender specific dose coefficients
- More biokinetic functions
- Improved time scale
- Improved biokinetic models
- Exploration of new monitoring procedures

Of course, the new version IDEAplus provides also all approved features of the last version of the IDEA software (Version MV-03.6.7).

Subscription

The full version of IDEAplus will be released at the end of March 2020 for the listed price of 7200 €. Users of IDEA pay only 50 % of the listed price. There is the possibility to subscribe by 14. February 2020 for the reduced price of 4800 € for new users or 2400 € for users of IDEA, respectively (customers in Germany have to pay additional 19 % VAT on all prices).

Subscribers will receive a beta version of IDEAplus at the end of February 2020 for testing. They are encouraged to share their experience with other users and to submit suggestions for further improvement of the software.

	Listed price, €	Subscription price, €
New user	7200	4800
User of IDEA	3600	2400

References

ICRP, 2016. Occupational Intakes of Radionuclides: Part 2. ICRP Publication 134. Ann. ICRP 45(3/4), 1–352. (Authors on behalf of ICRP: F. Paquet, M.R. Bailey, R.W. Leggett, J. Lipsztein, T.P. Fell,T. Smith, D. Nosske, K.F. Eckerman, V. Berkovski, E. Ansoborlo,A. Giussani, W.E. Bolch, J.D. Harrison)

ICRP, 2017. Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137. Ann. ICRP 46(3/4). (Authors on behalf of ICRP: F. Paquet, M.R. Bailey, R.W. Leggett, J. Lipsztein, J. Marsh, T.P. Fell, T. Smith, D. Nosske, K.F. Eckerman, V. Berkovski, E. Blanchardon, D. Gregoratto, J.D. Harrison)

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