NKS-355
ISBN 978-87-7893-439-0

Internal Dosimetry Exercise for enhanced Ability

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January 2016

Abstract

Within the previously performed NKS projects THYROID and THYROID-SEM, it became evident that there were large variations in the estimates of internal (thyroid) dose. The current activity was therefore initiated to enhance the ability to make correct calculations of internal dose following a release of radionuclides.

A seminar/course about internal dosimitry calculations program IMBA has been arranged. After the seminar, a number of scenarios, relevant for emergency preparedness, were distributed to authorities and departments involved in the Nordic emergency preparedness. The scenarios were also distributed to companies engaged in nuclear technology.

The exercises have shown that there is a wide variety of evaluation procedures, depending on the experience and the skill of the assessor as well as on assessment tools available. There is still a need for adequate training, experience and quality control. Such intercomparison exercises should be repeated on a regular basis. It is recommended that dose assessors in the Nordic countries frequently attend training (refreshing) activities that gather a number of experts and colleagues.

Key words

Internal dosimetry, intercomparison, dose estimations, course, scenarios

NKS-355
ISBN 978-87-7893-439-0
Electronic report, January 2016
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Final report for the NKS-B **IDEA** activity 2015
Contract AFT/B(15)8

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December 2015

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1 INTRODUCTION

Within the previously performed NKS-projects THYROID [1] and THYROIDSEM [2], it became evident that there were large variations in the estimates of internal (thyroid) dose. The current activity was therefore initiated to enhance the ability to make correct calculations of internal dose following a release of radionuclides.

A seminar/course about internal dosimetry calculations with the internal dosimetry program IMBA has been arranged. After the seminar, a number of scenarios, relevant for emergency preparedness, were distributed to authorities and departments involved in the Nordic emergency preparedness. The scenarios were also distributed to companies engaged in nuclear technology. The results of the dose calculations have then been evaluated and distributed to the participants.

This report is the final report of the IDEA research activity in the NKS-B research programme.

2 INTERNAL DOSIMETRY COURSE

Doses from intakes of radionuclides cannot be measured but must be assessed from monitoring, such as whole body counting or urinary excretion measurements. Such assessments require application of a biokinetic model and estimation of the exposure time, material properties, etc. Because of the variety of parameters involved, the results of such assessments may vary over a wide range, according to the skill and the experience of the assessor.

The NKS activity IDEA in 2015 had as objective to enhance the regional capacities, this including training and exercise. The target public for the IDEA activity has been the dosimetrists at Nordic nuclear sites, regulators and specialist couple to emergency response. The training effort was organized as a two days course that was held at the Swedish Radiation Safety Authority (SSM) 18 and 19 of May 2015. Participants from the following companies, organisations or authorities took part in the course (number of participants in brackets):

OKG AB, Sweden (2); AB SVAFO, Sweden; Linköping university, Seden; Westinghouse Electric Sweden AB, Sweden; (2), Forsmark kraftgrupp AB, Sweden; (4), Institutt for energiteknikk, Halden, Norway (2); Statens Institut for Strålebeskyttelse, Denmark; Norwegian Radiation Protection Authority, Norway (4); Studsvik Nuclear AB, Sweden (2); Stockholm university, Sweden; Icelandic Radiation Safety Authority, Iceland; Swedish Radiation Safety Authority, Sweden (4).

The lecturers for days 1 and 2 were respectively Prof Richard Doerfel, formerly with Karlsruhe Institute of Technology and nowadays founder and VD of the IDEAS system (IDEA System GmbH) and Prof. Mats Isaksson from Sahlgrenska Academy at University of Gothenburg.

The course on day 1 (Prof Doerfel) gave an overview over the state of the art of the determination of internal dose. It briefly went through the measuring techniques for individual incorporation monitoring i.e (i) direct measurement of activity in the whole body or organs, (ii) measurement of activity excreted with urine and faeces, and (iii) measurement of activity in the breathing zone or at the workplace, respectively. Next, the biokinetic models used for the interpretation of the monitoring data were described with special regard to the new models i.e. (i) the ICRP model for the human alimentary tract and (ii) the NCRP model for the biokinetics of radioactive materials in wounds. Finally the participants were given an overview of the application of the models for the assessment of committed dose from incorporation monitoring data, based mainly on the system IDEAS developed by Prof Doerfel.

Day 2 (Prof. Mats Isaksson) was devoted to the internal dose assessment tool IMBA. The lectures went through the theory behind the biokinetic models and specifically those implemented by the IMBA tool, the HRTM, HATM and wound model. This part also treated monitoring programs and issues regarding to the handling of data, backgrounds, uncertainties, decision threshold and handling data below detection limit. There was a hand-on session were basic examples were solved by the participants with the IMBA tool and discussed lately in plenum.

The solutions of the example exercises were address also by Doerfel's IDEA system after the course. This discussion was distributed to the participants and it is appended to this report.

3 SCENARIO EXERCISE - SCENARIOS

The scenarios, described below, were distributed to Nordic laboratories and hospitals that were assumed to be involved in internal dose estimations. The participants were instructed to send their solutions, clearly stating the assumptions made in order to solve each scenario. Correct answers, or best estimates, were sent back to the participants after the exercise.

3.1 Scenario 1

Inhalation of fine dust containing Co-60 (acute intake)

No earlier known intake

Male, 37 years old, 83 kg

After the incident the worker was followed up by the radiation protection organization at the facility. It was decided to collect urine samples and perform whole body counting.

Calculate the committed effective dose.

Measurement data

Urine bioassay (Relative uncertainty in urine data = 10 %)

Time after intake (d)	Collection period (d)	Bioassay (Bq/d)
1.000E+00	1.000E+00	2.0850E+04
2.000E+00	1.000E+00	9.822E+03
3.000E+00	1.000E+00	3.9533E+03
4.000E+00	1.000E+00	2.3266E+03
5.000E+00	1.000E+00	1.7948E+03
6.000E+00	1.000E+00	1.5516E+03
8.000E+00	1.000E+00	1.2651E+03
1.000E+01	1.000E+00	1.057E+03
1.300E+01	1.000E+00	8.2192E+02
1.600E+01	1.000E+00	6.5304E+02

Whole body bioassay (Relative uncertainty in whole body data = 10 %)

Time after intake (d)	Bioassay (Bq)
1.000E+00	9.76040E+05
2.000E+00	5.06890E+05
3.000E+00	2.89680E+05

4.000E+00	2.00500E+05
5.000E+00	1.64560E+05
6.000E+00	1.49340E+05
8.000E+00	1.37770E+05
1.000E+01	1.32220E+05
1.300E+01	1.25970E+05
1.600E+01	1.20740E+05

3.2 Scenario 2

I-125 Spot samples. Based on authentic data.

A labworker working with an I-125 radiolabelling solution gets sprayed on her arm from a leak in a syringe-to-needle fitting. The liquid is reportedly deposited on the labcoat above her gloves. The solution penetrates the coat and contaminates the skin. After removal of clothing a doserate of 2.2 mikroSv/h is measured on the skin. Thereafter the skin is decontaminated. No signal can be detected at the thyroid with a handheld monitor during the rest of day of the incident.

The chemical composition of the I-125 solution is unknown.

The spill happens at 5-aug-2105 11:00

The following activity concentrations were observed in urine spot samples (25 ml):

5-aug-2015 17:00: 406.6 Bq/l +- 10% (569.2 Bq/d)§

7-aug-2015 12:00: 18.7 Bq/l +-50% (26.2 Bq/d)§

2-sep-2015 12:00: <4.5 Bq/l (LOD) (<6.3 Bq/d)§

§ “Measured Rate Bq/d” is calculated as “A (Bq/l)*daily urine production (l/d)”. Assumed daily urine production: 1.4 l.

Questions:

What is the effective dose from either acute inhalation or injection (rapid skin absorption)?

Can IMBA be used to suggest the relative contribution from inhalation and skin absorption?

Is it surprising that no signal could be observed at the thyroid (handheld monitor)?

Is the sampling strategy optimal?

Hints and comments:

Time must be entered together with the date in IMBA. Date format is “dd-mm-yyyy hh:mm”.

The collection period is 25/1400=0.018d – not 1 d.

The stated uncertainty relates only to the measurement and does not include daily variation in urine excretion. A “scattering factor” of 2.0 (GSD, LOGNORM) may be entered instead.

Use “Intake to Bioassay” to generate excretion and activity functions for urine and thyroid. Use a high “Number of Dates” to get a smooth curve.

Bioassay data can be fitted to multiple intake regimes.

2.2 mikroSv/h corresponds to 5172 Bq I-125 at 1 cm distance (RadPro Calc). Worst case intake is expected to be below this.

3.3 Scenario 3

A laboratory assistant leaves the lab in a hurry at 6 pm and slams the door so that a vial containing I-131 falls from a shelf. The vial, containing 5 GBq I-131 in liquid form, is then broken in pieces when hitting the floor. The next day, at 7 am, the assistant returns to the lab and works at a computer for 3 h before the broken vial is discovered. Estimate the committed effective dose from inhalation of I-131, assuming the worst case that all the iodine in the vial is immediately evaporated, and that the ventilation in the lab is set at 0.3 air exchanges per hour. The volume of the room is 75 m^3.

4 SCENARIO EXERCISE – RESULTS AND DISCUSSION

4. 1 Scenario 1

This scenario was generated assuming acute inhalation of 1 MBq Co-60 (5 μm AMAD, absorption type M, f_1 = 0.1) and 1 MBq Co-60 (5 μm AMAD, absorption type S, f_1 = 0.01), giving a committed effective dose of 23.3 mSv. Results from the participants are given in Table 1.

Table 1. Estimated intake, committed effective doses reported by the participants. Also shown are the assumptions made by the participants.

Participant	**Estimated intake (MBq)**	**Committed effective dose (mSv)**	**Assumptions**
1		29.7	Inhalation and ingestion (1 μm AMAD, absorption type S)
2			
3	1.87	31.6	Inhalation (5 μm AMAD, light worker, absorption type S)
4		13	Inhalation (1 μm AMAD, absorption type M, f_1=0.1)
5		39.6	Inhalation (5 μm AMAD, absorption type S, f_1 = 0.05)
6	1.69	14.2	Inhalation ((5 μm AMAD, heavy worker, absorption type M, f_1 = 0.04)

4.2 Scenario 2

Five responses to Scenario 2 were received. Four of these included estimations of intake and effective dose (replies 1-4).

The type of intake chosen for fitting inhalation intake to bioassay data, was reported in reply 3 and 4 as “AMAD 5 μm, type F, f_1 = 1”. In reply 2, intake type was stated as “Default”. Replies 1 and 5 contained no information on intake type.

As the chemical form of the iodine is unknown, default parameters for inhalation must preferably be used for the ICRP deposition and absorption models (AMAD 5μm, Light worker, type F, f_1=1.0) (IMBA).

Fitting of observed urine activity concentrations to ICRP biokinetic models is performed in IMBA. In this scenario the urine sampling was of the spot-type, a small volume collected at a reported time of day. It was assumed that the sample volume was 25 ml and total daily urine production 1400 ml. The observed activity concentration must be converted to a daily excretion rate (Bq/d) by multiplying with the daily urine production. For bioassay fitting the integration interval (Collection period) should be a value representing the spot-sample volume fraction of daily urine volume (Col. Period = 25 ml/1400 ml d^{-1} = 0.018 d).

Screenshots of bioassay data entered into IMBA and the obtained bioassay fit was provided in reply 3 (Fig. 1).

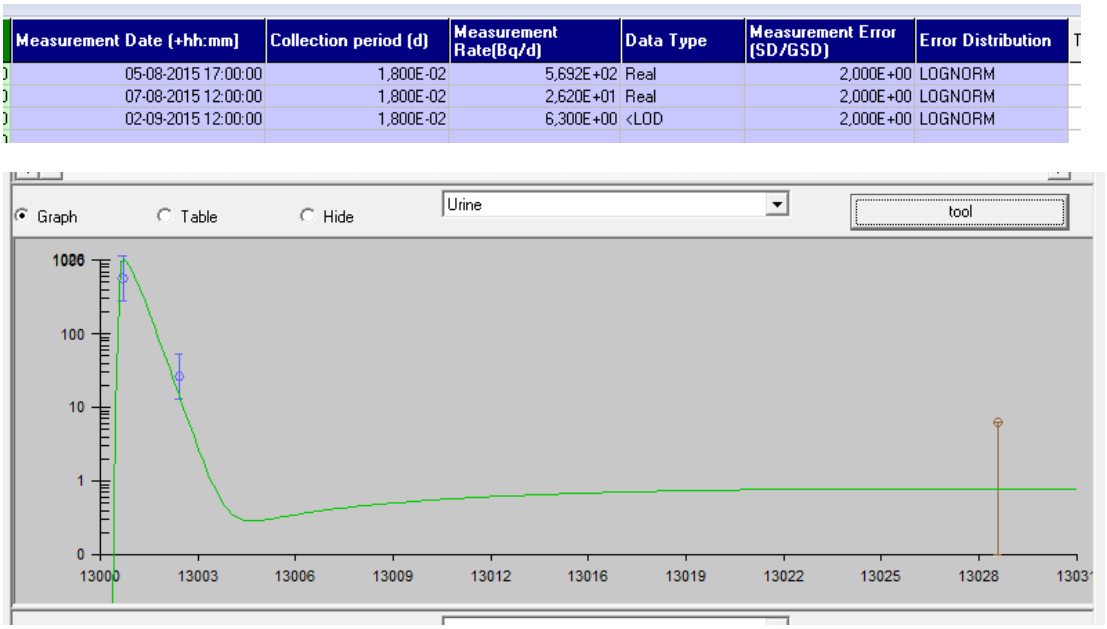


Fig. 1 Screenshot of bioassay data and obtained fit (from reply 3).

The estimated intakes and associated effective doses reported in replies are shown in Fig. 2. Three out of four replies agree on an inhaled activity of ca. 2.2 kBq and an effective dose of 0.016 mSv. The estimated intake as injection is ca. 1.2 kBq according to reply 1 and 2, with and effective dose of 0.018 mSv.

Reply 2 disagrees with estimates for both inhalation and injection. Reply 4 does not state an intake for injection, but reports an effective dose for injection more than four times higher than reply 1 and 3.

Working with IMBA, the procedure for changing the type of intake (e.g. from inhalation to injection) includes changing the intake scenario on the main screen, then repeat the calculation of intake from bioassay data and finally re-calculate dose.

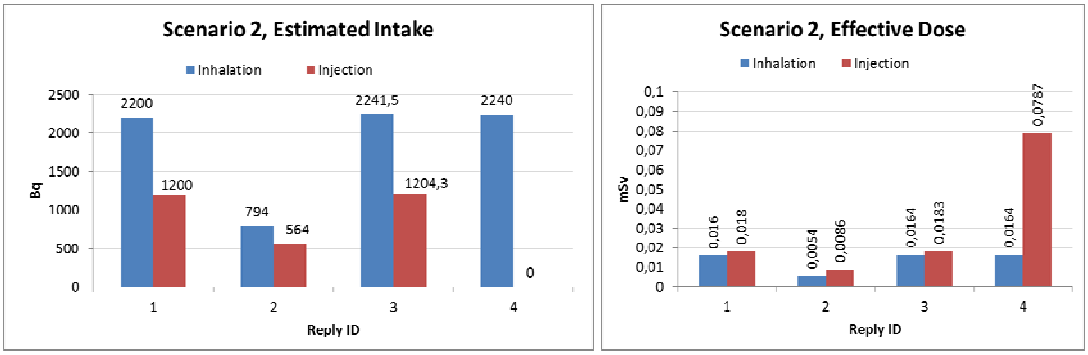
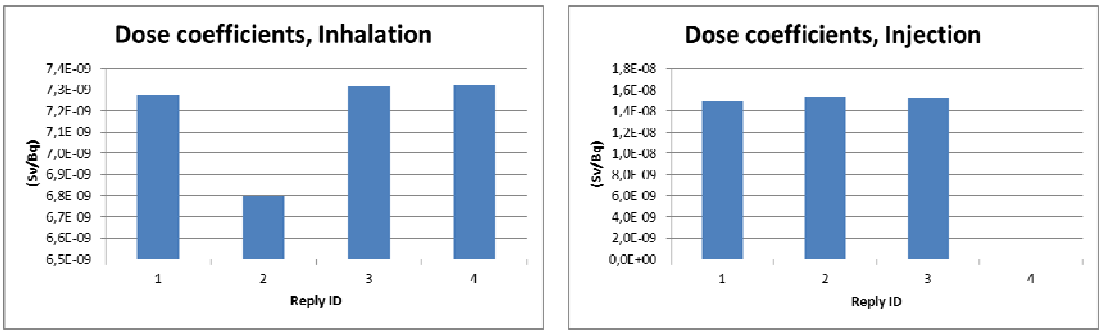


Fig. 2 Estimated intakes and effective doses reported in reply 1-4, by inhalation or injection.

The dose coefficient used can be derived by dividing the effective dose by the estimated intake. The same dose coefficient for inhalation seems to have been used by reply 1, 3 and 4, while that of reply 2 differs. For injection the dose coefficient used seems the same for all replies (reply 4 states no injection intake).



The dose coefficient, apart from reply 2 inhalation, are equal to those published by ICRP (Inhalation 5 µm, F, f_1 = 1: $7.3 \cdot 10^{-9}$ Sv/Bq; Injection or ingestion f_1 = 1: $1.5 \cdot 10^{-8}$ Sv/Bq)[3].

Since the thyroid is the organ that receives the highest organ dose from iodine radionuclides, the choice of either inhalation or injection intake has a minor effect on the effective dose (0.016 vs. 0.018 mSv) despite the greater difference in estimated intake (2.2 vs. 1.2 kBq).

Also, The dose coefficient for injection and ingestion is equal, as the relative effective dose to the GI tract (stomach and colon) exerted by iodine before absorption during ingestion is very small (less than 0,1%, $6.2 \cdot 10^{-12}$ Sv/Bq / $1.5 \cdot 10^{-8}$ Sv/Bq)(IMBA effective dose calculation).

Regarding the sampling strategy for the scenario, it was generally commented that more urine samples should have been collected during the period (the scenario is based on real data, where the individual left for vacation during the sampling period). It was also noted that 24-hour urine samples would be preferred over spot-samples. The use of spot samples introduces uncertainty as the activity must be normalized to an assumed daily urine volume and since the urine activity concentration may fluctuate during the

day. Spot samples, on the other hand, is likely more convenient for the user and may allow more samples to be collected.

In the scenario, in vivo thyroid monitoring was performed at the day of intake, with no reported signal detected. The retention-curve (Fig. 3) for thyroid generated in IMBA for inhalation of 2.2 kBq I-125, shows that a stable activity of 300 Bq would be present in the thyroid after two days. The fact that no thyroid activity was reported may be related to the early time-point of measuring (same day as intake) and the sensitivity of the in vivo measuring method (detection limit). It should be noted that I-125 emits only low-energy gamma and X-ray (ca. 30 keV) resulting in a low measuring efficiency due to absorption in overlaying tissue (efficiency lower than for I-131 e.g.). A typical achievable detection limit of 40 Bq for thyroid I-125 measurements with gamma-spectrometry has been stated [4].

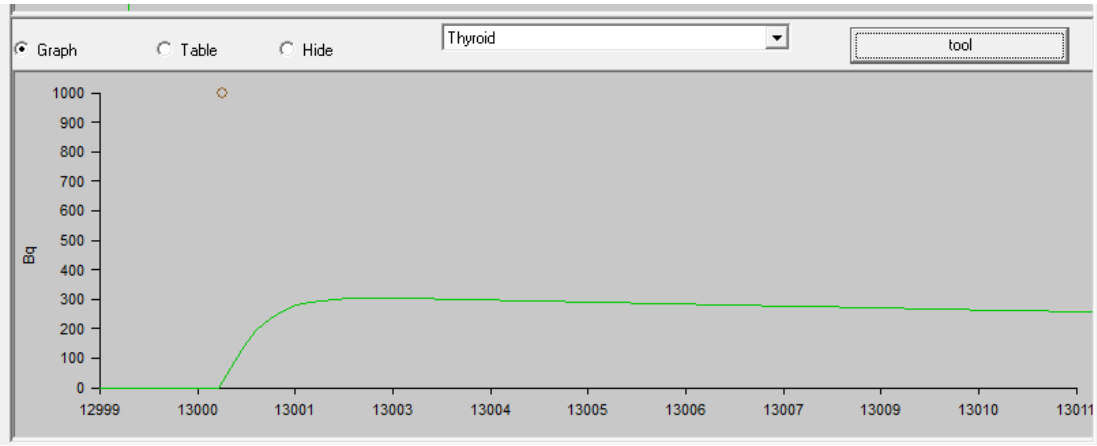


Fig. 3 Modelled thyroid retention curve generated by IMBA for the estimated intake.

As the estimated doses are below 0.1 mSv, there is no need to evaluate the received dose further – in accordance to Task Level 0 in the IDEAS Guidelines [4]. In fact, the dose received can be reported as “no dose” or “zero”.

In case further evaluation were needed, the dose estimation could be refined by the following (suggestions):

- Confirmation of exact sample time-points.
- Access to information on the iodine chemical form.
- Assess the likelihood for skin absorption vs. inhalation.
- New 24h urine sample(s).
- New thyroid measurement with appropriate (sensible) instrument.
- Use gender-specific value for daily urine volume.

The urine excretion rate modelled by IMBA shows a slightly different time-course if intake is given as either inhalation or injection, as shown by Fig. 4. This difference allows IMBA to fit the observed bioassay data to a mixed intake of inhalation and injection (multiple intake regimes).

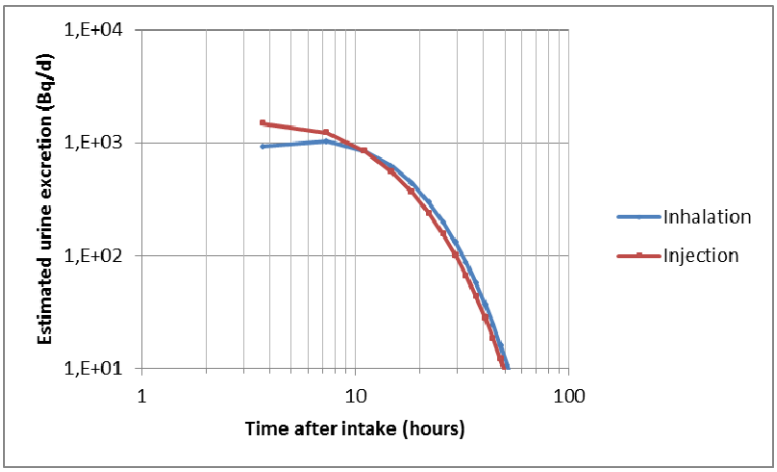


Fig. 4 Urine excretion curves modelled by IMBA, for estimated intake as inhalation or injection.

In the scenario, some activity from the spill (skin contamination) was likely absorbed through the skin and entered the bloodstream. Estimating this intake fraction as injected, requires the assumption that skin absorption was as fast as if injected.

Estimates of multiple intakes were given by reply 2 and 3. Reply 3 suggested a considerable contribution from injection while reply 2 did not (Table 2). Note that reply 2 and 3 also disagrees on total intake and dose.

Table 2 Estimates of relative intakes as inhalation or injection as presented in replies.

Reply ID	Inhalation intake (Bq)	Injection intake (Bq)
2	14	772
3	2242	$2.4 \cdot 10^{-13}$

Considering the limited number of bioassay data, uncertainty on skin absorption speed, and the fact that the type of intake has little effect on the final estimated dose, pursuing the route of intake through such an analysis may not be justified.

The sensitivity of the bioassay fit and estimated intake to variation in bioassay data can be investigated by gradually changing the input data. The data presented in the scenario is expected to be highly sensitive, as the bioassay samples 1 and 2 are located in the early phase where the excretion rate changes fast over time (see fit in Fig. 1).

To illustrate the sensitivity, the time-points for samples 1 and 2 has been altered one at a time by 1 hour steps. The resulting effect on the estimated intake (and dose) is presented in Fig. 5. It can be seen that a 1 hour uncertainty on sampling time point

results in up to 10% change in estimated intake. Note that the sensitivity found is valid only for this specific dataset.

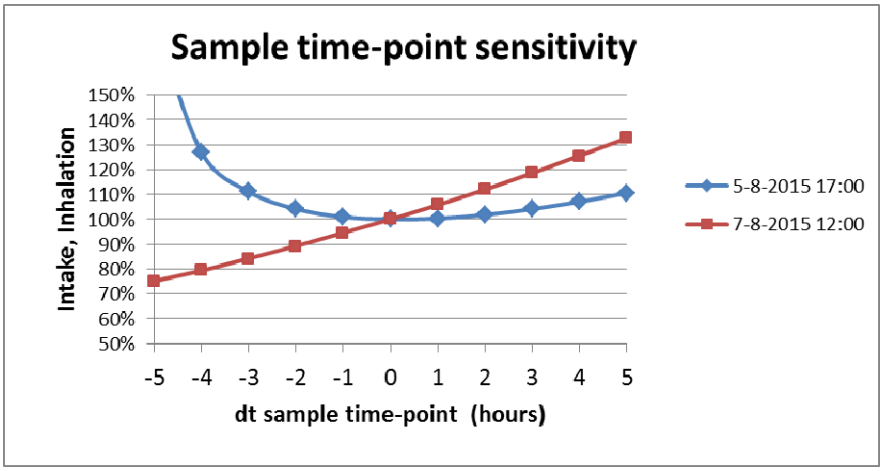


Fig. 5 Relative effect of varying sample time-points on estimated intake by inhalation and injection (multiple intake).

In face of the deviation in the submitted dose estimate (Scenario 2), it can be relevant to address the minimum reporting requirements in terms of documentation for bioassay data entry, biokinetic fitting and model parameters, and dose-coefficients. A high level of transparency and traceability will allow the estimation to be reproduced and validated.

Current international recommendation for dose-estimation (e.g. IDEAS Guidelines Version 2) does not state the level of details to be included in a report. A proposed international standard (Draft ISO-27048) on dose assessment however states that all details necessary for future reproduction of dose assessment shall be stored in a traceable manner. No requirements for including such details in reports are stated.

IMBA features a reporting function, which can present all relevant information in a single text-file, except from the Chi-square and related p-value for the Bioassay fit. It may be a good practice to accompany any assessed dose with a full report (like the one generated by IMBA) and additional information on the goodness of fit (screenshot of fitted curve or Chi-square p-value).

4.3 Scenario 3

We have to assume that the iodine is rapidly mixed with the laboratory air. The concentration can be expressed by:

$$C = C_0 e^{-pt}$$

where p (0.3 d^{-1}) is the air exchange rate, defined as Q/V, the ratio of exchange air flow between the room and environment (Q) by the room volume (V), The ratio Q/V can be estimated by measurements of tracer-gas dilution as the slope of a plot of $\ln(C)$ vs. t [5].

An exponential expressioncan also be deduced by the following argumentation. If the air exchange rate is 0.3 h^{-1}, the concentration after 1 h can be written:

$$C = C_0(1 - 0.3)$$

and after 2 hours, we have:

$$C = C_0(1 - 0.3)^2$$

Even if the air exchange rate is the same, fewer iodine atom will be removed due to the lower concentration. In reality, however, the removal of iodine atoms is a continuous process. Let p denote the number of air changes per hour and let n denote the number of measurements per hour. The above equation can then be written:

$$C = C_0\left(1 - \frac{p}{n}\right)^2$$

with p = 0.3 and n = 1 (i.e. one measurement per hour). In the general case, with *nt* measurements during *t* hours, we have:

$$C = C_0\left(1 - \frac{p}{n}\right)^{nt}$$

When *n* becomes very large, i.e. for very accurate calculations, it can be shown that:

$$C = C_0 e^{-pt}$$

Thus, the concentration may also, with greater accuracy, be found by assuming that the iodine concentration decrease with time is modelled by a «decay constant», equal to the air echange rate, p. We can neglect the physical decay of ^{131}I in the calculations.

The intake rate can be calculated by assuming a ventilation rate, B, e.g. 390 L h^{-1} for female, sitting (ICRP 66, Tab. 8, p. 24), yielding:

$$I(t) = BC_0 e^{-pt}$$

which can be integrated to give the intake between 13 h after spill to 16 h after spill:

$$I = \left[-\frac{BC_0}{p} e^{-pt}\right]_{13}^{16}$$

The activity 5 GBq dispersed in a volume of 75000 L gives the initial concentration $C_0 = 6.67 \cdot 10^4$ Bq L^{-1}., and thus:

$$I = \left[-\frac{390 \cdot 6{,}67 \cdot 10^4}{0.3} e^{-0.3t}\right]_{13}^{16}$$

that equals $1.04 \cdot 10^6$ Bq.

Applying a dose coefficient for elemental iodine in vapour form, $2.00 \cdot 10^{-8}$ Sv Bq^{-1}, gives an estimated committed effective dose of 20.8 mSv.

The assumptions made by the participants are given in Tab. 3. The air exchange rate is given in the scenario description, but all of the participants did not account for this decrease in concentration. Compared to the physical half-life of the radionuclide, the air exchange has a much larger impact on the concentration at the time of inhalation. Some of the participants calculated the inhaled activity by integrating the air activity concentration during three hours, but if a constant activity concentration is used, the inhaled activity will be overestimated by about 20%. According to the scenario description, the iodine was in liquid form and it would therefore be reasonable to assume that the inhaled iodine was a vapour.

Table 3. Assumptions made by the participants. Assumptions about physical decay and air exchange rate are indicated by "Decay" and "Air exchange", respectively. Assumptions about air concentration during inhalation are indicated by "Constant" and "Integrated", respectively.

Participant	**Air exchange and decay**	**Breathing rate**	**Element form**
1	Decay; Air exchange Constant	1.2 m^3/h	Vapour, SR-1. Absorption type F
2	Air exchange (continuous) Integrated	1.2 m^3/h (light worker)	
3	Air exchange (1 h time step) Integrated	0.39 m^3/h (sitting female, ICRP 66)	Elemental Iodine, Vapour, f_1 = 1.0
4	No details	1.2 m^3/h	Particle, Absorption type F, AMAD 5 μm, ICRP 68
5	Corrected (no details given)	0.92 m^3/h	Particle, Absorption type F, AMAD 1 μm
6	Decay	0.5 m^3/h (light worker)	

Tab. 4 gives the estimated intake and committed effective dose, calculated from the above assumptions. For comparison, the committed effective dose calculated by assuming that the iodine was in vapour form is also given.

Table 4. Estimated intake and committed effective doses reported by the participants. Also shown are committed effective doses calculated by estimated intakes reported by the participants, assuming iodine in vapour form.

Participant	**Estimated intake (Bq)**	**Committed effective dose (mSv)**	**Committed effective dose (vapour) (mSv)**
1	3 070 000	60.6	61.4
2	5 840 000	116	117

3	464 024	9.3	9.3
4	1 698 000	34.0	34.0
5	1 700 000	12.9	34.0
6	5 000 000	52.5	100

The committed effective doses reported by the participants are shown in Figure 6. The horizontal line shows the estimated committed effective dose calculated from the assumptions made in the scenario discussion above. The difference between the highest and the lowest estimated committed effective dose is 107 mSv. The mean committed effective dose is 48 mSv with a standard deviation of 39 mSv, giving a coefficient of variation of 81%. If a dose coefficient for iodine in vapour form is used for all reported inhaled activities, the mean committed effective dose will be 59 mSv, with a coefficient of variation of 71%.

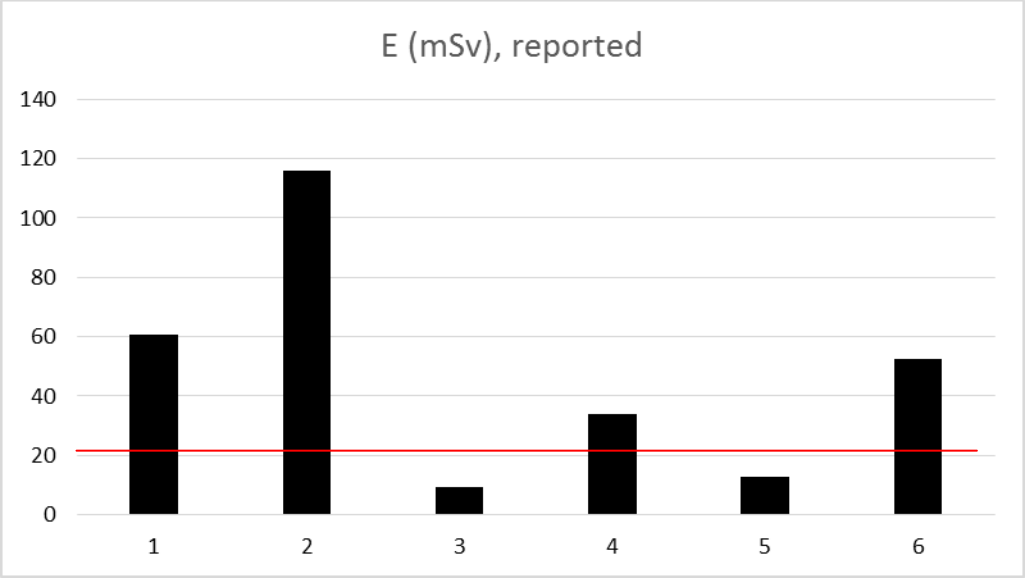


Fig. 6 Committed effective doses reported by the participants.

5 SUMMARY AND CONCLUSIONS

The exercises have shown that there is a wide variety of evaluation procedures, depending on the experience and the skill of the assessor as well as on assessment tools available. However, for a given set of internal monitoring data in terms of body/organ activity and/or urine/faecal activity there should be one standard estimate for the intake and the committed equivalent dose. This standard estimate is defined by the monitoring data, the biokinetic models for the description of the metabolism, dosimetric models, and – if available – some additional information, such as time of intake, route of intake, aerosol size, respiratory tract absorption type, gastro-intestinal (GI) tract absorption factor (f_1 value).

There is still a need for adequate training, experience and quality control. Such intercomparison exercises should be repeated on a regular basis. It is recommended that dose assessors in the Nordic countries frequently attend training (refreshing) activities that gather a number of experts and colleagues. Dose assessors may offer review of the work of colleagues as quality control.

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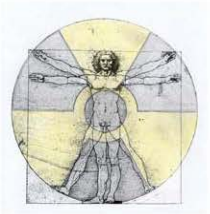
[5] Detlef Laussmann and Dieter Helm (2011). Air Change Measurements Using Tracer Gases: Methods and Results. Significance of air change for indoor air quality, Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality, Dr. Nicolas Mazzeo (Ed.), ISBN: 978-953-307-316-3, InTech, DOI: 10.5772/18600. Available from: http://www.intechopen.com/books/chemistry-emission-control-radioactive-pollution-and-indoor-air-quality/air-change-measurements-using-tracer-gases-methods-and-results-significance-of-air-change-for-indoor



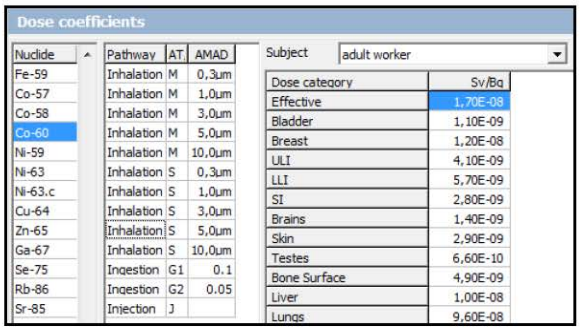
IDEA System
The Expert System for Internal Dosimetry

Newsletter No. 3/2015

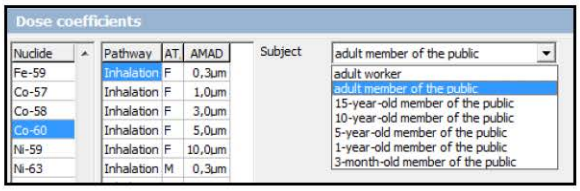
Lessons learnt from NKS IDEA IMBA workshop held in Stockholm on May 19th, 2015

Recently the board for Nordic Nuclear Safety Research (NKS) of the Swedish Radiation Safety Authority organized a workshop on internal dose assessment. About 25 professionals from all Scandinavian countries participated in this workshop on May 19th, 2015 in Stockholm. The focus of the workshop was the application of commercial software such as IMBA and IDEA for internal dose assessment. Nine exercises were given to the participants for evaluation with IMBA. Some of the exercises were evaluated in parallel with IDEA and the different approaches of both software tools were considered, this highlighting some characteristic differences in the approaches of IMBA and IDEA.

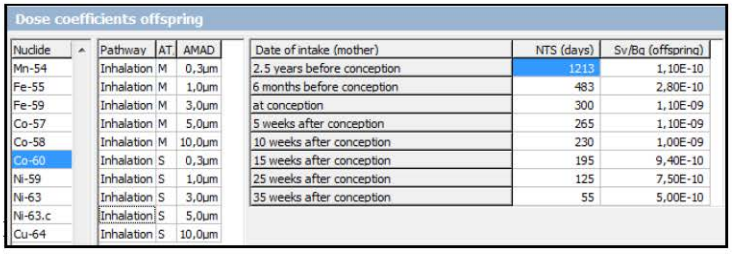
1. Exercise: Calculate the inhalation and ingestion dose coefficient for Co-60 (oxide).



In IDEA it is not necessary to calculate the dose coefficients, because all these values are available in the IDEA database. You can display the values when selecting "Dose coefficients" in the "Data" section. Here you can select the radionuclide and the intake parameters, i.e. pathway, absorption type and AMAD or f1 factor, respectively. The screenshot shows, for example, the dose coefficients for inhalation of aerosols with absorption type S and 5 µm AMAD (the list of organ specific dose coefficients is actually much longer). These dose coefficients refer to workers.



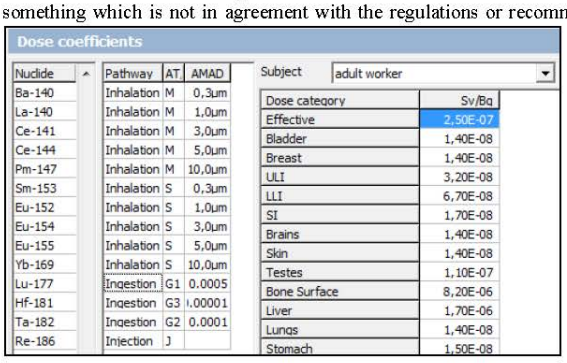
In addition you can display the age specific dose coefficients for members of the public and also the dose coefficients for the offspring due to intakes of the mother according to ICRP Publication 88. The latter dose coeffi-cients depend on the time of intake in relation to the conception. These dose coefficients are not provided by IMBA.



IDEA System

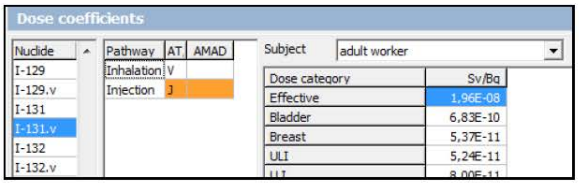
2. Calculate the committed effective dose from ingestion of 1 Bq Pu-239 aerosol. How much does the committed effective dose change if f_1 is changed from 0,0005 to 0,001? Explain the change.

Here we face a problem resulting from the general philosophy of IDEA. The main aspect of the philosophy is the following: The users of IDEA can be sure that any results derived with the software are in agreement with the current national and international regulations and recommendations. Or in other words, IDEA doesn't allow the user to do something which is not in agreement with the regulations or recommendations. According to these recommendations



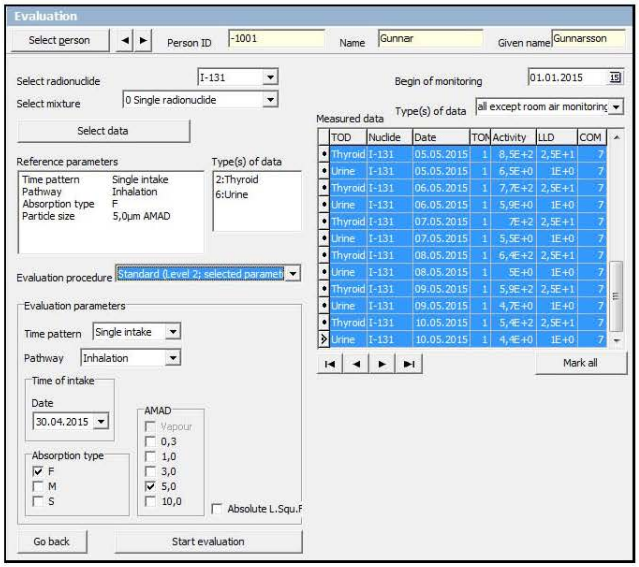
the f_1 factor for Plutonium is 0,0005 for unspecified compounds or 0,0001 for insoluble oxides, respectively. Because of this reason there are no data for f_1 = 0,001 in the database. As can be seen from the screenshot, there are dose coefficients for ingestion with the f1 factor being 0,0005 (absorption type G1), 0,0001 (G2) and – according to some other recommendation – 0,00001 (G3). So the committed effective dose from ingestion of 1 Bq Pu-239 with f_1 = 0,0005 is 0,25 µSv. The corresponding value for f_1 = 0,001 would be just twice as much because at this absorption level the committed effective dose is proportional to the absorbed activity, i.e. proportional to the f_1 factor.

3. Calculate the committed effective dose from inhalation of 1 MBq I-131 (methyl iodide, vapour).

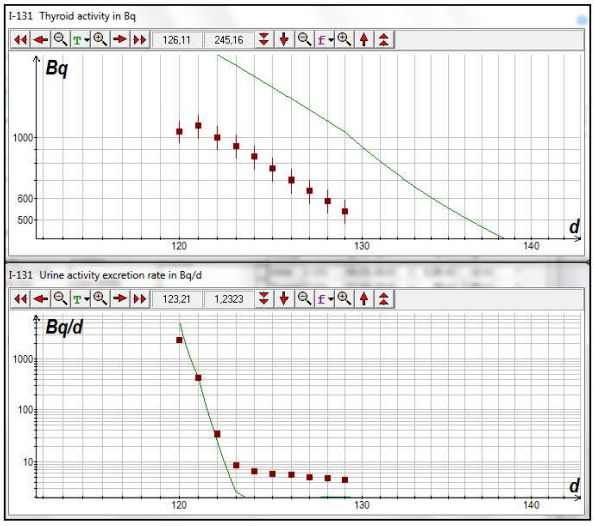


Methyl iodide (CH_3I) is allocated to absorption type V (instantaneous absorption to blood after inhalation). As can be seen from the screenshot, the dose coefficient for this compound is 1,96 E-08 Sv/Bq. So the committed effective dose from inhalation of 1 MBq is 19,6 mSv.

4. A worker inhaled I-131. Thyroid measurements and urine sampling started one day after inhalation. The activity values in the urine samples are normalized to daily excretion. Calculate the inhaled activity, the committed effective dose and the equivalent dose to the thyroid.

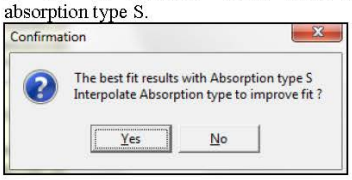


This is in principle a very simple case because most of the intake parameters are known. After having entered the measured data (blue table in the screenshot), you may evaluate the data assuming a single intake by inhalation one day before the first measurement. I-131 is allocated typically to absorption type F. The particle size may be assumed to be 5 µm because the subject is a worker.

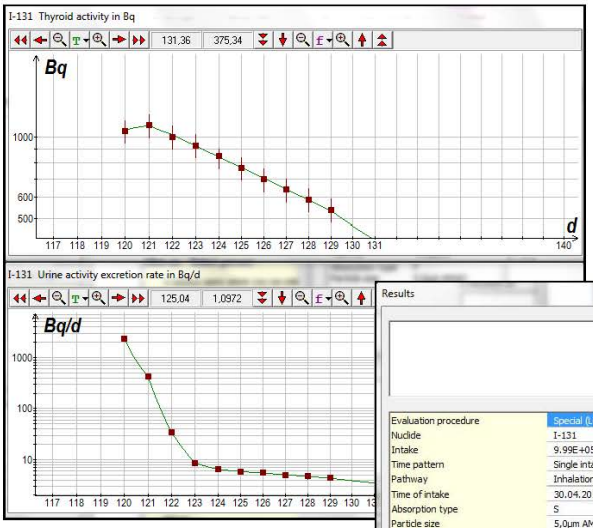


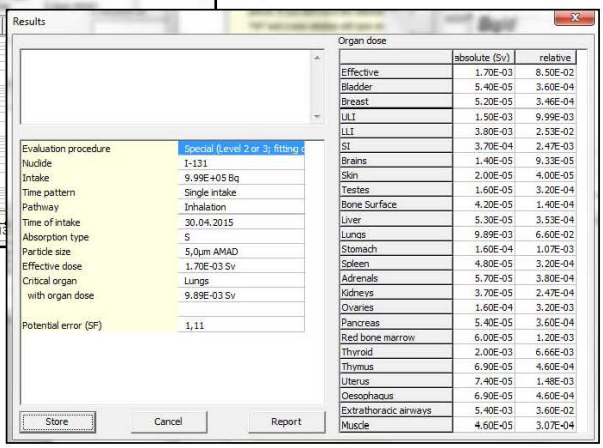
The results, however, are looking not that good. There is a significant discrepancy between the measured data and the fitted retention- and excretion function. The measured activity in the thyroid is about one order of magnitude lower than the model retention function and the measured activity in the urine is – after four days – almost one order of magnitude higher than the model excretion function. This is a typical finding when the assumed solubility is too high.

So you should try to adjust the absorption type. The software will tell you that the best fit can be achieved when assuming absorption type S.



However, if you apply absorption type S, the software will tell you that the respective dose coefficients are not available. So there is no way to calculate the dose for this case scenario. This might look like a bug but actually it is very reasonable. As mentioned already under the second exercise, IDEA doesn't allow the user to do something which is not in agreement with the regulations or recommendations. These regulations and recommendations say that I-131 should be allocated always to absorption type F. In fact you cannot find in the ICRP recommendations any compound of I-131 which could be allocated to absorption type S and so IDEA puts on the emergency brake if the user would try to apply type M or type S for I-131. The emergency brake, however, is put on only for workers, because the recommendations refer only for occupationally exposed persons. So you can avoid the brake when allocating the person to a member of the public. When doing so you will get a perfect fit of measured data (see screenshot on the left).

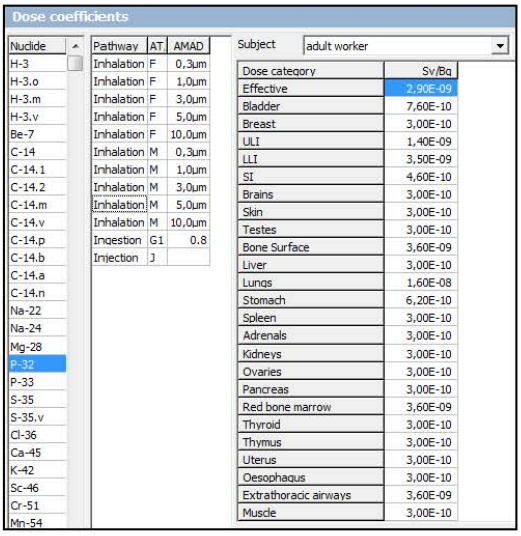




But in spite of the good fit you will get very strange results in terms of dose. So in this case the critical organ is the lung with the organ dose being 9,9 mSv. The dose to the thyroid is only 2 mSv. Here, finally, the alarm bell is ringing…

This exercise is an excellent example illustrating how IDEA is shortening the free pathway for making mistakes. If you evaluate such case with IMBA you will get perfect fitting of data but there will be no warning that something might be wrong with the data. There might be several reasons such as wrong positioning of detector for thyroid measurement or contamination of urine sample. Moreover, if thyroid measurements would have been performed with NaI(Tl) detectors, Ba-133 could have been identified by mistake as I-131 (contrary to Iodine, Barium has type S compounds). All these reasons are not very likely but they are much more likely as the existence of a type S compound of Iodine.

5. Calculate the committed effective dose after inhalation by a worker of 8 MBq P-32 aerosol. After particle size analysis, the particle size (AMAD) turns out to be 10 µm. How does this affect the previous calculation? Which organ receives the highest equivalent dose?



Dose coefficients

Nuclide
H-3
H-3.o
H-3.m
H-3.v
Be-7
C-14
C-14.1
C-14.2
C-14.m
C-14.v
C-14.p
C-14.b
C-14.a
C-14.n
Na-22
Na-24
Mg-28
P-32
P-33
S-35
S-35.v
Cl-36
Ca-45
K-42
Sc-46
Cr-51
Mn-54

Pathway	AT	AMAD
Inhalation	F	0,3µm
Inhalation	F	1,0µm
Inhalation	F	3,0µm
Inhalation	F	5,0µm
Inhalation	F	10,0µm
Inhalation	M	0,3µm
Inhalation	M	1,0µm
Inhalation	M	3,0µm
Inhalation	M	5,0µm
Inhalation	M	10,0µm
Ingestion	G1	0.8
Injection	J	

Subject: adult worker

Dose category	Sv/Bq
Effective	2,90E-09
Bladder	7,60E-10
Breast	3,00E-10
ULI	1,40E-09
LLI	3,50E-09
SI	4,60E-10
Brains	3,00E-10
Skin	3,00E-10
Testes	3,00E-10
Bone Surface	3,60E-09
Liver	3,00E-10
Lungs	1,60E-08
Stomach	6,20E-10
Spleen	3,00E-10
Adrenals	3,00E-10
Kidneys	3,00E-10
Ovaries	3,00E-10
Pancreas	3,00E-10
Red bone marrow	3,60E-09
Thyroid	3,00E-10
Thymus	3,00E-10
Uterus	3,00E-10
Oesophagus	3,00E-10
Extrathoracic airways	3,60E-09
Muscle	3,00E-10

P-32 may occur in the form of type F or type M aerosols. If the absorption type is not known, it is recommended to assume type M. This should be done also in this exercise. If the particle size is not known, the value of 5 µm AMAD should be used for dose assessment.

For calculation of the committed effective dose after inhalation of 8 MBq P-32 with these assumptions you have to multiply the respective dose coefficient 2,90E-09 Sv/Bq by 8E06 Bq, this resulting in 2,32E-02 Sv = 23,2 mSv.

For the particle size 10 µm AMAD the respective dose coefficient is 1,9E-09 and thus the resulting committed effective dose is 1,52E-02 Sv = 15,2 mSv.

For both particle sizes the lung receives the highest equivalent dose.

6. A worker inhales 1000 Bq of a Pu-239 aerosol and is asked to immediately start to collect urine for a 24 hour sample. How much Pu-239 is expected to be excreted during the first 24 hours? What activity is expected in a 24 hour sample taken on day 10?

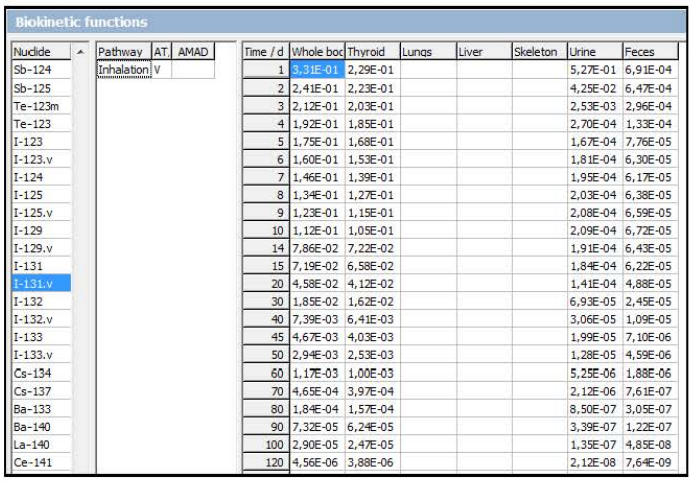
Pathway	AT	AMAD	Time / d	Whole bod	Thyroid	Lungs	Liver	Skeleton	Urine	Feces
Ingestion	G1		1	4,97E-01		5,76E-02			2,32E-04	1,08E-01
Ingestion	G2		2	2,63E-01		5,59E-02			1,31E-04	1,55E-01
Ingestion	G3		3	1,55E-01		5,50E-02			7,78E-05	7,97E-02
Inhalation	M	0,3µm	4	1,10E-01		5,41E-02			5,30E-05	3,35E-02
Inhalation	S	0,3µm	5	9,31E-02		5,33E-02			3,91E-05	1,33E-02
Inhalation	M	1,0µm	6	8,63E-02		5,26E-02			3,03E-05	5,36E-03
Inhalation	S	1,0µm	7	8,34E-02		5,18E-02			2,44E-05	2,33E-03
Inhalation	M	3,0µm	8	8,20E-02		5,11E-02			2,03E-05	1,19E-03
Inhalation	S	3,0µm	9	8,11E-02		5,03E-02			1,74E-05	7,54E-04
Inhalation	M	5,0µm	10	8,05E-02		4,96E-02			1,54E-05	5,83E-04
Inhalation	S	5,0µm	14							
Inhalation	M	10,0µm	15							
Inhalation	S	10,0µm	20	7,61E-02		4,34E-02			1,02E-05	3,68E-04
Injection	J		30	7,28E-02		3,84E-02			9,51E-06	2,81E-04

Pu-239 may occur in the form of type M or type S aerosols. If the absorption type is not known, it is recommended to assume type M. This should be done also in this exercise. If the particle size is not known, the value of 5 µm AMAD should be used for dose assessment.

For calculation of the expected excretion rate on the first day after inhalation of 1000 Bq Pu-239 you have to multiply the respective urine excretion function 2,32E-04 Bq/d per Bq by 1000 Bq, this resulting in 2,32E-01 Bq/d = 232 mBq/d. For day 10 the expected excretion rate would be 1,54E-02 Bq/d = 15,4 mBq/d. These excretion rates would be far above the lower limit of detection (1 mBq/d for alpha-spectrometry following radiochemical separation of Plutonium) and thus easily be detected.

It should be noted that Pu-239 may occur also in the form of type S aerosols. If so, the expected excretion rates would be only 2,35 E-03 Bq/d at day 1 and 2,24E-04 Bq/d at day 10. So in case of type S aerosols the inhalation of 1000 Bq Pu-239 would be detected on day 1 but not on day 10.

7. Make a graph showing the retention function for the thyroid after inhalation of 1 Bq I-131 in vapor form. Calculate the activity expected in a feces sample 2 days after intake



Biokinetic functions

Nuclide	Pathway	AT.	AMAD	Time / d	Whole boc	Thyroid	Lungs	Liver	Skeleton	Urine	Feces
Sb-124	Inhalation	V		1	3,31E-01	2,29E-01				5,27E-01	6,91E-04
Sb-125				2	2,41E-01	2,23E-01				4,25E-02	6,47E-04
Te-123m				3	2,12E-01	2,03E-01				2,53E-03	2,96E-04
Te-123				4	1,92E-01	1,85E-01				2,70E-04	1,33E-04
I-123				5	1,75E-01	1,68E-01				1,67E-04	7,76E-05
I-123.v				6	1,60E-01	1,53E-01				1,81E-04	6,30E-05
I-124				7	1,46E-01	1,39E-01				1,95E-04	6,17E-05
I-125				8	1,34E-01	1,27E-01				2,03E-04	6,38E-05
I-125.v				9	1,23E-01	1,15E-01				2,08E-04	6,59E-05
I-129				10	1,12E-01	1,05E-01				2,09E-04	6,72E-05
I-129.v				14	7,86E-02	7,22E-02				1,91E-04	6,43E-05
I-131				15	7,19E-02	6,58E-02				1,84E-04	6,22E-05
I-131.v				20	4,58E-02	4,12E-02				1,41E-04	4,88E-05
I-132				30	1,85E-02	1,62E-02				6,93E-05	2,45E-05
I-132.v				40	7,39E-03	6,41E-03				3,06E-05	1,09E-05
I-133				45	4,67E-03	4,03E-03				1,99E-05	7,10E-06
I-133.v				50	2,94E-03	2,53E-03				1,28E-05	4,59E-06
Cs-134				60	1,17E-03	1,00E-03				5,25E-06	1,88E-06
Cs-137				70	4,65E-04	3,97E-04				2,12E-06	7,61E-07
Ba-133				80	1,84E-04	1,57E-04				8,50E-07	3,05E-07
Ba-140				90	7,32E-05	6,24E-05				3,39E-07	1,22E-07
La-140				100	2,90E-05	2,47E-05				1,35E-07	4,85E-08
Ce-141				120	4,56E-06	3,88E-06				2,12E-08	7,64E-09

Again, this exercise refers to hypothetical prospective dose assessment. IDEA provides the retention and excretion functions in the form of tables rather than as graphs. The biokinetic functions represent per definition the activity per unit intake and so the exercise can be solved straight forward when looking at the tables (see the screenshot). As can be seen, the thyroid retention function decreases steadily with time, the effective halflife corresponding to the physical halflife of I-131 after the second day.

The second part of the exercise can be easily handled when looking at the feces excretion function at day 2, this being 6,47E-04 Bq/d per Bq. Thus, the inhalation of 1 Bq I-131 in vapor form would result in a feces excretion rate of just 6,47E-04 Bq/d, which is far below the typical lower limit of detection of conventional measuring procedures.

8. Assuming intake of 100 kBq U-235 by ingestion on 1 March 2010, followed by acute inhalation of 50 kBq U-235 on 5 March 2010, estimate the whole body activity of U-235 on 1 April 2010.

This exercise illustrates again the substantial difference in the philosophy of IMBA and IDEA. IMBA is a perfect tool for prospective internal dose assessment on a hypothetical basis, i.e. IMBA allows for prospective dose assessment for hypothetical intakes. In practice, however, you know the intake conditions but not the intake itself. You may know the involved radionuclides, the amount of handled material, the physical and chemical parameters of the handled material, the way of handling, the duration of handling and the protection measures, but you never know the intake. So IDEA provides the tools to calculate the potential intake and the resulting dose for the actual exposure conditions, i.e. IDEA is using information which is known rather than hypothetical information.

9. You are planning to study the behavior of I-131 in the body by distributing 100 kBq I-131 to a research subject. Since you are well aware of the ALARA principle you want to minimize the dose to the research subject. Should you then distribute the iodine by ingestion, inhalation of injection?

This exercise in principle can be solved without IMBA or IDEA. If you want to study the behavior of I-131 in the body you should distribute the activity directly into the system, i.e. into the body fluids. Thus, you should inject the activity. In this case the initial body activity is equal to the injected activity. If you want to achieve the same initial body activity via inhalation or ingestion you would have additional dose contributions from the respiratory or alimentary tract anyway. In the case of ingestion, however, the additional dose contributions from the alimentary tract are very small, i.e. the ingestion pathway is more or less equivalent to the injection pathway.

Conclusions

Most of the exercises at this workshop were related to prospective dose assessment, i.e. the calculation of internal dose from given intake parameters. In 7 out of 9 exercises the intake is known and all relevant parameters for calculation of the resulting internal exposure are provided in the description of the exercise. These exercises can be solved perfectly with IMBA. So IMBA is a perfect tool for theoretical investigations in the field of internal dosimetry. However, these 7 exercises don't reflect the normal situation in practical incorporation monitoring.

In practice you know – maybe – the involved radionuclides, in few cases also some intake parameters, such as time, mode and pathway if intake, physical and chemical form of involved materials, but never you would know the intake in terms of Bq a priori. So in IDEA all kind of prospective dose assessment is based on parameters which are known or which could be derived from official regulations or recommendations, respectively. Thus, with respect to prospective internal dosimetry, IDEA is orientated more to the practical requirements whereas IMBA is focused more on the theoretical aspects.

Similar conclusions can be drawn for the complex of retrospective internal dose assessment. As can be seen from exercise 4, the evaluation can be performed perfectly with IMBA. All intake parameters can be calculated with a high statistical significance but there is no check of the practical relevance of the results. So the results reflect the measured values rather than the real situation, i.e. there is no plausibility check of the results. With IDEA the measured values can be evaluated as well, but in addition to the pure mathematical evaluation there is a complex system of plausibility checks. These checks are mainly based in the structural approach of the IDEAS guidelines. In addition, the results are checked for consistency with the regulations and recommendations. So, for example in exercise 4, IDEA claims that I-131 cannot occur in the form of type S compounds and stops the evaluation procedure consequently. So, also with respect to retrospective internal dosimetry, IDEA is orientated more to the practical application whereas IMBA is focused on the pure mathematical aspects.

Thus IMBA and IDEA are complementary tools rather than competing products.

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Bibliographic Data Sheet **NKS-355**

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ISBN	978-87-7893-439-0
Date	January 2016
Project	NKS-B / IDEA
No. of pages	26
No. of tables	4
No. of illustrations	6
No. of references	5
Abstract	Within the previously performed NKS-projects THYROID and THYROIDSEM, it became evident that there were large variations in the estimates of internal (thyroid) dose. The current activity was therefore initiated to enhance the ability to make correct calculations of internal dose following a release of radionuclides. A seminar/course about internal dosimetry calculations with the internal dosimetry program IMBA has been arranged. After the seminar, a number of scenarios, relevant for emergency preparedness, were distributed to authorities and departments involved in the Nordic emergency preparedness. The scenarios were also distributed to companies engaged in nuclear technology. The exercises have shown that there is a wide variety of evaluation procedures, depending on the experience and the skill of the assessor as well as on assessment tools available. There is still a need for adequate training, experience and quality control. Such intercomparison exercises should be repeated on a regular basis. It is recommended that dose assessors in the Nordic countries frequently attend training (refreshing) activities that gather a number of experts and colleagues.
Key words	Internal dosimetry, intercomparison, dose estimations, course, scenarios

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