IAEA-TECDOC-1568

Intercomparison Exercise on Internal Dose Assessment

Final report of a joint IAEA–IDEAS project

IAEA
International Atomic Energy Agency

September 2007

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FOREWORD

There have been several intercomparison exercises organized already at national and international levels for the assessment of occupational exposure due to intakes of radionuclides. These intercomparison exercises revealed significant differences in approaches, methods and assumptions, and consequently in the results. Because of the relevance of the issue for internal dosimetrists, the IAEA organized a new intercomparison exercise in cooperation with the IDEAS project *General Guidelines for the Evaluation of Incorporation Monitoring Data*, launched under the 5th EU Framework Programme (EU Contract No. FIKR-CT2001-00160).

This new intercomparison exercise focused especially on the effect of the guidelines for harmonization of internal dosimetry. It also considered the following aspects:

— to provide possibilities for the participating laboratories to check the quality of their internal dose assessment methods in applying the recent ICRP recommendations (e.g. for the new respiratory tract model);

— to compare different approaches in interpretation of internal contamination monitoring data;

— to quantify the differences in internal dose assessments based on the new guidelines or on other procedures, respectively;

— to provide some figures for the influence of the input parameters on the monitoring results; and

— to provide a broad forum for information exchange.

Several cases have been selected for this exercise with the aim of covering a wide range of practices in the nuclear fuel cycle and in medical applications. The cases were:

1. Acute intake of HTO;
2. Acute inhalation of fission products ^{137}Cs and ^{90}Sr;
3. Intake of ^{60}Co;
4. Repeated intakes of ^{131}I;
5. Intake of enriched uranium;
6. Single intake of plutonium radionuclides and ^{241}Am.

An Internet based approach had been used for the presentation of the cases, collection of responses and potential discussion of the results. Solutions to these cases were reported by 80 participants worldwide. This report presents and discusses the main findings and recommendations for future actions.

The IAEA officer responsible for the compilation of this publication was J. Zeger of the Division of Radiation, Transport and Waste Safety.

EDITORIAL NOTE

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PART I. INTRODUCTION

1. BACKGROUND

During the last few years the ICRP has developed a new generation of more realistic internal dosimetry models, including the Human Respiratory Tract Model (HRTM ICRP Publication 66[1]) and recycling systemic models for actinides (ICRP Publications 67[2] and 69[3]). The 3rd European Intercomparison Exercise on Internal Dose Assessment carried out in the framework of EULEP/EURADOS/UIR concerted action *Environmental and occupational dosimetry: An integrated approach to radiation protection covering radioecology, dosimetry and biological effects* provided special insight into the effects of the new models and the choice of input parameters on the assessment of internal doses from monitoring results[4].

It also took into account some aspects which have not been considered in previous exercises, such as air monitoring, natural radionuclides, exposure of the public, artificially created cases and artificially reduced information. Seven case scenarios were distributed, dealing with ^{3}H, ^{90}Sr, ^{125}I, ^{137}Cs, ^{210}Po, ^{238}U and ^{239}Pu, and covering different intake scenarios and all monitoring techniques.

Results were received from 50 participants, 43 representing 18 European countries and 7 from five countries outside Europe. So it was by far the largest exercise of this type carried out to date. Most participants attempted more than half of the cases. Thus on average there were 35 responses per case with a total of about 240 answers, giving a good overview of the state of the art of internal dosimetry.

The results in terms of intake and committed effective dose appeared to be close to lognormally distributed with geometric standard deviation ranging from 1.15 for the cases dealing with ^{3}H and ^{137}Cs, up to 2.4 for the cases dealing with ^{239}Pu. These figures reflect large differences in the individual results which varied in worst cases within a range of five orders of magnitude. A key feature of the exercise was a workshop, involving most of the participants, at which each case and the various approaches taken to assessing it were discussed. Several reasons for the differences in the results were identified, including different assumptions about the pattern of intake, and the choice of model.

The most important conclusion of the exercise was the need to develop agreed guidelines for internal dose evaluation procedures in order to promote harmonization of assessments between organizations and countries, which has basic importance in EU countries.

2. STATE OF THE ART

There are some rough guidelines for the routine, special and task-related individual monitoring recommended by ICRP Publication 54[5] and by ICRP Publication 78[6].

These guidelines have the following general features:

– Routine monitoring is carried out at regular time intervals during normal operation. For the interpretation of the measurement data it is assumed that an acute intake occurs at the mid-point of the monitoring interval. The reconstruction of an intake is usually performed on a basis of a single data point in a time series of measurements. If more than 10 % of the actual measured quantity can be attributed to intakes in previous monitoring intervals, a respective correction is recommended.

– In special and task-related monitoring it is assumed that an acute intake has occurred at the respective time.

– In case of inhalation, all types of interpretation schemes require for *a priori* information about the absorption type of the aerosol and the distribution of particle sizes. If no information about the median particle size is available, it is recommended to assume the default value 5 μm[6].

These guidelines leave many assumptions open. This results in many different approaches to the interpretation of monitoring data, as demonstrated by the 3rd European Intercomparison Exercise on Internal Dose Assessment[4].

Recently, such guides as the *Guide for the Practical Application of the ICRP Human Respiratory Tract Model*[7] were developed for the application of the models. These guides, however, refer only to special issues of internal dosimetry. Consequently, there is a need for general guidelines consistently covering all relevant issues of the interpretation of monitoring data.

3. GENERAL REQUIREMENTS

All the intercomparison exercises have shown that there is a wide variety of evaluation procedures, depending on the experience and the skill of the dosimetrist as well as on the hardware and software tools. However, for a given set of internal monitoring data in terms of body/organ activity and/or urine/faecal activity two experts making the same hypothesis should obtain the same results of intake and committed dose equivalent.

These results depend on the monitoring data, the biokinetic models for the description of the metabolism, and – if available – some additional information, such as time of intake, route of intake, aerosol size, absorption type, f_1-value and possible previous internal exposures. The aim of the IDEAS project is to provide general guidelines that enable dosimetrists to derive a well defined standard estimate for any given set of data. This is of great importance for the harmonization of internal dose assessment in Europe, and elsewhere.

Ideally, the results of internal dosimetry in terms of committed dose should be comparable to the results of external dosimetry with respect to accuracy and reproducibility. If two persons are exposed to the same external irradiation field then their dosimeter readings are consistent with each other, and are considered as the estimate of the exposure. In some special cases the dose reading might be wrong because of some uncommon photon energy or some uncommon radiation incidence angle, but nobody worries about it as long as the dose reading is below the investigation level. In internal dosimetry we should aim at a similar philosophy, that means if two persons have the same internal exposure then the results of internal monitoring in terms of committed dose should be consistent with each other, and the results should be as close as possible to the real dose.

Similarly, in some special cases the results might be wrong because of some uncommon route of intake or some uncommon physical/chemical properties of the incorporated material, but dosimetrists should not worry as long as the committed effective dose is below some predefined dose level.

So, in internal dosimetry the reproducibility of the results should be made closer to the one of external dosimetry. This means, first that the monitoring procedure should be optimized in such a way that the activity monitoring results provide an accurate representation of the exposure. This optimization was recently the goal of the OMINEX project (Optimization of Monitoring for Internal Exposure). In a second time the optimization of the evaluation of the monitoring data should be provided by the IDEAS project. So both projects focus on the same goal of improving the reproducibility of internal dosimetry, but with clearly distinct approaches: OMINEX has improved the procedures for carrying out monitoring, and IDEAS will improve the procedures for assessing doses from the results of monitoring.

PART II. THE IDEAS PROJECT

4. ORGANIZATION

The IDEAS project commenced in October 2001 and was completed in June 2005.

The following partner institutions were involved in the project:

- Forschungszentrum Karlsruhe (FZK), Germany.
  Co-ordinator and Leader of Work Package 4.
- Belgian Nuclear Research Centre (SCK•CEN), Belgium.
  Leader of Work Package 1.
- Electricité de France (EdF), France.
- Italian National Agency for New Technology, Energy and the Environment (ENEA), Italy. Leader of Work Package 3.
- Institute for Radiation Protection and Nuclear Safety (IRSN), France.
- KFKI Atomic Energy Research Institute (AEKI), Hungary.
  Leader of Work Package 5.
- Radiation Protection Institute (RPI), Ukraine.
  Leader of Work Package 2.
- Radiation Protection Division of the Health Protection Agency (HPA) (former NRPB), United Kingdom.

The consortium consisting of representatives of the above eight institutions has come together through common interest in the problems to be addressed, complementary expertise, and contacts established through previous cooperation. Although the principal scientific personnel are all involved in internal dose assessment, they have a wide variety of backgrounds, being qualified in chemistry, radiobiology, engineering, medicine, pharmacology, and physics.

Similarly, their involvement in internal dose assessment comes from different directions. In most cases it mainly complements monitoring, both *in vivo* and bioassay measurements (EdF, ENEA, FZK, AEKI, SCK•CEN). However, in other cases it is mainly related to involvement in development of models used to relate intakes of radionuclides to organ doses and excretion (IRSN, HPA), and/or to development of computer programs to implement such models and hence to calculate intakes and doses from monitoring data (RPI, HPA).

The organizations involved have a range of functions: research institutes (ENEA, FZK, AEKI, IRSN, SCK•CEN), national radiation protection authorities (HPA, RPI), and operating organization (EdF), offering different perspectives.

There was a close cooperation between IDEAS and the ICRP Working Party on Bioassay Interpretation and with the IAEA. There was also information exchange between IDEAS and other 5th Framework Programme EU Projects such as OMINEX (Design and Implementation of Monitoring Programmes for Internal Exposure) and IDEA (Internal Dosimetry – Enhancements in Application).

5. DEVELOPMENT OF THE GENERAL GUIDELINES

The core of the IDEAS project was the development of general guidelines. The partners have derived a common strategy for the evaluation of monitoring data, drafted the general guidelines and discussed it with internal dosimetry experts by means of a "virtual" workshop based on the internet (http://www.ideas-workshop.de/). The discussion has improved the common strategy and permitted the finalization of the draft of the general guidelines.

Some of the IDEAS contractors were members of the ICRP Working Party on Bioassay Interpretation, which was involved in the development of an ICRP Supporting Guidance Document on *The Interpretation of Bioassay Data*. The aim is for this to complement the planned Occupational Intakes of Radionuclides (OIR) document that will replace ICRP Publications 30[18], 54[5], 68[20] and 78[6]. Work on the ICRP Guidance Document is now carried out within the ICRP Committee 2 Task Group on Internal Dosimetry (INDOS), of which several members of the IDEAS consortium are also members.

The aims of this Guidance Document are similar to those of the IDEAS project. Thus the development of both documents has been done in close cooperation to ensure that the IDEAS guidelines and the ICRP Guidance Document are consistent with each other.

There are, however some difference in scope. In particular, the ICRP Guidance Document will relate to the forthcoming ICRP Recommendations and the revised biokinetic and dosimetric models being applied in the OIR document (such as the Human Alimentary Tract Model, HATM), whereas the IDEAS Guidelines relate to the current models.

However, the draft ICRP Guidance Document is following similar principles and a structured approach to assessments, based on the IDEAS Guidelines.

6. THE IDEAS GUIDELINES FOR EVALUATION OF MONITORING DATA

6.1. Introduction

In carrying out the assessment (evaluation) of internal committed doses from monitoring data, the assessor has to make assumptions about factors such as the pattern of intake and properties of the material if the relevant information is missing.

When more than one measurement is available, the relative importance applied to the different data can substantially affect the result. Recent intercomparison exercises have shown the wide range in doses that can be assessed from the same data set as a result of different choices for such factors, and hence the need for guidance to harmonize evaluations.

The procedures proposed in the Guidelines are based on the following principles:

- Harmonization: by following the procedures any two assessors should obtain the same estimate of dose from a given data set
- Accuracy: the "best" estimate of dose should be obtained from the available data
- Proportionality: the effort applied to the evaluation should be proportionate to the dose — the lower the dose, the simpler the process should be.

6.2. Harmonization

A well-defined procedure is needed and for this reason the process is defined here primarily by means of a series of flow-charts. As far as possible, the process has been made widely applicable, i.e. it does not assume availability of sophisticated bioassay interpretation software.

For routine monitoring situations, where typically there is only one measurement relating to each potential intake, it is reasonably straightforward to define a procedure. However, in special monitoring situations, where typically there is more than one measurement and quite possibly more than one type of measurement (urine, faeces…) different options for data handling can easily lead to different evaluated doses, even when the same model, parameter values and software are used.

Another range of options, and opportunities for different evaluated doses, arises in situations where it is appropriate to consider changing parameter values from the ICRP defaults. Proposals are made here for a systematic approach to dose assessment in all these situations.

6.3. Accuracy

It is recognized that the uncertainties associated with assessed internal dose can be considerable, especially for actinides which are difficult to detect in the body and have relatively high dose coefficients (Sv Bq^{-1}). If the initial estimate of dose exceeds 1 mSv, it could well be that the possibility of a substantially higher dose (e.g. 6 mSv) cannot easily be excluded. It is then important to make best use of the available information. To do so may well involve changing parameter values from the ICRP default and guidance is therefore needed on which parameter values might reasonably be varied according to the circumstances.

6.4. Proportionality

The effort applied to the evaluation of incorporation monitoring data should broadly correspond to the expected level of exposure, and the complexity of the case. On the one hand, if the exposure is likely to be very low with respect to the dose limits, simple evaluation procedures with a relatively high uncertainty may be applied. On the other hand, if the monitoring values indicate the exposure to be close to or even above the dose limits, more sophisticated evaluation procedures will need to be applied. These take account of any case-specific information available, so that the uncertainty and bias on the best estimate are as low as reasonable achievable.

6.5. Level of task

With respect to operational radiation protection the following structure of “Levels of task” is proposed, which is primarily based on routine monitoring situations but may also be applied to other situations:

•

Level 0: Annual dose (committed effective dose from intakes of radionuclides that occur in the accounting year) <0.1 mSv. No evaluation of dose needed.

Level 1: Simple, “reference” evaluation, with ICRP defaults used for all parameter values, except where there is better *a priori* information available, e.g. for inhalation intakes information on the particle size distribution (dose from the intake typically 0.1 – 1 mSv).

Level 2: Sophisticated evaluation using additional information to give more realistic assessment of dose: typically a special assessment of an accidental intake. Comparisons are made of the model predictions (“the fit”) with the data, to choose between alternative parameter values, or to find optimum parameter values (a posteriori). At this Level, the parameters adjusted typically relate to the material (for inhalation intakes the AMAD and absorption type), and the time of intake if unknown (dose from the intake typically 1 – 6 mSv).

Level 3: More sophisticated evaluation, which applies to cases where there are comprehensive data available, as would be the situation after an accident. The evaluation is an extension of Level 2, typically to parameters relating to the subject (e.g. for inhalation intakes the HRTM particle transport rates). The fundamental approach at this Level is to adjust the model parameter values systematically, in a specific order (“step-by-step” approach), until the goodness of fit is acceptable (i.e. the fits obtained to all the data are not rejected by the specified criteria) (dose typically > 6 mSv).

PART III. PRACTICAL TESTING OF THE GENERAL GUIDELINES

7. BACKGROUND

Several intercomparison exercises have previously been organized at national and international levels for the assessment of occupational exposure due to intakes of radionuclides[8, 9, 10, 11, 12, 4]. These exercises revealed significant differences in the approaches, methods and assumptions used, and consequently in the results obtained by participating laboratories.

The validity of the draft guidelines needed to be tested by means of a dose assessment intercomparison exercise open to participants from all over the world (4th European Intercomparison Exercise on Internal Dose Assessment).

In parallel, the IAEA had planned to organize a new intercomparison exercise on internal dose assessment among the Member States of the IAEA. In view of the common goals there have been identified many advantages in organizing a joint IDEAS/IAEA exercise. This would save work and money for both the IDEAS project and the IAEA and it would most probably result in the largest intercomparison exercise ever organized in this field, providing much more information about the state of the art of internal dosimetry than an exercise on a European scale could do.

The joint IDEAS/IAEA intercomparison exercise has been organized in a way similar to the IDEAS Virtual Workshop on the internet (www.ideas-workshop.de).

This report presents the results of the joint IDEAS/IAEA intercomparison exercise. These results have been discussed with the participants during a workshop organized by the IAEA in Vienna, 18–20 April 2005. Based on these discussions the IDEAS general guidelines have been finalized.

7.1. Objectives

The new intercomparison exercise did focus especially on the benefit of the guidelines for harmonization of internal dosimetry[13]. In addition, it did consider the following aspects:

- to provide possibilities for participating laboratories to check the quality of their internal dose assessment methods in applying the ICRP recommendations;
- to compare different approaches in interpretation of internal contamination monitoring data;
- to quantify the differences in internal dose assessment based on the new guidelines or on other procedures;
- to provide some quantitative information on the influence of the input parameter values on the results; and
- to provide a broad forum for information exchange.

7.2. Scope of the intercomparison

Several cases were selected for the exercise with the aim of covering a wide range of practices in the nuclear fuel cycle and medical applications, namely:

1. Acute intake of ^{3}H
2. Acute inhalation of fission products ^{137}Cs and ^{90}Sr
3. Acute inhalation of ^{60}Co
4. Repeated intakes of ^{131}I
5. Intake of enriched uranium
6. Single intake of ^{239}Pu and ^{241}Am

Four of the cases (1, 2, 5 and 6) are real and all except case 5 have been published. Cases 3 and 4 were artificially constructed.

7.3. Schedule

This intercomparison exercise was the first totally web-based exercise for assessment of intakes by resolving electronically presented cases.

The exercise was open for all interested experts from around the world. The IAEA invited all Member States to nominate their experts for participation and finally received 31 nominations. The rest of 50 more participants registered through the internet.

The discussion and planning of the intercomparison exercise started at a meeting of the IDEAS workgroup with external participants at the end of June 2004.

The IAEA proposed a time schedule for the exercise, which could be kept throughout the exercise.

Invitation letter to Member States circulated by the IAEA	31 July 2004
Announcement of exercise on World-wide Web by IDEAS and IAEA	31 July 2004
Selection and preparation of cases	July–Sept 2004
Nomination of participants by Member States	15 Sept 2004
Cases on web site	30 Sept 2004
Evaluation of cases by participants	Oct - Dec 2004
Close of submission of evaluations	31 Dec 2004
Analysis of results	Jan-March 2005
Final Workshop	April 2005

Finally only the time given for submitting the answers had to be extended by one month to the end of January 2005. All other dates could be kept.

7.4. Participation

Because of the easy access to the cases and the worldwide promotion of the intercomparison exercise both by the IDEAS group and the IAEA, there was a large number of participants from all over the world (Table 7.1).

Table 7.1. Geographical distribution of the participants

Region	Countries	Participants	Reports received
Africa	3	4	1
America	7	12	12
Asia	12	19	17
Europe	20	45	41
IAEA	—	1	1
World	42	81	72

Not all participants solved all the prepared cases, as they were free to undertake only those cases that were relevant to their everyday work. Because of this, and the range in difficulty of the cases, the number of results reported per case differed widely (Table 7.2).

Table 7.2. Results reported per case

	Isotope	Number of results reported	% of 81 participants
Case 1	^{3}H	58	72 %
Case 2	$^{137}Cs + {}^{90}Sr$	58	72 %
Case 3	^{60}Co	62	77 %
Case 4	^{131}I	63	78 %
Case 5	enriched Uranium	41	51 %
Case 6 Part 1	^{241}Am	35	43 %
Case 6 Part 2	^{239}Pu	36	44 %

In terms of the presentation of the results, the responses from participants varied greatly. While some participants followed the Guidelines and provided the key information to facilitate compilation and analysis, some did not. Some of the responses were extremely detailed and followed the format proposed in the worksheet. Some others were too brief and hardly followed the format proposed.

Responses with insufficient data or ambiguous information not only increased the time and effort in compilation and analysis, it also increased the chance of error in these processes. In

these cases, clarifications were requested from participants and this increased the processing time and effort.

Similar to other prior intercomparisons, the geometric mean, the geometric standard deviation the arithmetic mean, the standard deviation, the minimum and the maximum values were compiled for each case and each exposure (if more than one).

The geometric mean and also the geometric standard deviation better reflect the statistical variation of the results and may provide a better graphical representation of the data.

Finally, since anonymity was important to some participants, the identity of the participants are not shown in the compilation of the results. The order of the listing of participants in Annex A is not the same as the laboratory number used in the other Annexes.

7.5. Procedure for selecting data for statistical evaluation

The procedures usually adopted to check the presence of outliers in a set of data are based on the hypothesis that all the data are pertaining to a defined statistical distribution and these procedures are able to identify data affected by gross errors due to a wrong reading or recording or transcription or some other kind of similar mistake. These procedures usually work on a high level of automatization in order to check large amounts of data.

The problem in this intercomparison exercise was to detect if one or more data are pertaining to the statistical distribution of the other data. As a consequence, one or more data had to be tested against the others. It has to be emphasized, that it is not the goal to identify some wrong data. In fact, the data not pertaining to the main distribution could be the only right ones. The goal of the procedure is to avoid the gross errors (in reading, recording, transmission or transcription) that are disturbing the statistical evaluation.

A second important point is that we know the meaning of the data and we are able to recognize data with low coherence in relation to the others. We need a method to verify if one or a little number of data completely distorts the statistical parameters of the distribution.

In another way, the data can't be considered as independent random samples from a statistical distribution as the differences in the values are mainly due to different choices in experimental data evaluation and treatment, in type and use of models. The empirical observation of the results leads us to consider a lognormal distribution as appropriate to summarize the central part of the distribution. It is important to check the effect of single data on the values of distribution parameters.

Adopting these concepts the basic starting points are:

- The results belong to a single lognormal distribution.
- Probability concepts were used to test if one or some specific results were pertaining to this distribution.

As a conclusion, the procedure has been based on the fact that a specific value belongs to the distribution of the other data (null hypothesis). If the specific value was outside the 98.8% confidence interval of the distribution, then the null hypothesis was rejected and the specific

value was regarded an outlier. Therefore, there was only a 1.2% chance of reporting a false outlier if the null hypothesis was true.

Based upon this approach the following procedure was adopted:

1. Calculation of the log-values of all the results, X_i
2. Calculation of the parameters of the lognormal distribution of all data:
   Geometric Mean (GM) and Geometric Standard Deviation (GSD)
3. Calculation of the deviation in unit of GSD for all values:
4. z = (1nXi - 1nGM)/1nGSD
5. Identification of all results with a deviation, z in step 3, of more than ± 2.5 (corresponding to 98.8% confidence interval). These values are considered as possible "outliers", and will not be used for the final statistical evaluation
6. Repetition of steps 2, 3 and 4 without the "outliers" identified in step 4 until the distribution parameters became stable
7. The final parameters of the lognormal distribution, GM and GSD, reported in the tables were the stable values found in step 5

When applying this procedure it could happen that one result was identified as outlier when considering the whole set of results, but it was not an outlier when considering some subset of the results. On the other hand it could happen that one result was identified as an outlier in a subset but not in the whole set of data, because the GSD could be much larger in the whole set than in the subset. The organizers were aware of this problem. However, the procedure was considered to be the only practicable one. This procedure is identical to the corresponding procedure adopted for the statistical analysis of the results of the 3rd European Intercomparison Exercise on Internal Dose Assessment[4].

PART IV. ASSESSMENT OF THE CASES

8. CASE 1: ACUTE INHALATION OF HTO

8.1. Case description

8.1.1. The event

Description of the working area	Unknown
Characteristics of work	Plant decontamination. The man was refilling a vacuum pump used for cleaning rooms contaminated with tritium.
Reasons for monitoring; initiating event	The man removed a filler cap resulting in the expulsion of contaminated air.
Actions taken	The man took a shower and changed his clothes. A urine sample was taken. The man was put on a plethoric hydrous diet (8 litres a day) to enhance the excretion of tritium.

8.1.2. Additional information

Air monitoring	None
Chemical form	Tritiated water (HTO).
Physical characteristics, particle size	Vapour
Nose swab, bronchial slime or similar	None
Non removable skin contamination	None
Wound site activity	Not applicable
Any intervention used (blocking, chelating, etc.)	Plethoric hydrous diet

8.1.3. Body monitoring data

Organ activity measurement	N.A.
Whole body activity measurement	N.A.

8.1.4. Excretion monitoring data

Urine activity measurement

Time after intake (d)	Urine activity concentration of ^{3}H. (MBq/l)
0	80.1
1	67.7
2	57.5
3	47.5
4	39.2
5	32
6	27.6
7	24.2
8	22.9
9	19.5
10	16.5
11	14.3
12	12.4
13	11
14	9.62
15	8.23
16	7.81
18	6.36
20	5.25
22	4.26
24	3.52
26	2.86
28	2.80
30	2.08
33	1.54
35	1.25
36	1.02

Time after intake (d)	Urine activity concentration of 3H. (MBq/l)
38	0.97
39	0.78
41	0.64
44	0.56
47	0.42
49	0.36
50	0.31
54	0.23
56	0.17
58	0.15
61	0.12
63	0.11
66	0.099
68	0.078
70	0.064
72	0.057
75	0.05
77	0.044
79	0.044
82	0.036
84	0.034
87	0.029
89	0.025
91	0.023
94	0.021
96	0.019
98	0.018
100	0.018

Time after intake (d)	Urine activity concentration of ^{3}H. (MBq/l)
103	0.014
142	0.0087
149	0.0081
156	0.0074
163	0.0066
169	0.0064
177	0.0057
184	0.0063
191	0.0043
196	0.0048

Time after intake (d)	Urine activity concentration of ^{3}H. (MBq/l)
216	0.004
219	0.0038
226	0.0041
233	0.0037
239	0.0033
246	0.0028
254	0.0025
268	0.002
270	0.0022
274	0.0021

Faeces activity measurement None

8.1.5. Personal data

Sex	Male
Age	32 years
Weight	71 kg

8.1.6. Other comments relevant for intake and dose estimation

Calculate the committed effective dose (E(50)) using the direct dose estimation method.

8.2. Assessment of case

8.2.1. Simple hand calculation

Before following the guidelines to assess the case it is useful to plot the available data (Figure 8.1.) and perform a simple calculation to assess the intake and dose.

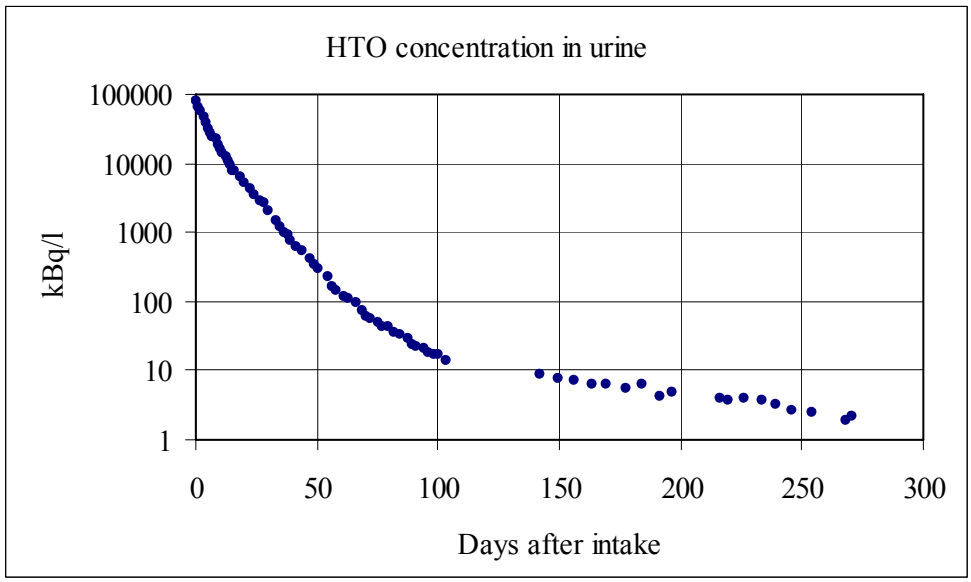


Fig. 8.1. Plot of the excretion data for Case 1

The effective dose from intakes of HTO can be assessed using the direct dose assessment method (Figure 8.2). This method involves calculating the area under the urine activity concentration data to determine the number of nuclear transformations.

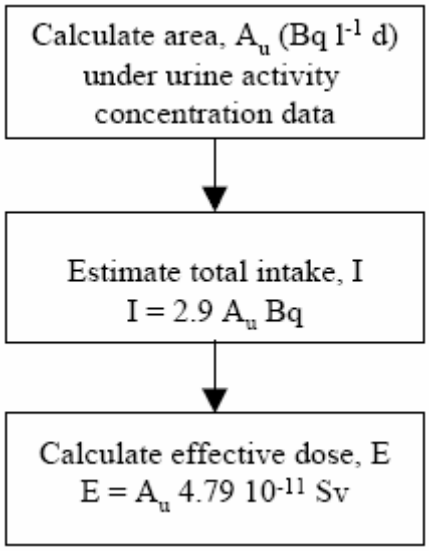


Fig. 8.2. Direct dose method for intakes of tritiated water

Assuming that the urine activity concentration data can be approximated by a series of exponentials, the area A_u under the data can be roughly estimated by the following equation:

$$A_U = \frac{e(t=0) \cdot T_{0.135}}{2}$$

with

A_u approximated area under the urine activity concentration data

$e(t=0)$ activity concentration in the urine at time t=0

$T_{1/ee}$ time after which the activity concentration is 0.135 e(t=0)

The initial activity concentration is $e(t=0) = 8.0\ 10^{7} Bq\ l^{-1}$

and thus $0.135\ e(t=0) = 1.08\ 10^{7}\ Bq\ l^{-1}$

which is reached on day 13.

Thus $T_{0.135} = 13\ d$

and with $A_u = 5.2\ 10^{8}\ Bq\ l^{-1}\ d$

Hence the effective dose is $E = A_u\ 4.79\ 10^{-11}\ Sv = 0.025\ Sv = 25\ mSv$

8.2.2. Assessment according to the guidelines

Following intakes of tritiated water (HTO), most monitoring programmes consist of measuring the activity concentration of ^{3}H in urine samples. The resulting effective dose from intakes of HTO can be assessed using the direct dose assessment method (Figure 8.3).

This method involves calculating the area under the urine activity concentration data to determine the number of nuclear transformations. Thus, the method is not covered by the Structured Approach provided by the IDEAS General Guidelines. There is, however, a special section in the Guidelines describing the direct dose assessment method in detail especially for HTO.

ICRP assumes that HTO is instantaneously translocated to blood following inhalation or ingestion. HTO is assumed to mix rapidly and completely with total body water after its entry to blood. It can be assumed that the activity concentration in urine *(Bq l^{-1})* equals that of total body water. Thus, the activity in total body equals the activity concentration in urine multiplied by the total volume of body water, which is 42 l for reference man (ICRP Publication 23).

Finding the area under the activity total body curve then gives the number of nuclear transformations in the total body.

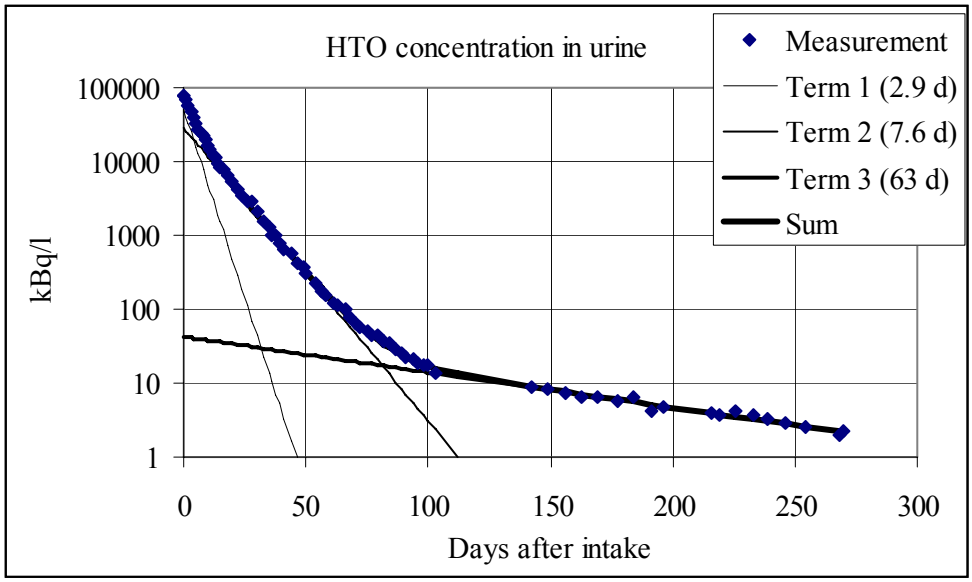


Fig. 8.3. Approximation of the measured data by a sum of three exponential terms

If A_u is the area under the urine activity concentration data *(Bq l^{-1} d)* from the time of the first intake (t=0) to infinity then the total number of nuclear transformations, U_s is given by:

$$U_s = A_u \, 42 \, b \qquad (1)$$

where b is a numerical constant converting days to seconds: 86400 s d^{-1}.

For intakes of HTO the equivalent dose to each of the target organs is identical and equal to the effective dose, E. Thus, E is obtained by multiplying U_s by the specific effective energy, for the source organ whole body, *SEE(T ← WB)*.

SEE(T ← WB) represents the equivalent dose in a target organ per disintegration in the whole body source organ.

For ^{3}H *SEE(T ← WB) = 1.32 10^{-17} Sv* per disintegration.

This is the value used by ICRP in calculating the dose coefficients for HTO given in ICRP Publication 68[20]. The mass of the source organ whole body is 68.831 kg (Cristy and Eckerman 1993)[14].

The committed (50y) effective dose, *E(50)* is thus approximated by:

$$E(50) = U_s \, 1.32 \, 10^{-17} \, Sv \qquad (2)$$

Substituting equation (1) into (2)gives:

$$E(50) = A_u\, 4.79\ 10^{-11}\ Sv \qquad (3)$$

The total intake, I can be determined by calculating the total amount of activity lost from the body. The ICRP Publication on the revised reference man (ICRP Publication 89, Table 2.30) [15], gives the total water loss per day as 2.9 l d^{-1} for an adult male.

Thus, the total activity lost from the body, which gives the total intake is given by:

$$I = 2.9\ A_u\ Bq \qquad (4)$$

The direct dose method does not depend upon a systemic biokinetic model, as U_s is obtained directly by calculating A_u from urine activity concentration data. The accuracy of the method depends on the accuracy of A_u. Errors occur in interpolating the data and in extrapolating the data to earlier or later times. If the measurements are frequent then linear interpolation, i.e. using the trapezoidal method, is recommended.

Thus, in the present case, the area under the measurement data is approximated by:

$$A_U = \sum_{i=1}^{n-1} \frac{(C_{i+1} + C_i)(t_{i+1} + t_i)}{2}\ Bq\ l^{-1}\ d \qquad (5)$$

where:

C_i is the activity concentration of HTO (Bq l^{-1}) in urine sample i
t_i is the corresponding measurement time (d) for urine sample i
n is the total number of urine samples.

In the present case the data cover a time period much greater than the effective half time of HTO in the body (4-18 d) [5] and thus the last data value is relatively low and the error caused by not extrapolating the data to later times is insignificant. This has been demonstrated already by the simple hand calculation (Section 8.2.1).

In the present case the last equation results in $A_u = 5.31\ 10^{8}\ Bq\ l^{-1}\ d$

Which is very close to the value derived from the simple hand calculation. Hence the effective dose is

$$E = A_u\, 4.79\ 10^{-11}\ Sv = 0.0254\ Sv = 25.4\ mSv$$

For an acute intake of HTO as in the present case, improved estimates of A_u can be obtained by fitting a sum of exponential terms, *f(t),* to the urine activity concentration data *(Bq l^{-1}).* The fitted function *f(t)* is defined as follows:

$$f(t) = \sum_{i=1}^{n} a_i\, e^{-\lambda_i t}\ \ Bq\, l^{-1} \qquad (6)$$

where t is time after the acute intake in days.

Table 8.1. Parameters of the exponential terms for the estimation of the area under the urine activity concentration data

Term *i*	a_i *in Bq* l^{-1}	λ_i *in* d^{-1}	A_{ui} *in Bq* l^{-1} *d*
1	5.10 E07	0.235	2.17 E08
2	2.85 E07	0.091	3.13 E08
3	4.20 E04	0.011	4.00 E06
Sum			5.34 E08

In the present case the measured data can be approximated by a sum of three exponential terms as shown in Figure 8.3. The respective parameters of the exponential terms are listed in the second and third column of Table 8.1.

The intake is given by:

$$I = 42 \sum_{i=1}^{n} a_i \quad Bq \tag{7}$$

A_u can be calculated by integrating f(t) between zero and infinity:

$$A_U = \sum_{i=1}^{n} A_{Ui} = \sum_{i=1}^{n} \frac{a_i}{\lambda_i} \quad Bq\, l^{-1}\, d \tag{8}$$

The A_{Ui} values derived in the present case are listed in the last column of Table 8.1.

So in the present case Equ. (8) results in $A_u = 5.34\ E08\ Bq\ l^{-1}\ d$

and thus in $E = A_u\ 4.79\ E\text{-}11\ Sv = 0.0254\ Sv = 25.4\ mSv$

Again, these values are very close to the values derived from the simple hand calculation. Note that the first term contributes about 40 % and the second term about 60 % whereas the contribution of the third term is less than 1 %. This demonstrates once more that in this case it is not necessary to extrapolate the measured data to infinity because more than 99 % of the dose is covered by the measured data.

8.3. Results of intercomparison exercise

8.3.1. Introduction

Fifty-eight participants assessed this case. These participants come from Europe (37), Asia (11), America (5) and Africa (4). The laboratory of the IAEA also participated to this intercomparison. The main represented countries are: Germany(6), UK and Slovenia (4), Italy (3), Hungary and Slovakia (2)

8.3.2. Overall distribution of results

The statistical evaluation of the results, excluding outliers is given in Table 8.2.

Table 8.2. Statistical evaluation of the results excluding outliers

	Committed effective dose	**Cumulated activity**
N	58	50
GM	25.8 mSv	5.35×10^{8} Bql^{-1} d
GSD	1.06	1.005
AM	25.7 mSv	5.35×10^{8} Bql^{-1} d
ASD	1.4 mSv	2.25×10^{6} Bql^{-1} d
Coefficient of variation (%)	5.5	0.4
Minimum	2.6 E-05 mSv	533 Bql^{-1} d
Maximum	64 mSv	1.95×10^{15} Bql^{-1} d
Outliers	11	17

8.3.3. Effective dose

The geometric mean (GM) of the estimated effective dose is almost identical with the arithmetic mean. The geometric standard deviation (GSD) of 1.06 is quite small and the coefficient of variation is only 5.5%.

There are, however, quite a lot of outliers and the range of all estimated doses including the outliers is very broad: $2.6\ 10^{-5}$ – 64 mSv (ratio max/min = $2.5\ 10^{6}$). The dispersion of the results without outliers is shown in Figure 8.4. and – with an expanded x-axis – in Figure 8.5.

Figure 8.6 shows the results of the individual participants.

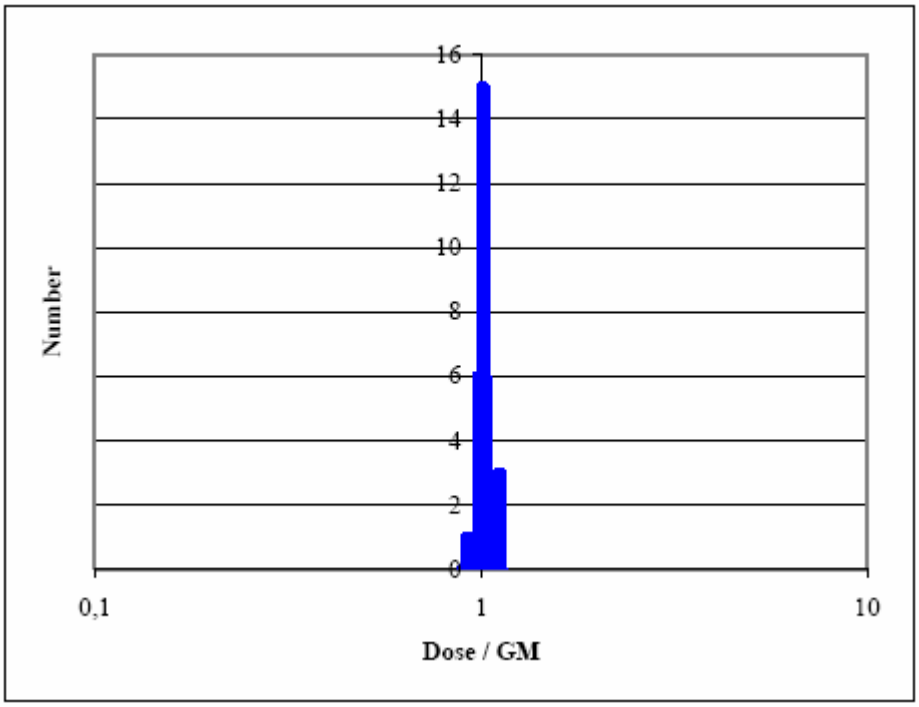


Fig. 8.4. Frequency distribution of results without outliers (N=47). Effective dose normalized to the geometric mean. (GM = 25.8 mSv, GSD = 1.06)

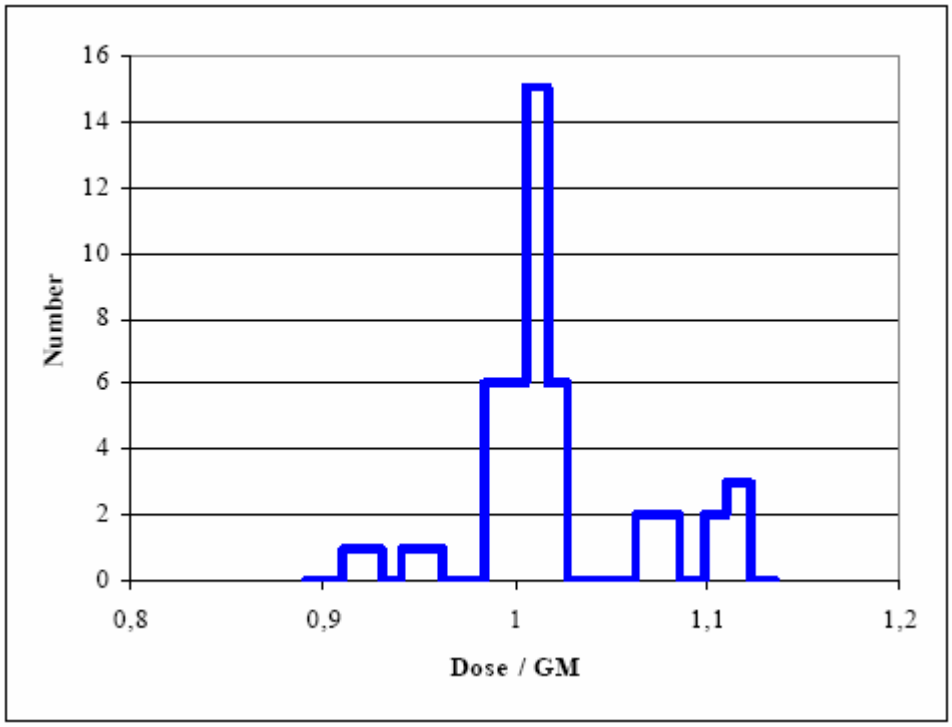


Fig. 8.5. Frequency distribution of results without outliers as in Figure 8.4., but with expanded x-axis

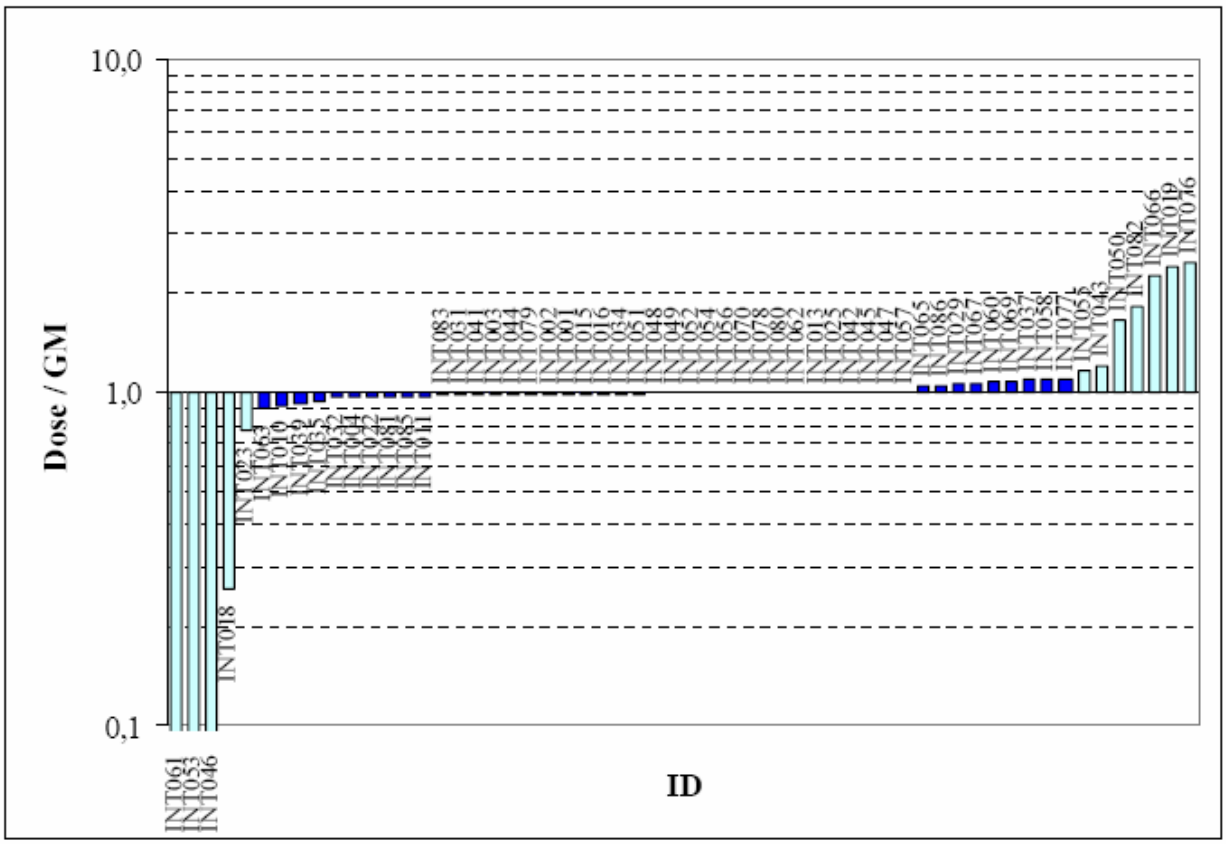


Fig. 8.6. Results of the individual participants: Effective dose normalized to the geometric mean. (GM = 25.8 mSv, GSD = 1.06, N=47) The light blue bars represent the outliers

8.3.4. Cumulated activity

The geometric mean (GM) of the estimated cumulated activity is practically identical with the arithmetic mean. The geometric standard deviation (GSD) of 1.005 is extremely small and the coefficient of variation is only 0.4 %.

Again there are quite a lot of outliers and the range of all estimated intakes, including the outliers, is very broad: 533 – 1.95 10^{15} Bql^{-1} d (ratio max/min = 3.7 10^{12}). The dispersion of the results without outliers is shown in Figure 8.7. and — with an expanded x-axis — in Figure 8.8.

Figure 8.9 shows the results of the individual participants.

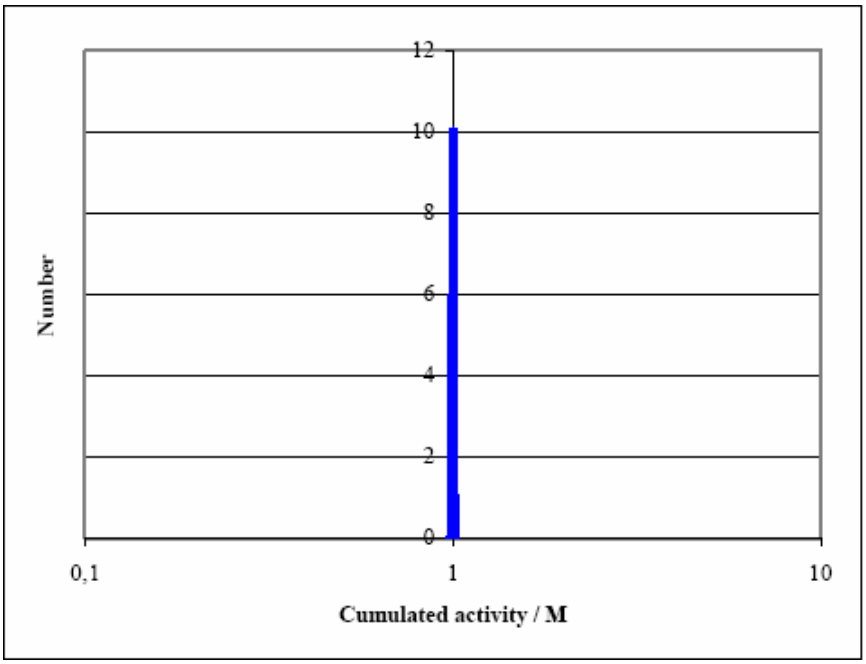


Fig. 8.7. Frequency distribution of results without outliers (N=33) Cumulated activity normalized to the geometric mean. (GM = 5.35 10^{8} Bql^{-1} d, GSD = 1.005)

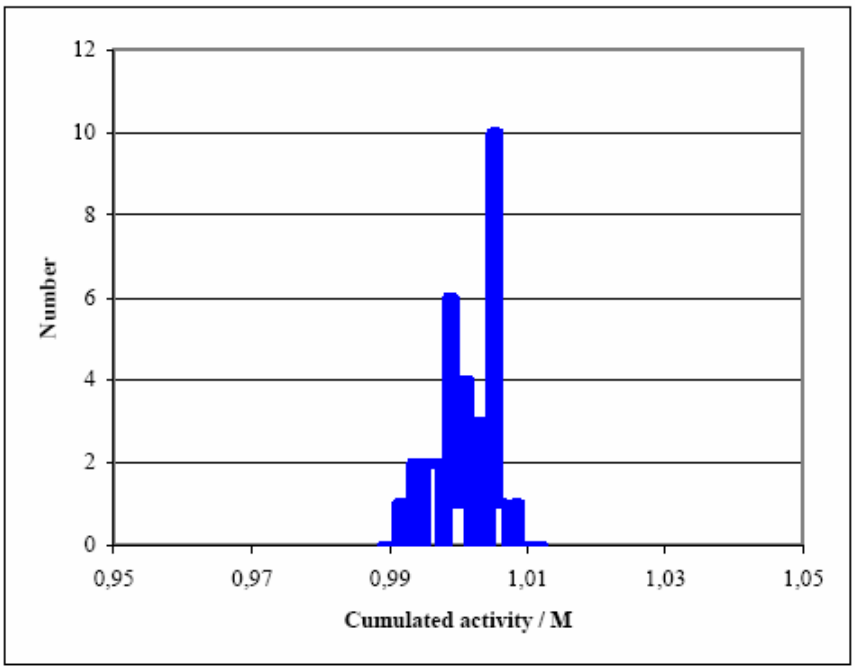


Fig. 8.8. Frequency distribution of results without outliers as in Figure 8.7., but with expanded x-axis

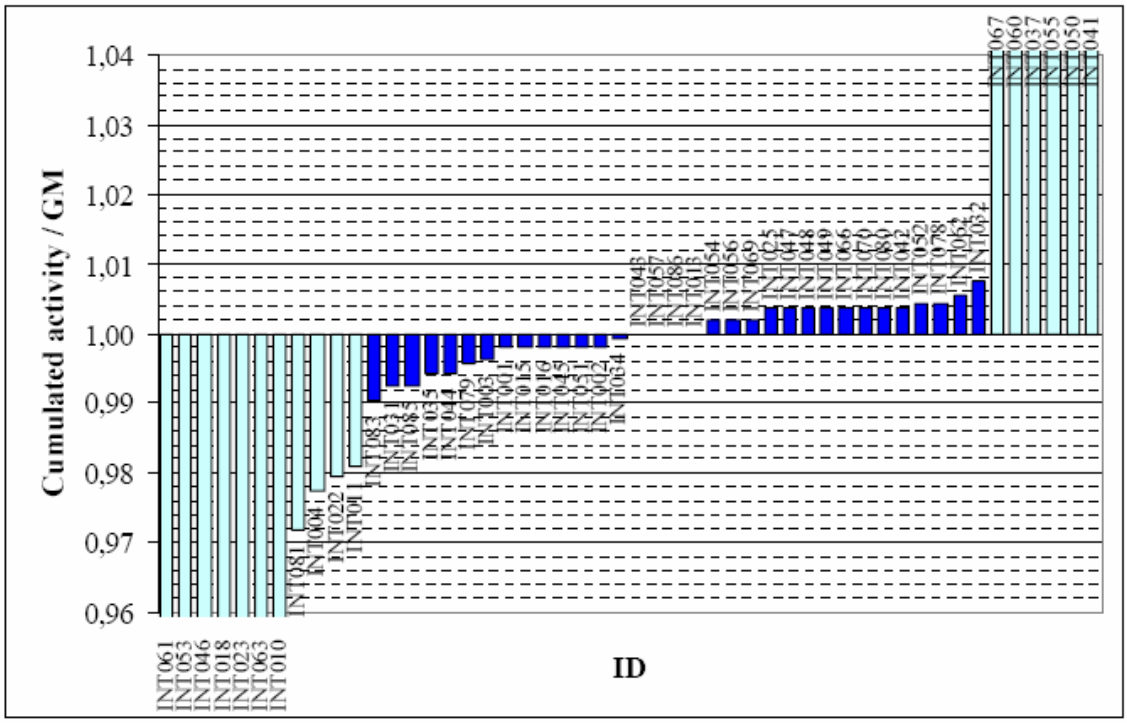


Fig. 8.9. Results of the individual participants: Cumulated activity normalized to the geometric mean. (GM = 5.35 10^8 Bql^{-1} d, GSD = 1.005) The light blue bars represent the outliers in terms of cumulated activity

8.3.5. Multiexponential fit

Seven participants applied multiexponential fitting procedures for the estimation of the cumulated area. Three of them used three exponential terms, two used two exponentials and one participant used four exponentials (Table 8.3).

Complete information about the parameters of the exponential terms was provided by three participants (Table 8.4).

One participant provided the half-life values only and the other three participant provided no information about the exponential functions.

The results in terms of cumulated activity are in most cases very close together. Participant INT023, however reported values about 20 % below the others. This might be due to the fact that he applied only two exponentials with a half-life of 7.9 d and 58.7 d, respectively. Thus, the exponentials correspond to the second and the third term of the exponentials used by the other participant (Table 8.4). As can be seen from Figure 8.3, the second term underestimates the measured excretion of the first days, this being most likely the reason for the discrepancy.

Table 8.3. Results of multiexponential fitting

			Results	
ID	**Number of exponential terms**	**Parameters of exponentials provided**	**Cumulated activity (Bq l^{-1} d)**	**Effective dose (mSv)**
INT004	3	Yes	5.23 E08	25.1
INT011	4	No	5.24 E08	25.1
INT023	2	Yes (half-life)	4.28 E08	20.0
INT042	2	No	5.37	E08
INT057	Not	specified	No	5.35
INT077	3	Yes	5.33	E08
INT079	3	yes	5.33	E08

Table 8.4. Parameters of exponential terms used for multiexponential fitting

ID	Half-life (percentage) of exponential terms		
	Term 1	Term 2	Term 3
INT004	3.73 d (73.43 %)	8.12 d (26.51 %)	64.2 d (0.055 %)
INT077	2.97 d (74.51 %)	8.08 d (25.45 %)	73.0 d (0.034 %)
INT079	2.95 d (64.10 %)	7.59 d (35.85 %)	62.8 d (0.053 %)

8.3.6. Identification of outliers

Outliers were identified by following the statistical criteria described in Section 7.5.

Figure 8.10 provides an overview over the outliers in terms of cumulated activity (light blue bars) in terms of dose (brown bars) and , and in terms of both dose and cumulated activity (red bars).

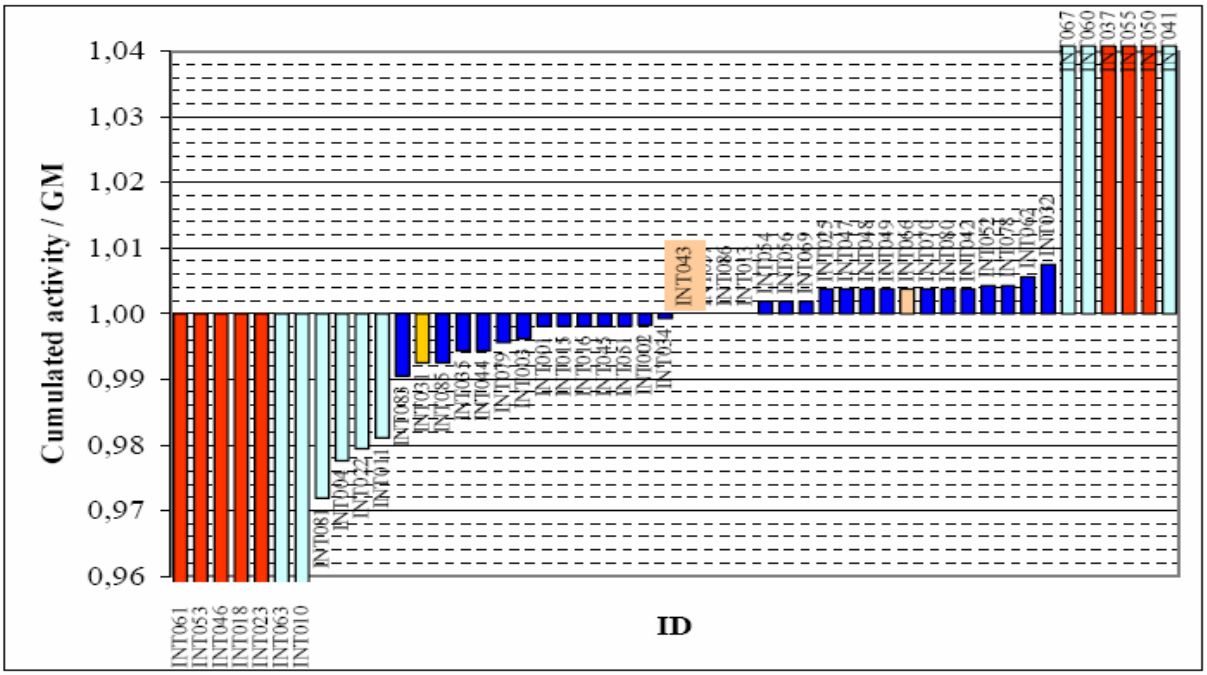


Fig. 8.10. Results of the individual participants: Cumulated activity normalized to the geometric mean. (GM = 5.35 10^8 Bqt^{-1} d, GSD = 1.005 The light blue bars represent the outliers in terms of cumulated activity; the brown bars represent the outliers in terms of both dose and cumulated activity

8.3.7. Number of values used for evaluation

Most of the participants have used all 75 values from the case description.

Two participants have used 74 values, so in total 45 participants have used practically all available information. In this group four outliers in terms of dose have been reported, this corresponds to app. 9 % of the answers (Table 8.5).

Seven participants have used from 37 up to 64 values. In this group only one outlier has been reported. This corresponds to app. 14 % of the answers.

Two participants have used only 6 or 16 values, and both of them have reported outliers.

Thus, there is an obvious tendency that the probability for producing outliers is increasing with decreasing number of data used for evaluation.

Table 8.5. Statistical evaluation with respect to the number of values used for evaluation

Number of values used for evaluation	Number of answers	
	Total	Outliers in terms of dose
74-75	45	4 (9 %)
63-64	2	-
50	2	1 (50 %)
37 – 40	3	-
16	1	1 (100 %)
6	1	1 (100 %)

8.3.8. SEE values

Thirty-six participants have used the ICRP default SEE value ($1.33\ 10^{-17}$ Sv/disintegration). Nine more participants have applied similar SEE values ranging from $1.29\ 10^{-17}$ to $1.45\ 10^{-17}$ Sv/disintegration. In this group seven outliers in terms of dose have been reported. This corresponds to app. 16 % of the answers (Tables 8.6 and 8.7). One participant has used a SEE value of $9.10\ 10^{-16}$ Sv/disintegration. This resulted in no outlier.

Two participants have applied SEE values which are about 6 orders of magnitude higher than the ICRP default value. One of the two reported outliers in terms of both cumulated activity and effective dose. The other participant, however, reported an effective dose of 27 mSv, which is no outlier at all. Ten participants did not provide any information about the applied SEE values, and four of these participants have reported outliers.

Table 8.6. Statistical evaluation with respect to the SEE values used for evaluation

SEE value (Sv/disintegration)	Number of answers	
	Total	Outliers in terms of dose
1.29 E-17	1	-
1.30 E-17	3	-
1.32 E-17	36	6
1.33 E-17	2	1
1.44 E-17	2	-
1.45 E-17	1	-
9.10 E-16	1	-
1.43 E-11	1	1
1.80 E-11	1	-
No value reported	10	4

Table 8.7. Statistical evaluation with respect to the SEE values used for evaluation (grouped)

SEE value (Sv/disintegration)	Number of answers	
	Total	Outliers in terms of dose
1.29 E-17 – 1.45 E-17	45	7 (16 %)
> 1.45 E-17	3	1 (33 %)
No value reported	10	4 (40 %)

8.3.9. Assumed distributions and uncertainty on measurement data

Fifteen participants (25.8 %) stated that they assumed the measurement data to be governed by a normal distribution, whereas 13 participants stated that they assumed a lognormal distribution. Two participants stated that they have used other distributions but they did not specify this in more detail. Seven participants indicated that they have assumed no distribution and the remaining 21 participants (36.2%) did not provide any information on this topic.

Most of the participants who have specified the distribution provided also some information about the assumed uncertainty values. In most cases (11 out of 24) a 10 % uncertainty was assumed for the normal distribution or 110 % (or SF = 1.1) for the lognormal distribution, respectively. The other uncertainty values cover the range from 1 % for the normal distribution and 27.45 for the lognormal distribution.

8.3.10. Use of guidelines.

The responses to following the guidelines, 25 participants (43 %) stated that they followed the IDEAS guidelines, four participants stated that they followed the guidelines only to some extend, and 24 did not follow the guidelines at all. Those that did not follow the guidelines gave the reasons summarized in Table 8.8.

Table 8.8. Reasons for not following the guidelines

Reason	**Number of participants**
Followed own established procedures or own software	6
Flowcharts are not relevant for the case	9
The case is too simple	1
No time to read the guidelines	2
Guidelines not available	2
Guideline for direct dose assessment has been followed	1
Direct internal dosimetry is out of the scope of the laboratory	2
No comment	1

The guidelines provide a structural approach only for the conventional evaluation of incorporation monitoring data (i.e. for the assessment of the committed dose via the intake of the radionuclide). For direct internal dosimetry, however, guidance is given by special "Guidelines for direct internal dose assessment" which have been provided together with the description of Case No. 1.

Some participants stated that they did not follow the general guidelines because they applied the special "Guidelines for direct internal dose assessment", others stated that there are no guidelines available or that the flowcharts of the guidelines are not relevant to the direct dose assessment method, respectively.

Thus, in some cases it is not clear if the participants actually followed the guidelines, and if so, what kind of guideline they have used. So it is difficult to derive a figure of the benefit of the guidelines for direct internal dosimetry.

When grouping the participants according to their statements, the percentage of outliers is 11.5 for those who followed the guidelines and 16.7 for those who did not follow the guidelines.

When taking into account the comments, however, at least 3 of the participants having stated that they did not follow the guidelines should be allocated to the group of those who followed the guidelines. When adjusting the grouping accordingly the percentage decreases to 10.3 for those who followed the guidelines whereas it increases to 19.0 for those who did not follow the guidelines. So, there is a significant difference in between the two groups.

Table 8.9. Grouping of the answers with respect to the application of the guidelines according to the statements of the participants (in brackets: numbers adjusted according to comments of participants)

	Total number of answers in terms of dose	**Number of outliers in terms of dose**	**Percentage of outliers in terms of dose**
Participants following the guidelines	26 (29)	4	15.4% (13.8%)
Participants partly following the guidelines	3	2	66.7%
Participants not following the guidelines	24 (21)	4	16.7% (19.0%)
No statement	5	2	40%

8.4. Conclusion for Case 1

Case 1 is a real case of intake of tritiated water. Because of the plethoric hydrous diet the excretion of the HTO was enhanced significantly and the biological half-life was reduced accordingly.

The case is a very good example for the benefits of direct internal dosimetry. Most of the participants (51) have applied this method using the trapezoid integration procedure and some participants (7) have applied the method using a multiexponential fitting procedure for the calculation of the cumulated activity.

The frequency distribution of the answers in terms of dose is very narrow. When neglecting the outliers the GSD is only 1.06. The frequency distribution of the answers in terms of cumulated activity is even more narrow with the GSD being only 1.005.

On the other hand the number of outliers is relative high. There are 12 outliers in terms of dose and 17 outliers in terms of cumulated activity. This corresponds to 21 % and 34 % of the answers respectively.

The relative high number of outliers is mainly due to the small GSD values. As may be expected the probability for producing outliers is increasing with decreasing number of data used for evaluation.

In some cases it is not clear if the participants actually followed the guidelines, and if so, what kind of guideline they have used. So it is difficult to derive a figure of the benefit of the guidelines for direct internal dosimetry.

When grouping the participants according to their statements, the fraction of outliers is 15.4% for those who followed the guidelines and 16.7 % for those who did not follow the guidelines.

When adjusting the grouping according to the comments of the participants the fraction of outliers decreases to 13.8 % for those who followed the guidelines whereas it increases to 19.0 % for those who did not follow the guidelines. So the percentage of outliers is reduced significantly by following the guidelines.

9. CASE 2: ACUTE INHALATION OF FISSION PRODUCTS

9.1. Case description

9.1.1. The event

Description of the working area	Unknown
Characteristics of work	Reprocessing graphite used in the reactor.
Reasons for monitoring; initiating event	Dust explosion of graphite containing fission products
Actions taken	External decontamination, nose swab, monitoring.

9.1.2. Additional information

Air monitoring	None
Chemical form	Graphite with fission products. Likely to be insoluble for strontium.
Physical characteristics, particle size	Aerosol
Nose swab, bronchial slime or similar	^{90}Sr activity in the nasal swab immediately after the accident is 1.9 kBq
Non removable skin contamination	None
Wound site activity	N.A.
Any intervention used (blocking, chelating, etc.)	None

9.1.3. Body monitoring data

Organ activity measurement None

Whole body activity measurement

Time of measurement after intake	^{137}Cs activity
(d)	(Bq)
0	7.0E+4
2	6.5E+4
7	5.0E+4
29	4.0E+4
62	3.5E+4
106	2.0E+4
226	6.2E+3
468	9.4E+2
595	8.0E+2

9.1.4. Excretion monitoring data

Urine activity measurement

Time of measurement after intake. (d)	Daily urine excretion rate of 90Sr/90Y (Bq/d)
1	65
4	13
7	7.1
29	1.2
47	1.4
76	1.0
202	0.66
227	0.64
314	0.47
492	0.78
634	0.45

Faeces activity measurement

Time of measurement after intake. (d)	Daily faecal excretion rate of ^{90}Sr/^{90}Y (Bq/d)
76	5.9
227	2.2
314	1.4
492	2.0
634	0.47

9.1.5. Personal data

Sex Male

Age 46 years

Weight Not available

9.1.6. Other comments relevant for intake and dose estimation

Estimate intake and committed effective dose E(50) for ^{90}Sr and ^{137}Cs.

9.1.7. Graphic presentation of available data

The available data for ^{137}Cs whole body measurements are reported in Figure 9.1., while the urine and faecal daily excretion rates for ^{90}Sr are reported in Figure 9.2.

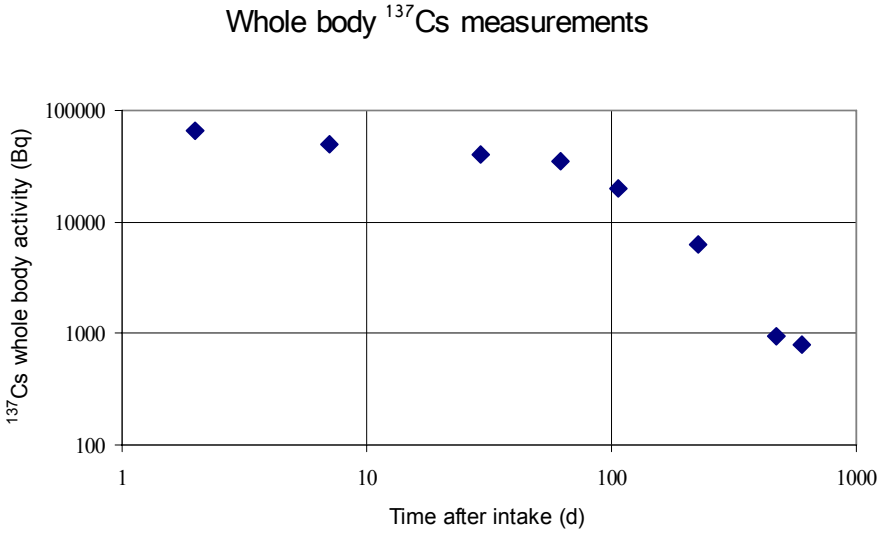


Fig. 9.1. Whole Body measurements of ^{137}Cs

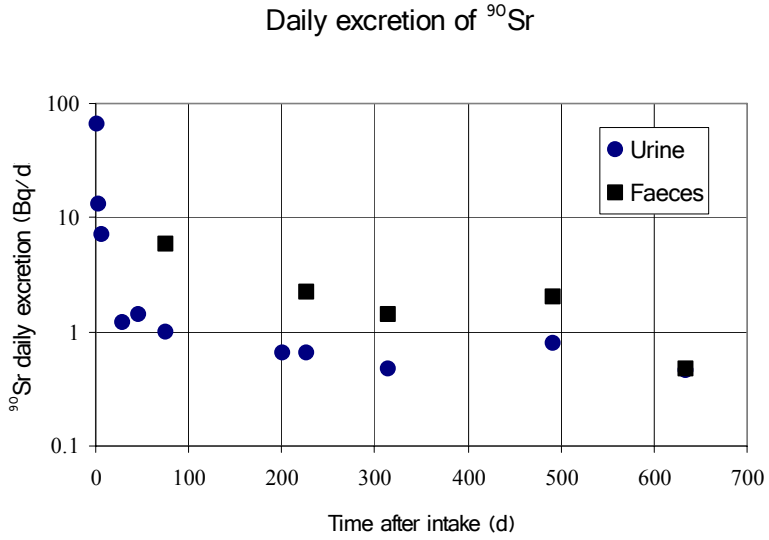


Fig. 9.2. Daily urinary and faecal excretion rates of ^{90}Sr

As can be seen from Figure 9.1 the value at 468 days after intake seems to be lower than the others and seems not to follow the behaviour of the other points.

Regarding the behaviour of the ^{90}Sr urinary and faecal excretion as can be seen in Figure 9.2. the value at 492 days after intake presents, both for urine and faeces, a value that shows a momentary increase in respect to the value at 314 days. The following data slightly decrease.

9.2. Assessment of case following IDEAS Guidelines

The case is assessed by following the IDEAS Guidelines (GL).

In the present paragraph a walk trough the guidelines is presented. The guidelines are used in the status they had during the evaluation period October 2004–January 2005.

The tables present for each flow chart the description of the items and the indication related to the application of the guidelines in Case 2. The description is the responsibility of the reviewer of the evaluations.

The different tables provide the relevant step number, the comments and reasons why this step was used and the action performed during the evaluation.

In Table 9.1 the initial path is indicated.

Table 9.1. Path in Step 1

Step	**Indication**	**Comment**	**Action performed**
1.1	Identification of monitoring value M	The first datum of WB measurement has been considered = 70 kBq. For 90Sr the value is 65 Bq/d.	Go to step 1.2
1.2	Comparison with Mc	70 kBq is greater of the maximum value for the critical monitoring quantity reported in the guidelines for 137Cs. Mc is equal to 2 kBq for T=360 d. For 90Sr the value of 65 Bq/d is greater than 0.4 Bq/d(T= 90d) so also in this case there is an indication to proceed in the evaluation.	M> Mc; go to step 1.3.
1.3	Test on routine monitoring	The case is the description of an accident, so typically this is special monitoring	Go to step 1.4
1.4	Special evaluation	Special evaluation needed.	Go to step 4

In Table 9.2 the actions related to step 4 are presented.

Table 9.2. Path in step 4

Step	**Indication**	**Comment**	**Action performed**
4	Special procedure	A special procedure is requested in case of special monitoring.	Go to 4.1
4.1	Test for pure inhalation	In this case there is evidence for ^{90}Sr presence in the nose activity, so also for ^{137}Cs pure inhalation is assumed.	Go to 4.1.1
4.1.1	Special evaluation for pure inhalation	Indication of special evaluation for pure inhalation.	Go to 5

Step 4 only relates to the choice of mode of intake. Pure inhalation has been chosen.

In Table 9.3 the actions related to step 5 are presented.

Table 9.3. Path in step 5

Step	**Indication**	**Comment**	**Action performed**
5	Subdivision in 5A, 5B and 5C	In the GL is indicated that the stage 5A is the same as the stage 3 “Standard procedure” but the main difference is that there are more data	Go to 5A

In step 5 there is the identification of all measurement data and the assignment of SF values for each type of measurement (step 5.1). There is no need to take account of the contribution of previous intakes as in the case description there is no indication about previous evaluated intakes (step 5.2).

Table 9.4. Path in step 5A: Evaluation with a priori parameter values

Step	Indication	Comment	Action performed
5A – 5.1	Identification of all measured data representing the case	In this case there are 9 whole body (WB) measurement data for ^{137}Cs; 11 urine and 5 faeces data for ^{90}Sr. As the WB ^{137}Cs-activity is measured using the 661.6 keV emission line, a high photon energy E >100 keV is used. The assignment of scattering factor (SF) has effects on the evaluation of the rejection of fitting. Values for direct WB measurement are reported in Table 2.2 of the Guidelines. A lognormal distribution has been assumed and a value of SF = 1.2 for ^{137}Cs-WB-measurements has been adopted. No further process is needed. The Guidelines in Table 2.3 give three different values for urine measurements (^{90}Sr) related to: a) a true 24-h sample (SF= 1.1), b) a simulated 24-h based on gravity normalization (SF=1.3) and c) spot urine samples (SF=2). Indication for Pu urine samples is shown as comment and the value of SF=1.8 has been reported. For Sr urine data a value of SF=1.8 has been assumed. For faeces measurements the Guidelines, in Table 2.3, provide a range of values (3 < SF < 7) instead of a single value. For Sr faeces data a value of SF=3 has been assumed. Both data of urine and faeces at time 492 d show an increase in respect to the previous measurement. Some probability check if they are inside the behaviour of the other measurements should be performed. No further operation for urine and faeces data is necessary, as they already presented as Bq/d (not concentration or else).	Go to 5.2
5.2	Contribution from previous intakes	No need to evaluate contribution from previous intakes as in the case description there is no indication related to routine measurements before the incident.	Go to 5.3

Step	Indication	Comment	Action performed
5.3	Assignment of a priori parameters	As indicated in the Guidelines: those for unspecified compounds in Table 3.2. For Cs: single intake, time of intake known, Inhalation, Type F, f1=1, AMAD = 5 μm. For Sr: single intake, time of intake known, Inhalation, Type F, f1=0.3, AMAD = 5 μm.	Go to 5.4
5.4	Check for knowledge of time of intake	The time of intake in this case is known.	Go to 5.5
5.5	Calculate the dose with a priori parameters	The evaluation of dose is performed via the evaluation of intake and the use of the correct dose coefficient. The dose coefficient has been calculated on the base of the same model used for the calculation of retention excretion functions. In the case of ^{137}Cs using IAEA SRS-37[16] values of the companion CD and power interpolation of data, geometric means of ratios (M_i/m(ti)) (for all data), Intake = 88.3 kBq E(50)=5.92E-4 Sv, chi-squared value = 32.0 Not considering the measurement at time 468 d, Intake = 96.8 kBq, E(50)=6.49E-4 Sv, chi-squared value = 13.95. Not considering the measurement at times 226 and 468 d, Intake = 103.6 kBq, E(50)=6.94E-4 Sv, chi-squared value = 6.20. This value has been accepted as best estimation. For Sr using the urine dataset : For Type F - Intake = 6.045 kBq, E(50)=1.81E-4 Sv, chi-squared value = 70.2. For Type S - Intake = 162.2 kBq, E(50)=0.0117 Sv, chi-squared value = 10.8.	Go to 5.6
5.6	Test for E(50) < 1 mSv	In the case of ^{137}Cs E(50) < 1 mSv as it is 0.69 mSv. In case of ^{90}Sr E(50) < 1 mSv for type F but E(50) > 1 mSv for type S. The fitting indicates a type S behaviour even if the compound is not present as Titanate. A Type S absorption has been assumed.	For ^{137}Cs go to 5.6.1. For ^{90}Sr go to 5B
5.6.1	Record dose with a priori parameters	For ^{137}Cs: single intake, time of intake known, Inhalation, Type F, f_1=1, AMAD = 5 μm, SF=1.2, discharged data points at 226 and 468 d. Intake = 103.6 kBq, E(50)=6.94E-4 Sv, chi-squared value = 6.2.	For ^{137}Cs: END

For the evaluation of the best estimate of intake in case of unique data set, the geometric mean of the ratio between measurements (M_i) and model predictions per unit intake ($m(t_i)$) has been used (see Eq. 9.1).

$$I = \sqrt[N]{\prod_{i=1}^{N} \frac{M_i}{m(t_i)}} \tag{9.1}$$

The observed chi-squared value has been evaluated on the base of the equation (9.2).

The value of SF is constant and related to that type of measurements.

$$\chi_0^2 = \sum_{i=1}^{N} \left(\frac{\ln(M_i) - \ln(I \bullet m(t_i))}{\ln(SF)} \right)^2 \tag{9.2}$$

This parameter has been used to check in step 5.5 the possibility to have another type of absorption instead of the default type F.

Table 9.5. Path in step 5B: for ^{90}Sr procedure with variation of AMAD and absorption type

Step	Indication	Comment	Action performed
5B 5.7	Test for the number of relevant data	Considering the column related to 1mSv<D<6mSv in the corresponding table of the guidelines , there are more that 3 urine data in an interval of 30 days.	Go to 5.8
5.8	Test if the time of intake is known	In this case the time is known.	Go to 5.9
5.9	Test on lung and faeces measurements	In this case early lung measurements are not available. Faeces measurements are available not earlier than 76 days post incident.	Go to 5.11

Step	Indication	Comment	Action performed
5.11	Assessment of dose by fitting of the absorption type.	The evaluation of dose for Type F and S, simultaneously using both data sets are as follows. For Type F - Intake = 9.051 kBq, E(50)=2.71E-4 Sv, chi-squared value = 116.2. For Type S - Intake = 135.8 kBq, E(50)=0.01046 Sv, chi-squared value = 15.2. In this step type S absorption has been adopted for the case. Both evaluations are again considered for the test of acceptance of goodness of fit.	Go to 5.11.1
5.11.1	Test of acceptance of goodness of fit	In the text “Criteria for rejecting fit” of the guidelines the equation to calculate the observed value of chi-squared statistic is related to normal distribution of measurement data which differs from the used equation reported after this table. Fit for type F is rejected, fit for type S is accepted as probability values are 1E-17 and 0.436 respectively.	Go to 5.11.2
5.11.2	Test for E(50)> 6 mSv	The dose for Type S is 10.46 mSv thus it is above 6 mSv.	Go to 5.11.4
5.11.4	Check for number of data	As in step 5.7 but for E(50) > 6 mSv. There are more than 3 urine and 3 faeces data points available in a 30 d period.	Go to 5.13
5.13	Assessment of dose by fitting a mixture of types	The fit of the data using a mixture of type F and S do not improve the fitting as the smaller chi-squared value is that related to pure type S. (see Table 9.6)	Go to 5C

If multiple datasets are available (as in the case of Sr) the equation used in step 5.11 for the best estimation of intake is reported in equation (9.3).

$$\ln(I) = \frac{\sum_{i=1}^{N_U}\left(\frac{\ln\left(\frac{M_{i,U}}{m(t_i)_U}\right)}{(\ln SF_U)^2}\right) + \sum_{i=1}^{N_F}\left(\frac{\ln\left(\frac{M_{i,F}}{m(t_i)_F}\right)}{(\ln SF_F)^2}\right)}{\sum_{i=1}^{N_U}\frac{1}{(\ln SF_U)^2} + \sum_{i=1}^{N_F}\frac{1}{(\ln SF_F)^2}} \quad \textbf{(9.3)}$$

where the subscripts U and F refer to urine and faeces respectively. The corresponding value of observed chi-squared has been calculated with equation (9.4).

$$\chi_0^2 = \sum_{i=1}^{N_U}\left(\frac{\ln(M_{i,U}) - \ln(I \bullet m(t_i)_U)}{\ln(SF_U)}\right)^2 + \sum_{i=1}^{N_F}\left(\frac{\ln(M_{i,F}) - \ln(I \bullet m(t_i)_F)}{\ln(SF_F)}\right)^2 \quad \textbf{(9.4)}$$

In Table 9.9 the different values of chi-squared, associated probability, intake and committed effective dose have been reported for the various possibility of mixing of types F and S. As can be seen, with a fraction of 1.7 % of type F the fit is rejected by the criteria based on the procedure of rejection with p=0.05 (doses > 6 mSv).

Table 9.6. Fitting of ^{90}Sr data with mixed types

Fraction of type F	Fraction of type S	Observed Chi-sq	Probability	Fit	Intake (Bq) related to type F	Intake (Bq) related to type S	E(50) (Sv)
0	1	15.21	0.436	Accepted	0	135837	0.0105
0.001	0.999	15.90	0.389	Accepted	132	131628	0.0101
0.002	0.998	16.57	0.345	Accepted	256	127751	0.0098
0.005	0.995	18.54	0.235	Accepted	592	117710	0.0091
0.010	0.990	21.58	0.119	Accepted	1058	104717	0.0081
0.015	0.985	24.32	0.060	Accepted	1443	94756	0.0073
0.017	0.983	25.33	0.046	Rejected	1580	91368	0.0071
0.020	0.980	26.78	0.031	Rejected	1771	86782	0.0067

In step 5.15 there is the test on the acceptance of the fitting. The fit for type S is accepted so it is possible to finish the procedure. (see Table 9.7)

Table 9.7. Path in step 5C: for ^{90}Sr

Step	Indication	Comment	Action performed
5C 5.15	Test on goodness of fit	The better fit has been evaluated with type S. As the guidelines are at the moment the procedure can stop.	Go to 5.15.1
5.15.1	Record dose with all parameters	The values of the evaluation are: Type S - Intake = 135.8 kBq, E(50)=10.46 mSv, observed-chi-squared = 15.2.	For ^{90}Sr: END

With an analysis by eye on a x-log scale (see Figure 9.3) it is however possible to find a systematic over-estimation of the urine excretion fitted values up to 47 days after the accident, followed by a systematic underestimation of the measured values. For the faeces values a systematic overestimation of the fitted values (for all the 5 data following day 76) in respect to the measured data, occurs. (see Figure 9.4)

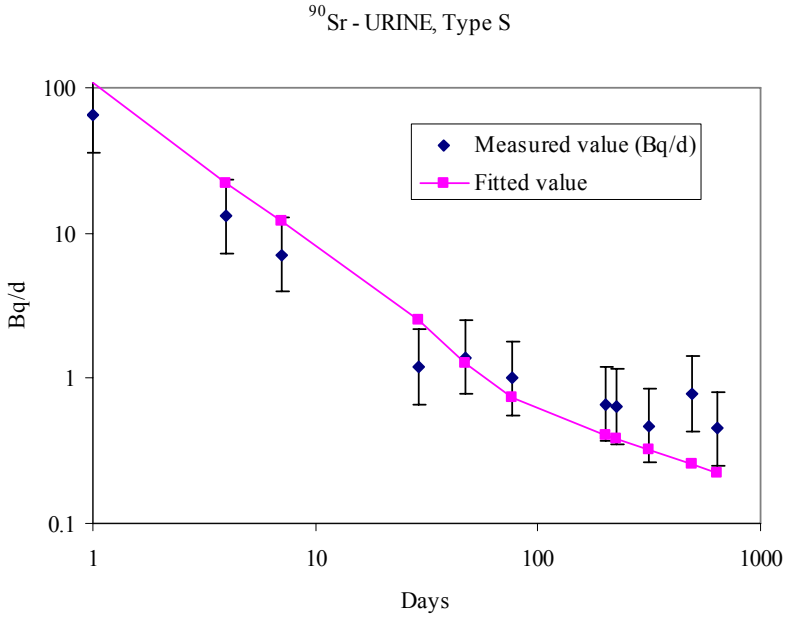


Fig. 9.3. Daily urinary excretion rates of ^{90}Sr and fitted values on the base of type S absorption.

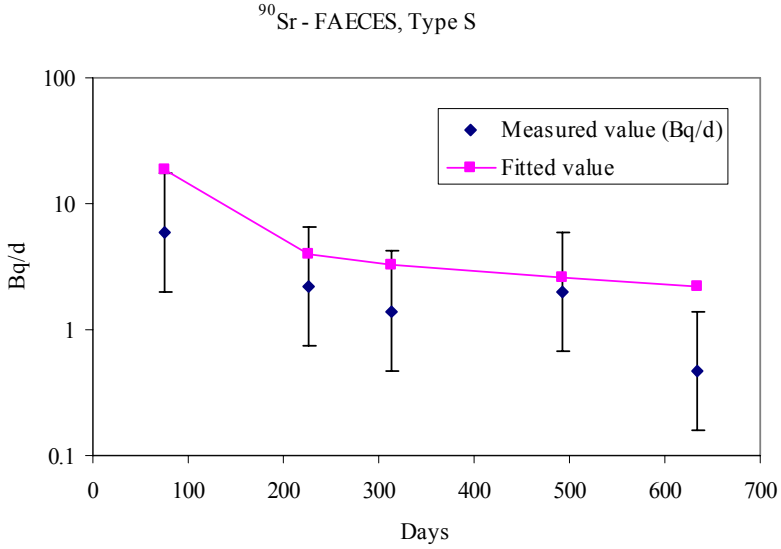


Fig. 9.4. Daily faecal excretion rates of ^{90}Sr and fitted values on the base of type S absorption

As alternative procedure (and having a fitting tool as IMBA® code [17]) it is possible to try to minimize the value of the observed chi-squared and go ahead with the 5C steps changing specific HRTM parameters. It must be emphasized that strictly applying the guidelines this is the correct step to finish the procedure of dose assessment for Strontium data.

In Table 9.11 the following steps of the evaluation are indicated as the application of them can improve significantly the fitting of the data.

Table 9.8. Path in step 5C: for ^{90}Sr, procedure with adjustment of model parameters of absorption type

Step	Indication	Comment	Action performed
5.16	Test on material	No, the material considered type F is less than 50 %.	Go to 5.17
5.17	Determine specific absorption parameters	Tried to increase the parameter related to the final dissolution rate from the compartment "Particles in transformed state" S_t. Instead of a value equal to 1E-4 d^{-1} (default value for type S) a trial and error evaluation has been performed using values between 3E-4 d^{-1} and 1E-3 d^{-1}, considering that the long term excretion seems more governed by a M type compound (see Table 9.9). The other 2 parameters, namely S_p and S_{pt}, have been maintained to the original type S default values: 0.1 d^{-1} and 100 d^{-1}	Go to 5.17 recursively

Step	Indication	Comment	Action performed
5.17.1	Test on goodness of fit	The trial and error evaluation permits to obtain the values of Table 9.9 in which the observed chi-squared values are reported. As can be seen, the minimum value of observed chi-squared is reached for a value of 5E-4 d^{-1} . With this modification of the parameter S_t at least a reduction of a factor of 2 in the evaluated intake and a factor of 3 in the evaluated E(50) in respect to the value assessed using default S type parameters, can be reached. The fit is accepted by the test on the goodness of fit (p = 0.99).	Go to 5.15.1
5.15.1	Record dose with all parameters	For the evaluation using Type S and the modified parameter S_t = 5E-4 d^{-1} the values of the evaluation for ^{90}Sr are as follows: Intake = 67.15 kBq; E(50) = 3.43 mSv, observed-chi-squared = 2.79.	END

Table 9.9. Evaluation of goodness of fit using SF Urine= 1.8, SF Faeces = 3

St value x 10^{-4} [d^{-1}]	χ_0^2	Intake [Bq]
3	4.09	85290
4	3.03	74598
4.5	2.84	#
4.7	2.80	#
4.9	2.79	#
5.0	2.79	67152
5.2	2.80	#
5.5	2.84	#
6	2.96	61620
8	3.92	53900
10	5.21	48740

= not reported

In Figure 9.5 the fit type S and S_t = 5 10^{-4} d^{-1} is indicated. The Y error bar represents 68 % confidence interval of the measured data based on lognormal distribution and proper SF value (1.8 for urine and 3 for faeces).

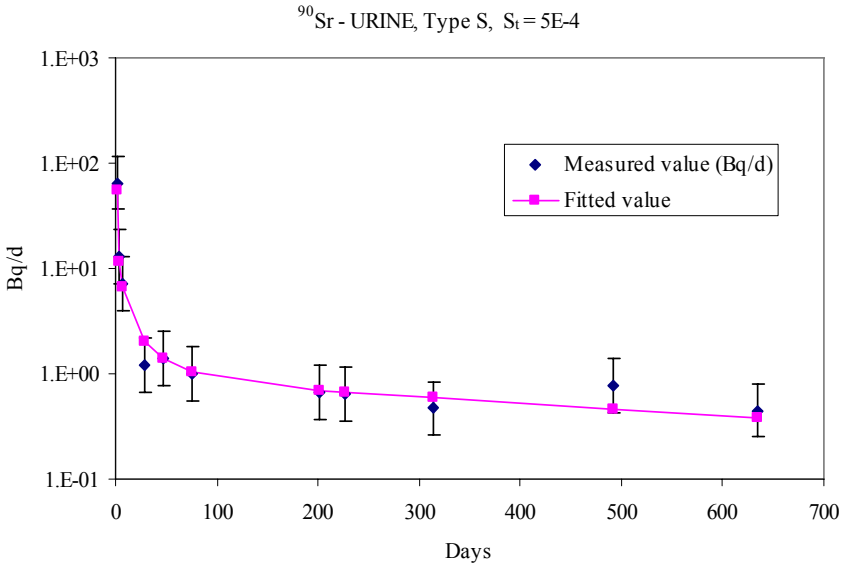


Fig. 9.5. Daily urinary excretion rates of ^{90}Sr and fitted values on the base of modified S type absorption

In Figure 9.6 the fitting of measured values for faeces using type S and $S_t = 5\ 10^{-4}.d^{-1}$ are shown. Also in this case the Y error bar represents 68 % confidence interval of the measured data based on lognormal distribution and proper SF value.

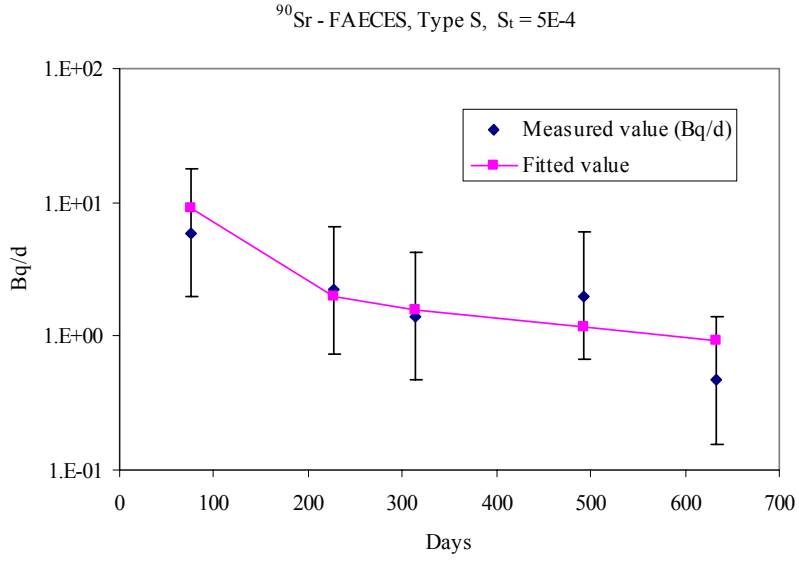


Fig. 9.6. Daily faecal excretion rates of ^{90}Sr and fitted values on the base of modified S type absorption

In Figure 9.7 the behaviour of urine daily excretion per unit intake for type S and for type modified-S (Mod-S) using the value of $S_t = 5\ 10^{-4}.d^{-1}$, are presented.

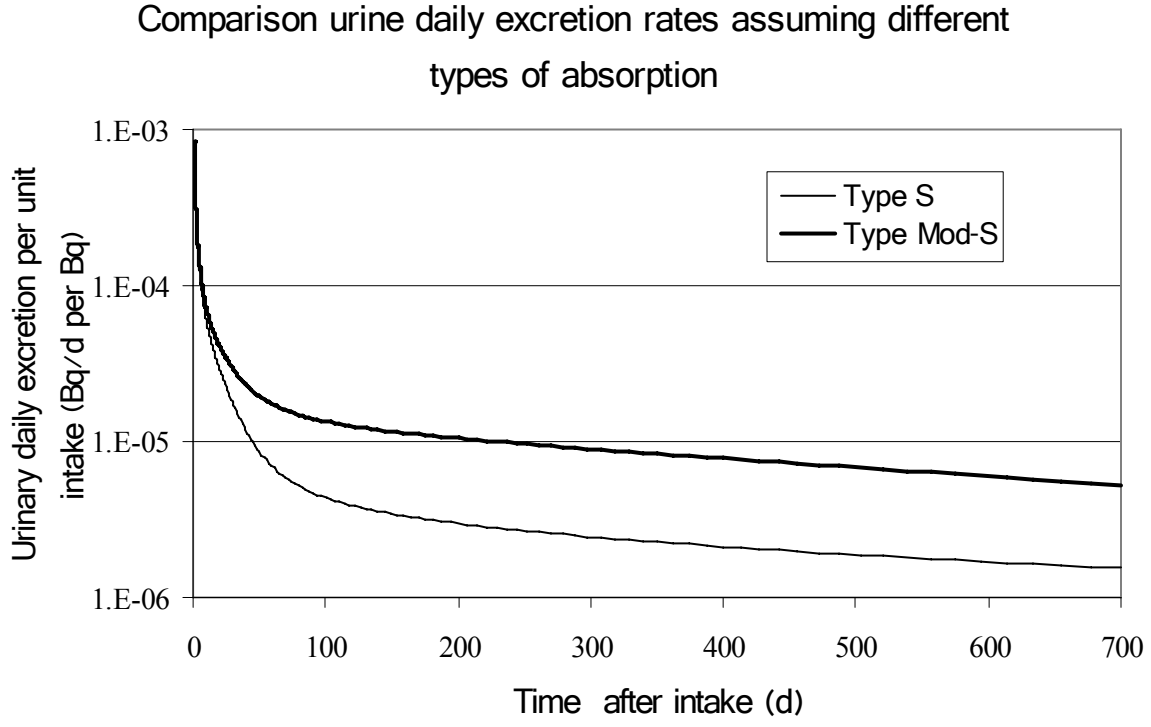


Fig. 9.7. Comparison of behaviour in time of urinary excretion rates of ^{90}Sr per unit intake for type S and modified type S absorption parameters

As can be seen the ratio in the urinary daily excretion between Mod-S and S types from 70 up to 650 days increases from 2.8 to 3.5 permitting to better fit the urinary data. The faeces behaviour is practically not affected by the change of the S_t parameter value.

9.3. Results of the intercomparison exercise

9.3.1. Introduction

This case has already been used in the first European Intercomparison Exercise in 1992. The results of this intercomparison have been summarized in the paper reported in reference [4] in which the description of the case is also presented.

The data for the present case description have been taken from Table 1 of that reference, referring to case 890615-0001.

At that time, the evaluations have been performed by 8 participants using the ICRP 30 [18] lung models with default parameters: AMAD = 1 μm, Class D for Cesium and Class Y for Strontium.

In Table 9.10 the main results of the previous intercomparison exercise are reported.

Table 9.10. Summary of the results of the case in the previous intercomparison exercise

No. of participants: 8	Average Intake (kBq)	Percentage spread of results (as standard deviation) on Intake (%)	Average Committed effective dose equivalent (mSv)	Percentage spread of results (as standard deviation) on CEDE (%)
^{137}Cs	90	18	0.73	17
^{90}Sr	36	26	14	40

In a recent paper published in Radiation Protection Dosimetry [19] from a group of the Research Center of Jülich, the follow up of whole body ^{137}Cs measurements up to 6000 days post incident, are graphically reported. The measurements of the first period are identical to the values reported in the case description and confirmation of the fact that the measurements are related to the same accident has been given by the authors of the paper.

The overall behaviour of the in vivo retention during the 6000 days period presents a decrease that can be fitted by 4 exponential terms two of them with long biological half time: 280 and 4500 days (3 % of the total evaluated intake). The radionuclide is mainly deposited in the lung and the retention is unusual for Cesium compound for which the ICRP has indicated only type F absorption. The available data used for the case description are related only to the first stages in which a fast clearance is almost present (main biological half times of 3.5 and 65 days). This fast clearance took account of 97 % of the total intake.

The authors indicate that the clearance behaviour is determined by the physical and chemical properties of an insoluble matrix of uranium oxide and not by the properties of the Cesium compound itself.

Fifty-eight participants assessed this case. They come mainly from Europe (39) then from Asia (11) and America (7). The mainly represented countries are: Germany (7 participants); US, India, Italy and UK (4); France and Slovenia (3).

The complete results of intakes and doses values are presented in the Annex related to Case 2. The assumptions made by the participants are also discussed.

9.3.2. Overall distributions of results

The overall distribution parameters [geometric mean (GM), Geometric standard deviation (GSD) and ratio maximum by minimum values (Max/min)] of all results (considering also outlier data) are reported in Table 9.14.

Table 9.11. Distribution parameters of all data

	Intake			E(50)		
	GM (Bq)	GSD	Max/min	GM (mSv)	GSD	Max/min
^{137}Cs	91030	2.02	176	0.67	1.91	198
^{90}Sr	50883	4.41	181	3.26	6.89	1453

The frequency distribution of the complete set (ratio of the results normalized to the reported geometric mean) as number of occurrences in given logarithmic intervals, for each parameter and radioisotope has a bell shape pattern. For intake of ^{137}Cs the distribution is symmetrical, that for E(50) of ^{137}Cs is left skewed. On the contrary a bimodal distribution with a lower mode related to the evaluation of F type absorption can be pointed out in the distributions of all the data related to ^{90}Sr (both intake and E(50)). This also gives reason for the large values of GSD related to such radioisotope distributions. The values of ratios Max/min in each dataset are between 176 and 1453.

9.3.3. Identification of outliers

Outliers were identified by following the statistical criteria described in Paragraph 7.5. In Table 9.12 the total numbers of identified outlier as well as the identification (ID) code of the participants are presented.

Table 9.12. Identification of outliers: total numbers and ID

	^{137}Cs		**^{90}Sr**	
	Intake	E(50)	Intake	E(50)
Number of identified outliers	3	6	14	10
ID codes of participants	18, 22, 39	5,18, 39, 47, 60,86	5, 19, 26, 29, 34, 46, 59, 60, 65, 67, 69,78, 84, 86	5, 22, 26, 34, 46, 59, 60, 78, 84, 86

Tables 9.13 and 9.14 summarize the values that have been identified as outliers, some of the assumptions used by the participants and, in the comment, some possible reasons.

Table 9.13 refers to ^{137}Cs, while Table 9.14 refers to ^{90}Sr; each of them is reporting both intake and E(50).

Table 9.13. Outlier assessment of intake and E(50) for ^{137}Cs. Bold values indicate outliers

Code	Intake (Bq)	E(50) (mSv)	AMAD (µm)	All data selected ?	Comment
5	118000	**0.31**	5	Yes	Incorrect dose coefficient calculated by software: a factor of 2.5 less than that usually used (a)
18	**9300**	**62.00**	5	Yes	Intake a factor of 10 less than the GM. Dose coefficient 1000 times greater than that usually used.
22	**185000**	0.63	16	No (day 0 excluded)	Fitted value of f_1=0.01. Dose coefficient a factor of 2 less than that usually used.
39	**1050**	**0.33**	5	No (day 0 excluded)	Fitting procedure determines an intake value a factor of 100 less than the GM Dose coefficient a factor of 50 times greater than usually used (E(50) is half)
47	73800	**0.35**	1	Yes	Model based on the real data: dose coefficient a factor of 1.4 less than that usually used.
60	76000	**0.42**	5	Yes	Dose coefficient a factor of 1.2 less than that usually used
86	118000	**0.31**	5	Yes	Incorrect dose coefficient calculated by software: a factor of 2.5 less than that usually used .

(a) The dose coefficient usually used is 6.7 10^{-9} Sv/Bq for 5 µm AMAD.

9.3.3.1. Intake

Applying the outlier criteria to the intake data produces 3 outliers for ^{137}Cs and 14 outliers for ^{90}Sr out of 58 results (Tables 9.13 and 9.14). Regarding ^{137}Cs the fitting procedure determines values that are one or two orders of magnitude less (respectively ID 18 and 39) the geometric mean of the other results. For participant ID 22 the great intake can be due to the fitted values of AMAD and f_1.

In the case of ^{90}Sr (Table 9.14) the main reason to evaluate a lower intake is the assumption of a type F or M absorption behaviour, the selection of partial urine data and, for ID 69, the assumption that measurements refer to the sum ^{90}Sr + ^{90}Y, that resulted in an underestimation of a factor of 2 of the assumed intake.

Table 9.14. Outlier assessment of intake and E(50) for ^{90}Sr. Bold values indicate outliers

Code	Intake (Bq)	E(50) (mSv)	AMAD (µm)	Absorption Type[(a)]	Data set used[(b)]	Comment
5	**1500**	**0.03**	5	F	U	Incorrect dose coefficient calculated by software.
19	**28300**	2.20	5	S	U partial	-
22	86400	**0.93**	16	fitted	U partial	Fitted dose coefficient a factor of 7 less than usually used S_p=1, S_{pt}=100, S_t=1E-3, f_1=0.001
26	**1104**	**0.03**	5	F	U partial	Dose coefficient for F
29	**45600**	3.51	5	S	F	Use of only faeces data
34	**990**	**0.03**	5	F	U partial	Dose coefficient for F
46	**9539**	**0.20**	5	M	U	Fitted value of f_1=0.01, Dose coefficient for M
59	**1229**	**0.04**	5	F	U	Dose coefficient for F
60	**17800**	**0.55**	5	F	U+F	Dose coefficient for F
65	**37000**	3.00	5	S	U partial	Used only 4 urine data
67	**21615**	1.82	1	S fitted	U+F	Fitted parameters S_t=7E-4, f_1=0.05
69	**34000**	1.74	5	S fitted	U+F	Half intake estimated due to assumption on data ^{90}Sr+^{90}Y S_t=5E-4
78	**1229**	**0.04**	5	F	U	Dose coefficient for F
84	**1500**	**0.05**	5	F	U	Dose coefficient for F
86	**1500**	**0.03**	5	F	U	Incorrect dose coefficient calculated by software

(a) U = urine, F = faeces

9.3.3.2. Committed effective dose, E(50)

Applying the outlier criteria to the committed effective dose E(50) for ^{137}Cs data produces 6 outliers (5, 18, 39, 47, 60 and 86). For ^{90}Sr, ten participants (5, 22, 26, 34, 46, 59, 60, 78, 84, 86) reported results identified as outliers. (Table 9.14).

For ^{137}Cs participants 5 and 86 reported outliers due to the use of an incorrect dose coefficient calculated by commercial software without taking into account the daughter ^{137m}Ba (this resulted in a dose coefficient a factor of 2.5 less then that usually used).

Participants ID 47 and 60 also used dose coefficients that are a factor of 1.2-1.4 less than the reference value, due also to 1 μm AMAD assumption on the basis of the fitting of data. Participants ID 18 and 39 overestimated the dose coefficient for a factor of 1000 and 50 respectively. For participant ID 39 there is some kind of compensation on E(50) due to the very low value of intake. However the final value of E(50) has been identified as outlier.

For ^{90}Sr the same two participants (5 and 86) made an incorrect calculation of dose coefficient with commercial software (see Table 9.14) using the incorrect bone model as indicated by ICRP 30 (surface instead of volume seeker) and without taking into account the daughter radionuclide ^{90}Y. ($1.7\ 10^{-8}$ Sv/Bq instead of $3.0\ 10^{-8}$ Sv/Bq as evaluated for type F compounds).

The other main reason to produce an outlier is the use of a dose coefficient for F instead of S ($3.0\ 10^{-8}$ Sv/Bq instead of $7.7\ 10^{-8}$ Sv/Bq) (ID 26, 34, 59, 60, 78, 84) or M (ID 46).

Special fitting and partial urine data for ID 22 can support the last outlier value of 0.93 mSv.

9.3.4. Evaluation of results excluding outliers

The procedure for identification of outliers tends to improve the result of the set of measurements reducing the value of geometric standard deviation. In Tables 9.15 and 9.16 the results of the descriptive statistic parameters of the set of results (excluding outliers) related respectively to ^{137}Cs and to ^{90}Sr are reported (AM = arithmetic mean, ASD = arithmetic standard deviation).

Table 9.15. Statistical evaluations of the results excluding outliers: ^{137}Cs

	Intake	**E(50)**
N	55	52
GM	101586 Bq	0.659 mSv
GSD	1.20	1.16
AM	103230 Bq	0.666 mSv
ASD	18416 Bq	0.095 mSv
Coefficient of variation (%)	17.8	14.3
Minimum	69940 Bq	0.47 mSv
Maximum	154000 Bq	0.82 mSv

Table 9.16. Statistical evaluations of the results excluding outliers: ^{90}Sr

	Intake	E(50)
N	44	48
GM	102436 Bq	7.22 mSv
GSD	1.33	1.94
AM	106571 Bq	8.97 mSv
ASD	30726 Bq	6.61 mSv
Coefficient of variation (%)	28.8	73.7
Minimum	60750 Bq	1.74 mSv
Maximum	179000 Bq	37.2 mSv

In figures from Figure 9.8 to Figure 9.11 the frequency distributions of individual results ratios of intake data (both Cs and Sr) normalized to the geometric mean calculated without outliers, and the related histograms, are presented. Figures from Figure 9.12 to Figure 9.15 relate to committed effective doses for both radionuclides.

9.3.4.1. Intake

The geometric mean (GM) of the estimated intakes of ^{137}Cs (101.6 kBq) is between the values evaluated from the reviewer 67.2 and 135.8 kBq following the IDEAS guidelines and related to the Modified-S type or default S type absorption behaviour.

The geometric standard deviation (GSD) is narrow: 1.20.

The range of the estimated intakes, excluding outliers, is relatively small: 69.9 – 154 kBq (ratio max/min = 2.2). However, the range is very large if outliers are included: 1.05 – 185 kBq (ratio max/min = 176).

For ^{90}Sr the value of the GM of intake, 102.4 kBq, can be considered as the average value for the results that take into account the type S as basic assumption.

The GSD is not wide even if it is bigger than that for ^{137}Cs intake (GSD = 1.33).

Also the ratio max/min = 2.9 is greater than the previous case. If the outliers are included the ratio becomes similar to that of the previous ^{137}Cs case: 0.99 – 179 kBq (ratio max/min = 181).

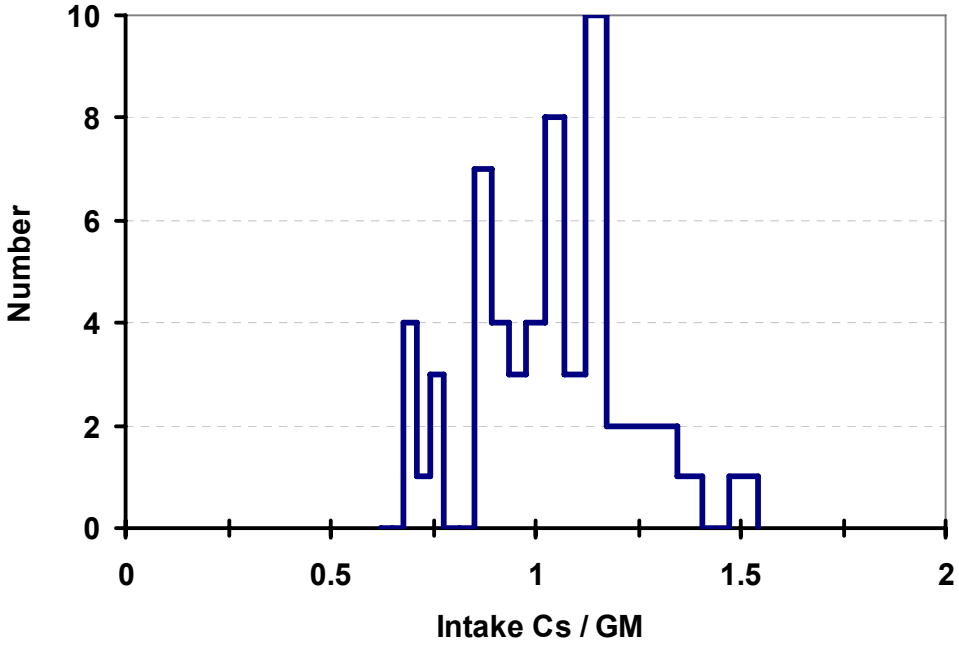


Fig. 9.8. Frequency distribution of results without outliers (N=55).
Intake ^{137}Cs normalized to the geometric mean. (GM = 101586 Bq; GSD = 1.20).

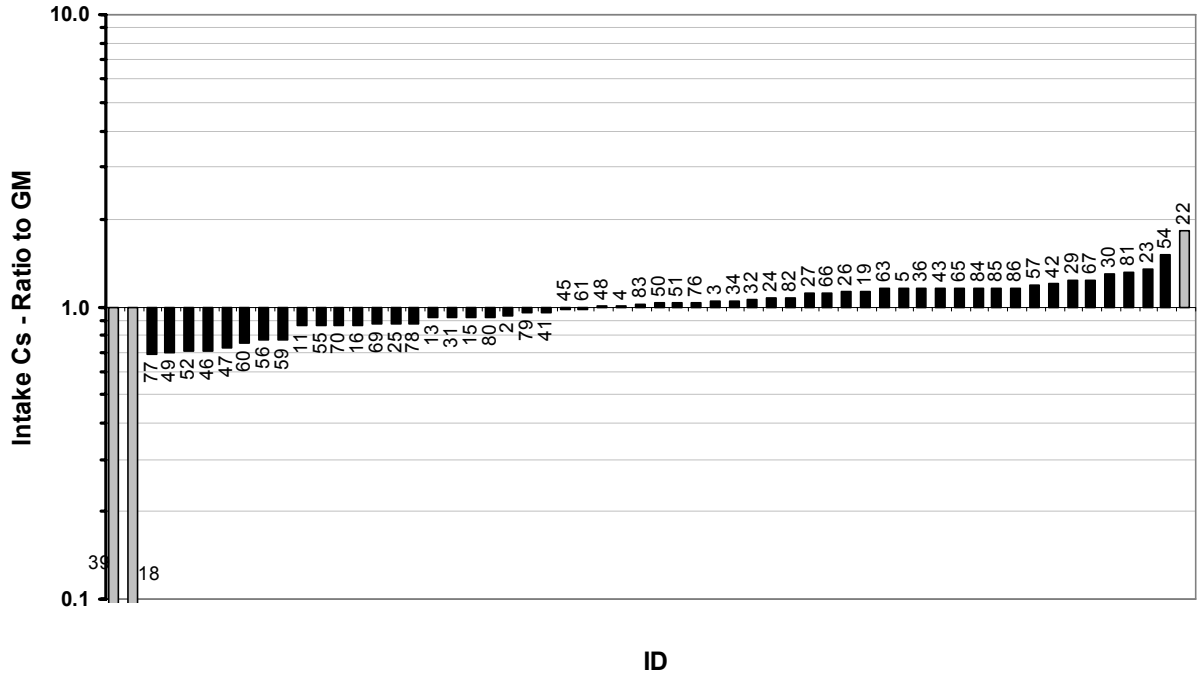


Fig. 9.9. Results of the individual participants (ID): Intakes ^{137}Cs normalized to the geometric mean. (GM = 101586 Bq; GSD = 1.20, N=55) The grey patterned columns are outliers.

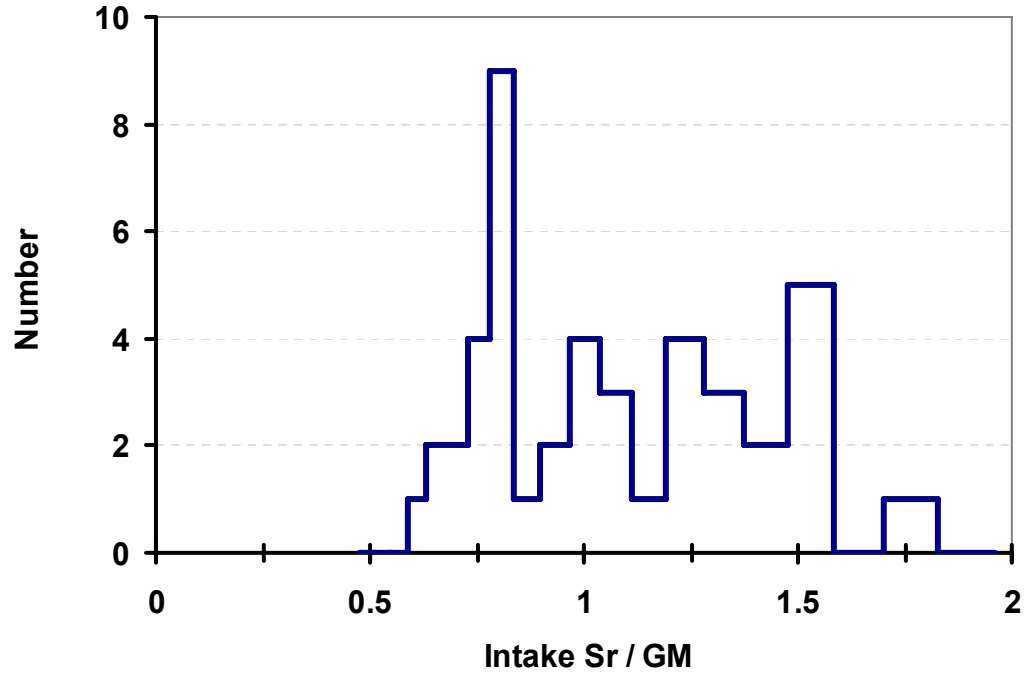


Fig. 9.10. Frequency distribution of results without outliers (N=44). Intake ^{90}Sr normalized to the geometric mean. (GM = 102436 Bq; GSD = 1.33).

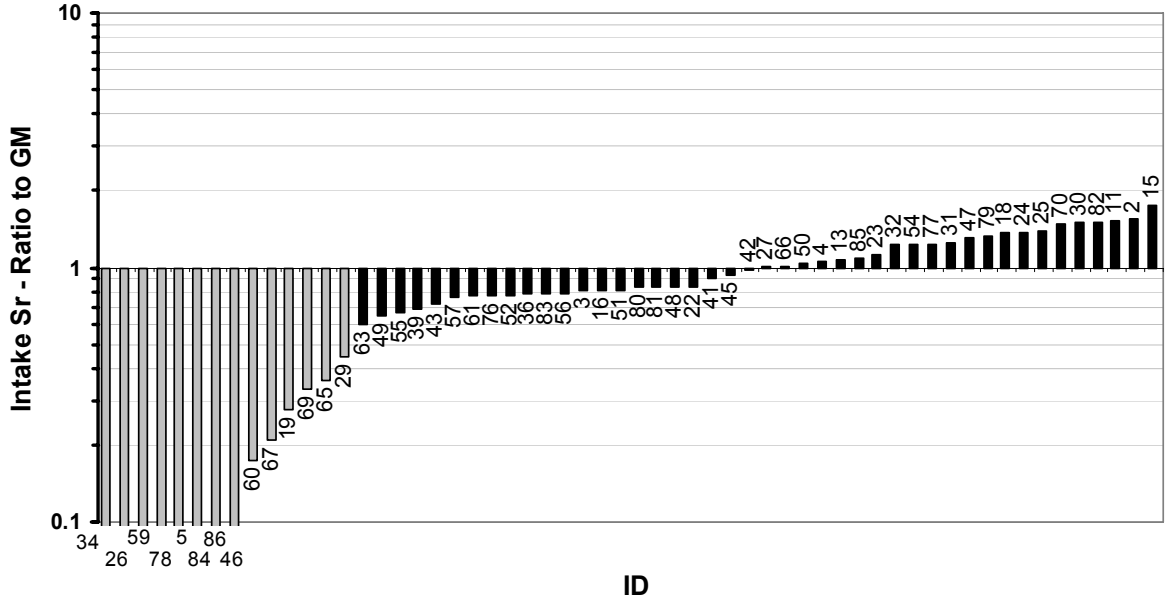


Fig. 9.11. Results of the individual participants (ID):Intakes ^{90}Sr normalized to the geometric mean. (GM = 102436 Bq; GSD = 1.33, N=44).The grey patterned columns are outliers.

9.3.4.2. Committed effective dose, E(50)

For the committed effective dose E(50) for ^{137}Cs, the GM (0.66 mSv) is very close to E(50) evaluated following the IDEAS guidelines (0.69 mSv); there is only about 4 % difference (see Table 9.15). The GSD is 1.16, for E(50).

Excluding outliers, the range of values is 0.47 – 0.82 mSv (ratio max/min = 1.7). However, including outliers the range is very large: 0.31 – 62 mSv (ratio max/min = 200).

The graphical representations of the ratios of the individual values of E(50) normalized to the GM are given in Figure 9.12 and Figure 9.13 (distribution and histogram).

For ^{90}Sr, the GM (7.22 mSv) is between the values of E(50) evaluated following the IDEAS guidelines (3.43 and 10.46 mSv): this reflects the choice of different absorption types and fitting of data. The GSD is 1.93.

Excluding outliers, the range is 1.74 – 37.2 mSv (ratio max/min = 21.4). However, including outliers the range is very much greater: 0.0256 – 37.2 mSv (ratio max/min = 1453).

The graphical representations of the individual values of the ratio of E(50) normalized to the GM are given in Figure 9.14 and Figure 9.15 (distribution and histogram). The shape of the distribution displayed in Figure 9.14 immediately indicates the large value of GSD of this subset in comparison to the others (the width of the interval, connected to the GSD value, immediately provide indication).

9.3.5. Route of intake

All the participants assumed inhalation as the route of intake. The time pattern of intake is set by default in the spread sheet of response at “single acute intake”.

9.3.6. Models assumed

All the participants declared to have used bioassay quantities and dose coefficients based on the ICRP Publication 66 Human Respiratory Tract Model (HRTM) [1] and few reported also ICRP Publication 68 [20] and 78 [6] as reference for the respiratory tract model.

The majority of participants indicated the ICRP Publication 30 Gastrointestinal tract model[18] as the one mainly used during the evaluations but there are also some citations of ICRP Publications 68, 78, 54 [5] and 67 [2]. It has been assumed that the same model as that reported in ICRP Publication 30 has been actually used by all participants.

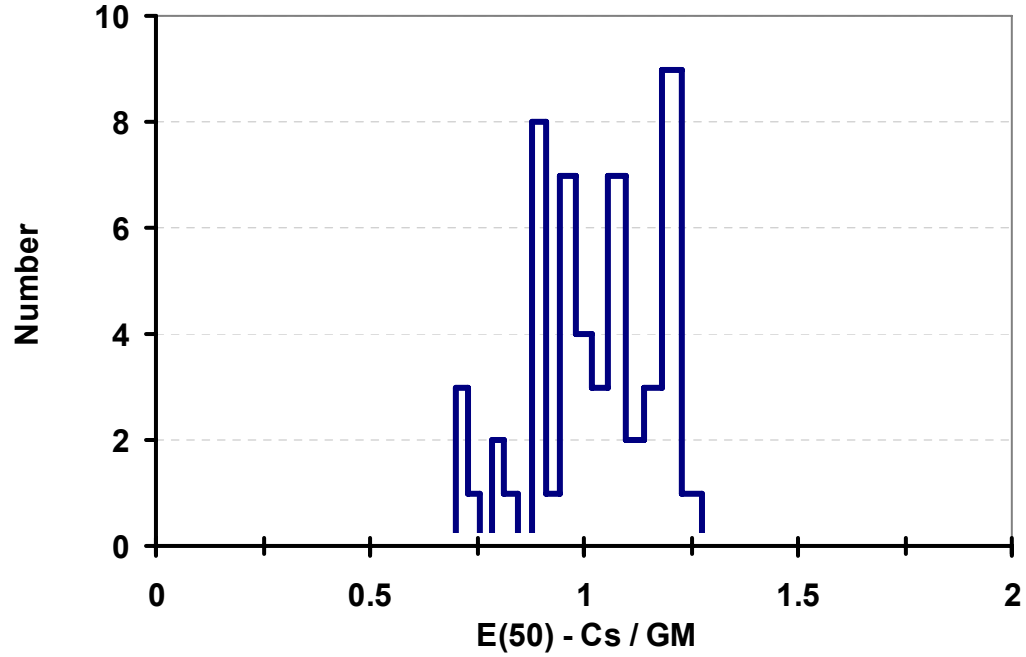


Fig. 9.12. Frequency distribution of results without outliers (N=52). E(50) ^{137}Cs normalized to the geometric mean. (GM = 0.659 mSv; GSD = 1.16).

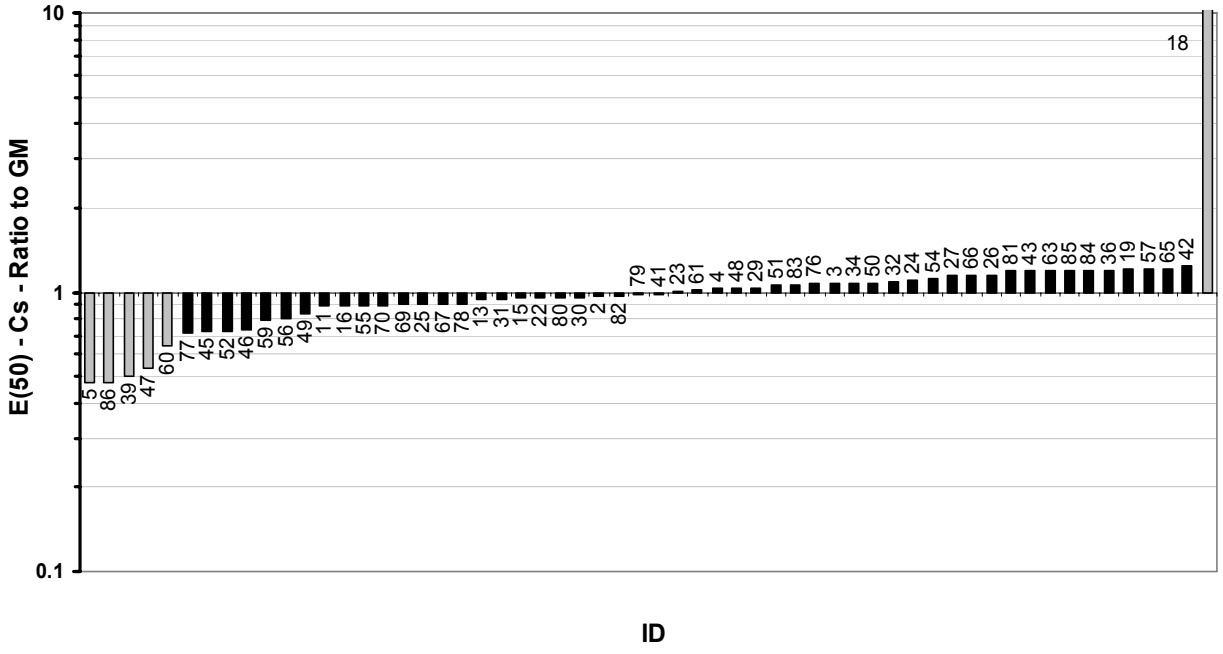


Fig. 9.13. Results of the individual participants (ID): E(50) ^{137}Cs normalized to the geometric mean (GM = 0.659 mSv; GSD = 1.16, N = 52). The grey patterned columns are outliers.

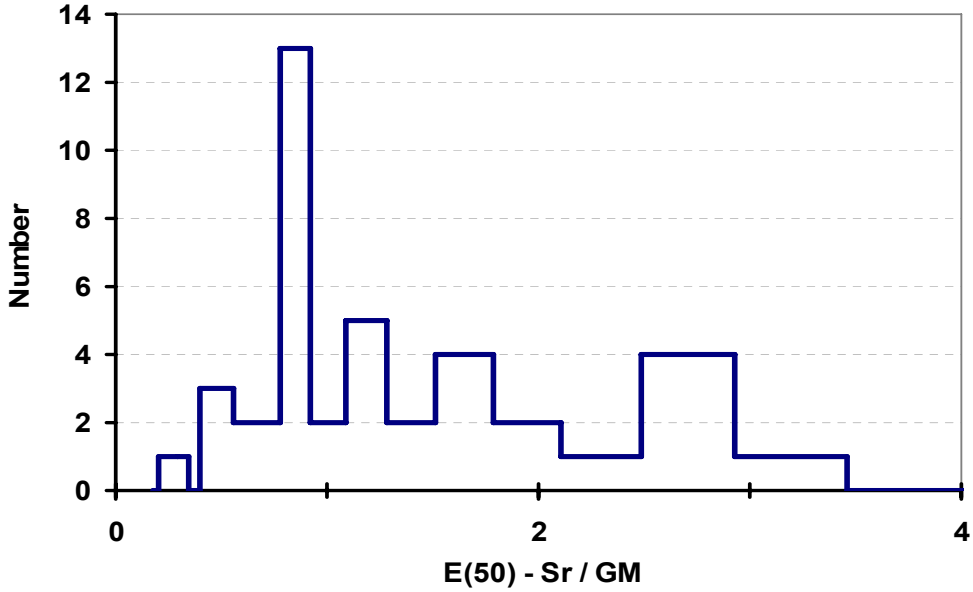


Fig. 9.14. Frequency distribution of results without outliers (N=48). E(50) ^{90}Sr normalized to the geometric mean. (GM = 7.22 mSv; GSD = 1.93).

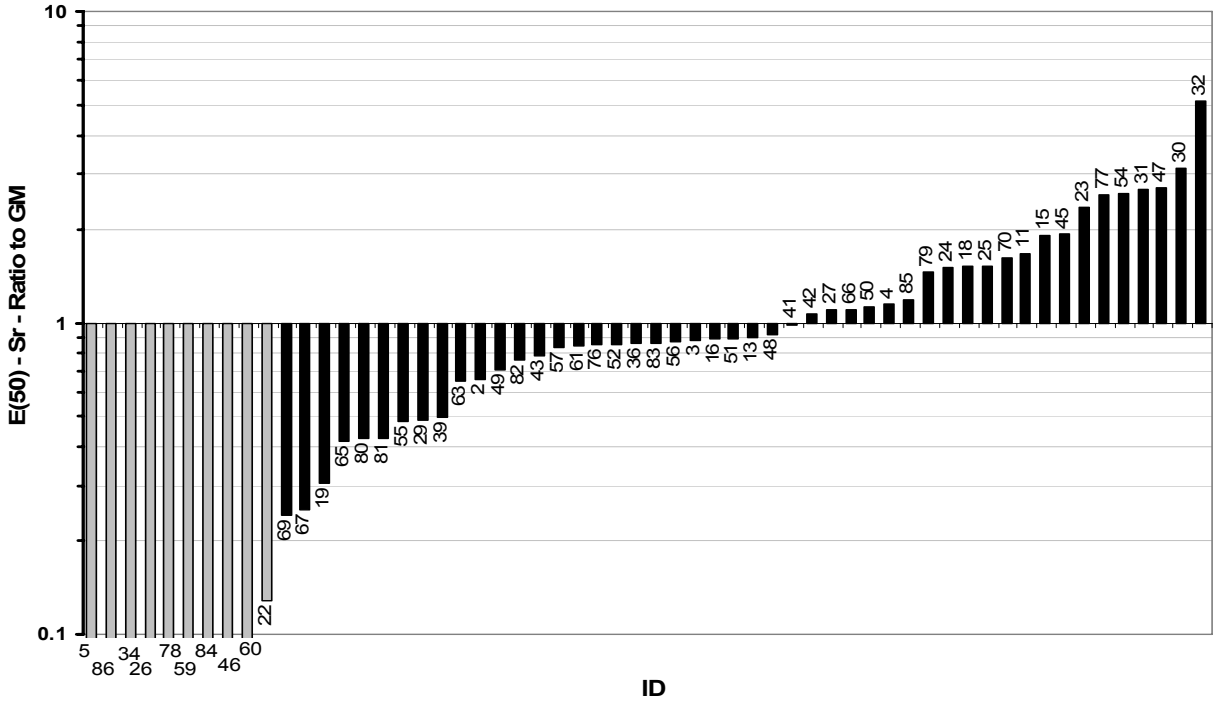


Fig. 9.15. Results of the individual participants (ID): E(50) ^{90}Sr normalized to the geometric mean (GM = 7.22 mSv; GSD = 1.93, N = 48). The grey patterned columns are outliers.

For the ^{137}Cs systemic biokinetic model a wide indication of publications has been presented by participants: ICRP Publication 30, 54, 56 [21], 67, 68, 71 [22], 72 [23] and 78. Some of them used fitted half lives as indicated by participant 47 (e.g. this determines a dose coefficient that is 28 % lower than that usually used and the identification of E(50) as outlier); another participant did not give indication on the used systemic model (participant ID 39) and used a dose coefficient a factor of about 50 above the usually used ($6.7\ 10^{-9}$ Sv/Bq). The f_1 value 1 was widely used in the evaluations; only participant ID 22 used a f_1 value of 0.01. This assumption, together with the use of 16 μm AMAD determines a dose coefficient that is approximately one half of the value usually used.

Also for the ^{90}Sr systemic biokinetic model a wide indication of publications has been presented by participants: ICRP publication 67, 68, 71, 72 and 78 but also ICRP 30 and 54 (the previous models before the ICRP 67 alkaline earth element model with recycling). The application of the proper old model (e.g. with the software LUDEP) leads to slightly different dose coefficients ($3.06\ 10^{-8}$ Sv/Bq instead $3.0\ 10^{-8}$ Sv/Bq) for Type F, AMAD = 5 μm and f_1= 0.3).

The default ICRP values of f_1 are 0.3 for type F and 0.01 for Type S. The majority of participants have indicated one of those two values. Few of them provided values for f_1 that were 0.05 (ID 67 fitted with S_t parameter), 0.001 for ID 22 (fitted parameter with absorption parameters S_p=1 instead of 0.1), S_{pt}=100 and $S_t = 10^{-3}$ (instead of 10^{-4}) dose coefficient is $1.08\ 10^{-8}$ Sv/Bq i.e. about a factor of more than 7 below the normal value) and f_1=0.1 for participant ID 5.

9.3.7. Absorption assumptions

The case description gave an indication of the chemical form of the inhaled material as "graphite with fission products; likely to be insoluble for Strontium". ICRP Publication 68 recommends Type F for all Cs compounds. For Sr compounds the same ICRP publication recommends Type F for unspecified compounds and type S for strontium titanate.

For Cs all participants used type F absorption.

For ^{90}Sr evaluation nine participants assumed type F, 42 type S, one a mixture of F/S (40/60%), one used type M and five a modified type S (with different values for the parameter S_t).

For the nine participants using the type F all results, except one (ID 2), have been identified as outliers. A very wide spread of results is recorded (GSD = 5.69 for intake and 6.12 for E(50)). For the others (8 participants) the descriptive statistic determines a value of GSD of 2.57 for intake and 2.76 for E(50). For seven of them the results are very close each other. (see Table 9.17)

Most of the participants (42), assumed Type S in evaluating the ^{90}Sr dose. The spread of results is small: the values of GSD are 1.47 for intake and 1.83 for E(50). The geometric mean of the intake value is 96 kBq and the E(50) is around 8 mSv.

For the group who used different absorption types (indicated with "ELSE" in Table 9.20) the overall GSD is 2.4 for intake and 3.16 for E(50) i.e. greater than the previous case. The mean intake is approximately one half of the mean value related to Type S and the E(50) is about a

factor of 5 less. For the participants ID 39, 55 and 69 (considering the fact that he halved the intake value) having used a S_t value around 5 10^{-4} d^{-1} the evaluations of intake and E(50) are practically the same: intake = 68 kBq E(50)= 3.5 mSv. That is in accordance with the values evaluated in paragraph 9.2 by the reviewer of this case, following the GL up to stage 5C.

Table 9.17. Comparison of results between different absorption assumptions(a) for ^{90}Sr evaluation

	F		S		ELSE (b)	
	Intake	**E(50)**	**Intake**	**E(50)**	**Intake**	**E(50)**
N	9	9	42	42	7	7
GM	2927 Bq	0.078 mSv	96140 Bq	8.09 mSv	43967 Bq	1.73 mSv
GSD	5.69	6.12	1.47	1.83	2.40	3.16
Min	990 Bq	0.026 mSv	28300 Bq	2.20 mSv	9539 Bq	0.195 mSv
Max	158797 Bq	4.76 mSv	179000 Bq	37.2 mSv	110000 Bq	6.5 mSv

(a) Considering also outliers.
(b) Includes also the results where the assessors assumed specific absorption values (5 participants).

In Figure 9.16 and Figure 9.17 the histograms of the ratios of the single results to the geometric mean evaluated without outliers, are reported both for intake and E(50). In grey patterned columns the results related to type F are reported, in white those related to Type S and in black the assumptions different from both F and S (indicated with "ELSE" in Table 9.20) . Comparing these figures with Figure 9.11 and Figure 9.15 it is possible to point out that the type F or M assumption is the main cause for being identified as an outlier. The main part of the distribution is related to Type S assumption. For this assumption the mean intake value is around 96 kBq and the E(50) is 8 mSv.

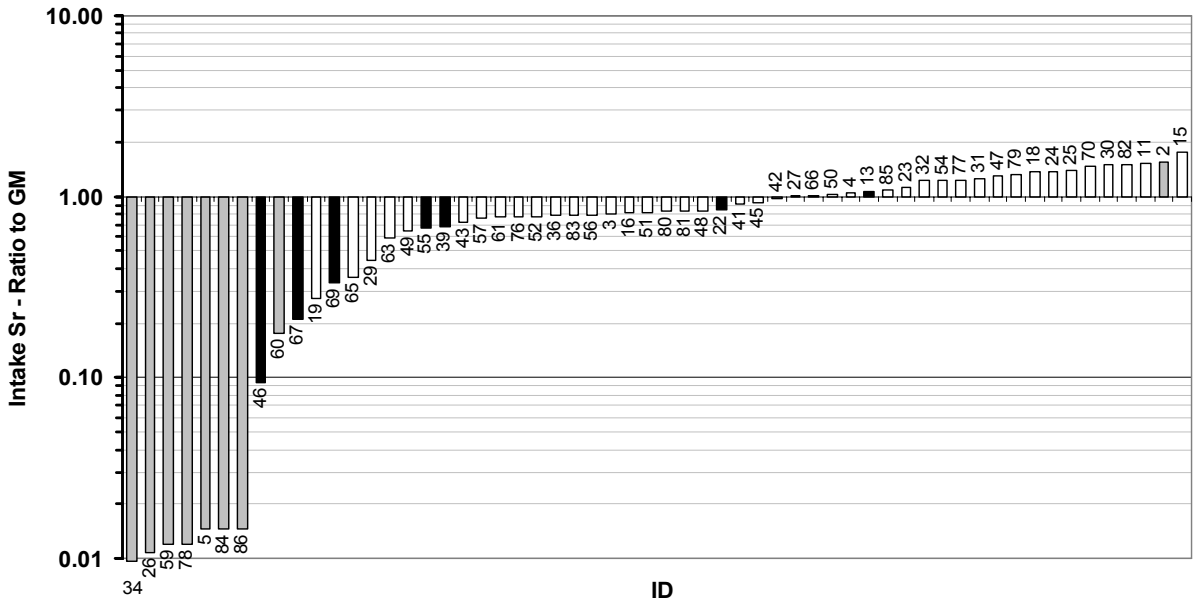


Fig. 9.16. Comparison of results between different absorption assumptions for the individual participants (ID) in case of ^{90}Sr. Intake normalized to the geometric mean (GM = 102436Bq). The grey patterned columns are Type F, those in white are Type S and those in black are "ELSE" assumptions.

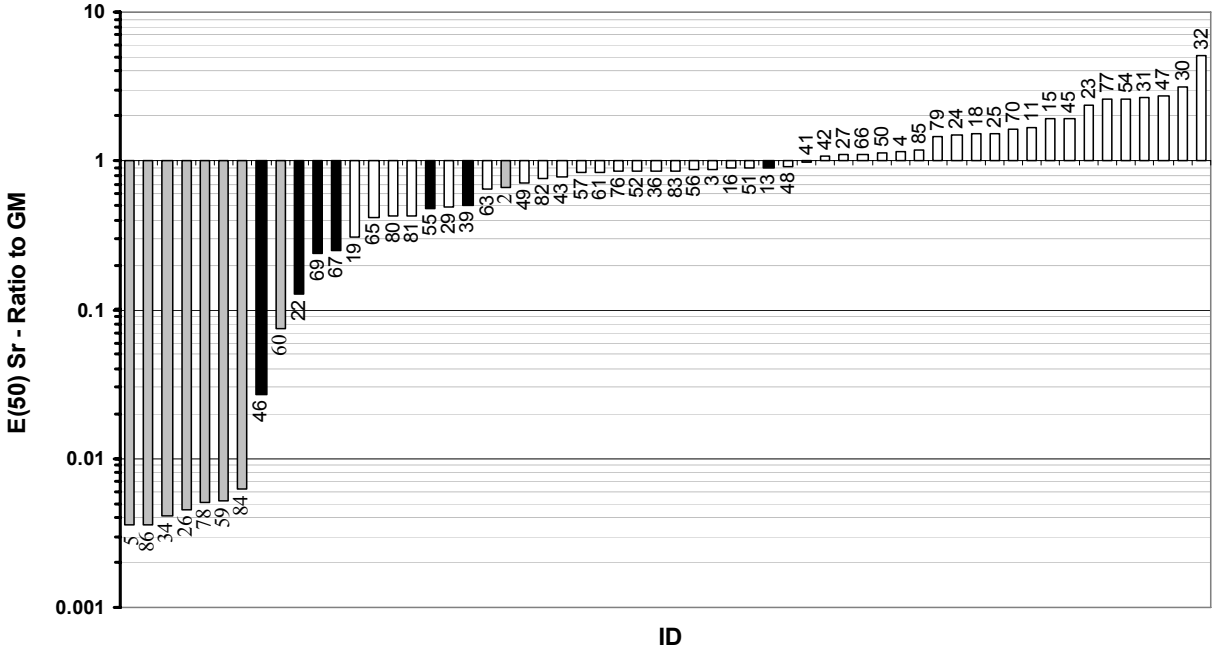


Fig. 9.17. Comparison of results between different absorption assumptions for the individual participants (ID) in case of ^{90}Sr. Committed effective dose normalized to the geometric mean (GM = 7.22 mSv). The grey patterned columns are Type F, those in white are Type S and those in black are "ELSE" assumptions.

9.4. AMAD assumed

The majority of participants (47 out of 58) used the default value of 5 μm for the AMAD. Six used 1 μm, three used 10 μm and one used 16 μm. Participant ID 31 used 5 μm for ^{137}Cs and 1 μm AMAD for ^{90}Sr. This assumption is almost incorrect as the particle size distribution in the same case scenario for the same subject is very unlikely different for different radionuclides: this would imply different sources of aerosol. On the other hand it is possible to imagine different particle size distribution for different subjects in the same incident scenario due to the distance from the source of each subject and the deposition and depletion of aerosol that could take place in the distance between the source and the worker.

In case of assumption of 10 μm AMAD (as in case of participants ID 80, 81 and 82) the dose coefficient is only a percentage of 12 % lower ($5.9\ 10^{-9}$ instead of $6.7\ 10^{-9}$ Sv/Bq) in case of ^{137}Cs but more than a factor of 2 less than that usually used ($3.6\ 10^{-8}$ instead of $7.7\ 10^{-8}$ Sv/Bq) for ^{90}Sr. This choice does not imply the identification of such results as outliers neither for intake nor for E(50).

9.5. Software used

Many types of software were used. In Table 9.21 the names of the different used software code and the number of participants using a certain software have been listed.

Table 9.18. Number of participants using the different software

Used software code	Number of participants using the indicated software
IMBA®	15
None	11
IMIE	6
LUDEP	6
Home-made	3
AIDE	3
MONDAL; IDEAS DV0102,IDEA-System	2
Mathematica; INDAC; INDOS, INDO2000;,BKFIT; MMK-01; IMBA®+IMIE+LUDEP; - Intake:Cindy,Dose:LUDEP/ICRP78	1

As can be seen the IMBA™ and the IMIE software codes, that were freely available for test and use during the period of this intercomparison exercise, are the most often used.

The LUDEP code has been used by six participants as stand alone or in conjunction with other software (e.g. participant ID 4 with IRFA) even if the systemic phase of Sr embedded in this code is different from that presented in ICRP 67 and 78. Other codes have been used for the evaluation. The code AIDE has been used by three participants and MONDAL, MONDAL2, IDEAS DV0102, IDEA-System by two participants each. One participant (ID 60) indicated that he has performed the evaluation of intake using Cindy and E(50) using LUDEP and ICRP 78 so not using the same models for the evaluation of intake and of E(50).

Three participants indicated to have used their own home-made software.

Eleven participants indicated not to have used any software. In this case it was possible to perform the evaluation without using any particular software for both radionuclides and approximately one out of five participants performed the evaluations in this way.

9.6. Datasets used for the final ^{90}Sr evaluation

Twenty-eight participants used only the urine dataset for the final evaluation of Sr; only three participants used only the faeces dataset and 27 used both datasets.

In Table 9.22 the results of the comparison of these subsets have been summarized. Considering all results (outlier included: 14 for intake and 10 for E(50)) related to the use of only the urine dataset showed a very wide spread of values (GSD = 7 for intake and 12.7 for E(50)). The ratio of max/min E(50) value in this case is about 890. The absolute values of intake (about 30 kBq) and E(50) (about 1.9 mSv) are quite unrealistic in consideration of the

possible results indicated following the guidelines. The three values related to the use of faeces data are very close each other with ratios max/min of app. 3.5 for intake and 1.4 for E(50). The geometric mean for intake is 76 kBq and for E(50) it is equal to 4.3 mSv. The subset of participants using both datasets presents limited spread of results (GSD = 1.7 for intake and 2.5 for E(50)), realistic geometric mean values are about 85 kBq for intake and 5.6 mSv for E(50).

Table 9.19. Comparison of results for participants which used the urine dataset, the faeces dataset or both for the final evaluation[(a)]

	Urine		**Faeces**		**Both**	
	Intake	**E(50)**	**Intake**	**E(50)**	**Intake**	**E(50)**
N	28	28	3	3	27	27
N outliers	10	8	1	0	3	2
GM	29.9 kBq	1.88 mSv	76.1 kBq	4.28 mSv	84.4 kBq	5.63 mSv
GSD	7.0	12.7	1.92	1.19	1.70	2.47
Min	0.99 kBq	0.026 mSv	45.6 kBq	3.51 mSv	17.8 kBq	0.55 mSv
Max	179 kBq	22.7 mSv	159 kBq	4.76 mSv	155 kBq	37.2 mSv

(a) Outliers given in Table 9.12 are considered.

Not considering the outliers for the subsets of evaluations based only on urine and on both datasets (results summarized in Table 9.23), the results in terms of geometric mean values present the same spread for intake (GSD = 1.31) and E(50) (GSD around 2) but the mean value related to the urine dataset is app. 9 % larger than the value evaluated on the base of both datasets. The increase of the corresponding values for E(50) is 30 %.

Table 9.20. Comparison of results for participants which used the urine dataset, and both datasets for the final evaluation[(a)]

	Urine		**Both**	
	Intake	**E(50)**	**Intake**	**E(50)**
N	18	20	24	25
GM	107.7 kBq	8.68 mSv	99.0 kBq	6.64 mSv
GSD	1.31	1.84	1.31	2.02
Min	78 kBq	2.2 mSv	66 kBq	1.74 mSv
Max	179 kBq	22.7 mSv	155 kBq	37.2 mSv

(a) Without the outliers given in Table 9.12.

The effect of using both datasets is to decrease the value of intake and E(50) bringing the results nearer to the IDEAS result with the S_t modified absorption parameter value (67.2 kBq, 3.43 mSv).

9.7. Methods for using the datasets in ^{90}Sr evaluations

When both datasets have been combined for the final evaluation of the intake the methods that have been selected by participants are summarized in Table 9.24.

Table 9.21. Methods used for combining the urine and faeces datasets

Method used for combining the two datasets	**No. of participants**
Maximum likelihood	8
Simultaneous way but unknown.	5
Weighted least square fit (WLSF)	4
Least square fit	3
Separate estimation of intakes from urine and faeces and then arithmetic mean of the two values	2
Adjustment of the intake values from urine and faeces	2
Assumed a weight of 50 % to urine and of 50 % to faeces during the estimation	1
Use of the biggest value between those evaluated by the two types of measurements	1
Ratio of slopes fit	1
Deconvolution	1

The eight participants using the maximum likelihood method (ID 22, 25, 32, 39, 55, 67, 77, 79) used either IMBA™ or BKFIT.

There are also some participants that made evaluations using separate estimations of intakes from urine and faeces and then averaging them. Another participant considered an equal weight to the two datasets to compose the final value. Another one used the largest intake value as accepted estimation. All these three last mentioned methods of averaging are in contrast with the “good technique” of simultaneous fit of all the available data on the base of the formula (9.3) given after Table 9.5.

Weighted or normal least square fits or ratio of the slopes fit are also reported by eight participants: these methods are derived from the maximum likelihood method under selected hypotheses. For their application one can refer to [24]. Other methods as “Deconvolution” or “Adjustment of intake values” are reported but it is not known to which procedure these methods refer as no further explanations have been provided by the participant.

9.8. Use of guidelines

9.8.1. Caesium 137

For ^{137}Cs 28 participants out of 58 (i.e. 48 %) stated that they have followed the IDEAS guidelines in performing the evaluation. The remaining participants either indicated that they did not follow them or made no information available. For the aims of the present intercomparison all the participants, who have not used the guidelines, have been considered as "Others".

For ^{137}Cs those, that did not follow the guidelines, gave the reasons summarized in Table 9.22.

Table 9.22. Reasons not to follow the guidelines: ^{137}Cs

Reason	Number of participants
Use of commercial software	4
Applied default method of the firm	2
Applied local laws	2
Not having time to read guidelines	2
Guidelines are not available	2
Guidelines are not clear enough	1

In Table 9.23 the description statistics parameters of results of the participants, as a whole and splitted in the two subsets of those who indicate that have followed the guidelines ("GL" in the table) and the remaining results ("Others" in the table) are reported. In this table only values not considered as outliers have been used.

Table 9.23. Comparison of results between participants that followed guidelines and the others. All the values are calculated not considering the outliers given in Table 9.12.

	GL		**Others**	
	Intake	**E(50)**	**Intake**	**E(50)**
N	28	28	27	24
GM	97.3 kBq	0.62 mSv	106.3 kBq	0.70 mSv
GSD	1.21	1.17	1.18	1.12
Min	69.9 kBq	0.47 mSv	71 kBq	0.55 mSv
Max	154 kBq	0.80 mSv	131 kBq	0.82 mSv

For ^{137}Cs none of the already identified outliers are present in the subset of those who indicate that have followed the guidelines. For the "Others" subgroup the statistics considering also the identified outliers is reported in Table 9.24.

As can be seen the application of guidelines produces the benefit to reduce the spread of results (GSD values from 2.62 to 1.21 for intake and from 2.43 to 1.17 for E(50)) and to avoid the occurrence of outlier values.

Comparing the results of Table 9.23 for the subsets not considering outliers a statistical difference between those indicating the use of the guidelines and the others can be pointed out for E(50) but not for intake. The value of E(50) increases of about 13 % for the participants that not uses the guidelines in respect to the others and intake increases of 9 % so for these subsets practically no difference can be pointed out.

Table 9.24. Comparison of results between participants that followed guidelines and the others. The values are calculated considering also the outliers given in Table 9.12

	Others	
	Intake	**E(50)**
N	30	30
GM	85.5 kBq	0.72 mSv
GSD	2.62	2.43
Min	1.05 kBq	0.31 mSv
Max	185 kBq	62 mSv

A very deep analysis of the comments and procedures applied when following the guidelines (specially the final step of evaluation) shows that only 12 participants (i.e. 21 % of the total) correctly applied the guidelines. In Table 9.25 the reported final steps of the evaluations are compiled.

Table 9.25. Indication of the final step of evaluation and correctness of application of guidelines. ^{137}Cs

Final step	**Number of participants**	**Correct ?**
1.3	1	Not correct
3.2, 3.3, 3.4.1	9	Not correct as these steps refer to routine monitoring. Special evaluation needed: Step 4 and following.
5	1	Not sufficient
5.6, 5.6.1	12	Correct
5.11, 5.11.3, 5.15.1	3	Not correct as the evaluated E(50) values are less than 1 mSv.
Unknown	2	Impossible to check

For the 12 participants that correctly used the guidelines the variability of overall results is reduced and the reported values are as indicated in Table 9.26. The participants mainly (11 out of 12) used type F, 5 μm AMAD. The GSD for them is 1.16 both for intake and E(50) (all use the same dose coefficient) and the ratio max/min is 1.64. The geometric mean values are 97.7 kBq for Intake and 0.65 mSv for E(50).

Table 9.26. Statistical values related to participants that correctly used the IDEAS guidelines

	Intake	E(50)
N	12	12
GM	100.2 kBq	0.66 mSv
GSD	1.18	1.16
Min	71.7 kBq	0.48 mSv
Max	133 kBq	0.79 mSv

Comparing these values with those reported in Table 9.10 for the results of the previous intercomparison exercise it can be stated that the variability of results is quite similar (18 % coefficient of variation in respect to a maximum GSD of 1.18) and a difference of +8.5 % in intake and -11 % in E(50) in respect to the values reported in the previous intercomparison exercise.

9.8.2. Strontium 90

For ^{90}Sr 22 participants out of 58 (i.e. 38 %) stated that they followed the IDEAS guidelines. For the remaining participants there is the explicit indication of not following the guidelines or no information is available. In Table 9.27 the reasons for not to follow the guidelines are summarized.

Table 9.27. Reasons not to follow the guidelines: ^{90}Sr

Reason	Number of participants
Use of commercial software	4
Applied local laws	3
Applied default method of the firm	2
Guidelines are not clear enough	2
Guidelines are not available	2
Participant software can't treat step 5C	1
Guidelines are judged as faulty and unnecessary complicated	1
Not having time to read guidelines	1
Because in GL it is indicated to use for Sr type F as default	1
Guidelines do not allow the fitting of AMAD	1
Because in the GL there is no tool for simultaneous fitting of urine and faecal measurements	1
Because in the GL it is unclear how to handle error distribution	1

The provided reasons for the first three items are quite similar to those indicated in Table 9.22 for ^{137}Cs, and relate to the use of commercial software, default method of the company and the application of local laws. This indicates the need that the process of assuming the guidelines as default method for internal contamination dose evaluation must reach, at the end, also the commercial and regulatory framework to be effective in the application.

Other reasons (e.g.: the guidelines are not applicable in this particular case as they assume the default value of F absorption type for unknown compounds of ^{90}Sr) will be considered for future revisions of the guidelines. Feedback from the participants (e.g.: missing tool for the simultaneous fitting of different types of measurements or a better routine for handling of uncertainty distribution) will be used to improve and clarify aspects in the guidelines that could be improved.

The statistical description of the results of the two subgroups has been presented in Table 9.28 and Table 9.29. In Table 9.28 the results of all data are reported while in Table 9.29 only the statistical parameters of the values without the outliers of Table 9.12 are summarized.

Table 9.28. Comparison of results between participants that followed guidelines and the others. All values

	GL		**Others**	
	Intake	**E(50)**	**Intake**	**E(50)**
N	22	22	36	36
GM	60.4 kBq	4.24 mSv	45.8 kBq	2.79 mSv
GSD	4.20	6.61	4.59	7.13
Min	0.99 kBq	0.03 mSv	1.1 kBq	0.03 mSv
Max	158.8 kBq	37.2 mSv	179 kBq	22.7 mSv

As can be seen the spread of the results is wide: GSD is not less than 4.2. Considering the application of the guidelines seems to reduce the spread of data a little bit changing GSD values from 4.59 to 4.2 for intake and from 7.13 to 6.61 for E(50).

Table 9.29. Comparison of results between participants that followed guidelines and the others. All the values are calculated not considering the outliers given in Table 9.12

	GL		**Others**	
	Intake	**E(50)**	**Intake**	**E(50)**
N outliers (%)	4 (18 %)	3 (14 %)	10 (28 %)	7 (19 %)
N	18	19	26	29
GM	107.8 kBq	8.31 mSv	98.9 kBq	6.69 mSv
GSD	1.32	2.09	1.33	1.83
Min	60.7 kBq	1.74 mSv	66 kBq	1.82 mSv
Max	158.8 kBq	37.2 mSv	179 kBq	12.5 mSv

As can be seen from Table 9.29 the percentages of outliers present in each subset reduces when applying the guidelines (from 28 % to 18 % for intake and from 19 % to 14 % for E(50)). The spread of the results inside each subset does not seem to vary much.

The spread of results inside the set of those who followed the guidelines is due to the assumptions that they applied during the evaluation. The use of absorption type M or F determines, also in this subset, the presence of several outliers.

In Table 9.30 the numbers of the final step of the evaluation and the correctness of these choices are reported.

Table 9.30. Indication of the final step of evaluation and correctness of application of guidelines. ^{90}Sr

Final step	Number of participants	Correct ?
1.3	1	Not correct (also outlier)
3.3 & 5.1	1	Not correct as the evaluated E(50)is > 6 mSv.
3.3.1	1	Not correct for special monitoring (also outlier)
5	1	Not sufficient
5.6	1	Not correct as the evaluated E(50)is > 6 mSv.
5.6.1	1	Correct, but value is an outlier.
5.11.2	1	Not correct as it is a test step
5.11.3	3	Correct, evaluated E(50)> 6 mSv
5.11.4	1	Not correct as it is a step for the check of number of data
5.15, 5.15.1	7	Correct
5.15.1	2	Not correct as the evaluated E(50)is < 6 mSv.
5.19	1	Correct as changed particle transport parameters
Unknown	2	Impossible to check

In the set of results for those participants that have performed a correct evaluation (not considering the outliers) it is possible to enucleate two subsets related to the assumed parameters for lung absorption either standard type S or modified type S. These sets are centered on values that are around 10 and 3.4 mSv as presented in Table 9.7 and Table 9.8.

In Table 9.31 the descriptive statistical values of these two sets are reported. As can be seen the central values of the two subsets are not dissimilar to the reported values for the reference evaluation.

Table 9.31. Statistical values related to participants that correctly used the IDEAS guidelines. ^{90}Sr

	Step 5.15.1 - 5.19		Step 5.11.3	
	Intake	**E(50)**	**Intake**	**E(50)**
N	8	8	3	3
GM	121.3 kBq	11.6 mSv	86.9 kBq	4.27 mSv
GSD	1.17	1.78	1.69	1.19
Min	93 kBq	6.5 mSv	60.7 kBq	4.76 mSv
Max	143 kBq	37.2 mSv	158.8 kBq	1.37mSv

9.9. Conclusion for Case 2

The main aim of the presented intercomparison exercise was to provide a test for the application of the IDEAS Guidelines as a tool for accurate dose assessment.

The current case is a real case already used in a previous intercomparison exercise in the ninetieths.

The overall distribution of the results presents data below the geometric mean that skewed the ^{90}Sr distributions to the left. In this case the F type lung absorption assumption determines values even a factor of 100 below the geometric mean.

When the outlying values, that accounts from 5 to 24 % of the total number of data (mainly in the ^{90}Sr data-subsets) were removed, the comparison of the current results with the ones from the previous intercomparison exercise on the same case, but using ICRP 30 models, indicates these main evidences:

- For ^{137}Cs the spread of results is quite similar (18 % for intake and 14-17 % for E(50)) but the arithmetic mean values slightly increase for intake (+14 %) and decrease (- 9 %) for E(50) in respect to the previous intercomparison exercise results.

- For ^{90}Sr the spread of intake results are quite similar (26-29 %) for intake, but not for the E(50) results. There the coefficient of variation increases from 40 % of the previous intercomparison to 74 % in the present one. The value of the arithmetic mean of the previous intercomparison exercise is 36 kBq while the corresponding value now is 107 kBq. Regarding the E(50) a decrease of a factor of 1.5 can be observed, changing the value from 14 mSv in the previous exercise to 9 mSv in the present one.

- Generally it can be stated that the main central and dispersion parameters are maintained for ^{137}Cs while for the ^{90}Sr data only the spread of intake data is comparable and all other descriptive statistics parameters are changed.

Following the guidelines a value of 104 kBq for intake and 0.69 mSv for the E(50) for ^{137}Cs is assessed.

The corresponding correct value for ^{90}Sr is 136 kBq and 10.5 mSv. A more detailed procedure of fitting via the modification of the S_t absorption parameter up to a value 5 times higher than

that related to default type S, allows to determine the more accurate value of intake of 67 kBq and for E(50) of 3.4 mSv.

Fifty eight participants assessed this case. The overall distributions of ^{137}Cs results both for intake and E(50) are narrow (GSD ~2). Limited numbers of outliers have been identified with the statistic procedure mainly due to the exclusion of the first whole body measurement at time zero. When considering only corrected data both distributions (intake and E(50)) are very narrow (GSD values ≤ 1.2).

The overall distributions of ^{90}Sr results are wide both for intake and E(50) when considering all data (GSD ~ 4.4 - 6.9). Numerous outliers are present, especially on intake. These are mainly determined through the assumption of type F or M for the lung absorption behaviour, use of single data set (urine) instead of both, and reduction of data points. When considering correct evaluations narrower distributions (GSD < 2) occur.

Forty-eight per cent (^{137}Cs) and 39 % (^{90}Sr) of participants indicate that they have used IDEAS guidelines. The main effect of the use of the guidelines for ^{90}Sr is the reduction of occurrences of outliers inside the subset ("following the guidelines" in respect to the "others") from 28 % to 18 % for intake and from 19 % to 14 % for E(50). In the case of ^{137}Cs the use of the guidelines establishes the absence of outliers in the subset of those who followed them.

No differences in descriptive statistic parameters can be found between the results of those who followed the guidelines and the others.

A deeper analysis of the reported data reveals that only a fraction of those who have reported a use of the guidelines, have used them correctly. Actually only 21/19 % (^{137}Cs, ^{90}Sr) of all participants correctly used the guidelines providing the final step in coherence with the estimated E(50) value and were following a correct path.

The descriptive statistics central parameters of these participants get closer to the values considered as reference values.

During the evaluation of the reported results of this case, relevant errors made by the participants during their assessments, have been detected, namely in:

- dose coefficient calculations,
- intake and dose models application coherence, and
- different assumptions in AMAD values for ^{137}Cs in respect to ^{90}Sr.

Different incorrect ways of using the available datasets have also been detected for ^{90}Sr intake evaluation, e.g.: separate estimation of intake from urine and faeces and then building the arithmetic mean of intake values; separate estimation of intake and then assuming the largest value of intake as best estimation; weighing of 50 % to urine and 50 % to faeces in intake estimation. The prevention of such mistakes will also be part of future guidelines development.

For this Case 2, twenty per cent of participants correctly used the guidelines and reached results that can be considered as accurate.

10. CASE 3: ACUTE INHALATION OF ^{60}CO

10.1. Case description

10.1.1. The event

Description of the working area	Preparation facility for ^{60}Co sources.
Characteristics of work	Cobalt wires irradiated by neutrons in a nuclear reactor facility were used for the preparation of sealed ^{60}Co sources.
Reasons for monitoring; initiating event	An irradiated capsule containing 900 TBq of ^{60}Co wire was opened in a hot cell and after 10 minutes dose rate alarms sounded.
Actions taken	Operators closed the source, put on protective clothing and respirators, stopped the leakage and decontaminated the workplace. A program of in-vivo monitoring was carried out ten days after the event and continued up to 3 years. Urine samples were also taken.

10.1.2. Additional information

Air monitoring	Not available
Chemical form	Cobalt metal and/or oxide (temperature during irradiation was around 300°- 400°C).
Physical characteristics, particle size	Aerosol
Nose swab, bronchial slime or similar	None
Non removable skin contamination	None
Wound site activity	N.A.
Any intervention used (blocking, chelating, etc.)	None

10.1.3. Body monitoring data

Organ activity measurement None

Whole body activity measurement

Time of measurement after intake (d)	Whole body activity of ^{60}Co (Bq)
10	2.39E+04
14	2.92E+04
17	2.01E+04
20	1.82E+04
27	2.16E+04
40	1.98E+04
60	2.16E+04
80	1.75E+04
190	1.16E+04
370	8.1E+03
747	4.8E+03
1010	2.7E+03

10.1.4. Excretion monitoring data

Urine activity measurement

Time of measurement after intake. (d)	Daily urinary excretion rate of ^{60}Co (Bq/d)
14	7.09E+02
27	6.4E+01
40	7.1E+01
60	3.7E+01
80	2.9E+01
190	1.1E+01
370	1.7E+00

Faeces activity measurement None

10.1.5. Personal data

Sex Male
Age 35 years
Weight 70 kg

10.1.6. Other comments relevant for intake and dose estimation

It was recommended to assume that the in-vivo measurements can be approximated by a lognormal distribution. The scattering factor (SF) due to counting uncertainties (i.e. Type A uncertainty) was assumed to be 1.07 whereas the SF due to other uncertainties (i.e. Type B uncertainty) was assumed to be 1.18. The SF is the geometric standard deviation of the lognormal distribution.

It was commended to assume that the urine measurements can be approximated by a lognormal distribution with a total SF, due to Type A and Type B uncertainties, of 1.8.

Estimate the intake and the committed effective dose E(50).

10.2. Assessment of the case

Before following the guidelines to assess the case it is useful to plot the available data (Figure 10.1) and perform a simple calculation to estimate intake and dose.

From the case description (Section 10.1) the time of intake was known and the intake pathway could be considered as inhalation. Furthermore, the data appeared to be consistent with an acute inhalation of ^{60}Co (Figure 10.1).

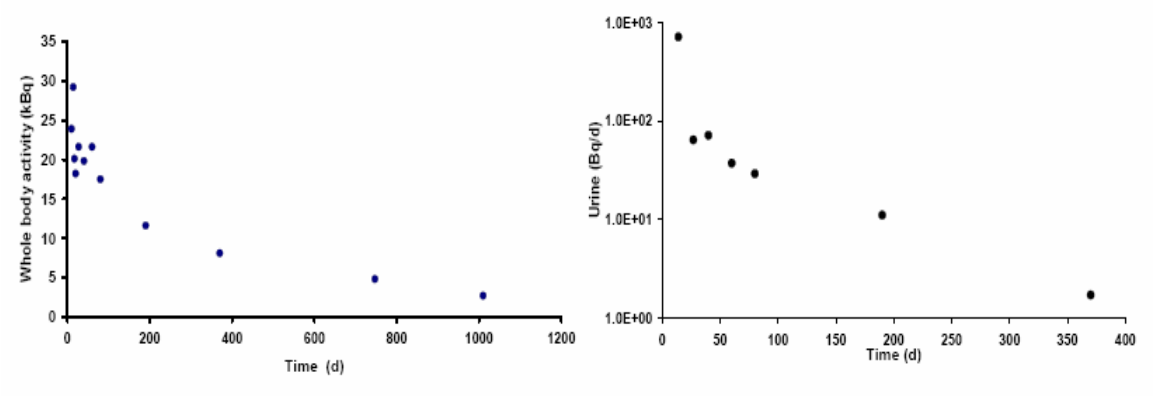


Fig. 10.1. A plot of the measurement data given in Case 3
Twelve whole body data and seven urine data are given.

The first whole body measurement at day 10 resulted in 2.39 10^4 Bq. As the chemical form is given as metallic Cobalt or Cobalt oxide it is reasonable to assume absorption Type S for a simple calculation of intake and dose.

ICRP Publication 78[6] gives a whole body activity content of 0.065 Bq for a worker after 10 days following an acute inhalation of 1 Bq of ^{60}Co assuming Type S and a 5 μm AMAD aerosol.

Therefore, on this basis alone, the intake is 2.39 10^4 / 6.5 10^{-2} = 3.7 10^5 Bq (i.e. about 370 kBq).

The corresponding dose coefficient given in ICRP Publication 68[20] for inhalation of ^{60}Co by a worker assuming Type S and a 5 μm AMAD aerosol is 1.7 10^{-8} Sv/Bq.

This gives an E(50) value of 3.7 10^5 Bq × 1.7 10^{-8} Sv/Bq = 6.3 10^{-3} Sv (i.e. about 6 mSv).

So by carrying out a simple calculation the estimated intake is about 370 kBq and the resulting E(50) is about 6 mSv. This finalizes a rough estimate of the intake and dose.

The following sections describe the assessment of the case following the IDEAS guidelines. As this is a special monitoring case for inhalation the steps in flow chart 5 are followed. The models that will be used to assess the intake and dose include the ICRP Publication 66 Human Respiratory Tract model[1], the ICRP Publication 30 Gastrointestinal Tract model[18] and the ICRP Publication 67 systemic biokinetic model for Cobalt[2].

10.2.1. Step 5.1: Identification of data and assignment of realistic uncertainties

Twelve whole body measurement data and seven urine data points are available (Figure 10.1).

The case description prompted the assessor to assume that the whole body measurements are lognormally distributed. Scattering factor (SF) values for Type A uncertainties (i.e. counting uncertainties) of 1.07 and for Type B uncertainties (i.e. other uncertainties such as calibration uncertainties) of 1.18 were given for the whole body measurements.

By using the following formula, which is given in the guidelines, an overall SF of 1.2 is calculated for the whole body measurements.

$$\text{Overall SF} = \exp\left[\sqrt{\sum_i \ln^2(SF_i)}\right]$$

Where SF_i is the scattering factor for each component i (i.e. Type A and Type B uncertainties).

Thus, for the whole body measurements a lognormal distribution is assumed with a SF of 1.2. The SF is the geometric standard deviation of the lognormal distribution. The case description prompted the assessor to assume that the urine data are lognormally distributed with an overall SF value of 1.8. Thus, for the urine data a lognormal distribution is assumed with a SF of 1.8.

At this stage there is no reason to reject any of the data so all of the data will be used to assess the intake.

10.2.2. Step 5.2: Assessment of contributions from previous intakes

In this case, no information is given about previous intakes so it is assumed that the measured activities all arise from this incident..

10.2.3. Step 5.3: Assign a priori parameters (default or site-specific)

In the case description the chemical form of the material was given as metallic Cobalt or Cobalt oxide. The ICRP default absorption type for Cobalt oxide is Type S[20].

The default parameter values assumed are:

- 5 μm AMAD aerosol
- Absorption Type S
- f_1 value 0.05
- Reference worker

10.2.4. Step 5.4: Is the time of intake known?

The time of intake is known so proceed to step 5.5.

10.2.5. Step 5.5: Calculate dose with a priori parameters

To estimate the intake it is necessary to calculate the predicted values, $f(t_i)$ of each of the measured quantities assuming unit intake. The best estimate of intake (I) is determined so that the product $I\ f(t_i)$ best fits the measurement data (M_i, t_i) . The fitting method recommended by the guidelines is the maximum likelihood method. The equations given in the section entitled 'Best estimate of intake' of the guidelines can be applied to cases where multiple types of measurement data are available. The equations given in the guidelines are analytical solutions to the maximum likelihood method where the measurement data are lognormally distributed

with a given SF. It should be noted that the equations do not apply to data that are reported as being below the limit of detection.

The equation giving the best estimate of intake, is given by:

$$\ln(I) = \frac{\sum_{i=1}^{N}\left(\frac{\ln(I_i)}{(\ln SF_i)^2}\right)}{\sum_{i=1}^{N}\frac{1}{(\ln SF_i)^2}} \qquad \textbf{(10.1)}$$

where
SF_i is the scattering factor for M_i
I_i is the estimated intake derived from each measurement value M_i and is given by:

$$I_i = \frac{M_i}{f(t_i)}$$

For this case, 19 intake estimates are determined (12 from the 12 whole body measurements and 7 from the 7 urine measurements). Substituting the SF of 1.2 for the whole body data and 1.8 for the urine data into equation 10.1 gives:

$$\ln(I) = \frac{\sum_{i=1}^{12}\left(\frac{\ln(I_i)}{(\ln 1.2)^2}\right) + \sum_{j=1}^{7}\frac{\ln(I_j)}{(\ln 1.8)^2}}{\sum_{i=1}^{12}\frac{1}{(\ln 1.2)^2} + \sum_{j=1}^{7}\frac{1}{(\ln 1.8)^2}}$$

where I_i refers to the intake estimates from the whole body data and I_j refers to the intake estimates from the urine data.

Alternatively, the best estimate of intake can be determined using appropriate internal dosimetry software. The IMBA Professional software was used to assess this case.

Briefly described, the software implements the current ICRP dosimetric and biokinetic models while enabling the user to alter parameter values from the ICRP defaults. It uses the maximum likelihood method to fit multiple data and has the ability to assess the intake by fitting predicted values to different types of data simultaneously. The intake was estimated by fitting the predicted values to both, the whole body data and the urine data, simultaneously. This is identical to calculating the intake using the above equations.

With the default parameter values given in step 5.3 the estimated intake is 389 kBq and E(50) is 6.4 mSv. The fits to the data are shown in Figure 10.2. However, the fit to the urine data is poor, and this indicates that the model parameter values are incorrect.

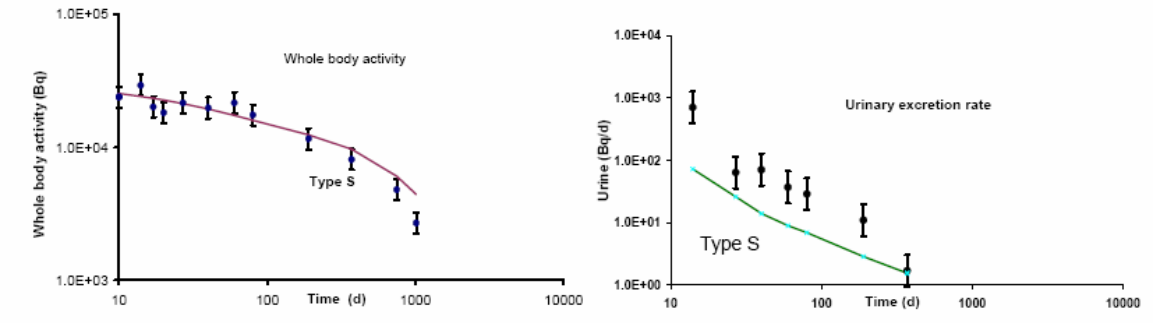


Fig. 10.2. Model fits to whole body and urine data assuming Type S (step 5.5)

10.2.6. Step 5.6: Is E(50) < 1 mSv?

With the default parameter values E(50) was calculated to be 6.4 mSv. As this is greater than 1 mSv proceed to the next step

10.2.7. Step 5.7: Are there sufficient relevant data?

The guidelines suggest a minimum number of data that is required for a dose assessment for certain radionuclides. The minimum number suggested depends on the dose level. For ^{60}Co the minimum number is five whole body measurements over a time period of 30 days if the dose level is greater than 6 mSv. In this case, there are 12 whole body measurements and seven urine measurements. Therefore there are enough data for this dose assessment, so proceed to the next step.

However, it should be pointed out that suitable early data that can be used to estimate an effective AMAD are lacking.

10.2.8. Step 5.8: Is the time of intake known?

The time of intake is known so proceed to step 5.9.

10.2.9. Step 5.9: Are early and lung faeces measurement results available?

There are no early lung and faecal data available so proceed to step 5.11.

10.2.10. Step 5.11: Assessment of dose by fitting absorption type

In this step intakes and doses are assessed using the default absorption types for Cobalt given in ICRP Publication 68[20]. This document suggests Type S for Cobalt oxide and Type M for unspecified compounds of Cobalt.

10.2.11. Type S

Assuming Type S the fit to the urine data is poor (step 5.5, Figure 10.2). The estimated intake is 389 kBq and E(50) is 6.4 mSv.

10.2.12. Type M

Assuming Type M with f_1= 0.1 and 5 μm AMAD, the estimated intake is 481 kBq and E(50) is 3.4 mSv. The fit to the data is poor (Figure 10.3).

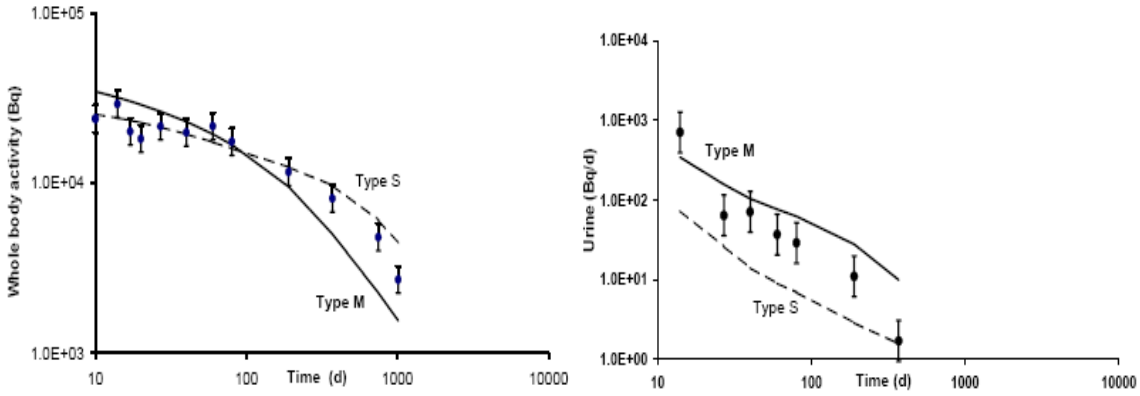


Fig. 10.3. Model fits to whole body and urine data assuming default absorption types (step 5.11). ***[------- Type M; – – – Type S]***

10.2.13. Step 5.11.1: Is the goodness of fit acceptable?

The guidelines suggest rejecting a fit if:

– the chi squared test (χ^2) fails (i.e. if p-value < 0.05).
In other words if the fit is inadequate at the 5 % level of significance, or if

– the fit displayed graphically looks unreasonable by eye.

It is acknowledged that whether or not the fit, as displayed graphically, looks unreasonable by eye is a subjective judgment. However, generally, a fit would be considered unreasonable if all, or a long series, of data were systematically underestimated or overestimated.

As the measurements are lognormally distributed, the χ_o^2 is calculated using the following formula for N measurements

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{\ln(M_i) - \ln[I f(t_i)]}{\ln(SF_i)} \right)^2 :$$

When fitting predicted values to different types of data simultaneously, the overall χ_o^2 is the sum of the calculated χ_o^2 values for each data set. The number of degrees of freedom is the total number of measurements minus one. In this case it is 18 (i.e. 12 whole body data + 7 urine data – 1 = 18). The expected value of χ^2 is equal to the number of degrees of freedom.

For the calculated χ_o^2 value with N-1 degrees of freedom, the corresponding p-value can be obtained from Statistical Tables. Alternatively, the p-value can be obtained from Microsoft Excel® using the function CHIDIST(χ_o^2 , N-1). The p-value is the fraction of the actual χ^2 distribution that lies above the calculated χ_o^2 value. So if p is very small, the calculated χ_o^2 value is very much larger than expected and therefore it can be concluded that the fit is inconsistent with the data.

Assuming Type S the overall χ_o^2 is 57 with 18 degrees of freedom and the corresponding p value is $6.2\ 10^{-6}$. As the p-value is < 0.05, the fit is rejected.

Assuming Type M the overall χ_o^2 is 72 with 18 degrees of freedom and the corresponding p value is $2.3\ 10^{-8}$. As the p-value is < 0.05, the fit is rejected.

To summarize, for both, Type M and Type S assumptions, the p-value is < 0.05. On this basis the fits are rejected and so it is necessary to proceed to step 5.13. It is also worth pointing out that the fits also look unreasonable by eye (Figure 10.3).

10.2.14. Step 5.13: Assessment of dose by fitting a mixture of default absorption types

In this step, the intake is estimated by fitting a mixture of absorption types (M and S) to the whole body and urine data simultaneously.

The best fit to the data was obtained for a mixture consisting of 44 % Type M and 56 % Type S (Figure 10.4).

The estimated intake is 404 kBq and E(50) is 5.0 mSv.

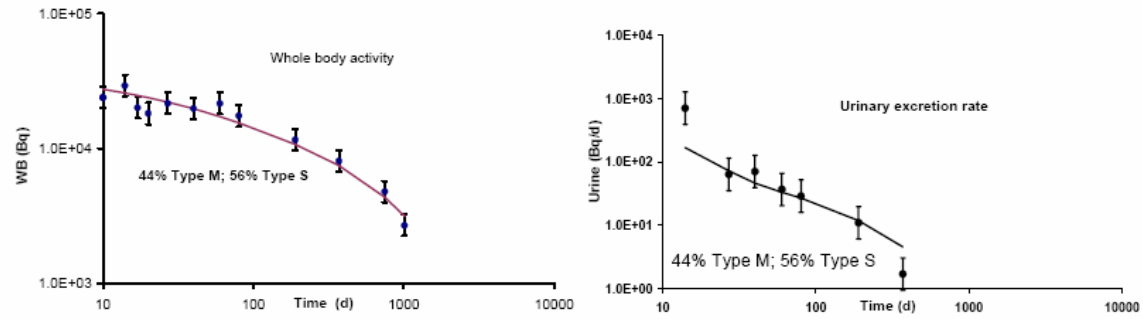


Fig. 10.4. Model fits to whole body and urine data assuming 44 % Type M and 56 % Type S (step 5.13).

10.2.15. Step 5.15: Is the goodness of fit acceptable?

For a mixture consisting of 44 % Type M and 56 % Type S, the fits to the data are good (Figure 10.4). The overall χ_o^2 is 17 with 18 degrees of freedom and the corresponding p-value is 0.5. As the p-value is > 0.05, the fits are not rejected. This is, therefore, the best estimate of intake and dose. So the intake and dose with the corresponding parameter values are recorded in the next step (i.e. step 5.15.1).

10.2.16. Step 5.15.1: Record dose with all parameter values

The intake and the dose are recorded with the corresponding parameter values.

- Intake: Acute inhalation of 404 kBq of ^{60}Co
- Committed effective dose, E(50): 5.0 mSv
- Mixture of Absorption Types M and S
  - 44 % Type M; 56 % Type S
- f_1 = 0.10 (Type M); f_1 = 0.05 (Type S)
- 5 μm AMAD aerosol
- Reference worker
- ICRP Publication 66 Human Respiratory Tract model[1]
- ICRP Publication 30 Gastrointestinal Tract model[18]
- ICRP Publication 67 systemic biokinetic model for cobalt[2]

10.2.17. Summary of assessments

A summary of the assessments of intake and dose is given in Table 10.1, including each calculated χ_o^2 value and the corresponding p-value.

It was not possible to obtain good fits to both the whole body and urine data with the ICRP default absorption types. However, good fits were obtained to both data sets by fitting a mixture of absorption Types (44 % Type M and 56 % Type S).

This was carried out in step 5.13.

Table 10.1. Summary of estimated intakes of ^{60}Co and resulting doses[a, b]

Assessment procedure step	Absorption Type	Goodness of fit		Comment	Intake (kBq)	E(50) (mSv)
		χo^2[c]	p- value[d]			
Steps 5.5 and 5.11	Default: Type S	57	$6.2\ 10^{-6}$	Very poor fit to urine data	389	6.4
Step 5.11	Type M	72	$2.3\ 10^{-6}$	Very poor fit to whole body and urine data	481	3.4
Step 5.11.3	Mixture of absorption Types (44 % Type M and 56 % Type S)	17	0.50	Good fit to both whole body and urine data sets	404	5.0

(a) Intake estimates were obtained by fitting the predicted bioassay values to the whole body and urine data simultaneously with IMBA Professional.
(b) The default AMAD of 5 μm was assumed in all assessments.
(c) The expected value of χ^2 is equal to the number of degrees of freedom; (i.e. number of data points – 1 = 18).
(d) The p- value is the probability that χ^2 is greater than χ_o^2 for 18 degrees of freedom.

It is interesting to note that, if Type S is assumed, the intake estimated using the whole body data alone is about a factor of 4 lower than the value obtained using only the urine data. Furthermore, if Type M is assumed, then the intake estimated using only the whole body data is about a factor of 2 greater than that obtained using only the urine data. This indicates that the material is not purely Type S or purely Type M.

However, if a mixture of absorption types (i.e. 44 % Type M and 56 % Type S) is assumed, the estimates of the intakes using either the whole body data or the urine data are very similar with only 12 % difference.

It is worth noting that the simple calculation, carried out at the beginning of the assessment, resulted in an intake of 370 kBq and E(50) of about 6 mSv.

The final estimate of intake of 404 kBq and the resulting E(50) of 5.0 mSv are similar to that obtained with the simple calculation. This can give the assessor some confidence that no error has been made while using software to assess the intake and dose.

10.3. Results of intercomparison exercise

10.3.1. Introduction

This case is an artificially generated case, designed to illustrate the IDEAS guidelines.

As can be seen from Section 5.2 the case illustrates the guidelines for the first two stages of flow chart 5 (special evaluation for inhalation, stages 5A and 5B). In particular, the case emphasizes step 5.13 ‘the assessment of dose by fitting a mixture of absorption Types’.

Although the data were artificially generated, the description of the case is based on a real case that was used in the 1997- 1998 intercomparison exercise on internal dose assessment organized by the IAEA[12] .

The subject inhaled ^{60}Co at a known time. Both urine and whole body data were provided. The chemical form of the inhaled material was given as metallic cobalt or cobalt oxide. The particle size was unknown (Section 10.1). The data were artificially generated, by assuming the following:

- Intake — Acute inhalation of 400 kBq of ^{60}Co
- Aerosol parameters — 5 μm AMAD with the ICRP default value for the geometric standard deviation of 2.5 [1].
- Absorption and f_1 values — 50 % Type M ($f_1 = 0.1$) + 50 % Type S ($f_1 = 0.05$)
- Reference worker
- Whole body data — Uncertainty on each of the whole data points was simulated by assuming that each data value is lognormally distributed about the true value with a scattering factor (SF) of 1.2. The SF is the geometric standard deviation of the lognormal distribution.
- Daily urinary excretion data — Uncertainty on each of the urine data points was simulated by assuming that each data value is lognormally distributed about the true value with a SF of 1.8.

For the whole body measurements, the case description recommended SF values for Type A uncertainties (i.e. counting uncertainties) of 1.07 and for Type B uncertainties (i.e. other uncertainties such as calibration uncertainties) of 1.18. The assessor was expected to calculate the overall SF for the whole body measurements of 1.2 using the formula given in the guidelines (Section 5.2). The case description also recommended an overall SF value of 1.8 for the urine data.

Both urine and whole body data were given so that the assessor could assess the mixture of absorption types. By following the IDEAS guidelines a mixture of 44 % Type M + 56 % Type S can be determined with the urine and whole body data (Section 5.2). This is not exactly the same as the original fraction (50 % Type M + 50 % Type S) because of the scatter imposed on the data.

Sixty two participants assessed this case. The results of intakes and doses are presented. The assumptions made by the participants are discussed.

10.3.2. Identification of outliers

Outliers were identified by following the statistical criteria described in Section 7.5 (presented in Table 10.2). However, for the effective dose two additional outliers were identified based on the methodology used by these two participants.

Table 10.2. Identification of outliers (^{60}Co assessment)

	Intake		E(50)
	All participants	Subset: 5μm AMAD	All participants
Number of participants[(a)]	62	49	62
Number of identified outliers	19	7	6

(a) Including outliers

Table 10.3 summarizes some of the assumptions used by the participants that have been identified as outliers in terms of intake or dose. Possible reasons are identified.

10.3.2.1.Intake

Applying the outlier criteria to the intake data produces 19 outliers out of 62 results (Table 10.2). Nearly all the outliers pertain to estimates of intake where the assumed AMAD was not 5 μm AMAD (Table 10.3).

As the estimated intake is very dependent on the assumed AMAD, the evaluation of the intake data was repeated for a subset of the data where the assumed AMAD was 5 μm. For this subset, applying the outlier criteria produces only seven outliers (35,42, 34, 51, 65, 2 and 5) (Table 10.2).

10.3.2.2.Dose

Applying the outlier criteria to the committed effective dose E(50) data produces four outliers (42, 35, 34, 73). However it was also judged that participants 46 and 26 should also be regarded as outliers. This is because participant 46 assumed Type F absorption and participant 26 used a bioassay function for 5 μm AMAD to calculate the intake and then multiplied the intake with a dose coefficient for 1 μm AMAD to calculate the dose. Thus, six outliers were considered for E(50) data (Table 10.2).

Participants 42, 35 and 34 are outliers for the assessed dose, as the estimated intakes were very low or very high (Table 10.3). Participant 73 calculated the intake using the predicted bioassay values given in ICRP Publication 78[6] that are for a 5 μm AMAD, but then multiplied the intake with a dose coefficient for 1μm AMAD to calculate the dose. This resulted in a higher assessed dose.

Table 10.3. Outlier assessment for intake and dose, E(50) for ^{60}Co.
Bold values indicate outliers.

Code	Intake (kBq)	E(50) (mSv)	AMAD (μm)	Absorption Type[(a)]	Data set used[(b)]	Comment
	404	5.0	5	M/S; 44/56	Both	Assessment carried out using IDEAS guidelines. Values very close to GM.
35	**24**	**0.4**	5	S	WB	Low intake corresponding to whole body content at 10 days[(c)].
46	394	**2.5**	5	F	Both	Low dose as Type F was assumed.
5	**499**	3.6	5	M	WB	Gives a poor fit if a SF of 1.2 is assumed.
22	**304**	4.7	4	Specific	Both	Dose assessment close to 'IDEAS' assessment.
69	**566**	4.8	10	Specific	Both	(d)
2	**515**	5.2	5	M/S; 70/30	Both	Did not select all the urine data, but not an outlier for dose.
54	**670**	5.8	10	M/S	Both	(d)
81	**770**	6.1	10	M/S; 40/60	Both	(d)
85	**770**	6.1	10	M/S; 40/60		(d)
25	**764**	6.2	10	M/S; 37/63	Both	(d)
51	**580**	6.3	5 + ing	S	Both	Intake estimate high, as a mixture of inhalation and ingestion was assumed
80	**866**	6.4	10	M/S; 30/70	Both	(d)
39	**1200**	6.5	16.8	Specific	Both	(d)
31	**784**	7.8	10	S	Both	(d)
45	**2400**	8.2	15	S	Both	(d)
65	**542**	9.0	5	S	Both	Only selected some of the data; (3 WB and 2 urine measurements)
67	**2022**	9.5	20	S	Both	(d)
26	418	**12.2**	5	S	WB	Incorrect dose coefficient(e)
73	**552**	**16.0**	5	S	Both	Incorrect dose coefficient(e), and only selected some of the data
34	**1390**	**23.6**	5	S	Urine	High intake as urine activity is underestimated for Type S compared with a mixture of absorption Types.
42	**5415**	**92.0**	5	S	WB	Needs further investigation, but probably a mistake was made.

(a) The ratios of the mixture of absorption types are given.
(i.e. M/S; 44/56 means 44 % Type M and 56 % Type S).

(b) WB represents the whole body data set and 'Both' means that the assessment was carried out using both the whole body and urine data.

(c) For a Type M or Type S material the whole body retention of ^{60}Co at 10 days after intake is about7 % of the intake[6]. Therefore, on this basis alone, the intake is about a factor of 14 greater than the whole measurement value at 10 days.

(d) High intake as a high AMAD was assumed. However, the assessed dose is not an outlier.

(e) A predicted bioassay value for 5 μm AMAD was used to calculate an intake and then the intake was multiplied by a dose coefficient for 1μm AMAD to calculate the dose.

10.3.3. Distribution of results

The statistical evaluations of the results, excluding outliers are given in Table 10.4.

Table 10.4. Statistical evaluations of the results excluding outliers for ^{60}Co

	Intake	**Intake**	**E(50)**
	All participants	Subset: 5 µm AMAD	All participants
N	43	43	56
GM	395 kBq	395 kBq	5.0 mSv
GSD	1.08	1.08	1.40
AM	396 kBq	396 kBq	5.2 mSv
ASD	30 kBq	30 kBq	1.7 mSv
Coefficient of variation	7 %	7 %	31 %
Minimum	333 kBq	333 kBq	2.73 mSv
Maximum	470 kBq	470 kBq	9.45 mSv

10.3.3.1.Intake

The data set, excluding the outliers, for the subset group where the assumed AMAD was not 5µm AMAD is identical to the data set, excluding outliers, where all the participants were considered. This is due to the fact that the participants that did not assume 5 µm AMAD are outliers in the latter group.

The geometric mean (GM) of the estimated intakes (395 kBq) is very close to the intake estimated by following the IDEAS guidelines (404 kBq). The difference is only 1.5 % (Table 10.1 and 10.4). The geometric standard deviation (GSD) is only 1.08 for the estimated intakes. The range of the estimated intakes, excluding outliers, is relatively small: 333 – 470 kBq (ratio max/min = 1.4). If outliers are included the range is very large: 24 – 5420 kBq (ratio max/min = 226). The graphical representations of the results are given in Figures 10.5, 10.6 and 10.7.

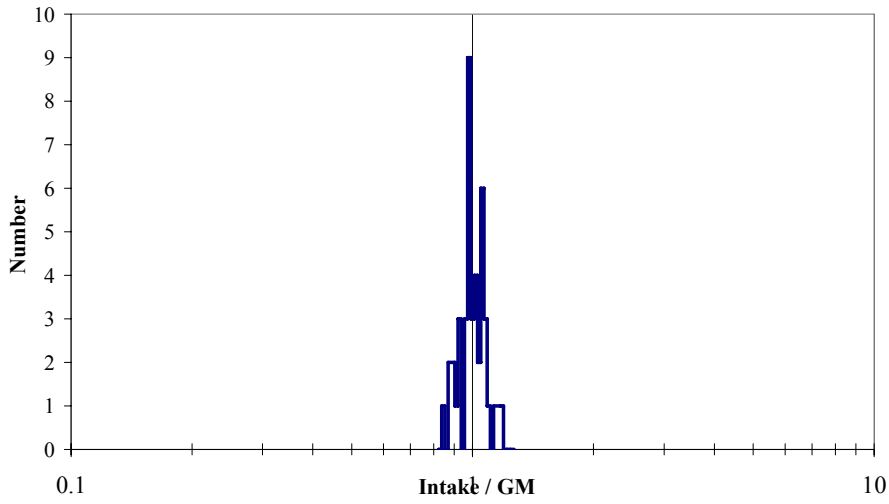


Fig. 10.5. Frequency distribution of results without outliers (N=41). Intake of ^{60}Co normalized to the geometric mean. (GM = 395 kBq; GSD = 1.08).

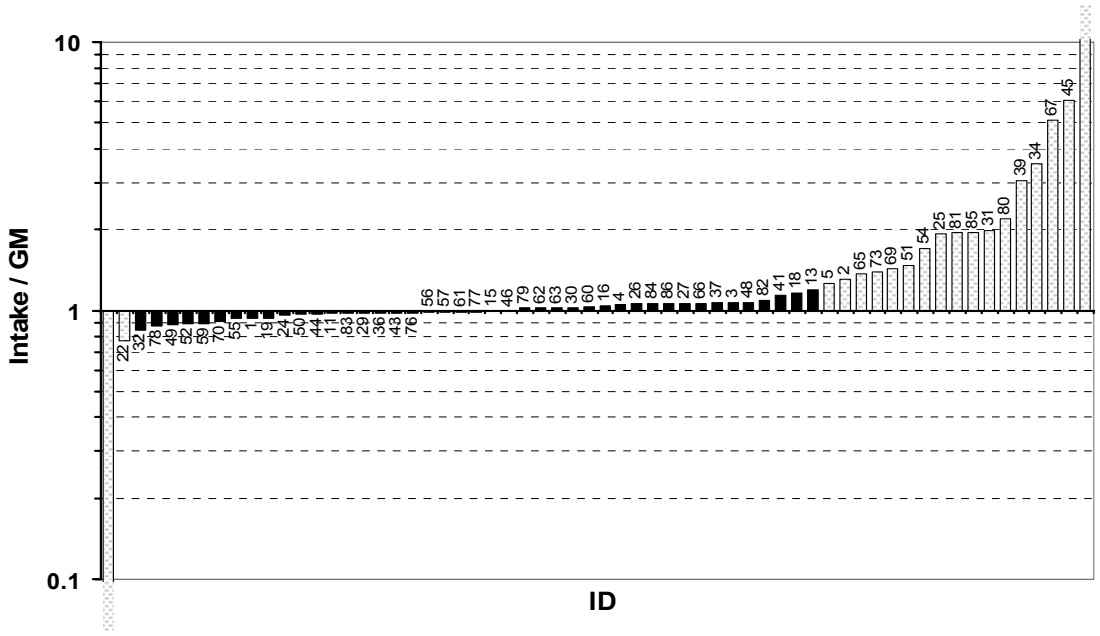


Fig. 10.6. Results of the individual participants (ID): Intakes of ^{60}Co normalized to the geometric mean. (GM = 395 kBq; GSD = 1.08) The grey patterned columns are outliers.

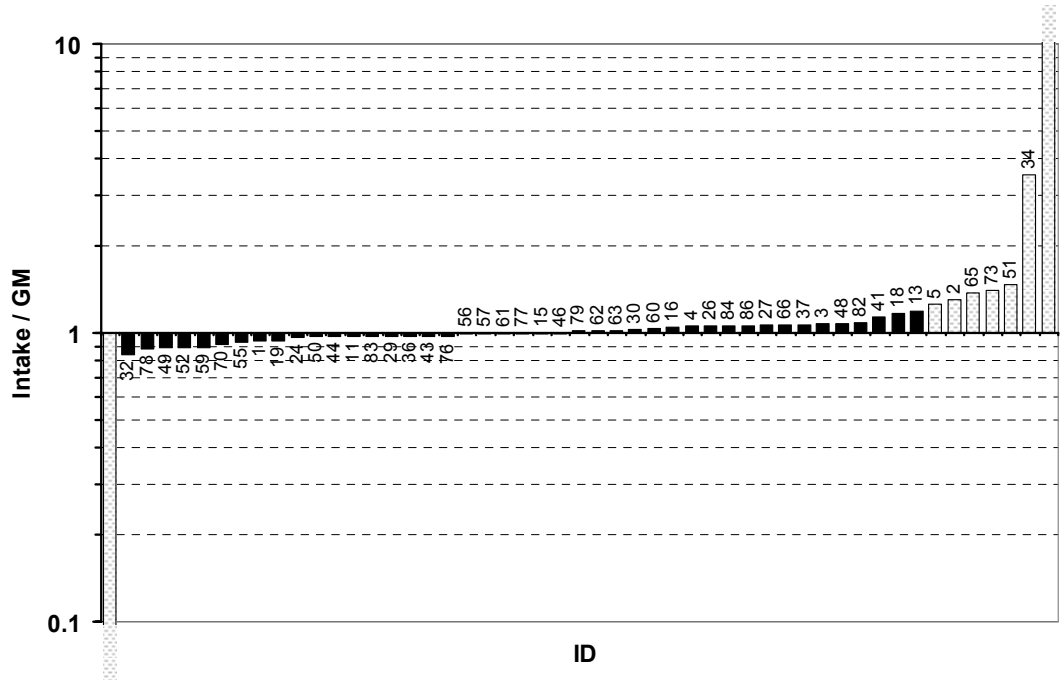


Fig. 10.7. Results of the individual participants (ID) who assumed 5 μm AMAD : Intakes of ^{60}Co normalized to the geometric mean (GM = 395 kBq; GSD = 1.08; N=43). The grey patterned columns are outliers.

10.3.3.2. Dose

For the committed effective dose E(50) the GM (5.0 mSv) is equal to the result evaluated by following the IDEAS guidelines (5.0 mSv) (Table 10.1 and 10.4). The GSD is 1.4.

For E(50), excluding outliers, the range is 2.73 – 9.45 mSv (ratio max/min = 3.5). However, including outliers the range is very large: 0.4 – 92 mSv (ratio max/min = 230).

The graphical representations of E(50) normalized to the GM are given in Figures 10.8 and 10.9.

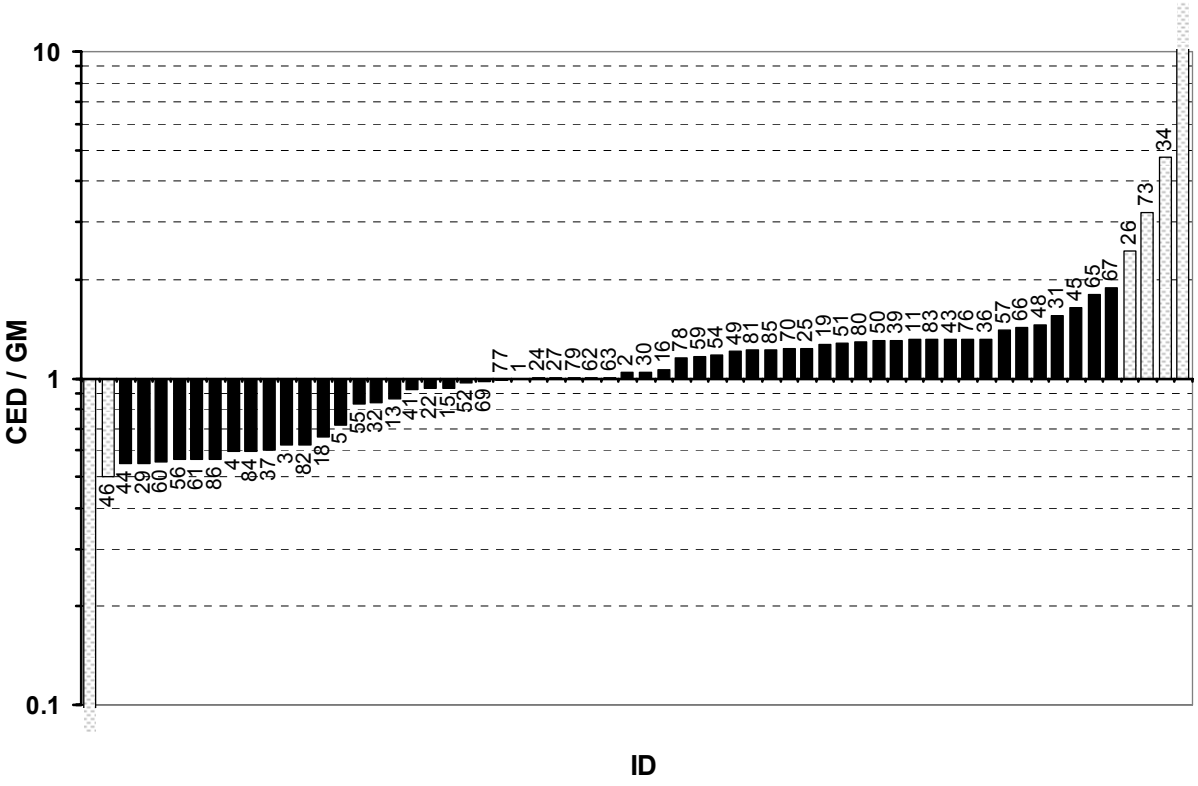


Fig. 10.8. Results of the individual participants (ID) for ^{60}Co: E(50) normalized to the geometric mean (GM = 5.0 mSv; GSD = 1.40, N = 56). The grey patterned columns are outliers.

10.3.4. Route of intake

All the participants assumed an acute inhalation only participant 51 assumed a mixture of inhalation and ingestion (60 % inhalation, 40 % ingestion).

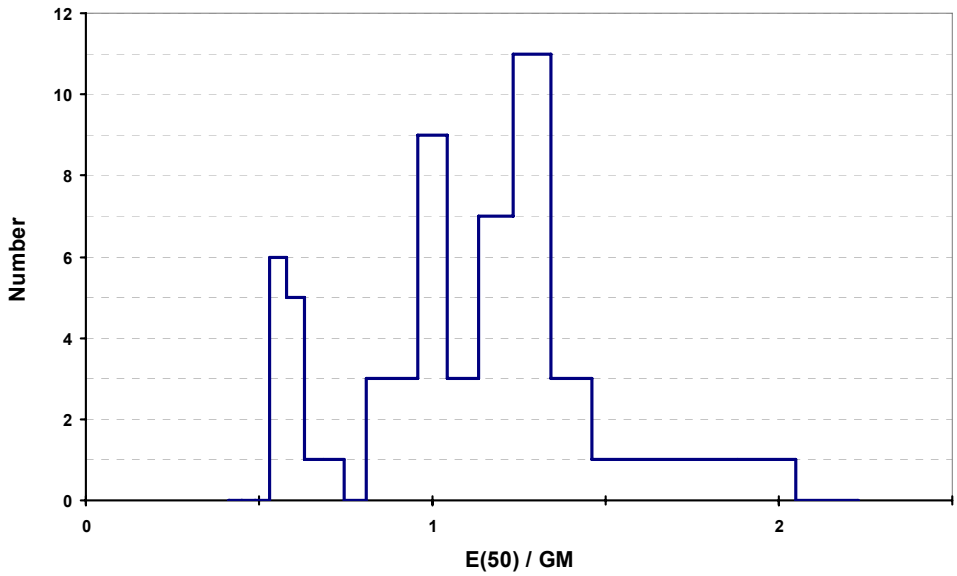


Fig. 10.9. Frequency distribution of results without outliers for ^{60}Co. E(50) normalized to the geometric mean (GM = 5.0 mSv; GSD = 1.40, N = 56).

10.3.5. Models assumed

Nearly all the participants used bioassay quantities and dose coefficients based on the ICRP Publication 66 Human Respiratory Tract Model[1] (HRTM), the ICRP Publication 30 Gastrointestinal Tract model[18], the ICRP Publication 67 systemic biokinetic model for Cobalt[2] and the f_1 values recommended in ICRP Publication 68[20].

Two of the participants (60 and 86) used a f_1 value of 0.05, recommended in ICRP Publication 30, for a Type M material. This resulted in a slightly lower dose coefficient (6 % lower) compared with the value given in ICRP Publication 68[20] for Type M (f_1 = 0.1) material.

The ICRP Publication 67 systemic biokinetic model for Cobalt[2] is the same as the one given in ICRP Publication 30[18] apart from the modeling of the excretion process, where the excretion path is via the urinary bladder and the upper large intestine. For ^{60}Co, the increase in the effective dose due to the excretion process is small (about 2 %).

10.3.6. Absorption assumptions

The case description gave the chemical form of the inhaled material as metallic Cobalt or Cobalt oxide. ICRP Publication 68[20] recommends Type S for cobalt oxide and Type M for unspecified compounds.

Thirteen participants assumed Type M, 24 participants assumed Type S, 19 participants assumed a mixture of Type M and Type S, and 5 participants assumed specific absorption parameter values. Only one participant assumed Type F, which is incorrect.

It was not possible to obtain adequate fits to both the urine and whole body data assuming Type M or Type S. By following the IDEAS guidelines it is was possible to determine the mixture of absorption Types by fitting the predicted amounts to both the urine and whole body data (step 5.13 of guidelines).

Twenty two of the participants used both data sets to determine the mixture of absorption Types or specific absorption parameter values. However, participant 24 used the whole body data alone to determine the mixture of absorption Types.

The results of E(50) are correlated with the assumed absorption Type (Figure 10.10).

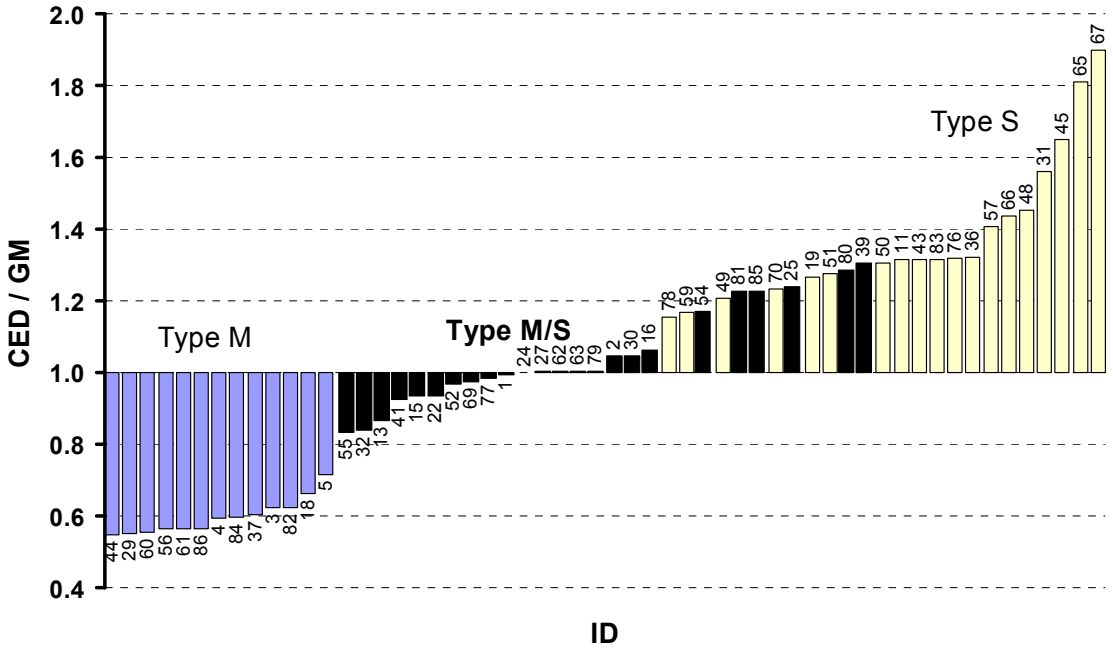


Fig. 10.10. Comparison of results between different absorption assumptions for the individual participants (ID). E(50) normalized to the geometric mean (GM = 5.0 mSv; GSD = 1.40; N = 56; without outliers). The columns labeled Type M/S includes those 5 participants that assumed specific absorption values.

The dose, E(50) is sensitive to the lung to blood absorption assumptions (Figure 10.10 and Table 10.5). If the material is assumed to be Type S then E(50) is higher compared with that of Type M. This is because the lower the solubility of the material the longer it stays in the lung, increasing the dose to the lung.

Table 10.5. Comparison of results for E(50) between different absorption assumptions[(a)]

Statistics for E(50) distributions	Type M	Type M/S[(b)]	Type S
N	13	24	19
GM	2.96 mSv	5.12 mSv	6.85 mSv
σ_g	1.08	1.14	1.15
Min	2.73 mSv	4.14 mSv	5.75 mSv
Max	3.56 mSv	6.50 mSv	9.45 mSv

(a) Without the outliers for dose given in Table 10.3. The outliers calculated for each group based on the statistical criteria given in Section 7.5 are the same as given in Table 10.3.

(b) Includes the result where the assessors assumed specific absorption values; (only 5 participants assumed specific absorption values).

10.3.7. AMAD assumed

Ten participants varied the AMAD from its default value of 5µm and obtained values between 10 and 20µm. One of the effects of having a higher AMAD is estimation of a higher intake, as the amount deposited in the lung is lower compared with that from a 5µm AMAD aerosol. The intake is much more sensitive to the assumed AMAD than the assessed dose.

For a given lung activity the amount of activity cleared by particle transport to the GI tract is larger for large AMAD values (10 to 20µm). Thus, assuming larger AMAD values increases the amount of activity passed to the blood via the GI tract. To compensate for this, the fitted mixture of absorption types have a lower Type M component than that obtained for a 5µm AMAD aerosol (Table 10.3).

The fit to the urine data improves for larger AMAD values. However, it is difficult to determine the AMAD unless suitable early data is available. For example, the IDEAS guidelines suggest estimating the effective AMAD from the ratio of faecal activity excreted over the first few days to the activity in the deep lung at early times.

In this case no early data was available.

10.3.8. Measurement uncertainties

The type of measurement distribution assumed and the magnitude of the measurement uncertainty determines the relative weighting of the data in the fitting process. Also the measurement uncertainty is a parameter in the chi-squared test that can be used to decide whether the fit is adequate or not. For these reasons it is important to assess realistic measurement uncertainties (steps 5.1 and 2.1 of the guidelines).

The case description recommended the assessor to assume that both, the urine and the whole body measurements, are lognormally distributed. Scattering factors were given for Type A (i.e. counting uncertainties) and Type B uncertainties (i.e. other uncertainties such as calibration uncertainty) for the whole body measurements. Combining these uncertainties results in a total SF of 1.2.

All but one participant (i.e. 59 participants) used the whole body data in their assessment of intake. Thirty participants assumed the whole body measurements were lognormally distributed and out of these 15 assumed SF of 1.2. Other SF values for the whole body measurements that were assumed include 1.07, 1.18, 1.3 and 2.25.

Thirty-seven participants used both the urine and whole body measurements in their assessment of intake. For the urine measurements, 28 participants assumed lognormal distributions and out of these 21 assumed a SF of 1.8, which was the value recommended in the case description. Other SF values for the urine measurements that were assumed include 1.6, 1.3 and 1.1.

The guidelines recommend using the maximum likelihood method for fitting the predicted values to the measurement data to estimate the intake. For this method, it is necessary to define the measurement distribution (i.e. the likelihood function).

As stated above, the case distribution recommended a lognormal distribution. However, some of the participants assumed a normal distribution and this has resulted in a different estimation of intake. Generally, assuming a normal distribution instead of a lognormal distribution will make little difference to the estimated intake if the fit to the data is good. In this case, assuming a normal distribution (with relative uncertainties) instead of a lognormal distribution results in differences of about 8 % and 2 % in the estimated intake and dose respectively, when fitting a mixture of absorption types to both the whole body and urine measurements.

It is worth pointing out that the weighted least squares method is the mathematically equivalent to the maximum likelihood method if a normal distribution is assumed and when none of the data are reported as being less than the limit of detection.

10.3.9. Software used

The most frequently used software codes were IMBA, IMIE and LUDEP. Twenty participants used IMBA whereas five used IMIE and four used LUDEP.

Other codes that were used include MONDAL, AIDE, BKFIT, CINDY, INDOS, INDAC, IDEAS DV0102, IDEA system, INDO 2000, MMK-01 and NIRS. One participant stated that he had used Mathematica and Microsoft Excel, whereas eleven participants declared that they had not used any software.

10.3.10. Use of guidelines

Almost 50 % of the participants (i.e. 28 of them) stated that they followed the IDEAS guidelines. Those that did not follow the guides gave the reasons summarized in Table 10.6.

Table 10.6. Reasons not to follow the guidelines

Reason	Number of participants
Followed own established procedures	8
Did not have the software to follow the guidelines strictly	5
Guidelines not clear enough	4
No time to read guidelines	1
Guidelines not available	3
No comment	12

Table 10.7 compares the statistics between the participants that declared that they followed the guidelines and those that did not.

Table 10.7. Comparison of results for 60Co between participants that declared that they followed guidelines and those that stated that they did not[(a)]

	All participants		Did not follow guidelines		Followed guidelines	
	Intake[(b)]	E(50)	Intake[(b)]	E(50)	Intake[(b)]	E(50)
N	43	56	23	30	20	26
GM	395 kBq	5.0 mSv	400 kBq	4.76 mSv	390 kBq	5.23 mSv
σ_g	1.08	1.40	1.06	1.50	1.09	1.25
Min	333 kBq	2.73 mSv	350 kBq	2.74 mSv	333 kBq	2.73 mSv
Max	470 kBq	9.45 mSv	460 kBq	9.45 mSv	470 kBq	8.20 mSv

(a) Without the outliers given in Table 10.3.
(b) The statistics for the intake data are evaluated for the data where the assumed AMAD was 5 μm

The GM of E(50) for each group is similar and close to 5.0 mSv (the value obtained by following the guidelines).

For E(50), the GSD for those that had followed the guidelines is significantly smaller than the GSD for those that did not follow the guidelines (Table 10.7). In other words, the range of doses is smaller for the group that declared that they had followed the guidelines.

This is because out of those that declared that they had followed the guidelines only one participant assumed Type M. The others were assuming either Type S or a mixture of Type M and Type S (Figure 10.11).

In comparison those that did not follow the guidelines assumed Type M, Type S or a mixture of Type M and Type S (Figure 10.12).

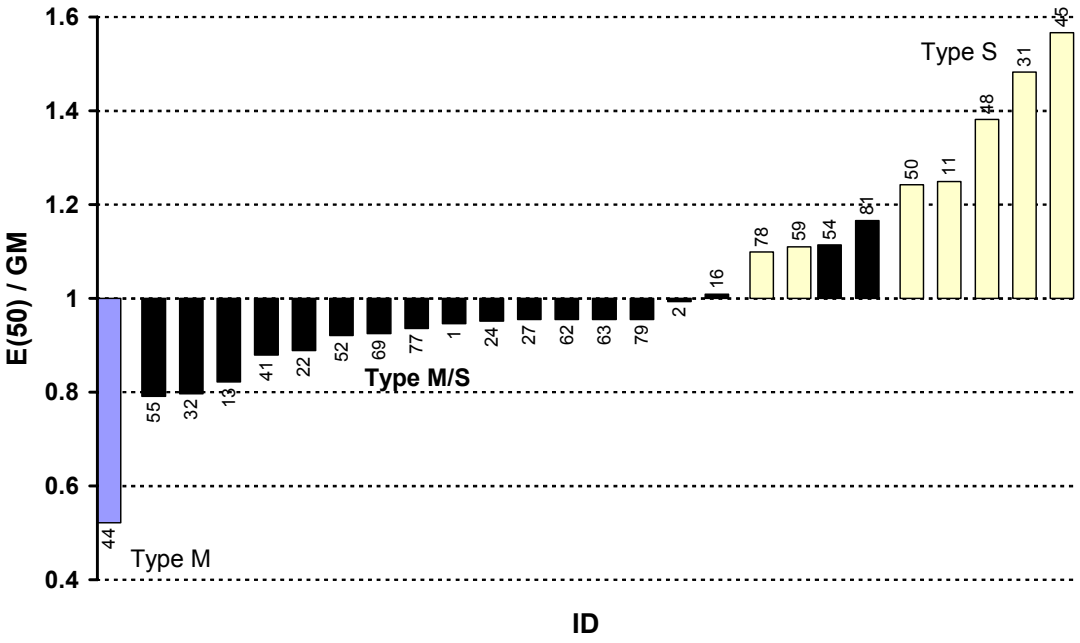


Fig. 10.11. Comparison of results between different absorption assumptions for the individual participants (ID) that had declared that they had followed the Guidelines. E(50) normalized to the geometric mean (GM = 5.23 mSv; GSD = 1.25, N = 26; without outliers) The black columns labelled Type M/S include those four participants that had assumed specific absorption values.

The participants, who had declared that they had followed the guidelines reported the final step number (Table 10.8). If the participants had followed the guidelines correctly using both data sets then the final step number should have been 5.15.1 via 5.15.

By fitting a mixture of absorption types to the data (step 5.13) the estimated intake is 404 kBq and the resultant E(50) is 5.0 mSv.

Out of the 29 participants, that declared that they had followed the guidelines, 14 fitted a mixture of absorption types. For this group the GM is 5.1 mSv with a GSD of 1.09.

It should be noted that if only the whole body data is used in the assessment then an acceptable fit is obtained assuming Type S. This gives an intake of 361 kBq with an E(50) of 6.0 mSv. However, as the dose is not less than 6 mSv (step 5.11.2), the guidelines suggest fitting a mixture of absorption types to the data. This should lead to an intake of 394 Bq and an E(50) of 5.1 mSv.

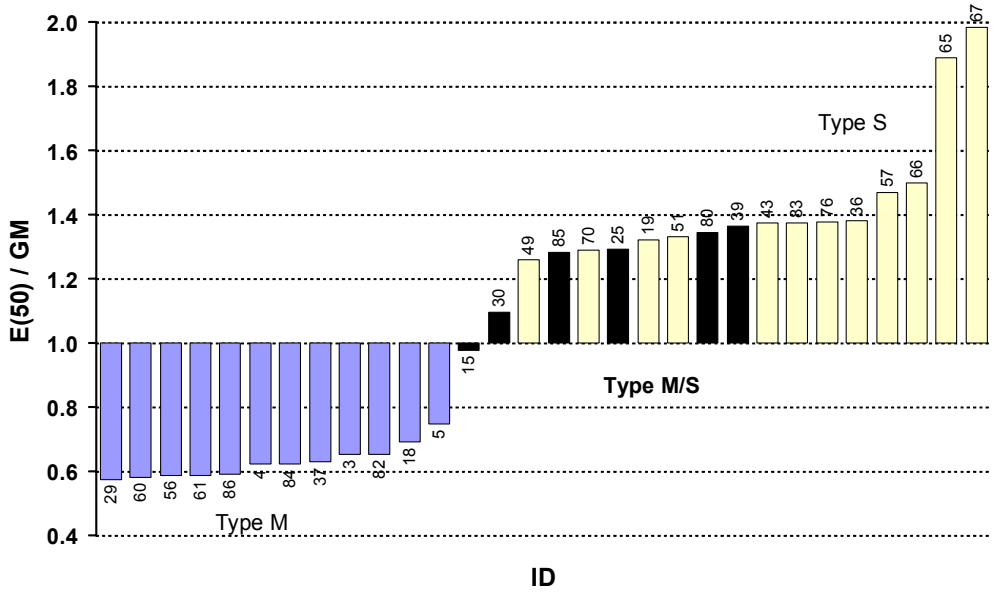


Fig. 10.12 Comparison of results between different absorption assumptions for the individual participants (ID) that had declared that they had not followed the Guidelines E(50) normalized to the geometric mean (GM = 4.76 mSv; GSD = 1.50, N = 30; without outliers). The black columns labelled Type M/S includes participants 39 that had assumed specific absorption values.

Table 10.8. Final step numbers reached by the participants who had followed the guidelines

Absorption	Number of participants	Final step number	Comment
Type M	1	5.11.3	Used whole data only and assumed large uncertainties (SF=2.25)
Type M/S	**14**	**5.15.1 (via 5.15)[a]**	**Fitting a mixture of default absorption types gives an acceptable fit to both data sets (whole body and urine).**
Specific	4	5.15.1 (via 5.17)	Specific absorption types were determined[b]
Type S	1	5.11.3	Fitting Type S to whole body data only gave an acceptable fit.
	3	5.15.1 (via 5.15)[c]	Two of the participants only selected some of the data.
	1	3.3	Initial assessment with default parameter values carried out only.
	2	5.14 & 1.3	Unclear why these final step numbers were given

(a) This was the final step that the participants were expected to reach. For this group the GM is 5.1 mSv with a GSD of 1.09.
(b) Participant 32 varied the particle transport rates to improve the fit to the urine data (step 5.19).
(c) Participant 50 noted that a component of the inhaled material was Type M but decided to assume Type S as it would make little difference to the dose.

10.4. Conclusion for Case 3

This case was an artificially generated case designed to illustrate the IDEAS guidelines. By following the guidelines an intake of 404 kBq of ^{60}Co by inhalation is estimated. The resulting E(50) is 5.0 mSv.

Sixty two participants assessed this case. For the assessed doses there >were only 6 outliers. Excluding outliers the distribution of the E(50) >results had a GSD of 1.4.

Excluding outliers the GM of the assessed doses is 5.0 mSv and the GSD is 1.4. The GM is equal to the assessed E(50) obtained by following the guidelines.

Excluding the outliers the range is 2.73 – 9.45 mSv (ratio max/min = 3.5).

The assessed dose is dependent upon the absorption assumptions. It was not possible to obtain adequate fits to both, the whole body and urine data, with the ICRP default absorption Types M and S used alone. However, by following the guidelines, good fits were obtained to both data sets by fitting a mixture of absorption these two types. Twenty four of the participants assumed a mixture of absorption types or specific absorption parameter values. For this group the GM is 5.1 mSv and the GSD is only 1.14.

Almost 50 % of the participants (i.e. 29 of them) stated that they had followed the IDEAS guidelines. Out of these 14 participants had fitted a mixture of absorption types and had reached the expected final step (i.e. step 5.15.1 via 5.15). For this group the GM is 5.1 mSv and the GSD is only 1.09.

11. CASE 4: REPEATED INTAKE OF ^{131}I

11.1. Case description

11.1.1. The event

Description of the working area	Chemical laboratory in a medical institution.
Characteristics of work	Preparing and handling radiopharmaceuticals of ^{131}I for therapeutic purposes.
Reasons for monitoring; initiating event	This type of work with highly radioactive material had just started in the laboratory. The person who did the work carried out the same procedure, handling the same amount of radioactive material on three consecutive days of the week, namely on Tuesday, Wednesday and Thursday. During the work no uncommon event was observed. On the following Monday the person was routinely monitored via thyroid measurement.
Actions taken	Because a high level of ^{131}I activity was measured in the thyroid, the measurement was repeated on the following 2 days.

11.1.2. Additional information

Air monitoring	Not available
Chemical form	Elementary iodine
Physical characteristics, particle size	Vapour
Nose swab, bronchial slime or similar	None
Non removable skin contamination	None
Wound site activity	N.A.
Any intervention used (blocking, chelating, etc.)	None

11.1.3. Body monitoring data

Organ activity measurement

Week days (d)	Time after the first day of handling (d)	Thyroid activity of ^{131}I (Bq)	Comment
Tuesday	0		1st day of handling
Wednesday	1		2nd day of handling
Thursday	2		3rd day of handling
Friday	3		
Saturday	4		
Sunday	5		
Monday	6	2.1E+04	1st day of measurement
Tuesday	7	2.5E+04	2nd day of measurement
Wednesday	8	1.5E+04	3rd day of measurement

Whole body activity measurement None

11.1.4. Excretion monitoring data

Urine activity measurement None
Faeces activity measurement None

11.1.5. Personal data

Sex Female
Age 28 years
Weight 60 kg

11.1.6. Other comments relevant for intake and dose estimation

Estimate the total intake during the three day working period and the corresponding committed effective dose E(50).

11.2. Generation of data set

The data set was generated artificially assuming an acute intake of 40 kBq of ^{131}I on each day of the three day working period. Thus, these intakes during the three consecutive days (a total

of 120 kBq) would give a committed effective dose of 2.40 mSv applying the appropriate dose coefficient of 2.0 10^{-8} Sv/Bq (ICRP 68[20] & ICRP 78[6]).

One table of ICRP 78 (page 79) provides the values of intake retention fractions that is the ^{131}I thyroid activities for inhalation of 1 Bq of ^{131}I as a vapor (Bq per Bq intake).

These values can be used to calculate thyroid activities for 1 Bq/d acute intake on the three day working period as well as on the days of measurements. These values are presented in Table11.1.

Table 11.1. Thyroid activities for 1 Bq/d over the 3-day working period

Week days [(d)]	**Thyroid activity (Bq)**			
	Intake on Tuesday (1 Bq)	Intake on Wednesday (1 Bq)	Intake on Thursday (1 Bq)	Horizontal sum (Bq for 1 Bq/d over the three day working period)
Tuesday				
Wednesday	2.3E-01			
Thursday	2.2E-01	2.3E-01		
Friday	2.0E-01	2.2E-01	2.3E-01	
Saturday	1.9E-01	2.0E-01	2.2E-01	
Sunday	1.7E-01	1.9E-01	2.0E-01	
Monday	1.5E-01	1.7E-01	1.9E-01	5.1E-01
Tuesday	1.4E-01	1.5E-01	1.7E-01	4.6E-01
Wednesday	1.3E-01	1.4E-01	1.5E-01	4.2E-01

In generating the data set it was assumed that:

- Gas/Vapor class: SR-1
- Absorption Type: Type F
- f_1 value: 1.0

The predicted thyroid activities were generated with IMBA internal dose assessment code the results of which can be seen in Table 7.2. Uncertainties (i.e. scatter of data) were then included by assuming that the measurements follow a lognormal distribution with a geometric standard deviation (i.e. SF) of 1.2.

Table 11.2. Generation of data set

Week days (d)	Time after the first intake (d)	Acute Intake (Bq)	Predicted thyroid activity of ^{131}I (Bq)	Measured thyroid activity of ^{131}I (Bq) Includes uncertainty	Comment
Tuesday	0	4.0E4			1st day of handling
Wednesday	1	4.0E4			2nd day of handling
Thursday	2	4.0E4			3rd day of handling
Friday	3				
Saturday	4				
Sunday	5				
Monday	6		2.03E+04	2.1E+04	1st day of measurement
Tuesday	7		1.85E+04	2.5E+04	2nd day of measurement
Wednesday	8		1.68E+04	1.5E+04	3rd day of measurement

Three estimates of the intake per day can be obtained from the three measurements:

1st day measurement: $2.1\ 10^4$ Bq; thus intake per day is: $2.1\ 10^4/5.1\ 10^{-1} = 41.2$ kBq/d.

2nd day measurement: $2.5\ 10^4$ Bq; thus intake per day is: $2.5\ 10^4/4.6\ 10^{-1} = 54.4$ kBq/d.

3rd day measurement: $1.5\ 10^4$ Bq; thus intake per day is: $1.5\ 10^4/4.2\ 10^{-1} = 35.7$ kBq/d.

The best estimate of the intake per day is given by the geometric mean of the three estimates, as suggested in the IDEAS Guidelines if assuming the measurements lognormally distributed with a constant geometric mean (SF=1.2).

Best estimate of intake per day is 43.2 kBq, Therefore the rounded total intake during the three day working period is 130 kBq. From this the committed effective dose can be calculated as: $1.3\ 10^5 \times 2.0\ 10^{-8} = 2.6\ 10^{-3}$ Sv = 2.6 mSv.

11.3. Assessment of case

After the routine thyroid measurement on the 6th day (Monday) it turned out, that a significant intake had occurred in the monitoring period. It is obvious to assume that the intake occurred during the working period in the previous week. Since the same chemical procedures were repeated on each working day, we can assume that the intake probability is uniformly distributed over the three days.

In the given case one can assume either three acute intakes of same amount of radionuclide in the three consecutive days or chronic intake pattern over the whole working period.

Let us assume repeated acute intakes. The case description clearly defines the chemical and physical forms that make obvious to assume the intake pathway as inhalation. On this basis one can identify the respiratory tract deposition pattern (see ICRP 68 and 78) as Class SR-1 for soluble or reactive gases with subsequent behaviour of absorption of Type F.

The following sections describe the assessment of the case by following the IDEAS Guidelines.

11.3.1. Step 1.1: Identify monitoring value M

The monitoring value has been identified on Monday as a significantly high activity of ^{131}I radionuclide deposited in the thyroid of the worker who was assigned to routine monitoring. Since ^{131}I was the only radionuclide involved in the working procedure, no intake from other isotope is assumed.

11.3.2. Step 1.2: Compare measurement with critical monitoring quantity M_c

According to the Guidelines one has to compare the monitored value with a limit below which no further action is needed. In the present case the measured thyroid activity of 21 kBq is much higher than 26 Bq given in the related table of the guidelines, so further steps have to be taken for intake and dose assessment.

11.3.3. Step 2.0: Understanding the case

Rough dose assessment can be done based on the first measurement by most conservative assumptions, that is assuming the time of intake occurring at the first working day.

The simple calculation is as follows:

Intake: $2.1\ 10^{4} / 1.5\ 10^{-1} = 1.4\ 10^{5}$ Bq
Committed effective dose: $1.4\ 10^{5} \times 2.0\ 10^{-8} = 2.8\ 10^{-3}$ Sv

These values necessitate further investigations by repeated measurements as it is demonstrated in the case description. The thyroid activity measurement on the second day showed higher value ($2.5\ 10^{4}$ Bq) that can be explained by the overall monitoring uncertainty because no other possibility of additional intake can be expected based on the case description. This assumption has been confirmed by the result of $1.5\ 10^{4}$ Bq on the third day of measurement that properly corresponds to the expected decrease of thyroid activity. According to the first dose assessment the level of contamination exceeds the category of Level 1 defined in the Guidelines.

11.3.4. Step 2.1: Assessment of the uncertainty on M

Since no uncertainty data were given for the monitored activity values in the case description, we should take the suggested value from the guidelines. In case of in vivo measurements a lognormal distribution is assumed with a SF of 1.2, where SF is the geometric standard deviation of the lognormal distribution.

11.3.5. Step 2.2: Contributions from previous intakes

It is clear from the case description that no previous intakes have to be taken into account. The level of expected dose points directly to a continuation with Step 4.

11.3.6. Step 4.1: Identification of pathway of intake for special evaluation above Level 1

It is evident from the case description that the way of intake was pure inhalation. In this case the special evaluation procedure given in Step 5 of the Guidelines should be applied.

11.3.7. Step 5.1: Identification of data and assignment of realistic uncertainties

According to the first evaluation (Step 2.0) the received dose most probably exceeds 1 mSv, consequently more than one measurement for a reliable dose assessment is required. There are three measurement results available in this case, which is in good agreement with the suggestion given in the guidelines.

Since no uncertainty values are given for the measurements a scattering factor of 1.2 is assumed as default (Step 2.1).

11.3.8. Step 5.2: Assessment of contributions from previous intakes

Based on the case description no previous intake is assumed (Step 2.2).

11.3.9. Step 5.3: Assign a priori parameters (default or site specific)

In the case description the chemical form of the material was given as elemental Iodine and the physical form as vapor.

The ICRP default parameter values assumed are:

- Gas/Vapor class: SR-1
- Absorption Type: Type F
- f_1 value: 1.0
- Reference worker

11.3.10. Step 5.4: Is the time of intake known?

The exact time of intake is unknown however the most probable time period according to the case description (three days of work) can be considered as well defined either assuming three

acute intakes occurred on the three consecutive working days or simply assuming chronic intake during the whole working period.

11.3.11. Step 5.5: Calculate dose with a priori parameters

In the Step 2.0 a rough conservative estimate of the received dose has already been done, now this is the right stage to calculate the internal dose more precisely, considering all three measured results. The simplest way is to carry out the calculation manually. Assuming uniform, repeated, acute intake pattern and using the notation of M_1, M_2 and M_3 as the measured thyroid activities on the first, second and third monitoring days respectively.

Measurements:

$$M_1 = 2.1\ 10^4\ \text{Bq}$$

$$M_2 = 2.5\ 10^4\ \text{Bq}$$

$$M_3 = 1.5\ 10^4\ \text{Bq}$$

In order to calculate the expected intakes from the monitored data the intake retention fractions (m(t)) for the thyroid should be used, considering the different times between the days of possible intakes and the days of measurements. These values can be found in various publications among others in the IAEA Safety Report Series No.37 or in ICRP Publication 78. In our case these values are as follows:

Intake retention fractions: $m(t = 4d) = 0.19$

$m(t = 5d) = 0.17$

$m(t = 6d) = 0.15$

$m(t = 7d) = 0.14$

$m(t = 8d) = 0.13$

The calculated total intakes for each monitoring day are given as I_1, I_2 and I_3 taking into account the sum of all three acute intakes and assuming the same daily intakes during the whole exposure period:

These intakes can be expressed in the following way:

$$I_1 = 3 \times 2.1\ 10^4 / (0.15 + 0.17 + 0.19) = 1.24\ 10^5\ \text{Bq}$$
$$I_2 = 3 \times 2.5\ 10^4 / (0.14 + 0.15 + 0.17) = 1.63\ 10^5\ \text{Bq}$$
$$I_3 = 3 \times 1.5\ 10^4 / (0.13 + 0.14 + 0.15) = 1.07\ 10^5\ \text{Bq}$$

Deriving the average total intake (I) by calculating the geometric mean of the three values:

$$I = \sqrt[3]{(I_1 \times I_2 \times I_3 / 3)} = 1.29\ 10^5\ \text{Bq}$$

The committed effective dose due to the above total intake:

$$E(50) = e(50) \times I = 2.0\ 10^{-8}\ Sv/Bq \times 1.29\ 10^{5}\ Bq = 2.58\ 10^{-3}\ Sv$$

Alternatively, the best estimate of intake can be determined using appropriate internal dosimetry software like IMBA, IMIE or MONDAL2. In the following table the results obtained by applying different methods, software tools and assumptions on intake patterns are compared.

Table 11.3. Calculated intake and dose depending on the assumptions and tools used

Tools	**Assumptions**	**Total intake** (kBq)	**CED-E(50)** (mSv)
Manual	Repeated acute	129	2.58
Manual	Single acute	133	2.66
IMBA	Repeated acute	130	2.57
IMBA	Single acute	130	2.56
IMBA	Chronic	123	2.43
MONDAL2	Single acute	130	2.6
MONDAL2	Chronic	126	2.52
MONDAL2	Uneven chronic	130	2.6
IMIE	Single acute	125	2.46

It is seen that the preliminary rough dose estimation (Step 2.0) did not give a very much different result from that based on more precise evaluations.

11.3.12. Step 5.6: Is E(50) < 1 mSv?

Making any assumption one has to follow the Guidelines at Step 5.7 in any case since the preliminary dose assessment showed significantly higher value than 1 mSv.

11.3.13. Step 5.7: Are there sufficient relevant data?

The guidelines suggest a minimum number of data that is required for a dose assessment for certain radionuclides. The minimum number suggested depends on the dose level. For ^{131}I the minimum number is three thyroid measurements over a time period of seven days if the dose level is greater than 1 mSv. In this case, there are three thyroid measurements. Therefore there are enough data for this dose assessment, so proceed to the next step.

11.3.14. Step 5.8: Is the time of intake known?

The time of intake is known so proceed to step 5.9.

11.3.15. Step 5.9: Are early and lung faeces available?

This step is not relevant in this case so proceed to step 5.11.

11.3.16. Step 5.11: Assessment of dose by fitting absorption type

In this step intakes and doses are assessed using the default absorption types. Since in the case description the compound and physical form of the inhaled material are defined as elemental Iodine in vaporous form, the question is whether the corresponding default absorption type provides a good fit or not. A check is made on the Goodness of Fit (Step 5.11.1) using this default absorption type.

11.3.17. Step 5.11.1: Is the goodness of fit acceptable?

The guidelines suggest rejecting the fit if the chi-squared test (χ^2) fails (if p-value < 0.05). In other words if the fit is inadequate at the 5 % level of significance, or if the fit displayed graphically looks unreasonable by eye.

Making the chi-squared test by means of the IMBA software a p-value of 0.261 was obtained, which is higher than 0.05 so the fit is acceptable. This result can be confirmed by looking to the graphical representation of the measured data as it is shown in Figure 11.1.

Since the goodness of fit is acceptable continuation is with Step 5.11.2

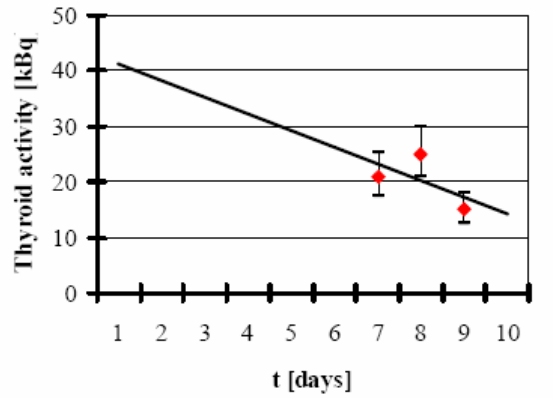


Fig. 11.1. Variation of ^{131}I activity in the thyroid.

11.3.18. Step 5.11.2: Is E(50) < 6 mSv?

As it was shown in previous sections that the calculated committed effective dose is less than 6 mSv, there is no need for further investigation. The dose assessment procedure is finished at Step 5.11.3.

11.3.19. Step 5.11.3: Record dose with all parameter values

The intake and the dose are recorded with the corresponding parameter values.

- Total intake: Repeated acute inhalation of 129 kBq of ^{131}I
- Committed effective dose, E(50): 2.58 mSv
- Gas/Vapour class: SR-1
- Absorption Type: Type F

– • $f_1 = 1.0$

– • Reference worker

11.3.20. Summary of assessments

A summary of the assessments of intake and dose is given in Table 11.4.

Table 11.4. Summary of estimated intakes of ^{131}I and resulting doses

Assessment procedure step	Absorption Type	Goodness of fit		Comment	Total intake (kBq)	E(50) (mSv)
		Chi square[(a)]	p-value[(b)]			
Data generation	SR-1 Type F	Not available		True value	120	2.40
Step 2.0	SR-1 Type F	Not applicable		First conservative estimate	140	2.80
Step 5.11.1	SR-1 Type F	2.68	0.261	Fitted results by IMBA software	130	2.57
Step 5.5 and Step 5.11.3	SR-1 Type F	Not applicable		Manual evaluation	**129**	**2.58**

(a) The expected value of Chi square is equal to the number of degrees of freedom; (i.e. number of data points – 1 = 2).

(b) The p probability value shows the goodness of fit. If the value is greater than the chosen level of significance (here 0.05) then the fit is acceptable.

It is worth noting that either the simple manual calculation or the application of any sophisticated software provided very similar results. All obtained results are a bit higher in comparison with the true values, which can be explained by the scattered monitoring values and related uncertainties when the data were generated.

11.4. Results of intercomparison exercise

11.4.1. Introduction

This case is an artificially generated case designed to illustrate the use of IDEAS guidelines.

In Section 11.2 the data generation procedure is described. The case is characterizing a situation when the intake has been discovered in the course of routine monitoring of potentially exposed workers. However the working conditions practically identify the most probable time(s) of intake which allows to handle the monitoring data according to the guidelines as results of. special monitoring.

The case was also created to simulate multiple and/or protracted intake conditions. Therefore the case description provided a freedom for the assessor how to define the intake pattern. To

make the evaluation easier the physical and chemical characteristics of the ^{131}I material and consequently also the intake pathway have been defined in the case description.

Although the data were artificially generated, the description of the case tried to simulate a real situation.

Table 11.5. Summary of the main assumptions, which were considered when the case was generated:

Intake	Repeated inhalation of 120 kBq (40 kBq/day) of ^{131}I
Chemical and physical form	Elemental Iodine in vaporous form.
Deposition and absorption	SR-1 and Type F
Monitored person	Reference worker
Thyroid retention	Iodine model applied as given in ICRP Publication 78
Thyroid monitoring data	Uncertainty on each of the data points was simulated by assuming that each data value is lognormally distributed about the true value with a scattering factor (SF) of 1.2. The SF is the geometric standard deviation of the lognormal distribution.

Sixty-three evaluations have been submitted from 62 participants. This number of assessors represented 35 countries. Besides the results of intakes and doses several other information have also been given on the assumptions made by the participants and on the use of IDEAS guidelines. The main data and submitted information are summarized in tabulated form in the Annex. In the following sections these submitted results are analyzed.

11.4.2. Overall distribution of results

Assessors were asked to estimate the total intake occurred over the three working days and to calculate the corresponding committed effective dose, E(50) for the radionuclide ^{131}I.

As it was mentioned previously the full set of data was assumed to be belonging to one lognormal distribution. The statistical evaluation of the results, excluding outliers is given in Table 11.6.

Table 11.6. Characteristic parameters of the statistical evaluation (excluding outliers)

Parameters	**Intake**	**E(50)**
N	58	50
GM	160133 Bq	2.57 mSv
GSD	1.39	1.07
AM	169659 Bq	2.58 mSv
ASD	62153 Bq	0.17 mSv
Minimum	88000 Bq	2.2 mSv
Maximum	329000 Bq	3.0 mSv
Max/Min ratio	3.74	1.36.
Outliers	5	13

11.4.2.1.Intake

The GM (geometric mean) of the estimated intake of ^{131}I (160133 Bq) is very close to the AM (arithmetic mean) of 169659 Bq. The GSD (geometric standard deviation) of 1.36 for the intake is not too large and is quite similar to the value of the ASD (arithmetic standard deviation) of 62153 Bq. The ratio of the max/min value of the estimated intakes .(excluding outliers) is just within a factor of 4 which is a bit high considering the relative simple case.

The graphical representation in Figure 11.2 demonstrates the dispersion of the results

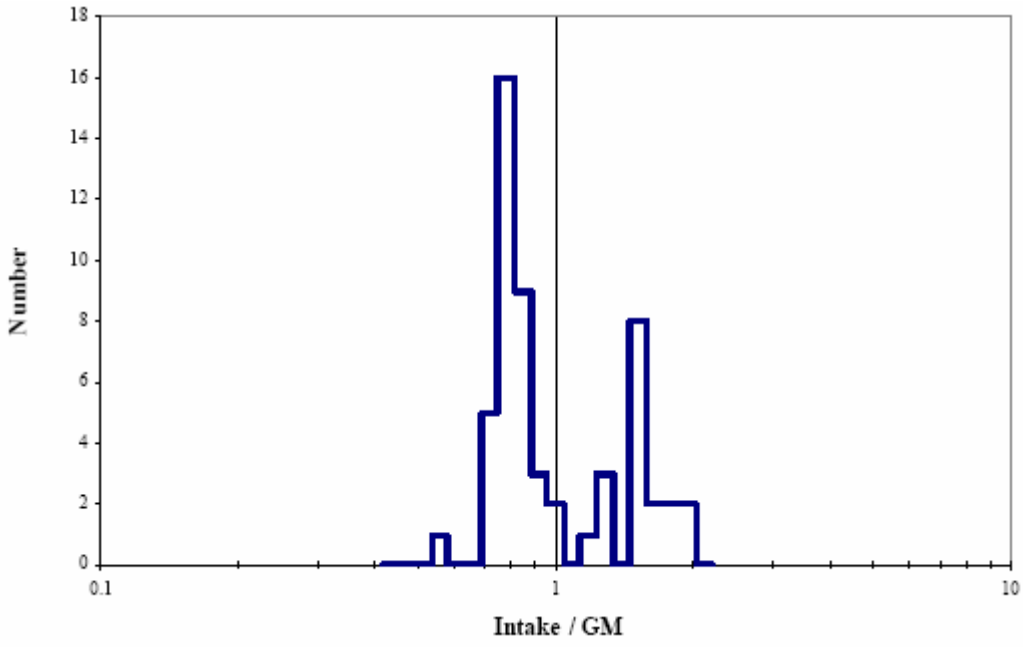


Fig. 11.2. Frequency distribution of results without outliers (N=58) ^{131}I intake normalized to the geometric mean. (GM = 160133 Bq, GSD = 1.36).

Another representation of the results on intakes can be seen in Figure 11.3 where the ratios of individual results normalized to the geometric mean are displayed. The outliers are indicated as blank columns in the figure.

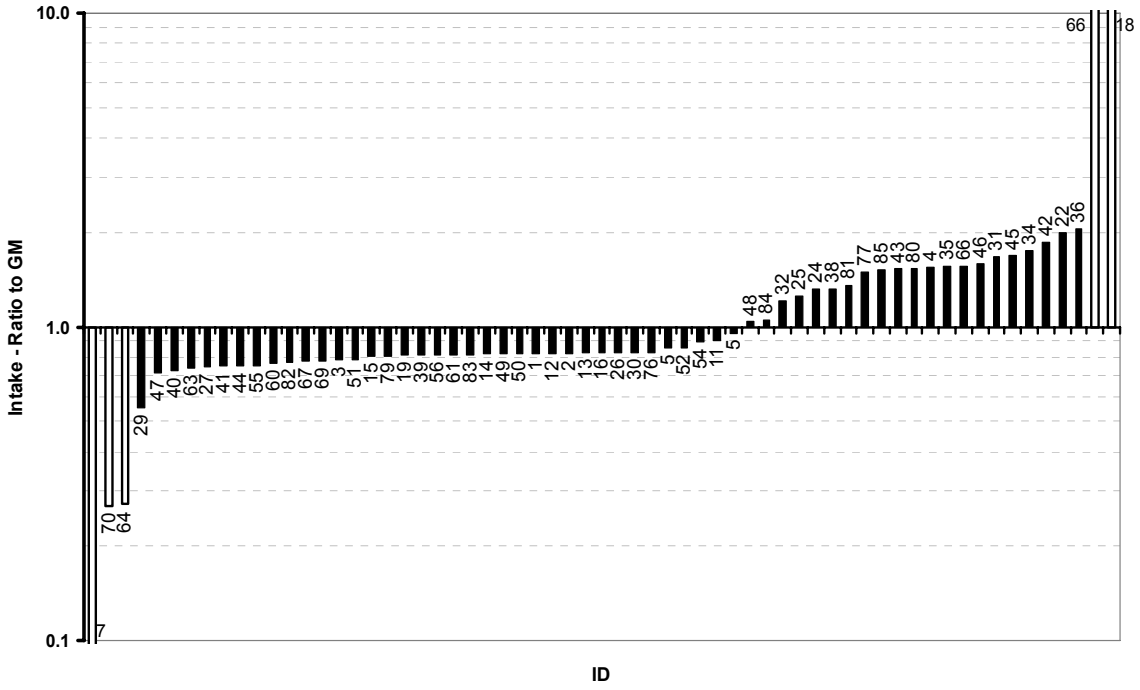


Fig. 11.3. Ratios of all individual results normalized to the geometric mean (GM = 160133 Bq, GSD = 1.36, N=58) The outliers are indicated with blank columns.

As it is well seen in Figure 11.2 a bimodal frequency distribution is characterising the results on intakes. The intake values belonging to the two modes differ from each other by a factor of about two. This is because the assumptions made by the participants can be divided into two main groups.

One group used for intake calculation the intake retention fractions (m(t)) calculated for vapours for intake calculation while the other group applied the values given for aerosols. This is obvious when looking to the following two sets of m(t) values for the thyroid:

Table 11.7. Two sets of m(t) values for the thyroid

	Radionuclide: ^{131}I	Radionuclide: ^{131}I
	Inhalation of vapour	Inhalation Type F
		5.0 micron AMAD
	f_1: 1	f_1: 1
Time (d)	Thyroid	Thyroid
1	2.30E-01	1.20E-01
2	2.20E-01	1.20E-01
3	2.00E-01	1.10E-01
4	1.90E-01	9.90E-02
5	1.70E-01	9.00E-02
6	1.50E-01	8.20E-02
7	1.40E-01	7.40E-02
8	1.30E-01	6.80E-02

The above mentioned systematic difference is responsible for the relatively high values of geometric and arithmetic standard deviations of the frequency distributions.

11.4.2.2.Dose

The GM of the estimated committed effective dose of ^{131}I (2.57 mSv) is very close to the AM of 2.58 mSv. The GSD of 1.07 for the dose shows that the submitted results on the dose are very close to each other so the corresponding frequency distribution is quite narrow. When assuming normal distribution pattern the value of ASD of 0.17 mSv is also very small and agrees well with the GSD.

Consequently also the ratio of the max/min values of the estimated dose .(excluding outliers) is 1.36 which demonstrates that the submitted data are very close to each other. Graphical representation of the frequency distribution is shown in Figure 11.4.

The results on the received dose submitted by the participants can be seen in Figure 11.5 where the ratios of individual results are normalized to the GM. Outliers are also indicated in this figure using blank columns.

As shown in the figures, the submitted results on dose are very close to each other. The surprising feature of the frequency distribution of dose values, where the bimodal distribution pattern of intake values disappeared, can be explained by different values of dose coefficients

applied in dose calculation assuming either vaporous or aerosol forms. The values of the corresponding dose coefficients are as follows:

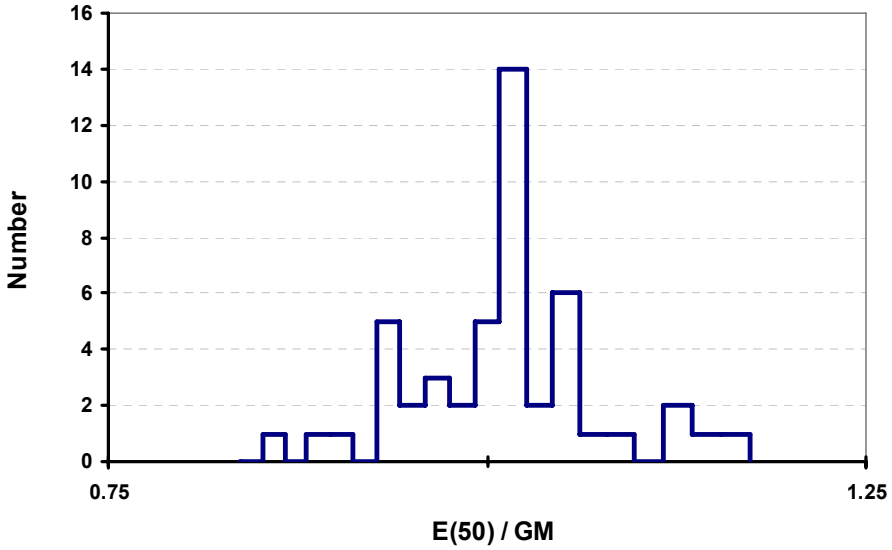


Fig. 11.4. Frequency distribution of results without outliers (N=58). Values of committed effective dose due to ^{131}I normalized to the geometric mean. (GM = 2.57 mSv, GSD = 1.07).

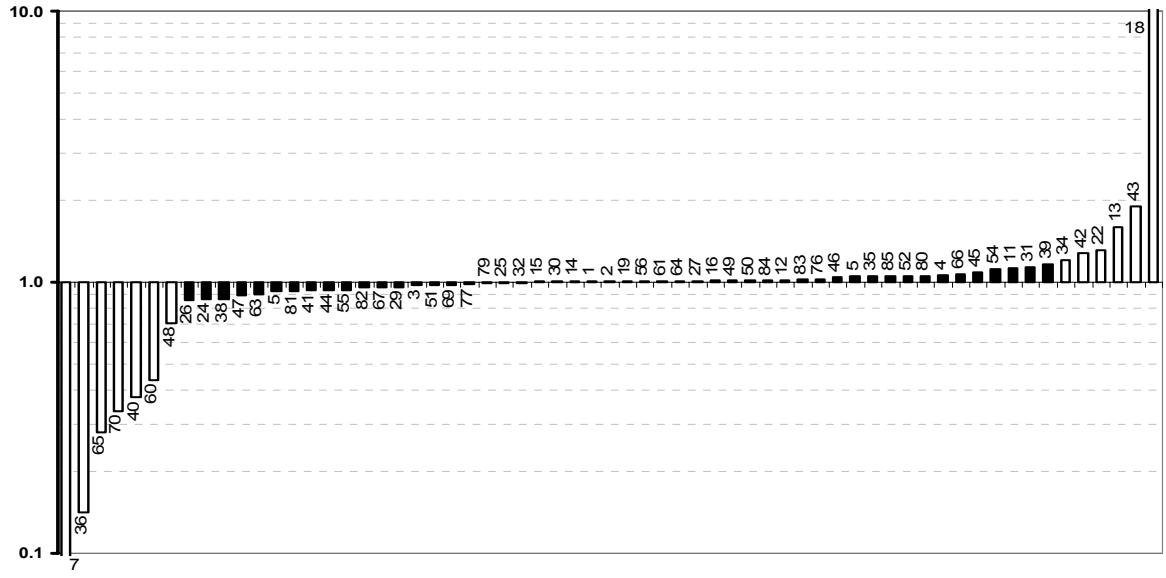


Fig. 11.5. Ratios of all individual results normalized to the geometric mean (GM = 2.57 mSv, GSD = 1.07, N=50) The outliers are indicated with blank columns.

Table 11.8. dose coefficients

Radionuclide: ^{131}I	Radionuclide: ^{131}I
Inhalation of vapour	Inhalation Type F
	5.0 micron AMAD
f_1: 1	f_1: 1
$2.0E^{-8}$ Sv/Bq	**$1.1E^{-8}$ Sv/Bq**

These values differ from each other by a factor of two. This difference was counteracted by the corresponding m(t) values. This resulted in a compensation effect for dose calculation. Through this effect, as far as dose assessment is concerned, it is irrelevant whether the participant assumed vapor or aerosol.

11.4.3. Identification of outliers

The submitted data on the assessed intake and calculated dose were statistically analyzed assuming that all the data follow one lognormal distribution. Outliers were identified by following the statistical criteria described in a previous section. According to this criteria shaded cells indicate the outlying data in the Table I-1 of the Annex and in Table 11.10. The total numbers of outliers are given in Table 11.9.

Table 11.9. Number of outliers

	Intake	E(50)
Total number of results(a)	63	63
Number of identified outliers	5	13

11.4.3.1.Intake

Applying the outlier criteria to the intake data produces only five outliers out of 63 results.

This relatively small number of outliers is partly because the broad bimodal distribution resulted in a broader range around the calculated GM according to the statistical criteria set for outlying data. There were participants (64, 70) who submitted data probably on daily intake instead of total intake which resulted in outlying data and an underestimation of the intake by a factor of 3. The possible reason of other outlying data (07, 18, 65) could not be identified.

Table 11.10. Summary table on outlying data (shaded cells and bold letters)

code	Intake [kBq]	E(50) [mSv]	Assumed pathway	Time pattern of intake[a,b]	Assumed Gas/Vapour Class [b]	Assumed Absorption Type [b]	Assumed f1 [b]
07	0.001	0.00001578	INH	SI	SR-1	F	1
13	132	4.1	INH	RI	SR-1	V	
18	9930	199	INH	CI	SR-1	V	1
22	320	3.37	INH	RI	Gas	F	1
34	281.22	3.09	INH	RI		F	1
36	329	0.363	INH	RI	SR-1	F	1
40	116.336	0.97	INH	SI	D (Fast)	F	1
42	29.8017	3.3	INH	SI	Vapour	F	1
43	245	4.91	INH	RI	SR-1	F	1
48	166	1.82	INH	CI at steps	SR-1	F	1
60	122	1.12	INH	SI		F	1
64	43.746	2.6	INH	SI	SR-1	F	1
65	2670	0.72	INH	CI	SR1		1
70	43	0.86	CHR	CI		V	

(a) SI = Single intake
RI = Repeated intake
CI = Continuous intake
CI at steps = Constant intake at steps
(b) NA = Not Applicable

11.4.3.2.Dose

Applying the outlier criteria to the committed effective dose E(50) data produces 13 outliers out of 63 submitted results. This large number of outlying data is mostly because the majority of data are very close to each other and consequently the statistical criteria for the outliers became very strict.

One participant (13) submitted fairly good result on intake but used a dose coefficient recommended for a 15 year old member of the public (which approximately corresponds in weight to females) therefore the calculated dose was too high. One participant (40) used ICRP 30 models. More data were submitted (22, 34, 36, 42, 43) where the estimated intake data proved to be acceptable, however the more strict statistical criteria for the dose defined them as outliers. Results of two participants (48, 60) had to be regarded as outliers, although they had used correct m(t) values for intake calculation but the dose coefficient was not properly chosen. One of the participants (70) submitted daily intake values, but calculated the dose due to one day intake only. The possible reason of other outlying data (07, 18, 65) could not be identified.

11.4.4. Route of intake

All the participants assumed an inhalation route of intake apart from participant 27, who assumed injection.

11.4.5. Intake pattern

The case description suggests to assume repeated uniform intake during the working days, however one may assume continuous intake in the exposure period or for simplicity just one single intake preferably on the second day of work. As it has already been shown previously, this assumption does not considerably influence the results. The assumptions made by the participants show a quite distributed picture, as it is seen in Table 11.11.

Table 11.11. Assumed intake pattern and number of participants

Assumed intake pattern	Number of participants
Repeated acute intake	24
Single acute intake	16
Continuous intake	17
Constant intake at steps	4
Not given / Not applicable	2

11.4.6. Models assumed

Nearly all the participants used intake retention fractions and dose coefficients based on ICRP Publication 66 “Human Respiratory Tract Model” including those indicated in the questionnaire like the ICRP Publication 67, 68 and 78. Only two participants referred to the ICRP Publication 30. As for the Gastrointestinal Tract Model almost all participants gave the reference to ICRP Publication 30. There are a long list of ICRP publications given by the participants on the used systemic biokinetic model such as ICRP Publication 30, 54, 56, 67, 68, 71 and 78. Practically all participants indicated the use of f_I=1 for gut absorption of iodine.

11.4.7. Absorption assumptions

The case description gave the chemical compound of the inhaled material as elemental Iodine in vaporous form. ICRP Publication 66 and subsequently Publication 68 recommend three classes for respiratory tract deposition. For elemental Iodine vapor the Class SR-1 is defined that assumes 100 % total deposition. The subsequent retention in the respiratory tract and absorption to body fluids are determined by the chemical properties of the gas or vapour. By default, reference values for an absorption type are normally Type F (absorption rate 100 d^{-1}) or Type V (instantaneous absorption). ICRP Publication 68 recommends using Type F for Iodine vapour. However in case of ^{131}I there is no difference between assuming Type F or Type V.

According to the submitted information two participants (05A, 40) assumed particle inhalation instead of vapour and one (76) defined SR-2 for the inhalation class. Out of 63 participants 40 indicated the use of Type F and 13 of Type V for respiratory absorption.

It has to be mentioned that some computer programs, used by the participants, were not able to handle iodine in vaporous form.

11.4.8. Applied dose coefficients

According to the recommendations of the ICRP the dose coefficient to be applied for ^{131}I in vaporous form is 2.0 10^{-8} Sv/Bq. Although the vast majority of participant assumed iodine in vaporous form, many of them applied dose coefficient for aerosols.

As it has already been mentioned previously, this did not cause significant error in dose assessment since the differences cancelled themselves out in intake calculations. In some cases the origin of the given dose coefficient could not be identified and surprisingly it also occurred in few cases that the given value for dose coefficient could not be derived from the submitted intake and dose values. The different dose coefficients mentioned by the participants are shown in Table 11.12.

11.4.9. Measurement uncertainties

The case description recommended the assessor to assume that the thyroid measurements follow lognormal distribution. According to the IDEAS guidelines scattering factors were indicated for Type A (i.e. counting uncertainties) and Type B uncertainties (i.e. other uncertainties, such as calibration uncertainties) for direct in vivo measurements. Combining these uncertainties produces a total SF of 1.2. It was suggested to the participants to use this value.

Eighteen participants indicated that they had assumed the thyroid measurements were lognormally distributed. Twenty-three assumed normal distribution. Altogether 34 participants provided some information on the assumed monitoring uncertainty values and only seven participants accepted the use of the suggested total scattering factor of 1.2.

Table 11.12. Dose coefficients given by the participants

Dose coefficient Sv/Bq	Number of participants
8.0 E-9	1
1.01 E-8	1
1.05 E-8	4
1.10 E-8	14
1.30 E-8	2
1.57 E-8	3
1.97 E-8	7
2.00 E-8	24
2.20 E-8	1
2.80 E-8	1
3.1 E-8	1
5.93 E-8	1
Not given	3

11.4.10. Software used

Altogether 20 different internal dosimetry software were used by the participants. The most frequently used software code was IMBA, but other programmes were also used by more participants. Twelve participants used IMBA, six used LUDEP, four used MONDAL, whereas three participants used IMIE or AIDE, two indicated the use of IDEAS DV0102 and Mathematica – Excel, while one participant used other 13 codes. As many as 17 participants declared that they used no software but manual evaluation methods.

11.4.11. Use of guidelines

Almost 50 % of the participants (27) stated that they followed the IDEAS guidelines. Those who did not follow the guidelines (25) gave the following reasons:

- National guidelines or own assessment procedures were followed
- Did not have the software to follow the guidelines strictly
- Guidelines were not easily available
- Guidelines were not applicable for this case
- No time to read guidelines

Eleven participants did not comment whether they used the guidelines or not.

Table 11.13. Comparison of results between participants that declared that they followed guidelines and those that stated that they did not (without outliers)

	All participants		**Did not follow guidelines**		**Followed guidelines**	
	Intake	E(50)	Intake	E(50)	Intake	E(50)
N	58	50	24	21	24	21
GM	160 kBq	2.57 mSv	154 kBq	2.59 mSv	174 kBq	2.56 mSv
σ_g	1.39	1.07	1.39	1.05	1.40	1.09
Min	88 kBq	2.2 mSv	88 kBq	2.39 mSv	118 kBq	2.20 mSv
Max	329 kBq	3.0 mSv	329 kBq	2.88 mSv	320 kBq	3.09 mSv

Table 11.13 compares the statistics between the participants that declared that they followed the guidelines and those that did not.

Based on this table it can be concluded that both the GM and GSD values for intakes as well as for doses do not differ significantly from each other whether the participant had used or did not use the IDEAS guidelines.

This outcome is probably because even those participants who had declared the use of the guidelines in fact did not use them at all or had used them only partly. This deduction can be proved by other information provided by them.

The participants that had declared that they had followed the guidelines reported the final step number (Table 11.11). If the participants had followed the guidelines correctly then the final step number should have been 5.11.3.

Table 11.14. Final step numbers reached by the participants who followed the guidelines

Number of participants	**Final step number**
1	3.3, 5.1
1	3.4.21
2	5.5
2	5.6.1
8	5.11.3
2	5.12.3
3	5.15
4	Not relevant

11.5. Conclusion for Case 4

This case was an artificially generated case simulating repeated intake pattern of ^{131}I vapour.

By following the IDEAS guidelines an intake of 129 kBq of ^{131}I by inhalation is estimated. The resulting E(50) is 2.58 mSv. These values are quite close to the corresponding true values of 120 kBq intake and 2.40 mSv committed effective dose.

Sixty-three participants have assessed this case. Due to the broad frequency distribution of intake data the number of outliers were only five, whereas for the assessed doses there were already 13 outliers.

The calculated GM from the estimated intake values without outliers was 160 kBq, which is considerably higher than the true value of 120 kBq. This difference also leads to the relatively high GSD value of 1.39.

Excluding outliers the GM of the assessed doses is 2.57 mSv, which is very close to the expected value. The GSD is 1.07 showing a very narrow frequency distribution.

The following summary conclusions can be drawn from analysis of the data:

- The assumed intake pattern does not influence the results considerably.
- Two main groups of intake values were reported by the participants (factor of about 2) according to the selected respiratory deposition class.
- The calculated E(50) values are very close to each other due to the compensation effect of applied dose coefficients.
- No significant difference was found between the values of GM and GSD depending whether the IDEAS guidelines were followed or not (based on the participant's declaration).

12. CASE 5: ENRICHED URANIUM INTAKE

12.1. Case description

12.1.1. The event

Description of the working area	Fuel fabrication plant.
Characteristics of work	Transporting a bag containing a powder of enriched (3.5 %) uranium.
Reasons for monitoring; initiating event	A worker received directly on his head a bag containing enriched uranium powder. The worker realized that the bag was not sealed properly and he tried to hold his breath and left the area. He did not wear any protective equipment (no mask). The worker began to work in this plant on the 3rd January 1984 until

	the date of the incident that occurred on 21st March 1997.
Actions taken	He came directly to the health department and then took a shower. After that a programme of lung measurements and urine monitoring was started. Because of the incident he was removed from radioactive work.

12.1.2. Additional information

Air monitoring	The air sample device showed an air concentration of 100 Bq/m^3.
Chemical form	Uranium oxide: U_3O_8
Physical characteristics, particle size	Aerosol Uranium isotopic activity composition of total uranium: ^{234}U 83 %, ^{235}U 4 % & ^{238}U 13 %.
Nose swab, bronchial slime or similar	Not available
Non removable skin contamination	Not available
Wound site activity	Not available
Any intervention used (blocking, chelating, etc.)	None

12.1.3. Body monitoring data

Organ activity measurement: Lungs

Date of measurement	Total alpha uranium activity in the lungs ($^{234}U + ^{235}U + ^{238}U$) (Bq)
6 March 1997	< MDA #
21 March 1997	160
21 April 1997	150
21 July 1997	< MDA #

The Minimum Detectable Amount (MDA) is 140 Bq of total alpha uranium activity.

Whole body activity measurement None

12.1.4. Excretion monitoring data

Urine activity measurement

Date of measurement	Daily urinary excretion rate of total alpha uranium activity (^{234}U + ^{235}U + ^{238}U)* (mBq/24 h)
22 March 1997	90
11 April 1997	94
15 May 1997	84
22 July 1997	54

* It is assumed the Uranium isotopic activity composition of total uranium was: ^{234}U 83 %, ^{235}U 4 % and ^{238}U 13 %.

Faeces activity measurement None

12.1.5. Personal data

Sex Male

Age Unknown

Weight Unknown

12.1.6. Other comments relevant for intake and dose estimation

Estimate the total intake of ^{234}U, ^{235}U and ^{238}U for the occupational exposure from 3rd January 1984 to 21st March 1997 at the plant and resulting committed effective dose E(50) for each radionuclide.

12.1.7. Important remark concerning the case

This case is a real case but it emerged from the meeting in Vienna that the case description is incomplete.

Besides the lung and urine measurements, faecal data were also available. These faecal data contained also information about the isotopic distribution and show that the acute and chronic inhalation is due to enriched uranium as stated in the case description. It is assumed the Uranium isotopic activity composition of total uranium was ^{234}U 83 %, ^{235}U 4 % and ^{238}U 13 %.

In the case description it is also stated that the worker was remove from radioactive work. This is true just after the incident **but this worker resumed its usual work after some time. The duration of his working period after the incident has a minor impact due to the aim of this exercise to assess the intake from 3rd January 1984 to 21st March 1997. To be complete, the working post of this worker was thoroughly investigated and modified so that no chronic inhalation could take place anymore.**

12.2. Assessment of case

Before following the guidelines to assess the case it is useful to plot the available data (Figure 12.1 and 12.2) and perform a simple calculation to assess the intake and dose.

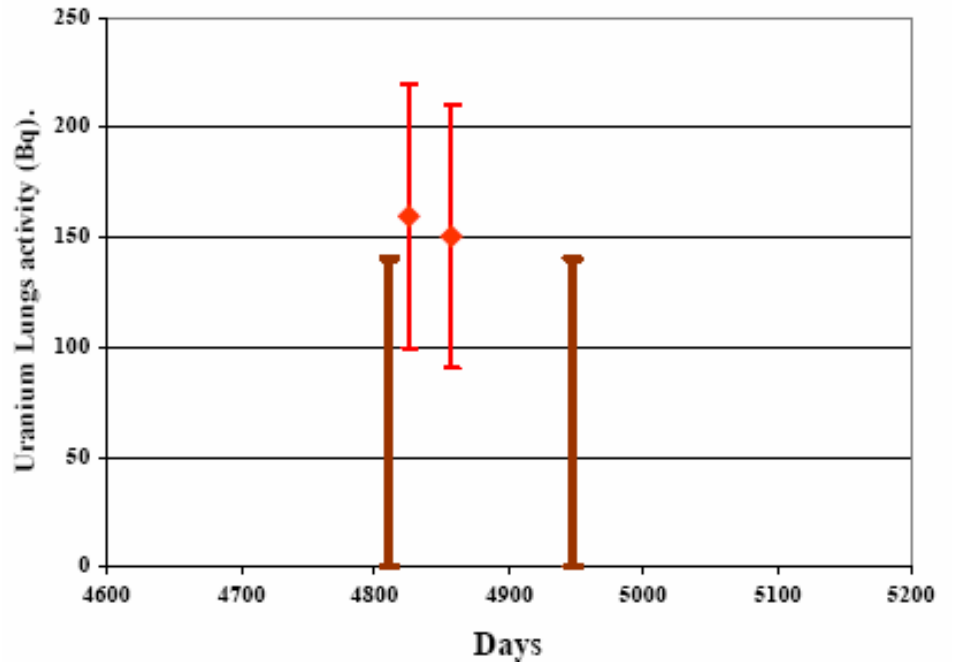


Fig. 12.1. Plot of the uranium lung measurements data for Case 5.

An important assumption is that the different uranium isotopes behave identically with regard to absorption in the human body. In this assessment, the lung and urine measurement data have been assessed as ^{234}U. (Note: Uranium lung measurements are based on the gamma rays from ^{235}U). At the end of the assessment process, the intake results will need to be scaled to the isotopic composition given in the description of the case and then using the correct dose coefficient the committed effective dose will be assessed.

From the case description (Section 12.1), the time of intake is known and the intake pathway can be considered as inhalation. The uranium compound involved is U_3O_8, which is considered to be absorption Type S. As no information is given about the AMAD the default value from ICRP 78[6] of 5 µm is assumed.

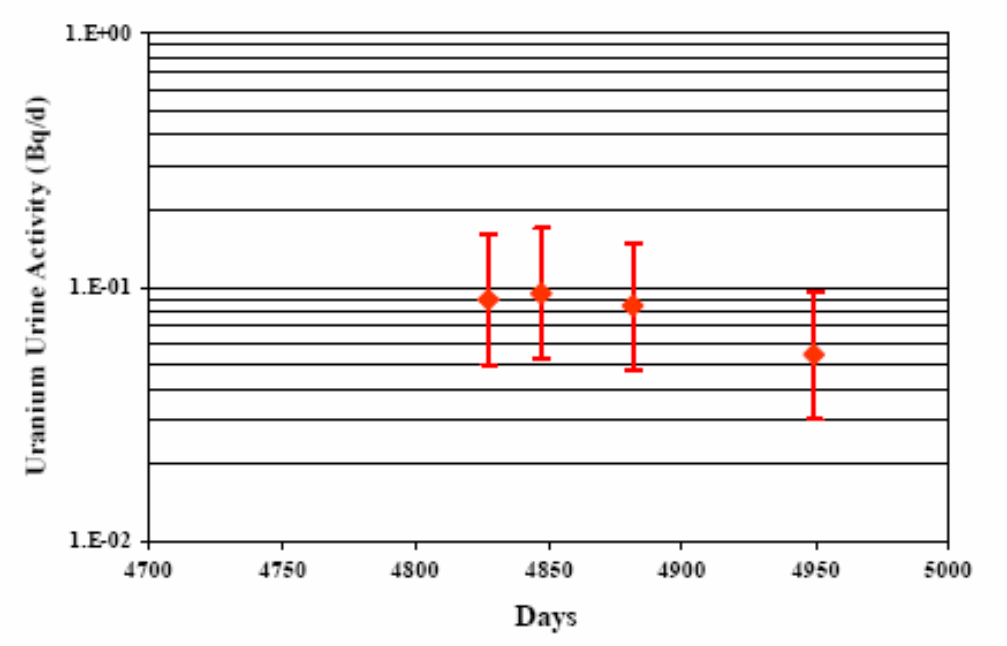


Fig. 12.2. Plot of the urine measurements data for Case 5.

From the two positive lung measurements, it is possible to calculate a quick estimate of the intake. ICRP Publication 78[6] gives a lung activity content of 0.064 Bq for a worker after one day following an acute inhalation of 1 Bq of Uranium, assuming Type S and a 5 µm AMAD aerosol. Similarly after 30 days the lung activity content is 0.049 Bq.

Therefore:

- After 1 day, the intake is 160 / 0.064 = 2500 Bq and E(50) = 17 mSv
- After 30 days, the intake is 150 / 0.049 = 3060 Bq and E(50) = 21 mSv

The dose coefficient of 6.8 10^{-6} Sv/Bq from ^{234}U was used for the committed effective dose estimation.

ICRP Publication 78[6] reports for an acute inhalation a predicted value for the daily urinary excretion of 7.0 10^{-4} after 1 day. After 21, 55 and 123 days, these predicted values for daily urinary excretion can be estimated respectively at 1.0 10^{-5}, 5.2 10^{-6} and 4.6 10^{-6}.

Therefore:

- After 1 day, the intake is 0.090 / 7.0 10^{-4} = 129 Bq
- After 21 days, the intake is 0.094 / 1.0 10^{-5} = 9400 Bq
- After 55 days, the intake is 0.084 / 5.2 10^{-6} = 16154 Bq
- After 123 days, the intake is 0.054 / 4.6 10^{-6} = 11739 Bq

Obviously this does not look right and we can assume that the urine data do not originate from an acute intake but most probably from a chronic intake.

The following sections describe the assessment of the case by following the IDEAS guidelines. As this is a special monitoring case for inhalation (at least concerning the lung data) the steps in flow chart 5 are followed.

12.2.1. Step 5.1: Identification of all measured data representing the case

There are only four data points for the lung measurements (two above the MDA of 140 Bq and at this MDA) and four data for urine measurements. With the scarcity of data, it is absolutely necessary to try to use all of these data.

12.2.2. Step 5.2: Assessment of contributions from previous intakes

There is no information given about possible previous intake except that from our first analysis, it is possible to assume a chronic inhalation intake since the start of the work. The scattering factor for lung data is 1.2 and for the urine data 1.8.

12.2.3. Step 5.3: Assign a priori parameters (default or site specific)

In the case description the chemical form of the material was given as Uranium oxide U_3O_8. The ICRP default absorption Type for U_3O_8 is Type S[6]. The default parameter values assumed are:

- 5 μm AMAD aerosol;
- Absorption Type S;
- f_1 value 0.002;
- Reference worker.

12.2.4. Step 5.4: Time of intake is known

The time of acute intake is known 21/04/1997 and the start of the chronic intake can be taken as the start of the work 03/01/1984. Contrary to what was stated in the description of the case, we have considered that the chronic intake did not stop at the time of the incident and thus continued until an arbitrary date of 20/12/1997, that is to say during 5100 days.

12.2.5. Step 5.5: Calculate dose with a priori parameters

The IMBA Professional software was used to assess this case. Briefly, the software implements the current ICRP dosimetric and biokinetic models but enables the user to alter parameter values from the ICRP defaults. It uses the maximum likelihood method to fit multiple data and has the ability to assess the intake by fitting predicted values to different types of data simultaneously and different patterns of intake such as chronic and acute intake.

In first instance, the intake was estimated by fitting the predicted values to both the lung data and the urine data simultaneously.

With the default parameter values given in step 5.3, the estimated intake is 2.7 Bq/d for chronic intake and 567 Bq for the acute intake. The total chronic intake for 5100 days is thus 13770 Bq. Taking these results as ^{234}U, the dose from the acute intake would be 3.9 mSv and from the chronic intake 94 mSv.

The fits to the data are shown in Figures 12.3 and 12.4 for the lung and urine data respectively.

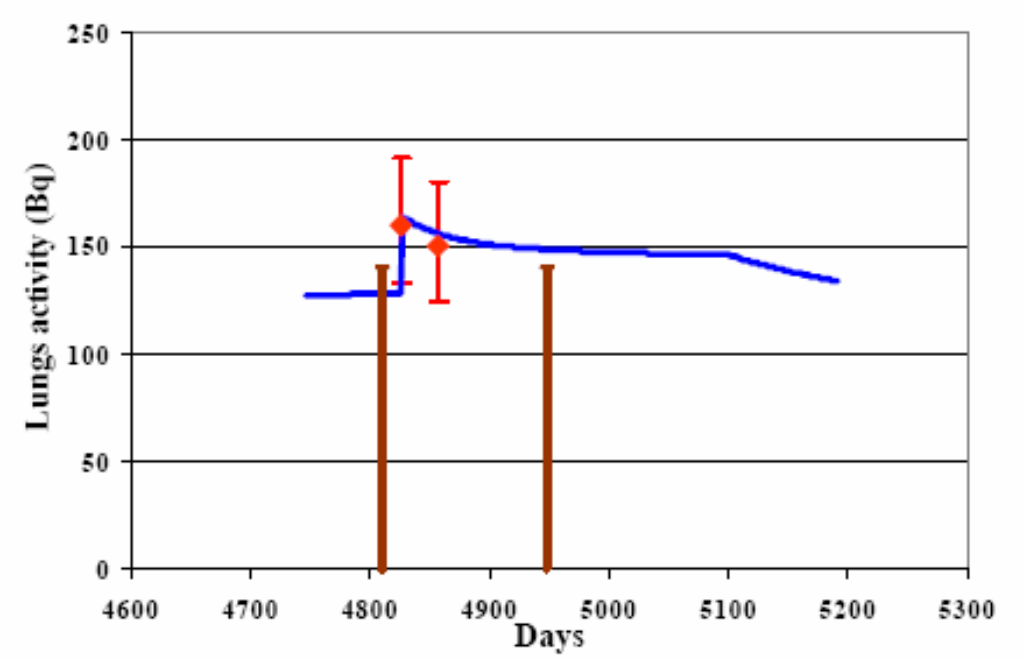


Fig. 12.3. Model fit to lung data assuming Type S compound for an acute intake and a chronic intake of 5100 days using lung and urine for the assessment.

The model fit to the lung data looks pretty good (Figure 12.3). Before the incident the chronic intake is not detected (below MDA). The acute intake is detected hence the two lung data above the MDA but for the last lung data, the fit should go below the MDA.

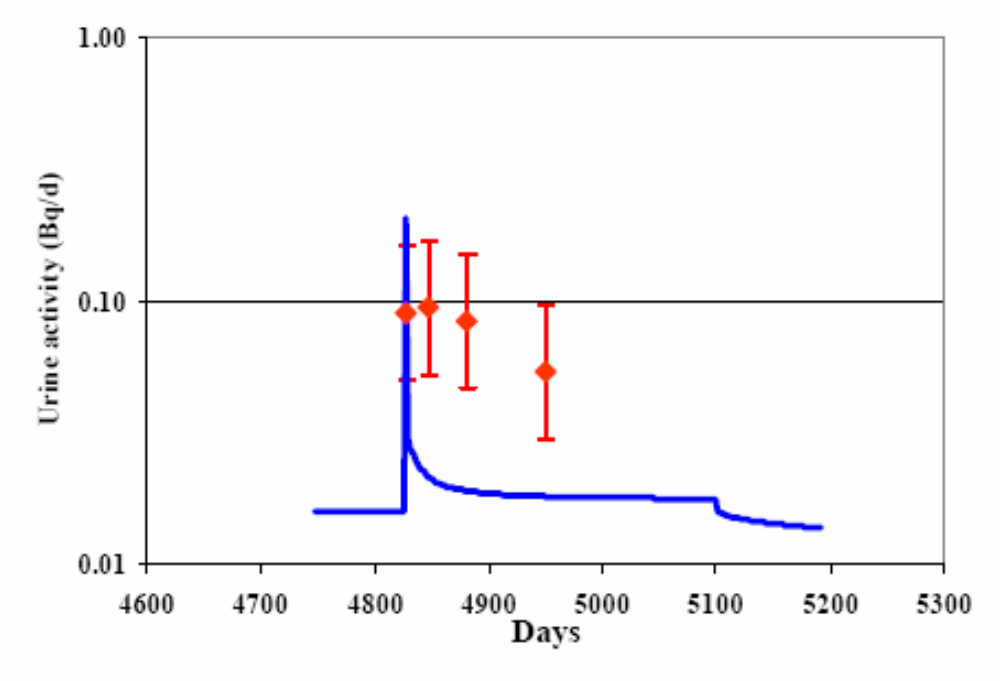


Fig. 12.4. Model fit to urine data assuming Type S compound for an acute intake and a chronic intake of 5100 days using lung and urine for the assessment.

The fit to the urine data is poor (Figure 12.4). This indicates that the model's parameter values or some assumptions made are incorrect. The fit to the urine data is too low and this also indicates that the urine data are due to the chronic intake. If only the urine data are used for the chronic intake assessment, the intake is 13.4 Bq/d and a total intake of 68340 Bq for 5100 days and an E(50) of 466 mSv.

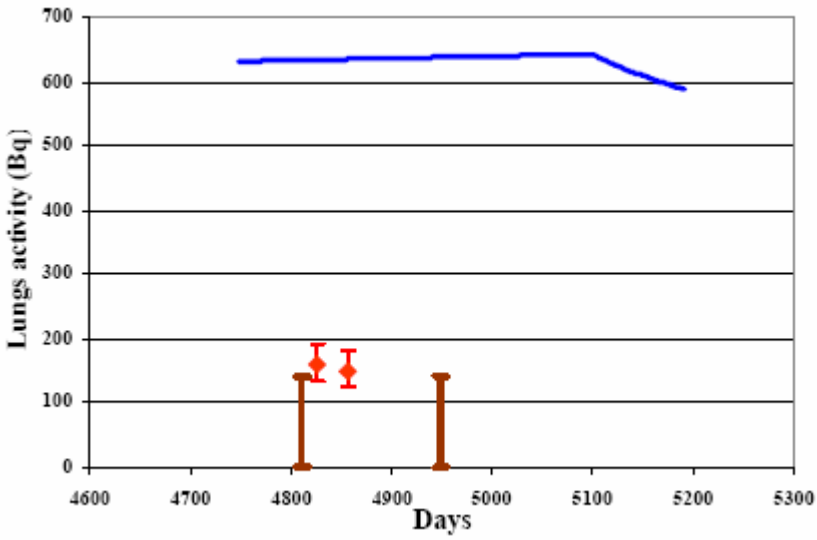


Fig. 12.5. Model fit to lung data assuming Type S compound for a chronic intake of 5100 days using only the urine data set for the assessment.

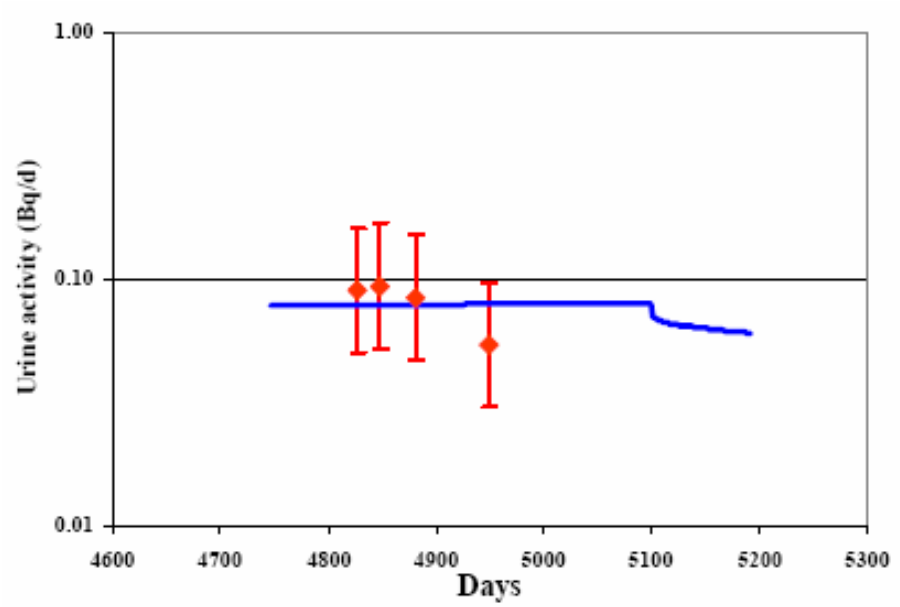


Fig. 12.6. Model fit to urine data assuming Type S compound for a chronic intake of 5100 days using only the urine data set for the assessment.

12.2.6. Step 5.6: E(50) < 1 mSv

With the default parameter values E(50) was calculated to be much higher than 1 mSv. Assessment has to proceed to the next step

12.2.7. Step 5.7: There are sufficient relevant data

The guidelines suggest a minimum number of data that is required for a dose assessment for certain radionuclides. The minimum number suggested depends on the dose level. For uranium the minimum number is five lung measurements, three urine and faeces measurements over a time period of 30 days if the dose level is greater than 6 mSv.

Information for this case is far from the requirement with only four lung and urine measurements over a period of 120 days. So it is necessary to get some additional relevant data.

This case is carried on as if…

12.2.8. Step 5.8: Time of intake is known

The time of intake is known so proceed to step 5.9.

12.2.9. Step 5.9: Early lung and faeces data available

There are no early lung and faecal data available so proceed to step 5.11.

12.2.10. Step 5.11: Assessment of dose by fitting absorption type

In this step intakes and doses are assessed using the default absorption Types for U_3O_8 provided in ICRP Publication 78[6]. The document suggests Type S for this Uranium oxide.

12.2.10.1. Type S

As seen above, assuming Type S the fit to the urine data is poor (step 5.5, Figure 12.4).

The estimated chronic intake is 2.7 Bq/d, the acute intake is 567 Bq and E(50) is 94 mSv from the chronic intake and 3.9 mSv from the acute intake.

12.2.10.2. Type M

Assuming Type M with f_1= 0.02 and 5 µm AMAD, IMBA only gives a result of 14.3 Bq/d for the chronic intake. The E(50) is 154 mSv.

The fit to the lung data could be acceptable (Figure 12.7) in the sense that the chronic intake rises the lung activity to less than 140 Bq. On the other hand, the fit to the urine data (Figure 12.8) is not acceptable.

Concluding, a chronic intake of Uranium Type M compound would not been detected in the lungs and would produce an urinary excretion 10 times higher than what is observed.

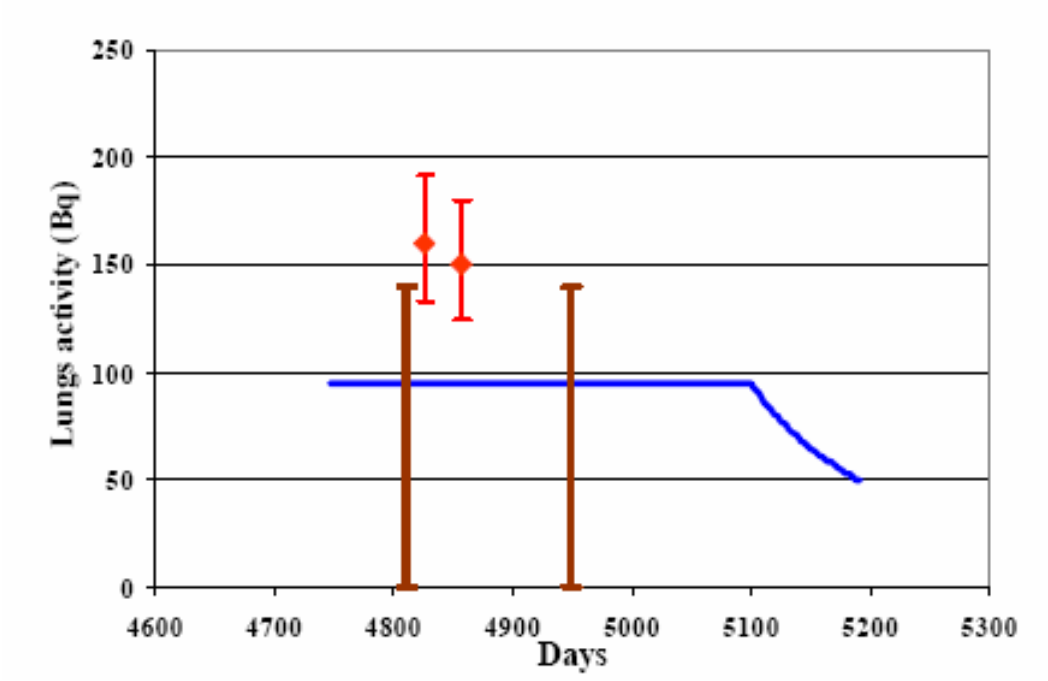
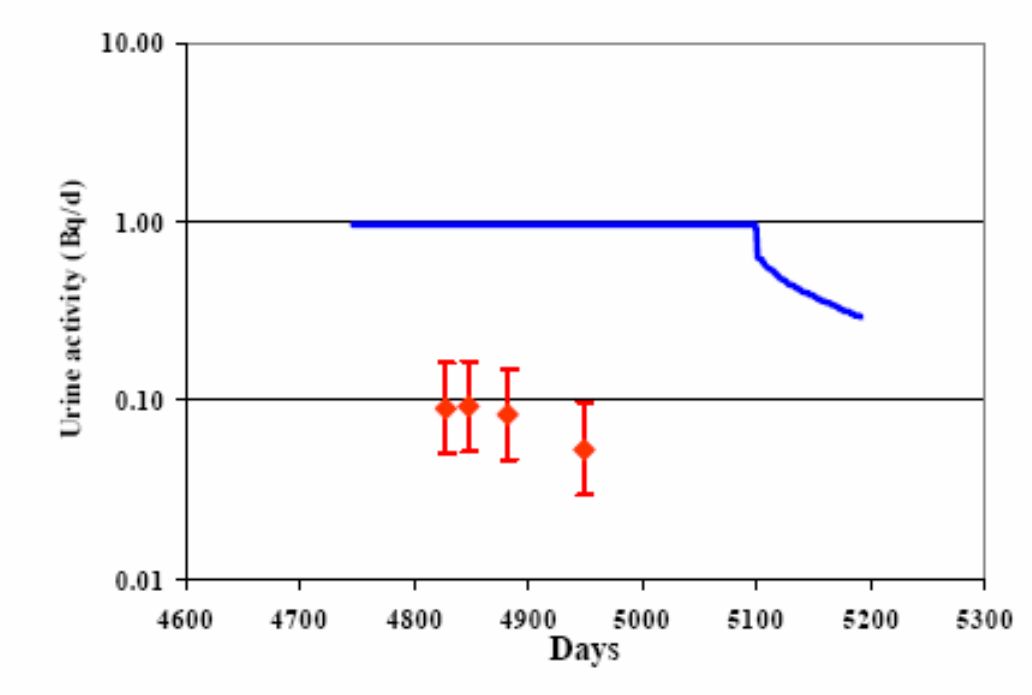


Fig. 12.7. Model fit to lung data assuming Type M compound for an acute intake and a chronic intake of 5100 days using the lung and urine data set for the assessment.

Fig.



12.8. Model fit to urine data assuming Type M compound for an acute intake and a chronic intake of 5100 days using the lung and urine data set for the assessment.

12.2.11. Step 5.11.1: Goodness of fit is acceptable

If only by eyes, the fit is rejected.

12.2.12. Step 5.13: Assessment of dose by fitting of the mixture of default absorption types

In this step, the intake is estimated by fitting a mixture of absorption Types (M and S) to the lung and urine data simultaneously. The software IMBA allows the fitting simultaneously of a chronic intake of Type M, a chronic intake of Type S, an acute intake of Type M and an acute intake of Type S to the lung and urine data. The results of this fitting are shown Table 12.1.

Table 12.1. Assessment of dose by fitting of the mixture of absorption Type M & S

Chronic intake			**Acute intake**	
	Type M	Type S	Type M	Type S
Intake per day Total intake	0.79 Bq/d 4029 Bq	2.5 Bq/d 12750 Bq	$1.6\ 10^{-7}$ Bq	314 Bq
	24 %	76 %	0 %	100 %
E(50)	8.5 mSv	86 mSv	2.1 mSv	

The fit to the lung and urine data is shown Figure 12.9 and 12.10 respectively.

Visually both fits are quite good. The fit to the lung data shows the chronic component below the MDA and the acute component above this MDA. In this case the fit to the urine data only shows the chronic component of the intake. The chronic component of the intake is a mixture of Type M and S (24 % – 76 %), whereas the acute intake component consists of absorption Type S.

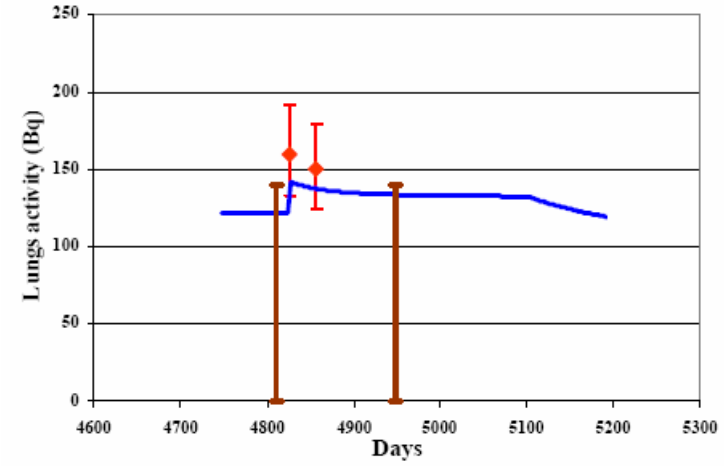


Fig. 12.9. Model fit to lung data assuming a mixture of Type M and S compound for an acute intake and a chronic intake of 5100 days using the lung and urine data set for the assessment.

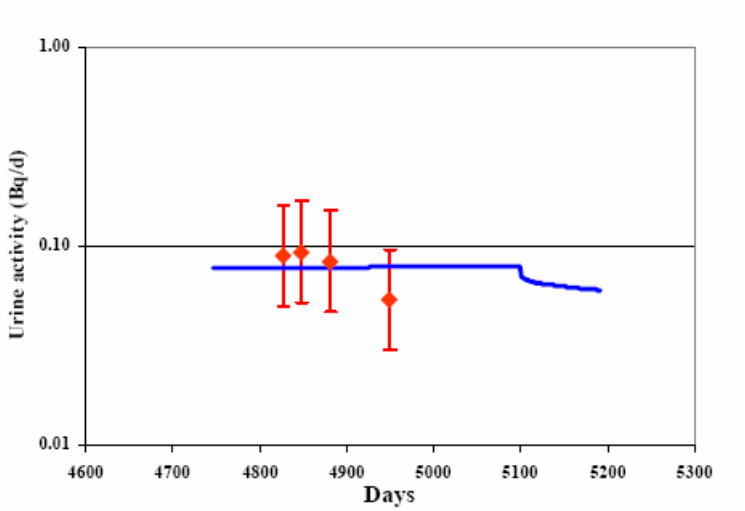


Fig. 12.10. Model fit to urine data assuming a mixture of Type M and S compound for an acute intake and a chronic intake of 5100 days using the lung and urine data set for the assessment.

12.2.13. Step 5.15: Is the goodness of fit acceptable?

For a mixture consisting of 24 % Type M and 76 % Type S for the chronic intake and 100 % Type S for the acute intake, the fits to the data are good. The overall χ_o^2 is 1.57 with seven degrees of freedom and the corresponding p-value is 0.98. As the p-value is > 0.05, the fits are not rejected. This is, therefore, the best estimate of intake and dose. So the intake and dose with the corresponding parameter values are recorded in the next step (i.e. step 5.15.1).

12.2.14. Step 5.15.1: Record dose with all parameter values

The intake and the dose are recorded with the corresponding parameter values. But in this case the results will have to be scaled up according to the isotopic composition given in the description of the case.

Table 12.2. Final results of Case 5 assessment

	Intake	**E(50)**
Chronic intake	(Bq)	(mSv)
^{234}U	13927	79
^{235}U	671	3.4
^{238}U	2181	10.3
Total Chronic	16779	92.7
Acute Intake		
^{234}U	261	1.77
^{235}U	13	0.08
^{238}U	41	0.23
Total Acute	314	2.1
Chronic + Acute		
^{234}U		81
^{235}U		3.5
^{238}U		10.5
Total Uranium		95

Total uranium committed effective dose, E(50): 95 mSv;

- Mixture of Absorption Types M and S for chronic intake;
- 24 % Type M; 76 % Type S;
- $f_1 = 0.02$ (Type M); $f_1 = 0.002$ (Type S);
- 5 μm AMAD aerosol;
- Reference worker;
- ICRP Publication 66 Human Respiratory Tract model[1];

- ICRP Publication 30 Gastrointestinal Tract model[18];
- ICRP Publication 67 systemic biokinetic model for uranium[2].

12.2.15. Summary of assessments

The analysis of this case showed a chronic intake during the period of work beginning at the 3rd January 1984 and a small acute intake on 21st March 1997. The description of the case did not mention that the chronic intake carried on after the incident on the 21st March 1997.

12.3. Results of intercomparison exercise

12.3.1. Introduction

Forty-one participants assessed this case. These participants come mainly from Europe (25), then from Asia (8) and America (7). The laboratory of the IAEA also participated in this intercomparison. The main represented countries are: Germany and UK (5), US (4), Italy (3), China, France, India, Japan, Republic of Korea and Slovenia (2).

12.3.2. Overall distribution of results

The exercise task was to estimate the total intake of ^{234}U, ^{235}U and ^{238}U for this exposure from 3rd January 1984 to 21st March 1997 at the plant and the resulting committed effective dose E(50) for each radionuclide.

The presentation below will deal mainly with results from ^{234}U.

Although not specified by the participants, probably most of them used ^{234}U for estimation and applied scaling factors for the other radionuclides.

ID39 calculated no results for ^{235}U and ^{238}U for intake and for dose and must have applied scaling factors to arrive at the total uranium dose. ID46 used another isotopic distribution in the intake assessment (^{234}U 94 %, ^{235}U 5 % and ^{238}U 1 %).

The statistical evaluation of the results, excluding outliers is given Table 12.3.

12.3.2.1.Intake

The geometric mean (GM) of the estimated intake of ^{234}U (5054 Bq) is very different to the arithmetic mean (AM) (9719 Bq). The geometric standard deviation (GSD) of 3.0 for the intake of ^{234}U is quite large and has a coefficient of variation of 147 %.

The range of the estimated intakes, excluding the outlier (only one in this case), is very broad: 761 – 68000 Bq (ratio max/min = 89). The graphical representation demonstrates this dispersion of the results in Figure 12.11.

Table 12.3. Statistical evaluation of the results excluding outliers: ^{234}U

	Intake	**E(50)**
N	40	38
GM	5054 Bq	27 mSv
GSD	3.0	2.4
AM	9719 Bq	39 mSv
ASD	14275 Bq	33 mSv
Coefficient of variation (%)	147	84
Minimum	761 Bq	8.2 mSv
Maximum	68000 Bq	118 mSv
Outliers	1	3

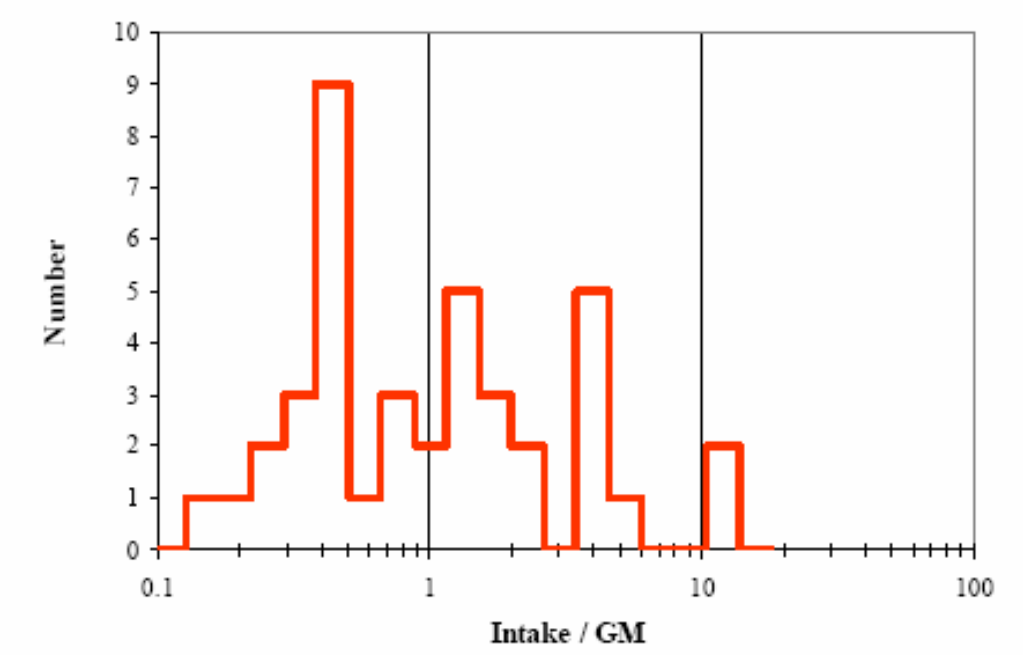


Fig. 12.11. Frequency distribution of results without outliers (N=40). ^{234}U intake normalized to the geometric mean. (GM = 5054 Bq, GSD = 3.0).

The histogram of the ratios of the individual results of the geometric mean (calculated without the outlier) shows also this dispersion of the results.

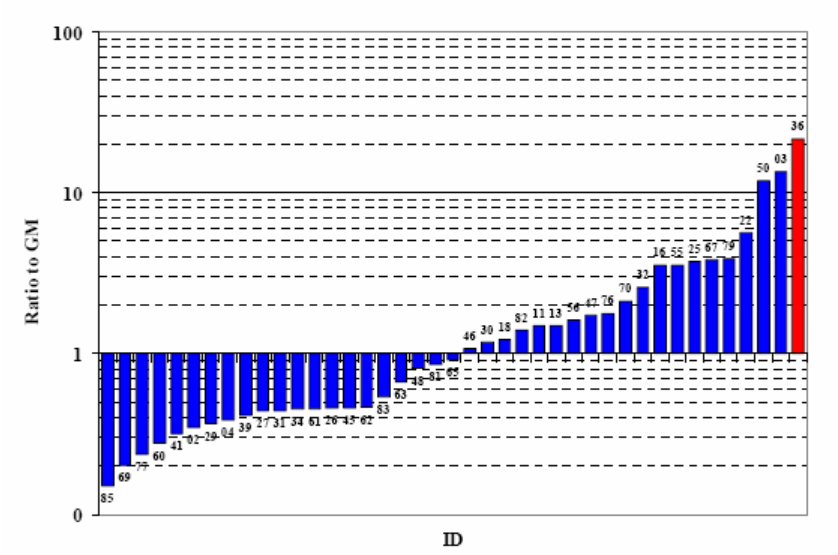


Fig. 12.12. Results of the individual participants: Intake ^{234}U normalized to the geometric mean. (GM = 5054 Bq, GSD = 3.0, N=40) The red bar is the outlier.

12.3.2.2.Dose

The geometric mean of the committed effective dose E(50) for ^{234}U (27 mSv) is closer to the arithmetic mean (39 mSv) than it was for the intake. The geometric standard deviation is still large (2.4) with a coefficient of variation of 84 %. The range of the estimated dose, excluding outliers, is broad: 8.2 – 118 mSv (ratio max/min = 14). Outstanding from the graphical representation of the frequency distribution is the bimodal mode of the distribution, as shown in Figure 12.13. This could be explained by the assumption made for the analysis of the case.

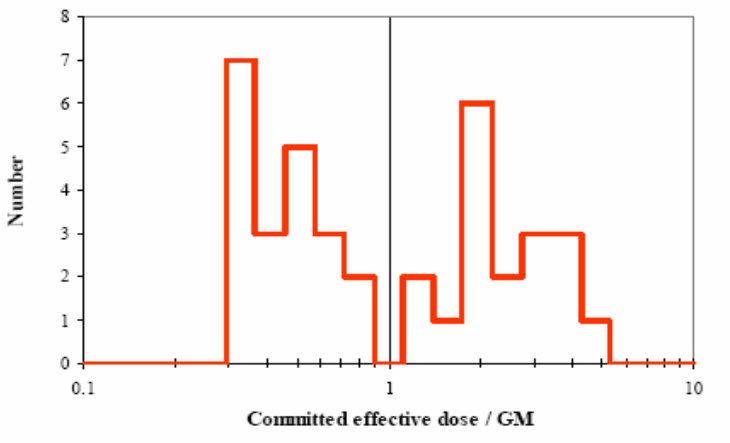


Fig. 12.13. Frequency distribution of results without outliers (N=38) E(50) ^{234}U normalized to the geometric mean (GM = 27 mSv, GSD = 2.4).

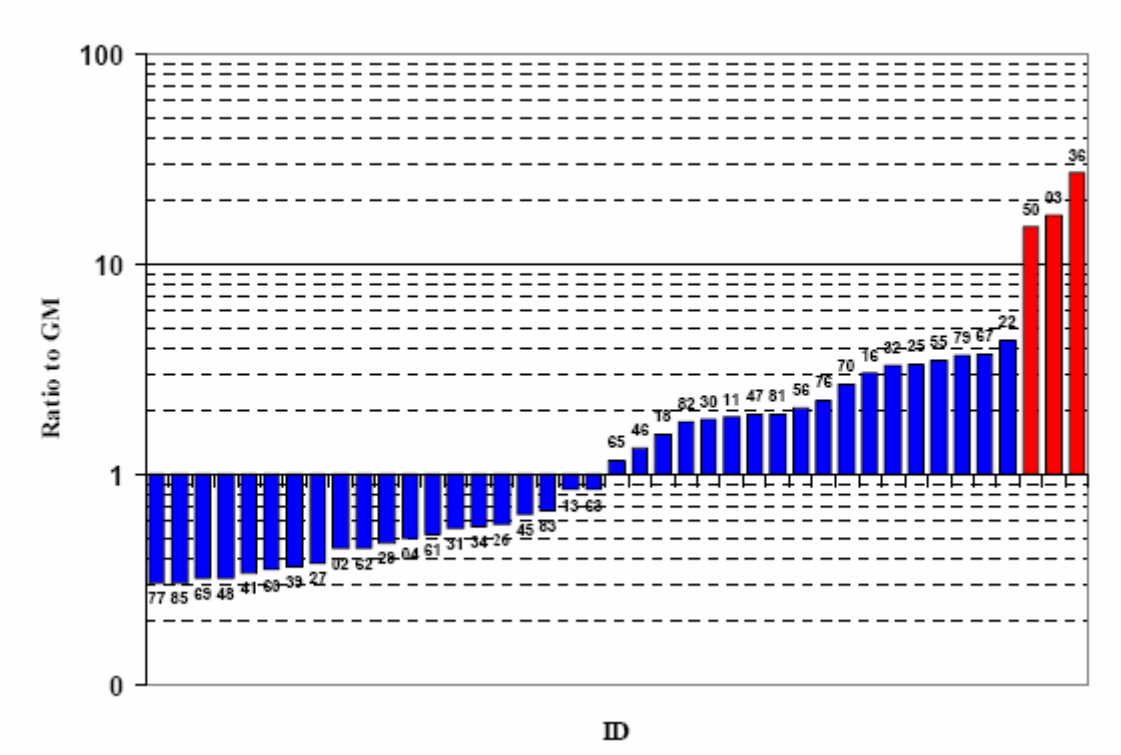


Fig. 12.14. Results of the individual participants (ID): E(50) ^{234}U normalized to the geometric mean (GM = 27 mSv, GSD = 2.4, N = 38). The red bars are outliers.

The histogram of the ratio of the individual results to the geometric mean (calculated without the outlier) also shows this bimodal distribution of the results Figure 12.14.

12.3.3. Identification of outliers

Outliers were identified by following the statistical criteria described in Section 7.5 The obvious reason for reporting outliers is that participants only used the urine data for their assessment (Table 12.4).

Table 12.4. Outlier assessment of intake and dose, E(50), for ^{234}U. Bold values indicate outliers

Code	Intake (Bq)	E(50) (mSv)	Intake regime	Data used
03	68000	**460**	Chronic	Urine
36	**109000**	**739**	Acute	Urine
50	60100	**408**	Chronic	Urine

12.3.4. Route of intake

Most of the participants assumed an inhalation route of intake. Participants 32 and 77 took into account a mixture of inhalation and ingestion.

12.3.5. Models used

Besides few exceptions, all the participants used the ICRP Publication 66 "Human Respiratory Tract Model"[1] (HRTM), the ICRP Publication 30 "Gastrointestinal Tract Model"[18], the ICRP Publication 78 "Systemic Biokinetic Model for Uranium"[6] and the f_1 value recommended in ICRP Publication 68[20] ($f_1 = 0.002$ for U_3O_8).

Some of the participants (13, 16, 22, 25, 27, 30, 41, 55, 61, 62, 67 and 85), assuming a mixture of absorption types or modifying the lung parameters, recalculated the dose coefficients (See Annex for Case 5).

- Participant 45 used an f_1 value of 0.02 although assuming absorption Type S. More over he used an identical dose coefficient for all the uranium isotopes ($7.5\ 10^{-6}$ Sv/Bq).
- Participant 46 used an $f_1 = 0.05$ for an absorption Type F compound, but with the dose coefficient more like from a Type S compound.
- Participant 48 assumed an absorption Type M with f1 = 0.02.
- Participant 65 assumed an absorption Type S used f1 = 0.02.
- Participant 79 used specific absorption parameter and recalculated the f_1 value to 0.005.

12.3.6. Absorption assumptions

The case description gave the chemical form of the inhaled material as highly insoluble compound U_3O_8. ICRP Publication 68 recommends Type S for Uranium oxide. Twenty-five participants assumed Type S, six participants assumed Type S with modification of the absorption parameters, seven participants assumed a mixture of Type M and Type S, and one participant used specific absorption parameter values from an NRPB report. One participant assumed Type M, which is incorrect. Only one participant assumed Type F, which is totally incorrect.

12.3.7. AMAD assumed

With the few bioassay data available, there is no reason change the default value of 5 μm and so the majority of the participants (32) used the it. The other AMAD assumed are 0.3 (2), 1.0 (3), 4.0 (1) and 7.0 (1).

12.3.8. Time pattern of intake and bioassay data used for the assessment

In this Uranium case, the time pattern of intake and the data used for the assessment have a large influence on the results obtained. The results of the participants can be divided in four groups:

- **Acute intake**: If only a single intake is considered, it will be mainly influenced by the lung measurements. In this group, all the participants having used only lung data or lung and urine data have obtained an Uranium intake lower than the other assessments. In fact these assessments only take into account the incident of the 21st March 1997.

- **Chronic intake**: If a chronic intake is considered, this will be mainly influenced by the urine data. The participants in this group have used either only urine data or lung and urine data for their assessment and the chronic intake over 13 years is higher than the single intake from 21st March 1997.

- **Acute intake with Urine data**: As stated above the urine data are due to the chronic intake. As an acute intake without knowledge of the time of intake can be compared to a chronic intake over a certain period of time, the participants using only urine data for their assessment, have obtained results similar than those having assumed chronic intake.

- **Acute + Chronic intake**: provided that lung data and urine data are used, this is the most correct assessment as the lung data represent the acute intake and the urine data the chronic intake. One participant (ID 26) assumed acute and chronic intake but used only the lung data for his assessment, thus he did not take the data due to the chronic intake and his result was assimilated to a single acute intake. This result is included in the first group as an acute intake.

As seen above, the distribution is bimodal. The acute intake is represented by the first group and has a lower estimated intake. The incident of the 21st March 1997 is quite mild. The second set of results represent assessments, where some chronic intake has been assumed and the participants from the last 3 groups (above) are included into this set of results. These two subsets can easily be distinguished in Figure 12.15 and 12.16. in the intake and dose assessment respectively.

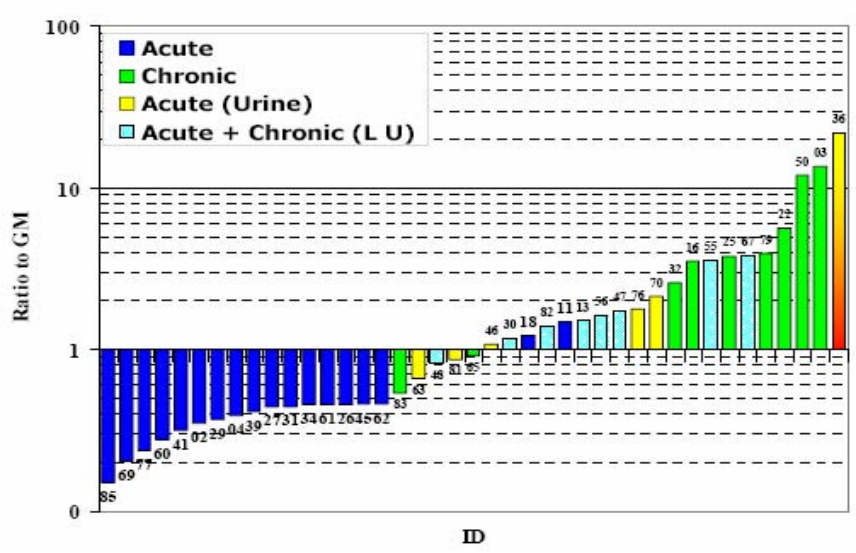


Fig. 12.15. Comparison of results between the different assumptions by the participants for the assessment of ^{234}U intake. ^{234}U intake normalized to the geometric mean (GM = 5054 Bq, GSD = 3.0, N=40).

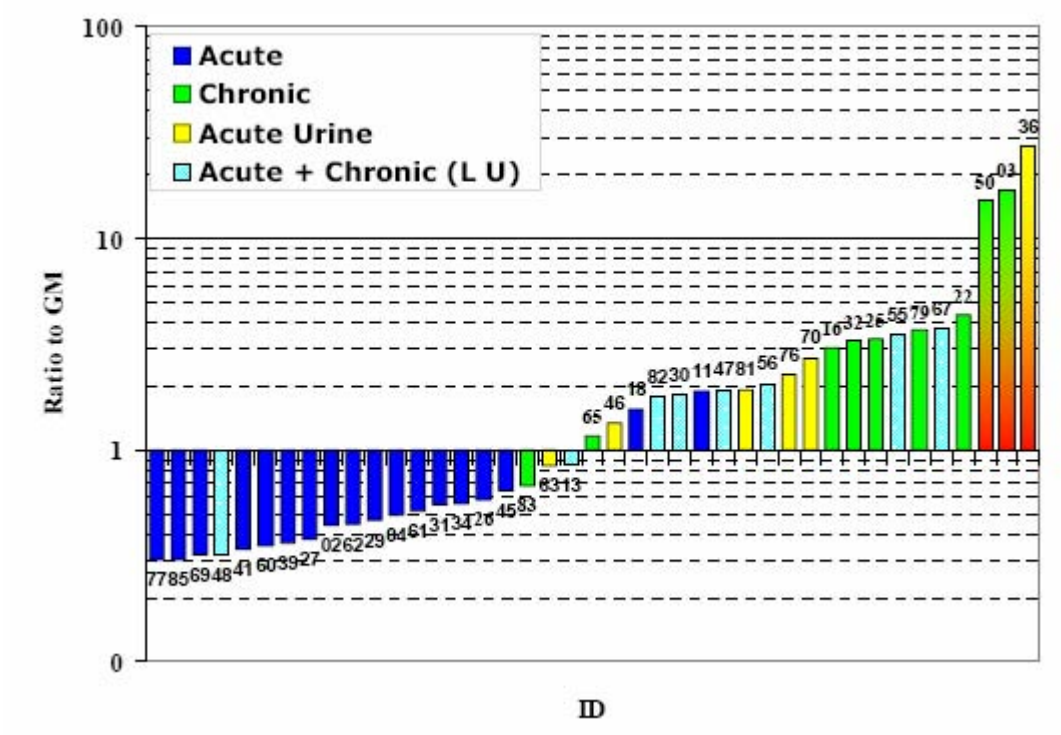


Fig. 12.16. Comparison of results between the different assumptions by the individual participants for the assessment of E(50). ^{234}U E(50) normalized to the geometric mean (GM = 27 mSv, GSD = 2.4, N = 38).

12.3.9. ^{234}U intercomparison results divided in two subsets

In these paragraphs, we will analyze the results of the participants in two subsets. The first one describes the group assuming an acute intake. The second set of results contains the group assuming chronic intake with or without acute intake.

In this analysis, participant 46 has not been taken into account for several reasons:

- absorption Type F was assumed with the dose coefficient more like Type S compound;
- time pattern of intake "3 stages" without giving any explanation;
- used another isotopic composition.

This participant used only urine data for his assessment and in the two previous figures he was assigned to the group of results of acute intake with urine data set. In view of this, it was considered more appropriate not to include this result in the following analysis.

12.3.9.1. Acute intake subset

The statistical evaluation of the results of this subset is given in Table 12.5.

The geometric mean of the estimate of intake of ^{234}U (2058 Bq) is comparable to the arithmetic mean (1907 Bq). The geometric standard deviation of 1.72 is reasonable in this

case and would have been even better without the two higher values (6200 and 7520 Bq). Following the statistical criteria described earlier, these two participants are not outliers for the intake estimates but are outliers for the E(50) estimates.

ID 18 used Mathematica/Excel for his assessment and ID 11 did not use any software. Other participants (69, 02, and 26) also did not use specific software.

At the lower end of the distribution, ID 85 (761 Bq) and ID 69 (1020 Bq) assumed an AMAD of 0.3 and 1µm respectively, hence their lower intake estimates. In this group they are the only ones who have not used the AMAD default value of 5 µm.

Table 12.5. Statistical evaluation of the ^{234}U results for the acute intake subset (excluding outliers).

	Intake	**E(50)**
N	18	16
GM	2058 Bq	11.6 mSv
GSD	1.72	1.28
AM	1907 Bq	12.0 mSv
ASD	1700 Bq	2.95 mSv
Coefficient of variation (%)	71	25
Minimum	761 Bq	8.2 mSv
Maximum	7520 Bq	17.4 mSv
Outliers	0	2

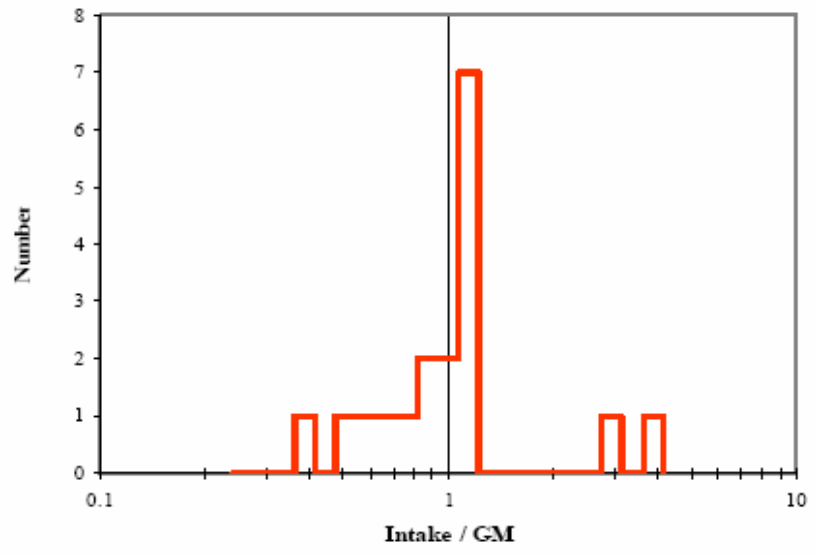


Fig. 12.17. Frequency distribution of results of the Acute intake subset without outliers (N = 18). ^{234}U Intakes normalized to the geometric mean (GM = 2058 Bq, GSD = 1.72).

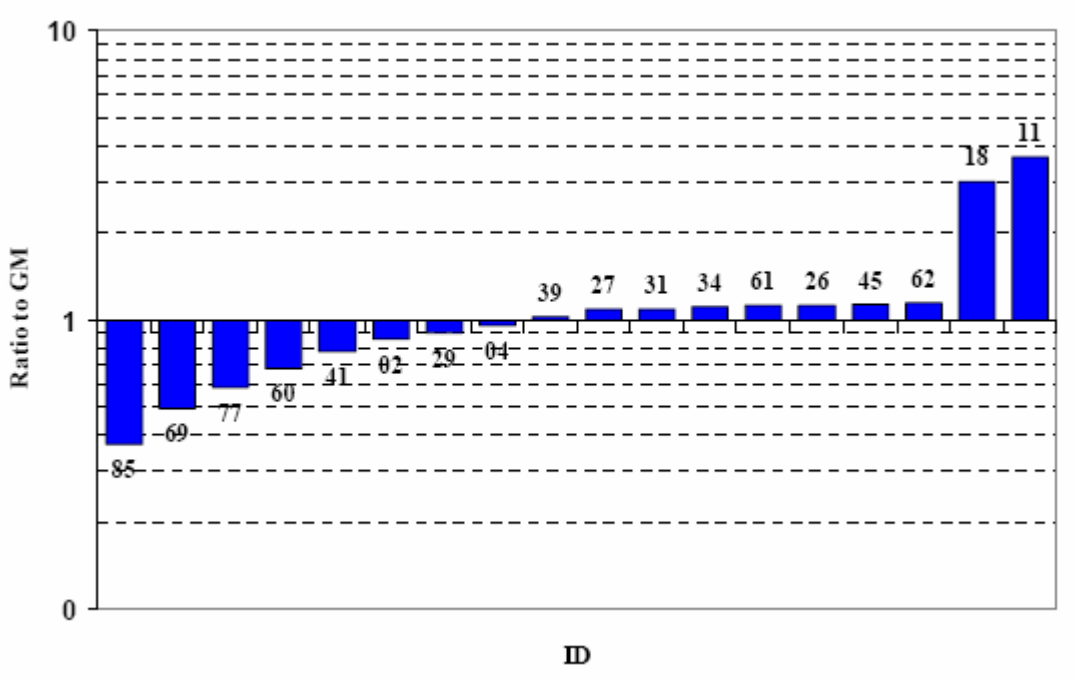


Fig. 12.18. Results of the individual participants (ID) from the Acute intake subset. ^{234}U intakes normalized to the geometric mean (GM = 2058 Bq, GSD = 1.72).

For the committed effective dose E(50), the Geometric mean (11.6 mSv) and the arithmetic mean (12.0 mSv) are equal. The two higher values (42 and 51 mSv) from ID 18 and 11 are statistically outliers. The two participants with the assumed AMAD of 0.3 and 1 µm used the adequate higher dose coefficient and so reduce the dispersion of the assed committed dose. The geometric standard deviation (1.28) and the coefficient of variation (25 %) also show the lower dispersion of the results. This is exemplified in the Figures 12.19 and 12.20.

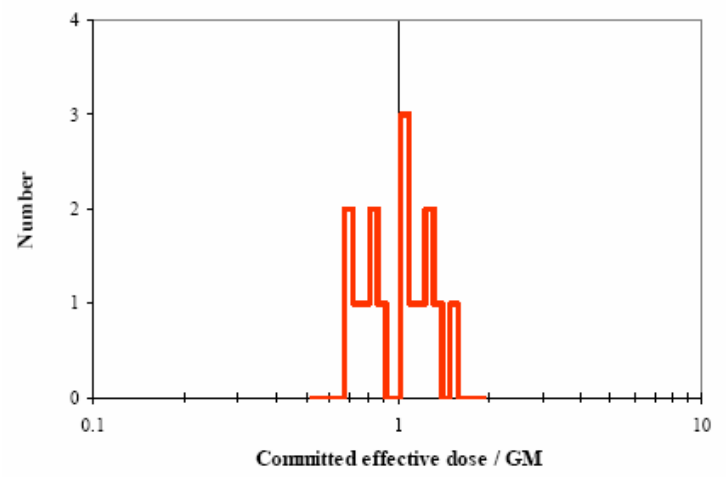


Fig. 12.19. Frequency distribution of results of the Acute intake subset without outliers (N = 16). ^{234}U E(50) normalized to the geometric mean (GM = 11.6 mSv, GSD = 1.28).

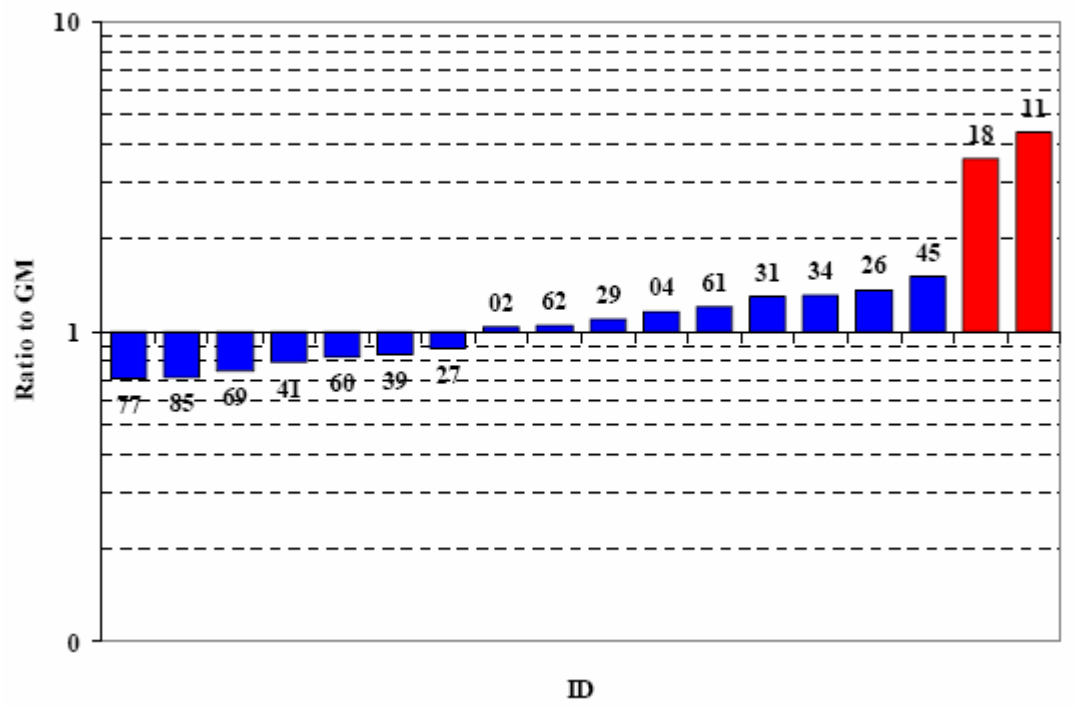


Fig. 12.20. Results of the individual participants (ID) from the acute intake subset. ^{234}U E(50) normalized to the geometric mean (GM = 11.6 mSv, GSD = 1.28). The red bars are outliers.

12.3.9.2. Chronic intake subset

The statistical evaluation of the results of this subset is given Table 12.6.

Table 12.6. Statistical evaluation of the results for the Chronic intake subset excluding outliers: ^{234}U

	Intake	E(50)
N	22	22
GM	12077 Bq	70 mSv
GSD	2.7	2.8
AM	20400 Bq	126 mSv
ASD	26060 Bq	178 mSv
Coefficient of variation (%)	128	141
Minimum	2710 Bq	8.7 mSv
Maximum	109000 Bq	739 mSv
Outliers	0	0

The geometric mean of the estimate of intake of ^{234}U (12077 Bq) is far apart from the arithmetic mean (20400 Bq). The geometric standard deviation of 2.7 is high as the coefficient of variation (128 %). Following the statistical criteria described earlier, there are no outliers for the intake estimates as well as for E(50) estimates. The range of intakes is relatively broad: 2710 – 109000 Bq (ratio max/min = 40). There are no obvious reasons for this spread of the results.

The three groups of time pattern of intake and dataset used for the assessment (namely: chronic intake, acute intake with urine dataset and Acute + Chronic intake), are spread over the whole range of results (Figure 12.21). Whenever Chronic intake has been assumed, the start of intake is the 3 January 1984.

- Participant 48 assumed absorption Type M. Participants 30, 13, 16 and 25 assumed a mixture of absorption Type M and S.
- Participant 81 assumed an AMAD of 0.3 µm, Participants 30 and 47, 1 µm and Participant 22, 7 µm. All the other participants used the default value of 5 µm.
- Participant 55 used U_3O_8 (F) transfer parameters for the lungs from the NRPB document and 67, 79 and 22 used their own modified parameters.
- Participant 50 did not use any software. 48, 30 and 82 used home made software and all the others used one of the available software programmes.

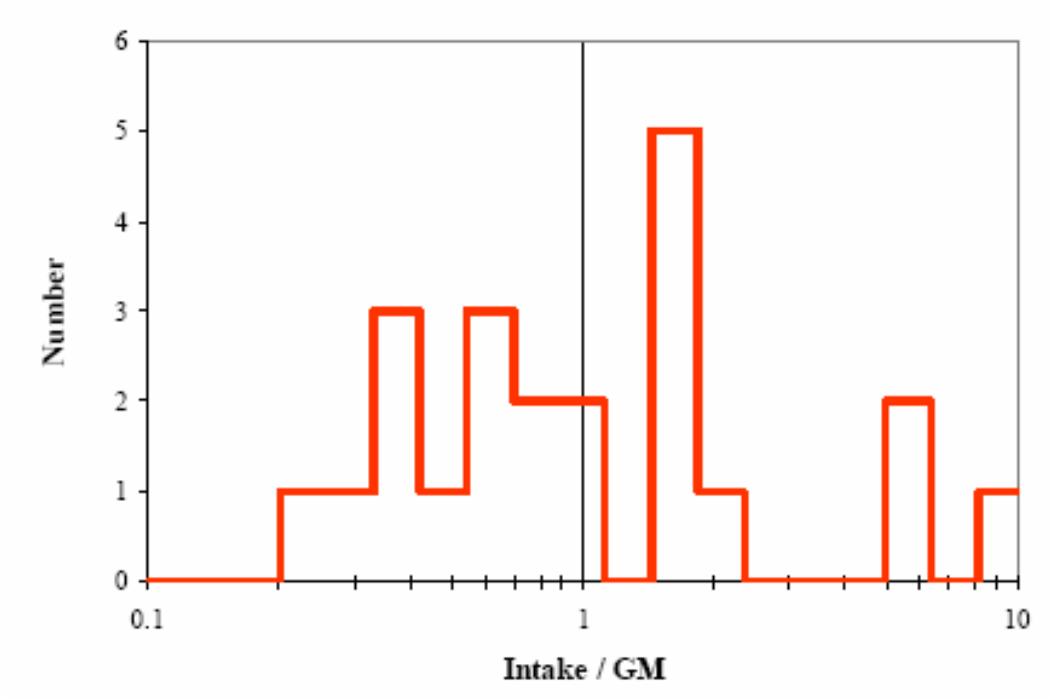


Fig. 12.21. Frequency distribution of results of the Chronic intake subset without outliers (N = 22). ^{234}U Intakes normalized to the geometric mean (GM = 12077 Bq, GSD = 2.7).

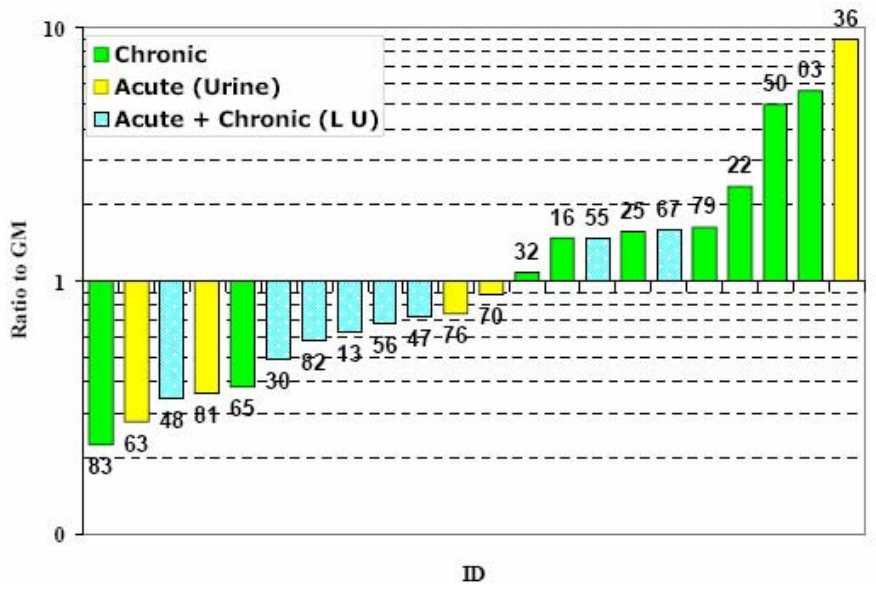


Fig. 12.22. Results of the individual participants (ID) from the Chronic intake subset. ^{234}U intakes normalized to the geometric mean (GM = 12077 Bq, GSD = 2.7).

As for the ^{234}U intake, the geometric mean of ^{234}U committed effective dose (70 mSv) is far apart from the arithmetic mean (126 mSv). The geometric standard deviation (2.8) is high as the coefficient of variation (148 %). The range of E(50) is very broad: 8.7 – 739 mSv (ratio max/min = 85). The lowest value of 8.7 mSv for E(50) from ID 48 is due to the assumption of absorption Type M compound. The highest value of 739 mSv from ID 36 is due to the only use of urine data set in conjunction with a single acute intake. These two results are not statistically outliers, but without them, the geometric mean is 69 mSv with a geometric standard deviation of 2.3 and the range of results is much smaller: 18.3 – 460 mSv (ratio max/min = 25).

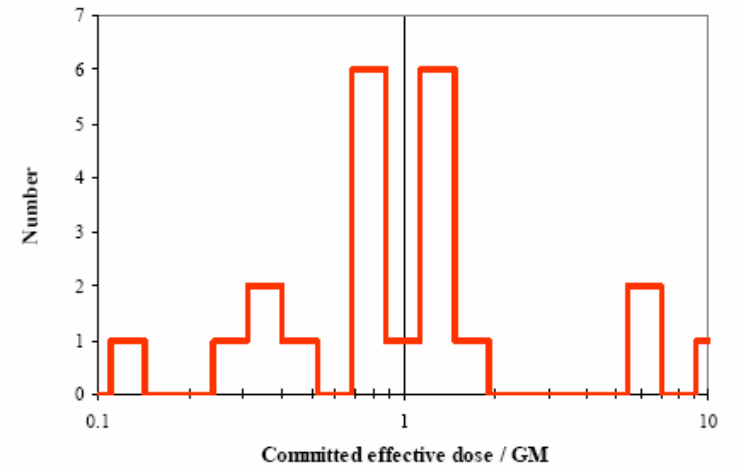


Fig. 12.23. Frequency distribution of results of the Chronic intake subset without outliers (N = 22). ^{234}U E(50) normalized to the geometric mean (GM = 70 mSv, GSD = 2.8).

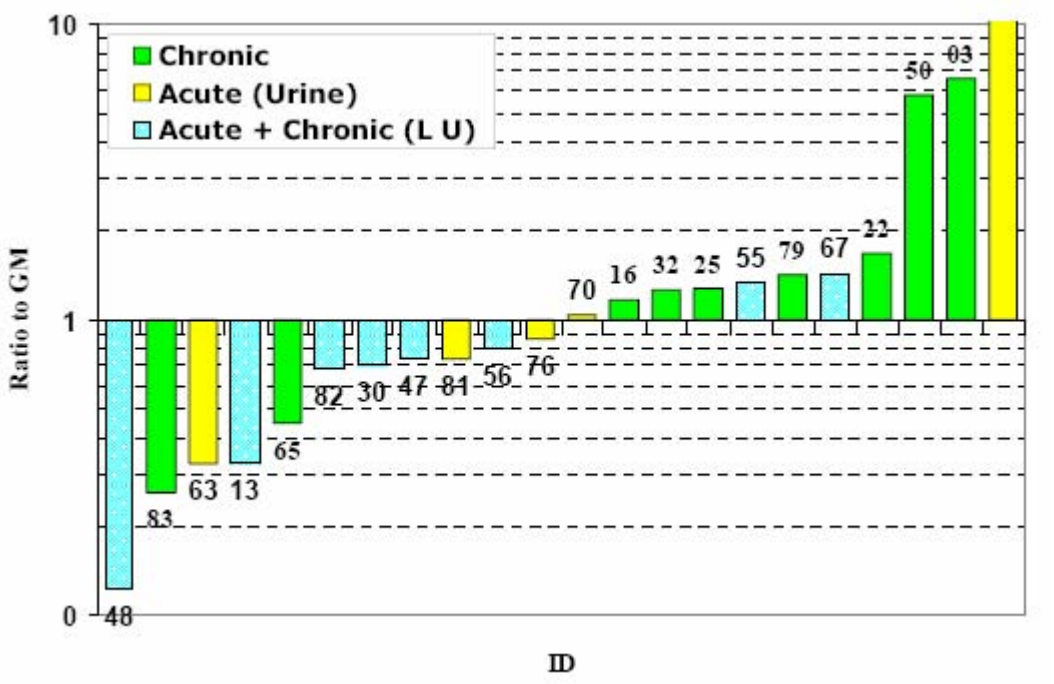


Fig. 12.24. Results of the individual participants (ID) from the Chronic intake subset. ^{234}U E(50) normalized to the geometric mean (GM = 70 mSv, GSD = 2.8).

12.3.9.3. Summary of the ^{234}U results

The following tables show the summary of the evaluation of the results for ^{234}U intake and committed effective dose E(50).

Table 12.7. Statistical evaluation of the results of ^{234}U intake excluding outliers

	All results	**Acute intake subset**	**Chronic Intake subset**
N	40	18	22
GM	5054 Bq	2058 Bq	12077 Bq
GSD	3.0	1.72	2.7
AM	9719 Bq	1907 Bq	20400 Bq
ASD	14275 Bq	1700 Bq	26060 Bq
Coefficient of variation	147 %	71 %	128 %
Minimum	761 Bq	761 Bq	2710 Bq
Maximum	68000 Bq	7520 Bq	109000 Bq
Outliers	1	0	0

Table 12.8. Statistical evaluation of the results of ^{234}U E(50) excluding outliers.

	All results	**Acute intake subset**	**Chronic Intake subset**
N	38	16	22
GM	27 mSv	11.6 mSv	70 mSv
GSD	2.4	1.28	2.8
AM	39 mSv	12.0 mSv	126 mSv
ASD	33 mSv	2.95 mSv	178 mSv
Coefficient of variation	84 %	25 %	141 %
Minimum	8.2 mSv	8.2 mSv	8.7 mSv
Maximum	118 mSv	17.4 mSv	739 mSv
Outliers	3	2	0

12.3.10. Intercomparison results of total uranium committed effective dose

The statistical evaluation of the total Uranium committed effective dose results excluding outliers is given Table 12.9. The results for the total Uranium committed effective dose are very similar than the results for ^{234}U as this isotope is the main component of the dose. The graphical representation demonstrates this similarity (Figure 12.25 to 12.30). The frequency distribution of the results for total Uranium E(50) for the chronic intake subset (Figure 12.29) is identical to the same subset for ^{234}U E(50) (Figure 12.23).

Table 12.9. Statistical evaluation of the results of total Uranium E(50) excluding outliers

	All results	Acute intake subset	Chronic Intake subset
N	38	16	22
GM	32 mSv	13.7 mSv	83 mSv
GSD	2.4	1.27	2.8
AM	46 mSv	14.1 mSv	149 mSv
ASD	39 mSv	3.4 mSv	210 mSv
Coefficient of variation	84 %	24 %	141 %
Minimum	9.7 mSv	9.7 mSv	10.1 mSv
Maximum	138 mSv	21 mSv	868 mSv
Outliers	3	2	0

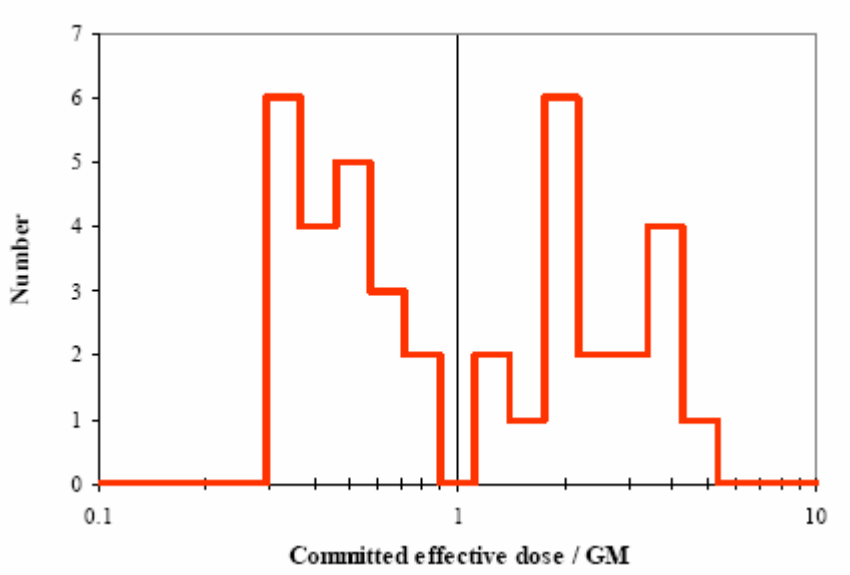


Fig. 12.25. Frequency distribution of results without outliers (N = 38): Total Uranium E(50) normalized to the geometric mean. (GM = 32 mSv, GSD = 2.4).

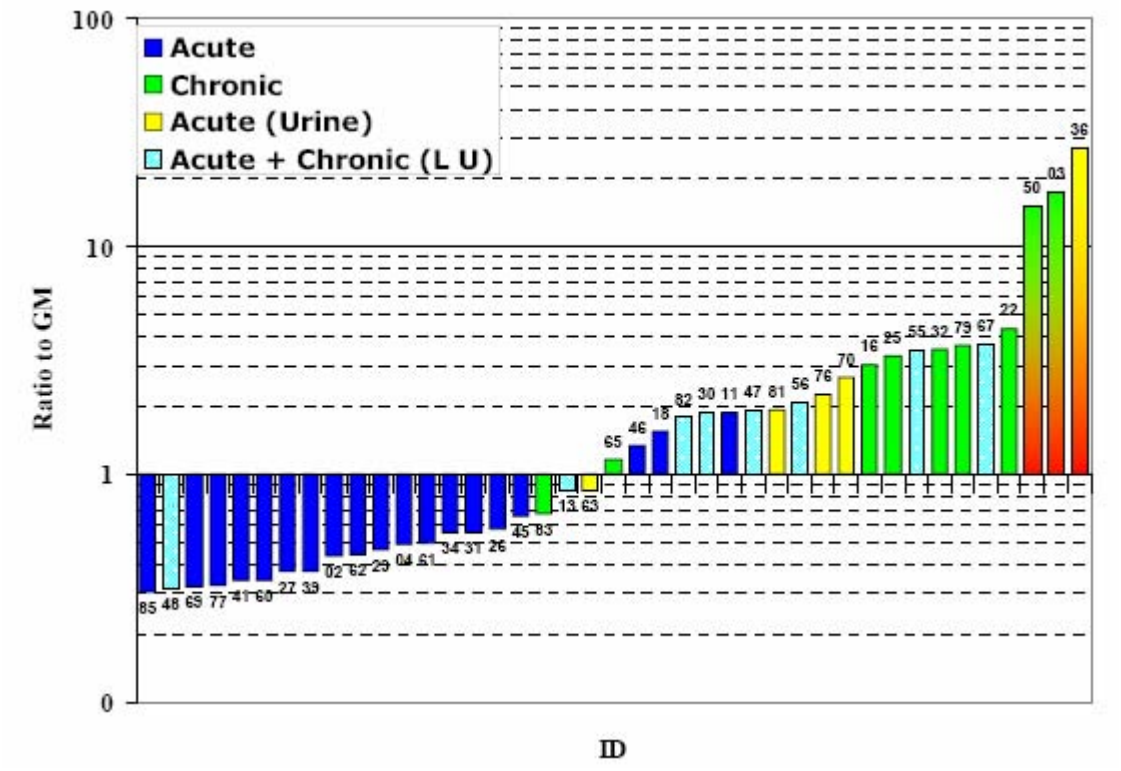


Fig. 12.26. Results of the individual participants: Total Uranium E(50) normalized to the geometric mean (GM = 32 mSv, GSD = 2.4). The red bar are outliers.

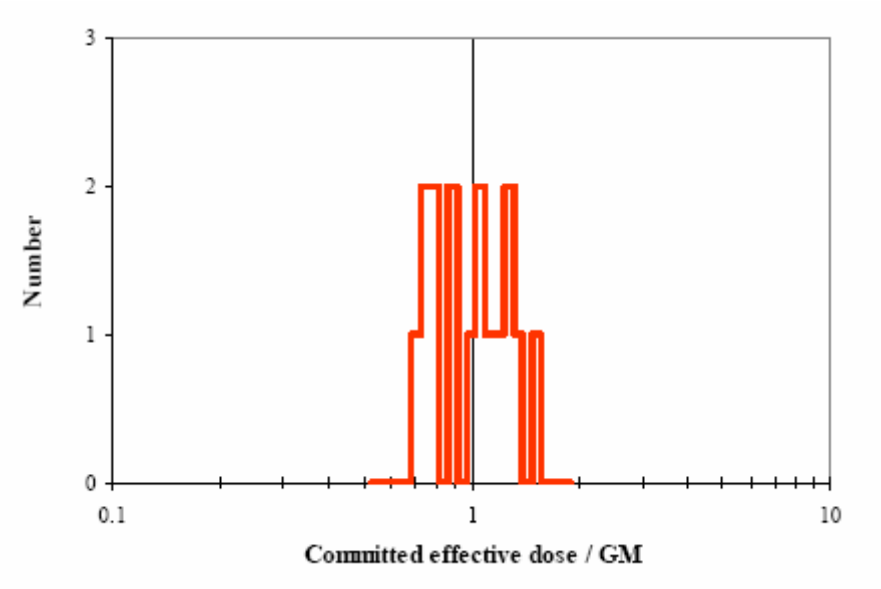


Fig. 12.27. Frequency distribution of results without outliers (N = 16), from the Acute intake subset. Total Uranium E(50) normalized to the geometric mean (GM = 13.7 mSv, GSD = 1.27).

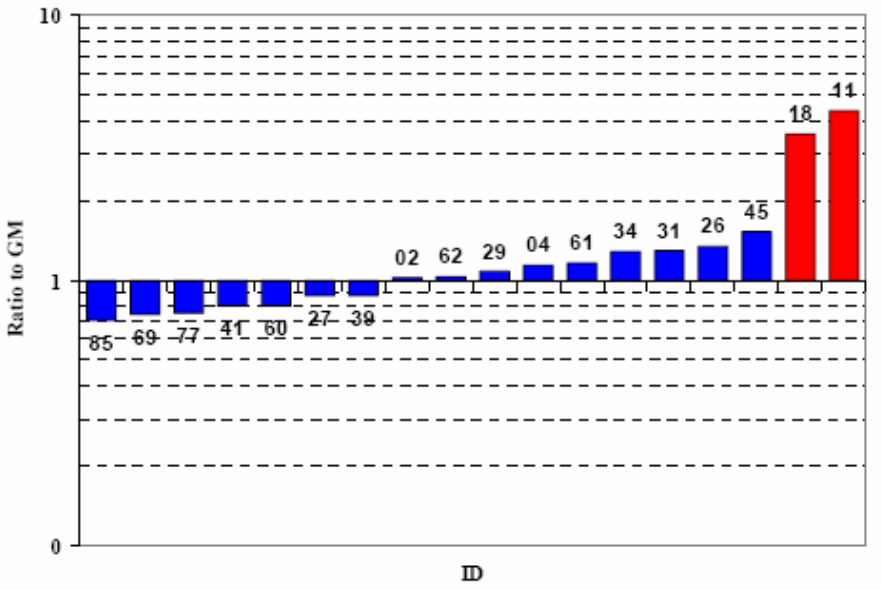


Fig. 12.28. Results of the individual participants from the acute intake subset: Total Uranium E(50) normalized to the geometric mean (GM = 13.7 mSv, GSD = 1.27). The red bars are outliers.

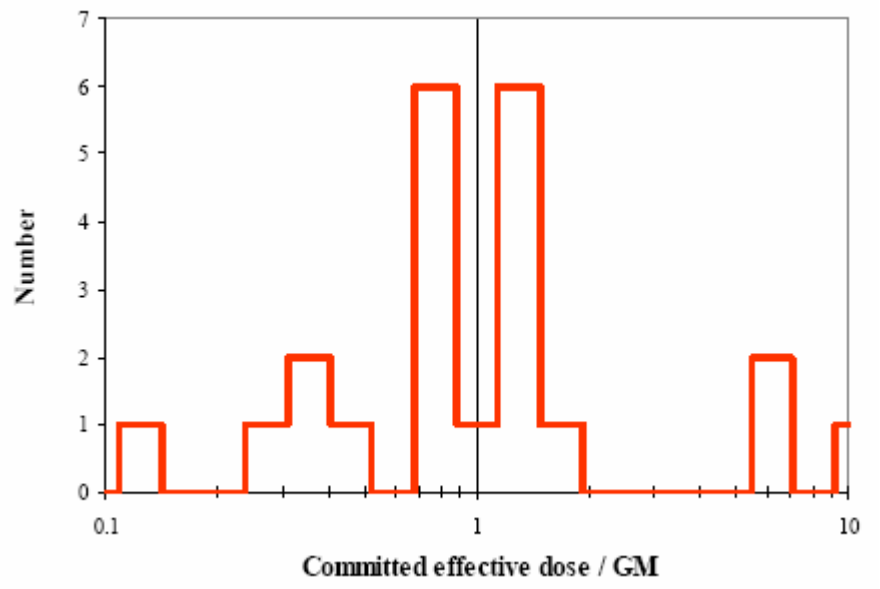


Fig. 12.29. Frequency distribution of results (N = 22) from the Chronic intake subset. Total Uranium E(50) normalized to the geometric mean (GM = 83 mSv, GSD = 2.8).

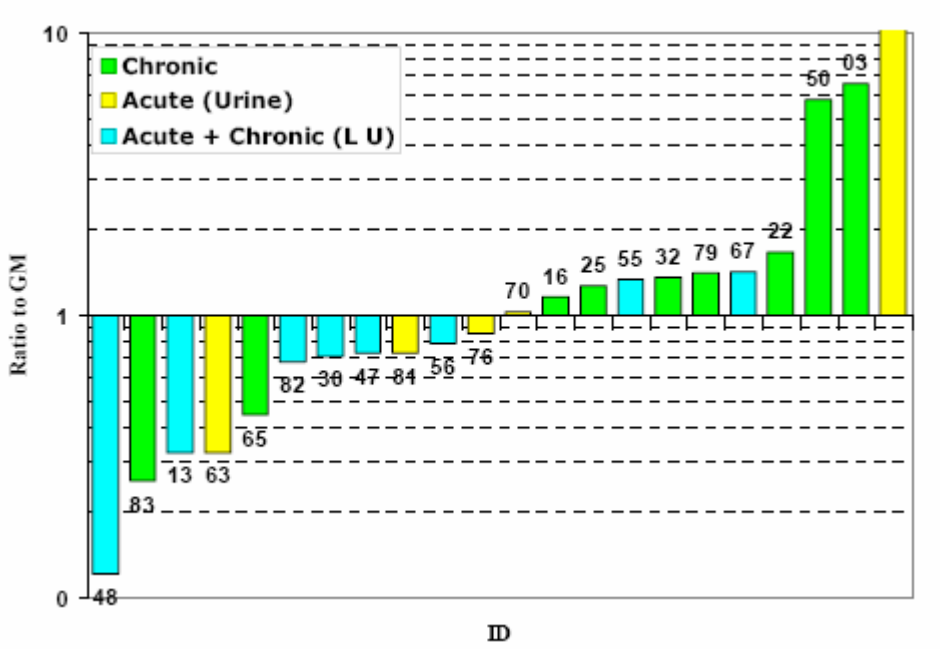


Fig. 12.30. Results of the individual participants from the chronic intake subset: Total Uranium E(50) normalized to the geometric mean (GM = 83 mSv, GSD = 2.8).

12.3.11. Software used

The most frequently used software code was IMBA (which was freely available for this intercomparison exercise). Fourteen participants had used IMBA whereas three had used AIDEe, two had used MONDAL, LUDEP or IDEAS DV0102. Other codes that were used include BKFIT, CINDY, IMIE, INDOS, INDAC, IDEA system, INDO 2000, MMK-01 and NIRS.

Three participants had used homemade software. One participant stated that he had used Mathematica and Excel whereas five participants declared that they had used no software.

12.3.12. Use of guidelines

The responses to following the guidelines, 41 % of the participants (i.e. 17 of them) stated that they had followed the IDEAS guidelines, 39 % did not follow the guidelines and 20 % did not reply. Those that did not follow the guidelines gave the reasons summarized in Table 12.10.

Table 12.10. Reasons for not following the guidelines

Reason	Number of participants
Followed own established procedures or the software	4
Case not adequate or very special case	4
Guidelines not clear enough, not user friendly	2
No time to read guidelines	1
Guidelines not available	1
No comment	2

12.4. Conclusion for Case 5

The aim of the present exercise is to provide a test for the application of the IDEAS guidelines as a tool for accurate dose assessment. This Case 5 of enriched Uranium intake is probably not the best example to test the application of the guidelines but nevertheless raised some interesting issues.

A problem in this case is the scarcity of data. However, this scarcity of data raises an important point and that is that all data available have to be taken into account to estimate the intake and assess the dose. Participants using only the lung data for their assessment missed the chronic intake component and consequently their assessed committed effective dose is much lower by nearly a factor 10.

In view of the scarcity of data, there is no reason to modify the default AMAD of 5µm suggested by ICRP. Other AMAD than the default can be used when site specific data are provided or if early lung and faecal data are available.

An incorrect assumption about the case can lead to a more or less correct assessed dose. Participants assuming an acute intake but using only the urine data for their assessment reached the committed effective dose obtained from a chronic intake. This is due to the fact that an acute intake can also be represented by a chronic intake and vice versa. In this case, the urine data were representative of the chronic intake.

Wrong information was supplied in the case description and that is that the worker was removed from radioactive work after the incident of 21st March 1997. This was true just after the incident, but the worker resumed work after a while.

Most of the participants if not all of them tried to fit the urine data assuming that the chronic intake had stopped after the incident. The urine data span over a period of 5 months and do not show a decreasing trend as should happen if the chronic intake had not persisted. This raises another issue: should you trust all the information given? If the data contradict the information given, the information and / or the data should be checked.

The IDEAS guidelines are an important tool for accurate dose assessment, but judgment is still needed for the correct assessment of a contamination case.

13. CASE 6: SINGLE INTAKE OF PLUTONIUM RADIONUCLIDES AND ^{241}AM

13.1. Case description

13.1.1. The event

Description of the working area	Radiochemical laboratory for the development of advanced nuclear fuels in a nuclear research centre.
Characteristics of work	In the laboratory nuclear fuel microspheres had been produced in a glove box using a special gelling technique. The waste water resulting from this technique was routinely collected and evaporated in the box. The residual waste was transferred into a second glove box for further evaporation and disposal.
Reasons for monitoring; initiating event	On 24.05.83 at 4.15 p.m. there was an explosion in the second glove box during evaporation of 3 l waste as a consequence of an unexpected exothermic reaction. The pressure of the explosion opened the sluice of the box and destroyed the gloves. A person working at the first box left the laboratory immediately after the explosion. However, he was strongly contaminated on the face, hair and clothes.
Actions taken	The person involved was decontaminated in the radiation protection unit of the research centre. Nose swabs and also bronchial slime samples were taken. He was also measured in the lung counter of the research centre on the same day as the incident.

13.1.2. Additional information

Air monitoring	There were stationary room air samplers.
Chemical form	Uranium/plutonium hydroxide gel in washing water containing about 10 % ammonium nitrate and about 3.5 % hexamethylen-tetramine.
Physical characteristics, particle size	Alpha activity composition of the inhaled substance was 9 % ^{238}Pu, 55 % ^{239}Pu, 26 % ^{240}Pu and 10% ^{241}Am. The ^{241}Pu activity was 750 % of the total alpha activity. The diameter of the particles containing plutonium is supposed to be between 3 – 40 µm according to scanning electron microscopy and qualitative X-ray analyses of dust samples from the laboratory.
Nose swab, bronchial slime or similar	Nose swab contained 5.5 kBq activity of ^{239}Pu and ^{240}Pu. The bronchial slime activity was 1.4 kBq of ^{239}Pu and ^{240}Pu.

Non removable skin contamination	None
Wound site activity	None
Any intervention used (blocking, chelating, etc.)	None

13.1.3. Body monitoring data

Organ activity measurement

^{241}Am chest measurements

Time after intake (d)	**Chest ^{241}Am (Bq)**	**Percentage uncertainty (1 σ)[(a)] (%)**
0.1	390	25
1	310	25
3	230	25
6	240	25
15	230	25
34	230	25
38	260	25
44	230	25
160	220	25
164	230	25
357	220	25
1077	240	25
2925	180	25

(a) Uncertainty (1 σ) is due to counting statistics only.

^{241}Am lung (organ) measurements

Time after intake (d)	Lung ^{241}Am (Bq)	Percentage uncertainty (1 σ)[(a)] (%)
3724	120	13
3828	120	21

(a) Uncertainty (1 σ) is due to counting statistics only.

^{241}Am liver (organ) measurements

Time after intake (d)	Liver ^{241}Am (Bq)	Percentage uncertainty (1 σ)[(a)] (%)
3724	57	16
3828	24	33

(a) Uncertainty (1 σ) is due to counting statistics only.

^{241}Am bone (organ) measurements

Time after intake (d)	Bone ^{241}Am (Bq)	Percentage uncertainty (1 σ)[(a)] (%)
3724	69	12
3828	65	12

(a) Uncertainty (1 σ) is due to counting statistics only.

Whole body activity measurement None

13.1.4. Excretion monitoring data

Urine activity measurement

^{241}Am urine measurements

Time after intake (d)	Daily urinary excretion rate ^{241}Am (Bq/d)
1	1.09E-01
2	9.54E-02
14	1.55E-02

Time after intake (d)	Daily urinary excretion rate ^{241}Am (Bq/d)
21	1.06E-02
31	5.19E-03
37	4.98E-03
43	4.79E-03
181	4.19E-03
368	3.61E-03
606	3.08E-03
1076	2.30E-03
1922	4.07E-03
2090	3.14E-03
2527	4.30E-03
2922	2.30E-03
3902	2.25E-03

^{239}Pu urine measurements

Time after intake (d)	Daily urinary excretion rate^{239}Pu (Bq/d)
1	7.47E-03
2	2.78E-02
14	3.19E-03
21	2.51E-03
31	2.51E-03
37	3.80E-03
43	2.51E-03
181	2.51E-03
368	2.38E-03

Time after intake (d)	Daily urinary excretion rate ^{239}Pu (Bq/d)
606	1.97E-03
1076	2.51E-03
1922	4.01E-03
2090	4.21E-03
2527	4.09E-03
2922	2.81E-03
3902	2.31E-03

Faeces activity measurement

^{241}Am faecal measurements

Time after intake (d)	Daily faecal excretion rate ^{241}Am (Bq/d)
1	9.22E+02
2	4.07E+02
3	2.51E+01
13	8.56E-02
21	7.00E-02
30	4.56E-02
37	5.02E-02
44	3.57E-02
181	4.75E-02
369	3.03E-02
606	4.65E-02
1076	1.80E-02
1922	2.50E-02
2526	1.20E-02
2922	5.60E-03

^{239}Pu faecal measurements

Time after intake (d)	Daily faecal excretion rate ^{239}Pu (Bq/d)
1	3.53E+03
2	2.04E+03
3	2.99E+02
13	4.55E-01
21	4.89E-01
30	4.55E-01
37	1.70E-01
44	1.43E-01
181	2.85E-01
369	1.77E-01
606	1.77E-01
1076	4.28E-02
1922	5.81E-02
2526	2.08E-02
2922	7.94E-03

13.1.5. Personal data

Sex	Male
Age	26 years (at year of intake)
Weight	80 kg

13.1.6. 9.1.6 Other comments relevant for intake and dose estimation

The data presented here are a subset of the original data. The ^{239}Pu data have been calculated from the $^{239+240}$Pu data and the plutonium isotopic activity ratios of the inhaled material. The ^{241}Am urine and faecal data have been calculated from the ^{241}Am+^{238}Pu data, the $^{239+240}$Pu data and the plutonium isotopic activity ratios of the inhaled material.

Estimate the intake of ^{239}Pu and ^{241}Am and the resulting committed effective doses E(50) of these radionuclides only.

13.2. ^{241}Am intake and dose assessment

Before following the guidelines to assess the case it is useful to plot the available data (Figure 13.1) and perform a simple calculation to assess the intake and dose.

From the case description (Section 13.1), the time of intake is known and the intake pathway can be considered as inhalation. Furthermore, the data appears to be consistent with an acute inhalation of ^{241}Am (Figure 13.1).

The amount deposited in the respiratory tract can be estimated approximately from the nose swab, faecal data and lung data as follows:

- *Amount deposited in ET_1 can be estimated from the nose swab.*
  Activity of nose swab is 5.5 kBq of $^{239+240}$Pu. The initial activity ratio of ^{241}Am: $^{239+240}$Pu is 0.12, so this gives an activity of 5.5 × 1.4 = 0.7 kBq of ^{241}Am.
- *Amount deposited in (ET_2 + BB +bb) can be estimated from the early faecal excretion.*
  The cumulative faecal excretion over the first three days (1.5 kBq of ^{241}Am) is approximately equal to the amount deposited in (ET_2 + BB +bb).
- *Amount deposited in AI region can be estimated from lung measurements.*
  The activity measured in the lung on day three (0.2 kBq of ^{241}Am) is approximately equal to the amount deposited in AI region.

Adding all these up produces a total of 2.4 kBq of ^{241}Am.

For a 5 μm AMAD aerosol 80% of the intake is deposited in the respiratory tract as predicted by the ICRP Publication 66 *Human Respiratory Tract Model (HRTM)* [1]. From this the intake is approximately 2.4/0.8 = 3.0 kBq.

The ICRP Publication 68 [20] states the dose coefficient for ^{241}Am, assuming Type M and a 5 μm AMAD aerosol, is 2.7 10^{-5} Sv/Bq. Therefore, E(50) is approximately 80 mSv. This gives us a rough estimate of the intake and dose.

The following sections describe the assessment of the case by following the IDEAS guidelines. As this is a special monitoring case for inhalation the steps in flow chart 5 are followed.

The models that were used to assess the intake and dose include the HRTM [1], the ICRP Publication 30 *Gastrointestinal Tract model* [18] and the ICRP Publication 67 *Systemic Biokinetic Model for Americium* [2].

The intake and dose was assessed with the software IMBA Professional. This version of IMBA accounts for the in-growth of ^{241}Am from ^{241}Pu automatically when assessing the intake of ^{241}Am from measurement data of ^{241}Am. (See advanced dosimetry options of the IMBA Professional software).

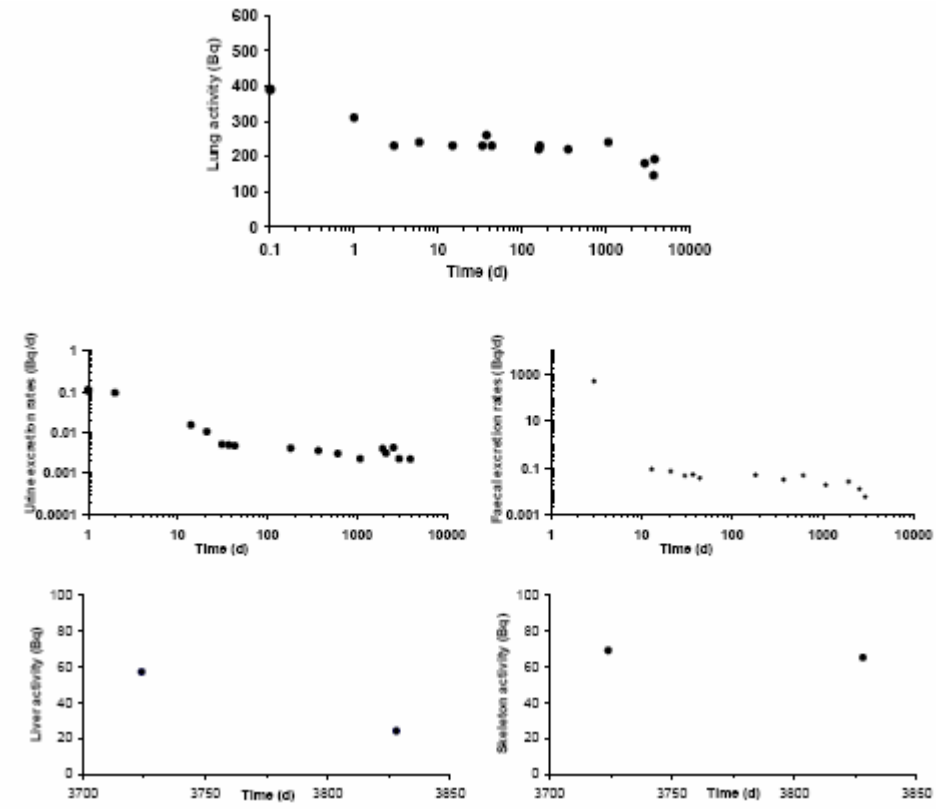


Fig. 13.1. A plot of the Americium measurement data given in case 6 . Five data sets are given: lung, urine, faeces, liver and skeleton data sets. The lung data are the chest measurements with two extra data points: the lung organ measurements were added to lymph organ measurements to produce total 'lung activity' (Section 13.2.1).

13.2.1. Step 5.1: Identification of data and assignment of realistic uncertainties

The ^{241}Am data given are:

- Chest measurements (13 data points)
- Lung & Lymph measurements (4 data points)
- Liver (2 data points)
- Skeleton (2 data points)
- Urine (16 data points)
- Faeces (15 data points)

At this stage there is no reason to reject any of these data, so all of the data will be used to assess the intake of ^{241}Am and to calculate the resulting dose, E(50).

The "Bronchial Slime Activity", that would have appeared in the faeces in the first day or soon afterwards, was added to the faeces (day 1).

The activity of the bronchial slime was 1.4 kBq of ^{239}Pu and ^{240}Pu. The initial ratio of ^{241}Am /(^{239}Pu + ^{240}Pu) of the inhaled activity is 10/(55+26). Assuming this ratio applies to the bronchial slime, the ^{241}Am activity in the bronchial slime is:

$$1.4\ 103 \times\ 10/(55+26) = 173 \text{ Bq.}$$

This is added to the ^{241}Am faecal data at day one (922 Bq) to give 1095 Bq.

The average activity excreted in the faeces over three days was calculated and used in IMBA with a three-day collection period. This average activity is given by:

$$(1095 + 407 + 25.1)/3 = 509 \text{ Bq/d}$$

Therefore, the faecal data set will consist of 13 data points.

The organ 'lung' data and organ 'lymph' data were added together to give the amount in the thoracic region (Tables 13.1, 13.2 and 13.3).

13.2.1.1.Assignment of realistic uncertainties for the in-vivo data

Only counting statistics uncertainties are given (Type A uncertainties). Type B uncertainties were combined as suggested in the guidelines. Also it was assumed that the measurements are lognormally distributed, as suggested in the guidelines.

Chest measurements

For all of the chest data Type A uncertainties are 25% (SF = exp(0.25) = 1.28). Type B uncertainties have SF of 1.25 (Table 2.2 of the IDEAS guidelines). This gives a total SF of 1.4 using the following equation:

$$SF = \exp\left[\sqrt{\sum_i \ln^2(SF_i)}\right] \qquad \textbf{(13.1)}$$

with SF total scattering factor

SF_i scattering factor due to component i

Organ 'lung' and lymph data

Two more data points were included with the chest data: The organ 'lung' and organ 'lymph' data were added together to give the amount in the thoracic region.

Again, only Type A uncertainties are given for these measurements. Type B uncertainties (SF=1.25) were combined with Type A uncertainties to give a total SF for each measurement (Tables 13.1 and 13.2). Assuming these uncertainties are independent the total uncertainties on the thoracic activity (i.e. lung plus lymph) was calculated using the following formulae:

$$\sigma_{\text{thoracic}} = \sqrt{\sigma_{\text{lung}}^2 + \sigma_{\text{lymph}}^2}$$

where the σ represents the absolute uncertainties on the measurement value, m. Thus,

$$\sigma = m \times \ln(SF)$$

The total scattering factor for the thoracic activity is given by:

$$SF_{\text{thoracic}} = exp\left(\frac{\sigma_{\text{thoracic}}}{m_{\text{thoracic}}}\right)$$

These scattering factors are given in Table 13.3.

Table 13.1. ^{241}Am lung (organ) measurements

Time after intake	**Lung ^{241}Am**	**Type A uncertainty [a]**		**Type B**	**Total SF**
(d)	(Bq)	%	SFA	SFB	
3724	120	13	1.14	1.25	1.29
3828	120	21	1.23	1.25	1.36

(a) Uncertainty (1 σ) is due to counting statistics only.

Table 13.2. ^{241}Am lymph (organ) measurements

Time after intake	**Lymph ^{241}Am**	**Type A uncertainty [a]**		**Type B**	**Total SF**
(d)	(Bq)	%	SFA	SFB	
3724	26	14	1.15	1.25	1.30
3828	72	29	1.34	1.25	1.44

(a) Uncertainty (1 σ) is due to counting statistics only.

Table 13.3. ^{241}Am thoracic activities (i.e. lung plus lymph)

Time after intake (d)	**Thoracic ^{241}Am (Bq)**	**SF_{thoracic}**
3724	146	1.24
3828	192	1.27

Liver data

The total scattering factors for the liver data are given in Table 13.4.

Table 13.4. ^{241}Am liver (organ) measurements

Time after intake	**Liver ^{241}Am**	**Type A uncertainty [(a)]**		**Type B**	**Total SF**
(d)	(Bq)	%	SFA	SFB	
3724	57	16	1.17	1.25	1.32
3828	24	33	1.39	1.25	1.49

(a) Uncertainty (1 σ) is due to counting statistics only.

Skeleton data

The total scattering factors for the skeleton data are given in Table 13.5.

Table 13.5. ^{241}Am skeleton (organ) measurements

Time after intake	**Skeleton ^{241}Am**	**Type A uncertainty [(a)]**		**Type B**	**Total SF**
(d)	(Bq)	%	SFA	SFB	
3724	69	12	1.13	1.25	1.29
3828	65	12	1.13	1.25	1.29

(a) Uncertainty (1 σ) is due to counting statistics only.

13.2.1.2. Assignment of realistic uncertainties for the excretion data

Urine data

Lognormal distribution with a SF of 1.8. This value is given in the guidelines and is based on an analysis of Plutonium in urine measurements of Sellafield workers carried out by Riddell and Britcher (1994) [25].

Faecal data

Lognormal distribution with a SF of 3.0 (lower value given in Table 2.2 of guidelines). The actual data suggests the SF is about 2.2 so it is justifiable to assume the lower value (SF=3.0) given in Table 2.2 of guidelines. One could argue that the uncertainty on the average faecal excretion rate over the first three days is less than a SF of 3. However it is difficult to quantify the error on the faecal excretion rate on the first day, so for simplicity assume that the SF for the average faecal excretion rate is 3.

13.2.2. Step 5.2: Assessment of contributions from previous intakes.

In this case, no information is given about previous intakes so assume that the measured activities all arise from this incident.

13.2.3. Step 5.3: Assign a priori parameters (default or site specific)

ICRP Publication 68[20] recommends Type M for all Americium compounds. The default parameter values assumed are:

- 5 μm AMAD aerosol
- Absorption Type M
- f_1 value $5.0\ 10^{-4}$
- Reference worker

13.2.4. Step 5.4: Is the time of intake known?

The time of intake is known so proceed to step 5.5.

13.2.5. Step 5.5: Calculate dose with a priori parameters

As stated above the IMBA Professional software was used to assess this case. Briefly, the software implements the current ICRP dosimetric and biokinetic models but enables the user to alter parameter values from the ICRP defaults. It uses the maximum likelihood method to fit multiple data and has the ability to assess the intake by fitting predicted values to different types of data simultaneously. The IDEAS guidelines recommends the maximum likelihood method and therefore the guidelines can be followed using this software.

Intakes were estimated by fitting simultaneously the predicted lung retention, liver retention, skeleton retention, and urine and faecal excretion rates to the ^{241}Am data sets. When accounting for the in-growth of ^{241}Am from ^{241}Pu to estimate the intake of ^{241}Am, IMBA Professional assumes ^{241}Pu behaves in the same way as does ^{241}Am, i.e. it follows the systemic Americium model and has the same absorption characteristics.

With the default parameter values given in step 5.3 the estimated intake is 135 kBq and E(50) is 3.65 Sv. However, the fits to the data are very bad (Figure 13.2), and this indicates that the model parameter values are incorrect.

13.2.6. Step 5.6: Is E(50) < 1 mSv?

With the default parameter values E(50) was calculated to be 3.65 Sv.

As this is greater than 1 mSv proceed to the next step

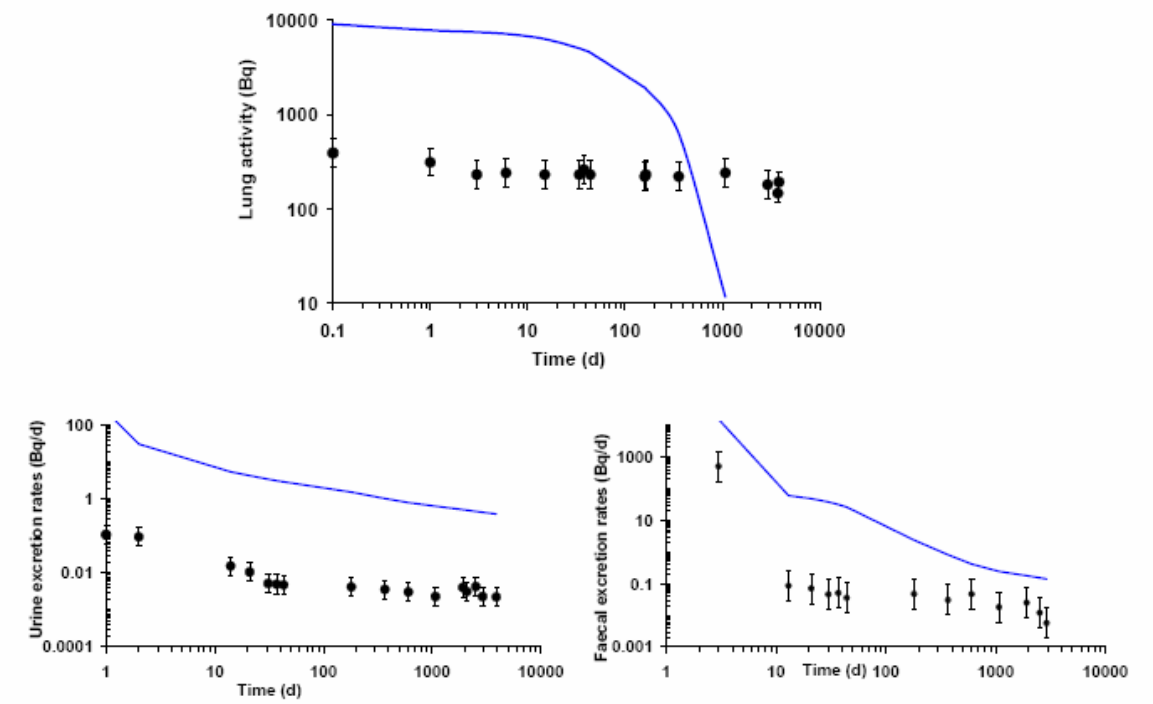


Fig. 13.2. Model fits to lung, urine and faecal data assuming Type M (step 5.5).

13.2.7. Step 5.7: Are there sufficient relevant data?

The guidelines suggest a minimum number of data that is required for a dose assessment for certain radionuclides. In this case there is comprehensive data spanning over 10 years. In total there are 48 data points. It can, therefore, be concluded that there are enough data for this dose assessment, so proceed to the next step.

13.2.8. Step 5.8: Is the time of intake known?

The time of intake is known so proceed to step 5.9.

13.2.9. Step 5.9: Are early and lung faeces available?

There are early lung and faecal data available so proceed to step 5.10.

13.2.10. Step 5.10: Derive effective AMAD from early lung and faecal data

The effective AMAD was estimated from the ratio of the cumulative ^{241}Am faecal activity over the first 3 days after intake (1095 + 407 + 25.1 = 1527 Bq), to activity in lung on day 3 (230 Bq). Ratio = 1527/230 = 6.6. Note, the estimate of three-day faeces includes bronchial slime. As predicted by the HRTM, for a relatively insoluble material (i.e. Type M or Type S), this ratio increases almost linearly from about 2 at 1 µm AMAD to 12 at 10 µm AMAD. For a Type S material, a ratio of 6.6 indicates that the AMAD is between 5.5 and 6 µm whereas for a Type M material this indicates that the AMAD is between 5 and 5.5 µm. As this is close to the ICRP default value for a worker, assume this default value of 5 µm AMAD. Thus, the assumption is that a standard worker has inhaled an aerosol of 5 µm AMAD.

13.2.11. Step 5.11: Assessment of dose by fitting absorption type

In this step intakes and doses are assessed using the default absorption types. However, ICRP Publication 68 [20] suggests Type M for all compounds of Americium.

As can be seen from step 5.5, for Type M, the fits to the data are very bad (Figure 13.2). The estimated intake is 134.5 kBq and E(50) is 3.65 Sv.

Assuming Type S also gives very bad fits to lung and faecal data but a good fit to the urine data (Figure 13.3). The estimated intake is 9.2 kBq and E(50) is 79 mSv.

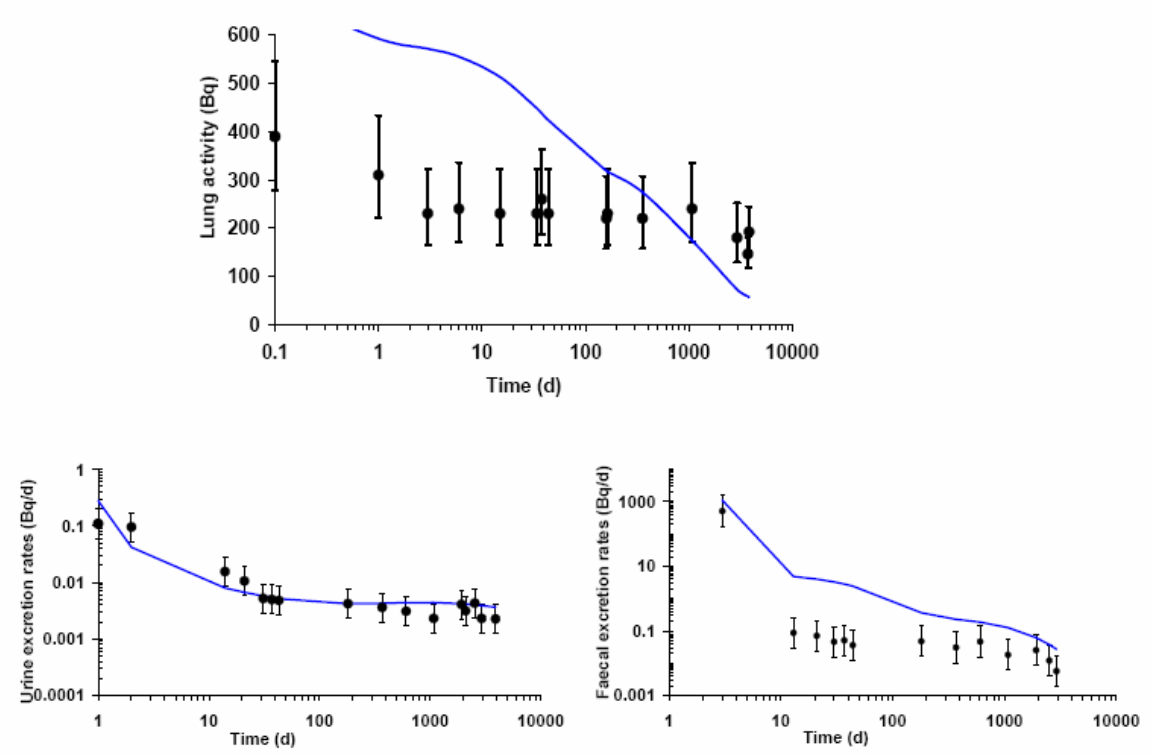


Fig. 13.3. Model fits to lung, urine and faecal data assuming absorption Type S (step 5.11).

13.2.12. Step 5.11.1: Is the goodness of fit acceptable?

The guidelines suggest rejecting the fits if

- the chi squared test (χ^2) fails (i.e. if p-value < 0.05). In other words if the fit is inadequate at the 5% level of significance, or if
- the fit displayed graphically looks unreasonable by eye.

It is acknowledged that whether or not the fit displayed graphically looks unreasonable by eye is a subjective judgment. However, generally, a fit would be considered unreasonable if all, or a long series, of data were systematically underestimated or overestimated.

In this case, the fits for both Type M and Type S, can be rejected on the basis that they look unreasonable by eye (Figures 13.2 and 13.3).

Assuming Type M, the overall χ_o^2 is 1.6 10^4 with 47 degrees of freedom and the corresponding p value $\approx$ 0. If Type S is assumed then, the overall χ_o^2 is 226 with 47 degrees of freedom and the corresponding p-value $\approx$ 0. So for both Type M and Type S assumptions the p-values are < 0.05. The fits are therefore rejected and so it is necessary to proceed to the next step.

13.2.13. Step 5.13: Assessment of dose by fitting a mixture of default absorption types

In this step, the intake is estimated by fitting a mixture of absorption Types (M and S) to all the data simultaneously. The best fit to the data was obtained for a mixture consisting of 1% Type M and 99% Type S.

13.2.14. Step 5.15: Is the goodness of fit acceptable?

The fits to the data for a mixture of absorption Types (1% Type M and 99% Type S) are rejected as the χ^2 test fails. The fits are not shown as they are so similar to that for Type S (Figure 13.3).

13.2.15. Step 5.17: Determine specific HRTM absorption parameters

The lung activity does not change significantly between 3 and 1000 days. This is inconsistent with the HRTM prediction assuming a Type S material. Even if no absorption occurred then the fit to the lung data is still very bad; it does not account for the lack of clearance between three and 1000 days. So it is necessary to proceed to the next step.

13.2.16. Step 5.18: Determine specific f_1 value

Generally, it is not justifiable to change the f_1 value as well as the HRTM absorption parameter values. Occasionally, for inhaled materials that are relatively insoluble, it is necessary to reduce the value of f_1 to predict systemic activities or urinary excretion rates that are consistent with the data, but not in this case.

13.2.17. Step 5.19: Determine specific HRTM particle transport parameters

The lung activity does not change significantly between 3 and 1000 days. Thus the particle transport parameter values were varied in order to improve the fits to all the measurement data. The 'fitted' parameter values are given in Table 13.6 for the particle transport rates. The following points should be emphasized:

Particle transport parameters

To reduce clearance from the lung, particle transport clearance from the AI was slowed down by reducing the clearance from AI_2 to bb_1 and increasing AI_2/AI as suggested in ICRP Publication 66, para. E218, page 381[1]. This improved the fit to the lung (Figure 13.4).

It is interesting to note that a rough estimate of the total clearance from the AI region can be calculated by the ratio of the daily faecal excretion rate (Bq d^{-1}) at time 't' to activity in lung (Bq) at time 't', where t > 5 days. Taking t = 14 d the ratio is given by 8.56 10^{-2} Bq d^{-1}/230 Bq = 3.7 10^{-4} d^{-1}. The actual value assumed was about 2 10^{-4} d^{-1} (Table 13.6).

Slow bronchial clearance

An improved fit to the faecal data between 10 and 50 d was achieved by assuming there was no slow bronchial clearance. This has the effect of clearing material to the GI tract at early times rather than later. Thus particle transport rate from bb_2 to BB_1 was set at 2 d^{-1} and rate from BB_2 to ET_2 was set at 10 d^{-1}.

The estimate intake is 5.0 kBq and E(50) is 89 mSv.

Absorption Type S was assumed for these fits (Figure 13.4). The fits to the lung and faecal data are good. The overall χ_o^2 is 52 with 47 degrees of freedom and the corresponding p-value is 0.30. This does not indicate the fits are inadequate. However, the early urine data are underestimated and it was judged that the fit to the urine data is inadequate. Therefore, '*Step 5.17: Determine specific HRTM absorption parameters'* was repeated.

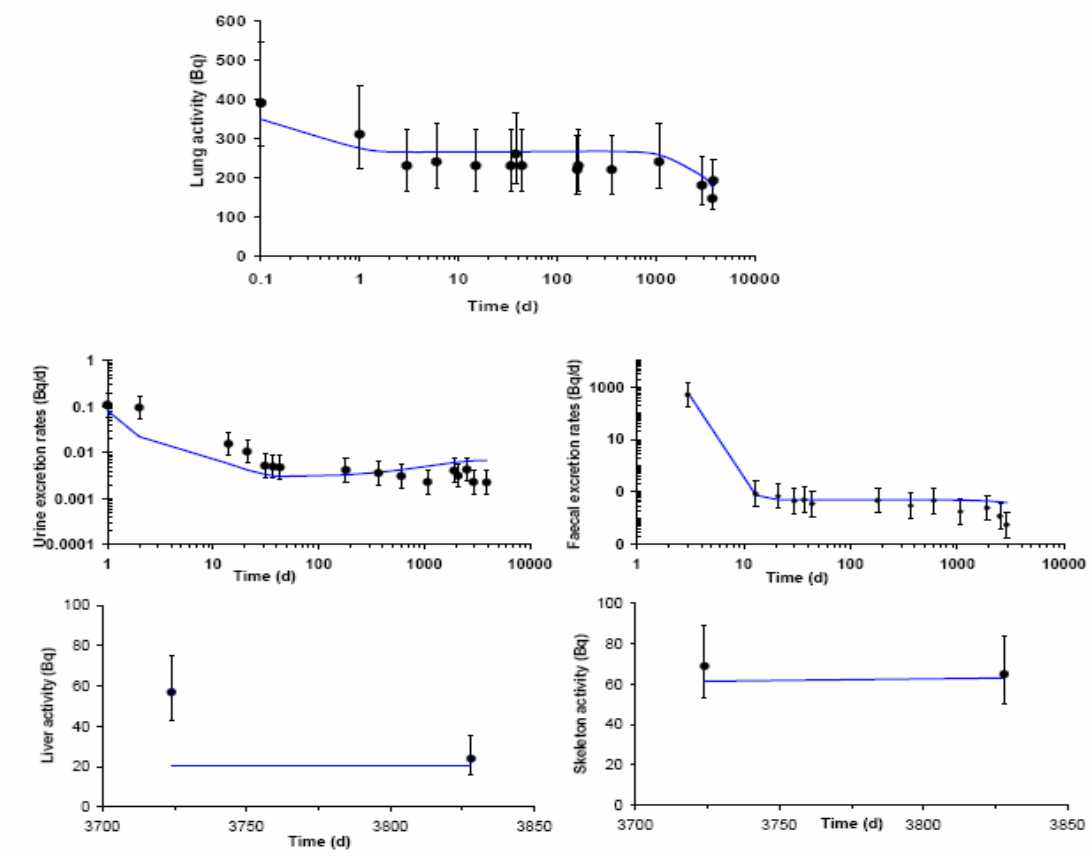


Fig. 13.4. Model fits to lung, urine, faecal, liver and skeleton data assuming specific particle transport rates (Table 13.6) and absorption Type S (step 5.19).

13.2.18. Step 5.17 Repeated: Determine specific HRTM absorption parameters

The fitted absorption parameter values are given in Table 13.6. The value of f_r was increased from 0.001 to 0.005 to improve the fit to early urine data. Also, for completeness, the parameters for the bound state were fixed at values determined experimentally for ^{241}Am

nitrate from rat data: f_b=0.87 and s_b=0.15 d^{-1} (ICRP Supporting Guidance 3, 2002, Section E7.3.2) [7]. It is emphasized that this is only an interim assessment of the extent of Americium binding. However, the bound state does slightly improve the fit to the urine data at early times, but has little affect on the estimated intake and dose (about 1% difference).

The estimated intake is 4.6 kBq and the resulting E(50) is 84 mSv.

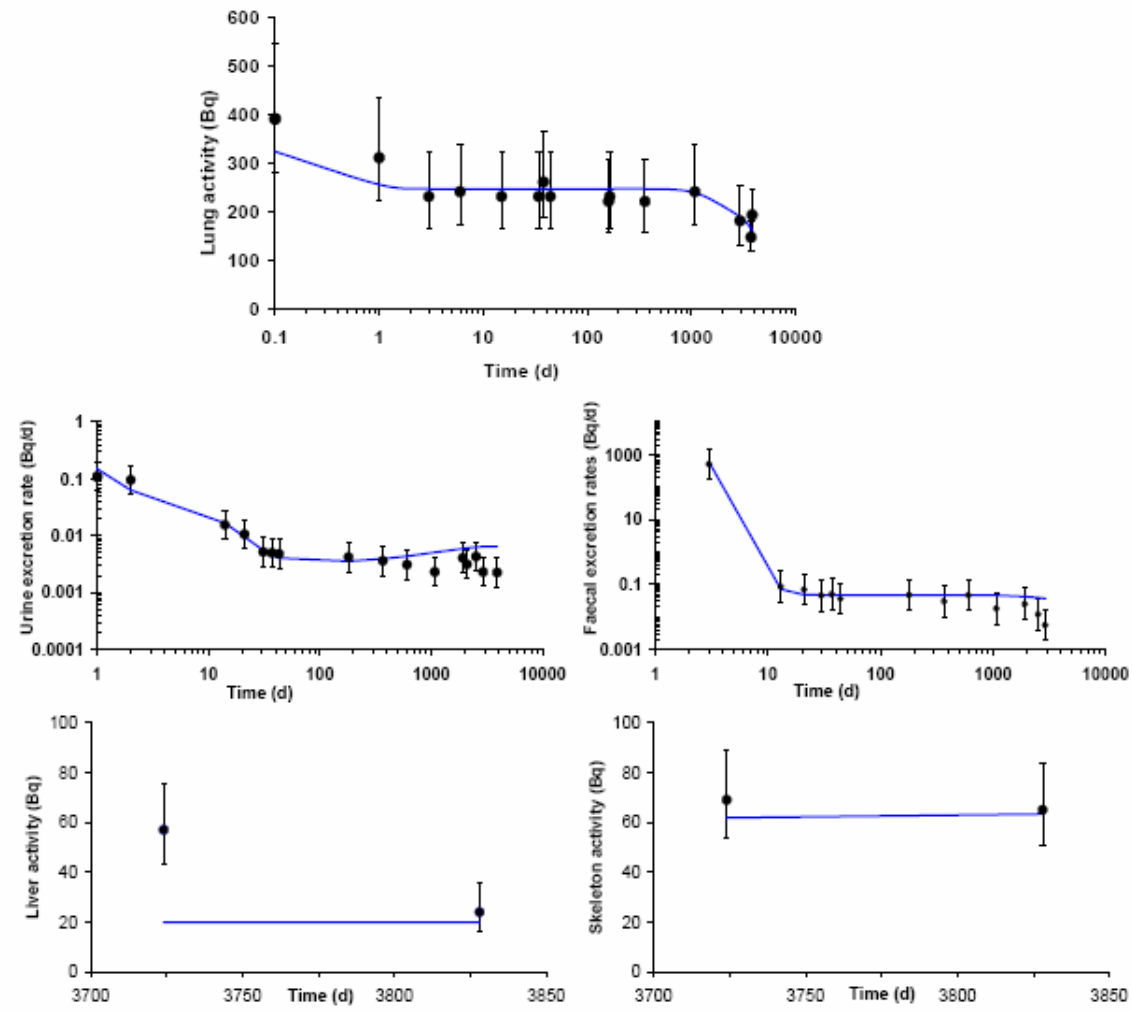


Fig. 13.5. Model fits to lung, urine, faecal, liver and skeleton data assuming specific particle transport rates and specific absorption parameter values (Table 13.6).

The overall χ_o^2 is 34 with 47 degrees of freedom and the corresponding p-value is 0.92. As the p-value is greater than 0.05 the fits are not rejected. Also fits displayed graphically were not judged to be unreasonable by eye (Figure 13.5). Therefore, the best estimate of intake is 4.6 kBq and the corresponding E(50) is 84 mSv.

Table 13.6. Comparison of the specific HRTM parameter values with default values

Absorption	Fitted	Default		
	^{241}Am	Type F	Type M	Type S
f_r	0.005	1.0	0.1	0.001
s_r (d–1)	100 (fixed)	100	100	100
s_s (d–1)	1 10^{-4} (fixed)	–	5 10^{-3}	1 10^{-4}
f_b	0.87 (fixed) (a)	0	0	0
s_b (d–1)	0.15 (fixed) (a)	–	–	–
f_l	5 10^{-4} (fixed)	5 10^{-4}	5 10^{-4}	5 10^{-4}
Particle transport	Fitted	Default		
Fractions (%) AI_1 /AI	0	30		
AI_2 /AI	90	60		
AI_3/ AI	10 (fixed)	10		
Rates (d^{-1})				
AI_1 to bb_1	-	0.02		
AI_2 to bb_1	2.0 10^{-4}	1.0 10^{-3}		
AI_3 to bb_1	1.0 10^{-4} (fixed)	1.0 10^{-4}		
BB_2 to ET_2	10 (b)	0.03		
bb_2 to BB_1	2 (b)	0.03		

(a) Determined experimentally for ^{241}Am nitrate from rat data (ICRP Supporting Guidance 3, 2002, Section E7.3.2[7]).
(b) It is assumed that there is no slow bronchial clearance

13.2.19. Summary of assessments for ^{241}Am

A summary of the assessments of intake and dose for ^{241}Am is given in Table 13.7.

It was not possible to obtain good fits to all the data (lung, urine, faecal, liver and skeleton) with the default HRTM parameter values. In particular, the lack of clearance from the lung between 3 and 1000 days could only be predicted by the HRTM, if the particle transport clearance from the AI region was reduced (step 5.17).

This resulted in an increase in E(50) as the material has longer retention in the lung. After fitting the particle transport rates to the data the absorption parameter values were varied to obtain the best estimate of intake of 4.6 kBq and a corresponding E(50) of 84 mSv.

It is interesting to note that if Type S is assumed with the reference particle transport rates then the intake is underestimated by a factor of about six if the faecal data are only used in the assessment. This is because, in this case, the HRTM predicts too much faecal excretion with the reference particle transport rates and as a result the intake is underestimated. Reducing particle transport from the AI region not only increases lung retention but also reduces the predicted faecal excretion at later times.

Table 13.7. Summary of estimated intakes of ^{241}Am and the resulting doses[a, b]

Assessment procedure step	**Absorption parameters**	**Particle transport values**	**Goodness of fit**		**Intake (kBq)**	**E(50) (mSv)**
			χ_o^2 (a)	**p-value(b)**		
5.5	Type M	Reference	1.6 104	0	135	3650
5.11	Type S	Reference	226	0	9.2	79
5.13	99% Type S & 1% Type M	Reference	224	0	8.7	77
5.17	Type S	Reduce clearance from AI & no slow bronchial clearance	52	0.30	5.0	89
Repeat: 5.13	f_r increased & bound state	Reduce clearance from AI & no slow bronchial clearance	34	0.92	**4.6**	**84**

(a) Intake estimates were obtained by fitting the predicted bioassay values to the lung, urine, faecal, liver and skeleton data simultaneously with IMBA Professional.

(b) The default AMAD value of 5 μm was assumed in all assessments as the effective AMAD derive from the early lung and faecal data was close to 5 μm (Section 13.2.10).

(c) The expected value of χ^2 is equal to the number of degrees of freedom; (i.e. number of data points – 1 = 47).

(d) The p-value is the probability that χ^2 is greater than χ_o^2 for 47 degrees of freedom. If the p-value is less than 0.05 then fit is rejected by the χ^2 test.

13.3. ^{239}Pu intake and dose assessment

Both ^{241}Am and ^{239}Pu measurement data are available and the initial activity ratios of the inhaled material are given. The IDEAS guidelines do not give advice on how to use the known initial activity ratios when bioassay data for each nuclide is available.

Two approaches are presented. The first approach (*assessment 1*) does not consider the initial activity ratio of ^{239}Pu: ^{241}Am and the second approach (*assessment 2*) takes this into account.

Before following the guidelines to assess the case it is useful to plot the available data (Figure 13.6) and perform a simple calculation to assess the intake and dose.

The best estimate of the ^{241}Am intake is 4.6 kBq (Section 13.2.19). The initial activity ratio of ^{239}Pu: ^{241}Am is 55/10 = 5.5. Therefore, the intake of ^{239}Pu is 4.6 × 5.5 = 25.3 kBq.

The ICRP Publication 68[20] dose coefficient for ^{239}Pu, assuming Type S and a 5 µm AMAD aerosol, is 8.3 10^{-6} Sv/Bq. Therefore, E(50) is approximately 0.2 Sv. On the other hand, if Type M is assumed, then the dose coefficient is 3.2 10^{-5} Sv/Bq and E(50) is about 0.8 Sv. This gives us an order of magnitude of the intake and dose.

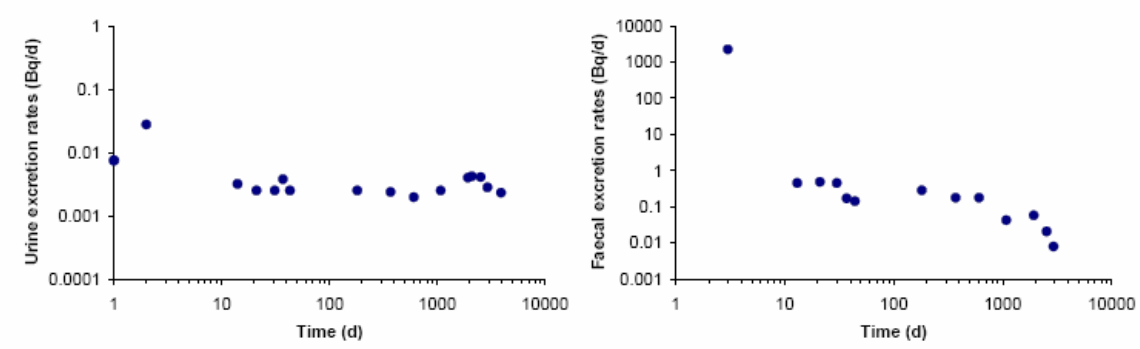


Fig. 13.6. A plot of ^{239}Pu urine and faecal measurement data given in case 6.

The models that were used to assess the intake and dose include the HRTM [1], the ICRP Publication 30 Gastrointestinal Tract model [18] and the ICRP Publication 67 *Systemic Biokinetic Model for Plutonium* [2].

As stated in Section 13.2, this is a special monitoring case for inhalation so the steps in flow chart 5 are followed. Again, the software code IMBA Professional was used in this assessment.

13.3.1. Step 5.1: Identification of all measurement data representing the case

The ^{239}Pu data given are:

- urine measurements (16 data points), and
- faecal measurements (15 data points).

At this stage there is no reason to reject any of the data so all of the data will be used to assess the intake of ^{239}Pu and to calculate the resulting dose, E(50). The "Bronchial slime activity" that would have appeared in the faeces in the first day, or soon afterwards, was added to the faeces (day 1). The activity of the bronchial slime was 1.4 kBq of ^{239}Pu and ^{240}Pu. The initial ratio of ^{239}Pu/(^{239}Pu + ^{240}Pu) of the inhaled activity is 55/(55+26). Assuming this ratio applies to the bronchial slime, the ^{239}Pu activity in the bronchial slime is:

$$1.4\ 10^3 * 55/(55+26) = 951 \text{ Bq.}$$

This is added to the ^{239}Pu faecal data at day one

$$(3530 \text{ Bq}) \text{ to give } 4.48\ 10^3 \text{ Bq.}$$

The average activity excreted in the faeces per day over three days was calculated and used in IMBA with a three-day collection period. This average activity is given by:

$$(4480 + 2040 + 299)/3 = 2273 \text{ Bq/d of } ^{239}\text{Pu}$$

Therefore, the faecal data set will consist of 13 data points.

13.3.1.1. Assignment of realistic uncertainties

The urine and faecal data were assumed to be lognormally distributed with a σ_g (i.e. SF) of 1.8 for the urine data and a SF of 3.0 for the faecal data as for the ^{241}Am data.

13.3.2. Assessment 1 (Intake of ^{239}Pu determined from ^{239}Pu bioassay data)

In this assessment the intake of ^{239}Pu is determined using the ^{239}Pu bioassay data (i.e. urine and faecal data).

An effective AMAD of about 5 μm AMAD has already been determined from the Americium data (Section 13.2.10, step 5.10). Therefore, an AMAD of 5 μm is assumed.

The particle transport rates determined from the Americium data (Section 13.2.17, step 5.19) are also assumed. These rates are given in Table 13.6. It is clear that in this case the doses are much greater than 1 mSv as shown above by the simple calculation. So it is necessary to proceed to step 5.11, 'assessment of dose by fitting absorption type.'

Assuming Type M, the intake of ^{239}Pu is 1.1 kBq and E(50) is 42 mSv. However, the fits are bad and the χ^2 test fails (Figure 13.7). The overall χ_o^2 is 203 with 28 degrees of freedom and the corresponding p-value $\approx$ 0. As the p-value is <0.05 the fits are rejected and therefore the assumption of Type M is not valid.

Assuming Type S, the intake of ^{239}Pu is 10.9 kBq and E(50) is 201 mSv. The fits to the urine and faecal data are good (Figure 9.7). The overall χ_o^2 is 22 with 28 degrees of freedom and the corresponding p value is 0.8. As the p-value is >0.05 and the fits look reasonable by eye, the fits are not rejected. Therefore, on this basis, the best estimate of intake is 10.9 kBq of ^{239}Pu and E(50) is 201 mSv.

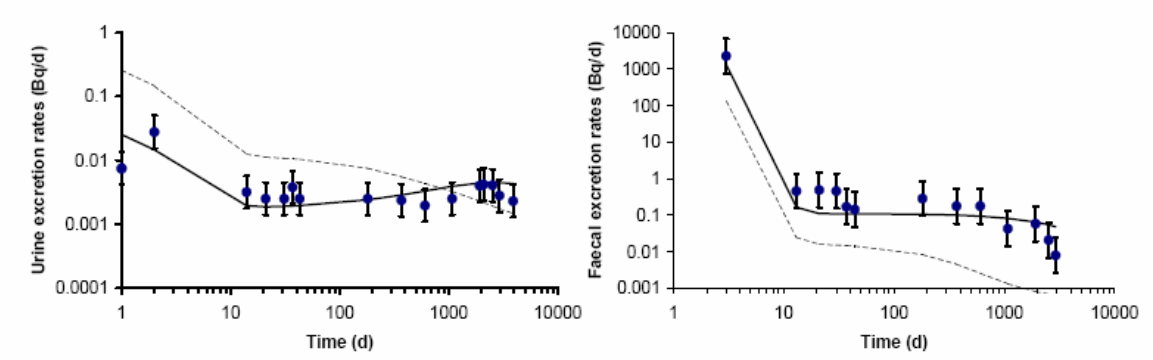


Fig. 13.7. Model fits to ^{239}Pu urine and faecal data assuming Type M [- -] or Type S [------].

The ^{239}Pu / ^{241}Am initial activity ratio given in the case description is 55/10 = 5.5 whereas the ratio of the independently-estimated intakes (^{239}Pu /^{241}Am) is 10.87 /4.6 = 2.4. Therefore, there is a discrepancy of about a factor of two between these two numbers.

It is expected that the intake activity ratios should be the same as the initial activity composition of the inhaled material. As the material is relatively insoluble, the faecal data can be used to estimate the initial ^{239}Pu / ^{241}Am activity ratio. The early faecal data (cumulative over three days) suggests a ratio of 4.3:

$$^{239}\text{Pu} / ^{241}\text{Am} = (3530 + 2040 + 299) / (922 + 407 + 25.1) = 4.3$$

If the other faecal data is considered, but corrected for decay and in-growth of ^{241}Am from ^{241}Pu, a mean value of 4.9 with a standard error of 0.5 is obtained for this activity ratio (Figure 13.8). This is close to the initial activity composition of the inhaled activity (^{239}Pu / ^{241}Am =5.5).

So the initial activity ratio of ^{239}Pu to ^{241}Am given in the case description is consistent with the ^{239}Pu and ^{241}Am faecal data.

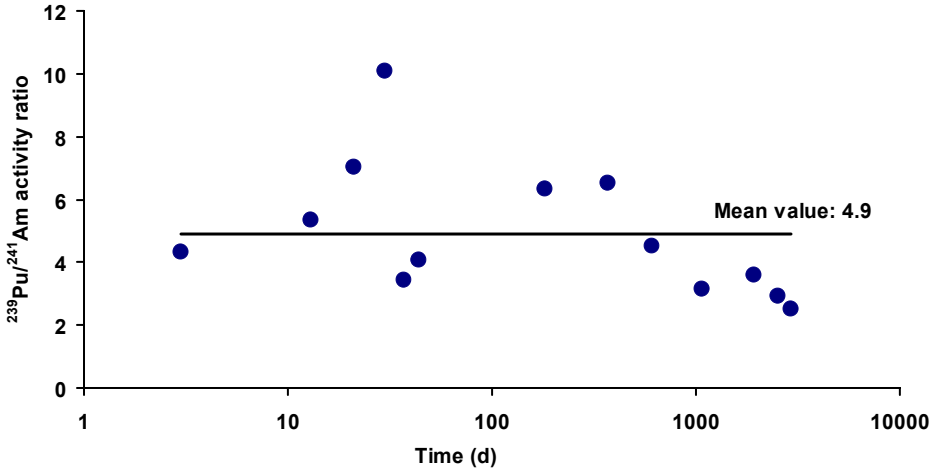


Fig. 13.8. Activity ratio of ^{239}Pu : ^{241}Am calculated from faecal data. The activities have been correct for decay and for in-growth of ^{241}Am from ^{241}Pu.

13.3.3. Assessment 2 (Intake of ^{239}Pu fixed at 25.3 kBq)

In this assessment the intake of ^{239}Pu was fixed at 25.3 kBq, which was calculated from the intake estimate of ^{241}Am (4.6 kBq) and the given initial activity ratio of ^{239}Pu : ^{241}Am (55/10). It is reasonable to calculate the intake from the ^{241}Am data as the Americium data forms the most complete data set, comprising of lung, urine, faecal, liver and skeleton data.

With the intake of ^{239}Pu fixed at 25.3 kBq, the measurement data was used to determine the HRTM absorption parameter values. The AMAD was assumed to be 5µm as determined from the Americium data (Section 13.2.10, step 5.10). The particle transport rates determined from the Americium data (Section 13.2.17, step 5.19) are also assumed. These rates are given in Table 13.6.

The predicted bioassay quantities are compared with the Plutonium data for Type M and Type S assumptions (Figure 13.9). In both cases the predictions are not consistent with the urine data.

Assuming Type M, the overall χ^2 is 756 with 29 degrees of freedom and a corresponding p-value of about 0. For Type S, the overall χ^2 is 62 with 29 degrees of freedom and a corresponding p-value of 0.0003. As the p-value is <0.05 in both cases, the predictions are rejected.

The absorption parameter values were therefore varied so that the predicted bioassay quantities fitted the data. The 'fitted' parameter values are given in Table 13.8. The following points should be emphasized:

- *Absorption parameters:* f_r, s_r, s_s

The value of s_r was fixed at the default value (100 d^{-1}). The value of s_s was reduced from its default Type S value of 1 10^{-4} d^{-1} to 3 10^{-5} d^{-1} to fit the urine data points at later times. The value of f_r was not changed from its default Type S value of 0.001.

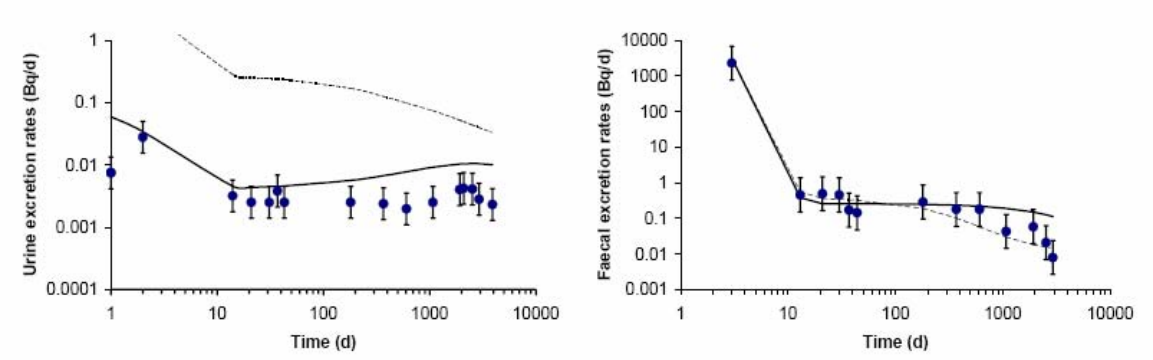


Fig. 13.9. Comparison of the predicted bioassay quantities with the ^{239}Pu urine and faecal measurement data assuming Type M [- -] or Type S [--------]. The intake of ^{239}Pu was fixed at 25.3 kBq.

- *Absorption parameters: Bound state*

The parameters for the bound state were fixed at values determined experimentally for Plutonium Nitrate from rat data: f_b=0.57 and s_b=0.21 d^{-1} (Birchall et al.) [26].

However, in this case the bound state makes very little difference to the intake and the dose (< 0.5% difference).

The fits to the urine and faecal data are good (Figure 13.10). The overall χ^2 is 22.2 with 28 degrees of freedom and the corresponding p-value is 0.77. As the p-value is greater than 0.05, the fits are not rejected. Also the fits displayed graphically were not judged to be unreasonable by eye. However, it is noted that the faecal fit overestimates the last few faecal data points.

For the absorption parameter values given in Table 13.8 and the particle transport rate values given in Table 13.6, the dose coefficient for ^{239}Pu is 1.664 10^{-5} Sv Bq^{-1}.

For an intake of 25.4 kBq of ^{239}Pu, E(50) is 0.421 Sv. The dose is high because of the high dose to the lung. This arises because:

- the material is very insoluble (s_s was reduced from its default Type S value of 1.10^{-4} d^{-1} to 3 10^{-5} d^{-1});

- the particle transport clearance from the lung is reduced for this subject.

The best estimate of the intake is 25.4 kBq of ^{239}Pu and resulting E(50) is 0.421 Sv.

Table 13.8. Comparison of the specific HRTM parameter values for ^{239}Pu with default values

Absorption	Fitted		Default	
	^{239}Pu	Type F	Type M	Type S
f_r	0.001	1.0	0.1	0.001
s_r (d^{-1})	100 (fixed)	100	100	100
s_s (d^{-1})	$3\ 10^{-5}$	–	$5\ 10^{-3}$	$1\ 10^{-4}$
f_b	0.57 (fixed)	0	0	0
s_b (d^{-1})	0.21 (fixed)	–	–	–
f_l	$1\ 10^{-5}$ (fixed)	$5\ 10^{-4}$	$5\ 10^{-4}$	$1\ 10^{-5}$

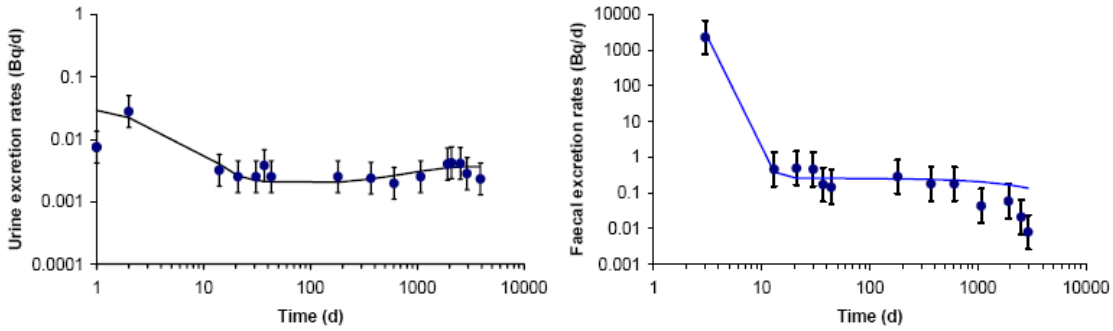


Fig. 13.10. Comparison of the predicted bioassay quantities with the ^{239}Pu urine and faecal measurement data assuming the specific absorption parameter values given in Table 13.8 and the specific particle transport rate values given in Table 13.6.
The intake of ^{239}Pu was fixed at 25.3 kBq.

13.3.4. Summary of assessments for ^{239}Pu

A summary of the assessments of intake and dose for ^{239}Pu is given in Table 13.9, including each calculated χ_o^2 value and the corresponding p-value.

The IDEAS guidelines do not give advice on how to use the known initial activity ratios of the inhaled material when bioassay data for each nuclide is available. So two approaches were carried out to assess the intake of ^{239}Pu and the resulting dose. In both approaches the specific particle transport values (Table 13.6) and the effective AMAD (5 μm) determined using the Americium data were assumed.

In the first approach (*assessment 1*) the intake and absorption Types were fitted to the urine and faecal data simultaneously. Good fits were obtained with Type S, and the best estimate of intake was 10.9 kBq and E(50) was 201 mSv. However, the ratio of the independently-

estimated intakes of ^{239}Pu to ^{241}Am (10.9 /4.6 = 2.4) gave a value of about a factor of 2 lower than the known initial activity ratio of the inhaled material (^{239}Pu : ^{241}Am = 5.5) . So a different approach was carried out in *assessment 2*.

In *assessment 2*, the intake of ^{239}Pu was fixed at 25.3 kBq, which was calculated from the intake estimate of ^{241}Am (4.6 kBq) and the given initial activity ratio of ^{239}Pu : ^{241}Am (55/10). With the intake of ^{239}Pu fixed at 25.3 kBq, the ^{239}Pu bioassay data was used to determine the HRTM absorption parameter values (Table 13.8). The best estimate of intake was 25.3 kBq and E(50) was 421 mSv. This dose is high compared with Type S Plutonium because the Plutonium, in this case, is very insoluble and because for this subject there is reduced clearance from the deep lung.

Table 13.9. Summary of estimated intakes of ^{239}Pu and the resulting doses[a, b]

Assessment	**Absorption parameters**	**Comment**	**Goodness of fit**		**Intake (kBq)**	**E(50) (mSv)**
			$\chi o\ 2$ [c]	p-value [d]		
Assessment 1	Type M	Reject fits	203	0	1.1	42
	Type S	Good fits	22	0.8	10.9	201
Assessment 2	Type M	Reject fits	756[e]	0	25.3 (fixed)[f]	810
	Type S	Reject fits	62[e]	0.0003	25.3 (fixed)[f]	210
	specific	Good fits	22	0.77	25.3 (fixed)[f]	421

(a) In all the assessments the specific particle transport values given in Table 13.6 are assumed.
(b) The default AMAD value of 5 µm was assumed in all assessments as the effective AMAD derived from the early lung and faecal ^{241}Am data was close to 5 m (Section 13.2.10).
(c) The expected value of χ^2 is equal to the number of degrees of freedom; (i.e. number of data points–1 = 28.
(d) The p-value is the probability that χ^2 is greater than χ_o^2 for a given number of degrees of freedom. If the p-value is less than 0.05 then fit is rejected by the χ^2 test.
(e) As the intake was fixed and no parameters varied, the number of degrees of freedom is equal to the number of data points, 29.
(f) The intake was fixed at 25.3 kBq, which was calculated from the intake estimate of ^{241}Am (4.6 kBq) and the given initial activity ratio of ^{239}Pu : ^{241}Am (55/10).

13.4. Results of intercomparison exercise for ^{241}Am (Part 1)

13.4.1. Introduction

This case is one of the best-documented cases of a single intake of transuranium elements worldwide. There is a set of excretion and organ burden data available over a 10-year period starting from the first day after intake. In addition, the subject was not given any chelating therapy.

With this comprehensive data, it is possible to determine some of the HRTM parameter values. Therefore, this case illustrates the guidelines for stage 5C of flow chart 5 (special evaluation for inhalation).

This case has been used in two prior intercomparison exercises; the 1997–1998 intercomparison exercise on internal dose assessment organized by the IAEA [12] and the third European intercomparison exercise on internal dose assessment [4].

For the IAEA intercomparison exercise all the data collected on this case was given, consisting of almost 100 measurements. In the IAEA intercomparison only three participants used the latest ICRP models (ICRP 66 HRTM [1] and ICRP 67 *Americium systemic biokinetic model* [2]). For these three, the GM of the intakes of ^{241}Am is 4.7 kBq and GM for the corresponding E(50) is 50 mSv. Again, for these three participants the GM of the intakes of ^{239}Pu is 29 kBq and GM for the corresponding E(50) is 334 mSv.

For the third European intercomparison exercise, the amount of measurement data was reduced. Only urine and faecal data for $^{239+240}$Pu were given. In the third European intercomparison 16 participants used the latest ICRP models (ICRP 66 HRTM[1] and ICRP 67 Plutonium Systemic Biokinetic Model[2]). The GM of the intakes of $^{239+240}$Pu is 27 kBq with a GSD of 2.29. For E(50), the GM is 185 mSv with a GSD of 2.27. As the initial activity ratio of ^{239}Pu: $^{239+240}$Pu is known (i.e. 0.68), the statistics for ^{239}Pu can be determined: The GM of the intakes of ^{239}Pu is 18 kBq and GM for the corresponding E(50) is 126 mSv.

In this exercise all the data sets were given but only the activities of ^{241}Am and ^{239}Pu were given. These activities had been calculated from the original measured activities using the known initial activity ratios of the inhaled material.

The ^{241}Am data form the most complete set of data consisting of chest, lymph, bone, liver, urine and faecal data. Most of the participants, in this exercise, used the Americium data to assess the intake. Only two participants (81 and 85) used the ^{239}Pu data and the known initial activity ratio of ^{239}Pu: ^{241}Am to estimate the intake of ^{241}Am.

Thirty-five participants assessed this case. The results of the intakes and the doses are presented. The assumptions made by the participants are discussed.

13.4.2. Identification of outliers

Outliers were identified by following the statistical criteria described in Section 7.5 (Table 13.10)

Table 13.10. Identification of outliers (^{241}Am assessment)

	Intake	**Intake**	**CED**
	All participants	Subset: 5μm AMAD	All data
Number of participants[(a)]	35	24	35
Number of identified outliers	8	3	3

(a) Including outliers

13.4.2.1.Intakes

Applying the outlier criteria to the intake data produces eight outliers (46, 31, 59, 21, 65, 34, 81, 50) out of 35 results (Table 13.10). Table 13.11 gives reasons why these are outliers. For example, participants 31 and 21 assumed 100% ingestion. Participants 46 and 65 assumed Type F and Type M respectively and estimated a very low intake using the urine data alone.

As the estimated intake is dependent on the assumed AMAD, the evaluation of the intake data was repeated for a subset of the data in which the assumed AMAD was 5 µm. For this subset, applying the outlier criteria produces three outliers (46, 59 and 65) (Table 13.10).

13.4.2.2.Effective dose

Applying the outlier criteria to the E(50) data produces three outliers (21, 46, 59) out of 35 results (Table 13.10). Reasons why these are outliers are given in Table 13.11. For each of the three outliers the intakes are low giving rise to low doses.

Table 13.11. Outlier assessment of intake and dose, E(50) for ^{241}Am. **Bold** values indicate outliers

Code	Intake (kBq)	E(50) (mSv)	AMAD (µm)	Absorption Type	Particle transport rate	Data set used to estimate intake	Comment
	4.6	84	5	Specific[(a)]	Specific [(b)]	All[(c)]	Assessment carried out using IDEAS guidelines.
21	**0.28**	**0.056**	-	-	-	Urine	Assumed 100% ingestion
46	**0.006**	**0.7**	5	F	reference	Urine	Low intake as urine activity is overestimated for Type F[(d)].
59	**0.16**	**4.3**	5	M	reference	Urine Faeces	Gives a poor fit to data.
65	**0.3**	8	5	M	reference	Urine	Low intake as urine activity is overestimated for Type M[(d)].
31	**105**	21	-	-	-	Urine Faeces Skeleton	Assumed 100% ingestion. Very poor fit to the data.

Code	Intake (kBq)	E(50) (mSv)	AMAD (µm)	Absorption Type	Particle transport rate	Data set used to estimate intake	Comment
34	**0.94**	25	5	M	reference	Faeces	Low intake as faecal activity is overestimated for reference particle transport rates.
81	**0.94**	25	5	M	reference	Based on ^{239}Pu intake	-
50	**1.3**	35	5	M	reference	Faeces	Low intake as faecal activity is overestimated for reference particle transport rates.

(a) The specific absorption parameter values derived were: f_r= 0.005 , s_r = 100 d^{-1}, s_s = 1 10-4, f_b =0.87, s_b = 0.15 d^{-1}. This indicates that the material is relative insoluble; between a Type M and a Type S material.
(b) In order to obtain good fits to the lung data it was necessary to reduce lung clearance by reducing the particle transport rates from the AI region.
(c) All the data sets include lung, urine, faecal, liver and skeleton.
(d) As the material is relatively insoluble assuming Type F or Type M will overestimate urine activity. Therefore, low intake estimates are obtained from the urine data alone if Type F or M is assumed.

13.4.3. Distribution of results

The statistical evaluations of the results, excluding outliers are given in Table 13.12.

Table 13.12. Statistical evaluation of the results excluding outliers for ^{241}Am

	Intake	Intake	E(50)
	All participants	**Subset: 5µm AMAD**	**All data**
N	27	21	32
GM	4.0 kBq	3.4 kBq	52.3 mSv
GSD	1.40	1.81	2.13
AM	4.3 kBq	3.9 kBq	69.5 mSv
ASD	1.5 kBq	1.8 kBq	62.2 mSv
Coefficient of variation	35%	46%	90 %
Minimum	1.8 kBq	0.9 kBq	8 mSv
Maximum	8.5 kBq	8.5 kBq	331 mSv

13.4.3.1.Intakes

For the 'all participant' data set, the geometric mean (GM) of the estimated intakes is 4.0 kBq, excluding the outliers (Table 13.12). The GM is 15% lower than the intake estimated by following the IDEAS guidelines (4.6 kBq). The geometric standard deviation (GSD) is 1.5. The range of the estimated intakes, excluding outliers, is: 1.8 – 8.5 kBq (ratio max/min = 4.7). However, the range is very large if outliers are included: 0.006 – 105 kBq (ratio max/min = 1.8 10^4).

The GM, for the subset where 5 µm AMAD was assumed, is 3.4 kBq and the GSD is 1.8 (Table 13.12). This distribution is wider compared with the 'all participant' data set indicating that, in this case, the assumed AMAD was not the main factor influencing the estimated intake. The estimated intake also depends on the absorption assumptions if the urine data is used to estimate the intake (Table 13.11).

The graphical representations of the results are given in Figures 13.11 and 13.12.

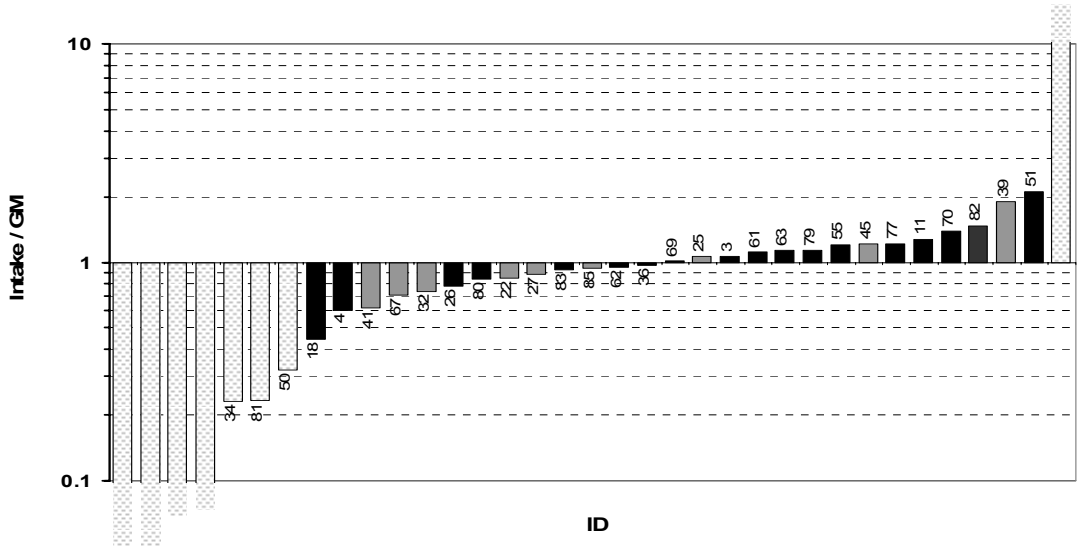


Fig. 13.11. Results of the individual participants (ID): Intakes of ^{241}Am normalized to the geometric mean (GM = 4.0 kBq; GSD = 1.40). The grey patterned columns are outliers The black columns are for estimated intakes where a 5 µm AMAD aerosol was assumed, whereas the solid grey columns are for participants that assumed a value other than 5 µm.

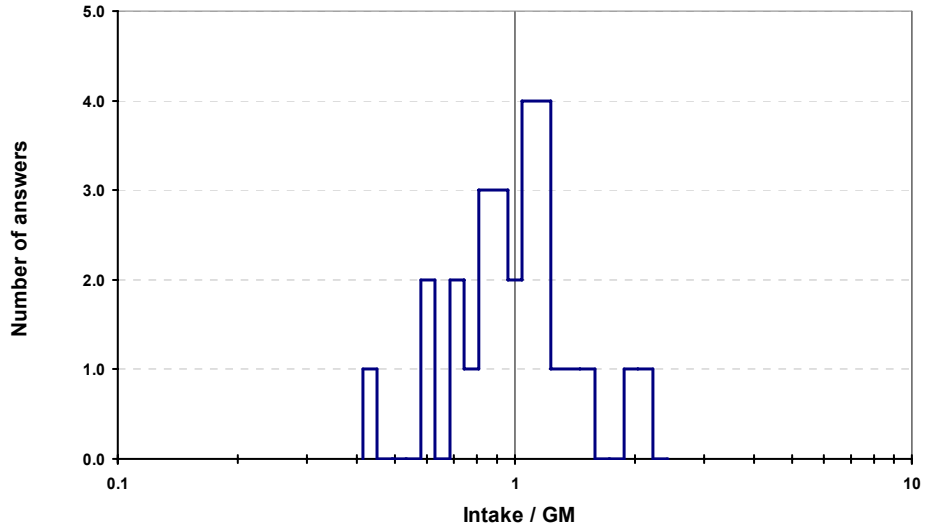


Fig. 13.12. Frequency distribution of results without outliers (N=27). Intakes of ^{241}Am normalized to the geometric mean (GM = 4.0 kBq; GSD = 1.40).

13.4.3.2. Effective doses

For the committed effective dose (E(50)), the GM is 52.3 mSv whereas the dose assessed by following the guidelines is 84 mSv (Table 13.12).

The GSD is 2.1, for E(50). Excluding outliers, the range is 8 – 331 mSv (ratio max/min = 41). However, including outliers the range is very large: 0.056 – 331 mSv (ratio max/min = 5.9 10^3).

The graphical representations of E(50) normalized to the GM are given in Figures 13.13 and 13.14.

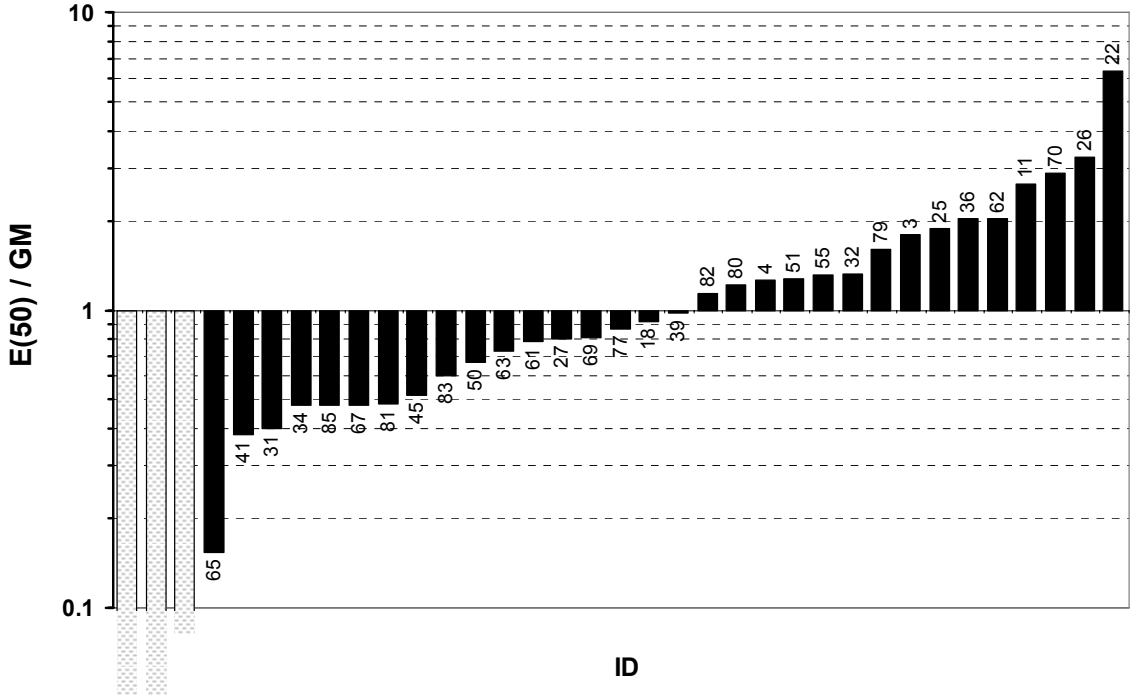


Fig. 13.13. Results of the individual participants (ID) for ^{241}Am: Committed effective dose, E(50), normalized to the geometric mean (GM = 52.3 mSv; GSD = 2.13). The grey patterned columns are outliers.

13.4.4. Route of intake

The case description states that there was an explosion and therefore radioactivity was airborne. As a result the person was contaminated on the face, hair and clothes. Activity was measured in the nose swab and in the lungs, so this is clearly an inhalation case.

Thirty participants out of 35 assumed 100% inhalation. Two participants assumed the worker inhaled and ingested the material; for example participant 51 assumed 90% inhalation and 10% ingestion. Two participants, incorrectly, assumed 100% ingestion.

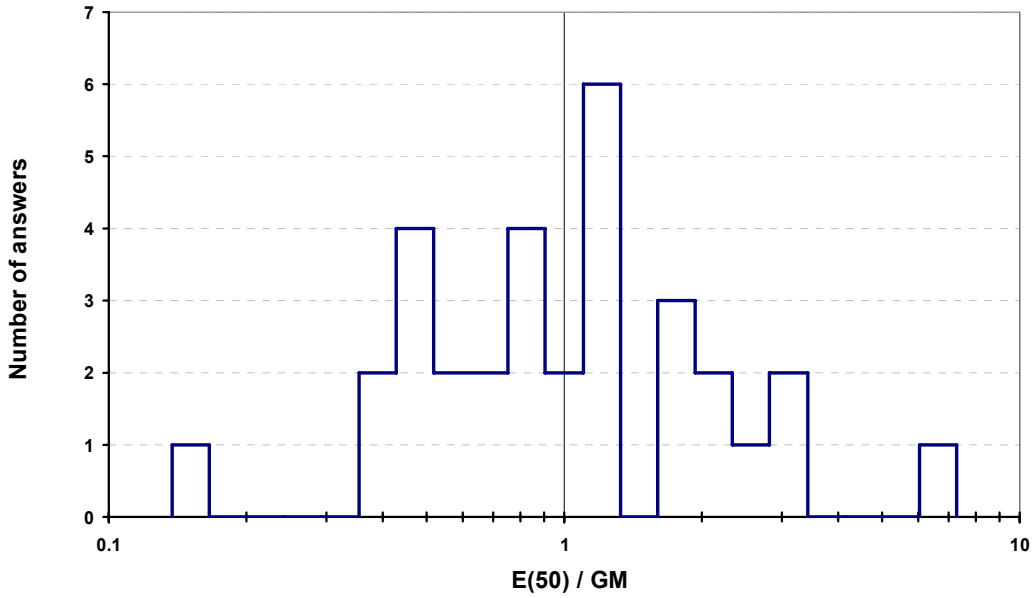


Fig. 13.14. Frequency distribution of results without outliers for ^{241}Am (N=32). Committed effective dose, E(50), normalized to the geometric mean (GM = 52.3 mSv; GSD = 2.13).

13.4.5. Models assumed

Nearly all the participants (i.e. 33 participants) used bioassay quantities and dose coefficients based on the ICRP Publication 66 *Human Respiratory Tract Model (HRTM)* [1], the ICRP Publication 30 *Gastrointestinal Tract Model* [18] and the ICRP Publication 67 *Systemic Biokinetic Model for Americium* [2]. Only one participant (participant 63) implemented the ICRP Publication 30 *Systemic Biokinetic Model* for Americium. Participant 26 did not declare what models they used.

13.4.6. AMAD assumed

As given in the guidelines, the effective AMAD can be inferred from the ratio of the cumulative faecal excretion over three days to the lung activity on day three (Section 13.2.10).

This ratio indicates an effective AMAD close to 5 µm.

Twenty-four participants out of 35 assumed an AMAD of 5 µm. Other AMAD values that were assumed include 3, 3.7, 6, 7.5 and 10 µm.

13.4.7. Absorption assumptions

The ICRP Publication 68 [20] states the default absorption type for all compounds as Type M. However, the lung activity does not change significantly between 3 and 1000 days. This indicates that the material is relatively insoluble.

Despite the long-term retention in the lung 12 participants assumed Type M and one participant assumed Type F, which is clearly incorrect. Six participants assumed Type S and nine participants derived specific parameter values from the data.

As there was comprehensive data available it was possible to derive specific absorption parameter values by fitting these parameters to all the measurement data.

However, in this case, it was necessary to repeat this step (i.e. step 5.17 of the guidelines) after varying the particle transport rates (Section 13.2.18).

13.4.8. Particle transport rates from the AI region

It is not possible to obtain good fits to the measurement data, in particular to the lung data, by varying the absorption parameters alone. The lung activity does not change significantly between 3 and 1000 days. The predicted lung activity is inconsistent with the data even if it is assumed that there is no absorption.

Clearance from the lung is competitive between particle transport to the GI tract and absorption into blood. So to reduce the clearance from the lung to fit the lung data, it was necessary to reduced the particle transport rates from the AI region. This is step 5.19 of the guidelines.

Seven participants reduced the particle transport rates from the AI region to fit the lung data (Table 13.13). The effect of this is to increase E(50) because the dose to lung increases as the material is retained longer in the lung. Therefore, those participants that reduced lung clearance assessed higher values of E(50) (Figure 13.15).

When varying particle transport rates, the assessor needs to do this with care as the E(50) is very sensitive to these parameter values. Participant 22 reduced the rates by a factor of about 100 and as a result obtained a very high dose (Table 13.13).

ICRP Publication 66 (paragraph E4, page 304) suggests that the inter-subject variation in any particle clearance rate can be represented by a lognormal distribution with a median (χ_{50}) equal to the reference value and σ_g= 1.7. This gives 95% confidence limits at $\chi_{50}/3$ and $3\chi_{50}$. So on this basis, the rates proposed by participant 22 are unrealistic. Excluding participant 22, the GM of E(50) for the group that varied the particle transport rates is 85 mSv with a GSD of 1.2.

Table 13.13. Comparison of the specific particle transport parameter values with default values. Values in bold were fitted to the data. (^{241}Am assessment)

Particle transport Fractions (%)	**Default values**	**Participant code**						
		55	**32**	**79**	**3**	**25**	**62**	**22**
AI1 /AI	30	30	30	**0**	30	30	30	30
AI2 /AI	60	60	60	**90**	60	60	60	60
AI3/ AI	10	10	10	10	10	10	10	10
Rates (d^{-1})								
AI1 to bb1	$2.0\ 10^{-2}$	**$6.67\ 10^{-3}$**	**$1.0\ 10^{-4}$**	-	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$2.0\ 10^{-5}$**
AI2 to bb1	$1.0\ 10^{-3}$	**$3.33\ 10^{-4}$**	**$5.0\ 10^{-4}$**	**$2.0\ 10^{-4}$**	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-5}$**
AI3 to bb1	$1.0\ 10^{-4}$	**$3.33\ 10^{-5}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.75\ 10^{-4}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.0\ 10^{-6}$**
AI3 to LNTH	$2.0\ 10^{-5}$	**6.6710^{-6}**	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	**$2.0\ 10^{-6}$**
BB2 to ET2	0.03		0.03	**10** [(b)]	0.03	0.03	0.03	
bb2 to BB1	0.03		0.03	**2** [(b)]	0.03	0.03	0.03	**$3.0\ 10^{-4}$**
Intake (kBq)		4.9	3.0	4.6	4.3	4.3	3.9	3.4
E(50) (mSv)		69	69	84	94	98	106	331

(a) Participant 22 also assumed the following rates: BB_1 to ET_2 = 100 d^{-1}, BB_{seq} to LN_{TH} = 1.0 10-3 d^{-1}, ET_2 to GI = 10 d^{-1}, and ET_{seq} to LN_{ET} = 0.1 d^{-1}.
(b) It is assumed that there is no slow bronchial clearance based on the faecal data.

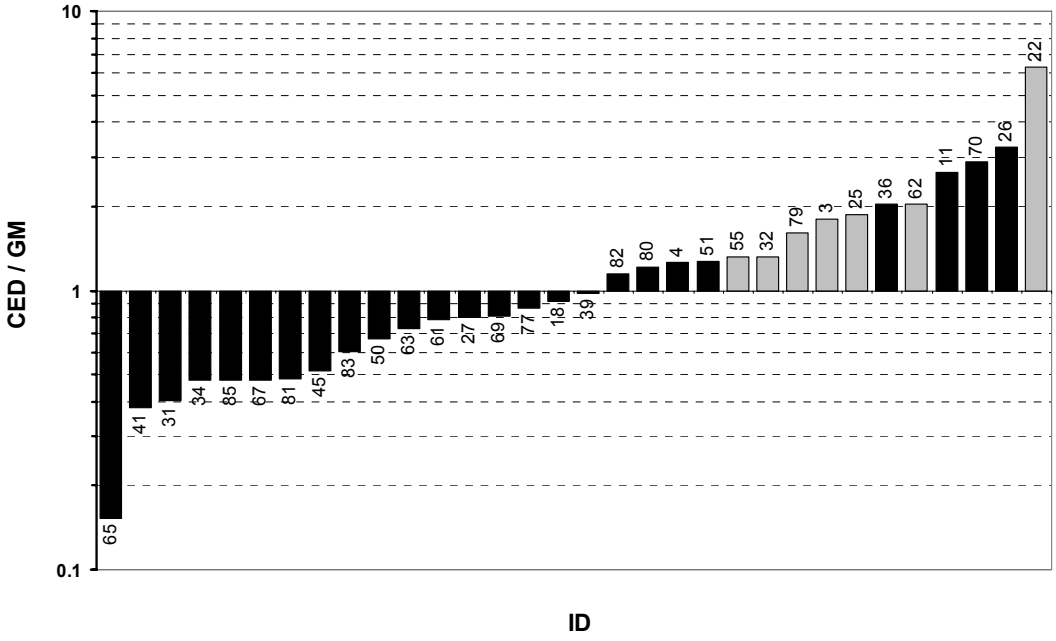


Fig. 13.15. Results of the individual participants (ID) excluding outliers for ^{241}Am: Committed effective dose normalized to the geometric mean (GM = 52.3 mSv; GSD= 2.13). Columns in grey are those participants that reduced the particle transport rates from the AI region.

13.4.9. Software used

The most frequently used software code was IMBA - 14 participants used this code. Other codes that were used include LUDEP, MONDAL, AIDE, BKFIT, INDOS, IDEAS DV0102, IDEA system, INDO 2000, IMIE, MMK-01 and NIRS. Three participants stated that they used Mathematica and/or Excel whereas 4 participants declared that they used no software.

13.4.10. Ingrowth of ^{241}Am from ^{241}Pu

Ingrowth of ^{241}Am affects the long-term lung retention and excretion of ^{241}Am, and this is significant for times greater than 1000 days. For example, about 25% of the measured ^{241}Am activity is due to ingrowth at 1000 days and about 50% of the activity is due to ingrowth at 3828 days, (the time of the last lung measurement).

Thus, when fitting bioassay predictions to the Americium data ingrowth need to be considered. If ingrowth is ignored and the particle transport rates from the AI region are varied to fit the lung data then the predicted long-term clearance is slower than it actually is.

This gives rise to a greater lung dose and E(50) is overestimated by about 20 to 30%.

Out of those seven participants that assumed specific particle transport parameter values in order to fit the lung data (Table 13.13), four participants (25, 32, 55, 79) took account of ingrowth.

13.4.11. Use of guidelines

Forty percent of the participants (i.e. 14 of them) stated that they had followed the IDEAS guidelines. Those that did not follow the guides gave the reasons summarized in Table 13.14.

Table 13.14. Reasons for not following the guidelines (^{241}Am assessment)

Reason	Number of participants
Followed own established procedures	3
Guidelines not clear enough	1
No time to read guidelines	1
Guidelines not available	1
Calculation done for screening purposes	1
Not enough information in the case description[(a)]	1
Guidelines too complex and time consuming	1
No comment	12

(a) Participant 55 stated that it was not possible to calculate the effective AMAD from the ratio of the cumulative faecal excretion over three days to the lung activity on day three as only the chest measurement was given. However, as the material is relatively insoluble the chest measurement on day three gives a good estimate of the activity in the lung.

Table 13.15. Comparison of results for ^{241}Am between participants that had followed the guidelines and those that had not[(a)]

	All		No		Yes	
	Intake	**CED**	**Intake**	**CED**	**Intake**	**CED**
N	27	32	17	20	10	12
GM	4.0 kBq	52.3 mSv	3.8 kBq	51.0 mSv	4.0 kBq	54.6 mSv
σ_g	1.40	2.13	1.48	2.06	1.27	2.31
Min	1.8 kBq	8 mSv	1.8 kBq	8 mSv	2.5 kBq	20 mSv
Max	8.5 kBq	331 mSv	8.5 kBq	170 mSv	5.2 kBq	331 mSv

(a) Without outliers given in Table 13.11.

Table 13.15 compares the statistics between the participants that declared that they had followed the guidelines and those that had not. For E(50), the GM and the GSD are similar for each group. This indicates that for this case the guidelines did not have much effect on the results for those that declared that they had followed them.

The participants that declared that they had followed the guidelines reported the final step number (Table 13.16). If the participants had followed the guidelines correctly using all the

data sets then the final step number should have been 5.15.1 via 5.19. By assuming specific HRTM particle transport parameter values (step 5.19) it was possible to obtain a good fit to all the data (Section 13.2.17). Out of the 14 participants that declared that they had followed the guidelines only four carried out step 5.19.

Table 13.16. Final step numbers reached by the participants who had followed the guidelines (^{241}Am assessment)

Number of participants	Final step number	Comment
2	3.3	Assumed default parameter values[(a)]
1	5.5	Assumed default parameter values
2	5.15.1 (via 5.15)	A mixture of absorption Type M and Type S was fitted to the data.
4	**5.15.1 (via 5.19) [(b)]**	**Specific particle transport parameter values were determined**
2	5.22	This is the last step in flow chart 5, however, the participants did not assume specific particle transport parameter values
3	?	It was not clear what step was declared.

(a) Participant 46 incorrectly assumed Type F for Americium compounds.
(b) This was the final step that the participants were expected to reach.

13.4.12. Conclusion for Case 6 (Part 1 – ^{241}Am assessment)

Case 6 is one of the best-documented cases of a single intake of actinides. Bioassay measurements over a 10-year period were carried out. With this comprehensive data it is possible to determine specific HRTM parameter values. The case illustrates the guidelines for stage 5C of flow chart 5 (special evaluation for inhalation).

Thirty-five participants assessed the intake of ^{241}Am and calculated the resulting E(50). For the assessed doses there are three outliers and the reasons why these are outliers have been identified (Table 13.11). Excluding outliers, the GM of the assessed E(50) is 52 mSv with a GSD of 2.1.

This can be compared with results from the previous IAEA intercomparison exercise on internal dose assessment[12]. For the previous exercise only three participants used the latest ICRP models, and for these three the GM of the assessed E(50) for ^{241}Am is 50 mSv. The geometric means are only about 4% different.

The assessment of the intake of ^{241}Am and E(50) can be carried out by following the guidelines. It is not possible to obtain good fits to the measurement data using the ICRP default/reference values. To obtain good fits to the data, in particular to the lung data, it was necessary to reduce the particle transport rates from the AI region (step 5.19 of the guidelines). Seven participants assumed specific particle transport rates. For this group, excluding participant 22 who had used unrealistically slow particle transport rates, the GM of

E(50) is 85 mSv with a GSD of 1.2. This GM is in good agreement with the E(50) of 84 mSv obtained by following the IDEAS guidelines (Section 13.2.19).

Those participants that had "correctly" followed the guidelines and therefore reached step 5.19 obtained results for ^{241}Am that have a relatively narrow distribution. However, for this case the guidelines did not have much effect on the results for those that declared that they had followed them.

13.5. Results of intercomparison exercise for ^{239}Pu (Part 2)

13.5.1. Introduction

The participants were asked to assess the intake of ^{239}Pu and ^{241}Am, and the resulting E(50) for each of these two nuclides. In this Section (Part 2) the results for ^{239}Pu are discussed.

Case 6 is unique in that there is comprehensive measurement data for both ^{241}Am and ^{239}Pu. There is ^{239}Pu urine and faecal data available over a 10-year period. The initial activity ratios of the inhaled material are given as well as comprehensive measurement data for ^{241}Am (Sections 13.1). The bioassay data given in this case are in terms of activity of ^{239}Pu and ^{241}Am only. These activities have been calculated from the original measured activities using the known initial activity ratios of the inhaled material.

The IDEAS guidelines do not give detailed advice on how to use all the available information to assess the intake and dose when bioassay data from more than one radionuclide is available and the initial activity ratios are given.

The assessment of ^{239}Pu should not be carried out in isolation of the assessment of ^{241}Am. Section 13.3 describes two approaches to assess the ^{239}Pu intake and dose. In the first assessment (Assessment 1, Section 13.3.2) the intake is assessed using the ^{239}Pu urine and faecal data. However, the assumed AMAD value and the assumed specific particle transport parameter values are the values derived from the ^{241}Am data. This assessment results in an intake of ^{239}Pu of 10.9 kBq and a resulting E(50) of 201 mSv.

In the second assessment the intake of ^{239}Pu was fixed at 25.3 kBq, which was calculated from the intake estimate of ^{241}Am (4.6 kBq) and the given initial activity ratio of ^{239}Pu : ^{241}Am (55:10). It is justifiable to base the assessment of intake on the Americium data as they form the most complete set of data. With the intake of ^{239}Pu fixed at 25.3 kBq, the ^{239}Pu bioassay data was used to determine the HRTM absorption parameter values. The best estimate of intake was 25.3 kBq and E(50) was 421 mSv.

Thirty-six participants assessed this case. The results of the intakes and the doses are presented. The assumptions made by the participants are discussed.

13.5.2. Identification of outliers

Outliers were identified by following the statistical criteria described in Section 7.5 (Tables 13.17 and 13.18)

Table 13.17. Identification of outliers (^{239}Pu assessment)

	Intake	**Intake**	**E(50)**
	All participants	Subset: 5µm AMAD	All participants
Number of participants[(a)]	36	27	36
Number of identified outliers	3	2	5

(a) Including outliers

Table 13.18. Outlier assessment of intake and dose, E(50) for ^{239}Pu.
Bold values indicate outliers.

Code	**Intake (kBq)**	**E(50) (mSv)**	**AMAD (µm)**	**Absorption Type**	**Particle transport rate**	**Data set used**	**Comment**
21	12.9	**0.133**	-	-	-	Urine	Assumed 100% ingestion, which gave a low dose.
46	**0.0368**	**1.2**	5	M	Reference	Urine	Assumed that the measurements were normally distributed with uncertainty proportional to measurement value. Low intake as urine activity is overestimated for Type M.
59	**0.94**	**7.86**	5	S	Reference	Urine Faeces	Assumption that measurements were normally distributed with uncertainty proportional to measurement value gave a low intake, which led to a low dose.

Code	Intake (kBq)	E(50) (mSv)	AMAD (µm)	Absorption Type	Particle transport rate	Data set used	Comment
60	**3.96**	172[(a)]	5	M	Reference	Urine Faeces	Low intake, as material is less soluble than Type M. Assumed a specific f_1 value ($1\ 10^{-4}$).
36	17.2	**549**	5	S	Reference	Urine Faeces	Type S used to calculate intake, but Type M dose coefficient used to calculate dose. Had the Type S dose coefficient been used, this would not be an outlier.
22	18.3	**1110**	10	Specific[(b)]	Specific[(c)]	Urine Faeces	High dose as very slow absorption and particle transport rates were assumed.

(a) Dose coefficient ($4.34\ 10^{-5}$ Sv Bq^{-1}) applied to intake is inconsistent with the dose coefficient ($3.23\ 10^{-5}$ Sv Bq^{-1}) calculated with the ICRP models (ICRP Publication 66 HRTM[1], ICRP Publication 67 systemic biokinetic model for plutonium[2]) and model parameter values declared by the participant.

(b) The specific absorption parameter values used were: $f_r = 6\ 10^{-4}$, $s_r = 1000\ d^{-1}$, $s_s = 1\ 10^{-4}\ d^{-1}$, $f_b = 0$. This indicates that the material is less soluble than a Type S material.

(c) The specific particle transport parameter values used were (d^{-1}): Al_1 to $bb_1 = 2\ 10^{-5}$, Al_2 to $bb_1 = 1.10^{-5}$, Al_3 to $bb_1 = 1\ 10^{-6}$, Al_3 to $LN_{TH} = 2\ 10^{-6}$, bb_2 to $BB_1 = 3\ 10^{-4}$, BB_1 to $ET_2 = 1\ 10^{2}$, BB_{seq} to $LN_{TH} = 1\ 10^{-3}$, ET_2 to GI = 10, ET_{seq} to $LN_{ET} = 1\ 10^{-1}$. These rates are a factor of 100 lower than the default values

13.5.2.1.Intakes

Applying the outlier criteria to the intake data results in three outliers (46, 59, and 60) out of 36 results (Table 13.17). Table 13.18 gives reasons why these are outliers. For example, participant 46 assumed Type M, but the material is in fact less soluble than a Type M, participant 46 estimated a very low intake using the urine data alone.

As the estimated intake is dependent on the assumed AMAD, the evaluation of the intake data was repeated for a subset of the data in which the assumed AMAD was 5 µm. For this subset, applying the outlier criteria results in two outliers (46 and 59) out of 27 results (Table 13.17). These are also identified as outliers for the data set consisting of all the participants.

13.5.2.2. Effective dose

Applying the outlier criteria to the E(50) data results in five outliers (21, 46, 59, 22, 36) out of 36 results (Table 13.17). Reasons why these are outliers are given in Table 13.18. For example, participant 21 assumed 100% ingestion which gave rise to a very low dose.

13.5.3. Distribution of results

The statistical evaluations of the results, excluding outliers are given in Table 13.19.

Table 13.19. Statistical evaluation of the results excluding outliers for 239Pu

	Intake All participants	**Intake** Subset: 5μm AMAD	**E(50)** All participants
N	33	25	31
GM	13.1 kBq	12.3 kBq	140 mSv
GSD	1.52	1.63	1.58
AM	14.2 kBq	13.7 kBq	155 mSv
ASD	5.3 kBq	5.81 kBq	78 mSv
Coefficient of variation	37%	42%	50%
Minimum	5.14 kBq	3.96 kBq	49 mSv
Maximum	26.2 kBq	26.2 kBq	421 mSv

13.5.3.1. Intakes

For the 'all participants' data set, the geometric mean (GM) of the estimated intakes is 13.1 kBq, excluding the outliers (Table 13.19). The geometric standard deviation (GSD) is 1.5. The range of the estimated intakes, excluding outliers, is: 5.14 – 26.2 kBq (ratio max/min = 5.1). However, the range is very large if outliers are included: 0.0368 – 26.2 kBq (ratio max/min = 7.1 10^2).

The GM, for the subset where 5 μm AMAD was assumed, is 12.3 kBq and the GSD is 1.6 (Table 13.19). This distribution is similar to the complete data set, and has a larger GSD than the complete data set. This indicates that the assumed AMAD was not the main factor influencing the estimated intake. However, the estimated intake depends on the absorption assumptions if the urine data is used to estimate the intake (Table 13.18).

The graphical representations of the results are given in Figures 13.16 and 13.17.

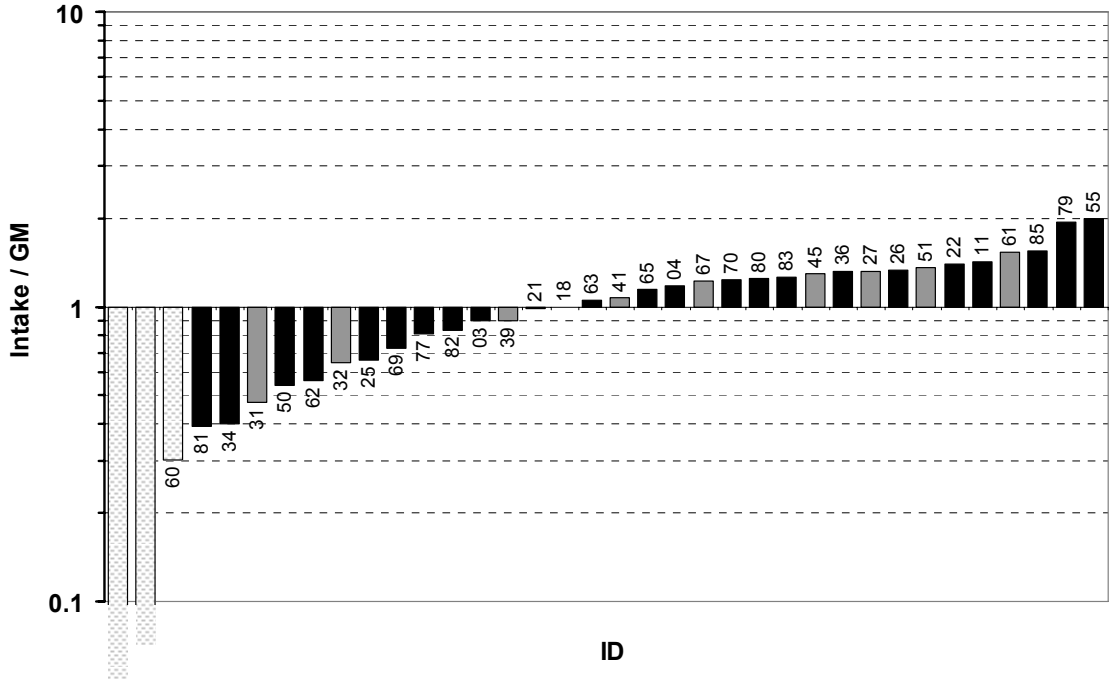


Fig. 13.16. Results of the individual participants (ID): Intakes of ^{239}Pu normalized to the geometric mean (GM = 13.1 kBq; GSD = 1.52). The grey patterned columns are outliers. The black columns are for the estimated intakes where a 5 µm AMAD aerosol was assumed whereas the solid grey columns are for those participants that assumed a value other than 5 µm.

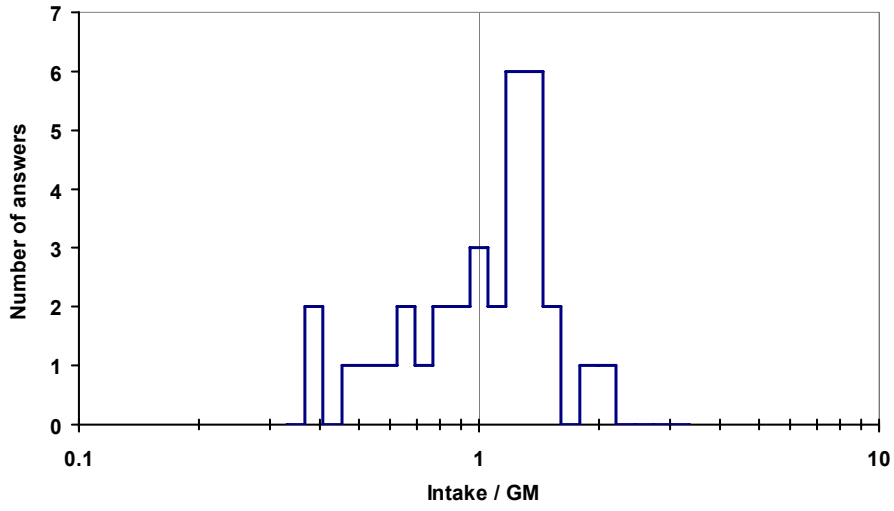


Fig. 13.17. Frequency distribution of results without outliers (N=33). Intakes of ^{239}Pu normalized to the geometric mean (GM = 13.1 kBq; GSD = 1.52).

13.5.3.2. Effective doses

For the committed effective dose (E(50)), the GM is 140 mSv and the GSD is 1.6.
Excluding outliers, the range is 49 – 421 mSv (ratio max/min = 8.6). However, including outliers the range is very large: 0.133 – 1110 mSv (ratio max/min = 8.3 10^3). The graphical representations of E(50) normalized to the GM are given in Figures 13.18 and 13.19.

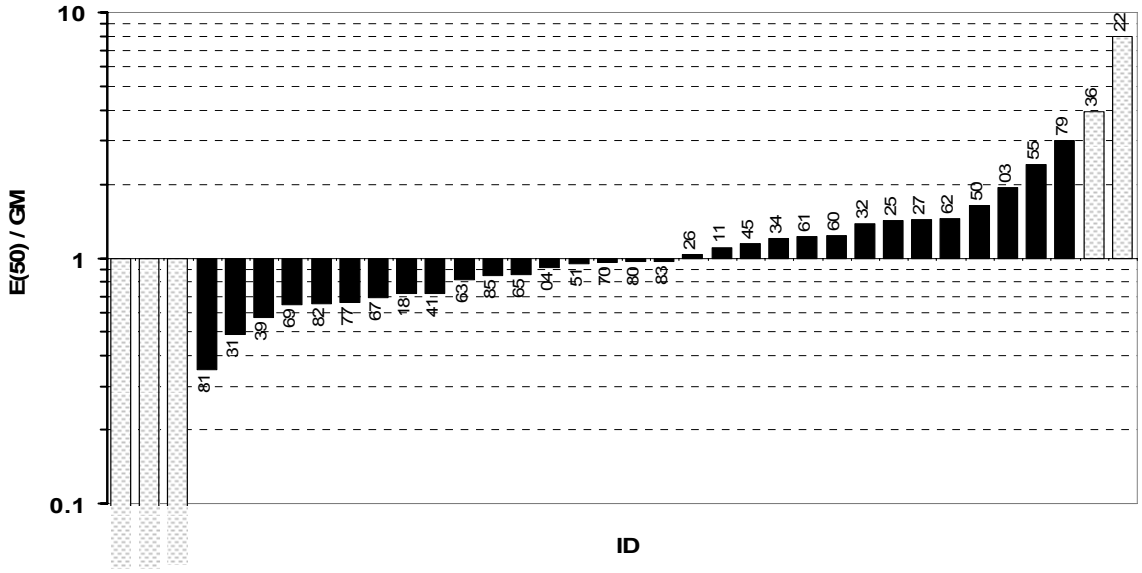


Fig. 13.18. Results of the individual participants (ID) for 239Pu: Committed effective dose, E(50), normalized to the geometric mean (GM = 140 mSv; GSD = 1.6). The grey patterned columns are outliers.

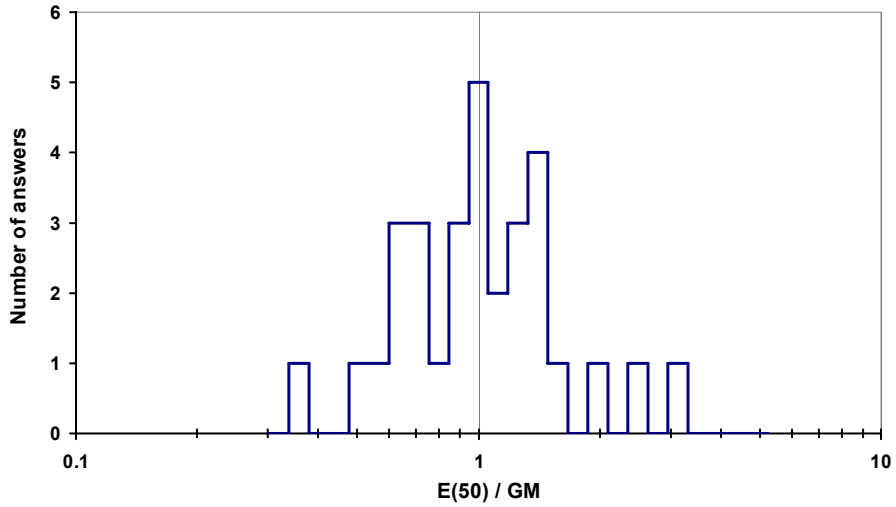


Fig. 13.19. Frequency distribution of results without outliers (N=31) for ^{239}Pu. Committed effective dose, E(50), normalized to the geometric mean (GM = 140 mSv; GSD = 1.6).

13.5.4. Route of intake

The case description states that there was an explosion and therefore radioactivity was airborne. As a result the person was contaminated on the face, hair and clothes. Activity was measured in the nose swab and in the lungs, so this is clearly an inhalation case.

Thirty-three participants out of 36 assumed 100% inhalation. Two participants assumed the worker inhaled and ingested the material; for example participant 51 assumed 90% inhalation and 10% ingestion. One participant, incorrectly, assumed 100% ingestion.

13.5.5. Models assumed

Nearly all the participants used bioassay quantities and dose coefficients based on the ICRP Publication 66 *Human Respiratory Tract Model (HRTM)* [1], the ICRP Publication 30 *Gastrointestinal Tract Model* [18] and the ICRP Publication 67 *Systemic Biokinetic Model* [2] for Plutonium. Participant 27 used the Jones urinary excretion function [27] to estimate the intake from the urine data but used the above ICRP models to calculate the dose.

13.5.6. AMAD assumed

As given in the guidelines, the effective AMAD can be inferred from the ratio of the cumulative faecal excretion over three days to the lung activity on day three. This ratio can be determined from the Americium data, and the calculated ratio indicates an AMAD close to 5 μm (Section 13.2.10).

Twenty-six participants out of 36 assumed an AMAD of 5 μm. Other AMAD values that were assumed include 3, 3.7, 7.5 and 10 μm.

13.5.7. Absorption assumptions

The ICRP Publication 68 [20] default absorption Type for unspecified compounds of Plutonium is Type M and Type S for insoluble Plutonium oxides. The material is found to be relatively insoluble. Eighteen participants assumed Type S whereas four participants assumed Type M.

Four participants used a mixture of Types M and S; all of these mixtures were heavily dominated by the Type S component. Eight participants derived specific parameter values from the Plutonium data, with one participant using the specific parameter values derived from the Americium data to assess the ^{239}Pu intake and dose. One participant assumed 100% ingestion and so the absorption Type was not applicable.

13.5.8. Particle transport rates from the AI region

Seven participants used specific particle transport rates. In all of these cases, the particle transport rates were derived from the ^{241}Am data and applied to assess the ^{239}Pu intake and dose. These specific values reduce the clearance from the AI region compared with the ICRP reference values (Table 13.6, Section 13.2.18). Therefore, the effect of using these specific particle transport parameter values is to increase E(50), because the dose to lung increases as the material is retained longer in the lung. Those participants that used specific particle transport rates assessed higher values of E(50) (Figure 13.20).

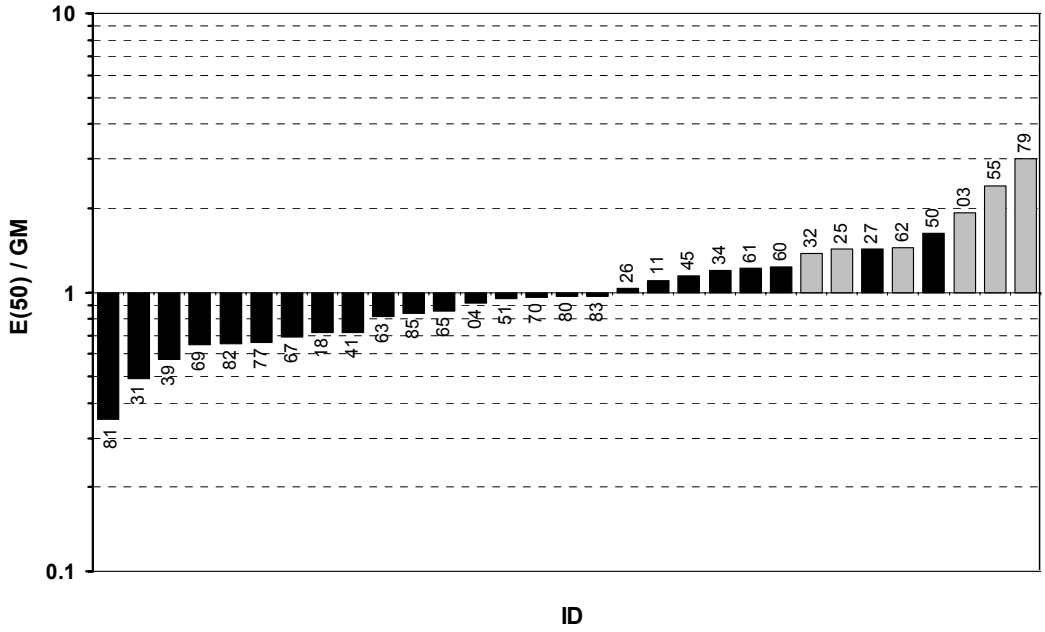


Fig. 13.20. Results of the individual participants (ID) excluding outliers for ^{239}Pu: Committed effective dose normalized to the geometric mean (GM = 140 mSv; GSD =1.6). Columns in grey are those participants that used specific particle transport rates.

Participant 22 reduced the particle transport rates from the AI region by a factor of about 100, which is unrealistic (Section 9.4.8). Excluding participant 22, the GM of E(50) for the group that varied the particle transport rates is 258 mSv with a GSD of 1.38.

13.5.9. Software used

The most frequently used software code was IMBA - 14 participants used this code. Other codes that were used include LUDEP, MONDAL, AIDE, BKFIT, INDOS, IDEAS DV0102, IDEA system, INDO 2000, IMIE, MMK-01, CINDY and NIRS.

Three participants stated that they used Mathematica and/or Excel whereas three other participants declared that they had used no software.

13.5.10. Ratio of estimated intakes of ^{239}Pu to ^{241}Am

Most of the participants (34 participants) used the ^{239}Pu bioassay data directly to assess the intake of ^{239}Pu. Only 2 participants used the known initial activity ratio of ^{239}Pu : ^{241}Am and the intake estimate of ^{241}Am to estimate the intake of ^{239}Pu.

It is interesting to compare the ratio of the estimated intakes of ^{239}Pu to ^{241}Am with the known initial activity ratio of ^{239}Pu : ^{241}Am. Twelve participants have a ratio of intakes that is within 10% of the known initial activity ratio of ^{239}Pu : ^{241}Am.

13.5.11. Use of guidelines

About 40% of the participants (i.e. 14 of them) stated that they had followed the IDEAS guidelines.

Those that did not follow the guidelines gave the reasons summarized in Table 13.20.

Table 13.20. Reasons for not following the guidelines (^{239}Pu assessment)

Reason	Number of participants
Followed own established procedures	5
Guidelines not clear enough	2
Guidelines not available	1
Calculation done for screening purposes	1
Used specific model parameter values derived from ^{241}Am data.	2
Guidelines too complex and time consuming	1
No comment	10

Table 13.21 compares the statistics between the participants that declared that they had followed the guidelines and those that had not. For E(50), the GSD is slightly greater for those participants that declared that they had followed the guidelines compared with those that had not. This indicates that for this case, the guidelines did not have much effect on reducing the spread of results for those that declared that they had followed them.

The participants that declared that they had followed the guidelines reported the final step number (Table 13.22). Different final step numbers were declared. It can be concluded that further guidance is required to assess cases like case 6, where bioassay data from more than one radionuclide is available and the initial activity ratios are given.

Table 13.21. Comparison of results for ^{239}Pu between participants that followed guidelines and those that did not[(a)]

	All		No		Yes	
	Intake	**E(50)**	**Intake**	**E(50)**	**Intake**	**E(50)**
N	33	31	21	20	12	11
GM	13.1 kBq	140 mSv	15.5 kBq	149 mSv	9.72 kBq	123 mSv
σ_g	1.52	1.58	1.33	1.54	1.59	1.64
Min	5.14 kBq	49 mSv	7.37 kBq	80 mSv	5.14 kBq	49 mSv
Max	26.2 kBq	421 mSv	26.2 kBq	421 mSv	18.6 kBq	228 mSv

(a)Without outliers given in Table 13.18.

Table 13.22. Final step numbers reached by the participants who followed the guidelines

Number of participants	Final step number	Comment
1	1.3	This participant is an outlier (participant 59), see Table 13.18
1	2.3	This participant is an outlier (participant 46), see Table 13.18
1	3.3	Assumed default parameter values
1	5.6.1	Assumed default parameter values
4(a)	5.15	Assumed a mixture of absorption Types
2	5.15	Participant 31 assumed Type S whereas participant 50 assumed Type M.
2	5.19	Specific particle transport parameter values derived from ^{241}Am data were used.
1	5.22.1	Assumed specific absorption parameter values, so probably reached step 5.17.

13.5.12. Conclusion for Case 6 (Part 2 – ^{239}Pu assessment)

Case 6 is one of the best-documented cases of a single intake of actinides. Bioassay measurements over a 10-year period were carried out. With this comprehensive data it is possible to determine specific HRTM parameter values. The case is complicated and requires a lot of effort to make a thorough assessment of the intake and the dose.

Thirty-six participants assessed the intake of ^{239}Pu and calculated the resulting E(50).

For the assessed doses there are five outliers and the reasons why these are outliers have been identified (Table 13.18). Excluding outliers the GM of the assessed E(50) is 140 mSv with a GSD of 1.58.

This can be compared with results from the third European intercomparison exercise, where only a sub-set of the $^{239+240}$Pu measurement data was available. For this exercise excluding outliers the GM of the assessed E(50) for ^{239}Pu was 126 mSv and the GSD was 2.27. The geometric means are only about 9% different.

The assessment of the intake of ^{239}Pu and E(50) should not be carried out in isolation of the assessment of ^{241}Am. Using the ^{241}Am data it is possible to determine specific particle transport parameter values and the effective AMAD. These specific values should be applied to assess the ^{239}Pu intake and E(50). Seven participants applied the specific particle transport rates derived from the ^{241}Am data to assess the ^{239}Pu intake and E(50).

For this group, excluding participant 22 who used unrealistically slow particle transport rates, the GM of E(50) is 258 mSv with a GSD of 1.38.

This GM of 258 mSv can be compared with the assessment carried out in Section 13.3.2 where ^{239}Pu data was used to assess the intake and the specific particle transport values

derived from the ^{241}Am data were assumed. The resulting E(50) from the intake of ^{239}Pu was 201 mSv.

The IDEAS guidelines do not give detailed advice on how to use all the available information to assess the intake and dose when bioassay data from more than one radionuclide is available and the initial activity ratios are known. However, 14 participants declared that they had followed the guidelines. For this case the guidelines did not have much effect on reducing the spread of results for those that declared that they had followed them.

14. CONCLUSIONS ON THE INTERCOMPARISON

This internet based intercomparison showed that the guidelines for evaluation of incorporation monitoring data as they have been created by the IDEAS group could have a positive influence on the harmonization of reported intake and dose results.

Considering the strict time provided for the solution of the cases, the need to be acquainted with the guidelines and their use, the number of participants that have correctly applied the guidelines is not negligible. A tendency in the reduction of outlying values when applying the guidelines can also be mentioned.

The largest effect will be on new professionals in the field, whereas experienced evaluators of incorporation monitoring data seem to have their own established procedures of assessment which are of equal effectiveness.

The individual results of participating laboratories in this intercomparison will help them to prove their efficiency in performing the task of assessing occupational dose to individuals due to the intake of radioactive isotopes, to their customers and, if wanted or required, to their regulatory bodies.

ANNEX I. LIST OF PARTICIPANTS

First name	Last name	Country	Organization
de las Mercedes	ALFARO	Mexico	Laboratorio de Dosimetria Interna
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*independent response by two members of a national internal dosimetry advisory group, not authorized by a laboratory.

ANNEX II. CASE 1 — ACUTE INTAKE OF HTO — RESULTS

Table II-1. All participants results to Case 1 (Shaded figures are outliers)

Code N°	Committed effective dose (Sv)	Cumulated activity (Bq l^{-1} d)
INT001	2.56E-02	5.34E+08
INT002	2.56E-02	5.34E+08
INT003	2.55E-02	5.33E+08
INT004	2.51E-02	5.23E+08
INT010	2.36E-02	4.93E+08
INT011	2.51E-02	5.25E+08
INT013	2.60E-02	5.35E+08
INT015	2.56E-02	5.34E+08
INT016	2.56E-02	5.34E+08
INT018	6.70E-03	1.40E+08
INT019	6.20E-02	No answer
INT022	2.51E-02	5.24E+08
INT023	2.00E-02	4.28E+08
INT025	2.60E-02	5.37E+08
INT029	2.74E-02	No answer
INT031	2.54E-02	5.31E+08
INT032	2.50E-02	5.39E+08
INT034	2.56E-02	5.35E+08
INT035	2.42E-02	5.32E+08
INT037	2.83E-02	5.90E+08
INT039	2.40E-02	No answer
INT041	2.54E-02	1.95E+15

Code N°	Committed effective dose (Sv)	Cumulated activity (Bq l^{-1} d)
INT042	2.60E-02	5.37E+08
INT043	3.10E-02	5.35E+08
INT044	2.55E-02	5.32E+08
INT045	2.60E-02	5.34E+08
INT046	5.27E-04	6.45E+06
INT047	2.60E-02	5.37E+08
INT048	2.57E-02	5.37E+08
INT049	2.57E-02	5.37E+08
INT050	4.27E-02	4.62E+09
INT051	2.56E-02	5.34E+08
INT052	2.57E-02	5.37E+08
INT053	2.76E-06	5.76E+04
INT054	2.57E-02	5.36E+08
INT055	3.01E-02	6.29E+08
INT056	2.57E-02	5.36E+08
INT057	2.60E-02	5.35E+08
INT058	2.84E-02	No answer
INT060	2.80E-02	5.82E+08
INT061	2.60E-08	5.33E+02
INT062	2.58E-02	5.38E+08
INT063	2.34E-02	4.88E+08
INT065	2.70E-02	No answer
INT066	5.80E-02	5.37E+08
INT067	2.75E-02	5.80E+08
INT069	2.80E-02	5.36E+08

Code N°	Committed effective dose (Sv)	Cumulated activity (Bq l^{-1} d)
INT070	2.57E-02	5.37E+08
INT076	6.40E-02	No answer
INT077	2.84E-02	No answer
INT078	2.57E-02	5.37E+08
INT079	2.55E-02	5.33E+08
INT080	2.57E-02	5.37E+08
INT081	2.51E-02	
INT082		4.70E-02
INT083	2.54E-02	5.30E+08
INT085	2.51E-02	5.31E+08
INT086	2.72E-02	5.35E+08
GM	2.58E-02	5.35E+08
GSD	1.06	1.005
AM	2.57E-02	5.35E+08
SD	1.4E-03 (5.5 %)	2.25E+06 (0.4 %)
Min	2.6E-08	5.33E+02
Max	6.4E-02	1.95E+15

Table II-2. Number of data used for evaluation
(total number of data given for the evaluation: 75)

Code N°	Total number of data used in the evaluation	Are all the data selected?
INT001	75	Yes
INT002	50	No
INT003	75	Yes
INT004	75	Yes
INT010	75	Yes
INT011	75	Yes
INT013	75	Yes
INT015	75	Yes
INT016	75	Yes
INT018	75	Yes
INT019	No answer	No answer
INT022	75	Yes
INT023	75	Yes
INT025	75	Yes
INT029	37	No
INT031	75	Yes
INT032	75	Yes
INT034	63	No
INT035	75	Yes
INT037	75	Yes
INT039	74	No
INT041	75	Yes
INT042	75	Yes

Code N°	Total number of data used in the evaluation	Are all the data selected?
INT043	39	No
INT044	75	Yes
INT045	74	No
INT046	50	Yes
INT047	75	Yes
INT048	75	Yes
INT049	75	Yes
INT050	75	Yes
INT051	75	Yes
INT052	75	Yes
INT053	No answer	No answer
INT054	75	Yes
INT055	75	Yes
INT056	75	Yes
INT057	40	Yes
INT058	75	Yes
INT060	75	Yes
INT061	75	Yes
INT062	75	Yes
INT063	75	Yes
INT065	64	No
INT066	First 16 days for intake estimation	No
INT067	75	Yes
INT069	75	Yes

Code N°	Total number of data used in the evaluation	Are all the data selected?
INT070	75	Yes
INT076	6	No
INT077	75	Yes
INT078	75	Yes
INT079	75	Yes
INT080	75	Yes
INT081	75	Yes
INT082	75	Yes
INT083	75	Yes
INT085	75	Yes
INT086	75	Yes

All data used	45 participants (77.6%)
74 data used	2 participants (3.4%)
63 data used	2 participants (3.4%)
50 data used	2 participants (3.4%)
37-40 data used	3 participants (5.2%)
16 data used	1 participant (1.7%)
6 data used	1 participant (1.7%)

Table II-3. Assumed distribution and uncertainty of measurement data

Code N°	Assumed distribution of measurement data	Assumed uncertainty value
INT001	Lognormal	SF 1.1
INT002	No answer	No answer
INT003	Normal	0.1
INT004	Normal	No answer
INT010	Lognormal	27.45
INT011	n.a.	n.a.
INT013	n.a.	0.18
INT015	Normal	0.1
INT016	None	None
INT018	Normal	n.a.
INT019	No answer	No answer
INT022	Lognormal	None
INT023	(Normal)	10 %
INT025	None	n.a.
INT029	No answer	No answer
INT031	Normal	10 %
INT032	None1)	n.a.
INT034	Lognormal	110 % (1.1)
INT035	(Normal)	16 %
INT037	None2)	n.a
INT039	Lognormal	S
INT041	Lognormal	SF = 1.046 3)
INT042	Normal	2.2
INT043	No answer	No answer

Code N°	Assumed distribution of measurement data	Assumed uncertainty value
INT044	Exponential	110 %
INT045	Lognormal	110 %
INT046	Normal	10 %
INT047	Lognormal	No answer
INT048	Others	130 %
INT049	No answer	No answer
INT050	Normal4)	10 %
INT051	No answer	No answer
INT052	Lognormal	200 %
INT053	No answer	No answer
INT054	None	n.a.
INT055	Normal	SAAM5)
INT056	n.a.	n.a.
INT057	No answer	No answer
INT058	No answer	No answer
INT060	No answer	No answer
INT061	No answer	No answer
INT062	None6)	None
INT063	Lognormal	180 %
INT065	No answer	No answer
INT066	n.a.	none
INT067	No answer	No answer
INT069	None	n.a
INT070	Lognormal	n.a.
INT076	Lognormal	19 %

Code N°	Assumed distribution of measurement data	Assumed uncertainty value
INT077	Normal	1 %
INT078	No answer	No answer
INT079	Normal	10 %
INT080	No answer	No answer
INT081	No answer	No answer
INT082	(Normal)	1 %
INT083	Lognormal	No answer
INT085	n.a.	n.a.
INT086	Normal	2000 %
Normal distribution	15 participants (25.8%)	
Normal distribution	13 participants (22.4%)	
Other distribution	2 participants (3.4%)	
None	7 participants (12.1%)	
No answer (or n.a.)	21 participants (36.2%)	

Table II-4. Application of the Guidelines

Code N°	Did you strictly follow the guidelines	If not, why not ?
INT001	Yes	
INT002	Yes	
INT003	No	Facility Dose Assessment Practices Applied
INT004	Yes	
INT010	Yes	
INT011	Yes	
INT013	Yes	
INT015	No	The flowcharts of the Guidelines are not relevant to the direct dose assessment method
INT016	No	direct dose assessment method
INT018	Yes	
INT019	No answer	
INT022	Yes	
INT023	Yes	
INT025	Yes	
INT029	No	I use INDAC code
INT031	No	special case with HTO and nonuniform retention
INT032	Yes1)	
INT034	Yes	
INT035	No	Seeing the references of the guidelines. i.e. ICRP 23 and 68. modification in values for SEE. total water volume. and area under the activity concentration curve seems to give more correct answer.
INT037	No	I tried to follow it but some steps are not very clear.
INT039	No	no time
INT041	Yes	
INT042	Yes	

Code N°	Did you strictly follow the guidelines	If not, why not ?
INT043	No	Were not available
INT044	Yes	
INT045	No	I followed the “Guidelines for direct internal dose assessment” provided together with the Case No.1description
INT046	Partial	plethoric hydrous diet to enhance the urine output.
INT047	Not completely	
INT048	Yes (I tried!)	
INT049	Yes	
INT050	Not exactly	The method used seems to be more adequate. as in the excretion in the ”zeroth” day there is biggest uncertainty.
INT051	No	The case was too simple
INT052	Yes	
INT053	No	Because. measurements of internal dose assessment are not made in our laboratory and our laboratory is not accredited yet. But accreditation procedure is being continuing.
INT054	No	direct dose method
INT055	Yes	
INT056	No	Canada has a similar regulated method based on linear interpolation
INT057	Yes	
INT058	No	Lack of time
INT060	No	Don’t have the guideline
INT061	No answer	
INT062	Yes	
INT063	No	direct method of dost evaluation is used
INT065	No	Use of ICRP 78
INT066	Yes	
INT067	No	our usual procedure
INT069	No	This is a special case. Urinary excretion isn’t directly available

Code N°	Did you strictly follow the guidelines	If not, why not ?
		for dose assessment.
INT070	No answer	
INT076	No	I used AIDEe program ARCAL
INT077	Yes	
INT078	No	
INT079	Yes	
INT080	No	Use of national guidelines and experience
INT081	Yes	
INT082	No	Plethoric hydrous diet
INT083	Yes	
INT085	n.a.	
INT086	No answer	
Following the guidelines		26 participants (44.8%)
Not following the guidelines		24 participants (41.4%)
Partially following the guidelines		3 participants (5.2%)
No answer (or n.a.)		5 participants (8.6%)

ANNEX III. CASE 2 — ACUTE INHALATION OF FISSION PRODUCTS ^{137}CS & ^{90}SR — RESULTS

Table III-1. All participants results to Case 2: Fission products Intake
(Shaded figures are outliers)

Code N°	^{137}Cs Intake [Bq]	^{137}Cs E(50) [mSv]	^{90}Sr Intake [Bq]	^{90}Sr E(50) [mSv]
2	95056	0.64	158797	4.76
3	106000	0.71	82800	6.38
4	102067	0.68	107910	8.31
5	118000	0.31	1500	0.03
11	87855	0.59	156000	12.01
13	93000	0.62	110000	6.50
15	93700	0.63	179000	13.80
16	88300	0.59	83100	6.42
18	9300	62.00	140000	11.00
19	115000	0.80	28300	2.20
22	185000	0.63	86400	0.93
23	137000	0.66	115000	17.00
24	108500	0.73	141200	10.90
25	88600	0.59	143000	11.00
26	114000	0.76	1104	0.03
27	113000	0.76	103000	7.95
29	125000	0.69	45600	3.51
30	131000	0.63	155000	22.69
31	93100	0.62	129000	19.40
32	107400	0.72	125300	37.20

Code N°	^{137}Cs Intake [Bq]	^{137}Cs E(50) [mSv]	^{90}Sr Intake [Bq]	^{90}Sr E(50) [mSv]
34	106000	0.71	990	0.03
36	118000	0.79	80400	6.19
39	1050	0.33	70000	3.60
41	97000	0.65	93000	7.10
42	121753	0.82	100564	7.70
43	118000	0.79	73900	5.69
45	100000	0.48	95200	13.90
46	72020	0.48	9539.4	0.20
47	73800	0.35	134000	19.60
48	102000	0.68	85800	6.61
49	71000	0.55	66000	5.10
50	105000	0.71	106000	8.10
51	105000	0.70	83100	6.42
52	71700	0.48	79800	6.16
54	154000	0.74	125600	18.80
55	88100	0.59	68100	3.48
56	78000	0.53	81000	6.30
57	120000	0.80	78000	6.00
59	78410	0.52	1229	0.04
60	76000	0.42	17800	0.55
61	100000	0.67	79000	6.10
63	117800	0.79	60750	4.68
65	118000	0.80	37000	3.00
66	113000	0.76	103000	7.95

Code N°	^{137}Cs Intake [Bq]	^{137}Cs E(50) [mSv]	^{90}Sr Intake [Bq]	^{90}Sr E(50) [mSv]
67	125000	0.60	21615	1.82
69	88500	0.59	34000	1.74
70	88100	0.59	152000	11.70
76	105000	0.70	79600	6.13
77	69940	0.47	126220	18.70
78	89000	0.60	1229	0.04
79	96958	0.65	135770	10.50
80	94000	0.63	85200	3.07
81	133000	0.78	85200	3.07
82	109000	0.64	155000	5.50
83	104000	0.70	80400	6.19
84	118000	0.79	1500	0.05
85	118000	0.79	111000	8.60
86	118000	0.31	1500	0.03
GM	101586	0.66	102436	7.22
GSD	1.20	1.16	1.33	1.94
AM	103230	0.67	106571	8.97
SD	18416	0.10	30726	6.61
Min	69940	0.47	60750	1.74
Max	154000	0.82	179000	37.20

Table III-2. ^{137}Cs: Models and dose coefficients

Code N°	Software used for the evaluation	Respiratory tract model used in the evaluation	GI tract Model used in the evaluation	Systemic biokinetic model used in the evaluation	Dose Coefficient used for ^{137}Cs
2	None	ICRP 66	ICRP 30	ICRP 30, ICRP 56	6.70E-09
3	IMBA	ICRP 66	ICRP 30	IMBA w/ICRP 68	6.70E-09
4	LUDEP 2.06; IRFA	ICRP 66	ICRP 30	ICRP 56	6.70E-09
5	LUDEP V 2.06	ICRP 66	ICRP 30	ICRP 54	2.65E-9
11	NONE	ICRP 66	ICRP30	ICRP68	6.7 E -09
13	MONDAL	ICRP 66	n.a.	MONDAL	6.7E-09
15	MONDAL 2, IMIE	ICRP 66	ICRP 30, 54, 78	ICRP 30	6.70E-09
16	IMIE	ICRP 66	ICRP 30	ICRP 67	6.70E-09
18	Mathematica	ICRP 66	ICRP 30	ICRP 67	6.70E-07
19	LUDEP	ICRP 66	ICRP 30	ICRP 56 + fitted half-life	6.70E-09
22	IMBA	ICRP 66	ICRP 30	ICRP 68	3.40E-09
23	IMIE INT 04	ICRP 66	ICRP 30	ICRP 56	4.80E-09
24	IMBA	ICRP 66	ICRP 30	ICRP 71	1.90E-09
25	IMBA	ICRP66	ICRP30	ICRP56	6.70E-09
26	NO	ICRP 78 (67)	NO	ICRP 78 (30)	6.7E-9
27	None	ICRP78	ICRP78	ICRP78	6.70E-09
29	INDAC	Default in INDAC	Default in INDAC	Default in INDAC	5.48E-09
30	Self-made calculation program				4.81E-09
31	IDEAS DV0102	ICRP pub 66	NONE	ICRP 78	6.7E-09

Code N°	Software used for the evaluation	Respiratory tract model used in the evaluation	GI tract Model used in the evaluation	Systemic biokinetic model used in the evaluation	Dose Coefficient used for ^{137}Cs
32	IMBA	ICRP 66	ICRP 30	ICRP 67	6.70E-09
34	none	ICRP 66	ICRP30	ICRP 68	6.70E-09
36	INDOS	ICRP 78	ICRP 78	ICRP 78	6.70E-09
39	BKFIT	ICRP66	ICRP30		
41	MMK-01	ICRP 66	ICRP 30	ICRP 56	6.7E-09
42	LUDEP2.05	ICRP 66	ICRP 30	ICRP 30	6.70E-09
43	none	ICRP 66	ICRP 30	ICRP 30	6.70E-09
45	IMIE	ICRP 68	ICRP 68	ICRP 68	
46	IMBA+DOE (ii) V3.2.04	ICRP 66	ICRP 30	ICRP 72	2.04E-08
47	AIDE	ICRP 66	ICRP 30	model based on the real data	4.80E-09
48	homemade	ICRP default	ICRP default		6.70E-09
49	none	ICRP78		none	
50	none	ICRP 78		ICRP 78	6.70E-09
51	IMIE	ICRP 78	ICRP 78	ICRP 78	6.70E-09
52	IMIE-INT04	ICRP66	ICRP30; ICRP 67	ICRP 71	6.67E-09
54	IMBA	default	default	ICRP 56	6,7 E-09
55	EXCEL, IMBA	ICRP 66	ICRP 30	ICRP 67	6.70E-09
56	IMBA Special	ICRP 66	ICRP 30	ICRP 56	6.70E-09
57	none	ICRP 66	ICRP 30	ICRP 78	6.70E-09
59	IMBA, IMIE, LUDEP	ICRP	ICRP	ICRP	6.70E-09
60	Intake : Cindy,Dose : Ludep /	ICRP 30 / 66	ICRP 30	ICRP 30 Cs(D)	6.61E-09

Code N°	Software used for the evaluation	Respiratory tract model used in the evaluation	GI tract Model used in the evaluation	Systemic biokinetic model used in the evaluation	Dose Coefficient used for ^{137}Cs
	ICRP78				
61	INDO2000	ICRP 66	ICRP 30	ICRP 78	6.70E-09
63	IMBA	ICRP 66	ICRP 30	ICRP 56	6.7 E-09
65	none, Excel and ICRP78	ICRP 67		ICRP 78	6.70E-09
66	None	ICRP 78	ICRP 78	ICRP 78	6.70E-09
67	IMBA	ICRP 66	ICRP 30	ICRP 71	
69	IMBA Ver 3.1	ICRP 66	ICRP 30	ICRP 56	6.70E-09
70	MONDAL2	ICRP 66	ICRP 30	ICRP 56	6.70E-09
76	AIDEe ARCAL	ICRP 66		ICRP 66	6.7 E-09
77	IMBA	ICRP 66	ICRP 30	ICRP 56	6.70E-09
78	IMBA Lite Edition	ICRP 66	ICRP30	ICRP 67, default in IMBA	6.70E-09
79	IMBA Professional v3.2.09	ICRP 66	ICRP 30	ICRP 30	6.70E-09
80	none, IDEA-System	ICRP 66	ICRP 30	ICRP 78	6.70E-09
81	IDEAS DV0102	ICRP 78		ICRP 78	5.90E-09
82	personal	ICRP 66	ICRP 30	ICRP 56	5.90E-09
83	AIDEe and MONDAL	ICRP 66	ICRP 30	ICRP 56	6.70E-09
84	LUDEP 2.07	ICRP 66		ICRP 30	6.70E-09
85	IDEA System	ICRP 66	ICRP 30	ICRP 56	6.70E-09
86	LUDEP 2.06	ICRP 66	ICRP 30	ICRP 54	2.65E-09

Table III-3. ^{137}Cs: Model parameters, selection of data.

Code N°	Assumed AMAD (µm)	Assumed Absorption type	Assumed f_1	All whole body data used for assessment?
2	5	F	1	No
3	5	F	1	Yes
4	5	F	1	Yes
5	5	F	1	Yes
11	5	F	1	Yes
13	5	F	1	Yes
15	5	F	1	Yes
16	5	F	1	No
18	5	F	1	Yes
19	5	F	1	Yes
22	16	User defined: Sp=100	0.01	No
23	1	F	1	Yes
24	5	F	1	No
25	5	F	1	Yes
26	5	F	1	Only 2/7/29/62/106 d data are used
27	5	F	1	No
29	5	F	1	YES
30	1	F		Yes
31	Cs-137: 5; Sr-90: 1	F	1	Yes
32	5	F	1	Yes
34	5	F	1	No
36	5	F	1	Except the value at t=0

Code N°	Assumed AMAD (µm)	Assumed Absorption type	Assumed f_1	All whole body data used for assessment?
39	5	F	1	No
41	5	F	1	Yes
42	5	F	1	No
43	5	F	1	Yes
45	1		1	Yes
46	5	F	1	Yes
47	1	F		Yes
48	5	F	1	Yes
49	5	F	1	Yes
50	5	F		No
51	5	F	1	No. We used 6 WB data points.
52	5	F	1	Yes
54	1	F	1	No
55	5	F	1	Yes
56	5	F	1	Yes
57	5	F	1	No
59	5	F	1	Yes
60	5	F	1	Yes
61	5	F	1	Yes
63	5	F	1	Yes
65		F	1	Yes
66	5	F	1	No
67	1	F	1	Yes
69	5	F	1	Yes

Code N°	Assumed AMAD (µm)	Assumed Absorption type	Assumed f_1	All whole body data used for assessment?
70	5	F	1	Yes
76	5			No
77	5	F	1	No
78	5	F	1	Yes
79	5	F	1	No, excluded one data point; only 8 were used in the evaluation.
80	10	F	1	Yes
81	10	F	1	Yes
82	10	F	1	Yes
83	5	F	1	Yes
84	5	F	1	Yes
85	5	F	1	Yes
86	5	F	1	Yes

Table III-4. ^{137}Cs: Use of guidelines

Code N°	Did you follow strictly the guidelines?	If not, why not?	If Yes please provide the final step number of the Guidelines
2	Yes		Step 5.11.3
3	No	Applied Default Techniques applied at ORNL.	
4			
5	No	I followed our internal norm.	
11	Yes		3.3
13	Yes		3.4.1
15	No	The evaluation using MONDAL 2 and IMIE software does not allow to follow strictly the Guidelines however the logic of the flowchart could be used.	
16	Yes	None.	3.4.1
18	No	Guidelines are faulty.	
19	No		
22	No	Following the Guidelines last step would be 3.4.1, but I assumed a relation Cs-137 to Sr-90 of about 2 to 1 for reprocessing	
23	Yes		5
24	Yes		5.6.1
25	Yes		5.6.1
26			
27	Yes		5.6
29	No	I use INDAC code.	
30	No	No time.	
31	Yes		5.6.1
32	No	Broadly followed guidelines.	
34	Yes		5.6.1

Code N°	Did you follow strictly the guidelines?	If not, why not?	If Yes please provide the final step number of the Guidelines
36	No	We have not it yet.	
39	No	No time.	
41	Yes		5.6.1
42			
43	No	Were not available.	
45	Yes		5.11
46	Yes		3.2
47	Not completely		
48	Yes (I tried)		3.4.1
49			
50	Yes		3.4.1
51	No		
52	Yes		5.6
54	Yes		5.15.1
55	Yes		5.6.1
56	Yes		
57	No	Swiss Ordinance.	
59	Yes		1.3
60			
61			
63	Yes	NA	5.6.1
65			
66	Yes		5.6

Code N°	Did you follow strictly the guidelines?	If not, why not?	If Yes please provide the final step number of the Guidelines
67	No		
69	Yes		5.6
70			
76	No	I used AIDEe Program ARCAL.	
77	Yes		3.4.1
78	Yes		3,4,1
79	Yes		3.4.1
80	No	Use of national guidelines and experience.	
81	Yes		5.6
82	Yes		
83	No		
84	No		
85	No		
86	No	I estimated intake and E(50) by LUDEP.	

Table III-5. ^{90}Sr: Models and dose coefficients

Code N°	Software used for the evaluation	Respiratory tract model used into the evaluation	GI tract Model used into the evaluation	Systemic biokinetic model used into the evaluation	Dose Coefficient used for ^{90}Sr
2	None	ICRP 66	ICRP 30	ICRP 67	3.00E-08
3	IMBA	ICRP 66	ICRP 30	IMBA w/ ICRP 68	7.71E-08
4	LUDEP 2.06; IRFA	ICRP 66	ICRP 30	ICRP 67	7.70E-08
5	LUDEP V 2.06	ICRP 66	ICRP 30	ICRP 54	1.7E-8
11	NONE	ICRP66	ICRP30	ICRP 67	7.7E-08
13	MONDAL	ICRP 66	N.A.	MONDAL	5.8E-08
15	MONDAL 2, IMIE	ICRP 66	ICRP 30, 54, 78		7.70E-08
16	IMIE	ICRP 66	ICRP 30	ICRP 67	7.70E-08
18	Mathematica	ICRP 66	ICRP 30	ICRP 67	7.70E-08
19	LUDEP	ICRP 66	ICRP 30	ICRP 78	7.70E-08
22	IMBA	ICRP 66	ICRP 30	ICRP 67	1.08E-08
23	IMIE INT 04	ICRP 66	ICRP 30	ICRP 67	1.50E-07
24	imba	ICRP 66	ICRP 30	ICRP 71	7.70E-08
25	IMBA	ICRP 66	ICRP 30	ICRP 67	7.70E-08
26	NO	ICRP 78 (67)	NO	ICRP 78 (67)	3.00E-08
27	None	ICRP 78	ICRP 78	ICRP 78	7.70E-08
29	INDAC	Default in INDAC	Default in INDAC	Default in INDAC	
30	selfmade calculation program	see comments or remarks	see comments or remarks	see comments or remarks	1.46E-07
31	IDEAS DV0102	ICRP 66	None	ICRP 78	1.50E-07

Code N°	Software used for the evaluation	Respiratory tract model used into the evaluation	GI tract Model used into the evaluation	Systemic biokinetic model used into the evaluation	Dose Coefficient used for ^{90}Sr
32	IMBA	ICRP 66	ICRP 30	ICRP 67	
34	none	ICRP 66	ICRP 30	ICRP 68	3.00E-08
36	INDOS	ICRP 78	ICRP 78	ICRP 78	7.70E-08
39	BKFIT	ICRP 66	ICRP 30		
41	MMK-01	ICRP 66	ICRP 30	ICRP 67	7.7E-08
42	LUDEP2.05	ICRP 66	ICRP 30	ICRP 54	7.7E-08
43	none	ICRP 66	ICRP 30	ICRP 30	7.70E-08
45	IMIE	ICRP 68	ICRP 68	ICRP 68	
46	IMBA+DOE (ii) V3.2.04	ICRP 66	ICRP 30	ICRP 72	
47	AIDE	ICRP 66	ICRP 30	ICRP 67	1.46E-07
48	homemaid	ICRP default	ICRP default		7.70E-08
49	none	ICRP78		None	7.7 E-8
50	none	ICRP 78		ICRP 78	7.70E-08
51	IMIE	ICRP 78	ICRP 78	IMIE	7.70E-08
52	IMIE-INT04	ICRP 66	ICRP30; ICRP 67	ICRP 67	7.73E-08
54	IMBA	default	default	ICRP 67	3.0E-08
55	EXCEL, IMBA	ICRP 66	ICRP 30	ICRP 67	5.10E-08
56	IMBA Special	ICRP 66	ICRP 30	ICRP 67	7.70E-08
57	none	ICRP 66	ICRP 30	ICRP 78	7.70E-08
59	IMBA, IMIE, LUDEP	ICRP	ICRP	ICRP	3.00E-08
60	Intake : Cindy, Dose : Ludep / ICRP78	ICRP 30 / 66	ICRP 30	ICRP 30, Sr(D)Vapor	3.06E-08

Code N°	Software used for the evaluation	Respiratory tract model used into the evaluation	GI tract Model used into the evaluation	Systemic biokinetic model used into the evaluation	Dose Coefficient used for ^{90}Sr
61	INDO2000	ICRP 66	ICRP 30	ICRP 78	7.70E-08
63	IMBA	ICRP 66	ICRP 30	ICRP 67	7.70E-08
65	none, excel and ICRP78	ICRP 67		ICRP 67	7.70E-08
66	None	ICRP 78	ICRP 78	ICRP 78	7.70E-08
67	IMBA	ICRP 66	ICRP 30	ICRP 71	
69	IMBA Ver 3.1	ICRP 66	ICRP 30	ICRP 67	5.12E-08
70	MONDAL2	ICRP 66	ICRP 30	ICRP 67	7.70E-08
76	AIDEe ARCAL	ICRP 66		ICRP 66	7.70 e-08
77	IMBA	ICRP 66	ICRP 30		1.48E-07
78	IMBA Lite Edition	ICRP 66	ICRP 30	ICRP 67, default in IMBA	3.00E-08
79	IMBA Professional v3.2.09	ICRP 66	ICRP 30	ICRP 67	7.70E-08
80	none, IDEA-System	ICRP 66	ICRP 30	ICRP 78	3.60E-08
81	IDEAS DV0102	ICRP 78		ICRP 78	3.60E-08
82	personal	ICRP 66	ICRP 30	ICRP 67	3.60E-08
83	AIDEe and MONDAL	ICRP 66	ICRP 30	ICRP 67	7.70E-08
84	LUDEP 2.07	ICRP 66		ICRP 30	3.00E-08
85	IDEA System	ICRP 66	ICRP 30	ICRP 67	7.70E-08
86	LUDEP 2.06	ICRP 66	ICRP 30	ICRP 54	1.71E-08

Table III-6. ^{90}Sr: Model parameters, selection of dataset used for the final evaluation.

Code N°	Assumed AMAD (um)	Assumed Absorption type	Assumed f1	Which data set has been used for the final evaluation?	When using both datasets, how did you estimate the intake?
2	5	F	0.3	Only faeces	
3	5	S	0.01	Only urine	N/A
4	5	S	0.01	Both: urine and faeces	Intake estimation based on Weighted Least Square Fit
5	5	F	0.1	Only urine	
11	5	S	0.01	Urine	NA
13	5	Mixture F/S (40/60)		Both urine and faeces	Arithmetic mean of the intakes calculated from the individual measurements assuming mixed F/S absorption as above
15	5	S	0.01	Urine	
16	5	S	0.01	Both urine and faeces	Weight(50:50)
18	5	S	0.01	Both	Used ratio of slopes with all intake retention fractions and data values
19	5	S	0.01	Urine	
22	16	Sp=1; Spt=100; St=1e-3	0.001	Both	Best fit
23	1	S	0.01	Only urine	
24	5	S	0.01	Both urine and faeces	
25	5	S	0.01	Both	Maximum Likelihood
26	5	F		Urine	
27	5	S	0.01	Urine	Fecal data not used
29	5	S	0.01	Only faeces	
30	1	S		Urine data, because they yield higher intake and body doses than faecal data	
31	Cs-137: 5; Sr-90: 1	S	0.01	Only urine	
32	5	S	0.01	Urine and faeces	Maximum likelihood fit. See general remarks
34	5	F	0.3	Only urine	
36	5	S	0.01	Only urine	
39	5	Type S, but St=4.7e-4	0.01	16 U + F	Max likelihood

Code N°	Assumed AMAD (um)	Assumed Absorption type	Assumed f1	Which data set has been used for the final evaluation?	When using both datasets, how did you estimate the intake?
41	5	Type S	0.01	Both urine and faeces	Finding absorption type and value of AMAD that give the most similar results
42	5	S	0.01	Urine	It is chosen the biggest value
43	5	S	0.01	Both urine and faeces	
45	1		0.01	Urine	
46	5	M	0.01	Only urine	n/a
47	1	S	0.01	Urine	
48	5	S	0.01	Both	Weighted Least Squares Fit
49	5	S		Both urine and faeces	Separate estimation of intake from both data sets - the final value is arithmetic mean
50	5	S		Finally only urine	
51	5	S	0.01	Both	Simultaneous analysis - Minimal Distance ; Weighting method - WLSF-UD
52	5	S	0.01	Both	best intake with WLSF using all data accepted; model accepted by chi-squared test
54	1	S	0.01	Both	
55	5	Modified Type S (Ss=5E-4)	0.01	Both urine and faeces	Maximum Likelihood method on both data sets
56	5	S	0.01	Urine	na
57	5	S	0.01	Only Urine	
59	5	F	0.3	Urine	
60	5	F	0.3	Both urine and faeces	
61	5	S	0.01	Both urine and faeces	LSF
63	5	S	0.01	Faeces	NA
65			0.01	Urine	
66	5	S	0.01	Urine	Faecal data not used
67	1	S, St =7.0E-04	0.05	Both urine and faeces	
69	5	Type S (St=5.0E-04, Sp and St=Default)	0.01	Both	Fitting curves for both dataset are adjusted reasonably.
70	5	S		Only urine	

Code N°	Assumed AMAD (um)	Assumed Absorption type	Assumed f1	Which data set has been used for the final evaluation?	When using both datasets, how did you estimate the intake?
76	5			Only urine	
77	5	S	0.01	Both urine & faeces	IMBA used both data sets
78	5	F	0.3	Urine	
79	5	S	0.01	Both urine and faeces	Simultaneous, maximum likelihood fitting
80	10	S	0.01	Both urine and faeces	Least-Square-Fit
81	10	S	0.01	Both urine and faeces	Fit
82	10	S	0.01	Both	Deconvolution
83	5	S	0.01	Urine	
84	5	F	0.3	Only urine	
85	5	S	0.01	Both urine and faeces	Least squares fit
86	5	F	0.3	Only urine	

Table III-7. ^{90}Sr: Use of guidelines.

Code N°	Did you strictly follow the guidelines?	If not, why not ?	If yes, please provide the final step number of the Guidelines
2	Yes		Step 5.11.3
3	No	Facility dose assessment practices applied.	
4	No	Not user's friendly & not clear enough.	
5	No	I followed our internal norm.	
11	Yes		3.3 & 5.1
13	Yes		5.15.1
15	No	The evaluation using MONDAL 2 and IMIE software does not allow to follow strictly the Guidelines however the logic of the flowchart could be used.	
16	No	IMIE can not treat Step 5C.	None
18	No	Guidelines are faulty -- unnecessarily complicated.	
19			
22	No	Because of very bad fit results for Sr-90.	Step 5.22.1
23	Yes		5
24	Yes		5.15.1
25	Yes		5.15.1
26	ICRP 78		
27	No		
29	No	I use INDAC code.	
30	No	No time.	
31	No	Because Type F was given.	5.15.1
32	Yes		5.19

Code N°	Did you strictly follow the guidelines?	If not, why not ?	If yes, please provide the final step number of the Guidelines
34	Yes		5,6,1
36	No	We have not it yet.	
39			
41	Yes		5.15.1
42			
43	No	Were not available.	
45	Yes		
46	Yes		3.3.1
47	Not completely		
48	Yes		
49			
50	Yes		5.15.1
51	No		
52	YES		5.6
54	Yes		5.15.1
55	Yes		5.6.1 for Cs; 5.11.3 for Sr
56	No	Unclear how to handle error distributions.	
57	No	We used the Swiss ordinance	
59	Yes		1.3
60			
61			
63	Yes		5.11.3

Code N°	Did you strictly follow the guidelines?	If not, why not ?	If yes, please provide the final step number of the Guidelines
65			
66	No		
67	No		
69	Yes		5.22.1
70			
76	No	I used AIDE e Program ARCAL.	
77	Yes		5.15 5.15.1
78			
79	Yes		5.11.4
80	No	Use of national guidelines and experience.	
81	Yes		5.15.1
82			
83	No	No tool available for simultaneously fitting of urine and faecal measurements as well as for different ration of S/F types.	
84	No		
85	No	The guidelines do not allow for fitting of the AMAD.	
86	No	I estimated intake and E(50) by LUDEP.	

ANNEX IV. CASE 3 — ACUTE INHALATION OF CO — RESULTS

Table IV-1. Results of Case 3 for the assessment of ^{60}Co intake and E(50).

Code	^{60}Co Intake [kBq]	^{60}Co E(50) [mSv]	Assumed pathway	AMAD	Absorption Type	f_1	Data set used
1	370	5.0	INH	5	M/S, 30/70		WB, U
2	515	5.2	INH	5	M/S, 70/30		WB, U
3	425	3.1	INH	5	M	0.1	WB, U
4	417	3.0	INH	5	M	0.1	WB, U
5	499	3.6	INH	5	M	0.1	WB
11	385	6.5	INH	5	S	0.05	WB
13	470	4.3	INH	5	M/S, 80/20		WB, U
15	393	4.7	INH	5	M/S, 50/50		WB, U
16	413	5.3	INH	5	M/S		WB, U
18	460	3.3	INH	5	M	0.1	WB, U
19	370	6.3	INH	5	S	0.05	WB
22	304	4.7	INH	4	Specific	0.1	WB, U
24	380	5.0	INH	5	M/S, 36/63	M/S (0.1/0.05)	WB
25	764	6.2	INH	10	M/S, 37/63	0.1	WB, U
26	418	12.2	INH	1	S		WB
27	420	5.0	INH	5	M/S, 50/50		WB, U
29	386	2.7	INH	5	M	0.1	WB
30	406	5.2	INH	5	M/S, 46/54		WB, U
31	784	7.8	INH	10	S	0.05	WB, U
32	333	4.2	INH	5	Specific	0.1	WB, U
34	1390	23.6	INH	5	S	0.05	U
35	24	0.4	INH	5			WB
36	386	6.6	INH	5	S	0.05	WB
37	423	3.0	INH	5	M	0.1	WB
39	1200	6.5	INH	16.8	Specific	0.067	WB, U
41	450	4.6	INH	5	M/S, 70/30	M/S (0.1/0.05)	WB, U
42	5415	92.0	INH	5	S	0.05	WB
43	386	6.6	INH	5	S	0.05	WB, U

Code	^{60}Co Intake [kBq]	^{60}Co E(50) [mSv]	Assumed pathway	AMAD	Absorption Type	f_1	Data set used
44	384	2.7	INH	5	M	0.1	WB
45	2400	8.2	INH	15	S	0.05	WB, U
46	394	2.5	INH	5	F	0.01	WB, U
48	425	7.2	INH	5	S	0.05	WB, U
49	350	6.0	INH	5	S		WB
50	383	6.5	INH	5	S		WB
51	580	6.3	MIX (60% INH + 40% ING)	5	S	0.05	WB, U
52	352	4.8	INH	5	M/S, 30/70		WB, U
54	670	5.8	INH	10	M/S	0.1	WB, U
55	368	4.1	INH	5	Specific	0.05	WB, U
56	390	2.8	INH	5	M	0.1	WB
57	390	7.0	INH	5		0.05	WB
59	352	5.8	INH	5	S	0.05	WB
60	410	2.8	INH	5	M	0.05	WB
61	390	2.8	INH	5	M	0.1	WB, U
62	404	5.0	INH	5	M/S, 44/56	M/S (0.1/0.05)	WB, U
63	404	5.0	INH	5	M/S, 40/60	0.05	WB, U
65	542	9.0	INH	5	S	0.05	WB, U
66	420	7.14	INH	5	S	0.05	WB
67	2022	9.5	INH	20	S	0.05	WB, U
69	566	4.8	INH	10	Specific	0.05	WB, U
70	361	6.1	INH	5	S	0.05	WB
73	552	16.0	INH	1	S		WB, U
76	386	6.6	INH	5			WB
77	392	4.9	INH	5	M/S, 44.4.55.6	M/S 0.1/ 0.05	WB, U
78	348	5.8	INH	5	S	0.05	WB
79	404	5.0	INH	5	M/S, 44/56	M/S 0.1/0.05	WB, U
80	866	6.4	INH	10	M/S, 30/70	0.065	WB, U

Code	^{60}Co Intake [kBq]	^{60}Co E(50) [mSv]	Assumed pathway	AMAD	Absorption Type	f_1	Data set used
81	770	6.1	INH	10	M/S, 40/60	0.05	WB, U
82	430	3.1	INH	5	M	0.05	WB, U
83	385	6.6	INH	5	S	0.05	WB
84	418	3.0	INH	5	M	0.05	WB
85	770	6.1	INH	10	M/S, 40/60	0.07	WB, U
86	418	2.8	INH	5	M	0.05	WB
GM	395	5.0					
GSD	1.08	1.40					
AM	396	5.2					
ASD	30	1.7					
Min	333	2.73					
Max	470	9.45					

Table IV-2. Measurement uncertainties for the assessment of ^{60}Co intake (Case 3)

		Whole body (WB) dataset			Urine dataset		
Code	Dataset used	Distribution	Uncert Type	Uncert Value	Distribution	Uncert Type	Uncert Value
1	WB, U	Lognormal	SF	1.18	Lognormal	SF	1.8
2	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
3	WB, U	Normal	Normal	N/A	Normal	Normal	N/A
4	WB, U						
5	WB	Normal	relative	50			
11	WB						
13	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
15	WB, U	Normal	relative	20%	Normal	relative	30%
16	WB, U	Normal	relative	20%	Normal	relative	30%
18	WB, U	Normal	proportional to square of expectation value	Expectation 2	Normal	proportional to square of expectation value	Expectation 2
19	WB	Lognormal	normal, absolute	?			

		Whole body (WB) dataset			Urine dataset		
Code	**Dataset used**	**Distribution**	**Uncert Type**	**Uncert Value**	**Distribution**	**Uncert Type**	**Uncert Value**
22	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
24	WB	Lognormal	normal, relative	16%	Lognormal	normal relative	18%
25	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
26	WB	Lognormal	SF	1.18			
27	WB, U	Lognormal	SF	1.26	Lognormal	SF	1.8
29	WB						
30	WB, U	none	none	none	none	none	none
31	WB, U	Normal	relative	10%	Normal	relative	10%
32	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
34	U	Lognormal	SF	1.2	Lognormal	SF	1.1
35	WB		0.031	0.031		None	None
36	WB			much less than factor of 3			
37	WB	Lognormal	None	None			
39	WB, U	Lognormal	SF	1.3	Lognormal	SF	1.65
41	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
42	WB	Lognormal	SF	0.2	Lognormal	SF	2
43	WB, U						
44	WB	Lognormal	SF	2.25	Lognormal	SF	1.8
45	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
46	WB, U	Lognormal	SF	1.07	Lognormal	SF	1.8
48	WB, U	Normal	SF	1.2	Lognormal	SF	1.8
49	WB						
50	WB	Normal	relative	20%			
51	WB, U	Normal	relative	20%		relative	30%
52	WB, U	Lognormal	SF	1.2	Lognormal	SF	110
54	WB, U	Lognormal	SF	1.2		SF	1.8
55	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
56	WB	Normal	relative	100%	Normal	relative	100%
57	WB						
59	WB	Lognormal	SF	1.18			
60	WB						
61	WB, U						
62	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8

		Whole body (WB) dataset			Urine dataset		
Code	**Dataset used**	**Distribution**	**Uncert Type**	**Uncert Value**	**Distribution**	**Uncert Type**	**Uncert Value**
63	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
65	WB, U						
66	WB						
67	WB, U	Lognormal	SF	1.3	Lognormal	SF	1.6
69	WB, U	Lognormal	SF	1.18	Lognormal	SF	1.8
70	WB						
73	WB, U						
76	WB	Normal	relative	16%			
77	WB, U	Normal	relative	20%	Lognormal	SF	1.8
78	WB	Lognormal	Uniform relative		Lognormal	SF	1.8
79	WB, U	Lognormal	SF	1.2	Lognormal	SF	1.8
80	WB, U						
81	WB, U						
82	WB, U	Lognormal		0.1	Lognormal	absolute	0.1
83	WB	Lognormal	Not used				
84	WB	Normal	absolute				
85	WB, U	n.a.	SF	depends on the value	n.a.	SF	depends on the value
86	WB	Normal	relative	30%			

ANNEX V. CASE 4 — REPEATED INTAKE OF ^{131}I — RESULTS

Table V-1. Participants results to Case 4 Intake of ^{131}I
(Shaded cells indicate outlying data)

code	Intake [Bq]	E(50) [mSv]	Assumed pathway	Time pattern of intake[a,b]	Assumed Gas/Vapour Class[b]	Assumed Absorption type[b]	Assumed f_1 [b]
01	131100	2.6	INH	RI	SR 1	V	1
02	131239	2.6	INH	RI	SR-1	V	1
03	125400	2.5	INH	CI	SR-1	F	1
04	246969	2.72	INH	RI		F	1
05A	153000	2.39	INH	SI	particle /0,001 _m/	F	1
05B	137000	2.7	INH	RI	SR-1	F	1
07	1	0.00001578	INH	SI	SR-1	F	1
11	144652	2.89	INH	RI	SR-1		1
12	131238	2.625	INH	CI at steps	SR-1		1
13	132000	4.1	INH	RI	SR-1	V	
14	131000	2.6	INH	SI	SR-1	F	1
15	129000	2.59	INH	CI at steps	SR-1	F	1
16	132000	2.61	INH	CI	SR-1	F	1
18	9930000	199	INH	CI	SR-1	V	1
19	130000	2.6	INH	RI	SR-1	F	1
22	320000	3.37	INH	RI	Gas	F	1
24	211000	2.22	INH	RI		F	1
25	200000	2.56	INH	CI	SR-1	F	1
26	132000	2.22		SI	SR-1	F	
27	119000	2.6	INJ	RI	NA		
29	88000	2.47	INH	CI		F	1
30	132000	2.59	INH	RI	NA	NA	NA
31	267000	2.93	INH	CI	SR-1	F	1
32	194001	2.56	INH	CI	SR-1		
34	281220	3.09	INH	RI		F	1
35	250000	2.7	INH			NA	
36	329000	0.363	INH	RI	SR-1	F	1
38	211400	2.22	INH	NA	Gas	F	1
39	130000	3	INH	RI	SR-1	F	1
40	116336	0.97	INH	SI	D (Fast)	F	1
41	120000	2.4	INH	SI special	SR-1		1
42	298017	3.3	INH	SI	Vapour	F	1
43	245000	4.91	INH	RI	SR-1	F	1

code	Intake [Bq]	E(50) [mSv]	Assumed pathway	Time pattern of intake[a,b]	Assumed Gas/Vapour Class[b]	Assumed Absorption type[b]	Assumed f_1 [b]
44	120000	2.4	INH	SI	SR-1	V	1
45	270000	2.8	INH	SI	SR-1	F	1
46	255300	2.68	INH	RI	SR-1	F	1
47	114000	2.3	INH	CI	SR-1	V	
48	166000	1.82	INH	CI at steps	SR-1	F	1
49	131000	2.62	INH	RI	SR-1	V	1
50	131000	2.62	INH	CI	Vapour	V	
51	126000	2.5	INH	CI	SR-1		1
52	137000	2.71	INH	SI	SR-1	F	1
54	144000	2.88	INH	CI	SR-1	F	1
55	120000	2.4	INH	RI	SR-1	F	1
56	130000	2.6	INH	RI	SR-1	F	1
60	122000	1.12	INH	SI		F	1
61	130000	2.6	INH	RI	SR-1	F	1
63	118000	2.33	INH	RI	SR-1	F	1
64	43746	2.6	INH	SI	SR-1	F	1
65	2670000	0.72	INH	CI	SR1		1
66	250000	2.75	INH	SI		F	1
67	124300	2.46	INH	SI	SR-1	V	1
69	125000	2.51	INH	CI	SR-1	V	1
70	43000	0.86	INH	CI		V	
76	132000	2.64	INH	SI	SR-2		
77	239910	2.52	INH	SI		F	1
79	129134	2.55	INH	CI at steps	SR-1	F	1
80	246000	2.71	INH	CI		F	1
81	217000	2.39	INH	CI	SR-1	F	1
82	123000	2.46	INH	RI	SR-1	V	1
83	130000	2.63	INH	RI	SR1	V	1
84	168000	2.62	INH	RI	SR-1	F	1
85	243000	2.7	INH	CI	SR-1	F	1

GM	160133	2.57
GSD	1.39	1.07
AM	169659	2.58
SD	62153	0.17
Min	1	0.00001578
Max	9930000	199

(a) SI = Single intake
RI = Repeated intake
CI = Continuous intake
CI at steps = Constant intake at steps
(b) NA = Not Applicable

Table V-2. Participants information to Case 4 Intake of ^{131}I

code	Dose Coefficient used for ^{131}I [Sv/Bq]	Assumed distribution of measurement data	Respiratory tract model	GI tract Model	Systemic biokinetic model	Did you strictly follow the guidelines?
01	2.00E-08	Normal	ICRP 66	ICRP 30	ICRP 67	No
02	2.00E-08	Normal	ICRP 66		ICRP 67	Yes
03	1.98E-08	Normal	ICRP 66	ICRP 30	ICRP 78	No
04	1.10E-08		ICRP 66	ICRP 30	ICRP 56	No
05A	1.56E-08	Normal	ICRP 66	ICRP 30	ICRP 54	No
05B	1.97E-08	Normal	ICRP 66	ICRP 30	ICRP 56	No
07	1.58E-08	Normal	ICRP 66	ICRP 30	ICRP 54	Yes
11			ICRP 66	ICRP 30	ICRP 67	Yes
12	2.00E-08	Normal	ICRP 66	ICRP 30	ICRP 78	No
13	3.10E-08	NA.	ICRP 66	NA	ICRP 56	Yes
14	1.01E-08	Normal	ICRP 66	ICRP 30	ICRP 54/78	No
15	2.00E-08	Lognormal	ICRP 66	ICRP 30	ICRP 56	Yes
16	1.98E-08	Normal	ICRP 66	ICRP 30	ICRP 67	Yes
18	2.00E-08	Normal	ICRP 66	ICRP 30	ICRP 56	No
19	2.00E-08		ICRP 66		ICRP 78	No
22	1.05E-08	Lognormal	ICRP 66	ICRP 30	ICRP 68	Yes
24	1.10E-08	Lognormal	ICRP 66	ICRP 30	ICRP 71	Yes
25	1.30E-08	Lognormal	ICRP 66	ICRP30	ICRP56	Yes
26	2.00E-08		ICRP 78/67		67	Yes
27	2.20E-08	Normal	ICRP 66	ICRP 30	ICRP 56/67	Yes
29	2.80E-08		INDAC default	INDAC default	INDAC default	No
30	1.97E-08	None	German reg.	German reg.	German reg.	No
31	1.10E-08	Normal	ICRP 66	none	ICRP 78	Yes
32	1.32E-08	Lognormal	ICRP 66	ICRP 30	ICRP 78/67	Yes
34	1.10E-08	Lognormal	ICRP 66	ICRP 30	ICRP 56	Yes
35	1.10E-08	None	None	None	None	No
36	1.10E-08	Other	ICRP 78	ICRP 78	ICRP 78	No
38		Normal	ICRP defaults	ICRP defaults	ICRP defaults	Yes
39		Lognormal				
40	8.00E-09	No	ICRP 30	ICRP 30	ICRP 30	No
41	2.0E-08	Normal	ICRP 66	ICRP 30	ICRP 67	No
42	1.10E-08	Normal	ICRP66	ICRP30	ICRP 30	
43	2.00E-08		ICRP 66	ICRP 30	ICRP 30	No
44	2.00E-08	Lognormal	ICRP 66		ICRP 71	Yes
45	1.10E-08	Lognormal	ICRP.68	ICRP.68	ICRP 68	Yes
46	1.05E-08	Normal	ICRP 66	ICRP-30	ICRP 67	Yes

code	Dose Coefficient used for ^{131}I [Sv/Bq]	Assumed distribution of measurement data	Respiratory tract model	GI tract Model	Systemic biokinetic model	Did you strictly follow the guidelines?
47	5.93E-08	Lognormal	ICRP 66	ICRP 30	ICRP 67	Yes/No
48	1.10E-08	Normal				Yes
49	2.0 E-08				ICRP 78	
50	2.00E-08	Lognormal	ICRP 78		ICRP 78	Yes
51	2.00E-08		ICRP 78	ICRP 78	ICRP 78	No
52	1.10E-08	Lognormal	ICRP66	ICRP30/67	ICRP 71	Yes
54	2.00E-08	No	Default	Default	Default	No
55	2.00E-08	Lognormal	ICRP 66	ICRP 30	ICRP 67	Yes
56	2.00E-08	Normal	ICRP 66	ICRP30	ICRP67	No
60	1.06E-08		ICRP 30/66	ICRP 30	ICRP 78	
61	2.00E-08		ICRP 66	ICRP 30	ICRP 78	
63	2.00E-08	Lognormal	ICRP 66	ICRP 30	ICRP 56	Yes
64	2.00E-08	Normal			ICRP 67	Yes
65	2.00E-08		ICRP 67			
66	1.10E-08					Yes
67	1.98E-08	Normal	ICRP 66	ICRP 30	ICRP 68	No
69	2.00E-08	Normal	ICRP 66	ICRP 30	ICRP 56	No
70	2.00E-08		ICRP 66	ICRP 30	ICRP 56	
76	2.00 E-08	Lognormal	ICRP 66		ICRP 68	No
77	1.05E-08	Normal	ICRP 67			Yes
79	1.97E-08	Lognormal	ICRP 66	ICRP 30	ICRP 68/71	Yes/No
80	1.10E-08		ICRP 66	ICRP 30	ICRP 78	No
81	1.10E-08		ICRP 78	ICRP 30	ICRP 78	Yes
82	2.00E-08	Lognormal	ICRP 66	ICRP 30		
83	1.1E-08	Lognormal	ICRP 66	ICRP 30	ICRP 67	No
84	1.56E-08	Normal	ICRP 66		ICRP 30	No
85	1.96E-08	NA.	ICRP 66	ICRP 30	ICRP 68	No

ANNEX VI. CASE 5 — ENRICHED URANIUM INTAKE — RESULTS

Table VI-1. All participants results to Case 5 Uranium Intake.
(Shaded figures are outliers)

Code	^{234}U intake [Bq]	^{235}U intake [Bq]	^{238}U intake [Bq]	^{234}U dose [mSv]	^{235}U dose [mSv]	^{238}U dose [mSv]	U total dose [mSv]
02	1770	85	277	12.0	0.5	1.5	14.0
03	68000	3300	10700	460.0	20.0	60.0	550.0
04	1960	95	308	13.4	0.6	1.8	15.7
11	7520	360	1170	51.1	2.2	6.7	60.0
13	7600	360	1200	23.0	1.0	2.9	27.0
16	17800	858	2790	81.9	3.5	10.6	96.0
18	6200	300	970	42.0	1.8	5.5	49.0
22	28600	1380	4470	118.0	5.0	15.2	138.0
25	19000	913	2970	90.0	3.9	12.0	105.0
26	2310	111	361	15.7	0.7	2.1	18.4
27	2240	108	351	10.2	0.4	1.3	12.0
29	1860	90	292	12.7	0.5	1.7	14.9
30	5940	286	931	49.4	2.4	7.7	59.5
31	2240	108	351	15.0	0.7	2.0	17.7
32	13100	631	2050	89.4	3.9	11.7	113.0
34	2290	111	359	15.2	0.7	1.8	17.7
36	109000	5290	17000	739.0	32.3	97.0	868.0
39	2100			9.8			12.0
41	1600	76	250	9.2	0.4	1.2	11.0
45	2320	112	364	17.4	0.8	2.7	21.0
46	5450	263	85	36.2	1.6	5.1	42.9
47	8700	420	1340	52.0	2.3	7.0	61.0
48	4130	200	647	8.7	0.4	1.0	10.1
50	60100	2900	9400	408.0	18.0	54.0	480.0
55	17900	863	2800	94.5	4.1	12.3	111.0
56	8200	400	1300	56.0	2.4	7.4	66.0
60	1400	68	220	9.6	0.4	1.3	11.0
61	2300	110	360	14.0	0.6	1.8	16.0
62	2350	113	367	12.1	0.5	1.6	14.2
63	3370	162	528	23.0	1.0	3.0	27.0
65	4620	223	719	31.4	1.4	4.1	36.9
67	19300	931	3030	101.0	4.3	13.1	118.0
69	1020	49	159	8.6	0.4	1.2	10.2
70	10700	516	1680	73.0	3.1	9.6	85.0
76	8960	432	1400	61.0	2.6	8.0	71.6
77	1200	58	188	8.2	0.4	1.1	9.6
79	19700	951	3090	99.6	4.3	12.9	117.0

Code	^{234}U intake [Bq]	^{235}U intake [Bq]	^{238}U intake [Bq]	^{234}U dose [mSv]	^{235}U dose [mSv]	^{238}U dose [mSv]	U total dose [mSv]
81	4340	209	679	52.0	2.3	6.8	61.1
82	7090	342	1110	48.2	2.1	6.3	56.6
83	2710	131	424	18.3	0.8	2.4	21.5
85	761	37	119	8.3	0.4	1.1	9.7
GM	5054	269	825	27.0	1.4	4.2	32.0
GSD	3.0	3.3	3.5	2.4	2.9	2.9	2.4
AM	9719	599	1920	39.0	2.2	6.6	46.0
ASD	14275	1026	3317	33.0	3.0	9.0	39.0
Min	761	37	85	8.2	0.4	1.1	9.7
MAX	68000	5290	17000	118.0	20.0	60.0	138.0

Table VI-2. Participants results for Acute intake subset.
(Shaded figures are outliers)

Code	^{234}U intake [Bq]	^{235}U intake [Bq]	^{238}U intake [Bq]	^{234}U dose [mSv]	^{235}U dose [mSv]	^{238}U dose [mSv]	U total dose [mSv]
02	1770	85	277	12.0	0.5	1.5	14.0
04	1960	95	308	13.4	0.6	1.8	15.7
11	7520	360	1170	51.1	2.2	6.7	60.0
18	6200	300	970	42.0	1.8	5.5	49.0
26	2310	111	361	15.7	0.7	2.1	18.4
27	2240	108	351	10.2	0.4	1.3	12.0
29	1860	90	292	12.7	0.5	1.7	14.9
31	2240	108	351	15.0	0.7	2.0	17.7
34	2290	111	359	15.2	0.7	1.8	17.7
39	2100			9.8			12.0
41	1600	76	250	9.2	0.4	1.2	11.0
45	2320	112	364	17.4	0.8	2.7	21.0
60	1400	68	220	9.6	0.4	1.3	11.0
61	2300	110	360	14.0	0.6	1.8	16.0
62	2350	113	367	12.1	0.5	1.6	14.2
69	1020	49	159	8.6	0.4	1.2	10.2
77	1200	58	188	8.2	0.4	1.1	9.6
85	761	37	119	8.3	0.4	1.1	9.7
GM	2058	99	322	11.6	0.51	1.55	13.7
GSD	1.72	1.75	1.75	1.28	1.31	1.31	1.27
AM	1907	117	381	12.0	0.52	1.60	14.1
ASD	1700	84	274	2.95	0.14	0.45	3.4
Min	761	37	119	8.2	0.36	1.08	9.7
MAX	7520	360	1173	17.4	0.84	2.70	21.0

Table VI-3. Participants results for Chronic intake subset

Code	^{234}U intake [Bq]	^{235}U intake [Bq]	^{238}U intake [Bq]	^{234}U dose [mSv]	^{235}U dose [mSv]	^{238}U dose [mSv]	U total dose [mSv]
03	68000	3300	10700	460.0	20.0	60.0	550.0
13	7600	360	1200	23.0	1.0	2.9	27.0
16	17800	858	2790	81.9	3.5	10.6	96.0
22	28600	1380	4470	118.0	5.0	15.2	138.0
25	19000	913	2970	90.0	3.9	12.0	105.0
30	5940	286	931	49.4	2.4	7.7	59.5
32	13100	631	2050	89.4	3.9	11.7	113.0
36	109000	5290	17000	739.0	32.3	97.0	868.0
47	8700	420	1340	52.0	2.3	7.0	61.0
48	4130	200	647	8.7	0.4	1.0	10.1
50	60100	2900	9400	408.0	18.0	54.0	480.0
55	17900	863	2800	94.5	4.1	12.3	111.0
56	8200	400	1300	56.0	2.4	7.4	66.0
63	3370	162	528	23.0	1.0	3.0	27.0
65	4620	223	719	31.4	1.4	4.1	36.9
67	19300	931	3030	101.0	4.3	13.1	118.0
70	10700	516	1680	73.0	3.1	9.6	85.0
76	8960	432	1400	61.0	2.6	8.0	71.6
79	19700	951	3090	99.6	4.3	12.9	117.0
81	4340	209	679	52.0	2.3	6.8	61.1
82	7090	342	1110	48.2	2.1	6.3	56.6
83	2710	131	424	18.3	0.8	2.4	21.5
GM	12077	583	1891	70	3.4	9.2	83
GSD	2.7	2.7	2.7	2.8	2.6	2.9	2.8
AM	20400	986	2193	126	5.7	16.6	149
ASD	26060	1264	4274	178	7.9	23	210
Min	2710	131	424	8.7	0.8	2.4	10.1
MAX	109000	5290	17000	739	32	97	868

Table VI-4. Participant assumption for their assessment of Case 5 Uranium intake

Code	Assumed pathway	Time pattern of intake[(a)]	AMAD (µm)	Assumed Absorption type[(b)]	Assumed f_1	Data set used[(c)]	Assumed date of intake or beginning of the chronic intake period
02	INH	A	5	S	0.002	L	21/Mar/97
03	INH	C	5	S	0.002	U	3/Jan/84
04	INH	A	5	S	0.002	LU	21/Mar/97
11	INH	A	5	S	0.002	LU	21/Mar/97
13	INH	A+C	5	MS 80/20		LU	3/Jan/84

Code	Assumed pathway	Time pattern of intake[a]	AMAD (µm)	Assumed Absorption type[b]	Assumed f_1	Data set used[c]	Assumed date of intake or beginning of the chronic intake period
16	INH	C	5	MS 50/50		LU	3/Jan/84
18	INH	A	5	S	0.002	LU	21/Mar/97
22	INH	C	7	S*	0.002	LU	3/Jan/84
25	INH	C	5	SM 52/48	0.002	LU	3/Jan/84
26	INH	A+C	5	S		L	3/Jan/84
27	INH	A	5	S*	0	LU	21/Mar/97
29	INH	A	5	S	0.002	L	
30	INH	A+C	1	M+S	*	LU	3/Jan/84
31	INH	A	5	S	0.002	LU	21/Mar/97
32	INH+ING	C	5	S	0.002	LU	3/Jan/84
34	INH	A	5	S	0.002	L	21/Mar/97
36	INH	A	5	S	0.002	U	21/Mar/97
39		A	5	S*	0.002	LU	
41	INH	A+C*	5	SM 80/20	0.002	LU	3/Jan/84
45	INH	A	4	S	0.02	LU	21/Mar/97
46	INH	3-stage	5	F	0.05	U	21/Mar/97
47	INH	A+C	1	S	0.002	LU	3/Jan/84
48	INH	A+C	5	M	0.02	LU	6/Mar/96
50	INH	C	5	S		LU	3/Jan/84
55	INH	A+C	5	N	0.002	LU	3/Jan/84
56	INH	A+C	5	S	0.002	LU	3/Jan/84
60	INH	A	5	S	0.002	LU	
61	INH	A	5	SM 80/20	0.002	LU	
62	INH	A	5	S*	0.002	LU	21/Mar/97
63	INH	A	5	S	0.002	U	21/Mar/97
65		C		S	0.02	LU	
67	INH	A+C	5	S*	0.002	LU	3/Jan/84
69	INH	A	1	S	0.002	L	21/Mar/97
70	INH	A	5	S		U	
76	INH	A	5	S		U	21/Mar/97
77	INH	A	5	S	0.002	L	3/Jan/84
79	INH	C	5	S*	0.005	LU	3/Jan/84
81	INH	A	0.3	S	0.002	U	21/Mar/97
82	INH	A+C	5	S	0.002	LU	3/Jan/84
83	CHR	C	5	S	0.002	U	
85	INH	A	0.3	SM 85/15	0.002	LU	20/Mar/97

[a] A = Acute, C = Chronic

[b] S* = Lungs parameters modified

[c] L = Lungs, U = Urine

ANNEX VII. CASE 6 – SINGLE INTAKE OF PU AND AM — RESULTS

Table VII-1. Results of case 6, Part 1, for the assessment of ^{241}Am intake and E(50)

Code	^{241}Am intake [kBq]	^{241}Am E(50) [mSv]	Assumed pathway	AMAD [µm]	Assumed absorption type	Assumed f_1	Particle transport parameters	Data set used to estimate intake
03	**4.32**	**94**	INH	5	Specific	5E-4	Specific	LUF
04	**2.44**	**66**	INH	5	M	5E-4	Default	UF liv bone
11	**5.15**	**139**	INH	5	M	5E-4	Default	LF
18	**1.80**	**48**	INH	5	M	5E-4	Default	LUF
21	**0.28**	**0.0562**	ING			5E-4	Default	U
22	**3.42**	**331**	INH	6	Specific	1E-5	Specific	UF
25	**4.30**	**98**	INH	6	S M 96.5 3.5	1E-3	Specific	LUF
26	**3.16**	**170**	INH	5			Default	
27	**3.56**	**42**	INH	3	S	1E-5	Default	L
31	**105**	**21**	ING			5E-4	Default	UF bone
32	**2.98**	**69**	INH	3.7	S	5E-4	Specific	LUF
34	**0.94**	**25**	INH	5	M	5E-4	Default	F
36	**3.92**	**106**	INH	5	M	5E-4	Default	F
39	**7.70**	**51**	INH	7.5	Specific	1E-5	Default	LUF
41	**2.50**	**20**	INH	10	S M 80 20	S M 1E-5 5E-4	Default	UF
45	**4.90**	**27**	INH, ING	10		5E-4	Default	LUF
46	**0.01**	**0.721**	INH	5	F	5E-4	Default	U
50	**1.30**	**35**	INH	5	M	5E-4	Default	F
51	**8.49**	**67**	INH ING 90 10	5	S	5E-4	Default	LU
55	**4.88**	**69**	INH	5	Specific	5E-4	Specific	LUF
59	**0.16**	**4.28**	INH	5	M	5E-4	Default	UF
61	**4.50**	**41**	INH	5	S	5E-4	Default	LUF liv bone
62	**3.85**	**106**	INH	5	Specific	5E-4	Specific	LUF
63	**4.59**	**38.1**	INH	5	S	1E-5	Default	L
65	**0.30**	**8**	INH	5	M	5E-4	Default	U
67	**2.86**	**25**	INH	10	Specific	5E-4	Default	UF
69	**4.11**	**42**	INH	5	Specific	5E-4	Default	LUF liv bone
70	**5.60**	**151**	INH	5	M	5E-4	Default	L
77	**4.90**	**45**	INH	5	S M 97 3	5E-4	Default	LUF
79	**4.60**	**84**	INH	5	Specific	5E-4	Specific	LUF liv bone
80	**3.39**	**64**	INH	5	M S 55 45	2.8E-4	Default	LUF liv bone
81	**0.94**	**25**	INH	5	M	5E-4	Default	intake

Code	^{241}Am intake [kBq]	^{241}Am E(50) [mSv]	Assumed pathway	AMAD [µm]	Assumed absorption type	Assumed f_1	Particle transport parameters	Data set used to estimate intake
								Based on ^{239}Pu
82	**5.97**	**60**	INH	5	S	5E-4	Default	LUF liv
83	**3.72**	**32**	INH	5	S	0	Default	F
85	**3.80**	**25**	INH	5 10	S	5E-4	Default	Based on ^{239}Pu intake
GM	4.0	52						
GSD	1.4	2.1						
AM	4.3	69						
ASD	1.5	62						
Min	1.8	8						
Max	8.5	331						

Table VII-2. Comparison of the specific absorption HRTM parameter values for ^{241}Am with default values

Absorption	Default Type		Participant code								
	M	S	67	45	69	39	55	79	3	62	22
f_r	0.1	$1\ 10^{-3}$	0.125	$5\ 10^{-2}$	$1\ 10^{-2}$	$1\ 10^{-3}$	$7.3\ 10^{-3}$	$5\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-2}$	$1\ 10^{-2}$
s_r (d^{-1})	100	100	20	100	100	100	100	100	100	100	100
s_s (d^{-1})	$5\ 10^{-3}$	$1\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-4}$	$2\ 10^{-4}$	$2.5\ 10^{-4}$	$4.8\ 10^{-4}$	$1\ 10^{-4}$	$1.75\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-4}$
f_b	0	0	0	0	0	0	0.87	0.87	0	0.8	0
s_b (d^{-1})	-	-	-	-		-	0.15	0.15	-	0.2	-
f_1	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$	$5\ 10^{-4}$

Table VII-3. Comparison of the specific HRTM particle transport parameter values with default values. Values in bold were fitted to the ^{241}Am measurement data.

Particle transport	Default values	Participant code						
		55	32	79	3	25	62	22
Fractions (%)								
AI_1 /AI	30	30	30	**0**	30	30	30	30
AI_2 /AI	60	60	60	**90**	60	60	60	60
AI_3/ AI	10	10	10	10	10	10	10	10
Rates (d^{-1})								
AI_1 to bb_1	$2.0\ 10^{-2}$	**$6.67\ 10^{-3}$**	**$1.0\ 10^{-4}$**	-	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$2.0\ 10^{-5}$**
AI_2 to bb_1	$1.0\ 10^{-3}$	**$3.33\ 10^{-4}$**	**$5.0\ 10^{-4}$**	**$2.0\ 10^{-4}$**	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-5}$**
AI_3 to bb_1	$1.0\ 10^{-4}$	**$3.33\ 10^{-5}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.75\ 10^{-4}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.0\ 10^{-6}$**
AI_3 to LN_{TH}	$2.0\ 10^{-5}$	**6.6710^{-6}**	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	**$2.0\ 10^{-6}$**
BB_2 to ET_2	0.03		0.03	**10** [(b)]	0.03	0.03	0.03	
bb_2 to BB_1	0.03		0.03	**2** [(b)]	0.03	0.03	0.03	**$3.0\ 10^{-4}$**
Intake (kBq)		4.9	3.0	4.6	4.3	4.3	3.9	3.4

Particle transport	Default values	Participant code						
		55	32	79	3	25	62	22
E(50) (mSv)		69	69	84	94	98	106	331

(a) Participant 22 also assumed the following rates: BB_1 to ET_2 = 100 d^{-1}, BB_{seq} to LN_{TH} = 1.0 10^{-3} d^{-1}, ET_2 to GI = 10 d^{-1}, and ET_{seq} to LN_{ET} = 0.1 d^{-1}.

(b) It is assumed that there is no slow bronchial clearance based on the faecal data.

Table VII-4. Models and software used for the assessment of ^{241}Am intake and E(50), [Part 1, Case 6].

Code	Software used	Respiratory tract model used	GI tract model used	Systemic biokinetic model used
3	IMBA	ICRP 66	ICRP 30	ICRP 67
4	LUDEP, IRFA	ICRP 66	ICRP 30	ICRP 67
11	NONE	ICRP 66	ICRP 30	ICRP 67
18	Excel	ICRP 66	ICRP 30	ICRP 67
21	Excel	ICRP 66	ICRP 30	ICRP 67
22	IMBA	ICRP 66	ICRP 30	ICRP 67
25	IMBA	ICRP 66	ICRP 30	ICRP 67
26	NONE			
27	IMBA	ICRP 66	ICRP 30	ICRP 67
31	IDEAS DV0102	ICRP 66	ICRP 30	ICRP 67
32	IMBA	ICRP 66	ICRP 30	ICRP 67
34	NIRS	ICRP 66	ICRP 30	ICRP 67
36	INDOS	ICRP 66	ICRP 30	ICRP 67
39	BKFIT	ICRP 66	ICRP 30	ICRP 67
41	MMK-01	ICRP 66	ICRP 30	ICRP 67
45	IMBA	ICRP 66	ICRP 30	ICRP 67
46	IMBA	ICRP 66	ICRP 30	ICRP 67[(a)]
50	NONE	ICRP 66	ICRP 30	ICRP 67
51	IMIE	ICRP 66	ICRP 30	ICRP 67
55	IMBA, Mathematica	ICRP 66	ICRP 30	ICRP 67
59	IMBA	ICRP 66	ICRP 30	ICRP 67
61	INDO 2000	ICRP 66	ICRP 30	ICRP 67
62	IMBA	ICRP 66	ICRP 30	ICRP 67
63	LUDEP	ICRP 66	ICRP 30	ICRP 30
65	Excel	ICRP 66	ICRP 30	ICRP 67
67	IMBA	ICRP 66	ICRP 30	ICRP 67
69	IMBA, REIDAC	ICRP 66	ICRP 30	ICRP 67
70	MONDAL	ICRP 66	ICRP 30	ICRP 67
77	IMBA	ICRP 66	ICRP 30	ICRP 67
79	IMBA	ICRP 66	ICRP 30	ICRP 67
80	IDEA-System	ICRP 66	ICRP 30	ICRP 67
81	NONE	ICRP 66	ICRP 30	ICRP 67
82	In house	ICRP 66	ICRP 30	ICRP 67
83	AIDEe and MONDAL	ICRP 66	ICRP 30	ICRP 67
85	IDEA System	ICRP 66	ICRP 30	ICRP 67

(a) Declared ICRP Publication 56 systemic biokinetic model for Americium but used IMBA that implements the ICRP Publication 67 systemic biokinetic model for Americium.

Table VII-5. Results of case 6, Part 2, for the assessment of ^{239}Pu intake and E(50)

Code	^{239}Pu intake (kBq)	^{239}Pu E(50) (mSv)	Assumed pathway	AMAD (μm)	Assumed absorption type	Assumed f_1	Particle transport parameters	Data set used to estimate intake
03	11.8	270	INH	5	Specific	1E-5	Specifc	UF
04	15.4	128	INH	5	S	1E-5	Default	UF
11	18.6	154	INH	5	S	1E-5	Default	U
18	13.0	100	INH	5	S	1E-5	Default	UF
21	12.9	0.133	ING			1E-5	Default	U
22	18.3	1110	INH	10	Specific		Specifc	UF
25	8.65	199	INH	6	S M 99.2 0.8	1E-5	Specifc	UF
26	17.4	144	INH	5	S	1E-5	Default	U
27	17.3	200	INH	3	S	1E-5	Default	U
31	6.20	68	INH	3	S	1E-5	Default	UF
32	8.51	192	INH	3.7	S	1E-5	Specifc	UF
34	5.26	168	INH	5	M	5E-4	Default	F
36	17.2	549	INH	5	S	1E-5	Default	F
39	11.8	80	INH	7.5	Specific	1E-5	Default	UF
41	14.0	100	INH	10	S M 90 10	S M 1E-5 5E-4	Default	UF
45	17.0	160	INH ING 90 10	4	Specific	5E-4	Default	UF
46	0.04	1.2	INH	5	M	5E-4	Default	U
50	7.10	228	INH	5.0	M	5E-4	Default	UF
51	17.8	133	INH ING 90 10	5	S	1E-5	Default	UF
55	26.2	336	INH	5	Specific	1E-5	Specifc	UF
59	0.94	7.86	INH	5	S	1E-5	Default	UF
60	3.96	172	INH	5	M	1E-4	Default	UF
61	20.0	170	INH	5	S	1E-5	Default	
62	7.37	202	INH	5	Specific	1E-5	Specific	UF
63	13.8	114	INH	5	S	1E-5	Default	Based on ^{241}Am intake
65	15.0	120	INH	5	S	1E-5	Default	U
67	16.1	96	INH	10	Specific	1E-5	Default	UF
69	9.49	90	INH	5	Specific	1E-5	Default	UF
70	16.1	134	INH	5	S	1E-5	Default	U
77	10.6	92	INH	5	S M 98.6 1.4	S M 1E-5 5E-4	Default	UF
79	25.3	421	INH	5	Specific	1E-5	Specific	Based on ^{241}Am intake
80	16.3	135	INH	5	S	1E-5	Default	UF
81	5.14	49	INH	5	S M 95 5	1E-5	Default	UF
82	10.9	91	INH	5	S	5E-4	Default	UF
83	16.4	135	INH	5	S	1E-5	Default	F
85	20.3	118	INH	5 10	S		Default	UF
GM	13.1	140						
GSD	1.5	1.6						
AM	14.2	155						
ASD	5.27	78						

Code	^{239}Pu intake (kBq)	^{239}Pu E(50) (mSv)	Assumed pathway	AMAD (μm)	Assumed absorption type	Assumed f_1	Particle transport parameters	Data set used to estimate intake
Min	5.14	49						
Max	26.2	421						

Table VII-6. Comparison of the specific absorption HRTM parameter values for Plutonium with default values

Absorption	Default Type		Participant code								
	M	S	67	45	69	39	55	79	3	62	22
f_r	0.1	$1\ 10^{-3}$	$5\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-3}$	$1\ 10^{-4}$	$1\ 10^{-3}$	$3\ 10^{-3}$	$6\ 10^{-4}$
s_r (d^{-1})	100	100	20	100	100	100	100	100	100	100	1000
s_s (d^{-1})	$5\ 10^{-3}$	$1\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-4}$	$2\ 10^{-4}$	$2.5\ 10^{-4}$	$4\ 10^{-5}$	$3\ 10^{-5}$	$1.75\ 10^{-4}$	$1\ 10^{-4}$	$1\ 10^{-4}$
f_b	0	0	0	0	0	0	0	0.56	0	0.8	0
s_b (d^{-1})	-	-	-	-	-	-	-	0.21	-	0.2	-
f_l	$5\ 10^{-4}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$5\ 10^{-4}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$1\ 10^{-5}$	$1\ 10^{-5}$

Table VII-7. Comparison of the specific HRTM particle transport parameter values with default values. Values in bold were fitted to the ^{241}Am measurement data

Particle transport	Default values	Participant code						
		55	32	79	3	25	62	22
Fractions (%)								
AI_1 /AI	30	30	30	**0**	30	30	30	30
AI_2 /AI	60	60	60	**90**	60	60	60	60
AI_3/ AI	10	10	10	10	10	10	10	10
Rates (d^{-1})								
AI_1 to bb_1	$2.0\ 10^{-2}$	**$6.67\ 10^{-3}$**	**$1.0\ 10^{-4}$**	-	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$2.0\ 10^{-5}$**
AI_2 to bb_1	$1.0\ 10^{-3}$	**$3.33\ 10^{-4}$**	**$5.0\ 10^{-4}$**	**$2.0\ 10^{-4}$**	**$1.75\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-4}$**	**$1.0\ 10^{-5}$**
AI_3 to bb_1	$1.0\ 10^{-4}$	**$3.33\ 10^{-5}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.75\ 10^{-4}$**	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	**$1.0\ 10^{-6}$**
AI_3 to LN_{TH}	$2.0\ 10^{-5}$	**$6.67.10^{-6}$**	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	$2.0\ 10^{-5}$	**$2.0\ 10^{-6}$**
BB_2 to ET_2	0.03		0.03	**10** [(b)]	0.03	0.03	0.03	
bb_2 to BB_1	0.03		0.03	**2** [(b)]	0.03	0.03	0.03	**$3.0\ 10^{-4}$**
Intake (kBq)		4.9	3.0	4.6	4.3	4.3	3.9	3.4
E(50) (mSv)		69	69	84	94	98	106	331

(a) Participant 22 also assumed the following rates: BB_1 to ET_2 = 100 d^{-1}, BB_{seq} to LN_{TH} = $1.0\ 10^{-3}$ d^{-1}, ET_2 to GI = 10 d^{-1}, and ET_{seq} to LN_{ET} = 0.1 d^{-1}.

(b) It is assumed that there is no slow bronchial clearance based on the faecal data.

Table VII-8. Models and software used for the assessment of ^{239}Pu intake and E(50), [Part 2, Case 6].

Code	Software used	Respiratory tract model used	GI tract model used	Systemic biokinetic model used
03	IMBA	ICRP 66	ICRP 30	ICRP 67
04	LUDEP, IRFA	ICRP 66	ICRP 30	ICRP 67
11	None	ICRP 66	ICRP 30	ICRP 67
18	Mathematica/Excel	ICRP 66	ICRP 30	ICRP 67
21	Excel	ICRP 66	ICRP 30	ICRP 67
22	IMBA	ICRP 66	ICRP 30	ICRP 67[(a)]
25	IMBA	ICRP 66	ICRP 30	ICRP 67
26	None	ICRP 66	ICRP 30	ICRP 67
27	IMBA	ICRP 66	ICRP 30	ICRP 67[(b)]
31	IDEAS DV0102	ICRP 66	ICRP 30	ICRP 67
32	IMBA	ICRP 66	ICRP 30	ICRP 67
34	NIRS	ICRP 66	ICRP 30	ICRP 67
36	INDOS	ICRP 66	ICRP 30	ICRP 67
39	BKFIT	ICRP 66	ICRP 30	ICRP 67
41	MMK-01	ICRP 66	ICRP 30	ICRP 67
45	IMBA	ICRP 66	ICRP 30	ICRP 67
46	IMBA	ICRP 66	ICRP 30	ICRP 67[(c)]
50	None	ICRP 66	ICRP 30	ICRP 67
51	IMIE	ICRP 66	ICRP 30	ICRP 67
55	IMBA, Mathematica	ICRP 66	ICRP 30	ICRP 67
59	IMBA	ICRP 66	ICRP 30	ICRP 67
60	Cindy (intake), LUDEP(dose)	ICRP 66[(d)]	ICRP 30	ICRP 67
61	INDO 2000	ICRP 66	ICRP 30	ICRP 67
62	IMBA	ICRP 66	ICRP 30	ICRP 67
63	LUDEP	ICRP 66	ICRP 30	ICRP 67[(e)]
65	Excel	ICRP 66	ICRP 30	ICRP 67
67	IMBA	ICRP 66	ICRP 30	ICRP 67
69	IMBA, REIDAC	ICRP 66	ICRP 30	ICRP 67
70	MONDAL	ICRP 66	ICRP 30	ICRP 67
77	IMBA	ICRP 66	ICRP 30	ICRP 67
79	IMBA	ICRP 66	ICRP 30	ICRP 67
80	IDEA System	ICRP 66	ICRP 30	ICRP 67
81	IDEAS DV0102	ICRP 66	ICRP 30	ICRP 67
82	In house	ICRP 66	ICRP 30	ICRP 67
83	AIDEe and MONDAL	ICRP 66	ICRP 30	ICRP 67
85	IDEA System	ICRP 66	ICRP 30	ICRP 67

(a) Declared ICRP Publication 30 systemic biokinetic model for Plutonium but used IMBA that implements the ICRP Publication 67 systemic biokinetic model for Plutonium.

(b) Used Jones function to estimate intake from urine data.

(c) Declared ICRP Publication 56 systemic biokinetic model for Plutonium but used IMBA that implements the ICRP Publication 67 systemic biokinetic model for Plutonium.

(d) Participant 60 also declared that they used the ICRP Publication 30 respiratory tract model as well as the ICRP Publication 66 HRTM. However, LUDEP implements the ICRP Publication 66 HRTM.

(e) Declared ICRP Publication 30 systemic biokinetic model for Plutonium but used ICRP Publication 68 dose coefficient that is calculated with the ICRP Publication 67 systemic biokinetic model for Plutonium.

Table VII-9. Measurement uncertainties [Part 2, Case 6].

Code	Urine data			Faeces data		
	Distribution	**Uncertainty Type**	**Uncertainty value**	**Distribution**	**Uncertainty Type**	**Uncertainty value**
03	NORM		0.1	NORM		0.2
04						
11			0.3			
18	NORM	Square		NORM	Square	
21						
22	LOGNORM	SF	1.8	LOGNORM	SF	5
25	LOGNORM	SF	1.8	LOGNORM	SF	5
26						
27[(a)]	LOGNORM	SF	1.8	NORM	Absolute	
31	NORM	Relative	0.1	NORM	Relative	0.1
32	LOGNORM	SF	1.3	LOGNORM	SF	4
34	LOGNORM	SF	1.1	LOGNORM	SF	3
36	Other		< a factor of 3	Other		< a factor of 3
39	LOGNORM	SF	1.65	LOGNORM	SF	4.5
41	LOGNORM	SF	2	LOGNORM	SF	3
45	LOGNORM	SF	1.1	LOGNORM	SF	5
46	NORM	Square root				
50	Other			Other	Relative	0.2
51		Relative	0.3		Relative	3
55	LOGNORM	SF	1.1	LOGNORM	SF	3
59	NORM	Relative	1	NORM	Relative	1
60						
61						
62	LOGNORM	SF	1.8	LOGNORM	SF	3
63	LOGNORM	SF	1.8	LOGNORM	SF	4
65						
67	NORM	Relative	0.5	NORM	Relative	0.8
69	LOGNORM	SF	1.3	LOGNORM	SF	4
70						
77	LOGNORM	SF	1.8	LOGNORM	SF	4
79	LOGNORM	SF	1.8	LOGNORM	SF	3
80						
81						
82	LOGNORM		0.2	LOGNORM		0.1
83				LOGNORM		
85		SF		LOGNORM	SF	

(a) Did not use faecal data in the final assessment of intake.

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